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# A Deep Percolation Model for Estimating Ground-Water Recharge: Documentation of Modules for the Modular Modeling System of the U.S. Geological Survey



Clark Well No. 1, Moxee Valley

Scientific Investigations Report 2006–5318

**U.S. Department of the Interior**
**U.S. Geological Survey**

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**U.S. Department of the Interior**
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

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# Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| cubic foot (ft$^3$) | 0.02832 | cubic meter |
| cubic foot per second (ft$^3$/s) | 0.02832 | cubic meter per second |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| inch (in.) | 2.54 | centimeter |
| inch (in.) | 25.4 | millimeter |
| inch per day (in/d) | 2.54 | centimeter per day |
| inch per year (in/yr) | 2.54 | centimeter per year |
| square foot (ft$^2$) | 0.09290 | square meter |
| square inch (in$^2$) | 6.452 | square centimeter |
| square mile (mi$^2$) | 2.590 | square kilometer |

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Altitude, as used in this report, refers to distance above the vertical datum.

# A Deep Percolation Model for Estimating Ground-Water Recharge: Documentation of Modules for the Modular Modeling System of the U.S. Geological Survey

By J.J. Vaccaro

## Abstract

A daily water-budget model for estimating ground-water recharge, the Deep Percolation Model, was modularized for inclusion into the U.S. Geological Survey's Modular Modeling System. The model was modularized in order to facilitate estimation of ground-water recharge under a large range in climatic, landscape, and land-use and land-cover conditions. The model can be applied to areas as large as regions or as small as a field plot.

An overview of the Modular Modeling System and the Deep Percolation Model is presented. Data requirements, parameters, and variables for the model are described. The modules that compose the Deep Percolation Model are documented.

## Introduction

Ground-water recharge is a major control on ground-water availability and also is needed as an input to ground-water flow models. To facilitate estimating ground-water recharge, the Deep-Percolation Model (DPM) of Bauer and Vaccaro (1987) as modified by Bauer and Mastin (1997) was modularized for inclusion into the U.S. Geological Survey's (USGS) Modular Modeling System (MMS, Leavesley and others, 1996).

An overview of MMS and information on the energy and water-budget components in DPM and the model limitations are presented in this report. The data requirements, model parameters, model variables, the MMS-required dimensions for the modules, and the order in which the modules are processed and executed are described for the modularized DPM. The modules composing DPM are documented using the MMS module documentation standard. Examples of model parameter input and output files are presented and described.

The report comprises four parts: (1) a descriptive part that includes appendixes, (2) the online module documentation for each module, (3) the source code (modules) for DPM, and (4) MMS dimension files and an MMS model schematic (described in a later section). References cited may be from part 1, 2 and (or) 3. Information and downloads for MMS, including DPM, can be obtained from the MMS web site: http://wwwbrr.cr.usgs.gov/mms/.

The DPM was designed principally to calculate independent, multiyear estimates of ground-water recharge for large areas or regions for input to ground-water flow models (see, for example, Bauer and Vaccaro [1990] and Bidlake and Payne [2001]). Regional recharge estimates generally have been developed by employing simplified monthly relations, by analysis of baseflow, or by model calibration. For detailed studies, recharge has been estimated using unsaturated flow models or formulations. Recharge is difficult to measure and, when measured, the values tend to reflect local scale rather than regional scale and are a function of the measuring site conditions. A physically based model that accounts for the major land-surface processes for a range of spatial scales and under a large variation in climatic, soil, and land-use and land-cover conditions is an alternative, independent, and potentially improved method to estimate recharge.

# Overview of the Modular Modeling System

The overview of MMS is largely taken from Leavesley and others (1996). Interested readers and users are referred to that report or the MMS web site listed above.

The MMS is an integrated system of computer software that provides a framework for the development and application of numerical models to simulate a variety of water, energy, and biogeochemical processes. Modules are in read-only directories where tested, documented, and approved code resides, and in user-defined work directories where new modules are being developed. The user selects and links modules from these directories to create a specific model using an interactive, graphical, model-builder tool ('xmbuild'). Modules are linked by coupling the outputs of user-selected modules to the required inputs of other user-selected modules. Tools are provided to display a module's input requirements and to list all modules available that will satisfy each of these inputs. When the inputs for all modules are satisfied and the proper processing order of the modules is delineated, the model is then compiled and saved for future use without repeating the 'xmbuild' step.

When a model is executed, the user interacts with the model through a series of pull-down menus in a graphical user interface, which provide the links to a variety of system features. These include the ability to (1) select and edit parameter files and data files, (2) select a number of model execution options such as a basic run, an optimization run, or a sensitivity analysis run, and (3) select a variety of statistical and graphical analyses of simulation output. During a basic run, as many as four graphical display windows can be opened to display any of the variables that have been declared and calculated in the model modules. As many as 10 variables can be displayed in each window.

# Description of the Deep Percolation Model

The DPM calculates, on a daily basis, the potential quantity of recharge to an aquifer via the unsaturated zone. Recharge is defined as the amount of water leaving either the active root zone (deep percolation) or, in the case of bare soils such as sand dunes, the mapped depth of the soil column (herein called the soil zone to distinguish it from the root zone). Recharge is derived from precipitation and irrigation. DPM includes hydrologic concepts from many sources, such as Curlin (1970), Saxton and others (1974), Haan and others (1982), Skaggs and Kahleel (1982), Leavesley and others (1983), Wallis and others (1983), Wight and Neff (1983), and Giles and others (1984). The model is physically based and,

to the extent possible, was developed so that few parameters need to be calibrated. It was developed to fill the need between rigorous unsaturated flow models (or complex land-surface process models) and overly simple methods for estimating ground-water recharge. The model can be applied to areas as large as regions or as small as a field plot. For a detailed description of DPM see Bauer and Vaccaro (1987) and Bauer and Mastin (1997).

DPM spatially distributes daily weather data, including solar radiation, if available, to distinct areas within a modeled region, watershed, or area, or to a point that has a unit area. These distinct areas subdivide the modeled area, and they can be of any size or shape and are called, using the terminology of MMS, Hydrologic Response Units (HRUs). For the case where DPM is being applied to a watershed, the HRUs would encompass the area of the watershed. Conversely, if an investigator is interested in deep percolation beneath fields of, say winter wheat, under irrigated and dryland conditions, there can be two HRUs that may be 50 mi apart. Generally, the physical properties for a HRU are such that the hydrologic response is assumed to be similar over the entire area of an HRU. The land use and land cover (LULC) can vary by HRU. For typical applications of DPM, the soil properties and LULC are the factors that define the HRU's hydrologic response. For forested mountainous terrains with winter snowpacks, a watershed model would provide better estimates of deep percolation than those calculated by DPM.

DPM calculates daily potential evapotranspiration, snow accumulation and ablation, plant interception, evaporation of intercepted moisture, soil evaporation, soil moisture changes (abstractions and accumulations), transference of unused energy, plant transpiration, and surface runoff (fig. 1). The residual, including any cumulative errors associated with calculations, is deep percolation (recharge). Transference is the amount of unused potential evapotranspiration that is transferred to potential plant transpiration after abstractions from snow sublimation, evaporation of intercepted water, and soil evaporation.

DPM includes components to calculate incoming clear-sky solar radiation on horizontal or sloped surfaces of any aspect. The solar radiation is used to estimate net radiation and potential evapotranspiration.

The original model of Bauer and Vaccaro (1987) was modified by Bauer and Mastin (1997) to include some of the features described above. In particular, the requirement for a quadrilateral model-grid system was eliminated; the ability to allow the soils in the root or soil zone to saturate was added; the method used to calculate surface runoff in the model was changed to a combination of an approximation of Darcy flow for saturated soils and saturation excess; and the Priestly-Taylor potential evapotranspiration method (Priestly and Taylor, 1972) was added for non-agricultural LULCs— agricultural LULCs use the original Jensen-Haise method of Bauer and Vaccaro (1987).
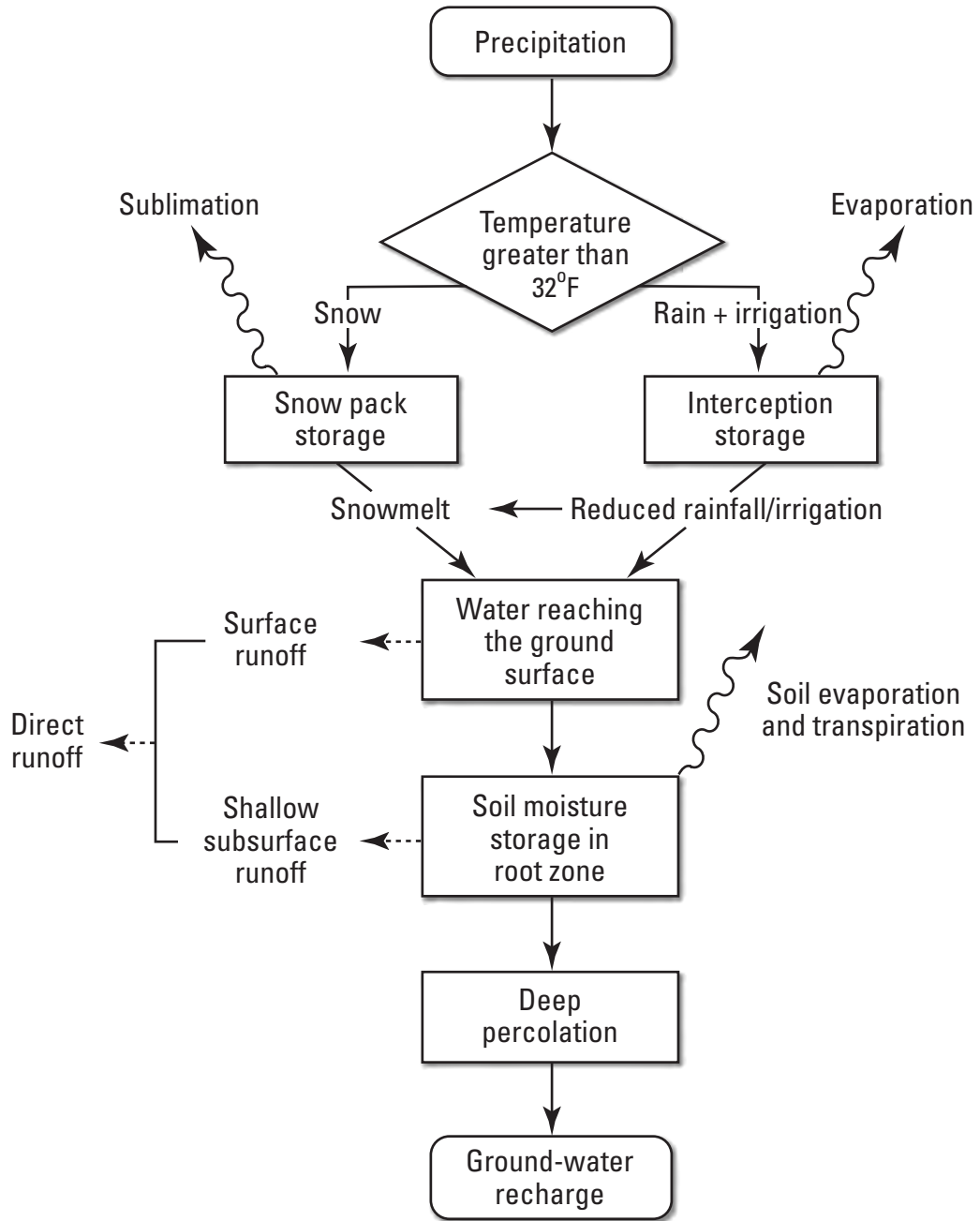
**Figure 1.**   Conceptual daily time-step routing of precipitation used in the Deep Percolation Model water-budget calculations.

DPM now includes three 'stores' for water for a HRU: the unsaturated store in the root or soil zone, the saturated store in the root or soil zone, and an excess store. The unsaturated store holds water up to a soil's field capacity, the saturated store holds water from field capacity to the effective porosity (essentially the specific yield), and the excess store is water in surplus of the filled saturated store. Water entering any store is derived from snowmelt, rain, and irrigation (fig. 1).

Surface runoff calculated by DPM is derived from (1) the saturated store in the root or soil zone using an approximation of Darcy flow and (2) the excess store. The calculated surface runoff can be used by the model, or direct surface runoff can be input and used. For the latter case, the direct values are allocated to HRUs based on their calculated surface runoff values. Direct surface runoff is defined as observed daily streamflow minus an estimate of daily baseflow made by a user, both in units of ft$^3$/s. Use of observed streamflow allows the model to calculate improved estimates of recharge, which generally is one of the smaller components of the water budget, because at times the potential error in calculated surface runoff can be larger than the calculated recharge. Calculated runoff can be used when direct runoff data are unavailable.

## Water and Energy Budget Components

DPM includes both energy and water-budget components that are represented as physical processes in DPM. The process components are represented in the following mass-balance equation for each HRU.

$$R = P - SE - PT - SRO - EI - SUB - (\pm SNO \pm SM \pm IS) \pm DS , \quad (1)$$

where

| | |
|---|---|
| $R$ | is recharge (deep percolation), |
| $P$ | is precipitation, |
| $SE$ | is soil evaporation, |
| $PT$ | is plant transpiration, |
| $SRO$ | is surface runoff |
| $EI$ | is evaporation of intercepted water, |
| $SUB$ | is snow sublimation, |
| $\pm SNO$ | is change in snowpack, |
| $\pm SM$ | is change in soil water in the root or soil zone, |
| $\pm IS$ | is change in intercepted moisture storage, and |
| $\pm DS$ | is deficit or surplus. |

The sum of *SE, PT, EI*, and *SUB* in equation 1 is the model calculated actual evapotranspiration (AET). The calculated deficit/surplus term (*DS*) in equation 1 accounts for direct surface runoff, if input, that the surplus water (water in excess of field capacity) cannot account for or is overaccounted for. Either case indicates that: (1) the daily estimates of baseflow made by a user may be either too large or small (even after user adjustments), (2) hydrologic phenomena, such as macropore flow, that are not included in the model can be locally important, or (3) there may be errors in either the soil information or the interpolated weather data. Although deficit/surplus is considered a separate term in DPM's output that is not part of the error term, it reflects an error due to one or more of the above three factors.

The equation is solved sequentially for each process that occurs after the daily weather data are distributed to the HRUs. The process components in equation 1 are briefly described in the order of model execution and are referenced to the DPM module name. A detailed description of each process and calculations (including equations) is presented in the later section titled 'Module Documentation'.

## Solar Radiation

Clear-sky solar radiation is calculated in module extrad_dpm.f. The calculated solar radiation values are used when there are no observed solar radiation data to distribute to the HRUs. If there are observed data, the daily values are distributed to each HRU on the basis of its slope and aspect. If there are no data, the module calculates solar radiation using complex trigonometric functions of Kaufman and Weatherred (1982) that use the average latitude of the basin, the HRU's average slope and aspect, and the day of the year.

## Net Radiation

Net radiation is calculated in module netrad_dpm.f that is based on Idso and Jackson (1969), Jarvis and others (1976), Spittlehouse and Black (1981), and Giles and others (1984). The module determines net radiation by calculating net long-wave and short-wave radiation. Net radiation is needed for the Priestly-Taylor potential evapotranspiration (PET) method (Priestly and Taylor, 1972) used in DPM.

## Potential Evapotranspiration

Potential evapotranspiration is calculated in module potet_dpm.f. For agricultural croplands the Jensen-Haise PET method (Jensen, 1973; Jensen and others, 1990) is used, and for non-agricultural lands (LULC of forest, grass, sage, water, bare soil, or impervious) the Priestly-Taylor method (Priestly and Taylor, 1972) is used.

The Jensen-Haise method is a radiation-temperature based method that has been shown to yield reasonable results for agricultural croplands (Jensen, 1973; Jensen and others, 1990). The Priestly-Taylor method provides reasonable results for non-agricultural lands (Priestly and Taylor, 1972; Shuttleworth and Calder, 1979; Spittlehouse and Black, 1981; Wallis and others, 1983; Giles and others, 1984).

## Interception

The interception of precipitation by plants is calculated in module intercept_dpm.f. After interception quantities are calculated, evaporation of the intercepted moisture and subsequent throughfall are calculated. The module tracks the current quantity and the changes in the quantity of moisture stored on the foliar cover. Interception is not calculated for the cover type of water. For bare soils or impervious areas, interception is set to zero and throughfall is set to precipitation. For all other cover types, calculations proceed based on whether interception is derived from observed precipitation and throughfall data or is calculated in the module on the basis of plant-growth stage and available moisture storage on the foliar cover-canopy. Intercepted water is allowed to evaporate at the potential rate, canopy storage is reduced by the amount evaporated, and throughfall is then calculated from the difference between precipitation and interception.

## Snow Accumulation and Ablation

The snowpack is calculated in module snowpck_dpm.f. The module retains the original temperature-index-based method for snowmelt calculations in Bauer and Vaccaro (1987). The formulation for melt under rain-on-snow conditions from U.S. Army Corps of Engineers (1956) has been changed to a simplified energy-component method of Anderson (1973, 1978). The module also calculates the sublimation loss during the daylight period using a specified daily sublimation-loss value.

## Soil Evaporation

Soil evaporation is calculated in module soilevap_dpm.f. Soil evaporation occurs from the upper two 6-inch layers of the soil column. Except for free water (water in excess of complete saturation of the soil column), these calculations are completed only for non-agricultural lands because the crop coefficients used in DPM with the Jensen-Haise method account for soil evaporation. The Priestly-Taylor method is used for soil evaporation from the saturated and unsaturated stores for the non-agricultural lands.

For a cover type of water, evaporation is set equal to the Priestly-Taylor PET value. For a cover type of impervious, surplus water is evaporated on the basis of the Priestly-Taylor PET. Soil evaporation from the saturated and unsaturated stores occurs only for the cover types of forest, sage, grass, and bare soil. Soil moisture for these cover types is evaporated using Priestly-Taylor PET values that are adjusted for the foliar cover (shading). In addition, these calculations are only completed when the foliar cover is less than 0.60. Soil evaporation from the unsaturated store follows the method of Saxton and others (1974).

## Plant Transpiration

Plant transpiration is calculated in module plantet_dpm.f. Plant transpiration is not calculated for cover types of water, impervious, or bare soil, and it is not calculated for a HRU if the average daily temperature is below freezing or the HRU is snow covered. Transpiration is first taken from the excess store with soil water nonlimiting, that is, at the potential rate (PET).

The remainder of the transpiration calculations is for the saturated and unsaturated stores. Transpiration occurs first from the saturated store (if saturated water exists in the root or soil zone), and then from the unsaturated store. For the saturated store, water is assumed to transpire at the potential rate adjusted for the current crop-growth stage. For the unsaturated store, transpiration can be calculated using an AET/PET relationship, based on soil texture and moisture content of Bauer and Vaccaro (1987) or using a soil-coefficient limiting method described in Bauer and Mastin (1997) that is from Spittlehouse and Black (1981) and Giles and others (1984). The original method of Bauer and Vaccaro (1987) is used for the unsaturated store if the soil-limiting coefficient is specified as zero.

## Surface Runoff and Deep Percolation

Surface runoff and deep percolation (recharge) are calculated simultaneously in module runoff_dpm.f. The original method in DPM for calculating surface runoff following Wight and Neff (1983) has been replaced by a simple, physically based formulation. This formulation uses Darcy's law for horizontal flow through partially saturated soil that is perched above a horizon of limited infiltration capacity (Bauer and Mastin, 1997). Calculated runoff is used to apportion direct surface runoff to the HRUs, if available. If there is saturated water, the vertical and lateral components of drainage are calculated simultaneously—the lateral component is runoff, and the vertical component is recharge (deep percolation). Water percolates/infiltrates from the root or soil zone at a specified infiltration rate. This rate or infiltration capacity is assumed to be equivalent to the saturated vertical hydraulic conductivity under unit gradient of the subsoil or bedrock below the root or soil zone.

For the cover type of water, DPM analyzes the precipitation and evaporation for a HRU to estimate its runoff. A water HRU can be a lake, river, pond, or other water body, and for DPM calculations it is assumed to have an outflow. Runoff may be negative, in which case the total storage in the water body is reduced. For an impervious cover type, any excess water after evaporation is set equal to runoff. For all other cover types, if there is no water in the saturated store, runoff is set to zero.

## Model Limitations

The physical-empirical relations in DPM are the basis for the process components that are linked together to compose the model. These relations allow for recharge estimates to be made with minimal calibration, but estimates are subject to error. Some errors may result from errors in the required input data, and others result from oversimplification in the physical-empirical relations.

One basic potential error is that the model-calculated recharge, defined as deep percolation leaving the bottom of the root or soil zone, may not be representative of the amount of recharge reaching the water table during the same time period (daily to annual). Depending on the climatic conditions, recharge may take hours to tens of years to reach the water table. For the case of a deep water table in arid regions, the long-term, average recharge calculated by the model may be consistent with the actual steady-rate recharge reaching the water table if the estimates and the actual quantity reaching the water table were produced under similar climatic conditions. To minimize the potential for such errors, recharge should be calculated for many years to capture the inherent climatic variability and the corresponding recharge variability. Similarly, in humid forested mountainous regions, a large part of deep percolation leaving the root or soil zone may supply water to the streams and would not reach the water table.

For the case of using observed daily discharge and baseflow estimates, the model may not have enough moisture (precipitation, soil moisture storage, and (or) irrigation) to account for direct surface runoff, or it may have too much moisture that can not be accounted for. Various physical phenomena can lead to this problem, including particular landscape characteristics or processes not accounted for in the model. If the modeled area is a large watershed, problems may arise because of the lag between precipitation and observed streamflow, but the user can lag the model input to account for such situations. These differences in moisture and direct surface runoff can be problematic in some areas.

The PET methods in DPM provide reasonable results, but limitations exist because of the unique local conditions present in any area. The PET methods were selected on the basis of the typical types of data available for large regions. The Food and Agriculture Organization (Allen and others, 1998) recommends the use of the Penman-Monteith method. However, data needed for this method generally are not available, and under the conditions of missing data, only ten-day to monthly estimates should be made. Estimates made at greater than a daily time step may not account for major recharge events in arid-to-humid environments (Bauer and Vaccaro, 1986; Giambelluca and Oki, 1987; Gee and Hillel, 1988; Vaccaro, 1992).

The PET methods have been shown to be applicable at the daily time scale, but the reference PET (alfalfa) may be in error. The error rises from the assumptions used in the methods and because the crop curves defined in DPM for use in the Jensen-Haise method can vary by irrigation scheduling, and climatic settings and variations. Although Allen and others (1998) state that the use of average crop coefficients (as used in DPM) is relevant and more convenient than the crop coefficients computed on a daily time step using a separate crop and soil coefficient, they recommend adjustments of crop coefficients based on local climatic conditions and water-management practices.

The interpolation of weather data to HRUs can lead to errors, especially if the modeled area has large spatial variations in weather. In many cases, these errors may be much larger than the inherent error in estimating PET and AET. For smaller areas, the interpolation should not be an important source of error, but the soil information becomes much more important. Lack of good soil information in this case can result in errors. In arid to semiarid areas, the total available water capacity (TWAC) of the root or soil zone is the principal control on recharge because the TWAC is similar to or larger than the annual or winter precipitation amounts. In DPM, the water input to the soil column, after abstractions by AET, must exceed the TWAC for recharge to occur; small quantities leaving the root or soil zone under unsaturated conditions are not accounted for in DPM.

Although errors can arise for various reasons, with the correct input, DPM's calculated deep percolation should generally approximate actual deep percolation because its

physical-empirical relations are solved in a mass-balance equation that preserves the total amount of water input to a HRU. Bauer and Mastin (1997) show a good match of seasonal soil-moisture profiles for two years for three catchments, and the resulting recharge values were consistent with recharge estimated using other techniques. Bauer and Vaccaro (1990) estimated recharge for 53 basins that encompass more than 20,000 mi$^2$. When the results for one HRU in one basin were compared to independent estimates, the values were similar (Nimmo and others, 1994). However, users should recognize that there may be errors in the estimates of recharge and should analyze them carefully. If more detailed data are available, then modifications to DPM can be made to account for the data. In addition, different physical process modules can be substituted in the modularized DPM if a user prefers to model some physical process in a different manner, for example, PET.

# Modularization of the Deep Percolation Model

As part of the modularization, the original 40 subroutines in DPM were combined into 19 MMS modules and the number of LULC types was expanded from 15 to 31; for example, citrus orchards and cotton were added as LULC types. The 31 LULCs are listed in appendix 1. The additional LULCs allow the model to be applied to many locations and to potentially be used for irrigation scheduling. However, DPM's most common use is to estimate recharge for large areas for input to ground-water flow models.

## Data Requirements

A basic set of input data is required to operate DPM. The input data follow the MMS format. The data comprise daily values of precipitation and maximum and minimum air temperature. Daily observed discharge and a users' estimates of daily baseflow are not required but are recommended when the modeled region is a defined watershed (in contrast to a field plot) or when such data are available for the modeled area. Daily observed discharge data may not be available or applicable in semiarid to arid environments, in irrigated areas, or in field-scale studies.

Other optional input includes daily values for throughfall, solar radiation, and snow-water content. Throughfall data allow for the direct calculation of interception and evaporation of intercepted precipitation/irrigation. Throughfall data for smaller modeled regions, where there are not large variations in precipitation and cover type, can be beneficial because the model uses simple formulations for the interception process. Solar radiation data should be used when available because it

will improve the accuracy of the evapotranspiration estimates. However, these data are generally not available in many areas, or are only available for short time periods. Comparison of model results for simulations with and without solar radiation data would provide information on the sensitivity of the recharge estimates to solar radiation data. For cold regions with a snowpack, the snow-water content provides information on how well the model is estimating the snowpack, which can be an important component of the water budget and, thus, of recharge.

## Model Parameters

DPM has 68 parameters (table 1) and, excluding MMS model-dimension parameters, they fall into four categories. The first category consists of descriptive information of the landscape-scale characteristics for the HRUs, such as the altitude, slope, aspect, monthly precipitation, cover type, x,y-location, and soil association. Altitude, slope, aspect, and monthly precipitation are averages for an HRU, and cover type and soil association are a majority. The second category contains information for the soil types in the modeled area. Characteristics (parameters) are related to each soil type. These parameters include total depth, total available water capacity (field capacity minus wilting point), specific yield (effective porosity), lateral hydraulic conductivity, and soil texture. The third category includes information on the weather sites whose data are used to drive the model. These parameters include the x,y-locations of the sites, mean monthly precipitation at each precipitation site, the mean monthly minimum and maximum temperature lapse rates, and the average July temperature at each temperature site. The fourth category contains parameters that generally are used in model equations or formulations. Unlike the above categories that require explicit characteristics, such as average altitude of an HRU, the parameters in this category involve some estimation. An example would be the vertical hydraulic conductivity of the subsoil (horizon of limited infiltration capacity). The implementation of DPM in MMS allows for a default value and an identified minimum and maximum value for each parameter.

The parameters are listed, by module, in table 1. Each parameter is declared in a MMS module. A description of the parameter can be seen by accessing a module's documentation or, in the model-run mode of MMS, can be brought up in a window that is accessed through the parameter-editing window of MMS. Appendix 2 lists the dimensions (described in the section 'Modular Modeling System Dimensions'), MMS-declared default, minimum and maximum parameter values, and the parameter type (integer or real). Some parameters are not required input to the model because they are calculated by the model, for example, the total modeled area; these calculated parameters are identified in table 1.

**Table 1.**   Module parameters for the Deep Percolation Model.

[Parameters in a module that are declared and associated with another module have the original module's shortened name listed in brackets next to the parameter name. Parameters calculated by the model have '(calculated)' next to the parameter name and do not need to be input]

| Module | Parameter | Description |
|---|---|---|
| basin_parms_dpm.f | hru_elev | Mean elevation for each HRU, in feet. |
| | hru_area | HRU area, in square miles. |
| | hru_slope | HRU slope as vertical feet/horizontal feet, in decimal percent. |
| | hru_aspect | HRU aspect in degrees from north: 0-360, in degrees. |
| | hru_ylat | HRU Y-location of centroid, latitude, in decimal degrees, or state plane, in feet. |
| | hru_xlong | HRU X-location of centroid, longitude, in decimal degrees, or state plane, in feet. |
| | hru_soil | HRU soil type, no units. |
| | cov_type | HRU cover type: land use type, from 1-31, no units. |
| | hru_appld | Application rate of irrigation water for HRU, in inches. |
| | hru_mon_ppt | Mean monthly precipitation for each HRU, in inches. |
| | hru_irr_methd | Method of irrigation, 0 is above canopy, 1 is below canopy (no interception by plants), no units |
| weather_siteinfo_dpm.f | kzone | National Oceanographic Survey number for state plane code, nounits. |
| | ratemn | Minimum monthly temperature lapse rate: for each month, in degrees Fahrenheit per 1,000 feet. |
| | ratemx | Maximum monthly temperature lapse rate: for each month, in degrees Fahrenheit per 1,000 feet. |
| | tsta_x | X for each temperature station, longitude, in decimal degrees, or state plane, in feet. |
| | tsta_y | Y for each temperature station, longitude, in decimal degrees, or state plane, in feet. |
| | tsta_elev | Temperature station elevation, in feet. |
| | tnjulav | Average July minimum temperature for each temperature station, in degrees Fahrenheit. |
| | txjulav | Average July maximum temperature for each temperature station, in degrees Fahrenheit. |
| | psta_x | X for each precipitation station, longitude, in decimal degrees, or state plane, in feet. |
| | psta_y | Y for each precipitation station, longitude, in decimal degrees, or state plane, in feet. |
| | psta_mon_ppt | Average monthly precipitation at each station, in inches. |
| | thrusta_x | X for each thrufall station, longitude, in decimal degrees, or state plane, in feet. |
| | thrusta_y | Y for each thrufall station, longitude, in decimal degrees, or state plane, in feet. |
| | covthru | Land use/cover for each thrufall station, no units. |
| | solsta_x | X for each solar radiation station, longitude, in decimal degrees, or state plane, in feet. |
| | solsta_y | Y for each thrufall station, longitude, in decimal degrees, or state plane, in feet. |
| | hru_ylat [basin] | |
| | hru_xlong [basin] | |
| obs_dpm.f | none | |
| cropcof_dpm.f | fcmax | Maximum foliar cover of a land use/cover, in decimal percent. |
| | maxint | Maximum interception capacity of a land use/cover, in inches. |
| | rdmax | Maximum root depth of a land use/cover, in inches. |
| | irrst1 | Start date for first irrigation scheduling period, in monthday (June 9 is 0609) |
| | irren1 | End date for first irrigation scheduling period, in monthday (June 9 is 0609) |
| | irrst2 | Start date for second irrigation scheduling period, in monthday (June 9 is 0609) |
| | irren2 | End date for second irrigation scheduling period, in monthday (June 9 is 0609) |
| | irrscd | Irrigation scheduling type: =0 constant, =1 growth stage, no units. |
| | sumcp (calculated) | Crop curve integrated over the input irrigation season, no units. |
| | iroot | Distribution of root mass in root zone: linear (=0) or exponential (=1), no units. |
| | fallow (calculated) | Winter wheat (2-yr cycle) swapping of land-use type 5 to 6, no units. |
| cov_type [basin] | | |
| grid_met_dpm.f | distp (calculated) | Inverse of square of distance between HRU and precipitation site, in 1/square feet. |
| | distt (calculated) | Inverse of square of distance between HRU and temperature site, in 1/square feet. |
| | distr (calculated) | Inverse of square of distance between HRU and solar radiation site, in 1/square feet. |
| | disttf (calculated) | Inverse of square of distance between HRU and thrufall collection site, in 1/square feet. |
| | elfac (calculated) | Elevation difference between HRU to each temperature site, divided by 1,000, in feet. |
| | cov_type [basin] | |

**Table 1.**    Module parameters for the Deep Percolation Model.—Continued

[Parameters in a module that are declared and associated with another module have the original module's shortened name listed in brackets next to the parameter name. Parameters calculated by the model have '(calculated)' next to the parameter name and do not need to be input]

| Module | Parameter | Description |
|---|---|---|
| grid_met_dpm.f—Cont. | hru_appld [basin]<br>hru_mon_ppt [basin]<br>hru_ylat [basin]<br>hru_xlong [basin]<br>hru_elev [basin]<br>ratemn [weather]<br>ratemx [weather]<br>tsta_x [weather]<br>tsta_y [weather]<br>tsta_elev [weather]<br>tnjulav [weather]<br>txjulav [weather]<br>psta_x [weather]<br>psta_y [weather]<br>psta_mon_ppt [weather]<br>thrusta_x [weather]<br>thrusta_y [weather]<br>covthru [weather]<br>solsta_x [weather]<br>solsta_y [weather] | |
| extrad_dpm.f | avelat<br>hru_slope [basin]<br>hru_aspect [basin] | Average latitude of basin used for solar radiation calculations, in degrees. |
| netrad_dpm.f | slrxfmx<br>cov_type [basin] | Maximum of observed daily incoming solar radiation, monthly, in fractions. |
| potet_dpm.f | ct (calculated)<br>tx (calculated)<br>petmin<br>hru_elev [basin]<br>cov_type [basin] | Jensen-Haise potential evapotranspiration equation coefficient, in 1/degrees Fahrenheit.<br>Jensen-Haise potential evapotranspiration equation coefficient, in degrees Fahrenheit.<br>Minimum daily potential evapotranspiration rate for each month, in inches. |
| intercept_dpm.f | cov_type [basin]<br>hru_appld [basin]<br>hru_irr_methd [basin] | |
| snowpck_dpm.f | strtsno<br>sblrate<br>snmcoef<br><br>uadj<br>hru_elev [basin]<br>cov_type [basin] | Initial snow-water equivalent for all HRUs, in inches.<br>Daily snow sublimation rate, generally 0.001-0.05, in inches.<br>Snowmelt coefficient for temperature index method, in inches water/degrees Celsius/ day.<br>Average wind function during rain-on-snow event, in kilometers at height of 1 meter. |
| soilms_dpm.f | unsatmax (calculated)<br>stormax (calculated)<br>avlcap<br><br>spcyld<br>solprm<br>soil_type | Maximum available water capacity for a soil for a HRU, in inches.<br>Maximum saturated water capacity for a soil for a HRU, in inches.<br>Total available water capacity (field capacity) for a soil association, no units-as decimal fraction.<br>Specific yield for a soil association, no units-as decimal fraction.<br>Lateral permeability/conductivity for a soil association, in feet/day.<br>Soil texture for a soil association, no units. |

**Table 1.**    Module parameters for the Deep Percolation Model.—Continued

[Parameters in a module that are declared and associated with another module have the original module's shortened name listed in brackets next to the parameter name. Parameters calculated by the model have '(calculated)' next to the parameter name and do not need to be input]

| Module | Parameter | Description |
|---|---|---|
| soilms_dpm.f—Cont. | nlayer | Number of 6 inch layers for a soil association, no units. |
| | strtsms | Initial soil moisture for all HRUs as fraction of field capacity-avlcap, no units. |
| | strtpor | Initial soil saturation for all HRUs, as fraction of total effective porosity-spcyld, no units. |
| | hru_soil [basin] | |
| | cov_type [basin] | |
| | hru_appld [basin] | |
| | hru_irr_methd [basin] | |
| soilevap_dpm.f | avlcap [soilms] | |
| | nlayer [soilms] | |
| | hru_soil [basin] | |
| | cov_type [basin] | |
| transfer_dpm.f | cov_type [basin] | |
| plantet_dpm.f | slmfac | Soil limiting transpiration coefficient for a soil, in inches/day. |
| | avlcap [soilms] | |
| | spcyld [soilms] | |
| | soil_type [soilms] | |
| | nlayer [soilms] | |
| | hru_soil [basin] | |
| | cov_type [basin] | |
| | iroot [cropcof] | |
| runoff_dpm.f | vksat | HRU vertical infiltration rate of subsoil, in inches/year. |
| | efflngth | One-half the average spacing between smallest drainage channels, in feet. |
| | effslp | Effective average slope between smallest drainage channels, no units. |
| | spcyld [soilms] | |
| | solprm [soilms] | |
| | nlayer [soilms] | |
| | hru_soil [basin] | |
| | cov_type [basin] | |
| runtru_dpm.f | bsnara | Basin area for stream discharge gage, in square miles. |
| | spcyld [soilms] | |
| | nlayer [soilms] | |
| | vksat [runoff] | |
| | hru_soil [basin] | |
| | cov_type [basin] | |
| masbal_dpm.f | dsum | Check to determine if outputting daily water-budgets, no units. |
| basin_soilmoist_dpm.f | cov_type [basin] | |
| | unsatmax (calculated) [soilms] | |
| | stormax (calculated) [soilms] | |
| print_masbal_dpm.f | mobdgt | Ending month for the annual water-budget summary, in months. |
| | nbdgdys (calculated) | Total number of days for this water-budget period, no units. |
| | kntmos (calculated) | Total number of months for water-budget, no units. |
| | dsum [masbal] | |

The parameters for the location of the weather sites and the centroid of the HRUs are required inputs to DPM. Location (x,y) values can be in decimal degrees or state plane coordinates (or any other consistent distance coordinates). If the values are in decimal degrees, they are converted to state plane coordinates by a National Ocean Service state-plane zone number (listed in appendix 3) using the USGS's General Cartographic Transformation Package (generalized plane coordinate conversion package). For DPM, the package has been modified for only forward transformations from geographic to plane, and for only the continental United States.

With the general availability of geographic information systems (GIS), it is suggested to preprocess the required input x,y-values from geographic to plane coordinates. The pre-processing will save model execution time and allows the input values to be analyzed external to the modeling process. In addition, the GIS Weasel (Leavesley and others, 1997; on the World Wide Web at http://wwwbrr.cr.usgs.gov/weasel/) has a plug-in for DPM (R. Viger, U.S. Geological Survey, written commun., 2005) that allows many of the parameters to be estimated using the GIS Weasel and readily available national GIS databases.

## Model Variables

Eighty-six variables are included in DPM, and the variables for each module are listed in table 2. The variables also are described in the online documentation for each module. Most of the water-budget variables calculated for each HRU have been renamed to begin with the prefix 'hru_'; this prefix identifies the variable as having a value for a particular HRU. The 86 variables in DPM are associated with either a single module or several modules. In many cases, variables calculated in one module, such as current moisture content for each layer in the unsaturated store, are used as input to another module. The variable of interest for most users is hru_rechrge, which is the recharge (deep percolation from the root or soil zone) for a HRU.

## Modular Modeling System Dimensions

Dimensions are numbers that set the size of a parameter or variable array. Dimensions and their names are included in the dimensions database of MMS. The MMS dimensions include all appropriate sizes, such as the maximum number of HRUs (MAXHRU). The dimensions are integers, and their maximum values, not necessarily the value for a particular model, are declared using MMS functions 'setdims' and 'decldim'. These functions are automatically included with DPM as part of model building.

The name for the maximum size of a dimension and its size are defined in an include file named 'fmodules.inc' that is for FORTRAN modules, and the maximum size name and the model dimension name used in DPM/MMS are defined in 'setdims.f'. For example, MAXHRU is defined in 'fmodules.inc' and its size, say 500, represents the maximum array space of HRUs currently allowed in a model. The model dimension name (in this case 'nhru') is set in 'setdims.f' and is declared to be MAXHRU. To change the maximum number, if for example one wants to construct a model for 11,000 HRUs, the include file ('fmodules.inc') must be edited and the model recompiled. The actual number used for a dimension in a particular model is set as part of the parameter input file, for example, 'nhru' is set as 237. That is, each model dimension is also a parameter. For a more detailed description of dimensions see Leavesley and others (1996).

In addition to the standard MMS dimensions, DPM uses additional dimensions that are part of the include/decldim (fmodules.inc) and setdims (setdims.f) files. These new dimensions are:

| New MMS dimension | Model name | Maximum number | Description |
|---|---|---|---|
| MAXTHRU | nthru | 10 | Number of throughfall stations |
| MAXSOILS | nsoils | 200 | Number of soil types |
| MAXLANDS | nlands | 40 | Number of LULCs |
| MAXBSFLW | nbsflw | 1 | Number of baseflow time series |
| MAXBUD | nbuds | 18 | Number of water-budget items for outputting |
| MAXCOEFS | ncoef | 6 | Number of coefficients for cover types (for example, root depth) |
| MAXLAYERS | nlayrsoil | 16 | Number of 6-inch soil layers |

The existing MMS dimensions that DPM uses are:

| Existing MMS dimension | Model name | Maximum number | Description |
|---|---|---|---|
| MAXHRU | nhru | 10,000 | Number of hydrologic response units |
| MAXRAIN | nrain | 200 | Number of rain gages |
| MAXTEMP | ntemp | 15 | Number of temperature stations |
| MAXOBS | nobs | 20 | Number of stream measurement stations |
| MAXSOL | nsol | 4 | Number of solar radiation stations |
| MAXMO | nmonths | 12 | Number of months in a year |
| MAXDAY | ndays | 366 | Number of days in a year |
| MAXSNOPIL | nsnow | 10 | Number of snow pillow or course stations |

**Table 2.**   Module variables for the Deep Percolation Model.

[Variables in a module that are delcared and associated with another module have the original module's shortened name listed in brackets next to the variable name]

| Module | Variable | Description |
|---|---|---|
| basin_parms_dpm.f | wght | HRU area as fraction of total area, as a fraction |
| weather_siteinfo_dpm.f | none | |
| obs_dpm.f | runoff | Observed runoff for each gage, in cubic feet per second. |
| | bsflw | Estimated baseflow for each gage, in cubic feet per second. |
| | thrufall | Fraction of total precipitation at gage that is throughfall, in decimal fraction of precipitation. |
| | precip | Observed precipitation at each rain gage, in inches. |
| | tmin | Observed minimum temperature, in degrees Fahrenheit. |
| | tmax | Observed maximum temperature, in degrees Fahrenheit. |
| | solrad | Observed solar radiation, in langleys. |
| | snow | Observed snow pillow/course data, in inches. |
| cropcof_dpm.f | coefs | Daily values of 6 parameters for each of the crop-types, units vary. |
| grid_met_dpm.f | hru_solrad | Daily incoming solar radiation for each of the HRUs. |
| | hru_ppt | Daily precipitation for each of the HRUs, in inches. |
| | tmaxf | Daily maximum temperature for each of the HRUs, in degrees Fahrenheit. |
| | tminf | Daily minimum temperature for each of the HRUs, in degrees Fahrenheit. |
| | tavf | Daily average temperature for each of the HRUs, in degrees Fahrenheit. |
| | tmxyst | Yesterdays daily maximum temperature for each HRU, in degrees Fahrenheit. |
| | tffrc | Throughfall for a HRU interpolated from throughfall site, in fractions. |
| | hru_tmxjuly | HRU mean maximum July temperature used for PET calculations, in degrees Fahrenheit. |
| | hru_tmnjuly | HRU mean minimum July temperature used for PET calculations, in degrees Fahrenheit. |
| | coefs [cropcof] | |
| | obs_tmax [obs] | |
| | obs_tmin [obs] | |
| | obs_precip [obs] | |
| | obs_solrad [obs] | |
| | obs_thru [obs] | |
| extrad_dpm.f | slrexthz | Solar radiation for horizontal surface for day, in langleys. |
| | slrext | Solar radiation for sloped surface for day, in langleys. |
| | frcdylts | Fraction of day with sun—daylight, in fraction. |
| | hru_solrad [grid] | |
| | tmaxf [grid] | |
| | tminf [grid] | |
| netrad_dpm.f | hru_netrad | Daily net radiation for each of HRUs, in cal/cm$^2$/dy. |
| | tmaxf  [grid] | |
| | tminf [grid] | |
| | hru_solrad [grid] | |
| | slrexthz [extrad] | |
| | frcdylt [extrad] | |
| potet_dpm.f | hru_potet | Potential evapotranspiration for HRU, in inches. |
| | hru_tmnjuly [grid] | |
| | hru_tmxjuly [grid] | |
| | hru_netrad [netrad] | |
| | hru_solrad [grid] | |
| | tavf [grid] | |

**Table 2.** Module variables for the Deep Percolation Model.—Continued

[Variables in a module that are delcared and associated with another module have the original module's shortened name listed in brackets next to the variable name]

| Module | Variable | Description |
|---|---|---|
| intercept_dpm.f | hru_thrufall | HRU throughfall for day, based on throughfall data or calculated, in inches. |
| | hru_intercpt | HRU interception for day:  throughfall data or calculated, in inches. |
| | hru_canopystor | Amount of water stored in the foliar cover/canopy for day, in inches. |
| | hru_evapinter | Amount of intercepted water evaporated from the canopy for day, in inches. |
| | hru_chnginter | Change in intercepted water from yesterday for a HRU, in inches. |
| | hru_adjustpet | Potential evapotranspiration for HRU adjusted as used, in inches. |
| | hru_irrigation | Amount of irrigation water applied to a HRU, in inches. |
| | hru_ppt [grid] | |
| | hru_potet [grid] | |
| | tffrc [grid] | |
| | coefs [cropcof] | |
| snowpck_dpm.f | hru_snow | Amount of snow-water-equivalent for a HRU, in inches. |
| | hru_rain | Amount of rain for a HRU for a day, in inches. |
| | hru_chngsno | Change in snowpack for the day for HRU, in inches. |
| | hru_snomelt | Snowmelt for the day for HRU, in inches. |
| | hru_sublmton | Amount of sublimation loss from snowpack for HRU, in inches. |
| | hru_adjustpet [intrcp] | |
| | hru_thrufall [intrcp] | |
| | hru_ppt [grid] | |
| | tavf [grid] | |
| | tminf [grid] | |
| | tmaxf [grid] | |
| | tmxyst [grid] | |
| soilms_dpm.f | smscapavg | Area-average of soil-moisture capacity for all HRUs, in inches. |
| | smscapmin | Minimum of soil-moisture capacity for all HRUs, in inches. |
| | smscapmax | Maximum of soil-moisture capacity for all HRUs, in inches. |
| | satcapavg | Area-average of soil-saturation capacity for all HRUs, in inches. |
| | satcapmin | Minimum of soil-saturation capacity for all HRUs, in inches. |
| | satcapmax | Maximum of soil-saturation capacity for all HRUs, in inches. |
| | sms | Soil moisture in unsaturated soil-moisture store, by layer, in inches. |
| | sms_init | Initial soil moisture in unsaturated soil-moisture store, by layer, inches. |
| | storpor | Soil moisture in saturated soil-moisture store, by layer, in inches. |
| | storpor_init | Initial soil moisture in saturated soil-moisture store, in inches. |
| | excess | Quantity of water in excess of saturation, in inches. |
| | hru_chngsm | Total change in soil moisture (saturated/unsaturated) for a day, in inches. |
| | unsatcur | Current available water capacity for a HRU, in inches. |
| | storcur | Current saturated water content for a HRU, in inches. |
| | wght [basin] | |
| | hru_rain [snowpck] | |
| | hru_snomelt [snowpck] | |
| | hru_irrigation [intrcp] | |
| | coefs [cropcof] | |
| soilevap_dpm.f | hru_pevsoil | Potential evaporation demand for soil evaporation, in inches. |
| | hru_actevsoil | Actual evaporation from upper 1 foot of the soil column, in inches. |
| | sms [soilms] | |
| | storpor [soilms] | |
| | unsatcur [soilms] | |
| | storcur [soilms] | |
| | excess [soilms] | |
| | hru_adjustpet [intrcp] | |
| | coefs [cropcof] | |
| | hru_snow [snowpck] | |

**Table 2.**    Module variables for the Deep Percolation Model.—Continued

[Variables in a module that are delcared and associated with another module have the original module's shortened name listed in brackets next to the variable name]

| Module | Variable | Description |
|---|---|---|
| transfer_dpm.f | hru_petloss | Amount of potential evapotranspiration loss--not transferred to potential plant evapotranspiration, in inches. |
| | hru_adjustpet [intrcp] | |
| | coefs [cropcof] | |
| | hru_pevsoil [soilev] | |
| | hru_actevsoil [soilev] | |
| | hru_snow [snowpck] | |
| plantet_dpm.f | hru_petplnt | Potential plant transpiration, in inches. |
| | hru_petcrop | Potential plant transpiration adjusted for crop growth, in inches. |
| | hru_aetplnt | Actual plant transpiration, in inches. |
| | sms [soilms] | |
| | storpor [soilms] | |
| | unsatcur [soilms] | |
| | storcur [soilms] | |
| | excess [soilms] | |
| | coefs [cropcof] | |
| | tavf [grid] | |
| | hru_snow [snowpck] | |
| | hru_adjustpet [intrcp] | |
| | hru_petloss [transfr] | |
| runoff_dpm.f | hru_rodrcy | Calculated surface (Darcy-flow) runoff from soils for a HRU, in inches. |
| | hru_roexcs | Calculated surface runoff from water in excess of saturation, in inches. |
| | hru_rototal | Total runoff for a HRU from Darcy flow and excess water, in inches. |
| | hru_rechrge | Calculated recharge-water leaving bottom of the root zone, in inches. |
| | storcurnew | Modified storage in saturated store due to runoff abstraction, in inches. |
| | hru_lakestor | Potential (actual) evapotranspiration for lakes for the case of no observed surface runoff or its = 0.0, in inches. |
| | excess [soilms] | |
| | storcur [soilms] | |
| | storpor [soilms] | |
| | sms [soilms] | |
| | storpor_init [soilms] | |
| | sms_init [soilms] | |
| | hru_chngsm [soilms] | |
| | hru_actevsoil [soilev] | |
| | hru_ppt [grid] | |
| runtru_dpm.f | hru_obsdisch | Apportioned observed discharge based on calculated runoff, in inches. |
| | disch | Observed discharge minus baseflow, in inches. |
| | bsnfac | Converts cubic feet per second to inches based on the basin area, in inches per cubic feet per second. |
| | surplus | Basin amount of excess not drained by observed discharge, in inches. |
| | deficit | Basin amount of observed discharge not supplied by free water, in inches. |
| | chgsmrobsn | Basin change in saturated soil moisture due to apportioning observed discharge, in inches. |
| | rchbsn | Basin amount of recharge for all HRUs, in inches. |
| | wght [basin] | |
| | runoff [obs] | |
| | bsflw [obs] | |
| | storpor [soilms] | |
| | hru_rechrge [runoff] | |
| | hru_roexcs [runoff] | |
| | hru_rototal [runoff] | |

**Table 2.**    Module variables for the Deep Percolation Model.—Continued

[Variables in a module that are delcared and associated with another module have the original module's shortened name listed in brackets next to the variable name]

| Module | Variable | Description |
|---|---|---|
| runtru_dpm.f | hru_lakestor [runoff] | |
| | excess [soilms] | |
| | storcur [soilms] | |
| masbal_dpm.f | qbaldy | Daily water balance for the modeled area, in inches. |
| | qbalmo | Monthly water balance for the modeled area, in inches. |
| | qbalyr | Annual water balance for the modeled area, in inches. |
| | wght [basin] | |
| | tavf [grid] | |
| | hru_ppt [grid] | |
| | hru_potet [potet] | |
| | hru_chnginter [intrcp] | |
| | hru_evapinter [intrcp] | |
| | hru_irrigation [intrcp] | |
| | hru_chngsno [snowpck] | |
| | hru_sublmton [snowpck] | |
| | hru_chngsm [soilms] | |
| | hru_pevsoil [soilev] | |
| | hru_actevsoil [soilev] | |
| | hru_petcrop [plantet] | |
| | hru_aetplnt [plantet] | |
| | hru_rototal [runoff] | |
| | hru_lakestor [runoff] | |
| | hru_rechrge [runoff] | |
| | hru_obsdisch [runtru] | |
| | chgsmrobsn [runtru] | |
| | surplus [runtru] | |
| | deficit [runtru] | |
| basin_soilmoist_dpm.f | smsavg | Area-average of soil-moisture capacity for all HRUs, in inches. |
| | satavg | Area-average of soil-saturation capacity for all HRUs, in inches. |
| | smsdefct | Deficit of water in the unsaturated soil-moisture store for a HRU, in inches. |
| | satdefct | Deficit of water in the saturated soil-moisture store for a HRU, in inches. |
| | smscellmn | Current minimum soil-moisture capacity for all HRUs, in inches. |
| | smscellmx | Current maximum soil-moisture capacity for all HRUs, in inches. |
| | smscelldefct | Current deficit soil-moisture capacity for all HRUs, in inches. |
| | satcellmn | Current minimum saturated-moisture capacity for all HRUs, in inches. |
| | satcellmx | Current maximum saturated-moisture capacity for all HRUs, in inches. |
| | satcelldefct | Current deficit saturated-moisture capacity for all HRUs, in inches. |
| | wght [basin] | |
| | unsatcur [soilms] | |
| | storcur [soilms] | |
| print_masbal_dpm.f | qblavyr | Average-annual water balance for the modeled area, in inches. |
| | qblavmo | Mean-monthly water balance for modeled area, in inches. |
| | mnthsall | Total number of months simulated no units. |
| | nym | Number of years that each month is simulated, no units. |
| | qbaldy [masbal] | |
| | qbalmo [masbal] | |
| | qbalyr [masbal] | |

## Model Schematic

A model schematic is created when a model is built in MMS. The schematic shows the links between modules; each module has input and output slots for variables. The schematic of a model resides in the 'models' directory of a user's MMS workspace. If a schematic is available when building a model, a user does not need to bring in each module and connect the input and output slots. An example of a model schematic for DPM is shown in figure 2, and an example of slots for the runoff_dpm.f module is shown in figure 3. Figure 3 is from a model building session using 'xmbuild'. The schematic is named 'xdpm.schem' and is provided in the downloads. A user would need to change the pathname in 'xdpm.schem' to correspond to their pathname for their MMS workspace.

## Order of Modules for Calculations

When a model is built in MMS using 'xmbuild', the order in which the modules will be processed (executed) needs to be defined. The order is defined by the input, physical process, and output of the modules.

The DPM module order is:

basin_parms_dpm.f
weather_siteinfo_dpm.f
obs_dpm.f
cropcof_dpm.f
grid_met_dpm.f
extrad_dpm.f
netrad_dpm.f
potet_dpm.f
intercept_dpm.f
snowpck_dpm.f
soilms_dpm.f
soilevap_dpm.f
transfer_dpm.f
plantet_dpm.f
runoff_dpm.f
runtru_dpm.f
masbal_dpm.f
basin_soilmoist_dpm.f
print_masbal_dpm.f
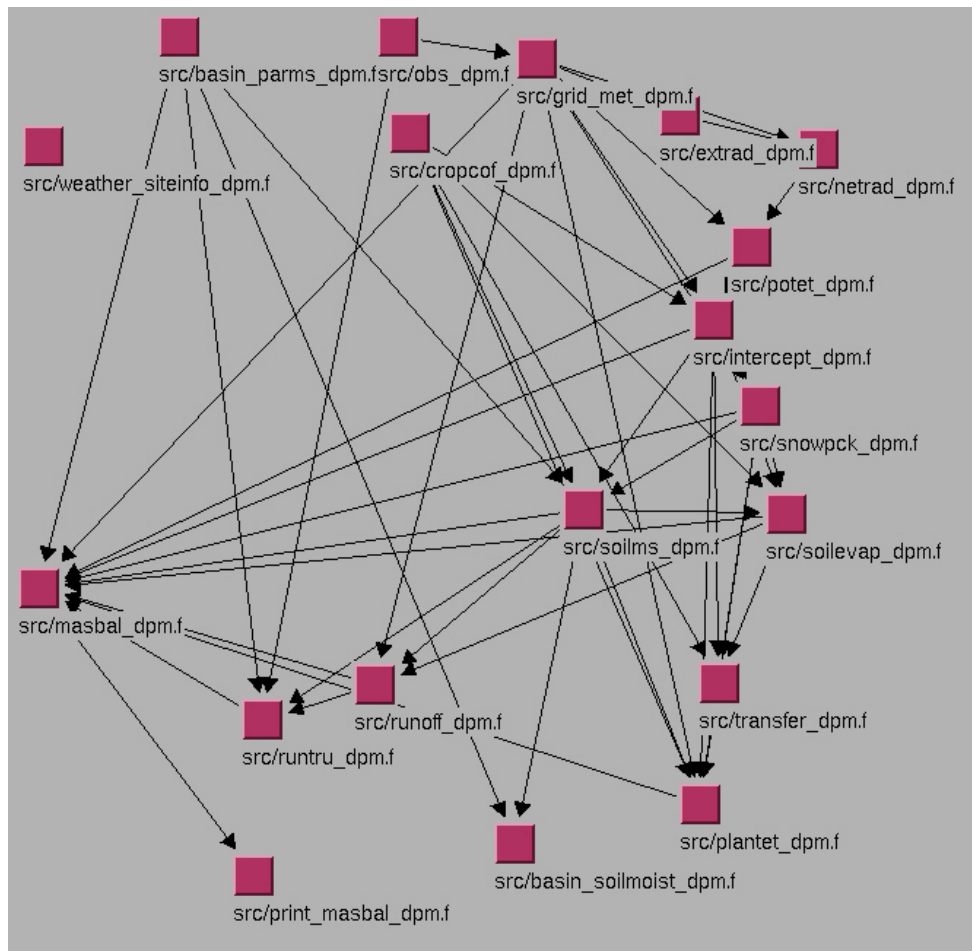


**Figure 2.**    Deep Percolation Model in the Modular Modeling System.
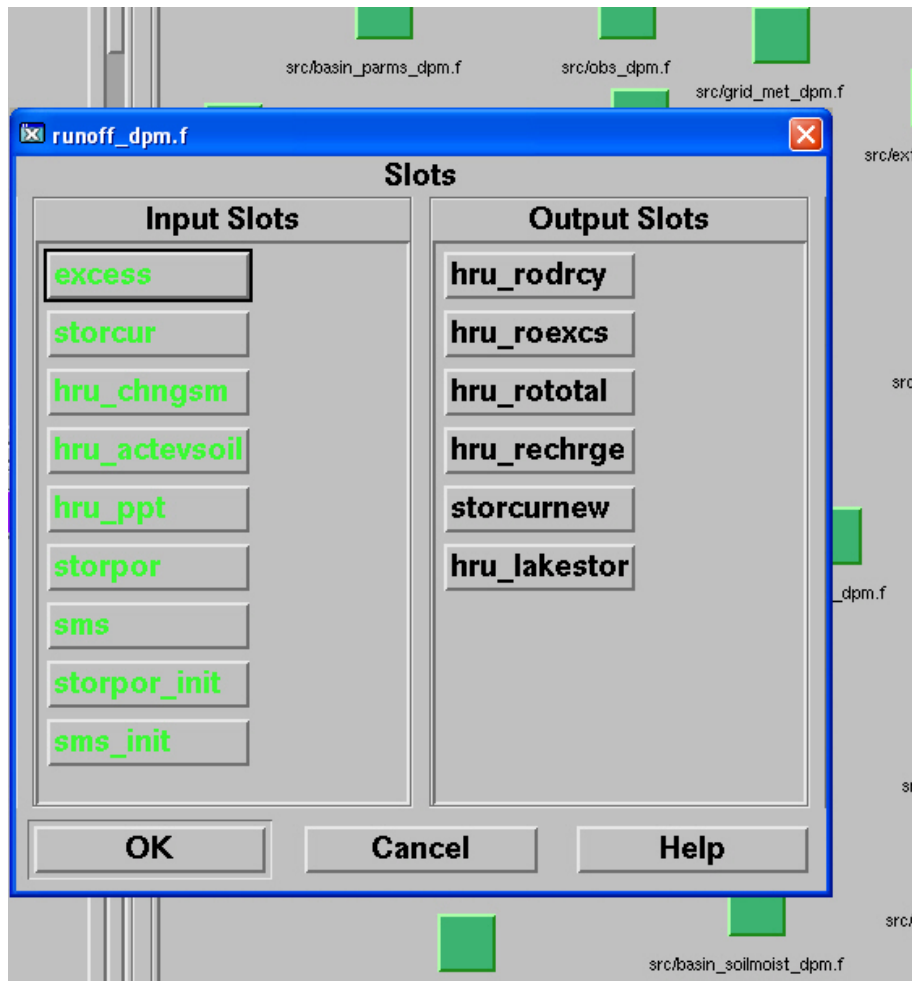
**Figure 3.**    Example of input and output slots for a model building part of the Modular Modeling System.

# Module Documentation

The modules are documented below, in the execution order, using the MMS module documentation standard. The documentation for each online module documentation can be seen by opening any of the highlighted module names. A short description of the purpose of the module is provided below the module name. The naming convention for modules that end in the suffix '.f' indicate a module is written in FORTRAN software language.

*basin_parms_dpm.f*—Establishes the parameters for the model area and writes input parameters to a file.

*weather_siteinfo_dpm.f*—Establishes the weather-station parameters for the model and writes input parameters to a file.

*obs_dpm.f*—Reads the observed data for each day.

*cropcof_dpm.f*—Declares, initializes, and then sets, for each day, the parameters for any of the 31 LULCs present in the modeled area.

*grid_met_dpm.f*—Declares, initializes, and then interpolates, for each day, the daily precipitation, maximum and minimum temperature, solar radiation, and throughfall data from meteorological observation sites to each HRU.

*extrad_dpm.f*—Calculates the clear sky solar radiation on horizontal and sloped surfaces for each HRU. The calculations can account for observed solar radiation values that have been interpolated to the HRUs. If there are no observed data, calculated values are used. The slope and aspect of the HRU are accounted for in the calculations.

*netrad_dpm.f*—Calculates the net radiation for a fir forest from incoming shortwave radiation (solar + sky reflected, as would be measured by a pyranometer). The formulation also is applied to cover types of water, grass, sage, barren soils, and impervious surfaces.

*potet_dpm.f*—Calculates potential evapotranspiration using either the Jensen-Haise or the Priestly-Taylor method for a HRU. Jensen-Haise incorporates coefficients that are a function of long-term average July minimum and maximum temperatures (warmest month of the year) and altitude. The Priestly-Taylor method uses net radiation.

*intercept_dpm.f*—Calculates intercepted part of precipitation and (or) irrigation for the HRUs, finds total amount of moisture on foliage/canopy, computes evaporated part of precipitation and (or) irrigation, reduces potential evapotranspiration by amount of intercepted water that has been evaporated, determines the change in canopy storage and the storage for the next day, and computes the throughfall part of precipitation/irrigation.

*snowpck_dpm.f*—Calculates snow accumulation, snowmelt, and sublimation. Calculates change in snowpack for the day for each HRU. Reduces available potential evapotranspiration by amount of energy used to sublimate snow.

*soilms_dpm.f*—Module only executes if there is surplus moisture after abstraction for plant interception. Surplus moisture is derived from precipitation as rainfall or snowmelt or from irrigation. Surplus moisture is used to first fill each layer in the field-capacity store from the top down. If there is remaining water, each layer in the saturated store is filled from the bottom up. Any water in excess of filling both stores for a HRU is saved in a variable. The soil is allowed to saturate with no percolation to subsoil (recharge) occurring. Recharge is controlled by user-specified infiltration rate, and it occurs after soils saturate in another module (runoff_dpm.f).

*soilevap_dpm.f*—Soil evaporation occurs from the three stores: excess water, saturated store, and unsaturated store. Excess water is evaporated at the potential evapotranspiration (PET) rate for all LULCs. Soil evaporation from the upper two 6-inch soil layers for the saturated and unsaturated stores is completed only for non-agricultural LULCs. Evaporation from the saturated store occurs at the PET rate. Soil evaporation from the unsaturated store is based on a relationship that is assumed to hold for all soils. The relationship uses the current percent volume of soil moisture in the uppermost foot and the remaining PET available after evaporation of intercepted moisture, evaporation of any excess water, and evaporation from the saturated store. PET is proportional to the amount of ground not shaded.

*transfer_dpm.f*—The part of potential evapotranspiration not used to evaporate soil moisture from the unshaded part of the soil is set to potential plant transpiration. This quantity is based on the foliar cover. The transfer is completed only for the cover types of forest, sage, grasslands, and bare soils and only when the foliar cover (cover density) is less than 60 percent. For all other cover types except water and impervious, all unused potential soil evaporation is transferred to potential plant transpiration.

*plantet_dpm.f*—Calculates the plant transpiration from available excess water, the saturated store, and the unsaturated store. Calculations are not completed for HRUs that have covers of water or impervious surfaces, are covered by snow, or the temperature is below freezing. Plant transpiration occurs first from excess water, then from the root or soil zone of the saturated store, and last from the root or soil zone of the unsaturated store. Note that for agricultural crops, the crop coefficients used in the Jensen-Haise method account for soil evaporation, and thus, the plant transpiration is representative of evapotranspiration.

*runoff_dpm.f*—Calculates the vertical infiltration into subsoil (recharge) using a constant infiltration rate, and lateral discharge from soil to stream (runoff), using Darcy's Law when the soil is fully or partially saturated.

*runtru_dpm.f*—Apportions observed stream discharge minus estimated baseflow (direct surface runoff) to each HRU. Apportioned discharge is based on ratio of simulated runoff for the HRU to the total for all HRUs without surface water. Soil moisture is reduced by the quantity of apportioned runoff and by the quantity of recharge.

*masbal_dpm.f*—Accumulates daily water-budget items for the HRUs, and calculates daily, monthly, and annual values and averages for the modeled area. If observed discharge data are used, then adjustments to the water budget are made on the basis of results from module runtru_dpm.f.

*basin_soilmoist_dpm.f*—Calculates current available water capacity and soil saturation for the modeled area, including the minimum and maximum HRU values. The deficit for each soil moisture store is also calculated for the modeled area. For each HRU, the deficit for each soil moisture store is also calculated.

*print_masbal_dpm.f*—Prints the daily, monthly, and annual water-budget (mass-balance) summary for the modeled area, and accumulates the monthly and annual water-budget items for outputting the simulation-period averages. Daily water budgets are optional.

# Example Parameter Input File

MMS has a defined format for the parameter input file, and the parameters for DPM are imbedded in this format. An example of a DPM-parameter-input file is listed in appendix 4. The listing should provide users with an understanding of the MMS format and a DPM parameter input file. The file also can be used as an input template for using the DPM plug-in for the GIS Weasel; the plug-in requires a DPM parameter-input file. Note that MMS input files have two lines before '** Dimensions **'.

The example DPM model has 1 HRU (nhru=1). The other model parameters identifying the dimensions for the data input show that there are 8 temperature gages (ntemp=8), 9 precipitation gages (nrain=9), and no observed streamflow/baseflow (nobs=0, nbsflw=0), solar radiation (nsol=0), snow (nsnow=0) or throughfall (nthru=0) data sites.

The HRU is located at 46° latitude (avelat=46.0) and its area is 1 mi$^2$ (hru_area=1.0). The slope of the HRU is 1 percent (hru_slope=1.0) with an aspect of 180° (south facing) (hru_aspect=180.), and an average elevation of 800 ft (hru_elev=800.). The long-term average monthly precipitation at the 9 (nrain) sites ranges from 0.18 in. during July to 3.71 in. during December.

In the example, the LULC is set to 28 (cov_type=28) for pasture. The pasture is irrigated from April 1 to September 15 (irrst1=0401, irren1=0509, irrst2=0510, irren2=0915). The application rate is 40 in. (hru_appld=40.), which will be applied equally (irrscd=0) for the scheduling period. The method of irrigation (hru_methd=0) has been defined as above the canopy (for example, wheel line), which allows for interception and subsequent evaporation of the applied water on the pasture grass.

The soil has eight 6-in. layers (nlayer=8) with a soil texture of loam (soil_type=2.0). The soil has a lateral hydraulic conductivity of 5 ft/d (solprm=5.) and a specific yield of 0.25 (spcyld=0.25). The vertical infiltration rate of the subsoil for the HRU is 10 in/yr (vksat=10.) The soil moisture limiting factor has been set to 0.0 (slmfac=0.0), indicating the AET/PET relation of Bauer and Vaccaro (1987) will be used and not the soil-coefficient limiting method described in Bauer and Mastin (1997).

The parameters required for the precipitation and temperature weather sites are at the end of the input file. Parameters that are calculated by the model, for example, the distance between a weather site and a HRU, are not included in the example file. If the parameters are edited and saved during the operation of MMS, the values for the calculated parameters are listed in the new parameter file and the order of the parameters will be different than in the example file.

# Example Output File

Output from operating DPM using the example parameter input file and a weather data input file is listed in appendix 5. The output principally lists (echoes) the input parameter file. A water budget for the modeled area for each month and year of simulation is at the end of the file, and includes the averages for the period of simulation. Output of daily water budgets is not listed, because the parameter dsum was less than 1 (dsum=0); for models that include either numerous HRUs or a long simulation period, it is not recommended to output daily water-budgets because of the potential large size of the output file.

The important part of the output file is the water and energy budgets. The items in the budgets are:

| | |
|---|---|
| DATE | Month and year |
| PRECP | Precipitation quantity |
| POTET | Potential evapotranspiration |
| CHGINT | Change in intercepted moisture on the plant foliage |
| RUNOFF | Direct surface runoff if input to model (none for this model) |
| RECHRG | Deep percolation leaving the root or soil zone |
| SOLPEV | Potential soil evaporation |
| ACTSEV | Actual soil evaporation (none because of agricultural crop) |
| SNWEVP | Snow evaporation (sublimation, a specified constant rate) |
| PPLTR | Potential plant transpiration |
| APLTR | Actual plant transpiration |
| CHGSM | Change in soil moisture |
| EVINT | Evaporation of intercepted water |
| CHGSNW | Change in snowpack |
| AVTMP | Average temperature |
| SYM-RO | Simulated surface runoff from root or soil zone |
| LAKE | Evaporation from water bodies |
| DEFCIT | Direct surface runoff not accounted for by incident moisture |
| IRRGTN | Irrigation rate |
| ERROR | Difference in mass balance |

The output of model variables is completed using MMS and not DPM. Users can select any variable or variables and create a MMS output file for the variable or variables for selected HRUs.

## Obtaining Model Code

Online module documentation can be accessed by opening any of the highlighted module names (which are URLs) listed in the 'Module Documentation' section.

The module source code is available at http://pubs.water.usgs.gov/sir20065318/source/. The source code for each module would reside in the 'modules/src' directory of a user's MMS workspace.

The model dimension files, 'fmodules.inc' and 'setdims.f', also can be obtained from http://pubs.water.usgs.gov/sir20065318/extras/. The 'fmodules.inc' file would replace the existing file in the user's MMS workspace directory 'modules/include'. The 'setdims.f' file would replace the existing file in the workspace directory 'modules/setdims'.

The model schematic file, 'xdpm.schem', also can be obtained at http://pubs.water.usgs.gov/sir20065318/extras/. This file would reside in the 'models' directory of the user's MMS workspace. The pathnames in the schematic file need to be changed to correspond to a user's pathnames.

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# Appendix 1.  Listing of Available Land Use and Cover Types for the Modules Composing the Deep Percolation Model.

[The cover type for each HRU is stored in the integer parameter cov_type. Each cover type is identified with a unique number, for example, a cover type of 1 means a HRU has a cover of conifer forests. Additional cover types are relatively easy to add, with all changes occurring in the module cropcof_dpm.f. For adding additional irrigated land uses, a subroutine in the module for an irrigated type, say, mint, could be used as a template and for native vegetation the grass or forest subroutines could be used as a template. Note that as described in the report, local conditions can affect both the single crop coefficients (Kc) and the length of a particular development stage for a cover type. These types of adjustments are readily completed by changing either the Kc values (called crp in the data line in a cover type subroutine) or the growing-season Julian dates (called jdate in a cover type subroutine) for the Kc values in a particular subroutine. Other changes would be needed in the initalization and run part of cropcof_dpm.f.]

| Cover type identifier | Cover type |
|---|---|
| 1 | Conifer forest |
| 2* | Grass—native or irrigated |
| 3 | Sagebrush |
| 4 | Winter wheat-harvested summer, planted fall |
| 5 | Winter wheat-harvested summner, fallow fall |
| 6 | Winter wheat-fallow summer, planted fall |
| 7 | Orchard-decidous trees and orchards, low latitudes |
| 8 | Alfalfa |
| 9 | Row crops-undifferentiated |
| 10 | Water |
| 11 | Corn |
| 12 | Potato |
| 13 | Barren soils-such as sand |
| 14 | Lentil |
| 15 | Spring wheat-planted, harvested fall |
| 16 | Impervious |
| 17 | Small vegetables–carrots, lettuce, etc., planted September, California |
| 18 | Cotton, Texas, expand growing season 40 days: Arizona or California |
| 19 | Mint |
| 20 | Grape, California |
| 21 | Grape, Washington and Oregon |
| 22 | Hops, Washington, Idaho, and Oregon |
| 23 | Olive tree, California |
| 24 | Citrus |
| 25 | Soybeans, central United States |
| 26 | Apple and other orchards |
| 27 | Sorghum, uses May 20 planting and 140-day growing season |
| 28 | Pasture–simplified for mid-latitudes |
| 29 | Bean |
| 30 | Pea |
| 31 | Asparagus |

*Representative of shallow rooted grasses; root depth, interception capacity, and growing season would need to be adjusted for native tall grass.

# Appendix 2.    Listing of the Dimensions, Modular Modeling System Declared Values, and Type for the Parameters for the Modules Composing the Deep Percolation Model.

[Parameters calculated by the model have '(calculated)' next to the parameter name and do not need to be input. Parameters are only listed if declared for the module under its name and parameters from other modules not listed. Units for parameters listed in table 1]

| Parameter | Dimension | Default value | Minimum value | Maximum value | Type |
|---|---|---|---|---|---|
| **MODULE:** basin_params_dpm | | | | | |
| hru_elev | nhru | 0 | -300 | 15,000 | Real |
| hru_area | nhru | 1.0 | 0.001 | 1e+09 | Real |
| hru_slope | nhru | 0 | 0 | .90 | Real |
| hru_aspect | hru | 0 | 0 | 360 | Real |
| hru_ylat | nhru | 0 | -1e+09 | 1e+09 | Real |
| hru_xlong | nhru | 0 | -1e+09 | 1e+09 | Real |
| hru_soil | nhru | 1 | 1 | 200 | Integer |
| cov_type | nhru | 1 | 1 | 31 | Integer |
| hru_appld | nhru | 0 | 0 | 72 | Real |
| hru_irr_methd | nhru | 0 | 0 | 1 | Integer |
| hru_mon_ppt | nhru,nmonths | 0 | 0 | 50 | Real |
| **MODULE:** weather_siteinfo_dpm.f | | | | | |
| kzone | one | 4,601 | 0 | 4,904 | Integer |
| ratemn | nmonths | 0 | .0 | 4 | Real |
| ratemx | nmonths | 2.0 | .0 | 4 | Real |
| tsta_x | ntemp | 0 | -10,000,000 | 10,000,000 | Real |
| tsta_y | ntemp | 0 | -10,000,000 | 10,000,000 | Real |
| tsta_elev | ntemp | 0 | -300 | 30,000 | Real |
| tnjulav | ntemp | 40 | 33 | 80 | Real |
| txjulav | ntemp | 70 | 40 | 100 | Real |
| psta_x | nrain | 0 | -10,000,000 | 10,000,000 | Real |
| psta_y | mrain | 0 | -10,000,000 | 10,000,000 | Real |
| psta_mon_ppt | nrain,nmonths | 0 | 0 | 60 | Real |
| thrusta_x | nthru | 0 | -10,000,000 | 10,000,000 | Real |
| thrusta_y | nthru | 0 | -10,000,000 | 10,000,000 | Real |
| covthru | nthru | 0 | 0 | 15 | Integer |
| solsta_x | nsol | 0 | -10,000,000 | 10,000,000 | Real |
| solsta_y | nsol | 0 | -10,000,000 | 10,000,000 | Real |
| **MODULE:** cropcof_dpm.f | | | | | |
| fcmax | nlands | 0.0 | 0.0 | 1.0 | Real |
| maxint | nlands | 0.0 | .0 | .3 | Real |
| rdmax | nlands | 0.0 | .0 | 60 | Real |
| irrst1 | nlands | 0 | 0 | 1231 | Integer |
| irren1 | nlands | 0 | 0 | 1231 | Integer |
| irrst2 | nlands | 0 | 0 | 1231 | Integer |
| irren2 | nlands | 0 | 0 | 1231 | Integer |
| irrscd | nlands | 0 | 0 | 1 | Integer |
| sumcp (calculated) | nlands | 0.0 | 0.0 | 26 | Real |
| iroot | one | 0 | 0 | 1 | Integer |
| fallow (calculated) | one | 0 | 0 | 1 | Integer |
| **MODULE:** grid_met_dpm.f | | | | | |
| distp (calculated) | nhru,nrain | 0 | -10,000,000 | 10,000,000 | Real |
| distt (calculated) | nhru,ntemp | 0 | -10,000,000 | 10,000,000 | Real |
| distr (calculated) | nhru,nsol | 0 | -10,000,000 | 10,000,000 | Real |
| disttf (calculated) | nhru,nthru | 0 | -10,000,000 | 10,000,000. | Real |
| elfac (calculated) | nhru,ntemp | .0 | .0 | 10.0 | Real |

# Appendix 2.    Listing of the Dimensions, Modular Modeling System Declared Values, and Type for the Parameters for the Modules Composing the Deep Percolation Model.—Continued

[Parameters calculated by the model have '(calculated)' next to the parameter name and do not need to be input. Parameters are only listed if declared for the module under its name and parameters from other modules not listed. Units for parameters listed in <u>table 1</u>]

| Parameter | Dimension | Default value | Minimum value | Maximum value | Type |
|---|---|---|---|---|---|
| **MODULE: extrad_dpm.f** | | | | | |
| avelat | one | 30 | 20 | 60 | Real |
| **MODULE: netrad_dpm.f** | | | | | |
| slrxfmx | nmonths | 1.0 | 0.20 | 1.0 | Real |
| **MODULE: potet_dpm.f** | | | | | |
| ct (calculated) | nhru | 0 | 0 | 600 | Real |
| tx (calculated) | nhru | 0 | 0 | 600 | Real |
| petmin | nmonths | 0 | 0 | 60 | Real |
| **MODULE: snowpck_dpm.f** | | | | | |
| strtsno | one | 0.0 | 0 | 400 | Real |
| sblrate | one | .01 | .001 | .02 | Real |
| snmcoef | one | .04 | .001 | .1 | Real |
| uadj | one | .15 | .001 | .20 | Real |
| **MODULE: soilms_dpm.f** | | | | | |
| unsatmax (calculated) | nhru | 2.0 | 0 | 24 | Real |
| stormax (calculated) | nhru | 2.0 | 0 | 24 | Real |
| avlcap | nsoils | .05 | 0 | .7 | Real |
| spcyld | nsoils | .20 | .02 | .45 | Real |
| solprm | nsoils | 5.0 | 0 | 500 | Real |
| soil_type | nsoils | 2.0 | 1.0 | 3.0 | Real |
| nlayer | nsoils | 4 | 1 | 14 | Integer |
| strtsms | one | 0.0 | 0.0 | 1 | Real |
| strtpor | one | 0.0 | 0.0 | 1 | Real |
| **MODULE: soilevap_dpm.f** | | | | | |
| None | | | | | |
| **MODULE: plantet_dpm.f** | | | | | |
| slmfac | nsoils | 0.0 | 0.0 | 0.9 | Real |
| **MODULE: runoff_dpm.f** | | | | | |
| vksat | nhru | 10 | 0 | 100 | Real |
| efflngth | nhru | 1,000 | 0 | 10,000 | Real |
| effslp | nhru | .05 | 0 | .75 | Real |
| **MODULE: runtru_dpm.f** | | | | | |
| bsnara | one | 1.0 | 0.01 | 1e+05 | Real |
| **MODULE: masbal_dpm.f** | | | | | |
| dsum | one | 0 | 0 | 1 | Integer |
| **MODULE: print_masbal_dpm.f** | | | | | |
| mobdgt | one | 9 | 1 | 12 | Integer |
| nbdgdys (calculated) | one | 1 | 1 | 5,000 | Integer |
| kntmos (calculated) | one | 1 | 1 | 5,000 | Integer |

# Appendix 3.   Listing of the National Ocean Service State-Plane Zone Numbers for the Continental United States.

[The zone number is used to convert the model parameters with latitude and longitude to state-plane coordinates]

| State | Zone name | Zone No. | State | Zone name | Zone No. |
|---|---|---|---|---|---|
| Alabama | East | 101 | Iowa | North | 1401 |
|  | West | 102 |  | South | 1402 |
| Arizona | East | 201 | Kansas | North | 1501 |
|  | Central | 202 |  | South | 1502 |
|  | West | 203 | Kentucky | North | 1601 |
| Arkansas | North | 301 |  | South | 1602 |
|  | South | 302 | Louisiana | North | 1701 |
| California | I | 401 |  | South | 1702 |
|  | II | 402 |  | Offshore | 1703 |
|  | III | 403 | Maine | East | 1801 |
|  | IV | 404 |  | West | 1802 |
|  | V | 405 | Maryland |  | 1900 |
|  | VI | 406 | Massachusetts | Mainland | 2001 |
|  | VII | 407 |  | Island | 2002 |
| Colorado | North | 501 | Michigan (Tr Merc) | East | 2101 |
|  | Central | 502 |  | Central | 2102 |
|  | South | 503 |  | West | 2103 |
| Connecticut |  | 600 |  | North | 2111 |
| Delaware |  | 700 |  | Central | 2112 |
| District of Columbia | Use Maryland or Virginia North |  | (Lambert) | South | 2113 |
| Florida | East | 901 | Minnesota | North | 2201 |
|  | West | 902 |  | Central | 2202 |
|  | North | 903 |  | South | 2203 |
| Georgia | East | 1001 | Mississippi | East | 2301 |
|  | West | 1002 |  | West | 2302 |
| Guam |  |  | Missouri | East | 2401 |
| Idaho | East | 1101 |  | Central | 2402 |
|  | Central | 1102 |  | West | 2403 |
|  | West | 1103 | Montana | North | 2501 |
| Illinois | East | 1201 |  | Central | 2502 |
|  | West | 1202 |  | South | 2503 |
| Indiana | East | 1301 | Nebraska | North | 2601 |
|  | West | 1302 |  | South | 2602 |

# Appendix 3.    Listing of the National Ocean Service State-Plane Zone Numbers for the Continental United States.—Continued

[The zone number is used to convert the model parameters with latitude and longitude to state-plane coordinates]

| State | Zone name | Zone No. | State | Zone name | Zone No. |
|---|---|---|---|---|---|
| Nevada | East | 2701 | South Dakota | North | 4001 |
| | Central | 2702 | | South | 4002 |
| | West | 2703 | Tennessee | | 4100 |
| New Hampshire | | 2800 | Texas | North | 4201 |
| New Jersey | | 2900 | | North Central | 4202 |
| New Mexico | East | 3001 | | Central | 4203 |
| | Central | 3002 | | South Central | 4204 |
| | West | 3003 | | South | 4205 |
| New York | East | 3101 | Utah | North | 4301 |
| | Central | 3102 | | Central | 4302 |
| | West | 3103 | | South | 4303 |
| | Long Island | 3104 | Vermont | | 4400 |
| North Carolina | | 3200 | Virginia | North | 4501 |
| North Dakota | North | 3301 | | South | 4502 |
| | South | 3302 | Washington | North | 4601 |
| Ohio | North | 3401 | | South | 4602 |
| | South | 3402 | West Virginia | North | 4701 |
| Oklahoma | North | 3501 | | South | 4702 |
| | South | 3502 | Wisconsin | North | 4801 |
| Oregon | North | 3601 | | Central | 4802 |
| | South | 3602 | | South | 4803 |
| Pennsylvania | North | 3701 | Wyoming | East | 4901 |
| | South | 3702 | | East Central | 4902 |
| Rhode Island | | 3800 | | West Central | 4903 |
| South Carolina | North | 3901 | | West | 4904 |
| | South | 3902 | | | |

# Appendix 4.    Listing of an Example Parameter Input File for the Deep Percolation Model.

Data are available for download at http://pubs.water.usgs.gov/sir2006-5318.

# Appendix 5.    Listing of Model Output File using the Example Parameter Input File for the Deep Percolation Model.

Data are available for download at http://pubs.water.usgs.gov/sir2006-5318.

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A Deep Percolation Model for Estimating Ground-Water Recharge:
Documentation of Modules for the Modular Modeling System of the U.S. Geological Survey

SIR 2006–5318