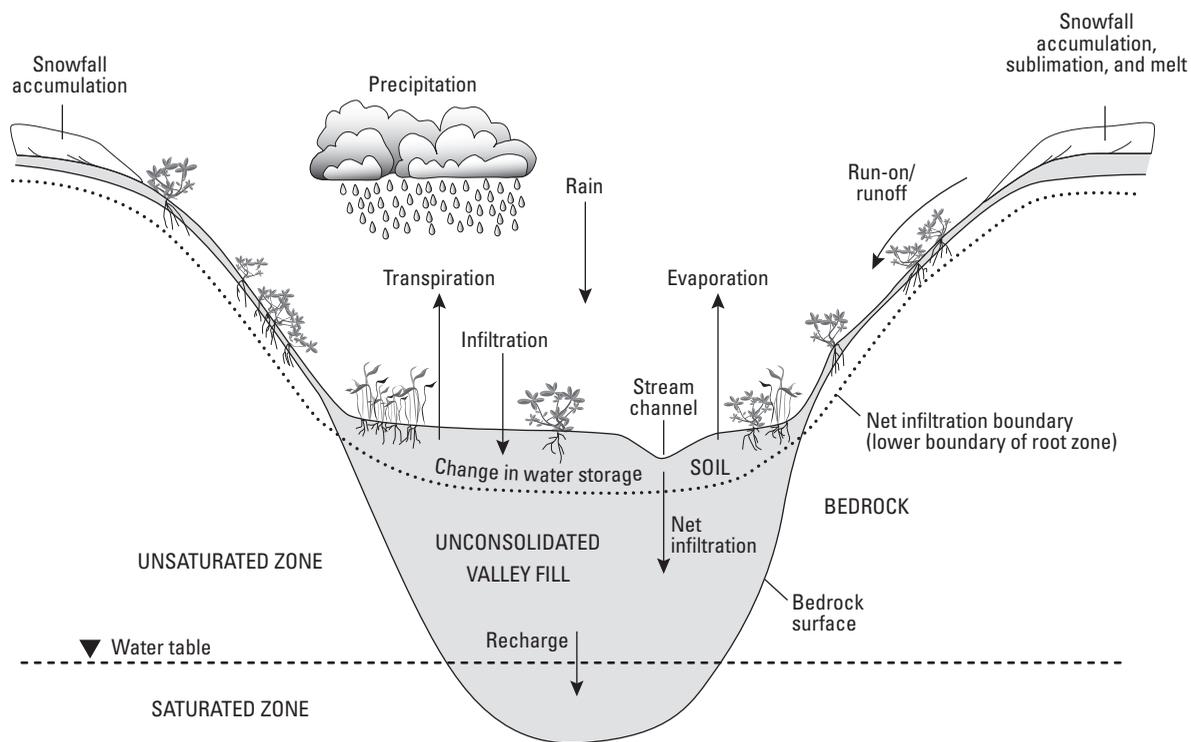


Documentation of Computer Program INFIL3.0— A Distributed-Parameter Watershed Model to Estimate Net Infiltration Below the Root Zone



Scientific Investigations Report 2008–5006

Cover. Schematic illustration showing some of the water-balance processes controlling net infiltration as simulated in the INFIL3.0 model.

Documentation of Computer Program INFIL3.0—A Distributed-Parameter Watershed Model to Estimate Net Infiltration Below the Root Zone

Scientific Investigations Report 2008–5006

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

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2008

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Preface

This report describes the computer program INFIL3.0, which is a grid-based, distributed-parameter, deterministic water-balance watershed model that calculates the temporal and spatial distribution of daily net infiltration of water across the lower boundary of the root zone. The bottom of the root zone is the estimated maximum depth below ground surface affected by evapotranspiration. In many field applications, net infiltration can be assumed to equal net recharge to an underlying water-table aquifer.

Earlier versions of the INFIL code were developed by the U.S. Geological Survey in cooperation with the Department of Energy to estimate net infiltration and ground-water recharge at the proposed Yucca Mountain high-level nuclear-waste repository site in Nevada. The version of the code described in this report (INFIL3.0) is a modification of these earlier versions. This version of the code was modified and tested by U.S. Geological Survey staff in the Office of Ground Water.

The code can be obtained using the Internet at address http://water.usgs.gov/software/ground_water.html. Instructions for running the program can be found at the same Internet address.

The performance of the program has been tested in a variety of applications. Future applications, however, might reveal errors that were not detected in the test simulations. Users are requested to send notification of any errors found in this report or the model program to:

Office of Ground Water
U.S. Geological Survey
411 National Center
Reston, VA 20192
(703) 648-5001

Updates might be made to both the report and to the model program. Users can check for updates at the Internet address above.

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
cubic meter (m ³)	0.0002642	million gallons (Mgal)
cubic meter (m ³)	35.31	cubic foot (ft ³)
Flow rate		
meter per second (m/s)	3.281	foot per second (ft/s)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year (ft/yr)
cubic meter per second (m ³ /s)	35.31	cubic foot per second (ft ³ /s)
cubic meter per day (m ³ /d)	35.31	cubic foot per day (ft ³ /d)
cubic meter per second (m ³ /s)	22.83	million gallons per day (Mgal/d)
millimeters per day (mm/d)	0.03937	inch per day (in/d)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
Pressure		
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
kilopascal (kPa)	0.01	bar
kilopascal (kPa)	20.88	pound per square foot (lb/ft ²)
kilopascal (kPa)	0.1450	pound per square inch (lb/in ²)
Density		
kilogram per cubic meter (kg/m ³)	0.06242	pound per cubic foot (lb/ft ³)
Energy		
joule (J)	0.0000002	kilowatthour (kWh)
Gravitational acceleration		
meter per square second (m/s ²)	3.281	foot per square second (ft/s ²)

Temperature in degrees Celsius ($^{\circ}\text{C}$) may be converted to degrees Fahrenheit ($^{\circ}\text{F}$) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit ($^{\circ}\text{F}$) may be converted to degrees Celsius ($^{\circ}\text{C}$) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Temperature in degrees Celsius ($^{\circ}\text{C}$) may be converted to degrees Kelvin ($^{\circ}\text{K}$) as follows:

$$^{\circ}\text{K}=^{\circ}\text{C}+273.15$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

The latent heat of vaporization of water is measured in megajoules per kilogram (MJ/kg), which can be converted to megacalories per pound by multiplying MJ/kg by 0.1083. Energy units are reported in megajoules per square meter per day (MJ/m²/d), which can be converted to megacalories per square foot per day by multiplying MJ/m²/d by 0.0222.

Documentation of Computer Program INFIL3.0— A Distributed-Parameter Watershed Model to Estimate Net Infiltration Below the Root Zone

Abstract

This report documents the computer program INFIL3.0, which is a grid-based, distributed-parameter, deterministic water-balance watershed model that calculates the temporal and spatial distribution of daily net infiltration of water across the lower boundary of the root zone. The bottom of the root zone is the estimated maximum depth below ground surface affected by evapotranspiration. In many field applications, net infiltration below the bottom of the root zone can be assumed to equal net recharge to an underlying water-table aquifer. The daily water balance simulated by INFIL3.0 includes precipitation as either rain or snow; snowfall accumulation, sublimation, and snowmelt; infiltration into the root zone; evapotranspiration from the root zone; drainage and water-content redistribution within the root-zone profile; surface-water runoff from, and run-on to, adjacent grid cells; and net infiltration across the bottom of the root zone.

The water-balance model uses daily climate records of precipitation and air temperature and a spatially distributed representation of drainage-basin characteristics defined by topography, geology, soils, and vegetation to simulate daily net infiltration at all locations, including stream channels with intermittent streamflow in response to runoff from rain and snowmelt. The model does not simulate streamflow originating as ground-water discharge. Drainage-basin characteristics are represented in the model by a set of spatially distributed input variables uniquely assigned to each grid cell of a model grid.

The report provides a description of the conceptual model of net infiltration on which the INFIL3.0 computer code is based and a detailed discussion of the methods by which INFIL3.0 simulates the net-infiltration process. The report also includes instructions for preparing input files necessary for an INFIL3.0 simulation, a description of the output files that are created as part of an INFIL3.0 simulation, and a sample problem that illustrates application of the code to a field setting. Brief descriptions of the main program routine and of each of the modules and subroutines of the INFIL3.0 code, as well as definitions of the variables used in each subroutine, are provided in an appendix.

Introduction

The estimation of net infiltration of water below the root zone is important for quantifying the potential recharge to an underlying water-table aquifer. Although many methods are available to estimate net infiltration and (or) ground-water recharge, one of the most technically advanced is watershed modeling, which allows for the determination of temporally distributed net infiltration and recharge at locations distributed throughout a watershed. One such watershed model is the INFIL computer code. INFIL is a grid-based, distributed-parameter, deterministic precipitation-runoff and net-infiltration water-balance simulation model. Net infiltration is defined as the downward drainage of water across the lower boundary of the root zone, in which the bottom of the root zone is the estimated maximum depth below ground surface affected by evapotranspiration. Net infiltration consists of three possible water sources—rain, snowmelt, and surface-water run-on (runoff and streamflow) to each grid cell within the simulation domain.

INFIL uses a daily simulation time step to estimate the water balance, an hourly simulation time step to estimate the solar-radiation energy balance used to define potential evapotranspiration, and a multilayered root zone for simulating the processes of net infiltration and actual evapotranspiration from the root zone. The primary climatic inputs to the model are daily precipitation and maximum and minimum air temperature. These data from one or more climatic stations represent climate within the simulation domain, even if the stations are not located within the simulation domain. The INFIL model provides a detailed representation of spatially distributed drainage-basin characteristics such as vegetation, soil, and bedrock types; topographic variables such as land-surface elevation, slope, and aspect; and hydrologic processes including calculation of potential evapotranspiration, actual soil-zone evapotranspiration, and snowfall accumulation, sublimation, and snowmelt. Simulation results include a continuous time series of the daily water balance for the root zone (and for the individual root-zone layers). The daily time-series output includes simulated runoff (streamflow for channel locations), which can be compared to measured streamflow for model calibration. A primary benefit of the

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INFIL modeling approach is the generation of spatially detailed daily, annual, and average annual values representing all components of the water-balance model; these simulated results help to provide an understanding of the mechanisms responsible for net infiltration, runoff, and potential recharge. Model results can be mapped and subsequently used to evaluate the integrated effect of spatially distributed climate, terrain, and watershed characteristics (for example, vegetation, soils, and geology) on the spatial distribution of runoff and potential recharge.

INFIL was initially developed for application to the Yucca Mountain area of Nevada (Flint and others, 2001) and was subsequently extended for application to the larger Death Valley region of Nevada and California within which Yucca Mountain is located (Hevesi and others, 2002; 2003). The model also has been applied to estimate recharge for the area near Joshua Tree, California, by Nishikawa and others (2004), the San Geronio Pass area, Riverside County, California, by Rewis and others (2006), and the Big Bear Lake area, California (L.E. Flint, U.S. Geological Survey, written commun., April 2007).

The purpose of this report is to document a new version of the INFIL code, which is called INFIL3.0. The report describes the conceptual model of net infiltration on which the computer code is based and discusses the methods by which INFIL3.0 simulates the net-infiltration process. The report includes instructions for preparing the input files for an INFIL3.0 simulation, a description of the output files that are created as part of an INFIL3.0 simulation, and a sample problem that illustrates application of the code to a field setting. Brief descriptions of the main program routine and of each of the modules and subroutines of the INFIL3.0 code, as well as definitions of the variables used in each subroutine, are provided in appendix 2.

Development of Computer Program INFIL3.0

Conceptual Model of Net Infiltration

The INFIL3.0 model is based on a conceptual model of the physical processes that control net infiltration. The conceptual model was developed to represent the major components of the water balance for arid to semiarid environments, but may be applicable to more humid regions as well. The components of the water balance considered in the conceptual model include precipitation; snowfall accumulation, sublimation, and snowmelt; infiltration of rain, snowmelt, and surface-water run-on into soil or bedrock; runoff; surface-water run-on; bare-soil evaporation; transpiration from the root zone; redistribution, or changes in water content, in the root zone; and net infiltration across the

lower boundary of the root zone. Many of these water-balance components are illustrated in figure 1. The conceptual model defines net infiltration as downward drainage, or flux, across the lower boundary of the root zone, or the depth at which the seasonal effects of evapotranspiration become insignificant. The conceptual model provides a framework for applying a water-balance modeling approach to develop a numerical net-infiltration model that uses a horizontal grid of model nodes (cells) and a vertical discretization representing the root zone as a series of layers having variable thicknesses (fig. 2).

The conceptual model defines rain, snowmelt, and surface-water run-on as inputs to a layered root-zone water-balance model with one to five soil layers and a lower bedrock layer (fig. 2). Rain, snowmelt, or surface-water run-on infiltrates the soil or bedrock across the air-soil or air-bedrock interface, and then drains downward through the root zone. For each model cell, the number and thickness of layers is dependent on soil thickness, with the thickness of the lower bedrock layer increasing with decreasing soil thickness. The layers define storage components for the root zone, where root density decreases from the top to the bottom layer, and where the processes of evapotranspiration and downward drainage are dependent on the quantity of water stored in each layer and variables estimated on the basis of the vegetation, soil, and geology at each grid-cell location.

Evapotranspiration is dependent on both the water content of the root zone and potential evapotranspiration, and is separated into a bare-soil evaporation component and a transpiration component. The transpiration component is dependent on estimated root densities for each root-zone layer. Downward drainage is constrained by the saturated vertical hydraulic conductivity of the layers, the relative saturation of the layers, and the available storage capacity of the underlying layer. When the input of water to the root zone exceeds the available storage or conductance capacity of the surface layer, runoff is generated as an output component of the root-zone water balance. Runoff is routed to downstream grid cells as surface-water run-on.

During the surface-water routing process, run-on may infiltrate back into the root zone, depending on the vertical hydraulic conductivity and available storage capacity of the top layer; thus, run-on becomes an input component to the root-zone water balance. In the conceptual model, all runoff originates as excess rain, snowmelt, or surface-water run-on, and all run-on to downslope grid cells originates as runoff. Streamflow is modeled as runoff that is routed downstream from the side slopes and interchannel areas and concentrated into the channels defined by the topography. Streamflow originating as discharge from springs or as streambank seepage along gaining streams is not included in the conceptual model of net infiltration.

Redistribution of water in the root zone occurs through the combined effects of downward drainage through soil or rock and evapotranspiration after water has stopped infiltrating at the ground surface. In the conceptual model, redistribution owing to lateral flow in the root zone is assumed to be

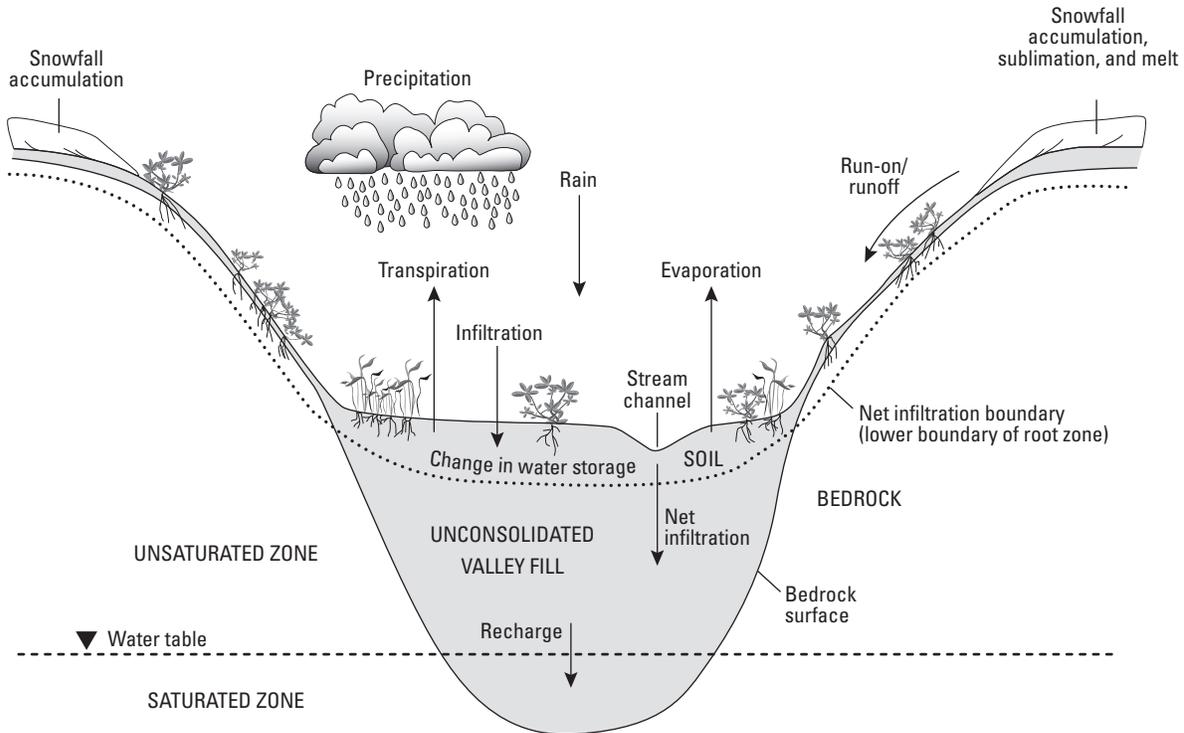


Figure 1. Some of the water-balance processes controlling net infiltration as simulated in the INFIL3.0 model.

negligible. Downward drainage through the root-zone layers can eventually result in drainage through the bottom layer (either bedrock or soil); drainage through the bottom layer is the net-infiltration output component from the root-zone water balance. Net infiltration is the drainage flux, or flow rate, at the shallowest depth beneath the ground surface where evapotranspiration no longer affects the downward drainage of infiltrated water (Flint and others 2001; Hevesi and others, 2002). In the conceptual model, the approximate depth of net infiltration is variable in both space and time. The INFIL3.0 model, however, is based on the assumption that the temporal variability in the depth of net infiltration is insignificant relative to the spatial variability in the depth of net infiltration as defined by the variable thickness of the root zone.

Simulation of Net Infiltration

The conceptual model of net infiltration forms the basis for development of a daily water-balance model that simulates the processes that affect net infiltration of water across the

lower boundary of the root zone. The lower boundary of the root zone is taken to be the maximum depth below ground surface at which plant roots can extract water and soil water can be evaporated—that is, the maximum depth affected by evapotranspiration. In the remainder of the report, the term “net infiltration” is used to refer to the movement of water across the lower boundary of the root zone.

This section describes the several components of INFIL3.0. A flowchart showing the major components of the INFIL3.0 code is provided in figure 3. In the discussion that follows, variables used in mathematical equations are written in upper- and lower-case plain italics (such as NI_d^i , which is the net infiltration for day d and grid location i , in millimeters), whereas variables used in the computer program are written in lower-case plain bold text (such as **celsize**, which is the length of each side of each model grid cell, in meters). Also, references are made to several input files that are required for an INFIL3.0 simulation. Each of these files is described in detail in the “Input Instructions” section of the report, and sample files are provided for many of the input files in the “Sample Problem” section of the report.

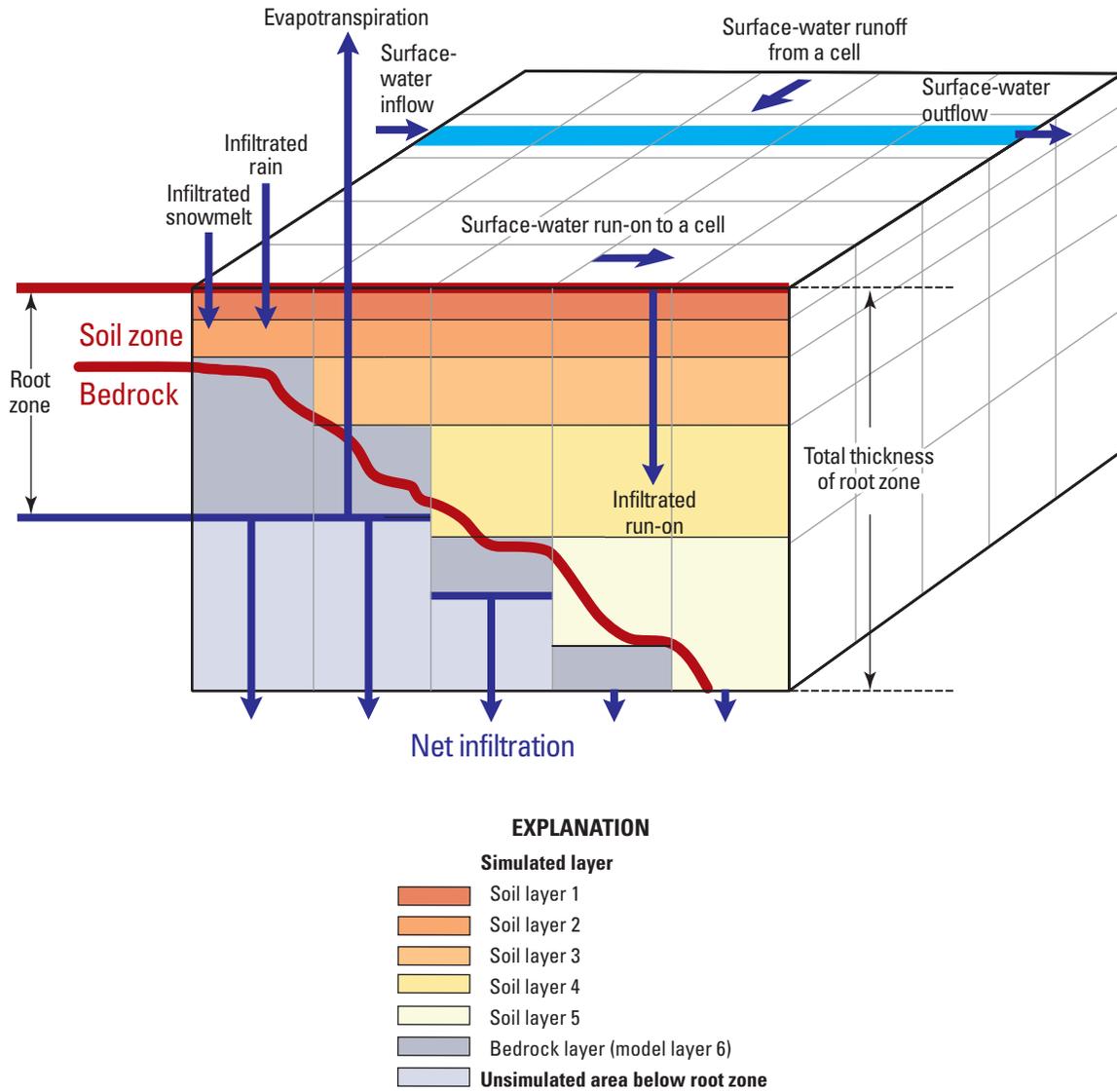


Figure 2. Vertical discretization of the root zone as a series of model layers.

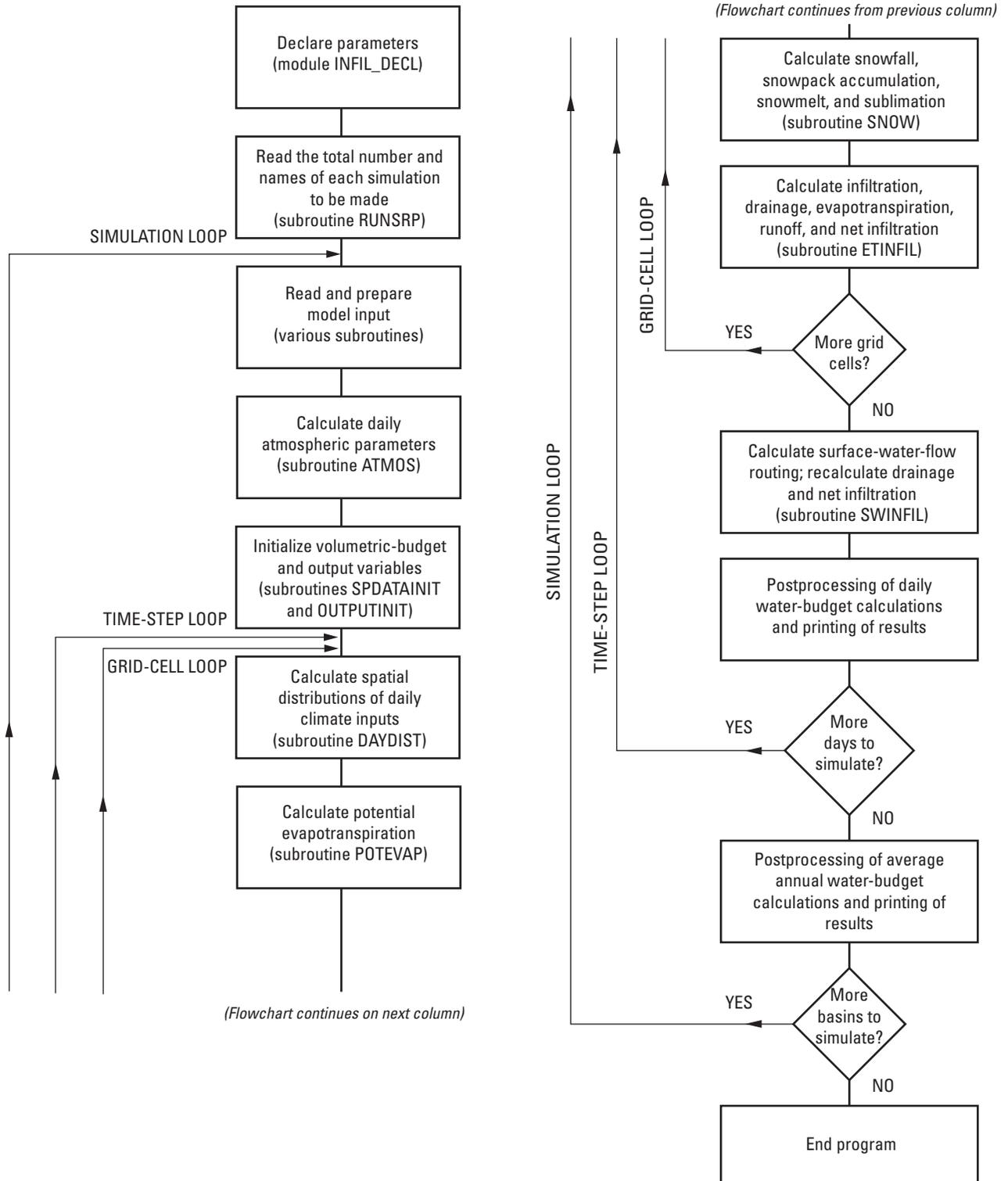


Figure 3. Flowchart of the primary components of the INFIL3.0 model algorithm for simulating net infiltration. (Code subroutines and modules associated with each component are shown in parentheses.)

Net-Infiltration Water-Balance Model and Overview of INFIL3.0 Program

The daily root-zone water-balance simulation model is based on the governing equation

$$NI_d^i = RAIN_d^i + MELT_d^i + Ron_d^i - Roff_d^i - \sum_{j=1}^6 (\Delta W_d^i)_j - ET_d^i, \quad (1)$$

where

NI_d^i	is the net infiltration for day d and grid location i , in millimeters;
$RAIN_d^i$	is precipitation occurring as rain for day d and grid location i , in millimeters;
$MELT_d^i$	is snowmelt for day d and grid location i , in millimeters;
Ron_d^i	is infiltration to the root zone due to surface-water run-on for day d to grid location i , in millimeters;
$Roff_d^i$	is surface-water runoff for day d from grid location i , in millimeters;
$\sum_{j=1}^6 (\Delta W_d^i)_j$	is the total change in root-zone water storage for all six model layers ($j = 1 - 6$) for day d and grid location i , in millimeters; and
ET_d^i	is the total bare-soil evaporation and root-zone transpiration for all six root-zone layers for day d and grid location i , in millimeters.

Water-balance calculations are based on water volumes under the assumption that temperature effects on water density are negligible. The water-balance calculations are done using water-equivalent depths, defined as the depth of water in millimeters over the area of each root-zone layer for each grid cell, because the model discretization uses equal-area grid cells. The simulation is done for a continuous time series of daily water-balance calculations. Secondary governing equations are used to represent other components of the daily water balance that are not directly defined by equation 1, such as the hourly energy-balance calculation used for potential evapotranspiration. These secondary equations are described in detail in the sections that follow.

INFIL3.0 requires several types of input information, including (1) an estimate of initial root-zone water contents; (2) a daily time-series input consisting of total daily precipitation and maximum and minimum air temperatures; and (3) a set of model input variables that define drainage-basin characteristics, model coefficients for simulating evapotranspiration, drainage, and the spatial distribution of daily precipitation and air temperature, average monthly atmospheric conditions, and user-defined run-time options. For a multiyear simulation period, the components of the daily water balance calculated by the model are used to calculate total monthly and annual quantities and average annual rates.

An INFIL3.0 simulation consists of (1) a set of preprocessing steps for developing model inputs, (2) model initialization, (3) a simulation loop used for multiple simulations of a single watershed domain or for simulating a drainage network consisting of multiple watershed domains, (4) a daily water-balance loop, and (5) postprocessing of the daily results for developing daily, monthly, annual, and average annual values for all water-balance terms. The daily water-balance loop includes subroutines that provide estimates of the components of the water balance, such as potential evapotranspiration, snowmelt, and sublimation. The potential evapotranspiration subroutine includes an hourly solar-radiation loop for calculating the net radiation-energy balance.

The primary computational subroutines are (fig. 3):

1. DAYDIST, a spatial-interpolation algorithm for estimating daily precipitation and air temperature at each grid cell;
2. POTEVAP, a potential-evapotranspiration model that uses incoming solar radiation calculated on an hourly basis;
3. SNOW, a snowfall, snow accumulation, snowmelt, and sublimation model;
4. ETINFIL, a root-zone infiltration and evapotranspiration routine; and
5. SWINFIL, a surface-water flow-routing and root-zone-infiltration algorithm.

Total daily net infiltration, which is based on a root-zone drainage function, is the sum of net infiltration calculated by the ETINFIL and SWINFIL routines.

For each daily time step, the application of the SWINFIL routine is dependent on whether runoff is generated at any model grid location following an initial water-balance calculation for the root zone by the ETINFIL routine. For the initial calculation, infiltration into the root zone, evapotranspiration, changes in the root-zone water content, and net infiltration in direct response to rainfall and snowmelt are calculated by ETINFIL to determine runoff generation. If runoff is not generated, the simulation is continued to the next day. If runoff is generated (as excess rainfall or snowmelt), the surface-water-routing algorithm is activated (subroutine SWINFIL). Although infiltration to and drainage through the root zone is simulated during the flow-routing algorithm (subroutine SWINFIL), evapotranspiration is not calculated during the algorithm. During the routing process, surface-water run-on may infiltrate into the root zone depending on the soil and bedrock vertical hydraulic conductivity and the available storage capacity of the root zone. The new value for root-zone water content is then used as the initial condition for the next day's water-balance calculations. Water that infiltrates into the root zone during the surface-water-routing process is subject to evapotranspiration the next day. Surface-water flow that does not infiltrate into the root zone becomes surface-water discharge from the drainage basin (watershed) being modeled. In closed basins, surface water is routed to a single grid cell at the lowest elevation of the basin and is assumed

to evaporate. Real-time streamflow is not simulated by the SWINFIL routine; all outflow is assumed to occur within a daily time step. For this reason, the INFIL3.0 model may not calculate accurate streamflow values for large watersheds characterized by a delayed response to runoff generated in upstream parts of the watershed.

The daily water balance is simulated as a continuous time series for multiyear periods, and an average net-infiltration rate is calculated on the basis of the daily results. Average annual water-balance calculations are made for each water-balance term, which allows for an overall water-balance check for each grid cell and for the entire model domain. The water-balance check for each grid cell is

$$MB^i = RAIN^i + MELT^i + Ron^i - Roff^i - \sum_{j=1}^6 (\Delta W^i)_j - ET^i - NI^i, \quad (2)$$

where

MB^i	is the water-balance check at grid location i , in millimeters;
$RAIN^i$	is precipitation occurring as rain at grid location i , in millimeters;
$MELT^i$	is snowmelt at grid location i , in millimeters;
Ron^i	is infiltration to the root zone from surface-water run-on at grid location i , in millimeters;
$Roff^i$	is surface-water runoff from grid location i , in millimeters;
$\sum_{j=1}^6 (\Delta W^i)_j$	is the total change in root-zone water storage for all six model layers at grid location i , in millimeters;
ET^i	is the total bare-soil evaporation and root-zone transpiration for all six root-zone layers at grid location i , in millimeters; and
NI^i	is the net infiltration at grid location i , in millimeters.

The water-balance check (MB^i) should be close to a value of 0.

Spatial Discretization

Water-budget calculations in the INFIL3.0 model are based on a three-dimensional grid-based representation of the drainage basin being simulated (figs. 2 and 4). The horizontal and vertical discretization methods used for an INFIL3.0 grid are described below.

Horizontal Discretization

All grid cells are square and of equal size in the horizontal plane. The length of each side of each grid cell (in meters) is specified by using the variable **celsize** in the Simulation-Control File. A grid of cells consisting of a set of rows and

columns is superimposed over the basin of interest with the origin of the grid (that is, row 1, column 1) positioned in the upper right-hand corner (fig. 4). The grid then serves as the basis for generating spatially distributed drainage-basin characteristics, including soil types, soil depth, hydrogeologic unit, vegetation type, elevation, slope, aspect, terrain variables (blocking-ridge values), and flow-routing variables. Information for a maximum of 60,005 grid cells and 3,350 row or column grid indices can be specified for each simulation in the current version of INFIL3.0.

Previous authors (for example, Hevesi and others, 2003) have used digital elevation models (DEMs) of study basins as a template grid, or base grid, from which other basin-characteristic data can be derived by using standard Geographical Information Systems (GIS) applications. Elevation, slope, aspect, and flow-routing variables are calculated in GIS, which uses the DEM as input. Terrain variables used as input for simulating potential evapotranspiration include blocking-ridge variables (discussed in more detail below) and are calculated by preprocessing routines (Hevesi and others, 2003). Identifiers for vegetation type, soil type, and bedrock type can be assigned to model-grid cells from digital maps of vegetation, soils, and surface geology by standard vector-to-raster or overlay GIS techniques.

Each model cell is assigned row and column numbers, which are specified by integer variables **row** and **col** in the Geospatial Watershed-Characteristics File. The **row** and **col** identifiers are used in postprocessing routines to reconstruct the raster grids for each simulated water-balance term, and the grids are imported into GIS to develop the map images. In addition to the **row** and **col** identifiers, the spatial location of the centroid of each grid cell is specified by defining an east-west (variable **easting**) and north-south (variable **northing**) spatial location and a latitude (variable **lat**) and longitude (variable **lon**) for each grid cell in the Geospatial Watershed-Characteristics file. In practice, the **easting** and **northing** location variables are based on standard map projections as defined in GIS. The **easting** and **northing** location variables are used for spatially interpolating the daily climate inputs across the model domain and thus must be consistent with the projections used to define the locations of the climate stations. The unit of horizontal distance is meters. The **lat** and **lon** location variables are used in the POTEVAP subroutine for simulating solar position for the day of the year and the hour of the day.

For efficiency, the preprocessing and parameterization is done by using the full extent of the base grid, which generally includes peripheral areas outside the area of interest. The base grid must extend over the entire basin or area of interest. The base grid is segmented into smaller watershed or catchment areas by using the developed flow-routing variables and standard GIS techniques for defining drainage networks (for example, Arc Hydro (Maidment, 2002)). The area of interest can be modeled using a single model domain or a series of subbasins, the only requirement being that any model domain or subbasin have a single outflow location, known as the pour

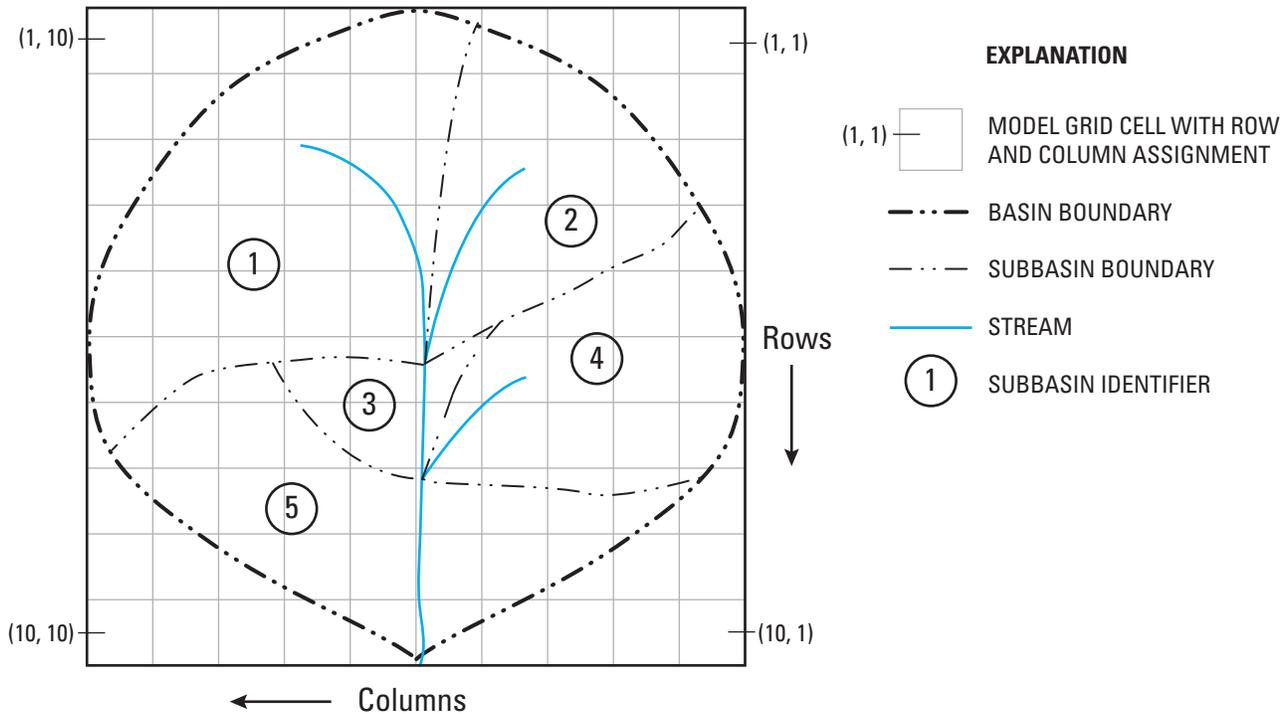


Figure 4. Horizontal discretization of a regional basin with five subbasins.

point. In the case of a closed basin or watershed, the pour point is defined as the grid cell at the lowest elevation within the basin or watershed.

The INFIL3.0 simulations are done separately for each of the individual subbasins within the larger watershed or basin area. The subbasins are defined by the modeler. Figure 4, for example, illustrates a grid of 10 rows and 10 columns that overlies the entire watershed of interest. The watershed consists of five subbasins that are simulated in five separate runs of the INFIL3.0 program. Simulations for the five separate basins are represented schematically on the INFIL3.0 flow-chart (fig. 3) by the outer “Simulation Loop.” Although the subbasins are simulated separately, the **row** and **col** identifiers assigned to each cell within each subbasin are referenced to the watershed-wide grid. This allows the simulation results for each subbasin to be integrated into the full extent of the base grid during postprocessing of model results.

It should be noted that the segmentation of the model domain into smaller subbasins that are simulated separately and then recombined is not a requirement for INFIL3.0. Segmentation generally improves run-time efficiency; for example, each subbasin can be simulated on separate processors, if the upstream subbasins are simulated prior to the downstream subbasins. Segmentation also can be helpful for model calibration and testing or if there is a need to identify results for separate subbasins contributing to a specific area

of interest, such as a water body (L.E. Flint, U.S. Geological Survey, written commun., April 2007) or a ground-water basin (Nishikawa and others, 2004; Rewis and others, 2006).

Vertical Discretization

Vertical discretization of the root zone of each grid cell is defined by using one to five soil layers and one underlying bedrock layer; the number and thickness of soil layers and the thickness of the bedrock layer are dependent on the estimated total soil and root-zone thickness at each grid-cell location (fig. 2). The unit of vertical discretization is meters. The root zone has multiple layers to account for spatially variable estimates of the maximum depth of bare-soil evaporation and for spatial differences in root density and root-zone water content as functions of depth and variables defined by vegetation type and canopy cover. The upper five layers of the model are used to define root-zone characteristics in soil. The bottom layer (layer 6) can be used to define either (1) root-zone characteristics in consolidated bedrock where roots may extend into fractures and other openings in the bedrock or (2) a sixth soil layer for locations with thick soils. In practice, layer 6 is used only to represent bedrock, and the variables defining layer thicknesses are set such that the thickness of layer 6 is zero at locations with thick soils. However, even when the thickness of layer 6 is zero, a hydraulic conductivity value must

be assigned to layer 6 because it will affect the calculation of net infiltration through soil layers 1 through 5. In general, the layering can be used to represent decreases in root density with increased depth in the root zone. All six layers of the model need not be active in each cell, and the total thickness of the root zone can differ from cell to cell. Root-zone layers are deactivated when assigned a thickness of zero.

INFIL3.0 calculates the thickness of each root-zone layer for each cell on the basis of several variables specified by the user in the program input files: total soil depth for each cell (variable **depth**, which is specified in either the Simulation-Control File or the Geospatial Watershed-Characteristics File); a soil-depth multiplication factor for the entire modeled area (variable **sdfact**, which is specified in the Simulation-Control File); root-zone depths for each soil layer for each vegetation type and the bedrock-layer thickness for each vegetation type (variable **rzdpth**, which is an array of six values that are specified in the Vegetation-Properties File); and a root-zone depth factor (variable **rzdpthf**, which is specified for each vegetation type in the Vegetation-Properties File). Note that the first five values of array **rzdpth** are depths below land surface and the sixth value is an actual thickness. Soil depths can be specified for each grid location by using the variable **depth** in the Geospatial Watershed-Characteristics File. For this alternative, variable **isdepthval** is set to a value other than 1 in the Simulation-Control File. Alternatively, the user can specify a constant soil depth for all grid cells by setting **isdepthval** equal to 1 and using variable **sdepthval** in the Simulation-Control File to specify the constant soil depth (in meters). When a constant soil depth is used, values entered for depth in the Geospatial Watershed-Characteristics File are ignored.

The first step done by INFIL3.0 to calculate root-zone layer thicknesses is to multiply the soil depth (**depth**) specified for each grid cell by the soil-depth factor **sdfact**. This multiplication factor was introduced because experience with the STATSGO database, which was the source of soil-depth values in previous studies that have used previous versions of the code, indicates that the values of soil depth reported in the STATSGO database can have considerable uncertainty, particularly when projected across mountainous watersheds. In addition, the increased soil thickness is used to account indirectly for surface-retention storage, which is not explicitly defined in INFIL3.0. Therefore, a user can use **sdfact** as a multiplication factor for the STATSGO-derived soil depths during the model-calibration process. For example, a user can specify an initial value of **sdfact** as 1.0 and then modify **sdfact** as necessary to improve simulation results during the model-calibration process. The use of **sdfact** in model calibration preserves the relative differences in estimated soil thickness across the model domain, but allows the absolute soil thickness to vary. In addition, model sensitivity to the estimated soil thickness, which in previous applications of the code has been observed to be high, can easily be evaluated by using the **sdfact** multiplier because this does not require repeating any of the preprocessing steps needed for the initial development of model inputs (Rewis and others, 2006).

The second step in the root-zone layer calculations sets the maximum root-zone depth equal to the bottom of the fifth root-zone layer for those cells in which total soil depth (**depth**) is greater than the root-zone depth for layer 5. This step prevents the soil-zone depth, which may have been increased by the multiplication factor **sdfact**, from extending beneath the root zone for the vegetation type. Thus, the **sdfact** multiplier generally affects only those grid cells that represent thin soils.

In the next step, INFIL3.0 calculates the thickness of each of the five soil root-zone layers by first identifying which layer is the bottom soil-zone layer for the cell and then subtracting the depths between intervening root-zone depths to determine the thickness of each layer. For example, if the user specifies root-zone depths for the five layers of a particular vegetation type as 0.1, 0.3, 1.0, 3.0, and 8.0 m below land surface, respectively, and the soil depth (**depth**) for the grid cell of interest is 1.3 m (and **sdfact** equals 1.0), then the resulting thicknesses for the five layers will be: layer 1, 0.1 m; layer 2, 0.2 m; layer 3, 0.7 m; layer 4, 0.3 m; and layer 5, 0.0 m.

In the last step, INFIL3.0 calculates the thickness of the bedrock root-zone layer by subtracting the ratio **depth/rzdpthf** from the bedrock root-zone layer thickness specified as part of the **rzdpth** array. For example, if in the previous example a bedrock-layer thickness of 4.0 m was specified, and an **rzdpthf** of 1.0 was specified, then the resulting thickness for the bedrock layer (layer 6) would be $4.0 - 1.3 = 2.7$ m. The factor **rzdpthf** allows the user to vary the total root-zone-thickness soil depth (**depth**) in relation to the estimated soil depth (**depth**) for locations with thin soils (and an active bedrock layer). For example, if the user wanted to increase the total thickness of the root zone according to the estimated soil thickness, then a value for **rzdpthf** greater than 1.0 could be specified; this value would reduce the ratio **depth/rzdpthf** and increase the resulting bedrock-layer thickness as the soil thickness increased (relative to the values of these variables calculated with **rzdpthf** equal to 1.0). As with the variable **sdfact**, variable **rzdpthf** allows the user to adjust the thickness of the bedrock layer easily during model calibration, rather than repeat a preprocessing step.

Time Steps and Initial Conditions

INFIL3.0 uses a daily time step for water-balance calculations. The user specifies the beginning and ending dates of a simulation in the Simulation-Control file using variables **yrstart**, **mostart**, and **dystart** for the simulation start date and **yrend**, **moend**, **dyend** for the simulation end date. INFIL3.0 can read in daily climate information (precipitation and minimum and maximum air temperature) from the climate files for dates that fall outside the beginning and ending simulation dates, but those climate records will not be used in the water-budget calculations.

Most of the water-balance terms in the INFIL3.0 model are given initial-condition values of 0, and are then updated for each day of the simulation. Initial conditions, however, must be specified for the water contents of the five soil layers.

Three options are provided for specifying initial soil-water contents depending on the value of variable **initopt** specified in the Simulation-Control File. If **initopt** is set to 0, then the initial water content of each layer at each cell is set equal to the product of the porosity of the soil at the cell (which is specified in the Soil-Properties File), the thickness of the soil layer (in millimeters), and variable **vwfact**, which is also specified in the Simulation-Control File. Variable **vwfact** is a multiplication factor that can be used during model calibration to vary the initial water contents. If **initopt** is set to 1, then the initial water content of each layer at each cell is set equal to the product of the residual water content of the soil (which is specified in the Soil-Properties File), the thickness of the soil layer (in millimeters), and variable **vwfact**. If **initopt** is set to 3, then the initial soil-water contents for each layer at each cell are read from the file specified by variable **restartfile** in the Simulation-Control File. The format of **restartfile** is exactly the same as that of the **crashfile**, whose name is also specified in the Simulation-Control File. The contents of **crashfile** are described in detail in the section of the report titled “Daily and Cumulative Output File for all Grid Cells for the Last Successful Day of a Simulation (Crashfile).”

Initial conditions for the bedrock water content are either set to 0 or are read from file **restartfile** if **initopt** has been set to 3. Initial conditions for the snow-pack storage term and the runoff-storage terms are also set to zero or are read from file **restartfile** if **initopt** has been set to 3. In other words, an assumption is made that there is no snow pack or runoff at the start of the simulation. In practice, a model ramp-up or warm-up period is used to minimize the effect of uncertainty in the initial conditions, which in the majority of model applications tends to be high. The ramp-up period is excluded from the simulation period used for model calibration or application. Model ramp-up periods of 2 to 3 years are generally sufficient to eliminate model sensitivity to the initial conditions.

Downstream Ordering of Grid Cells

Calculations made by the surface-water-flow routing algorithm in INFIL3.0 are based on the assumption that the grid cells have been entered in the Geospatial Watershed-Characteristics File in upstream-to-downstream order. For example, the cells might be entered in downstream order based on decreasing elevation from the top of the basin to the pour point of the basin. The correct upstream-to-downstream ordering is critical because as the model steps through each successive grid cell for each day, all runoff terms for all upstream grid cells (as calculated by ETINFIL and SWINFIL) must be known. Original applications of earlier versions of the INFIL code used FORTRAN preprocessing routines for developing the upstream-to-downstream ordering of the base grid on the basis of the DEM as input (Hevesi and others, 2003). More recent applications have used standard GIS applications such as Arc Hydro for processing the DEM, which is needed to define the upstream-to-downstream ordering of all grid cells (L.E. Flint, U.S. Geological Survey,

written commun., April 2007). The upstream-to-downstream ordering is an important part of the preprocessing procedure because this ordering defines the location and connectivity of streamlines for the model domain and subsequently defines the drainage network used for developing subbasins and identifying pour points. Techniques can be used to modify the DEM to ensure that the model streamlines representing the main stream channels agree with the known hydrography of the study area. For example, digital maps of hydrographic features (streams, canals, lakes, and playas) can be incorporated in GIS applications to modify the DEM prior to defining the upstream-to-downstream ordering.

Input variables associated with the upstream-to-downstream ordering are the upstream cell identifier **locid** and the downstream cell identifier **iwat**. Each grid cell can provide runoff to only one downstream cell, but each cell may have multiple cells that contribute surface-water run-on to it. A value of **iwat** equal to -3 is used to specify the pour-point cell location of the basin; this cell is not used in any of the water-balance calculations.

An additional input variable, **upcells**, is used to specify the total number of upstream cells that contribute water to the cell. **Upcells** is specified in the Geospatial Watershed-Characteristics File and is used in the surface-water flow-routing algorithm. The value of **upcells** can include cells that occur in upstream tributary subbasins that contribute surface-water inflow to the subbasin being simulated. **Upcells** is a standard output term calculated as part of the preprocessing used to define the upstream-to-downstream ordering. For example, in Arc Hydro applications, **upcells** is equivalent to the “flow accumulation” value calculated after the “flow direction” term is derived for each grid cell by the D-8 routing algorithm (Maidment, 2002) and prior to the calculation of streamline segments and subcatchment areas.

Surface-Water Inflows from Upstream Tributary Subbasins

INFIL3.0 allows surface-water inflows to a simulated basin from a maximum of five upstream tributary subbasins. Each upstream flow must occur to a single grid cell in the simulated basin (fig. 5). Inflows to a basin are model-calculated streamflows from upstream subbasins that have been calculated in previous simulations. As an example, simulations are made for each of the two upstream subbasins in figure 5 (subbasins 2 and 3), and the results of these simulations, including the model-calculated streamflow leaving each subbasin, are saved as part of the **pointfile(1)** output file for each upstream subbasin.

Surface-water inflows are simulated when variable **nupstream** is set equal to a value greater than 0 in the Simulation-Control File. The user then has the option of either specifying the names of the files from which upstream flows will be read or specifying a constant daily rate of inflow

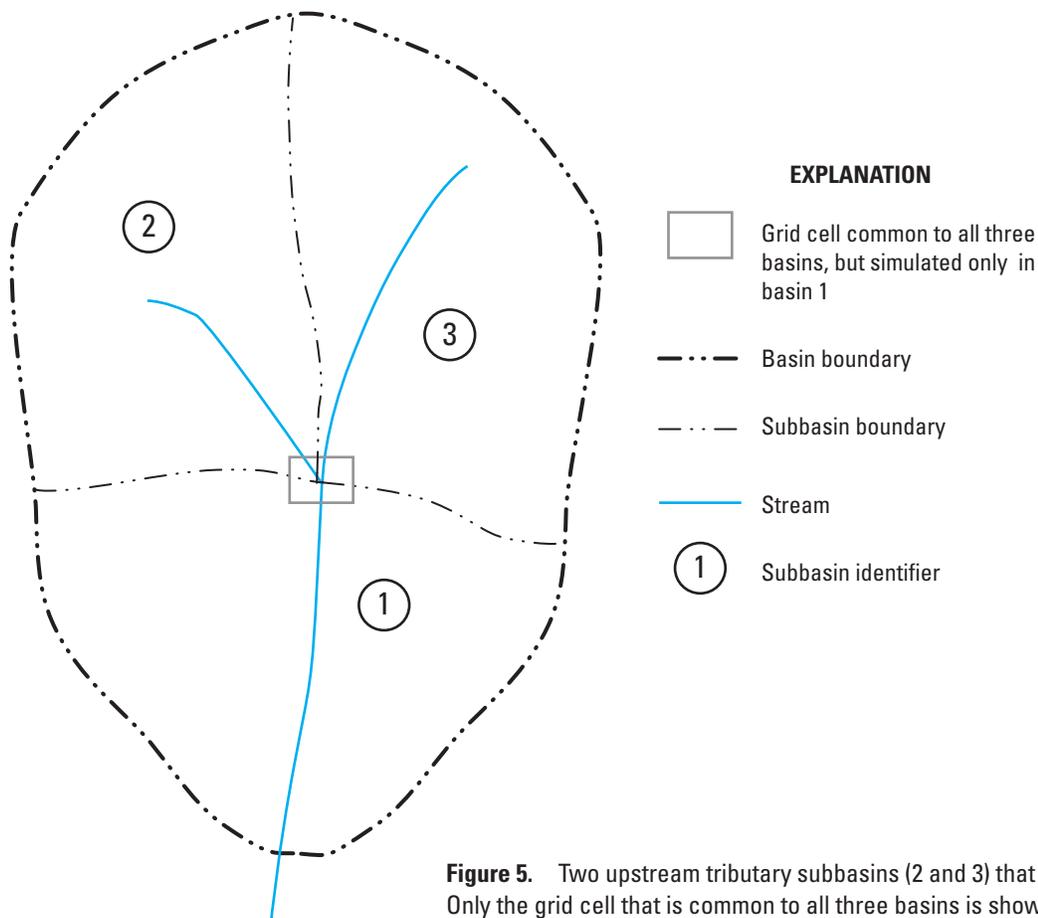


Figure 5. Two upstream tributary subbasins (2 and 3) that drain into simulated subbasin 1. Only the grid cell that is common to all three basins is shown.

(**upconst**) from each upstream basin. The constant daily rate of inflow is used as a testing parameter.

Two files are actually read by INFIL3.0 for each subbasin that contributes upstream flow. First, the user must specify the name of an **upgeoinp** file in the Simulation-Control File for each upstream subbasin. This file has the same format as the Geospatial Watershed-Characteristics File for the upstream subbasin; therefore, the Geospatial Watershed-Characteristics File for each upstream subbasin can be specified for **upgeoinp**. The entire contents of this file are read by INFIL3.0; however, the only purpose of reading data from this file is to ensure that the last grid cell specified in the file (with variable **iwat** = -3) has a value of **cellcode** that is the same as the last value of **cellcode** in each of the upstream subbasins and is equal to the **cellcode** of the grid cell that receives the upstream flow in the main basin. If any of the values of **cellcode** differ, INFIL3.0 will stop execution.

The second file that is read for each upstream subbasin is specified using variable **upfile**, also in the Simulation-Control File. As mentioned above, this is the **pointfile(1)** output file that contains the upstream daily flow for each upstream sub-

basin. Therefore, the user simply needs to specify the name of the **pointfile(1)** for each subbasin. The user also has the option of overwriting the upstream flows read from each **upfile** by using variable **ioptupflow** in the Simulation-Control File. If **ioptupflow** is set to a value other than 0, then a constant upstream flow equal to **upconst** can be used.

Spatial Distribution of Daily Climate Data (Subroutine DAYDIST)

Daily precipitation and air-temperature data are spatially distributed across the model domain by subroutine DAYDIST. INFIL3.0 provides two approaches to distribute precipitation and air-temperature data across the model domain: the first is by use of monthly precipitation/elevation and air-temperature/elevation regression models in combination with an inverse-distance-squared interpolation algorithm; the second is by use of a simpler inverse-distance-squared interpolation model. The regression models are described first, followed by the inverse-distance-squared interpolation approach.

Regression-model coefficients are developed prior to an INFIL3.0 simulation by using monthly data compiled from climate records. Regression models define average monthly precipitation and maximum and minimum air temperatures as functions of elevation. The monthly values for each climate variable (precipitation and maximum and minimum air temperatures) do not change with time; therefore, their values are calculated at the beginning of a simulation.

Two types of regression models are supported by INFIL3.0. The first is a linear model (regression-model type 1)

$$E_m^i = A_m (ELEV^i) + B_m, \quad (3)$$

and the second is a quadratic model (regression-model type 3)

$$E_m^i = A_m (ELEV^i)^2 + B_m (ELEV^i) + C_m, \quad (4)$$

where

- E_m^i is the estimated average monthly climate variable (daily precipitation, maximum air temperature, or minimum air temperature) for grid location i and month m ;
- A_m, B_m, C_m are the regression-model coefficients for each month m ; and
- $ELEV^i$ is the elevation for grid location i (in meters).

Regression models of the form of equations 3 and 4 also are used to estimate average monthly climate variables (precipitation and maximum and minimum air temperatures) at each of the climate stations; these estimates have the notation E_m^k , where the superscript k indicates climate-station k . The monthly estimate for the grid location is obtained by using the developed monthly regression models for each climate variable and the estimated elevation of the location being interpolated, as specified by a DEM. Estimates for the climate stations are done in subroutine MMPARAMRP.

In the first step of the spatial-interpolation routine, the sum of the inverse-squared distances between the grid location and each active climate station are calculated for each parameter by the equation

$$SDIST_{CV}^i = \sum_{k=1}^{NST} 1/(dist^k)^2, \quad (5)$$

where

- $SDIST_{CV}^i$ is the sum of the inverse-squared distances between grid location i and climate stations for climate-variable CV (P for precipitation and T for either maximum or minimum air temperature);
- NST is the total number of active climate stations (that is, those with data); and
- $dist^k$ is the distance between grid location i and climate station k .

In the next step of the routine, the interpolated daily value is calculated for the grid location by means of a modified inverse-distance-squared interpolation. For precipitation, this equation is

$$E_d^i = \sum_{k=1}^{NST} \{[(1/(dist^k)^2)/SDIST_p^i] \frac{(E_m^i)}{(E_m^k)} (X_d^k)\}, \quad (6)$$

where

- E_d^i is the estimated daily precipitation for grid location i and day d ;
- E_m^i is the estimated average monthly precipitation for grid location i and month m ;
- E_m^k is the estimated average monthly precipitation for climate station k and month m ; and
- X_d^k is the daily precipitation at climate station k and day d .

If the estimated precipitation is less than 0.254 millimeters (0.01 inches), then the estimated value is set to 0 under the assumption that 0.01 inch is the lower bound on the measurable precipitation data.

For maximum and minimum air temperature (in °F or °C), the modified inverse-distance-square interpolation equation used is

$$E_d^i = \sum_{k=1}^{NST} \{[(1/(dist^k)^2)/SDIST_T^i] [(E_m^i - E_m^k) + X_d^k]\}, \quad (7)$$

where

- E_d^i is the estimated daily maximum or minimum air temperature in °F or °C for grid location i and day d ;
- E_m^i is the estimated average monthly maximum or minimum air temperature for grid location i and month m ;
- E_m^k is the estimated average monthly maximum or minimum air temperature for climate station k and month m ; and
- X_d^k is the daily maximum or minimum air temperature at climate station k and day d .

Average daily air temperature for the grid cell is calculated as the average of the estimated maximum and minimum daily air-temperature values. If there are no air-temperature data for a particular date (that is, $NST = 0$), then the average daily air temperature is set to an assumed value of 15°C.

The second approach to distribute precipitation and air-temperature data across the model domain—that is, the simpler inverse-distance-squared interpolation model—also is based on equations 5 through 7. However, in the inverse-distance-squared interpolation model for precipitation, the ratio $\frac{E_m^i}{E_m^k}$ in equation 6 is replaced by a value of 1.0; for maximum and minimum air temperature, the term

$[(E_m^i - E_m^k) + X_d^k]$ in equation 7 is replaced by the simpler term $[X_d^k]$.

The user can override all of the previous calculations of precipitation and (or) air temperature described in this section by using variables **ipptval** and **iairval**, which are specified in the Simulation-Control File. If these variables are set to a value of 1, then the user can specify constant precipitation and (or) air-temperature values that are used for the simulation. These constant values of precipitation and air temperature are specified by variables **pptval** and **airval** in the Simulation-Control File. Also, the user can adjust the values of precipitation calculated by the methods described previously (or using **pptval**) by use of the multiplication factor **pptfact**, which can be used during model calibration to adjust the values of precipitation. Variable **pptfact** is also specified in the Simulation-Control File.

Potential Evapotranspiration (Subroutine POTEVAP)

Spatially distributed potential evapotranspiration is calculated in subroutine POTEVAP. A major component of the subroutine is the calculation of net incoming radiant energy $(Rn)_d^i$ for each day d and each grid location i . This calculation is done by use of a model of solar radiation similar to the SOLRAD model described in Flint and Childs (1987) and is based partly on work reported by Iqbal (1983).

Daily solar radiation is calculated by using National Weather Service monthly regional atmospheric properties, average daily temperature at each grid cell, and detailed geometric properties for each grid cell. The atmospheric properties are monthly averages of ozone, precipitable water, atmospheric turbidity, circumsolar diffuse radiation, and ground albedo. Site geometric properties include latitude, longitude, slope, aspect, elevation, and the blocking angles above a horizontal surface for direct-beam and diffuse sky radiation. The blocking angles define the effects of shading caused by the surrounding topography. For example, a location at the bottom of a steep, narrow canyon or valley will be shaded from direct-beam radiation more often than a location on the top of a south-facing hillslope. In addition, diffuse sky radiation will be reduced proportionally by the net effect of the surrounding terrain in blocking out the sky. However, ground-reflected radiation may be greater for a shaded location relative to a location on a ridgetop, depending on the orientation of the shaded location relative to solar position and the surrounding terrain. A separate FORTRAN program, SKYVIEW, which is a modified version of the original algorithm provided in Flint and Childs (1987), can be used to calculate the blocking angles (also referred to as blocking-ridge angles) above horizontal for each of 36 10-degree horizontal arcs around every grid cell (blocking-ridge angles). Calculations in SKYVIEW are made by using a DEM as input and a technique for approximating the 10-degree horizontal distances described in Flint and Childs (1987).

To calculate net incoming radiant energy, the position of the sun is calculated every hour, starting at sunrise on each day, with the site location (latitude and longitude) and the simulation day number as inputs (Flint and Childs, 1987). Direct-beam and diffuse sky radiation are calculated on the basis of the atmospheric properties and applied to the surface on the basis of slope, aspect, and the amount of sky and sun that would be blocked by the surrounding topography. Ground-reflected radiation is added on the basis of the area of the surrounding topography, the ground albedo, and the direct-beam and diffuse sky radiation that is reflected from the surrounding topography.

Net incoming radiant energy, $(Rn)_d^i$, is equal to the difference between net short-wave radiation and net long-wave radiation (Shuttleworth, 1993). The equations used for calculating net short-wave radiation are described in detail by Flint and Childs (1987). Net long-wave radiation is calculated from (Shuttleworth, 1993):

$$Ln = 5.6697 \times 10^{-8} (0.98 - \varepsilon_{ac}) (TA_d^i)^4 (HSTEP)(3600.), \quad (8)$$

where

Ln	is net long-wave radiation, in joules per square meter;
ε_{ac}	is clear sky emissivity, dimensionless;
TA_d^i	is the average daily air temperature on day d at grid location i in degrees Kelvin; and
$HSTEP$	is the time-step length, in hours, used for calculating total daily evapotranspiration.

Variable $HSTEP$ is specified by the user (by variable **hstep**) in the Simulation-Control File.

Clear-sky emissivity (ε_{ac}) is calculated from equation 10.11 in Campbell and Norman (1998):

$$\varepsilon_{ac} = 9.2 \times 10^{-6} (TA_d^i)^2, \quad (9)$$

where TA_d^i and ε_{ac} are defined in equation 8.

Daily evapotranspiration from each root-zone layer is calculated as an empirical function of potential evapotranspiration and soil-water content on the basis of a modified form of the Priestley-Taylor equation (Flint and Childs, 1991). The Priestley-Taylor equation (Priestley and Taylor, 1972) is used to calculate potential evapotranspiration:

$$\lambda(PET)_d^i = \alpha \left(\frac{S}{S + \gamma} \right)^i ((Rn)_d^i - G_d^i), \quad (10)$$

where

λ	is the latent heat of vaporization of water, in megajoules per kilogram (MJ/kg);
$(PET)_d^i$	is the rate of potential evapotranspiration at grid location i and day d , in millimeters per day;

- α is an empirical coefficient that is often set equal to 1.26 for freely evaporating surfaces (Priestley and Taylor, 1972; Stewart and Rouse, 1977; Eichinger and others, 1996), dimensionless;
- S is the slope of the saturation vapor-pressure/temperature curve, in kilopascals per degree Kelvin;
- γ is the psychrometric constant, in kilopascals per degree Kelvin;
- $(Rn)_d^i$ is net incoming radiant energy for location i and day d , in megajoules per square meter per day (MJ/m²/d); and
- G_d^i is soil heat flux for location i and day d , in megajoules per square meter per day (MJ/m²/d).

The product $\lambda(PET)_d^i$ is the latent heat flux (units of megajoules per square meter per day). The latent heat of vaporization (λ) is approximated in POTEVAP by equation 4.2.1 from Shuttleworth (1993),

$$\lambda = 2.501 - 0.002361T_s, \quad (11)$$

where T_s , the surface temperature of water, is assumed to be 20°C; therefore, λ is equal to 2.45 MJ/kg.

The term $\left(\frac{S}{S+\gamma}\right)_d^i$, which is the slope of the vapor-density deficit curve, is modeled as a function of average daily air temperature by the equation

$$\left(\frac{S}{S+\gamma}\right)_d^i = -13.281 + 0.083864(TA_d^i) - 0.00012375(TA_d^i)^2, \quad (12)$$

where TA_d^i is defined in equation 8. Equation 12 was defined by using parameter values obtained from a regression on data from Campbell (1977; table A.3) and provides an indication of the relative effect of air temperature on potential evapotranspiration, which varies for different temperature ranges.

Variable α is set equal to 1.0 in the POTEVAP subroutine (instead of 1.26) and later modified in the ETINFIL subroutine to account for soil-water-content conditions to derive an actual evapotranspiration value for each day and grid location. The modifications to α are described below in the section on the ETINFIL subroutine.

The available energy is $((Rn)_d^i - G_d^i)$. Variable $(Rn)_d^i$, total daily net incoming radiant energy, is the primary component of the energy balance. It is assumed for INFIL3.0 that G_d^i is about 0 for most cases for a daily time step; therefore, G_d^i is set equal to 0. Potential evapotranspiration is calculated on an hourly time step (**hstep** = 1.0 hours) or a time step defined by the user and added over a period of 1 day to obtain an estimate of total daily potential

evapotranspiration, which is then used as input for calculating actual evapotranspiration in the root zone.

Cloud cover is a variable affecting the energy-balance calculation and is indirectly accounted for in the model as an empirical function of the magnitude of daily precipitation. The assumption is that the energy for evapotranspiration is reduced in the presence of clouds (associated with precipitation); the greater the rainfall, the less the evapotranspiration. For days with precipitation, the modeled clear-sky potential evapotranspiration ($(PET)_d^i$) is reduced by the equation

$$(PETRS)_d^i = \frac{(PET)_d^i}{((PETADJ)(PPT)_d^i + 1)}, \quad (13)$$

where

- $(PETRS)_d^i$ is the adjusted rate of potential evapotranspiration at grid location i and day d for days on which there is precipitation, in millimeters;
- $(PET)_d^i$ is the (unadjusted) rate of potential evapotranspiration at grid location i and day d , in millimeters;
- $(PETADJ)$ is an empirical adjustment factor to the unadjusted potential evapotranspiration to account for cloud cover and precipitation, in millimeters⁻¹; and
- $(PPT)_d^i$ is the rate of precipitation at grid location i and day d , in millimeters per day.

Variable $(PETADJ)$ is specified by the model user (by variable **petadj**) in the Simulation-Control File. A value of **petadj** equal to about 0.16 has been shown to be effective in previous modeling studies (Hevesi and others, 2003). It should be noted that equation 13 is a highly empirical method to quantify the effects of cloud cover and precipitation on potential evapotranspiration, and that the relation between cloud cover, precipitation, and potential evapotranspiration is an area of active research. In particular, equation 13 may not be appropriate for climates with persistently dense cloud cover during periods with little to no precipitation (for example, climates characterized by frequent fog, such as coastal areas).

An additional potential evapotranspiration term—an approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and the Priestley-Taylor α coefficients—is calculated by the model. This approximate potential evapotranspiration is printed to several of the output files but is not used in any other calculations by INFIL3.0. The approximate potential evapotranspiration value is calculated as

$$(PET3)_d^i = \{(VEGCOV^i)(SOILET2) + (1 - VEGCOV^i)(BARSOIL2)\}(PET)_d^i, \quad (14)$$

where

- $(PET3)_d^i$ is the approximate potential evapotranspiration, in millimeters;

$(PET)_d^i$ is the (unadjusted) rate of potential evapotranspiration at grid location i and day d , in millimeters;
 $VEGCOV^i$ is the estimated vegetation cover for cell i , in decimal percent;
 $SOILET2$ is the α soil-transpiration coefficient, dimensionless; and
 $BARSOIL2$ is the α bare-soil coefficient, dimensionless.

The user can override the calculations of potential evapotranspiration by using variable **ietval**, which is specified in the Simulation-Control File. If **ietval** is set to a value of 1, the user can specify a constant potential evapotranspiration for all days of the simulation by assigning a value to variable **etval** in the Simulation-Control File. Also, the user can adjust the values of potential evapotranspiration by the methods described previously or by using **etval**, which is based on the multiplication factor **etfact**, during model calibration. Variable **etfact** is specified in the Simulation-Control File.

Snowfall, Snow Accumulation, Snowmelt, and Sublimation (Subroutine SNOW)

The user has the option of simulating snowfall, snow accumulation, snowmelt, and sublimation with the SNOW subroutine if variable **isnow** in the Simulation-Control File is specified as 2; otherwise, if **isnow** is set to 0, all precipitation is assumed to be rain for all days of the simulation.

If the SNOW subroutine has been activated, precipitation is simulated as rain ($RAIN_d^i$) for a grid-cell location if the average air temperature calculated for a day is greater than 0°C; otherwise, precipitation for that day is simulated as snow ($SNOW_d^i$). Because air temperature is distributed spatially by the elevation-correlation model, however, snowfall and snowpack accumulation may occur in some areas of the modeled watershed while rain occurs simultaneously in other areas of the watershed.

Daily snowfall is added to the snowpack-storage term in the daily water balance. Snowpack storage accounts for the water stored in the snowpack (that is, a water-equivalent depth of snow, in millimeters) and is based on snowfall accumulation and losses from snowmelt and sublimation. Snowpack storage is carried over as an antecedent condition for the following day's water-balance calculation.

When the daily maximum air temperature is higher than freezing (0°C) and snow cover is present, an empirical temperature-index model is applied to calculate the daily snowmelt (Gray and Prowse, 1993; equation 7.3.14). The snowpack is reduced by this quantity. The two components of the empirical model depend on the day of the year:

$$(MELT)_d^i = (SNOPAR1)(TMAX)_d^i \quad (15a)$$

applies when the day of the year is greater than or equal to ($SNODAY1$) and less than ($SNODAY2$), and

$$(MELT)_d^i = (SNOPAR2)(TMAX)_d^i \quad (15b)$$

applies for the remaining days of the year. In equations 15a and 15b,

$(MELT)_d^i$ is the quantity of snowmelt for day d for cell i , in millimeters per day;
 $SNOPAR1$ is the snowmelt-rate parameter that corresponds to the early-spring snowmelt period, in millimeters per day per degrees Celsius;
 $SNOPAR2$ is the snowmelt-rate parameter that corresponds to the late-spring snowmelt period, in millimeters per day per degrees Celsius;
 $SNODAY1$ is the starting (Julian) day for the timing of the early-spring snowmelt period;
 $SNODAY2$ is the starting (Julian) day for the timing of the late-spring snowmelt period; and
 $(TMAX)_d^i$ is the daily maximum air temperature for cell i , in degrees Celsius.

Variables **snopar1**, **snopar2**, **snoday1**, and **snoday2** are specified by the model user in the Simulation-Control File. If $(MELT)_d^i$ is greater than the available snowpack, then $(MELT)_d^i$ is set to the quantity of snowpack (multiplied by the 1-day time step). Example values for variables **snopar1** and **snopar2** are given in table 7.3.7 of Gray and Prowse (1993) and in the sample problem described later in this report.

Sublimation is calculated when variable **isublim** is set to a value of 1 in the Simulation-Control File. Sublimation is calculated on the basis of an empirical function of the adjusted potential evapotranspiration. For average air temperature less than or equal to 0°C, the function is

$$(SUBLIM)_d^i = (SUBPAR1)(PETRS)_d^i, \quad (16a)$$

and for average air temperature greater than 0°C, the function is

$$(SUBLIM)_d^i = (SUBPAR2)(PETRS)_d^i. \quad (16b)$$

In equations 16a and 16b,

$(SUBLIM)_d^i$ is the sublimation for day d for cell i , in millimeters;
 $(PETRS)_d^i$ is the adjusted rate of potential evapotranspiration for day d and cell i , in millimeters; and
 $(SUBPAR1)$ and $(SUBPAR2)$ are dimensionless sublimation variables.

Variables **subpar1** and **subpar2** are set by the model user in the Simulation-Control File and may be adjusted during model calibration. Values of **subpar1** and **subpar2** between 0.1 and 0.4 have been used in previous investigations (Hevesi

and others, 2003; Nishikawa and others, 2004; L.E. Flint, U.S. Geological Survey, written commun., April 2007). Typically, values of **subpar1** and **subpar2** in this range result in average annual sublimation losses of about 5 to 20 percent of precipitation falling as snow, with the highest relative losses just above the snowline where average air temperature is just above freezing. The approach used to simulate sublimation in INFIL3.0 is highly simplified; in actuality, sublimation depends on several factors that are not accounted for in INFIL3.0, such as relative humidity and wind speed.

If sublimation has occurred, then the adjusted rate of potential evapotranspiration is updated by the rate of sublimation

$$(PETRS)_d^i = (PETRS)_d^i - (SUBLIM)_d^i, \quad (17)$$

where $(PETRS)_d^i$ and $(SUBLIM)_d^i$ are defined previously.

Infiltration, Drainage, Evapotranspiration, and Runoff (Subroutine ETINFIL)

The root-zone water-balance calculation uses a two-step process to couple surface-water flow with the processes of infiltration, drainage, and evapotranspiration. The first step is done by subroutine ETINFIL and the second step by subroutine SWINFIL. ETINFIL has four primary steps, which are completed for each grid cell for each day: (1) calculation of infiltration to the root zone from rain and snowmelt and an initial calculation of runoff equal to rain and snowmelt in excess of the infiltration capacity of the soil or bedrock (that is, a Hortonian-runoff process caused by excess infiltration when the rate of rain and snowmelt exceeds the infiltration capacity of the surface materials); (2) redistribution of infiltration by downward drainage through all layers of the root zone and an initial calculation of the change in soil-water storage in each layer of the root zone; (3) calculation of evapotranspiration from each layer of the root zone; and (4) final calculations of net infiltration, change in soil-water storage in each layer of the root zone, and runoff from the grid cell. (This second runoff component represents a Durnian-runoff process caused by excess saturation when the root zone is fully saturated.)

In the remainder of the report, many references are made to the hydraulic conductivity of the soil and bedrock layers. In all cases, these references are to the vertical hydraulic conductivity of the materials.

(1) Infiltration and Initial Calculation of Runoff

Depending on soil depth, either the soil or the bedrock saturated hydraulic conductivity is used to calculate (1) the maximum infiltration to the root zone from rain and snowmelt and (2) an initial calculation of runoff equal to the quantity of rain and snowmelt that is in excess of the infiltration capacity of the soil or bedrock. The infiltration capacity of the soil

and bedrock for each grid cell is calculated on the basis of the saturated hydraulic conductivity of the soil or bedrock. The conductivity value is modified by the duration of the rain or snowmelt. For summer rainstorms (between Julian days **dysumbeg** and **dysumend**, which are program variables defined by the user in the Simulation-Control File), the resulting infiltration capacity is calculated by

$$IC_p = \frac{Ksat}{24 / stormsum}, \quad (18a)$$

whereas for winter rainstorms, the modified saturated hydraulic conductivity is calculated by

$$IC_p = \frac{Ksat}{24 / stormwin}. \quad (18b)$$

In equations 18a and 18b,

IC_p is the infiltration capacity for either soil or bedrock for rain, in millimeters;

$Ksat$ is the original saturated hydraulic conductivity for either soil or bedrock, in millimeters per day; and

$stormsum$ and $stormwin$ are the duration, in hours, of summer and winter storms, respectively.

The conversion factor 24 (hours/day) converts the units of hydraulic conductivity from millimeters per day to a rain-infiltration capacity in millimeters. Variables **stormsum** and **stormwin** are specified by the user in the Simulation-Control File.

An equivalent equation is used to calculate infiltration capacities for soil and bedrock for snowmelt:

$$IC_m = \frac{Ksat}{24 / melttime}, \quad (19)$$

where

IC_m is the infiltration capacity for either soil or bedrock for snowmelt, in millimeters;

$melttime$ is the estimated duration, in hours, of the daily snowmelt period; and

$Ksat$ is defined previously.

As is done for rain, the conversion factor 24 (hours/day) converts the units of hydraulic conductivity in millimeters per day into a snowmelt-infiltration capacity in millimeters. Variable **melttime** is specified by the user in the Simulation-Control File.

The maximum quantities of rain and snowmelt that can infiltrate into the soil or bedrock at a particular cell are IC_p and IC_m , respectively. If the quantities of rain and snowmelt are below IC_p and IC_m , then the infiltration to the root zone is the sum of the rainfall and snowmelt for the cell for that day. Also note that it is assumed that when rain occurs directly to a snowpack, the rain goes directly through the snowpack and infiltrates into the underlying soil or bedrock; that is, the

physics of the rain-on-snow process is simplified such that rain infiltrates as if there was no snowpack present. Finally, the initial runoff for the cell, $RoffI^i$, is calculated as the sum of the quantities of rain and snowmelt that are in excess of IC_p plus IC_m .

(2) Drainage and Redistribution in the Root Zone and Initial Calculation of Change in Soil-Water Storage

Infiltration from rain and snowmelt is redistributed downward through the soil layers by drainage when the thickness of the soil zone is greater than zero. Each soil layer has an initial soil-water content that is equal to the previous day's final water content. For the first day of a simulation, the initial soil-water content is specified for each grid cell on the basis of factors specified in the input files (see section above on "Model Time Steps and Initial Conditions"). For layer 1, the initial soil-water content is added to the infiltration to the root zone from rain and snowmelt; this sum is the total soil-water content for the layer.

Downward drainage is calculated beginning with the top layer. First, a calculation is made to determine if the total water content for the top layer minus the infiltration capacity of the underlying layer is greater than the maximum storage limit for the top layer. The maximum storage limit for the layer is equal to the product of the soil or rock porosity and the thickness of the soil layer (in millimeters). If the total soil-water content for the layer minus the infiltration capacity of the underlying layer is greater than or equal to the maximum storage limit (that is, the layer is saturated), then drainage to the second layer is set equal to the infiltration capacity of the soil. The total soil-water content for layer 1 (top layer) is then updated by subtracting the quantity drained to layer 2. If, however, the total soil-water content for the layer minus the infiltration capacity for the layer is less than the maximum storage limit (that is, the layer is unsaturated), then downward drainage to the second layer is calculated by using a modified form of an empirical drainage model in Jury and others (1991; pp. 144–150) for approximating water contents and the depth of the wetting front in a draining soil profile. The empirical drainage model is based on the following equations:

$$DR_j^i = (VWCA_j^i - VWCB_j^i)(THCK_j^i)(1,000), \quad (20)$$

where

DR_j^i is drainage through layer j into layer $j + 1$ at grid location i , in millimeters; and
 $THCK_j^i$ is the thickness of layer j at grid location i , in meters.

The conversion factor 1,000 (millimeters/meter) converts the units of thickness from meters to millimeters.

$VWCA_j^i$ is the initial volumetric water content, calculated by the equation

$$VWCA_j^i = (GA2_j^i)(GT_j^i + GC2_j^i)^{-GB^i}, \quad (21a)$$

and $VWCB_j^i$ is the final volumetric water content calculated by the equation

$$VWCB_j^i = (GA2_j^i)[(GT_j^i + 1) + GC2_j^i]^{-GB^i}. \quad (21b)$$

The additional terms in equations 21a and 21b are defined by

$$GA2_j^i = \{(SPOR_j^i)^{(GN^i+1)} [(THCK_j^i)(1,000)/(GN^i)(Ksat_j^i)(\Delta t)]^{1/GN^i}\}, \quad (22)$$

$$GT_j^i = [(VWCC_j^i/GA2_j^i)^{(1-GB^i)}] - GC2_j^i, \quad (23)$$

$$GC2_j^i = [(THCK_j^i)(1,000)(SPOR_j^i)]/[(GN^i)(Ksat_j^i)(\Delta t)], \quad (24)$$

$$GN^i = (2)(SOILB^i) + 3, \quad (25)$$

$$GB_j^i = 1/GN^i, \quad (26)$$

$$VWCC_j^i = SOILMM_j^i / THCK_j^i / 1,000, \quad (27)$$

where

$SPOR_j^i$ is the porosity of the soil for layer j at grid location i , dimensionless;
 $Ksat_j^i$ is the saturated hydraulic conductivity of the soil for layer j at grid location i , in millimeters per day;
 Δt is a time step, which for INFIL3.0 is equal to 1 day;
 $SOILB^i$ is the soil-drainage-function coefficient for grid location i , dimensionless; and
 $SOILMM_j^i$ is the simulated soil-water content for layer j at grid location i , in millimeters.

Downward drainage through the remaining soil layers is then calculated by using the same sequence of steps. In each case, the maximum quantity of water that can drain from one layer to the next is the infiltration capacity calculated by equation 18a or 18b. Any water that is in excess of the infiltration capacity and does not drain to the underlying layer is held in a temporary storage term for the layer. This water is used in subsequent calculations to calculate runoff and the final distribution of water in the root zone after abstraction by evapotranspiration.

(3) Evapotranspiration from Each Layer of the Root Zone

Evapotranspiration from each layer is calculated by using a modified form of the Priestley-Taylor equation and the updated soil-water content calculated by the

downward-drainage function for each layer. The modified Priestley-Taylor equation relates the empirical coefficient in equation 10, α , to seasonal changes in soil-water content (Davies and Allen, 1973; Flint and Childs, 1991). This modified version has been used successfully in arid and semiarid environments (de Bruin, 1988; Stannard, 1993). When expressed as a function of soil-water content, α is replaced by α' in the equation

$$\alpha' = \alpha(1 - e^{-\beta\theta}), \quad (28)$$

where α and β are coefficients, and θ is relative saturation.

The relative saturation θ is defined as

$$\theta = \frac{(\theta - \theta_r)}{(\theta_s - \theta_r)}, \quad (29)$$

where

- θ is the soil-water content, dimensionless;
- θ_r is the residual soil-water content for plant transpiration (that is, soil-water content at the soil-water potential at which desert plants no longer transpire, which is taken to be -60 bars water potential, also referred to as the wilting point); and
- θ_s is the porosity.

The modified Priestley-Taylor equation is used to calculate both bare-soil evaporation and plant transpiration. Bare-soil-evaporation demand is simulated first from the top two model layers that have nonzero thickness. For the top layer of the model, the modified Priestley-Taylor equation is

$$BSE_1^i = \{BARSOIL2[1 - e^{(BARSOIL1)(\Theta_1^i)}]\}(PEVAP_1), \quad (30)$$

where

- BSE_1^i is the daily evaporation for layer 1, in millimeters;
- $BARSOIL2$ is the α bare-soil coefficient, dimensionless;
- $BARSOIL1$ is the β bare-soil coefficient, dimensionless;
- Θ_1^i is the relative saturation for layer 1, dimensionless; and
- $PEVAP_1$ is the modified potential evaporation, in millimeters.

Variables $BARSOIL1$ and $BARSOIL2$ are specified by the model user in the Simulation-Control File (**barsoil1** and **barsoil2**). Variable $PEVAP_1$ for layer 1 is defined by

$$PEVAP_1 = (1 - VEGCOV^i)(PETRS_d^i), \quad (31)$$

where

- $VEGCOV^i$ is the estimated vegetation cover for cell i , in decimal percent; and

- $PETRS_d^i$ is the adjusted rate of potential evapotranspiration at grid location i and day d for days on which there is precipitation, in millimeters.

For the second layer of the model, the equation is

$$BSE_2^i = \{BARSOIL2[1 - e^{(BSEF)(BARSOIL1)(\Theta_2^i)}]\}(PEVAP_2), \quad (32)$$

where

- BSE_2^i is the daily bare-soil evaporation from layer 2, in millimeters;
- $BSEF$ is an adjustment factor specified by the user (variable **barsoilf** in the Simulation-Control File) to modify the value of $BARSOIL1$ used for layer 1 (a value of $BSEF$ equal to 1.0 causes the $BARSOIL1$ values for layers 1 and 2 to be the same), dimensionless; and
- Θ_2^i is relative saturation for layer 2, dimensionless.

Variable $PEVAP_2$ for layer 2 is defined by

$$PEVAP_2 = (PEVAP_1) - (BSE_1^i). \quad (33)$$

After bare-soil evaporation demand has been met, the modified form of the Priestley-Taylor equation then is used to simulate plant transpiration from all six model layers. The simulation of transpiration uses weighting factors (WGT_j^i) that account for root density and the distribution of available water in each of the root-zone layers. For the top five soil layers, the modified Priestley-Taylor equation is

$$TRANS_j^i = WGT_j^i \{SOILET2[1 - e^{(SOILET1)(\Theta_j^i)}]\}(PTRANS), \quad (34)$$

where

- $TRANS_j^i$ is the daily transpiration from layer j , in millimeters;
- WGT_j^i is the weighting factor for layer j , dimensionless;
- $SOILET2$ is the α soil-transpiration coefficient, dimensionless;
- $SOILET1$ is the β soil-transpiration coefficient, dimensionless;
- Θ_j^i is relative saturation for layer j , dimensionless; and
- $PTRANS$ is the modified potential evaporation, in millimeters.

Variables $SOILET1$ and $SOILET2$ are specified by the model user in the Simulation-Control File (variables **soilet1** and **soilet2**). Variable $PTRANS$ in equation 34 is defined by

$$PTRANS = (VEGCOV^i)(PETRS_d^i). \quad (35)$$

An equation similar to equation 34 is used to calculate transpiration from the bedrock layer, except that variables *SOILET1* and *SOILET2* are replaced by variables *ROCKET1* and *ROCKET2*, which are specified by the model user in the Simulation-Control File (**rocket1** and **rocket2**).

The weighting factors, WGT_j^i , for each layer of the model are calculated from

$$WGT_j^i = (\theta_j)(RZDEN_j^i) / \sum_{j=1}^6 (\theta_j)(RZDEN_j^i), \quad (36)$$

where

θ_j is the relative saturation for each layer j , dimensionless; and
 $RZDEN_j^i$ is the root-density factor for layer j at cell i , in decimal percent.

The variables $RZDEN_j^i$ are based on the values of vegetation cover specified as a percentage for each of the six layers of the model in the Vegetation-Properties File (variable **vegcover(6)**) and converted to decimal percent in ETINFIL. The sum of the weights for the six layers of the model will be 1.0. If any of the weighting factors for a layer calculated in equation 36 is greater than the corresponding root-density factor for that layer, then the respective final weight is reset to the root-density factor for that layer.

The total evapotranspiration within the six model layers, ET_d^i , is equal to

$$ET_d^i = BSE_1^i + BSE_2^i + \sum_{j=1}^6 TRANS_j^i. \quad (37)$$

(4) Final Calculations of Net Infiltration, Change in Water Storage in Each Layer of the Root Zone, and Runoff from the Grid Cell

Rain or snowmelt drains into layer 6 (the bedrock layer) either directly when a soil zone is absent, or from the bottom layer of the soil zone. If a bedrock layer is present (that is, the thickness of layer 6 is greater than zero), net infiltration (that is, drainage below layers 1–6 of the model) is calculated on the basis of the water content and hydraulic conductivity of the bedrock layer. If the sum of drainage into the bedrock layer and existing water content, minus the saturated hydraulic conductivity of the bedrock, is greater than the available storage capacity of the bedrock¹, net infiltration is equal to the saturated hydraulic conductivity of the bedrock (variable **imbibe2**, which is specified in the Bedrock-Properties File). If, however, the sum of the quantity of drainage into the bedrock layer and the existing water content is greater than zero but less than the available storage capacity of the bedrock (that is, the bedrock layer is unsaturated), then the quantity of net infiltration is equal to the unsaturated hydraulic conductivity

of the bedrock (variable **imbibe**, which is specified in the Bedrock-Properties File). After net infiltration has been calculated, the remaining quantity of water in the bedrock layer is calculated by subtracting net infiltration from the initial water in the bedrock layer.

If the root zone is underlain by thick soil (or unconsolidated deposits), it would typically be modeled as having five soil layers and a maximum root-zone thickness. In this case, the thickness of the bedrock layer is zero, because the root zone is underlain by unconsolidated deposits as opposed to consolidated rock (the bedrock layer is absent). If the bedrock-layer thickness is zero, the net-infiltration rate is limited only by the estimated saturated hydraulic conductivity of the underlying materials (**imbibe2**). The **imbibe2** parameter will become a limiting factor only if the simulated drainage rate through the overlying soil layer is greater than the saturated hydraulic conductivity defined by **imbibe2**.

Excess water in the root zone, which contributes to surface-water runoff ($Roff2_d^i$) as a saturated-excess or Dunnian-runoff component, is calculated by a redistribution algorithm that steps sequentially upward through all root-zone layers. To simulate $Roff2_d^i$ and the final water content of each of the five soil layers ($SOILMM_j$) and bedrock layer, ($ROCKMM$) the storage capacity of each layer is checked against the quantity of water held in the temporary-storage term for each layer. If the temporary-storage variable exceeds the storage capacity of the layer, the excess water is added to the overlying layer. The algorithm moves sequentially upward through the root-zone layers until all excess water held in temporary storage has been redistributed to overlying layers that have available storage capacity. If excess water remains after the upward redistribution has reached the top soil layer, the excess water is added to the runoff term. The runoff generated by the upward-redistribution process represents the fraction of inflowing water that exceeds the storage capacity of the root zone. Total runoff, $Roff_d^i$, for each cell is thus the sum of the excess root-zone water $Roff2_d^i$ and the initial runoff $Roff1_d^i$ calculated as excess rainfall and snowmelt.

The last calculation in the subroutine is the change in total water storage of all six layers of the model,

$$\sum_{j=1}^6 (\Delta W_d^i)_j,$$

which is equal to the final storage of all six layers ($j = 1$ through 6) minus the initial storage at the beginning of the call to the subroutine.

Surface-Water Routing (Subroutine SWINFIL)

Subroutine SWINFIL routes daily runoff $Roff_d^i$ (calculated in subroutine ETINFIL) to downstream cells as surface-water run-on, Ron_d^i . During the routing process, run-on can infiltrate back into the root zone and contribute to daily net infiltration (variable Ron_d^i in equation 1) when

¹ The storage capacity of the bedrock equals the product of the bedrock porosity and bedrock thickness (in millimeters).

variable **irout** is specified as 1 in the Simulation-Control File. Surface-water flow therefore can be coupled to the root-zone water balance by the infiltrated run-on component. The user also has the option of not allowing surface-water run-on to infiltrate back into the root zone by specifying variable **irout** equal to 0.

For each daily time step, SWINFIL is invoked if runoff has been generated at any model-grid location by ETINFIL. If runoff has not been calculated, SWINFIL is skipped and the simulation is continued to the next day. If there is runoff, the routing algorithm loops through the drainage-basin grid in the order in which the cells have been entered in the Geospatial Watershed-Characteristics File—from the lowest to the highest value of variable **locid** specified for each grid cell in the Geospatial Watershed-Characteristics File. Runoff from a cell is routed as run-on to the downstream cell identified by variable **iwat** in the Geospatial Watershed-Characteristics File, with variables **locid** and **iwat** acting as pointers to connect upstream and downstream cells. (A cell identified by a value of **iwat** equal to -3 is the outflow cell of the basin.) Each cell provides runoff to only one downstream cell, but may receive runoff from multiple upstream cells. Also, if upstream basins contribute runoff, this runoff is added to the cell that receives the upstream flow, and is then routed downstream.

It should be noted that SWINFIL is based on the assumption that for any daily time step, all runoff generated within the model domain is either infiltrated back into the root zone or is discharged as surface-water outflow from the model domain. The calculated surface-water outflow would not be representative of study areas characterized by lag times of several days or longer between the generation of runoff and subsequent outflow. A longer lag time may result in greater relative channel losses and attenuation compared to the simulated 1-day lag time for surface-water outflow. Model calibration also could be affected if multiday lag times affect measured streamflow used for model calibration.

The user can specify the fraction of each grid-cell area that is wetted by run-on (that is, the effective flow-area fraction of the grid cell). This fraction is used to scale the hydraulic conductivities of the soil and bedrock of the grid cell. Two options to determine the fraction of each grid-cell area that is wetted by run-on are provided by the assignment of two possible values of **ichanmod** specified in the Simulation-Control File. If **ichanmod** is set to a value other than 1, the fraction of the grid-cell area that is wetted, $FLAREA^i$, is set to a constant value defined by

$$FLAREA^i = CHAN1. \quad (38)$$

If, however, **ichanmod** is set to 1, an empirical model is used to define the effective flow-area fraction as a function of the upstream area, the quantity of surface-water inflow, and the slope of the grid cell:

$$FLAREA^i = CHAN1 + \frac{[(UPCELLS^i \times FLOWIN^i)^{(1-SL2^i)/2}]}{CHAN2 + CHAN3 - UPCELLS^i / 4} \quad (39a)$$

if $FLAREA^i \leq CHAN4$, and

$$FLAREA^i = CHAN4 \quad (39b)$$

if $FLAREA^i > CHAN4$. In equations 39a and 39b,

- $CHAN1$ is the surface-water minimum effective wetted-flow area, in decimal percent;
- $CHAN2$ is the surface-water wetted-flow area factor, dimensionless;
- $CHAN3$ is the surface-water maximum headwater wetted-flow area, dimensionless;
- $CHAN4$ is the surface-water maximum effective wetted-flow area per grid cell, as a decimal percent of the area of each grid cell;
- $SL2^i$ is the slope of grid cell i , in decimal percent;
- $UPCELLS^i$ is the number of cells upstream to grid location i , dimensionless; and
- $FLOWIN^i$ is the simulated surface-water run-on for grid location i , in millimeters.

Variables **chan1**, **chan2**, **chan3**, and **chan4** are specified by the user in the Simulation-Control File; representative values for these four variables are given in the sample problem. The headwater-flow area ($CHAN3$) is used to represent upland areas where overland-flow processes are more important than channel flow. For low-flow conditions, steep channels, or small upstream areas, the effective flow area is defined by the $CHAN1$ coefficient in equation 39a. The effective flow area increases as a continuous function and approaches or equals the $CHAN4$ coefficient as the surface-water run-on depth increases, the channel gradient decreases, and the number of upstream cells (and thus upstream area) increases. To account for dispersive flow across alluvial fans, the $CHAN4$ coefficient can be set to a value greater than 1, allowing the effective flow area to be greater than the grid-cell area.

$FLAREA^i$ is used to adjust (scale) the soil and bedrock hydraulic conductivities of each grid cell. For the soil hydraulic conductivity, $Ksat_{soil}$, the equation to calculate an adjusted soil hydraulic conductivity, $(Ksat_{soil})_{adj}$, is

$$(Ksat_{soil})_{adj} = (Ksat_{soil})(SKSFACT)(FLAREA^i). \quad (40a)$$

For both the unsaturated and saturated bedrock hydraulic conductivities, $Ksat_{rock}$, the equation to calculate an adjusted bedrock hydraulic conductivity, $(Ksat_{rock})_{adj}$, is

$$(Ksat_{rock})_{adj} = (Ksat_{rock})(IMBFACT)(FLAREA^i), \quad (40b)$$

where in equations 40a and 40b

SKSFACT is a scaling factor for soil hydraulic conductivity, dimensionless; and
IMBFACT is a scaling factor for unsaturated and saturated bedrock hydraulic conductivity, dimensionless.

Variables **sksfact** and **imbfact** are specified in the Simulation-Control File, and can be used during model calibration to adjust the hydraulic conductivity values as needed.

To account for differences in soil hydraulic conductivity between channel and interchannel locations (for example, channel beds may contain coarser, more permeable material), the adjusted soil hydraulic conductivity for a grid cell can be further scaled for stream-channel locations by using variable $Kschn^i$. The resulting hydraulic conductivity, $(Ksat_{soil})_{sch}$, is calculated as

$$(Ksat_{soil})_{sch} = (Ksat_{soil})_{adj} (Kschn^i). \quad (41)$$

$Kschn^i$ is initially set to a value of 1.0 but can be updated by the use of three variables, **kschn1**, **kschn2**, and **kschn3** that are specified in the Simulation-Control File. The first variable, **kschn1**, is the minimum number of cells upstream to a grid cell that are needed for an adjustment to take place. If the user specifies **kschn1** to be very high, then equation 41, with $Kschn^i$ equal to 1.0, will automatically be used. If, however, the number of cells upstream to a grid cell is greater than **kschn1**, then $Kschn^i$ will be modified depending on the value of **ikschnmod** specified by the user in the Simulation-Control File. If **ikschnmod** is set to 0, then

$$Kschn^i = Kschn3, \quad (42)$$

where $Kschn3$ is the maximum adjustment factor to the soil hydraulic conductivity. If, however, **ikschnmod** does not equal 0, then

$$Kschn^i = ((UPCELLS^i - Kschn1)/Kschn2) + 1, \quad (43)$$

where $Kschn2$ is the scaling factor for adjusting the saturated hydraulic conductivity for soil in channels. If the value of $Kschn^i$ calculated by equation 43 exceeds $Kschn3$, then $Kschn^i$ is set equal to $Kschn3$.

The final adjustment that is made to the soil and bedrock saturated hydraulic conductivities is their conversion to infiltration capacities based on the duration of summer and winter rain storms, as was done in the ETINFIL subroutine. For summer storms, the equation is

$$IC_p = \frac{Ksat}{24 / stormsum}, \quad (44a)$$

whereas for winter storms, the equation is

$$IC_p = \frac{Ksat}{24 / stormwin}, \quad (44b)$$

where in equations 44a and 44b

IC_p is the infiltration capacity for either soil or bedrock for rain, in millimeters; and
 $Ksat$ is the saturated hydraulic conductivity for either soil ($(Ksat_{soil})_{adj}$ or $(Ksat_{soil})_{sch}$) or bedrock ($(Ksat_{rock})_{adj}$), in millimeters per day.

Variables *stormsum* and *stormwin* are defined in equation 18. The conversion factor 24 hours/day converts the units of hydraulic conductivity in millimeters per day into a rain-infiltration capacity in units of millimeters. Variables **stormsum** and **stormwin** are specified by the user in the Simulation-Control File. Equations 44a and 44b are used to calculate infiltration capacity of the bedrock only if the total thickness of the soil is less than 0.1 m; if the total thickness of the soil is greater than or equal to 0.1 m, then equation 40b is used to calculate infiltration capacity of the bedrock.

Flow duration, wetted area, and channel characteristics are represented in the INFIL3.0 model by using equations 38 through 44b to scale the saturated hydraulic conductivity that controls infiltration into the root zone. For example, as the wetted area increases, the potential channel losses for streamflow increase because the $Kschn^i$ term increases. As storm duration decreases, the potential channel losses for streamflow decrease because the effective streamflow intensity increases relative to the infiltration capacity of the channel.

SWINFIL uses a simplified form of the ETINFIL downward-drainage algorithm. Water drains into the root zone and underlying layers only when the overlying layer has become fully saturated. Drainage from unsaturated layers, which is simulated in ETINFIL by equations 20–27, is not simulated in SWINFIL. The maximum drainage is limited to the saturated hydraulic conductivity of the underlying layer. If the quantity of water in the bottom layer (in millimeters) is greater than the saturated hydraulic conductivity of the layer multiplied by the 1-day time step (so that the resulting units are millimeters), then net infiltration is equal to the saturated hydraulic conductivity multiplied by the 1-day time step; if, however, the quantity of water in the bottom layer is less than the saturated hydraulic conductivity multiplied by the 1-day time step, then net infiltration is equal to the quantity of water in the bottom layer. The net infiltration from surface-water run-on is defined as run-on net infiltration and is added to the total daily net-infiltration term.

After the net infiltration has been calculated, excess water in the root zone is then calculated using a redistribution algorithm that steps sequentially upward through all root-zone layers, starting at the bottom and moving up to the top layer; this redistribution algorithm is the same as that used in the ETINFIL subroutine. If excess water remains after the upward

redistribution has reached the top soil layer, the excess water is added to the downstream-runoff term. The change in total water storage of all six layers of the model,

$$\sum_{j=1}^6 (\Delta W_d^i)_j,$$

which is equal to the final storage of all six layers minus the initial storage at the beginning of the call to SWINFIL, is then updated.

Surface-water flow that does not infiltrate into the root zone becomes surface-water discharge from the drainage basin (watershed) being modeled. In closed basins, surface water is assumed to evaporate, as where surface water discharges to a playa.

Applicability and Limitations of INFIL3.0

Earlier versions of the INFIL code were originally developed to calculate net infiltration at Yucca Mountain, Nevada. The Yucca Mountain study area, which is in the Basin and Range physiographic province, is characterized as arid to semiarid with small intermontane drainages having thin soils and sparse vegetation, and subject to intermittent runoff from infrequent rainfall and snowmelt. Subsequent modifications to the program were made to (1) allow for regional-scale simulations (in particular, simulations of the Death Valley regional-flow system) that use spatially distributed daily climate inputs, (2) allow for additional soil layers within the root zone, (3) provide a continuous drainage function for soil layers, and (4) allow for surface-water inflows from upstream catchments (Hevesi and others, 2003; Nishikawa and others, 2004; Rewis and others, 2006). These subsequent modifications have all been incorporated into INFIL3.0.

All previous model applications were done to characterize net infiltration or potential recharge for mountainous study areas in the Southwestern United States, with the primary objectives being (1) to estimate the magnitude and spatial distribution of diffuse recharge in direct response to precipitation and snowmelt over more permeable soils or rock units, (2) to estimate the magnitude and spatial distribution of recharge in response to runoff, primarily as channel losses in the more permeable streambeds, and (3) to estimate the temporal distribution of potential recharge or net infiltration in response to climate variability. All study areas for the previous applications of earlier versions of the INFIL code included thick unsaturated zones; very limited to no contribution to streamflow from ground-water discharge, but instead from Hortonian or Dunnian runoff in response to rain or snowmelt; a short lag time between runoff generation and surface-water discharge (less than 1 day for most cases); and steep terrain with thin soil cover. In general, applications of INFIL3.0 are likely to be most appropriate for study areas with similar characteristics.

If INFIL3.0 is used to estimate recharge, the role of the unsaturated zone may need to be considered. For study areas with thick unsaturated zones, the average annual potential recharge rates obtained from 30- to 70-year simulations may be representative of actual recharge, but the daily, monthly, and even annual results are likely not representative of actual recharge because of the dampening effect of the thick unsaturated zone on downward percolation. In other words, estimated net infiltration is usually highly dependent on climate variability, whereas actual recharge may be more dependent on the long-term average climate conditions and the hydrogeologic properties of the unsaturated zone.

INFIL3.0 may have limited applicability for study areas characterized by humid climates, thin unsaturated zones, perennial streamflow with significant contributions from ground-water discharge, and a high percentage of cloudy days with no precipitation (for example, coastal areas subject to foggy conditions). All streamflow simulated by INFIL3.0 is assumed to be routed through the entire study area within the 1-day time step. Therefore, study areas characterized by streamflow with a substantial lag-time relative to the generation of runoff may not be appropriate for an INFIL3.0 application. Options available in INFIL3.0 for representing channel characteristics likely to affect infiltration of routed surface water are limited to estimates of the effective wetted area and differences in hydraulic conductivity for channel versus interchannel soils. These options are based on an assumed continuous transition of channel characteristics from overland-flow conditions to narrow streambeds in low-order stream channels and to wider streambeds for higher-order channels. These limited options may not be adequate in representing more complex and variable channel and streambed characteristics for all study areas.

Although previous versions of the INFIL code have been applied to evaluate the effects of urbanization on runoff generation and subsequent potential recharge (Rewis and others, 2006), application of INFIL3.0 to highly urbanized watersheds with controlled flows, discharges, and diversions may not be appropriate (surface-water inflows from upstream areas were not intended to represent point sources such as wastewater discharges). The INFIL3.0 surface-water-routing algorithm does not include a reach storage component for surface-water storage in channel segments, retention basins, or reservoirs. In addition, INFIL 3.0 provides no interception storage term or surface-retention storage term. For some study areas with dense vegetation and forest canopy, such storage terms may be a significant component of the water balance.

An important consideration for INFIL3.0 applications is model calibration. Generally, streamflow records are used for model calibration, but matching simulated streamflow to measured streamflow does not ensure calibration for simulated net infiltration or potential recharge because simulated evapotranspiration, net infiltration, and potential recharge can vary but produce a negligible combined effect on simulated streamflow. Estimates of hourly or daily potential evapotranspiration are sometimes available for monitoring

sites (for example, California Irrigation Management Information System (CIMIS) stations in California), and these records can be compared to simulated potential evapotranspiration to reduce uncertainty in model calibration. Improved calibrations can be obtained if the recharge estimates are used in a ground-water-flow model calibrated to water-level data and known discharges for the area of interest.

Sources of Data

Sources of data used for developing and calibrating an INFIL3.0 model can be grouped into three general categories: (1) time series of daily climate data used to drive the water-balance simulation through time; (2) GIS data including raster-based data sources such as the DEM and vector-based digital maps defining vegetation, soils, and geologic units; and (3) time series of streamflow data used for calibration. This section provides some examples of data sources for study areas in the United States.

Daily climate data for stations throughout the United States can be obtained online from the National Climatic Data Center (NCDC; <http://www.ncdc.noaa.gov/oa/ncdc.html>) for individual stations or packaged by region into more efficient databases through vendors. Because the data will not be in the format required for input to INFIL3.0, at least some preprocessing of the data will be needed. Other examples of sources for climate data include CIMIS, which maintains a Web site at www.cimis.gov (this is limited to locations in California), and Remote Automated Weather Stations (RAWS), which maintain a Web site at www.wrcc.gov. These online sources provide near-real-time data including precipitation and air temperature for hourly, daily, and monthly time intervals. CIMIS data include estimates of potential evapotranspiration (reference ET_o), which can be compared to simulated potential evapotranspiration during model calibration. Regardless of the data source, the user should be aware of the quality of the data. Online data sources have the advantage of providing easy access to the most recent data, but quality checking for recent data may be minimal. In practice, at least some level of data screening should be incorporated into the preprocessing and reformatting of the climate data.

GIS data sources are essential for the efficient development of an INFIL3.0 model. The primary data source needed for the development of an INFIL3.0 model is the DEM. DEMs are widely available through a variety of sources. High-quality DEMs (having an approximate grid resolution of 10 to 30 meters) can be obtained online from <http://gisdata.usgs.net/Website/Seamless/>. Depending on study-area size, multiple panels may need to be downloaded and then merged into a single continuous raster grid or mosaic. Some degree of GIS processing will be required to develop the INFIL3.0 template grid; for example, clipping the DEM to the area of interest, reprojecting the area, and so forth.

Digital vegetation maps are available as statewide vector coverages from www.gap.gov. Many states also provide Web sites for obtaining statewide or county-wide vegetation maps. California provides several different statewide maps at www.csil.gov and <http://frap.cdf.ca.gov>. The California data were used to develop root-zone variables based on the mapped vegetation categories. A 30-meter raster-grid representation of forest canopy is also available at seamless.usgs.gov and was used in a recent study to develop estimates of vegetation cover (L.E. Flint, U.S. Geological Survey, written commun., April 2007).

Digital STATSGO soil maps are available by state at www.statsgo.gov. Documentation of STATSGO is available to help users in processing the STATSGO database (U.S. Department of Agriculture, 1994). Higher resolution, more spatially detailed SSURGO soil maps also are available at www.ssurgo.gov. The development of SSURGO map coverages is ongoing, however, and may not yet be available for a specific area of interest.

Digital geologic maps are available for most states as statewide coverages. The spatial resolution of the statewide maps may not be adequate for all study areas. For example, a recent study in California (L.E. Flint, U.S. Geological Survey, written commun., April 2007) used local-scale (1/24,000) geologic maps available for the study area to develop a spatially detailed representation of the surface geology, including both consolidated and unconsolidated units. The areal coverage of the unconsolidated units was used to define the location of thick soils and thus thick root zones.

Additional GIS data sources useful for model development include the National Hydrographic Dataset (NHD) available at <http://nhd.usgs.gov/>. The NHD data include low, medium, and high-resolution mapped streamlines and waterbodies. The NHD data are useful for defining the drainage network for the main stream channels and for defining important subbasins. For most locations in the United States, imperviousness can be obtained as a 30-meter raster coverage from <http://gisdata.usgs.net/Website/Seamless/>. The imperviousness can be used to help refine estimates of the permeability of surficial materials.

The preprocessing of the GIS data sources involves the application of several standard GIS procedures, such as reprojecting, merging, and clipping to the area of interest. After the DEM or base grid for the study area has been defined, vector-based GIS data (the vegetation, soils, and geology maps) are put in raster form and superimposed on the base grid, which assigns map identifiers to model cells.

A primary source of daily streamflow data for the United States is <http://waterdata.usgs.gov/nwis/sw>. Continuous records of daily mean discharge can be obtained for both current and historical streamflow-gaging sites. Real-time streamflow data can also be obtained for many locations. Quality flags are included with these data sets.

Input Instructions

This section of the report describes instructions for preparing the data-input files required for an INFIL3.0 simulation. The input files are grouped into three types: control files, basin/watershed-characteristics files, and climate data files. In the descriptions that follow, variables used in mathematical equations are written in italicized upper- and lower-case plain text, whereas variables used in the computer program are written in lower-case bold text. Filenames are written in italics.

Control Files

Two control files must be prepared prior to an INFIL3.0 simulation. These files are called the Batch-Control File and the Simulation-Control File, and are described in detail below.

Batch-Control File

The Batch-Control File specifies the total number of INFIL3.0 simulations that will be done in sequence (that is, as a batch run) and the name of the Simulation-Control File for each simulation. The name of the Batch-Control File must be specified as *infil3.ctl*. Upon execution, INFIL3.0 will search for the file *infil3.ctl* and sequentially run each specified simulation. When simulating an upstream and downstream sequence of subbasins as part of a drainage network, the upstream subbasins must be listed above the downstream subbasins in the *infil3.ctl* file. The *infil3.ctl* file consists of the following input items:

1. **header**
2. **nruns**
3. The following record is read for each of **nruns**:
runfile

Explanation of the variables:

header—is a character heading (character format A, maximum of 250 characters) used to identify the set of runs.

nruns—is an integer variable equal to the total number of simulations that will be made in the batch run. A maximum of 100 simulations can be specified in a batch run.

runfile—is a character variable (30 characters) that identifies the name of the Simulation-Control File associated with each simulation.

Simulation-Control File

A Simulation-Control File must be prepared for each simulation specified in the Batch-Control File. This file specifies several model-input variables, including the

simulation time period and the names of most data-input and model-output files. The name of each Simulation-Control File is specified by variable **runfile** in the Batch-Control File.

Table 1-1 in appendix 1 lists the input variables that must be specified in each Simulation-Control File; figure 6 shows a sample Simulation-Control File. Additional information for some of the variables shown in table 1-1 follows:

irout—Flag that specifies the type of flow routing to be simulated. If **irout** is set to 0, surface-water run-on is not allowed to infiltrate back into the root zone.

petadj—An empirical adjustment factor to the calculated potential evapotranspiration to account for cloud cover (precipitation). A value of about 0.16 has been used in previous modeling studies (Hevesi and others, 2003).

isksval—Flag that specifies whether soil saturated vertical hydraulic conductivity will be a constant value. If **isksval** is set to a value other than 0, then a constant value of soil saturated vertical hydraulic conductivity will be set by variable **sksval**, and variable **soilks** in the Soil-Properties File will be ignored.

iimbval—Flag that specifies whether bedrock saturated and unsaturated hydraulic conductivities will be a constant value. If **iimbval** is set to a value other than 0, constant bedrock hydraulic conductivities will be set by variable **iimbval**, and variables **imbibe** and **imbibe2** in the Bedrock-Properties File will be ignored.

upgeoinp—Name of file containing upstream cellcode identifiers for cells contributing inflow. This file has the same format as the Geospatial Watershed-Characteristics File for each upstream basin.

barsoil1, **rocket1**, **soilet1**—Parameter β (beta) in the modified Priestley-Taylor equation used for defining evaporation or plant transpiration from bare soil, rock matrix, and soil layers. A value of -10 for these three variables has been used in previous investigations (Flint and Childs, 1987; Hevesi and others, 2003).

barsoil2, **rocket2**, **soilet2**—Parameter α (alpha) in the modified Priestley-Taylor equation used for defining evaporation or plant transpiration from bare soil, rock matrix, and soil layers. A value of 1.04 has been used for **barsoil2** and of 1.50 for **rocket2** and **soilet2** in previous investigations (Flint and Childs, 1987; Hevesi and others, 2003).

barsoilf—An adjustment factor that can be used to modify the value of **barsoil1** for layer 2 of the model. A value of 1.0 causes the **barsoil1** value for layers 1 and 2 of the model to be the same and has been used in previous investigations.

hstep—Time-step length used for calculating total daily evapotranspiration. HSTEP can range from 1.0 to 4.0 and values of either 1.0 or 2.0 are recommended.

Basin-Characteristics Files

Several basin-characteristics files and an optional file named by variable **restartfile** are needed for an INFIL3.0 simulation. These files are: (1) Geospatial Watershed-Characteristics File, (2) Upstream Sources-of-Inflow Files, (3) Soil-Properties File, (4) Bedrock-Properties File, and (5) Vegetation-Properties File.

Geospatial Watershed-Characteristics File

Spatially distributed watershed characteristics for each grid cell of a model are specified in the Geospatial Watershed-Characteristics File. The name of the file is specified by the variable **infile**, which is defined in the Simulation-Control File (table 1-1). INFIL3.0 calculations in the surface-water-flow routing algorithm are based on the assumption that grid cells have been entered in an upstream to downstream order. Input variables associated with the upstream and downstream ordering are the upstream-cell identifier **locid** and the downstream-cell identifier **iwat**. Typically, the value of **locid** for the first cell entered will be 1, and each successive value of **locid** will be increased by 1.

Information for a maximum of 60,005 grid cells and 3,350 row or column grid indices can be specified for each simulation in the current version of INFIL3.0.

The file consists of the following input items:

1. **header**
2. The following free-format record is read for each grid cell:

cellcode	easting	northing	lat	lon
row	col	elev	sl	asp
locid	iwat	upcells	soiltype	
depth	rocktype	vegtype	skyview	
ridge(36)				

Explanation of the variables:

Record 1

header—is a character heading (character format A, maximum of 250 characters) for the file, and is not printed to an output file.

Record 2

cellcode—is an integer variable equal to the grid-cell (node) number. A maximum of 60,005 grid cells may be defined.

easting—is the east-west coordinate of the centroid of the grid cell, in meters (real variable).

northing—is the north-south coordinate of the centroid of the grid cell, in meters (real variable).

lat—is the latitude of the centroid of the grid cell (real variable).

lon—is the longitude of the centroid of the grid cell (real variable).

row—is the row assignment of the grid cell (integer variable).

col—is the column assignment of the grid cell (integer variable).

elev—is the land-surface elevation of the centroid of the grid cell, in meters (real variable).

sl—is the land-surface slope of the centroid of the grid cell, degrees (real variable).

asp—is the land-surface aspect of the centroid of the grid cell, degrees azimuth relative to north (real variable).

locid—is an integer variable equal to the sequential number of the grid cell in the upstream-to-downstream ordering. Grid cells must be numbered incrementally from 1 for the first grid-cell entry to the total number of grid cells in the modeled area for the last grid-cell entry.

iwat—is an integer variable equal to the downstream location identifier (variable **locid**) to which runoff is directed from the current cell. A value of **iwat** = -3 identifies the outflow cell of the basin, which is actually part of the downstream basin; a cell with **iwat** = -3, however, is excluded from the mass-balance calculations for the basin being simulated.

upcells—is the total number of cells upstream to the current grid cell (and is used for streamflow routing) (real variable).

soiltype—is an integer code for the soil type in the grid cell. The value specified must be one of the soil types identified by variable **soilid** in the Soil-Properties File.

depth—is the total soil depth for the grid cell (not including bedrock depth), in meters (real variable).

rocktype—is an integer code for the bedrock type in the grid cell. The value specified must be one of the bedrock types identified by variable **rockid** in the Bedrock-Properties File.

vegtype—is an integer code for the vegetation type in the grid cell. The value specified must be one of the vegetation types identified by variable **vegmap** in the Vegetation-Properties File.

skyview—is total fraction of viewable sky, as fraction of hemisphere (dimensionless) (real variable).

ridge(36)—are the 36 blocking ridge angles (real variable).

Figure 6. Simulation-Control File for sample problem.

```

sample.ctl: Sample problem Simulation-Control File
1 IROUT
0.15748 PETADJ
2 8.0 ISNOW, MELTTIME
305 0.96 121 1.14 SNODAY1, SNOPAR1, SNODAY2, SNOPAR2
1 0.40 0.40 ISUBLIM, SUBPAR1, SUBPAR2
0 0. IPPTVAL, PPTVAL : precipitation [mm]
0 0. IAIRVAL, AIRVAL : air temperature [C]
0 0. IETVAL, ETVAL : evapotranspiration
0 0. ISDEPTHVAL, SDEPTHVAL : soil depth [M]
0 0. ISKSVAL, SKSVAL : soil ksat [mm/day]
0 0. IIMBVAL, IMBVAL : rock ksat [mm/day]
30.0000 CELSIZE : node spacing [M]
2 NUPSTREAM: number of upstream inputs
0 0. IOPTUPFLOW(1), UPCONST(1)
upstream1.point1 UPFILE(1)
upstream1.gwc UPGEOINP(1)
0 0. IOPTUPFLOW(2), UPCONST(2)
upstream2.point1 UPFILE(2)
upstream2.gwc UPGEOINP(2)
12 31 MONTHWY, MONDAYWY
1964 1 1 YRSTART, MOSTART, DYSTART
1970 12 31 YREND, MOEND, DYEND
1965 1 1 YRSTART1, MOSTART1, DYSTART1
1970 12 31 YREND1, MOEND1, DYEND1
2 OUTPUTINTERVAL (years)
1.5 1.0 1.25 1.0 1.0 SDFACT, PPTFACT, ETFACT, IMBFACT, SKSFACT
0 0. IVEGC, FVEGC
1 0.20 500. 0.8 2.0 ICHANMOD, CHAN1, CHAN2, CHAN3, CHAN4
0 50.0 2000.0 5.0 IKSCHNMOD, KSCHN1, KSCHN2, KSCHN3
-10.0 1.04 1.0 BARSOIL1, BARSOIL2 BARSOILF
-10.0 1.50 ROCKET1, ROCKET2
-10.0 1.50 SOILET1, SOILET2
1 HSTEP: time step for PET model (hours)
183 274 DYSUMBEG, DYSUMEND
2.0 12.0 STORMSUM, STORMWIN
sample.daystations Climate-Stations Information File
sample.monthmod Monthly Climate-Regression Models File
sample.precip Daily Precipitation File
0 TUNIT
sample.tmax Daily Maximum Temperature File
sample.tmin Daily Minimum Temperature File
sample.soils Soil-Properties File
sample.bedrock Bedrock-Properties File
sample.atmos Monthly Atmospheric-Parameters File
sample.veget Vegetation-Properties File
1 1.500 INITOPT, VWCFAC (initial conditions)
sample.gwc Geospatial Watershed-Character. File
sample.crashfile Crashfile
sample.dayall Spatially Averaged Daily Output File
1 NDAYMAP
55 1969 IRDAY(1), NYROUT(1)
sample.daymap Daily Output File for All Grid Cells

```

Figure 6. Simulation-Control File for sample problem.—Continued

sample.point1	POINTFILE (1)
5	IPOINTFILE
517435.03 3792570.93	XPOINT (2), YPOINT (2)
sample.point2	POINTFILE (2)
517465.03 3792570.93	XPOINT (3), YPOINT (3)
sample.point3	POINTFILE (3)
518455.03 3791760.93	XPOINT (4), YPOINT (4)
sample.point4	POINTFILE (4)
519415.03 3792840.93	XPOINT (5), YPOINT (5)
sample.point5	POINTFILE (5)
519205.03 3792540.93	XPOINT (6), YPOINT (6)
sample.point6	POINTFILE (6)
sample.outfile	Summary Output File
sample.flxfile	Average-Annual Output for All Grid Cells
sample.spatialout	Grid-Cell Properties Output File
sample	Annual/Ave.-Annual Output Files (Prefix)
sample.outannual	Annual Output File for All Grid Cells
sample.outmonth	Monthly Output File for All Grid Cells

Upstream Sources-of-Inflow Files

Two files are needed for each upstream basin when simulating upstream surface-water inflows to a modeled area (that is, when variable **nupstream**, which is defined in the Simulation-Control File is greater than 0). The first is named by variable **upgeoinp**, which has the same format as the Geospatial Watershed-Characteristics File described in the previous section; therefore, the Geospatial Watershed-Characteristics File for each upstream basin can be used for **upgeoinp**. Although INFIL3.0 reads the entire contents of each **upgeoinp** file, the only value from each file that is used is the last value specified for variable **cellcode**. The last value of **cellcode** must be the same as the last value of **cellcode** for each of the other upstream basins and is equal to the **cellcode** of the grid cell that receives the upstream flow in the simulated basin. Surface-water inflows from a maximum of five upstream tributary subbasins can be simulated.

The second file that is required for each upstream basin is named by variable **upfile**. This file is a **pointfile(1)** output file generated for each upstream cell that contributes flow to a modeled area. Therefore, the user does not need to create this file but needs to have the name of an **upfile** for each upstream basin specified in the Simulation-Control File. (See the section “Daily Output Files for Specific Grid Locations” for a description of the contents of **pointfile(1)**.)

Soil-Properties File

Information about the soils of the watershed is read from the Soil-Properties File, which is specified by variable **soilprop** in the Simulation-Control File. If the user assigns a value other than 0 to **isksval** in the Simulation-Control File, then a constant value equal to **sksvval**, specified in the Simulation-Control File, is used for the soil saturated vertical hydraulic conductivity, and the value of **soilks** entered below will be ignored. Note, however, that the user must enter a value for **soilks** in the Soil-Properties File, even if it is ignored.

The Soil-Properties File consists of the following input items:

1. **head1**
2. **nsoilid**
- 3–4. **head2**—two records.
5. The following record is read **nsoilid** times for each type of soil. Each record should have the following format:
soilid soilmu soilporo fieldcap soilresid soilb soilks
Explanation of the variables:

Record 1

head1—is a character heading (character format A, maximum of 250 characters); the heading is not printed to an output file.

Record 2

nsoilid—is an integer variable equal to the total number of soil types to be entered. A maximum of 800 soil types may be specified in the current version of INFIL3.0.

Records 3–4

head2—are two lines of character headings (character format A, maximum of 250 characters); the headings are not printed to an output file.

Record 5

soilid—is an integer variable used to identify the soil-type number (integer format I6).

soilmu—is the name of the soil type (character format A10).

soilporo—is the soil porosity, dimensionless (real format F8.4).

fieldcap—is the soil field capacity, dimensionless (real format F8.4).

soilresid—is the residual soil-water content for plant transpiration, which is also referred to as the wilting point, dimensionless (real format F8.4).

soilb—is the soil-drainage-function coefficient, dimensionless (real format F7.3).

soilks—is the soil saturated vertical hydraulic conductivity, in millimeters per day (real format F8.1).

Bedrock-Properties File

Information about the bedrock properties of the watershed is read from the Bedrock-Properties File, which is specified by variable **rockprop**, which is defined in the Simulation-Control File. If the user assigns a value other than 0 to **imbval** in the Simulation-Control File, then a constant value equal to **imbval**, specified in the Simulation-Control File, will be used for both the effective unsaturated and saturated bedrock hydraulic conductivities, and the values of **imbibe** and **imbibe2** entered below will be ignored. Note, however, that the user must enter values for **imbibe** and **imbibe2** in the Bedrock-Properties File, even if they are ignored.

The Bedrock-Properties File consists of the following input items:

1. **header**
2. **header nrockid**
- 3–6. **header**—four records.
7. The following record is read **nrockid** times for each bedrock type. Each record should have the following format:

rockid rockname2 rockporo imbibe imbibe2

Explanation of the variables:

Record 1

header—is a character heading (character format A, maximum of 250 characters); the heading is not printed to an output file.

Record 2

header—is a fixed-format 5-character text identifier.

nrockid—is a fixed-format integer variable equal to the total number of bedrock types to be entered. A maximum of 800 bedrock types may be specified in the current version of INFIL3.0.

Records 3–6

header—are four lines of character headings (character format A, maximum of 250 characters); the headings are not printed to an output file.

Record 7

rockid—is an integer variable used to identify the bedrock-type number (integer format I6).

rockname2—is the bedrock-type descriptor (character format A52).

rockporo—is the effective root-zone porosity (storage capacity) for the bedrock layer, dimensionless (real format F8.3).

imbibe—is the effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define a lower-bedrock vertical hydraulic conductivity), in millimeters per day (exponential format E10.1).

imbibe2—is the effective saturated vertical hydraulic conductivity for the bedrock layer (used to define an upper-bedrock and deep-alluvium vertical hydraulic conductivity), in millimeters per day (exponential format E10.1).

Vegetation-Properties File

Information about the vegetation of the watershed is read from the Vegetation-Properties File, which is specified by variable **vegprop** defined in the Simulation-Control File. If the user assigns a value other than 0 to **ivegc** in the Simulation-Control File, then a constant value equal to **fvegc**, specified in the Simulation-Control File, will be used for the vegetation-cover variables **vegcover0** and **vegcover(6)**, and the values of **vegcover0** and **vegcover(6)** entered below will be ignored. Note, however, that the user must enter values for **vegcover0** and **vegcover(6)** in the Vegetation-Properties File, even if they are ignored.

The Vegetation-Properties File consists of the following input items:

1–4. **header**—four records

5. The following record is read for each vegetation type. A maximum of 500 vegetation types may be specified. The user does not need to specify the total number of vegetation types; INFIL3.0 will read each record until the last record has been read. Each record should have the following format:

```
vegname1    vegmap    vegcode    vegcover0
vegname2    vegcover(6)  rzdpth(6)  rzdpthf
```

Explanation of the variables:

Records 1–4

header—are four lines of character headings (character format A, maximum of 250 characters); the headings are not printed to an output file.

Record 5

vegname1—is the name of the vegetation type (character format A28).

vegmap—is a vegetation-type map-unit code. The values of **vegmap** must lie in the range -10,000 to 100,000 in the current version of INFIL3.0 (integer format I8).

vegcode—is a vegetation-code number (integer format I8).

vegcover0—is the percentage of land surface covered by vegetation (complementary value to the percent bare-soil cover) (real format F8.0).

vegname2—is a second name for the vegetation class (character format A30).

vegcover(6)—is the percentage of root density for each of the six layers of the model. Six values are entered, each in F8.0 real format.

rzdpth(6)—are the root-zone depths from land surface for layers 1 through 5 and the root-zone thickness for layer 6, in meters. Six values are entered, each in F8.0 real format.

rzdpthf—is the root-zone depth factor used in soil-layer-thickness determinations (real format F8.0).

Water-Budget Components for a Simulation Restart (Restart File)

If a user sets **initopt** = 3, then the initial soil-water contents for each layer at each cell are read from the file specified by variable **restartfile** in the Simulation-Control File. The user also must specify the day number (variable **ndayscrash**) of the last successful day of the simulation for

which the data read from the file named by variable **restartfile** apply. The format of **restartfile** is exactly the same as that of **crashfile**, which also specifies a filename in the Simulation-Control File. The contents of **crashfile** are described in detail in the “Output Files” section of this report [see subsection “Daily and Cumulative Output File for All Grid Cells for the Last Successful Day of a Simulation (Crashfile)”].

Climate Data Files

Several climate-data files are needed for an INFIL3.0 simulation. These are: (1) Climate-Stations Information File, (2) Monthly Climate-Regression Models File, (3) Monthly Atmospheric-Parameters File, and (4) Daily Climate Files (precipitation and maximum and minimum air temperatures).

Climate-Stations Information File

Information for each of the daily climate stations is read from the Climate-Stations Information File, which is specified by variable **daystations** defined in the Simulation-Control File. The stations must be entered in the same order in which precipitation and temperature data are entered in the Daily Climate Files. A maximum of 250 climate stations can be specified for each simulation in the current version of INFIL3.0. The file consists of the following input items:

1. **header**
2. The following record is read for each climate station. The user does not need to enter the total number of stations for which data will be entered because the program will add the stations as they are entered and store the total as program variable **nstations**. Each record has the following format:

```
name   statid  eutm   nutm   statelev
```

Explanation of the variables:

Record 1

header—is a character heading (character format A, maximum of 250 characters).

Record 2

name—is the name of the climate station (character format A28).

statid—is an integer-variable code for the climate station (integer format I9).

eutm—is the east-west coordinate of the climate station, in meters (real format F10.0).

nutm—is the north-south coordinate of the climate station, in meters (real format F11.0).

statelev—is the elevation of the climate station, in meters (real format F8.0).

Monthly Climate-Regression Models File

Information about the models used to spatially distribute daily climate variables (precipitation and minimum and maximum air temperature) across the model domain is read from the Monthly Climate-Regression Models File, which is specified by variable **monthmod** in the Simulation-Control File. The file consists of the following input items:

1. **header**
2. The following record is read a total of 12 times, once for each month (free format):

```
imonth  pptmod  ppta   pptb   pptc
tmaxmod tmaxa   tmaxb  tmaxc  tminmod
tmina   tminb   tminc
```

Explanation of the variables:

Record 1

header—is a character line (character format A, maximum of 250 characters).

Record 2

imonth—is an integer variable for each month of the year, starting with 1 for January.

pptmod, tmaxmod, tminmod—are integer variables used to define the spatial-distribution model type for daily climate data: a value of 0 for **pptmod, tmaxmod,** or **tminmod** indicates that the inverse-distance-squared interpolation model is used; a value of 1 for **pptmod, tmaxmod,** or **tminmod** indicates that the linear-regression model is used (equation 3 in text); a value of 3 for **pptmod, tmaxmod,** or **tminmod** indicates that the quadratic-regression model is used (equation 4 in text).

ppta, pptb, pptc—are the regression-model coefficients (real variables) for the precipitation-elevation model for each month **imonth**. Values must be specified for all three variables, even if the linear model is used; a value of 0.0 can be specified for **pptc** if the linear model is used.

tmaxa, tmaxb, tmaxc—are the regression-model coefficients (real variables) for the maximum air temperature-elevation model for each month **imonth**. Values must be specified for all three variables, even if the linear model is used; a value of 0.0 can be specified for **tmaxc** if the linear model is used.

tmina, tminb, tminc—are the regression-model coefficients (real variables) for the minimum air temperature-elevation model for each month **imonth**. Values must be specified for all three variables, even if the linear model is used; a value of 0.0 can be specified for **tminc** if the linear model is used.

Monthly Atmospheric-Parameters File

Information about the monthly atmospheric variables is read from the Monthly Atmospheric-Parameters File, which is specified by variable **atmosinput** in the Simulation-Control File. Input variables specified in this file are derived from climate-monitoring stations across the United States with long periods of record. The file consists of the following input items:

1. **header**
2. The following record is read a total of 12 times, once for each month (free format):

imonth ozone wp beta csr pg

Explanation of the variables:

Record 1

header—are four lines of character headings (character format A, maximum of 250 characters); the headings are not printed to an output file.

Record 2

imonth—is the month number (integer format).

ozone—is ozone-layer thickness for month **imonth**, in centimeters (real format).

wp—is the precipitable water in the atmosphere for month **imonth**, in centimeters (real format).

beta—is the mean atmospheric turbidity for month **imonth**, dimensionless (real format).

csr—is the circumsolar radiation for month **imonth**, dimensionless (real format).

pg—is the surface reflectivity for month **imonth**, dimensionless (real format).

Daily Climate Files—Precipitation and Maximum and Minimum Air Temperatures

Daily precipitation and maximum and minimum air temperatures for each climate station are read from three separate files, whose names are specified by variables **daypptinput**, **daytmaxinput**, and **daytmininput** defined in the Simulation-Control File. Each of the three files must have data for the same sequence of dates. Also, the precipitation and temperature data for each station must be entered in the same order in which climate-station information are entered in the Climate-Stations Information File. For example, the first values entered for **ppt**, **maxairt**, and **minairt** (array locations **ppt(1)**, **maxairt(1)**, and **minairt(1)**, respectively) in each of the precipitation and maximum and minimum air temperature files, respectively, must be for the first station listed in the

Climate-Stations Information File. Temperature data are assumed to have units of degrees Celsius; if the data are in degrees Fahrenheit, then the user must specify variable **tunit** equal to 1 in the Simulation-Control File.

A maximum of 40,000 days can be simulated in a single model run in the current version of INFIL3.0. The files have the following input structures:

Precipitation file:

1. **header2**
2. The following record is read for each day of the simulation. Each record uses free format.
dyn yr month monday yearday ppt(nstations)

Maximum air-temperature file:

1. **header2**
2. The following record is read for each day of the simulation. Each record uses free format.
dyn yr month monday yearday maxairt(nstations)

Minimum air-temperature file:

1. **header2**
2. The following record is read for each day of the simulation. Each record uses free format.
dyn yr month monday yearday minairt(nstations)

Explanation of the variables:

Record 1 for each file

header2—is a character heading (character format A, maximum of 250 characters); the heading is not printed to an output file.

Record 2 for each file

dyn—is the sequential day number in the simulation (integer format).

yr—is the calendar year (for example, 1900) (integer format).

month—is the calendar month of the year, starting with 1 for January (integer format).

monday—is the sequential day in the month (for example, 1 for the first day of January, 31 for the last day of January) (integer format).

yearday—is the sequential Julian day of the year (for example, 1 for first day of 1900, 365 for the last day of 1900) (integer format).

ppt(nstations)—is the daily precipitation at each climate station, in millimeters (real format).

maxairt(nstations)—is the daily maximum air temperature at each climate station, in degrees Celsius (real format).

minairt(nstations)—is the daily minimum air temperature at each climate station, in degrees Celsius (real format).

Output Files

INFIL3.0 generates several output files that provide simulation results. Each of these output files is described in detail below.

Summary Output File

The summary output file lists (1) the names of the input and output file names for the simulation, (2) a summary of the climate-input and watershed-characteristics data, (3) a summary of the simulation starting and ending dates and the simulation averaging period, (4) a summary of many of the water-budget components for all grid cells and for all days during a simulation averaging period, and (5) a summary of the root-zone mass balance for the simulation averaging period that is consistent with the water-budget terms given in equation 2. The simulation averaging period is defined by variables **yrstart1**, **mostart1**, and **dystart1** for the start date of the averaging period and **yrend1**, **moend1**, and **dyend1** for the end date of the averaging period; these variables are defined in the Simulation-Control File. These dates differ from the simulation starting and ending dates, which are defined by variables **yrstart**, **mostart**, and **dystart** for the simulation start date and **yrend**, **moend**, **dyend** for the simulation end date. A separate averaging period is included to allow the user the option of a model warm-up period, during which the system can respond to initial conditions. The name of the summary output file is specified by variable **outfile** in the Simulation-Control File.

Grid-Cell Properties Output File

The grid-cell properties file, which is specified by variable **spatialout** in the Simulation-Control File, includes several pieces of information for each grid cell in the watershed-modeling domain. The information is written to the file prior to the actual INFIL3.0 simulations and therefore includes only input data or information calculated on the basis of specified input data. Definitions of the variables printed to the **spatialout** file are given in table 1–2 in appendix 1.

Daily Output Files for Each Grid Cell

These files consist of water-budget components for each grid cell for specific days identified by the user by variables **ndaymap** (total number of daily map-output files) and **irday**

and **nyrout** (the day and year, respectively, for each daily output file). Variable **daymap** is the name of each output file. Each of these variables is specified in the Simulation-Control File. A maximum of 100 days can be specified in a particular simulation. Definitions of the variables printed to each **daymap** file are given in table 1–3 in appendix 1.

Daily Output Files for Specific Grid Locations

This file consists of water-budget components for each day of a simulation for grid cells identified by the user. INFIL3.0 automatically generates an output file for the last active grid cell in each model domain, and the user must use the variable **pointfile(1)** in the Simulation-Control File to specify the name of the file to which this output will be written. The user can then specify a maximum of an additional 19 grid cells for which output will be written by variables **ipointfile** (the number of additional output grid cells), **xpoint** and **ypoint** (the east-west and north-south coordinates of each additional grid cell, respectively), and **pointfile** (the name of the file for each additional grid cell). These variables are specified in the Simulation-Control File. Definitions of the variables printed to each **pointfile** are given in table 1–4 in appendix 1.

Annual and Average Annual Output Files for All Grid Cells

The user has the option of printing total annual or average annual water-budget components for regular time intervals during the simulation for all grid. These output intervals are specified by a combination of variables defined in the Simulation-Control File. The first set of variables that must be specified are those that designate the simulation time period by which the annual and average annual calculations will be made. These are set using variables **yrstart1**, **mostart1**, and **dystart1** for the start date of the period and **yrend1**, **moend1**, and **dyend1** for the end date of the period. The month and day of the month that designate the interval for which annual and average annual calculations will be made are specified by variables **monthwy** and **mondaywy**. The output interval, in years, for which calculations will be made is specified by variable **outputinterval**. Output is then written to user-defined files every **outputinterval** years. Each of these files has the prefix designated by variable **outyear1**. If the user does not want to provide this type of output, **outputinterval** should be set to 0. Definitions of the variables printed to each **outyear1** output file are given in table 1–5 in appendix 1.

Two examples illustrate how this output works. In both examples, the simulation period is January 1, 1964 (specified by variables **yrstart**, **mostart**, and **dystart**) through December 31, 1970 (specified by variables **yrend**, **moend**, and **dyend**), and the simulation period during which annual and average annual calculations will be made is January 1, 1965 (specified by variables **yrstart1**, **mostart1**, and **dystart1**) through

December 31, 1970 (specified by variables **yrend1**, **moend1**, and **dyend1**). For both examples, the date for which annual and average annual calculations will be made is December 31 (**monthwy** = 12, **mondaywy** = 31), and the prefix of the files to which output will be written (that is, variable **outyear1**) is *sample*. In the first example, the user wants to calculate annual totals for the water-budget components and therefore specifies **outputinterval** = 1. In this case, annual water-budget totals will be written to six output files for the periods January 1 through December 31, 1965; January 1 through December 31, 1966; and so forth. The output files will have the names *sample.0001*, *sample.0002*, ... *sample.0006*. In the second example, the user wants to calculate average annual totals for the water-budget components every 2 years and therefore specifies **outputinterval** = 2. In this case, average annual water-budget totals will be written to three output files for the periods January 1, 1965 through December 31, 1966; January 1, 1967 through December 31, 1968; and January 1, 1969 through December 31, 1970. The output files will have the names *sample.0001*, *sample.0002*, and *sample.0003*. Note that in both cases, if the averaging period started on a date other than January 1, the first averaging period would have been less than a full year (or 2 full years for the second example).

Daily and Cumulative Output File for All Grid Cells for the Last Successful Day of a Simulation (Crash File)

At the end of each successful simulation for December 31, several water-budget components are written to a file for all grid cells. This file is named by the variable **crashfile** and is defined in the Simulation-Control File. The contents of the file can then be used for a model restart. Depending on the day of a simulation crash (due to a power failure, for example), the maximum number of days that would need to be resimulated is 366 (if the crash occurred on the last day of a leap year). Definitions of the variables printed to **crashfile** are given in table 1–6 in appendix 1.

Spatially Averaged Daily Output File

This file consists of spatially averaged water-budget components for all active grid cells for each day of a simulation. The active grid cells include all of the cells except the outflow cell of the basin (that is, the cell with variable **iwat** equal to -3). A single line of output is written for each day of a simulation and consists of water-budget components averaged over all of the active grid cells. The name of the file to which the output is written is specified by variable **dayall** in the Simulation-Control File. Definitions of the variables printed to **dayall** are given in table 1–7 in appendix 1.

Monthly and Annual Output Files for All Grid Cells

The user has the option of printing total monthly and total annual water-budget components for all active grid cells. Output for these options is written to files **outmonth** and **outannual**, respectively, which are defined in the Simulation-Control File. Monthly output will be written for each month, but the first and last months may be based on fewer than a full month of days depending on the starting and ending dates of the simulation periods. Annual output will be written for simulation days between January 1 and month and day **monthwy** and **mondaywy**, respectively, which are defined in the Simulation-Control File. For example, if the user assigns **monthwy** a value of 12 and **mondaywy** a value of 31, total annual water-budget components will be added for each year starting on January 1 and ending on December 31. The first and last annual totals may be based on fewer than a full year of days depending on the starting and ending dates of the simulation periods. Water-budget components are written to the output files for both the monthly and annual totals, and the definitions of the variables printed to each output file are given in table 1–8 in appendix 1.

Average Annual Output File for All Grid Cells for a Specified Averaging Period

The user has the option of printing average annual water-budget components for all grid cells. The averaging period is defined by variables **yrstart1**, **mostart1**, and **dystart1** for the start date of the period and **yrend1**, **moend1**, and **dyend1** for the end date of the period. Output is written to the file defined by variable **flxfile** in the Simulation-Control File. Definitions of the variables printed to **flxfile** are given in table 1–9 in appendix 1.

Sample Problem

A sample problem is provided to illustrate how INFIL3.0 can be applied to a field setting. The sample problem provides a brief description of the modeled area, an overview of model input and output files, and a discussion of some results of the multiyear simulation.

Description of Basin

The modeled area is representative of conditions in the Big Bear Lake area of south-central California, about 130 kilometers east-northeast of Los Angeles. Although basin characteristics and model inputs were selected on the basis of reported field conditions, the sample problem is a simplified abstraction of field conditions and is not intended to yield an accurate simulation of the actual hydrologic conditions. Model

characteristics and input files are based on an ongoing study by the U.S. Geological Survey (L.E. Flint, U.S. Geological Survey, written commun., April 2007).

Hydrologic concerns within the study area center on overuse of the existing ground-water resources under climatic conditions such as drought. A primary goal of the study was to estimate the quantity, distribution, and source of recharge to the ground-water basin. This goal was addressed by the construction of a model of the study area by use of an earlier version of the INFIL code, because net-infiltration rates calculated by INFIL can be taken to be equivalent to recharge rates to an underlying water table.

The Big Bear Valley ground-water basin underlies Bear Valley and is bounded by crystalline rocks of the San Bernardino Mountains (L.E. Flint, U.S. Geological Survey, written commun., April 2007). The basin is predominantly underlain by alluvial deposits and older sedimentary deposits. Ground water in the basin is generally in the unconsolidated alluvial deposits on the lower slopes of the surrounding mountains and in the valley. The basin deposits consist of sands and gravels with interbedded clays. Precipitation as rain and snow provides the water available for recharge to the underlying ground-water basin. Average annual precipitation in the valley ranges from 900 mm on the western edge of the valley to 450 mm on the eastern edge of the valley. Ground-water levels within the basin vary in response to precipitation. In general, when precipitation quantities are in excess of average values, water levels rise, and when precipitation quantities are less than average values, water levels decline (L.E. Flint, U.S. Geological Survey, written commun., April 2007).

Big Bear Lake, in the western portion of the valley, is at the base of a north-facing slope at an elevation of approximately 2,073 m (6,800 ft). The surrounding mountains rise to approximately 2,377 to 2,621 m (7,800 to 8,600 ft) along the ridge to the south of the lake. Big Bear Lake is filled by runoff from creeks that drain the valley floor. Baldwin Lake, which is typically dry, lies in the northeastern portion of the valley.

Construction of INFIL3.0 Model

The area of the Big Bear Valley modeled by INFIL 3.0 was 186.5 km² (72 mi²) and included 11 surface-water drainage basins and 2 lakes. The modeled area was discretized into a base grid of square cells each having a length of 30 m (98.4 ft) on a side. The grid consisted of 1,279 rows and 1,875 columns. The 11 surface-water drainage basins and 2 lakes were further subdivided into a total of 40 simulation units, with 9 simulation units representing the Baldwin Lake drainage and 31 simulation units representing the Big Bear Lake drainage. Model subunits were based on surface-water drainage boundaries defined by a GIS computer package (ArcGIS and the Arc Hydro extension). The DEM that was used as part of the GIS basin delineations was modified on the basis of high-resolution hydrography data sets available from the U.S. Geological Survey National Hydrography Dataset (www.seamless.usgs.gov). The subdivision of the 11 surface-

water drainage basins into smaller simulation units is not required for application of INFIL3.0, but was done to improve the efficiency of model operation and to allow for a more direct comparison of INFIL3.0 recharge estimates with those made for the drainage basins in previous studies of the area.

A simulation unit in the Baldwin Lake drainage system is used to illustrate the input and output files of an INFIL3.0 simulation. The simulation unit is referred to as the “sample” basin. Two upstream basins drain into the sample basin and therefore provide upstream flows to the sample basin; these basins are referred to as “upstream basin 1” and “upstream basin 2.” The sample basin consists of a total of 2,357 active grid cells, with row numbers ranging from 460 through 522 and column numbers ranging from 1,300 to 1,378. The total size of the simulated area is therefore 2.12 km². The simulated areas of upstream basins 1 and 2 are 2.41 and 3.08 km², respectively.

A total of six model layers was used to represent the root zone to account for differences in root density and root-zone water content as a function of depth. The upper five root-zone layers were used to represent the soil component of the root zone. For locations estimated as having thick soils underlain by unconsolidated deposits, the root zone had a maximum total thickness of 8 m, as defined by the Vegetation-Properties File, and was discretized into five soil layers. Drainage from the root zone (net infiltration from layer 5) was a function of the water content of layer 5 and the estimated vertical hydraulic conductivity of the underlying material. For locations estimated as having thinner soils underlain by consolidated bedrock, the number and thickness of both the soil layers and the underlying bedrock layer (layer 6) was based on the estimated soil thickness. The thickness of the bedrock layer also was dependent on the vegetation type assigned to each grid cell, and was used to represent the extension of the root zone into bedrock (roots extending into fractures and weathered zones).

A summary of the input and output files for the sample problem is given in table 1. The names of all input and output files except that of the Simulation-Control File are defined in the Simulation-Control File (fig. 6). The name of the Simulation-Control File is defined in the Batch-Control File (*infil3.ctl*). Most of the additional variables defined in the Simulation-Control File are described in more detail below.

The simulation period selected for the sample problem was January 1, 1964 through December 31, 1970. The period selected for averaging of model results, however, was selected to be the 6-year period January 1, 1965 through December 31, 1970, which allowed a 1-year period for model initialization (warm-up). An **outputinterval** of 2 years was specified, as well as a date of December 31 for reporting the average annual results (**monthwy** = 12 and **mondaywy** = 31); therefore, average annual results were printed to output files *sample.0001*, *sample.0002*, and *sample.0003* for the periods January 1, 1965 through December 31, 1966; January 1, 1967 through December 31, 1968; and January 1, 1969 through December 31, 1970.

Table 1. Names of input and output files for the sample problem.

File type	File name
Input files	
Batch Control	infil3.ctl
Simulation Control	sample.ctl
Geospatial Watershed Characteristics	sample.gwc
Upstream Basin 1	
upgeoinp file	upstream1.gwc
upfile	upstream1.point1
Upstream Basin 2	
upgeoinp file	upstream2.gwc
upfile	upstream2.point1
Soil Properties	sample.soils
Bedrock Properties	sample.bedrock
Vegetation Properties	sample.veget
Climate-Station Information	sample.daystations
Monthly Climate-Regression Models	sample.monthmod
Monthly Atmospheric Parameters	sample.atmos
Daily Precipitation	sample.precip
Daily Maximum Air Temperature	sample.tmax
Daily Minimum Air Temperature	sample.tmin
Output files	
Summary Output	sample.outfile
Grid-Cell Properties	sample.spatialout
Daily Output for all Grid Cells	sample.daymap
Daily Output for Specific Grid Locations	sample.point1, sample.point2, sample.point3, sample.point4, sample.point5, sample.point6
Annual and Average Annual Output for all Grid Cells (prefix is "sample")	sample.0001, sample.0002, sample.0003
Crash File	sample.crashfile
Spatially Averaged Daily Output	sample.dayall
Monthly and Annual Output for all Grid Cells	sample.outmonth, sample.outannual
Average Annual Output for all Grid Cells During a Specified Averaging Period	sample.flxfile

Although the simulation period for the sample problem was 1964 through 1970, the study on which this sample problem was based used a much longer simulation period of 79 years, extending from October 1, 1926 through September 30, 2005. Daily climate data for that extended period were obtained from the NCDC (EarthInfo, Inc., 2004) for a network of 35 climate stations in the southern California region. All climate stations had precipitation data, but only 14 had air-temperature data. The selection of the 35 climate stations was based on proximity to the study site, similarity of climate characteristics, and adequacy of record (only stations with 4 or more years of record were included in the network). The calculated spatial distribution of air temperature is a critical factor affecting the simulation of precipitation as snow, snowmelt, sublimation, and potential evapotranspiration.

Sample input files for the climate stations (file *sample.daystations*) and for the precipitation data (file *sample.precip*) are shown in figures 7 and 8, respectively. The input format for the daily temperature data was similar to that for the daily precipitation data and is not shown. Average daily air temperature for the 1965 through 1970 averaging period was 8.7°C, and average annual precipitation for the same period was 778 mm.

Model coefficients for simulating snowmelt and sublimation were specified in the Simulation-Control File. For snowmelt, coefficients were based on those determined for the Sierra Nevada of California (Gray and Prowse, 1993; table 7.3.7), with **snopar1** equal to 0.96 and **snopar2** equal to 1.14. The starting day for the timing of the early-spring snowmelt period (Julian day 305; **snoday1**) corresponds to November 1, whereas the starting day for the timing of the late-spring snowmelt (Julian day 121; **snoday2**) corresponds to May 1. Sublimation variables **subpar1** and **subpar2** were each estimated to be 0.40 and were not changed during model calibration.

The input data in the Monthly Atmospheric-Parameters File (fig. 9; file *sample.atmos*) is the same as that used for previous applications of earlier versions of the INFIL code to the southern California region (Hevesi and others, 2003; Nishikawa and others, 2004; Rewis and others, 2006). The monthly precipitation elevation, maximum air-temperature elevation, and minimum air-temperature elevation regression models for defining average monthly precipitation and maximum and minimum air temperature on the basis of elevation (fig. 10) were developed by using a method described in Rewis and others (2006) and data from a subset of 14 climate stations having 9 or more years of record and centered over the Big Bear study area.

Several variables in the Simulation-Control File relate to the simulation of evapotranspiration. The first is the empirical adjustment factor to the calculated potential evapotranspiration to account for cloud cover during precipitation (variable **petadj**). Previous modeling studies used a value of about 0.16 for **petadj** (Hevesi and others, 2003), which also was used in the Big Bear study. The time-step length for calculating total daily evapotranspiration in the POTEVAP subroutine

Figure 7. Climate-Stations Information File for sample problem.

28	9	10	11	8
APPLE VALLEY	40244	480110.2	3819470.4	894.5
BEAUMONT	40606	502310.6	3754306.1	796.4
BEAUMONT PUMPING PLANT	40607	503075.8	3760304.8	929.9
BEAUMONT #2	40609	503059.4	3753873.9	792.4
BENNETT RANCH	40678	458524.7	3780731.1	563.9
BIG BEAR LAKE	40741	508849.2	3789237.1	2060.4
BIG BEAR LAKE DAM	40742	502357.4	3788922.8	2077.1
CABAZON	41250	520031.3	3752941.0	548.9
CAMP ANGELUS	41369	501816.1	3778699.4	1758.6
CRESTLINE	42162	472377.0	3789916.8	1484.9
FONTANA 5 N	43118	458532.8	3782571.7	601.0
HESPERIA	43935	472431.6	3808401.2	975.9
JOSHUA TREE	44405	563003.1	3777147.0	829.9
JOSHUA TREE 3 S	44407	563027.8	3773454.6	1064.0
KEE RANCH	44467	543014.5	3780738.0	1320.9
LAKE ARROWHEAD	44671	482661.3	3789526.2	1586.4
LUCERNE VALLEY	45182	504592.9	3812054.1	903.1
LYTLE CREEK PH	45215	458541.0	3784423.5	686.1
LYTLE CREEK R S	45218	456644.2	3788678.9	832.1
MILL CREEK 2	45629	496927.8	3771392.7	897.0
MILL CREEK INTAKE	45632	505867.0	3772292.1	1507.2
MORONGO VALLEY	45863	538466.5	3765926.5	780.9
PALM SPRINGS	46635	545369.7	3743137.9	129.5
RAYWOOD FLATS	47279	516917.4	3767715.1	2155.8
REDLANDS	47306	482520.1	3768026.5	401.7
RUNNING SPRINGS 1 E	47600	492040.5	3785078.2	1818.0
SAN BERNARDINO F S 226	47723	476589.9	3777087.3	347.5
SANTA ANA RIVER P H 3	47891	490213.6	3773437.5	604.7
SANTA ANA RIVER PH 1	47894	493850.0	3776938.2	844.9
SEVEN OAKS	48105	504607.5	3782481.4	1548.9
SOUTH FORK CABIN	48390	516914.1	3769566.7	2171.9
SQUIRREL INN 1	48476	476976.3	3788052.6	1598.0
SQUIRREL INN 2	48479	478514.3	3788048.9	1731.8
TWENTYNINE PALMS	49099	588808.0	3776778.4	602.0
VICTORVILLE PUMP PLANT	49325	471938.3	3821520.8	871.1

Figure 8. Part of Daily Precipitation File for sample problem.

[Note that data are shown only for the first 5 climate stations; data are not shown for the remaining 30 climate stations; -999.99 indicates missing data; precipitation values are in millimeters per day]

```

daynumb  year mon day ydy    40244    40606    40607    40609    40678
   1  1900   1   1   1 -999.99 -999.99 -999.99 -999.99 -999.99
   2  1900   1   2   2 -999.99 -999.99 -999.99 -999.99 -999.99

```

Several lines of input deleted here

```

  9770  1926  10   1 274 -999.99 -999.99 -999.99 -999.99 -999.99
  9771  1926  10   2 275 -999.99 -999.99 -999.99 -999.99 -999.99

```

Several lines of input deleted here

```

 28499  1978   1  10  10   15.75 -999.99 -999.99   35.56 -999.99
 28500  1978   1  11  11    1.02 -999.99 -999.99    7.62 -999.99

```

Several lines of input deleted here

```

 38715  2005  12  30 364 -999.99 -999.99 -999.99 -999.99 -999.99
 38716  2005  12  31 365 -999.99 -999.99 -999.99 -999.99 -999.99

```

Figure 9. Monthly Atmospheric-Parameters File for sample problem.

```

ATMOS routine parameters, 05/20/01
file sample.atmos
-----

```

month	ozone	wp	beta	csr	pg
1	0.29	1.000	0.075	0.85	0.24
2	0.31	1.000	0.075	0.85	0.24
3	0.32	1.050	0.075	0.85	0.24
4	0.33	1.100	0.085	0.85	0.24
5	0.33	1.500	0.085	0.74	0.24
6	0.32	1.800	0.090	0.74	0.24
7	0.30	2.200	0.090	0.57	0.24
8	0.29	2.440	0.084	0.57	0.24
9	0.28	2.000	0.077	0.66	0.24
10	0.27	1.400	0.075	0.74	0.24
11	0.27	1.050	0.075	0.90	0.24
12	0.28	0.950	0.075	0.90	0.24

Figure 10. Monthly Climate-Regression Models File for sample problem.

month	pptmod	ppta	pptb	pptc	tmaxmod	tmaxa	tmaxb	tmaxc	tminmod	tmina	tminb	tminc
1	1	5.29E-02	76.23	0	1	-7.00E-03	21.08	0	1	-5.30E-03	6.35	0
2	1	4.71E-02	63.34	0	1	-7.20E-03	22.62	0	1	-5.50E-03	7.43	0
3	1	3.04E-02	57.45	0	1	-7.10E-03	23.58	0	1	-5.60E-03	8.28	0
4	1	2.83E-02	26.17	0	1	-6.60E-03	26.19	0	1	-5.10E-03	9.83	0
5	1	9.80E-03	7.86	0	1	-5.30E-03	28.29	0	1	-4.40E-03	11.89	0
6	1	5.00E-04	2.21	0	1	-4.70E-03	32.17	0	1	-3.40E-03	13.86	0
7	1	4.20E-03	0.00	0	1	-5.10E-03	36.76	0	1	-2.40E-03	16.41	0
8	1	4.90E-03	0.94	0	1	-5.20E-03	36.74	0	1	-2.80E-03	16.88	0
9	1	8.10E-03	5.25	0	1	-5.90E-03	35.06	0	1	-3.90E-03	15.98	0
10	1	6.80E-03	9.63	0	1	-6.30E-03	30.53	0	1	-4.30E-03	12.61	0
11	1	3.29E-02	33.57	0	1	-7.00E-03	25.63	0	1	-4.80E-03	8.91	0
12	1	4.20E-02	44.49	0	1	-7.10E-03	22.06	0	1	-4.90E-03	6.44	0

Figure 11. Geospatial Watershed-Characteristics File for sample problem.

[Note that 29 of the blocking-ridge angles have been deleted for each entry, and that the record of input data for each grid cell wraps onto two lines of text.]

cellcode	easting	northing	latitude	longitude	row	column	elev	slope	aspect	locid	iwat
upcells	soil	depth	rock	veg	skyvw	1 2 3 4 5 6 ... 36					
611825	519505.03	3792780.93	34.27602	116.78810	466	1377	2136.0	10.99	292.39	1	3
0	442	0.70	18	19286	0.952	0 0 0 0 2 4 ... 0					
609105	519535.03	3792750.93	34.27575	116.78777	467	1378	2137.5	2.61	234.76	2	4
0	442	0.70	18	19286	0.967	1 0 0 1 2 5 ... 1					
634512	519475.03	3792810.93	34.27629	116.78842	465	1376	2122.5	12.76	310.80	3	5
1	442	0.70	18	19375	0.944	0 0 0 1 3 4 ... 0					
614087	519505.03	3792750.93	34.27575	116.78810	467	1377	2134.7	10.20	260.81	4	9
1	442	0.70	18	19286	0.951	1 0 0 3 4 4 ... 2					
644967	519445.03	3792840.93	34.27656	116.78875	464	1375	2116.6	8.00	305.52	5	11
2	442	0.70	18	19375	0.953	1 1 1 2 3 4 ... 1					

Several lines of input data deleted here

811392	517495.03	3792570.93	34.27415	116.80994	473	1310	2040.1	0.21	272.15	2354	2355
8451	442	6.00	85	19378	0.962	2 2 3 2 2 3 ... 2					
811409	517465.03	3792570.93	34.27416	116.81026	473	1309	2040.1	0.06	46.05	2355	2356
8452	442	6.00	85	19378	0.962	2 2 3 2 2 3 ... 2					
811191	517435.03	3792570.93	34.27416	116.81059	473	1308	2040.2	0.37	91.41	2356	2357
8453	442	6.00	85	19378	0.961	2 2 3 2 2 3 ... 2					
810689	517405.03	3792570.93	34.27416	116.81092	473	1307	2040.5	0.63	91.01	2357	2358
8454	442	6.00	85	19378	0.960	2 2 3 2 2 3 ... 2					
809882	517375.03	3792570.93	34.27416	116.81124	473	1306	2040.8	0.88	90.47	2358	-3
19692	442	6.00	85	19378	0.960	2 2 3 2 2 3 ... 2					

(variable **hstep**) was set to a value of 1 hour. Variables **barsoil1**, **rocket1**, and **soilet1**—the β variables in the modified Priestley-Taylor equation for defining evaporation or plant transpiration from bare soil, rock matrix, and soil layers—were each set to a value of -10 based on the previous work of Flint and Childs (1987) and Hevesi and others (2003). Variable **barsoil2**—the α parameter in the modified Priestley-Taylor equation for defining evaporation as a function of bare-soil water content and potential evapotranspiration—was set to a value of 1.04, which is a standard value used for bare-soil surfaces (Hevesi and others, 2003). Variables **rocket2** and **soilet2**—the α variables in the modified Priestley-Taylor equation for defining transpiration as a function of rock-matrix and soil-water content and potential evapotranspiration—were each set to a value of 1.50 based on Hevesi and others (2003). During model calibration, an adjustment factor to the evapotranspiration calculations was specified by setting variable **etfact** equal to 1.25 in the Simulation-Control File.

Soil-water initial conditions for most of the water-balance terms in the INFIL3.0 simulation—the product of the residual water content of the soil, the thickness of the soil layer, and a multiplication factor—were set by specifying a value of 1 for **initopt** in the Simulation-Control File. The multiplication factor, variable **vwfact**, was set to 1.5 in the Simulation-Control File. Residual water contents of the soils were specified in the Soils-Properties File (file *sample.soils*).

The topographic variables are used to estimate potential evapotranspiration, to distribute daily air temperature spatially over the drainage basin, and to route streamflow. The topographic variables for each model cell included location, elevation, aspect, slope, a set of 36 blocking-ridge angles (used to simulate the fraction of sky viewed for each grid cell in the calculation of incoming solar radiation), and streamflow-routing variables (location of adjacent upstream cell, location of adjacent downstream cell, and number of upstream cells). Many of these variables are specified in the Geospatial Watershed-Characteristics File; the Geospatial Watershed-Characteristics File (file *sample.gwc*) for the sample problem is given in figure 11.

The topographic variables in the Geospatial Watershed-Characteristics File were developed from standard GIS applications. The flow-routing variables were defined by a modified DEM and the D-8 routing algorithm available with GIS. The skyview and blocking-ridge angles were calculated by a FORTRAN preprocessing routine, SKYVIEW, modified from an original program developed by Flint and Childs (1987). The SKYVIEW routine approximates the 36 10-degree-azimuth sectors for the blocking-ridge angles by using the exact row-column position of surrounding grid cells relative to the central grid cell from which the blocking-ridge angles are being defined. For each of the 36 approximate 10-degree sectors, the blocking angle is defined by the horizontal distance and difference in elevation between the central grid cell and the potential blocking-ridge cell. The routine is applied to surrounding grid cells at successively greater distances from the central cell by increasing the number of rows and col-

umns applied to the search neighborhood, up to a user-defined maximum search distance (for the Big Bear study, a maximum search distance of 5,000 m was applied). For each of the 36 approximate 10-degree sectors, the maximum blocking angle within the search neighborhood is used to define the blocking-ridge angle for the central cell. The 36 blocking-ridge angles are added and this fraction of the hemisphere is subtracted from the total hemisphere area to calculate the SKYVIEW factor, expressed as a fraction of the total hemisphere area (a flat-grid DEM would result in SKYVIEW values of 1.0, whereas a grid at the base of a deep canyon might have a SKYVIEW value of 0.5 or less).

Soil variables were estimated for each model cell by using the State Soil Geographic Database (STATSGO) digital map and associated attribute tables (U.S. Department of Agriculture, 1994). The soil variables were estimated by applying a preprocessing routine, STATSGO34, developed for the application of an earlier version of the INFIL code to the Death Valley region (Hevesi and others, 2003). The STATSGO34 routine uses soil-texture data from the STATSGO database to estimate field capacity, wilting-point water content, and the drainage-function coefficient (variable **soilb** in the Soil-Properties File). Estimates of porosity, saturated vertical hydraulic conductivity, and total soil thickness also are calculated from data available in the STATSGO database. The estimated values for all soil variables are approximate values based on a weighted-averaging method because the STATSGO database generally includes several soil components, each with several soil layers, for each mapped soil unit, or soil Map Unit Identifier (MUID). Soil-layer thickness and relative areas of the soil components within each MUID are provided in the STATSGO database, and these values are used to calculate the weighted averages for the soil variables associated with the different MUIDs. A more detailed discussion of the STATSGO34 preprocessing routine is given in Hevesi and others (2003). A total of 21 STATSGO soil types (or MUIDs) were identified within the Big Bear watershed (fig. 12). The average depth of the soil zone within the watershed is 6.06 m. During model calibration, initial soil depths estimated from the STATSGO database were increased by a factor of 1.5 by using variable **sdfact** in the Simulation-Control File. This adjustment to the STATSGO soil thickness is consistent with a similar model applied to a nearby study area in the San Geronio Pass area (Rewis and others, 2006).

Spatially distributed bedrock and deep-soil variables that are needed for the bedrock (model layer 6) and deep-alluvium areas (soil depth of 8 m or greater), respectively, are root-zone porosity and vertical hydraulic conductivity (fig. 13; file *sample.bedrock*). The geologic units for the study area were identified on the basis of surficial geologic maps, and deep soil was identified on the basis of Quaternary alluvium geologic classifications. These units were assigned an initial value of root-zone porosity and vertical hydraulic conductivity consistent with those assigned to equivalent geologic units in the Death Valley region by Hevesi and others (2003). The original estimates of root-zone porosity were not

Figure 12. Soil-Properties File for sample problem.

```

Sample problem soil properties input
21
6      10      8      8      8      8      8
mapid MUID      POR      FC      WP      B      ksat01
425   CA671    0.4256  0.1207  0.0138  3.541  4780.0
426   CA665    0.3780  0.1542  0.0255  3.880  5225.0
427   CA909    0.3867  0.1567  0.0302  4.378  1935.0
432   CA919    0.3734  0.1952  0.0477  4.808  2046.0
435   CA652    0.3750  0.1918  0.0410  4.318  2263.0
437   CA646    0.4024  0.2432  0.0692  5.234  1295.0
438   CA670    0.3984  0.2018  0.0561  5.471  1566.0
439   CA913    0.3784  0.1676  0.0335  4.338  1437.0
440   CA617    0.3593  0.1621  0.0317  4.261  2840.0
442   CA669    0.4363  0.1628  0.0454  6.302   828.5
443   CA667    0.3509  0.1572  0.0300  4.210  4655.0
444   CA666    0.3971  0.1864  0.0410  4.543  3456.0
446   CA668    0.3859  0.2090  0.0531  4.889  2476.0
450   CA639    0.3558  0.1593  0.0260  3.710  5026.0
452   CA931    0.3516  0.1265  0.0131  3.004  6075.0
453   CA614    0.3566  0.2039  0.0534  4.978  2392.0
454   CA644    0.3737  0.2022  0.0435  4.249  3375.0
457   CA627    0.4054  0.2203  0.0662  5.721  1209.0
461   CA609    0.3563  0.2224  0.0695  5.731   924.8
675   CA635    0.3547  0.1826  0.0373  4.165  4147.0
696   CA618    0.3585  0.1437  0.0189  3.332  4022.0

```

Figure 13. Bedrock-Properties File for sample problem.

Sample problem bedrock characteristics
rocks 101

map code	rock descriptions	root-zone porosity	ksat1 mm/day	ksat2 mm/day
1	Monzonite of Fawnskin	0.01	0.001	0.001
2	Sultan Limestone, Crystal Pass Member	0.10	2.000	2.000
3	Monzogranite of John Bull Flat	0.01	0.001	0.001
4	Cataclastic rocks	0.01	0.100	0.100
5	Leucocratic quartz monzonite of Crystal Creek	0.01	0.001	0.001
6	Quartz diorite	0.01	0.050	0.050
7	Old alluvial valley deposits	0.30	100.000	100.000
8	Young landslide deposits	0.30	200.000	200.000
9	Monzogranite of Cactus flats, muscovite-bearing unit	0.01	0.001	0.001
10	Monzogranite of Cactus Flats	0.01	0.001	0.001

Several lines of input data deleted here

90	Gneissic granitoid rocks and gneiss	0.01	0.001	0.001
91	Very young lacustrine deposits	0.35	200.000	200.000
92	water	0.01	0.000	0.000
93	Sedimentary rocks south of Big Bear Lake	0.01	0.500	0.500
94	Mylonitic rocks, Baldwin Gneiss	0.01	0.050	0.050
95	Artificial fill	0.30	500.000	500.000
96	Granodiorite of Red Ant Hill	0.01	0.050	0.050
97	Alkalic granitic rocks, undifferentiated	0.01	0.050	0.050
98	Schist	0.01	0.001	0.001
99	Biotite granodiorite	0.01	0.050	0.050
100	Mafic gneiss and schist	0.01	0.050	0.050
101	Hornblende-biotite quartz diorite	0.01	0.005	0.005

modified during the model calibration; however, the initial estimates of vertical hydraulic conductivity were increased by a factor of about 5 during model calibration. The average thickness of the bedrock layer in the sample watershed is 0.82 m.

For the calculation of infiltration capacities from soil and bedrock saturated hydraulic conductivities by equations 18, 19, and 44, the duration of summer and winter storms (variables **stormsum** and **stormwin** in the Simulation-Control File) were set to 2 and 12 hours, respectively; the duration of the daily snowmelt period (variable **meltime** in the Simulation-Control File) was set to a value of 8 hours. Summer rainstorms were assumed to occur between Julian days 183 (variable **dysumbeg**) and 274 (**dysumend**), which correspond to July 2 and October 1.

Vegetation variables such as vegetation cover (estimated as a function of vegetation type) and root-zone variables including root-zone thickness are specified in the Vegetation-Properties File, an example of which is given in figure 14 (file *sample.veget*). These values were estimated by using the digital map provided by California Land Cover Mapping and Monitoring Program (2004). Vegetation-density estimates were based on a vegetation canopy map from the U.S. Geological Survey seamless Web site (Huang and others, 2001). Root-zone thickness is defined by vegetation variables unless soil-zone thickness is limiting, in which case the root-zone thickness is equal to soil-zone thickness. If soil-zone thickness is limiting and the vegetation is forest trees, then bedrock can be included in the root-zone thickness, allowing for the penetration of forest-tree roots into bedrock.

In the simulations of the Big Bear area, surface-water-flow routing was coupled with the root-zone water balance (variable **irout** was set to 1 in the Simulation-Control File) to allow run-on to each of the model cells to infiltrate back into the soil zone. A set of input variables provided in the Simulation-Control File was used to estimate stream-channel characteristics that were assumed to affect the quantity of routed surface-water run-on that could potentially infiltrate back into the root zone during the SWINFIL routing process. The variables defining stream-channel characteristics are **ichanmod**, **chan1**, **chan2**, **chan3**, and **chan4** and **ikschnmod**, **kschn1**, **kschn2**, and **kschn3**. These variables are used to define an empirical model that controls the relative magnitude of the saturated soil or bedrock vertical hydraulic conductivity in stream channels as a function of upstream area, streambed slope, and the magnitude of the simulated run-on.

The empirical model is used to represent the difference in the area of a grid cell relative to its conceptual wetted area covered by routed surface water. The model is based on the assumption that infiltration of surface water back into the root zone during the routing process is dependent on the wetted area (the greater the wetted area, the greater the infiltration capacity). For low-order channels having small upstream areas and generally subjected to small volumes (depths) of routed surface water, a smaller wetted area is defined by the empirical model. Additionally, smaller wetted areas are assumed for grid cells having greater slope (for example, cells representing

narrower, steeper channels). For high-order channels with large upstream areas and subjected to high volumes of routed surface water, a larger wetted area is defined by the empirical model.

Differences in the wetted area relative to the area of a grid cell are represented by adjusting the effective saturated vertical hydraulic conductivity of the soil or bedrock underlying the channel. For the low-order channels assumed to have smaller wetted areas relative to the grid cell area, the effective saturated vertical hydraulic conductivity is reduced to limit the infiltration capacity of the channel bed. For high-order channels assumed to have larger wetted areas relative to the grid cell area, the effective saturated vertical hydraulic conductivity is increased to enhance the infiltration capacity of the channel bed (the wetted area can be greater than the area of a grid cell).

For the sample problem, **ichanmod** was set to 1, **chan1** was set to 0.20 (the effective wetted area for runoff is assumed to be 20 percent of the grid cell area), **chan2** was set to 500, **chan3** was set to 0.8, and **chan4** was set to 2.0. The **ikschnmod** option was set to 0, and thus the vertical hydraulic conductivity of the streambed material was assumed to be the same as the vertical hydraulic conductivity of the inter-channel areas.

Simulation Results

INFIL3.0 generates several output files that provide results of each simulation. Selected output for the sample problem is provided here to demonstrate some of the time-series, spatial, and summary output. All of the output files generated by the simulation are listed in table 1.

Figure 15 shows the summary output file (file *sample.outfile*) created during the simulation. The first two blocks of the output file list the names of most input and output files for the simulation. The next two blocks of information provide a summary of some of the climate-input and watershed-characteristics data. The next block provides a summary of the simulation starting and ending dates and the simulation averaging period. The last block of information summarizes several of the water-balance terms for the averaging period, which for the sample problem is January 1, 1965 through December 31, 1970 (a total of 2,191 days). The water-balance terms represent, on a long-term basis, hydrologic conditions in the basin. For example, results shown in the output file indicate that precipitation as rain and snow account for about 67 and 33 percent of the total precipitation in the watershed, respectively. Information in the table also indicates that the average annual actual evapotranspiration within the soil zone (497.1 mm/yr) is about 39.8 percent of the adjusted potential evapotranspiration (that is, the potential evapotranspiration adjusted for cloudy days and sublimation) within the watershed (1,248.3 mm/yr). The last section of this block provides a summary of the root-zone mass balance based on the water-budget components given in equation 2. The mass-balance summary indicates a very small mass-balance error for the simulation on the order of 10^{-12} mm/yr.

Figure 14. Vegetation-Properties File for sample problem.

[The record of input data for each grid cell wraps onto two lines of text.]

```

Sample problem vegetation input (12/05/05)
28      8      8      8      8      8      8      28      8      8      8
Vegetation nam      mapunit code      %cover      VegClass      cover1      cover2      cover3
      cover4      cover5      cover6      rzdpth1      rzdpth2      rzdpth3      rzdpth4      rzdpth5      rzdpth6      rzdpthf
-----
Agricultural Land      19390      1      35      Agricultural Land      90.00      90.00      80.00
      80.00      30.00      30.00      0.10      0.30      1.00      3.00      8.00      1.00      1.00
Agricultural Land      19467      2      10      Agricultural Land      90.00      90.00      80.00
      80.00      30.00      30.00      0.10      0.30      1.00      3.00      8.00      1.00      1.00
Big Sagebrush Scrub      19220      3      35      Big Sagebrush Scrub      70.00      70.00      50.00
      50.00      30.00      30.00      0.10      0.30      1.00      3.00      8.00      2.00      1.00
Big Sagebrush Scrub      19316      4      35      Big Sagebrush Scrub      70.00      70.00      50.00
      50.00      30.00      30.00      0.10      0.30      1.00      3.00      8.00      2.00      1.00
Big Sagebrush Scrub      19360      5      10      Big Sagebrush Scrub      70.00      70.00      50.00
      50.00      30.00      30.00      0.10      0.30      1.00      3.00      8.00      2.00      1.00

Several lines of input data deleted here

Upper Sonoran Manzanita      19699      86      80      Upper Sonoran Manzanita      80.00      80.00      80.00
      80.00      60.00      50.00      0.10      0.30      1.00      3.00      8.00      4.00      1.00
Upper Sonoran Manzanita      19722      87      80      Upper Sonoran Manzanita      80.00      80.00      80.00
      80.00      60.00      50.00      0.10      0.30      1.00      3.00      8.00      4.00      1.00
Westside Ponderosa Pine      19553      88      50      Westside Ponderosa Pine      95.00      95.00      95.00
      85.00      85.00      85.00      0.10      0.30      1.00      3.00      8.00      4.00      1.00
Westside Ponderosa Pine      19557      89      50      Westside Ponderosa Pine      95.00      95.00      95.00
      85.00      85.00      85.00      0.10      0.30      1.00      3.00      8.00      4.00      1.00
Westside Ponderosa Pine      19591      90      50      Westside Ponderosa Pine      95.00      95.00      95.00
      85.00      85.00      85.00      0.10      0.30      1.00      3.00      8.00      4.00      1.00

```

Figure 15. Summary Output File for sample problem.

```

Net Infiltration Model Code INFIL3.0
sample.ctl: Sample problem Simulation-Control File

Input Filenames
-----
Daily climate stations ..... sample.daystations
Monthly climate models ..... sample.monthmod
Daily precipitation input ..... sample.precip
Daily maximum air temperature input ..... sample.tmax
Daily minimum air temperature input ..... sample.tmin
Watershed modeling domain parameters .... sample.gwc
Soil properties ..... sample.soils
Rock properties ..... sample.bedrock
Vegetation properties ..... sample.veget
Atmos properties ..... sample.atmos

Output Filenames
-----
Average daily mass balance terms ..... sample.dayall
24-hour mass balance map ..... sample.daymap
Average annual mass balance map ..... sample.flxfile
Summary statistics output ..... sample.outfile

Summary of Climate Data
-----
Total number of days read in ..... 28854
Total number of years ..... 78.998
Average annual precip (mm/year) ..... 420.11612
Maximum daily precip (mm/day) ..... 548.89001

Summary of Grid Data
-----
Total number of grid locations ..... 2358
Average elevation of grid (m) ..... 2053.52762
Maximum elevation of grid (m) ..... 2137.50000
Minimum elevation of grid (m) ..... 2039.59998
Average slope of watershed grid ..... 3.63235
Maximum slope of watershed grid ..... 23.71000
Average soil depth (m) ..... 6.0609837
Average soil layer 1 thickness (m) ..... 0.1000000
Average soil layer 2 thickness (m) ..... 0.2000000
Average soil layer 3 thickness (m) ..... 0.7000000
Average soil layer 4 thickness (m) ..... 1.4284026
Average soil layer 5 thickness (m) ..... 3.0271532
Average rock layer 1 thickness (m) ..... 0.8216780
Average rock ksats upper (mm/day) ..... 0.131240E+03
Average rock ksats lower (mm/day) ..... 0.131240E+03

```

Figure 15. Summary Output File for sample problem.—Continued

```

Simulation Period
-----
First day of simulation ..... 1964- 1- 1
Last day of simulation ..... 1970-12-31
First day of averaging period ..... 1965- 1- 1
Last day of averaging period ..... 1970-12-31
Length of averaging period (days) ..... 2191

Global Average Annual Values
-----
Air temperature (deg C) ..... 8.71

Precipitation (mm/yr)
  Rain ..... 0.521320916707E+03
  Snow
    Snowfall ..... 0.257024857690E+03
    Snow melt ..... 0.227539411858E+03
    Sublimation ..... 0.218280146489E+02
  Total (Rain + Snowfall) ..... 0.778345774397E+03

Evapotranspiration (mm/yr)
  Adjusted potential ET ..... 0.124834389646E+04
  Actual ET ..... 0.497080165297E+03

Surface Water Flow (mm/yr)
  Surface water inflow ..... 0.118937617834E+03
  Surface water outflow ..... 0.111987241619E+03

Root Zone Mass Balance
  IN (mm/yr)
    Rain ..... 0.521320916707E+03
    Snow melt ..... 0.227539411858E+03
    Infiltrated surface-water run-on .... 0.495611282455E+02
  OUT (mm/yr)
    Runoff generated ..... 0.426107520305E+02
    Actual ET ..... 0.497080165297E+03
    Net infiltration below root zone .... 0.154811349624E+03
  STORAGE CHANGE (mm/yr) ..... 0.103919189859E+03
  Balance (IN - OUT - STORAGE CHANGE) ... -0.227373675443E-12

```

The graphs on figure 16 show five of the daily water-budget components calculated for the sixth grid cell specified in the Simulation-Control File (from output file *sample.point6*). The cell is located along the main stream channel on the downstream end of the basin, near the basin outflow point. The top graph (fig. 16A) shows daily precipitation as rain (output variable **rain**) and daily snowmelt (output variable **snowmelt**) to the grid cell. The middle graph (fig. 16B) shows the daily actual evapotranspiration from the soil zone (output variable **et**), which is a small budget component at this cell, and the daily change in water content within the soil zone at the cell (output variable **delta-storage**). The bottom graph (fig. 16C) shows net infiltration at the cell (output variable **net-infil3**).

Figure 17 is a map of average annual net infiltration calculated for the averaging period. The data shown on the map represent net-infiltration values written to the file *sample.flxfile* (output variable **net-infil3**). Results obtained for the sample problem indicate the high range of net infiltration caused by the combination of the various factors and processes controlling net infiltration (fig. 17). Results include a maximum value of 12,496 mm/yr for a single cell in the northeast part of the catchment, and minimum values of zero in the southern part of the catchment. The mean net-infiltration rate is 154.8 mm/yr (fig. 15). Values greater than approximately 500 mm/yr indicate enhanced net infiltration caused by infiltrating surface-water run-on for grid cells along the boundary between impervious upstream areas generating runoff and more pervious downstream areas. For example, the zone of higher than average values (greater than 1,000 mm/yr) in the southern part of the sample catchment is along the base of a steep north-facing side slope having thin soil and low-permeability bedrock. The runoff generated from this side slope readily infiltrates into the higher permeability unconsolidated deposits downstream from the side slope. The high net-infiltration rates (greater than 2,000 mm/yr) in the northeastern part of the sample catchment are also in the more permeable unconsolidated deposits directly downstream from small drainage areas having thin soils and underlain by low-permeability bedrock. The maximum rate of 12,496 mm/yr was calculated for a channel location affected by a high frequency of focused runoff from the upstream drainage.

Net infiltration also is enhanced by infiltrating surface-water run-on along the main channel running through the central part of the sample catchment. Net infiltration in the main channel is calculated to be approximately 300 mm/yr, compared to about 150 mm/yr for the area alongside the channel. Although the average streamflow rate in the main channel is high—about 5,000 to 10,000 mm/yr per unit area of grid cell—it is not as high as in the channel of the small drainage

area in the northeastern part of the study area, where maximum streamflow rates are more than 200,000 mm/yr per unit area of grid cell. The streamflow rates are higher because of the higher frequency of streamflow in the small drainage area. Water flows in the main channel only in response to inflows from the upstream subbasins. Runoff generated within the sample basin is generally routed only a short distance before channel losses reduce the streamflow to zero, and thus does not reach the main channel.

Net infiltration also is affected by soil thickness, geology, soil type, and vegetation properties. Net-infiltration rates are calculated to be 200 to 500 mm/yr at locations having a thin root-zone soil layer (about 1.1 m) underlain by unconsolidated sediments with relatively high permeability. In contrast, net infiltration is only 100 to 200 mm/yr at locations with a thick root-zone soil layer of 6 m (central part of sample catchment), with the exception of the streamflow-enhanced net infiltration of 200 to 500 mm/yr in the main channel. In general, net infiltration is higher at locations underlain by unconsolidated deposits than at locations underlain by consolidated bedrock. Net infiltration in the southernmost part of the sample basin is approximately 0 mm/yr because the vertical hydraulic conductivity of rock type 76 (Quartzite of Wildhorse Meadows) is only 0.001 mm/day. Net infiltration for the consolidated rock in the northeastern part of the sample basin is higher (about 5 to 50 mm/yr) because the vertical hydraulic conductivity is higher (0.05 mm/day) for rock type 18 (Baldwin Gneiss). Within the area of rock type 18, higher net-infiltration rates of 10 to 50 mm/yr were calculated for locations with soil type 444, whereas net-infiltration rates were 5 to 50 mm/yr for locations with soil type 442; these rates are a function of the saturated vertical hydraulic conductivity, which is 681 mm/day for soil type 444, substantially higher than the saturated vertical hydraulic conductivity of 234 mm/day for soil type 442. Within the area of unconsolidated deposits having a root-zone soil layer of 6 m, the lowest net-infiltration rates of 10 to 100 mm/yr were calculated for locations with the Pinyon-Juniper vegetation type (19286 and 19375). The estimated vegetation cover was higher and root densities were deeper for the Pinyon-Juniper locations compared to locations with vegetation type 19467 (agricultural land). The simulated evapotranspiration rates for locations with Pinyon-Juniper in unconsolidated deposits were about 520 to 600 mm/yr, compared to 440 to 480 mm/yr for locations represented as agricultural land. The higher root densities estimated for the lower root zone layers at locations with Pinyon-Juniper vegetation were more critical in reducing net infiltration than the higher root densities in the shallow root-zone layers at locations represented as agricultural lands.

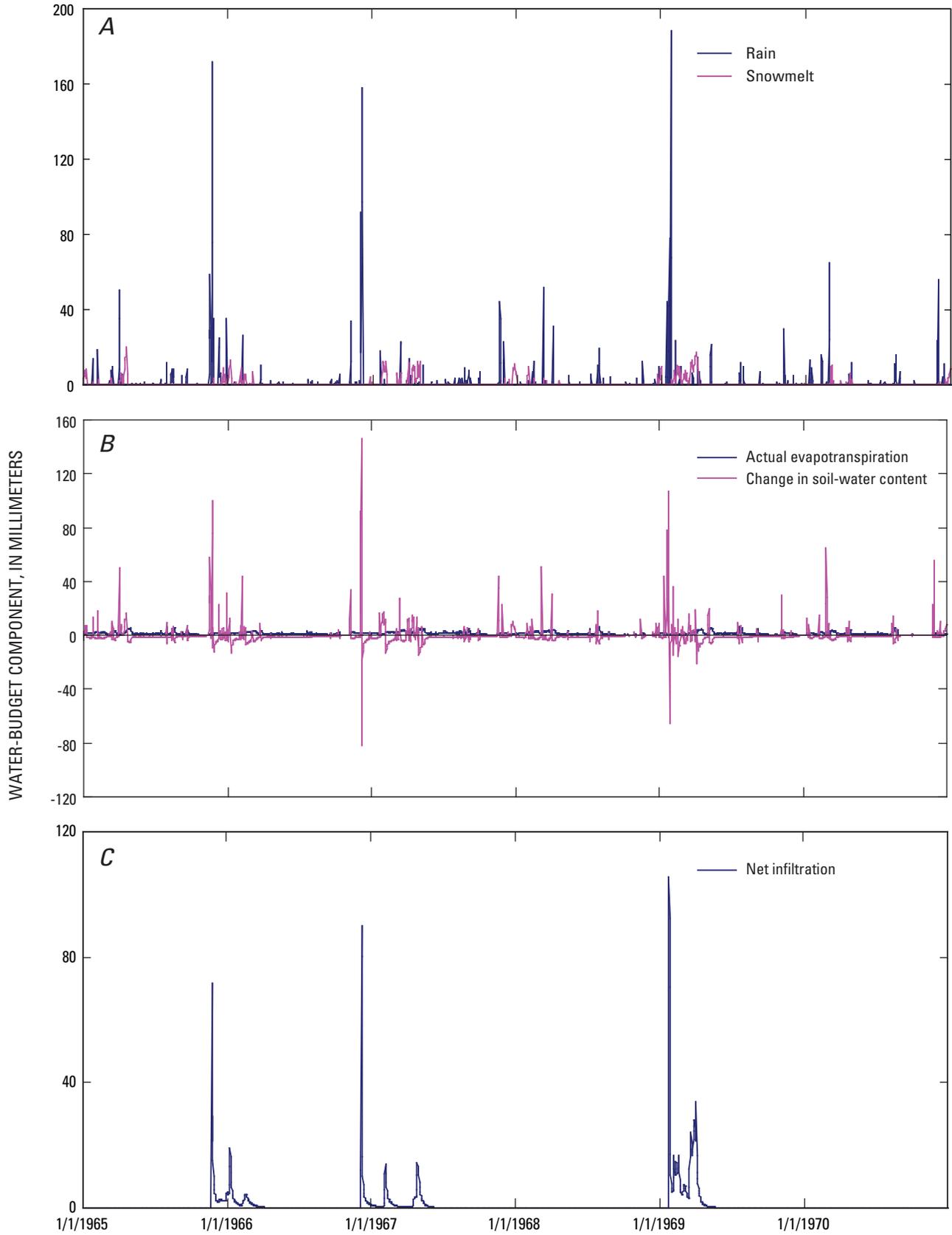


Figure 16. Selected model-calculated daily water-budget terms for a model cell in the sample-problem simulation: (A) rain and snowmelt, (B) actual evapotranspiration from the soil zone and change in water content within the soil zone, and (C) net infiltration.

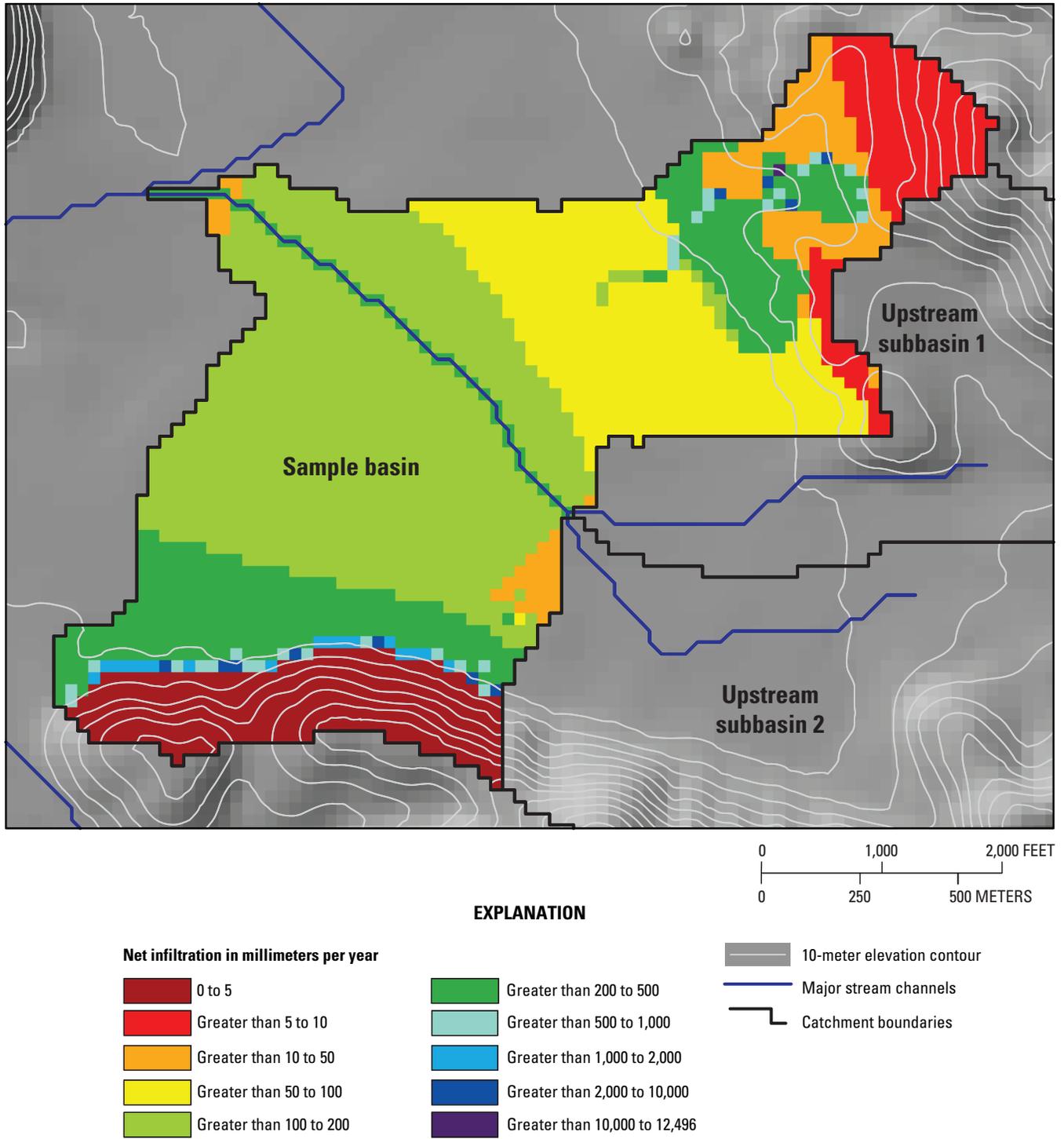


Figure 17. Model-calculated net infiltration for sample-problem simulation.

Summary

The estimation of net infiltration of water below the root zone is important for quantifying the potential recharge to an underlying water-table aquifer. Although many methods are available to estimate net infiltration and (or) ground-water recharge, one of the most technically advanced is watershed modeling, which allows for the determination of temporally distributed net infiltration and recharge at locations distributed throughout a watershed. This report documents one such watershed model—the INFIL3.0 computer code.

INFIL3.0 is a grid-based, distributed-parameter, deterministic precipitation-runoff and net-infiltration water-balance simulation model. The daily water balance simulated by INFIL3.0 includes precipitation as either rain or snow; snowfall accumulation, sublimation, and snowmelt; infiltration into the root zone; evapotranspiration from the root zone; drainage and water-content redistribution within the root-zone profile; surface-water runoff from, and run-on to, adjacent grid cells; and net infiltration. Net infiltration is defined as the downward drainage of water across the lower boundary of the root zone, in which the bottom of the root zone is the estimated maximum depth below ground surface affected by evapotranspiration.

Net infiltration consists of three possible water sources—rain, snowmelt, and surface-water run-on (runoff and streamflow) to each grid cell within the simulation domain. These three sources are inputs to a layered root zone with one to five soil layers (that is, model-grid layers) and a lower bedrock, or deep-alluvium, grid layer. For each model cell, the number and thickness of layers is dependent on soil thickness, with the thickness of the lower bedrock layer increasing with decreasing soil thickness.

The water-balance model uses daily climate records of precipitation and air temperature and a spatially distributed representation of drainage-basin characteristics defined by topography, geology, soils, and vegetation to simulate daily net infiltration at all locations, including stream channels with intermittent streamflow in response to runoff from rain and snowmelt. The model does not simulate streamflow originating as ground-water discharge or the rise of a water table into the root zone. Drainage-basin characteristics are represented in the model by a set of spatially distributed input variables uniquely assigned to each grid cell of a model grid.

INFIL3.0 simulation results include a continuous time series of the daily water balance for the root zone (and for the individual root-zone layers). The daily time-series output includes simulated runoff (streamflow for channel locations), which can be compared to measured streamflow for model calibration. A primary benefit of the INFIL3.0 modeling approach is the generation of spatially detailed daily, annual, and average annual values representing all components of the water-balance model; these simulated results help to provide an understanding of the mechanisms responsible for net infiltration, runoff, and potential recharge. Model results can

be mapped and subsequently used to evaluate the integrated effect of spatially distributed climate, terrain, and watershed characteristics (for example, vegetation, soils, and geology) on the spatial distribution of runoff and potential recharge.

INFIL3.0 was developed for application to arid and semiarid climates where surface-water flow consists primarily of overland runoff from rain and snowmelt, as opposed to base flow from ground-water discharge. INFIL3.0 may have limited applicability for study areas characterized by humid climates, thin unsaturated zones, perennial streamflow with significant contributions from ground-water discharge, and a high percentage of cloudy days with no precipitation (for example, coastal areas subject to foggy conditions). All streamflow simulated by INFIL3.0 is assumed to be routed through the entire study area within the 1-day time step. Therefore, study areas characterized by streamflow with a substantial lag-time relative to the generation of runoff may not be appropriate for an INFIL3.0 application.

Applications of earlier versions of the INFIL3.0 code have been made to the Yucca Mountain area of Nevada; the Death Valley region of Nevada and California within which Yucca Mountain is located; and the Joshua Tree, San Geronio Pass (Riverside County), and Big Bear Lake areas of California. INFIL3.0 data sets prepared for one of the subbasins within the Big Bear Lake watershed were used as the basis for a sample problem described in this report to demonstrate how INFIL3.0 can be applied to a field setting and to demonstrate the input and output files of an INFIL3.0 simulation.

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Appendix 1. Supplemental Tables

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Table 1-1. Definitions of variables specified in the Simulation-Control File.

[Numbers in parentheses after the variable type indicate the size of the variable. Double precision indicates a real variable type]

Record	Variable name	Variable type	Explanation	Units
1	title	Character	Title for the simulation (up to 250 characters).	dimensionless
2	irout ¹	Integer	Flag specifying the type of flow routing to be simulated. Options: irout = 0, surface-water routing is decoupled from the root-zone water balance; irout = 1, surface-water routing is coupled with the root-zone water balance; irout = -1, no flow routing will be done.	dimensionless
3	petadj ¹	Double precision	Empirical adjustment factor to the calculated potential evapotranspiration to account for cloud cover (precipitation).	1/millimeters
4	isnow	Integer	Flag specifying whether or not snow accumulation, melting, and sublimation will be simulated. Options: isnow = 0, snow processes will not be simulated, and all precipitation will be assumed to be rain; isnow = 2, snow processes will be simulated.	dimensionless
	meltime	Double precision	Duration of the daily snowmelt.	hours
5	snoday1	Integer	Starting (Julian) day for early spring snowmelt period.	dimensionless
	snopar1	Real	Snowmelt rate for early spring snowmelt period.	millimeters/day
	snoday2	Integer	Starting (Julian) day for late spring snowmelt period.	dimensionless
	snopar2	Real	Snowmelt rate for late spring snowmelt period.	millimeters/day
6	isublim	Integer	Flag specifying whether or not sublimation will be simulated. Options: isublim = 0, sublimation will not be simulated; isublim = 1, sublimation will be simulated.	dimensionless
	subpar1	Real	Sublimation factor for air temperature less than or equal to 0° Celsius.	dimensionless
	subpar2	Real	Sublimation factor for air temperature greater than 0° Celsius.	dimensionless
7	ipptval	Integer	Flag specifying whether precipitation will be a constant value. Options: ipptval = 0, precipitation will not be a constant value; ipptval = 1, precipitation will be a constant value.	dimensionless
	pptval	Double precision	Constant precipitation value for the simulation period.	millimeters
8	iairval	Integer	Flag specifying whether air temperature will be a constant value. Options: iairval = 0, air temperature will not be a constant value; iairval = 1, air temperature will be a constant value.	dimensionless
	airval	Real	Constant air-temperature value for simulation.	degrees Celsius
9	ietval	Integer	Flag specifying whether evapotranspiration will be a constant value. Options: ietval = 0, evapotranspiration will not be a constant value; ietval = 1, evapotranspiration will be a constant value.	dimensionless
	etval	Double precision	Constant evapotranspiration for simulation.	millimeters
10	isdepthval	Integer	Flag specifying whether a constant soil depth will be used for all grid cells. Options: isdepthval = 1, a constant value will be used; isdepthval ≠ 1, spatially variable depths will be used.	dimensionless
	sdepthval	Real	Constant soil depth for all grid cells.	meters
11	isksval ¹	Integer	Flag specifying whether soil saturated vertical hydraulic conductivity will be a constant value. Options: isksval = 0, soil saturated vertical hydraulic conductivity will not be a constant value; isksval ≠ 0, soil saturated vertical hydraulic conductivity will be a constant value (sksvval).	dimensionless
	sksvval	Real	Constant soil saturated vertical hydraulic conductivity.	millimeters/day

Table 1-1. Definitions of variables specified in the Simulation-Control File.—Continued

[Numbers in parentheses after the variable type indicate the size of the variable. Double precision indicates a real variable type]

Record	Variable name	Variable type	Explanation	Units
12	iimbval ¹	Integer	Flag specifying whether bedrock saturated and unsaturated hydraulic conductivities will be a constant value. Options: iimbval = 0, bedrock hydraulic conductivities are not constant values; iimbval ≠ 0, bedrock hydraulic conductivities are constant values (imbval).	dimensionless
	imbval	Real	Constant bedrock saturated and unsaturated vertical hydraulic conductivity.	millimeters/day
13	celsize	Double precision	Length of each side of each model grid cell.	meters
14	nupstream	Integer	Number of upstream basins contributing surface-water inflow. A maximum of 5 upstream basins can be specified.	dimensionless
			Repeat records 14a–14c nupstream times	
14a	ioptupflow	Integer(5)	Flag specifying a constant rate of inflow for all days. Options: ioptupflow = 0, use inflows from file upfile ; ioptupflow ≠ 0, use a constant rate of inflow equal to upconst .	dimensionless
	upconst	Double precision(5)	Constant rate of inflow from upstream basin.	millimeters/day
14b	upfile	Character(5)	Name of file containing daily upstream flow values (maximum of 30 characters).	dimensionless
14c	upgeoinp ¹	Character(5)	Name of file containing upstream cellcode identifiers for cells contributing inflow.	dimensionless
15	monthwy, mondaywy	Integer	Month and day for which annual and average annual output will be calculated.	dimensionless
16	yrstart, mostart, dystart	Integer	Year, month, and day of simulation start date.	dimensionless
17	yrend, moend, dyend	Integer	Year, month, and day of simulation end date.	dimensionless
18	yrstart1, mostart1, dystart1	Integer	Year, month, and day of starting date to calculate output flow averages.	dimensionless
19	yrend1, moend1, dyend1	Integer	Year, month, and day of ending date to calculate output flow averages.	dimensionless
20	outputinterval	Integer	Interval for which annual or average annual output will be printed.	years
21	sdfact, pptfacat, etfact, imbfact, sksfact	Double precision	Scaling (multiplication) factors: sdfact is soil-depth factor; pptfact is precipitation factor; etfact is evapotranspiration factor; imbfact is bedrock vertical hydraulic conductivity factor; sksfact is soil vertical hydraulic conductivity factor.	dimensionless
22	ivegc	Integer	Flag specifying vegetation-cover values. Options: ivegc = 0, use vegetation-cover values from vegetation-input file; ivegc ≠ 0, use a constant vegetation-cover value (fvegc).	dimensionless
	fvegc	Double precision	Constant vegetation-cover value.	decimal percent
23	ichanmod	Integer	Flag specifying how the wetted flow area for each grid cell will be specified. Options: ichanmod = 1, flow area will be calculated by equation 39; ichanmod ≠ 1, flow area will equal variable chan1 in equation 38.	dimensionless
	chan1	Double precision	Surface-water minimum effective wetted-flow area.	decimal percent
	chan2	Double precision	Surface-water wetted-flow area factor.	dimensionless
	chan3	Double precision	Surface-water maximum headwater wetted-flow area.	dimensionless

Table 1-1. Definitions of variables specified in the Simulation-Control File.—Continued

[Numbers in parentheses after the variable type indicate the size of the variable. Double precision indicates a real variable type]

Record	Variable name	Variable type	Explanation	Units
	chan4	Double precision	Surface-water maximum stream-channel wetted-flow area.	dimensionless
24	ikschnmod	Integer	Flag specifying how soil saturated vertical hydraulic conductivity will be modified for stream-channel locations. Options: ikschnmod = 0, use equation 42; ikschnmod ≠ 0, use equation 43.	dimensionless
	kschn1	Double precision	Minimum number of upstream cells for adjusting the soil saturated vertical hydraulic conductivity.	dimensionless
	kschn2	Double precision	Scaling factor for adjusting soil saturated vertical hydraulic conductivity in channels.	dimensionless
	kschn3	Double precision	Maximum adjustment factor to the soil saturated vertical hydraulic conductivity in channels.	dimensionless
25	barsoil1 ¹	Double precision	Variable β in modified Priestley-Taylor equation defining evaporation as a function of bare-soil water content and potential evapotranspiration.	dimensionless
	barsoil2 ¹	Double precision	Variable α in modified Priestley-Taylor equation defining evaporation as a function of bare-soil water content and potential evapotranspiration.	dimensionless
	barsoilf ¹	Double precision	Adjustment factor that can be used to modify the value of barsoil1 for layer 2 of the model.	dimensionless
26	rocket1 ¹	Real	Variable β in modified Priestley-Taylor equation defining transpiration as a function of rock-matrix water content and potential evapotranspiration.	dimensionless
	rocket2 ¹	Real	Variable α in modified Priestley-Taylor equation defining transpiration as a function of rock-matrix water content and potential evapotranspiration.	dimensionless
27	soilet1 ¹	Real	Variable β in modified Priestley-Taylor equation defining transpiration as a function of soil-water content and potential evapotranspiration.	dimensionless
	soilet2 ¹	Real	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration.	dimensionless
28	hstep ¹	Real	Time-step length used for calculating total daily evapotranspiration.	hours
29	dysumbeg, dysumend	Integer	Beginning and ending Julian day number for summer storms.	day
30	stormsum, stormwin	Double precision	Duration of summer (stormsum) and winter (stormwin) storms.	hours
31	daystations	Character	Name of Climate-Stations Information File (maximum of 30 characters).	dimensionless
32	monthmod	Character	Name of Monthly Climate Regression-Models File (maximum of 30 characters).	dimensionless
33	daypptinput	Character	Name of Daily Precipitation File (maximum of 30 characters).	dimensionless
34	tunit	Integer	Flag to convert from degrees Fahrenheit to degrees Celsius in the air-temperature/elevation regression models. If tunit = 1, temperatures are converted from degrees Fahrenheit to degrees Celsius.	dimensionless
35	daytmaxinput	Character	Name of Daily Maximum Air-Temperature File (maximum of 30 characters).	dimensionless
36	daytmininput	Character	Name of Daily Minimum Air-Temperature File (maximum of 30 characters).	dimensionless
37	soilprop	Character	Name of Soil-Properties File (maximum of 30 characters).	dimensionless
38	rockprop	Character	Name of Bedrock-Properties File (maximum of 30 characters).	dimensionless
39	atmosinput	Character	Name of Monthly Atmospheric-Parameters File (maximum of 30 characters).	dimensionless
40	vegprop	Character	Name of Vegetation-Properties File (maximum of 30 characters).	dimensionless

Table 1-1. Definitions of variables specified in the Simulation-Control File.—Continued

[Numbers in parentheses after the variable type indicate the size of the variable. Double precision indicates a real variable type]

Record	Variable name	Variable type	Explanation	Units
41	initopt	Integer	Flag for determining how initial soil-water content will be set. Options: initopt = 0, initial conditions based on soil porosity; initopt = 1, initial conditions based on residual soil-water content; initopt = 3, initial conditions read from file restartfile .	dimensionless
	vwfact	Double precision	Multiplication factor for setting initial soil-water content for each of the 5 soil layers.	dimensionless
Records 41a and 41b are only read if initopt = 3				
41a	restartfile	Character	Name of file with several mass-balance terms for each grid cell for the last successful day of a previous simulation (maximum of 30 characters).	dimensionless
41b	ndayscrash	Integer	Last day of successful simulation in a previous simulation that corresponds to data in file restartfile .	dimensionless
42	infile	Character	Name of Geospatial Watershed-Characteristics File (maximum of 30 characters).	dimensionless
43	crashfile	Character	Name of program crash file to hold several mass-balance terms for each grid cell for the last successful day of a simulation (maximum of 30 characters).	dimensionless
44	dayall	Character	Name of file for output of spatially averaged output terms for all grid-cell locations for each successive day of a simulation (maximum of 30 characters).	dimensionless
45	ndaymap	Integer	Number of daily output files of mass-balance results for each grid cell. Maximum of 100 output files is allowed. Must be at least 1.	dimensionless
Repeat records 45a and 45b ndaymap times				
45a	irday, nyrou	Integer(100)	Sequential number of the Julian day (irday) and year (nyrou) to write daily mass-balance results to a corresponding daymap file.	dimensionless
45b	daymap	Character(100)	Name of file for output of daily mass-balance terms for each grid cell for specific days identified by irday and nyrou (maximum of 30 characters).	dimensionless
46	pointfile(1)	Character(20)	Name of file for output of daily mass-balance terms corresponding to the last active grid cell in the model area (that is, the cell immediately above the outflow cell) (maximum of 30 characters).	dimensionless
47	ipointfile	Integer	Number of additional output files of daily mass-balance terms at specific grid cells. ipointfile must be less than or equal to 19 and can equal 0.	dimensionless
Repeat records 47a and 47b ipointfile times				
47a	xpoint, ypoint	Double precision(20)	East-west (easting; xpoint) and north-south (northing; ypoint) coordinates of grid cell for output file of daily mass-balance terms.	meters
47b	pointfile	Character(20)	Name of file for output of daily mass-balance terms corresponding to current xpoint, ypoint (maximum of 30 characters).	dimensionless
48	outfile	Character	Name of output file with summary information for the simulation, as well as summary statistics for the entire simulation (maximum of 30 characters).	dimensionless
49	flxfile	Character	Name of output file with average annual mass-balance terms during averaging period for each grid cell (maximum of 30 characters).	dimensionless
50	spatialout	Character	Name of output file to which summary information about spatial properties for each grid cell is written (maximum of 30 characters).	dimensionless
51	outyear1	Character	Prefix of the name of the output file for mass-balance terms for annual totals or multiyear averages by grid cell (maximum of 26 characters).	dimensionless
52	outannual	Character	Name of file to hold total annual flow terms for the entire grid (maximum of 30 characters).	dimensionless
53	outmonth	Character	Name of file to hold total monthly flow terms for the entire grid (maximum of 30 characters).	dimensionless

¹Additional information about this variable is provided in the text.

Table 1-2. Definitions for column headings printed to the grid-cell properties output file.

[Water-budget terms are in millimeters unless otherwise noted]

Column heading	Definition
easting	Grid-cell east-west coordinate, in meters.
northing	Grid-cell north-south coordinate, in meters.
locid	Sequential grid-cell number.
row	Row number of grid cell.
col	Column number of grid cell.
elev	Land-surface elevation of grid cell, in meters.
slope	Land-surface slope of grid cell, degrees.
aspect	Land-surface aspect of grid cell, degrees azimuth relative to north.
upcells	Total number of upstream cells that contribute flow to the grid cell.
soild	Total soil depth for grid cell (does not include bedrock thickness), in meters.
soild1, ..., soild6	Layer thickness for each layer of the grid cell, in meters.
soil	Integer code for soil type of the grid cell.
soilks	Soil saturated vertical hydraulic conductivity of the grid cell, in millimeters per day.
resid	Residual soil-water content for the grid cell, dimensionless.
fcap	Soil field capacity of the grid cell, dimensionless.
sporo	Soil porosity of the grid cell, dimensionless.
lay1mm, ..., lay5mm	Storage capacity of each soil layer of the grid cell, in millimeters.
rockmm	Storage capacity of the bedrock layer of the grid cell, in millimeters.
scapmmt	Total storage capacity of all six layers of the grid cell, in millimeters.
rock	Integer code for bedrock type of the grid cell.
ks(mm/dy)	Effective unsaturated vertical hydraulic conductivity for the bedrock layer of the grid cell, in millimeters per day.
ks(mm/yr)	Effective unsaturated vertical hydraulic conductivity for the bedrock layer of the grid cell, in millimeters per year.

Table 1-3. Definitions for column headings printed for specific dates to the daily output file for each grid cell.

[Water-budget terms are in millimeters unless otherwise noted]

Column heading	Definition
cellcode	Grid-cell (node) number.
easting	Grid-cell east-west coordinate.
northing	Grid-cell north-south coordinate.
elev	Land-surface elevation.
temp	Average daily air temperature.
swinflow	Surface-water inflow from upstream basins.
precip	Daily precipitation.
rain	Daily precipitation as rain.
snowfall	Daily precipitation as snow.
snowcover	Water-equivalent depth of snow cover.
snowmelt	Daily snowmelt.
sublimation	Daily sublimation.
pet3	Approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Potential evapotranspiration adjusted for cloudy days.
pet	Potential evapotranspiration adjusted for cloudy days and sublimation.
et	Total actual evapotranspiration from soil zone.
delta-storage1	Change in water content for all six soil layers of model cell in first step of flow routing.
delta-storage2	Change in water content for all six soil layers of model cell in second step of flow routing.
delta-storage	Total change in water content for all six soil layers of model cell for current day.
runoff	Runoff during first step of flow routing.
net-infil1	Net infiltration in first step of flow routing.
net-infil2	Net infiltration in second step of flow routing.
net-infil3	Total net infiltration.
runon-infil1	Water-content change caused by infiltration of runoff for all six layers.
sw-inflow	Infiltration into soil for second step of flow-routing algorithm.
sw-outflow	Runoff during second step of flow routing.
soilmm1, ..., soilmm5	Soil-water content for layers 1–5.
soilvwc1, ..., soilvwc5	Dimensionless volumetric soil-water content for layers 1–5.
et1, ..., et5	Evapotranspiration from soil layers 1–2 (et1 and et2) and evaporation from soil layers 3–5 (et3 , et4 , and et5).
flux1, ..., flux5	Flow from overlying to underlying layer in first step of flow routing.
fluxr1, ..., fluxr5	Flow from overlying to underlying layer in second step of flow routing.
rockmm1	Rock-water content.
rockvwc1	Dimensionless volumetric rock-water content for layer 6.
et6	Evaporation from rock layer.
c-day-balance	Mass-balance check for each grid cell.

Table 1-4. Definitions for column headings printed to the daily output file for specific grid cells.

[Water-budget terms are in millimeters unless otherwise noted]

Column heading	Definition
daynum	Sequential day number in simulation.
year	Year.
mo	Month.
md	Day of month.
yd	Day of year.
temp	Average daily air temperature.
swinflow	Surface-water inflow from upstream basins.
precip	Daily precipitation.
rain	Daily precipitation as rain.
snowfall	Daily precipitation as snow.
snowpack	Water-equivalent depth of snow cover.
snowmelt	Daily snowmelt.
sublimation	Daily sublimation.
pet3	Approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Total unadjusted potential evapotranspiration.
pet	Potential evapotranspiration adjusted for cloudy days and sublimation.
et	Total actual evapotranspiration from soil zone.
delta-storage1	Change in water content for all six soil layers of model cell in first step of flow routing.
delta-storage2	Change in water content for all six soil layers of model cell in second step of flow routing.
delta-storage	Sum of delta-storage1 and delta-storage2 .
runon	Total infiltration of run-on for both steps of flow-routing algorithm.
layer1mm, ..., layer6mm	Water content for each model layer.
layer1wc, ..., layer6wc	Dimensionless volumetric water content for each model layer.
layer1et, ..., layer6et	Evapotranspiration from model layers 1 and 2 (layer1et and layer2et) and transpiration from layers 3 through 6 (layer3et through layer6et).
layer1drain, ..., layer5drain	Flow from overlying to underlying model layer in first step of flow routing.
rundrain1, ..., rundrain5	Flow from overlying to underlying model layer in second step of flow routing.
runoff	Runoff during first step of flow routing.
net-infil1	Net infiltration in first step of flow-routing algorithm.
net-infil2	Net infiltration in second step of flow-routing algorithm.
net-infil3	Total net infiltration.
run-infil	Water-content change caused by infiltration of run-on for all six layers.
sw-inflow	Infiltration into soil in second step of flow-routing algorithm.
sw-outflow	Runoff during second step of flow routing.
tot-outflow	Total runoff estimated for both steps of the flow-routing algorithm.
c-day-balance	Mass-balance check for each grid cell.

Table 1-5. Definitions for column headings printed to the annual and average annual output files for all grid cells.

[Water-budget terms are in millimeters unless otherwise noted. In the variable definitions, annual indicates an averaging interval of one year, whereas average annual indicates an averaging interval greater than one year]

Column heading	Definition
cellcode	Grid-cell (node) number.
easting	Grid-cell east-west coordinate.
northing	Grid-cell north-south coordinate.
temp	Average daily air temperature, in degrees Celsius.
swinflow	Annual or average annual surface-water inflow from upstream basins.
precip	Annual or average annual precipitation.
rain	Annual or average annual precipitation as rain.
snowfall	Annual or average annual precipitation as snow.
snowcover	Annual or average annual water-equivalent depth of snow cover.
snowmelt	Annual or average annual snowmelt.
sublimation	Annual or average annual sublimation.
pet3	Annual or average annual approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Annual or average annual total unadjusted potential evapotranspiration.
pet	Annual or average annual potential evapotranspiration adjusted for cloudy days and sublimation.
et	Annual or average annual total actual evapotranspiration from soil zone.
delta-storage1	Annual or average annual change in water content for all six soil layers of model cell in first step of flow routing.
net-infil1	Annual or average annual net infiltration in first step of flow routing.
net-infil2	Annual or average annual net infiltration in second step of flow routing.
net-infil3	Annual or average annual total net infiltration.
runoff	Annual or average annual runoff during first step of flow routing.
run-infil	Annual or average annual water-content change caused by infiltration of run-on for all six layers.
run-on	Annual or average annual runoff for second step of flow-routing algorithm.
mass-balance	Annual or average annual mass-balance error term for net infiltration.

Table 1-6. Definitions for column headings printed to the daily and cumulative output file for the last successful day of a simulation.

[Water-budget terms are in millimeters unless otherwise noted]

Column heading	Definition
daynum	Sequential day number in simulation.
year	Year.
easting	Grid-cell east-west coordinate.
northing	Grid-cell north-south coordinate.
row	Row number of grid cell.
col	Column number of grid cell.
snowmm	Water-equivalent depth of snow cover for cell for last successful day of simulation.
soilmm1, ..., soilmm5	Soil-water content for layers 1–5 of cell for last successful day of simulation.
rockmm	Rock-water content of cell for last successful day of simulation.
aappt	Cumulative precipitation at cell through last successful day of simulation.
aaain	Cumulative precipitation as rain at cell through last successful day of simulation.
aasnow	Cumulative precipitation as snow at cell through last successful day of simulation.
aasnvc	Cumulative water-equivalent depth of snow cover at cell through last successful day of simulation.
aamelt	Cumulative snowmelt at cell through last successful day of simulation.
aasubl	Cumulative sublimation at cell through last successful day of simulation.
aapet	Cumulative potential evapotranspiration adjusted for cloudy days and sublimation for cell through last successful day of simulation.
aatet	Cumulative total evapotranspiration from soil zone for cell through last successful day of simulation.
aadsw1	Cumulative change in water content for all six soil layers in first step of flow routing at cell through last successful day of simulation.
aadsw2	Cumulative change in water content for all six soil layers in second step of flow routing at cell through last successful day of simulation.
aaifr	Cumulative water-content change caused by infiltration of run-on for all six layers of cell through last successful day of simulation.
aaif1	Cumulative net infiltration in first step of flow routing at cell through last successful day of simulation.
aaif2	Cumulative net infiltration in second step of flow routing at cell through last successful day of simulation.
aaoff	Cumulative runoff in first step of flow routing at cell through last successful day of simulation.
aarun	Cumulative runoff in second step of flow routing at cell through last successful day of simulation.

Table 1-7. Definitions for column headings printed to the daily output file for the spatially averaged water-budget components.

[Water-budget terms are average values for all active grid cells, in millimeters unless otherwise noted]

Column heading	Definition
daynum	Sequential day number in simulation.
year	Year.
mo	Month.
md	Day of month.
yd	Day of year.
temp	Daily air temperature.
nrun3	Number of grid cells generating runoff (either Hortonian- or Durnian-type runoff) for a given daily time step.
swinflow	Surface-water inflow from upstream basins.
precip	Daily precipitation.
rain	Daily precipitation as rain.
snowfall	Daily precipitation as snow.
snowcover	Water-equivalent depth of snow cover.
snowmelt	Daily snowmelt.
sublimation	Daily sublimation.
pet3	Approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Unadjusted potential evapotranspiration.
pet	Potential evapotranspiration adjusted for cloudy days and sublimation.
et	Total actual evapotranspiration from soil zone.
delta-storage1	Change in water content for all six soil layers of model cell in first step of flow routing.
delta-storage2	Change in water content for all six soil layers of model cell in second step of flow routing.
delta-storage	Total change in water content for all six soil layers of model cell for current day.
layer1mm, ..., layer6mm	Water content for each model layer.
layer1wc, ..., layer6wc	Water content for each model layer divided by the average layer thickness, dimensionless.
lay1etday, ..., lay6etday	Evapotranspiration for each model layer.
layer1drain, ..., layer6drain	Flow from one model layer to the underlying layer in first step of flow routing; layer6drain is net infiltration.
rundrain1, ..., rundrain6	Flow from one model layer to the underlying layer in second step of flow routing; rundrain6 is net infiltration.
runoff	Runoff during first step of flow routing.
net-infil1	Net infiltration in first step of flow routing.
net-infil2	Net infiltration in second step of flow routing.
net-infil3	Total net infiltration.
rinfdy	Infiltrated run-on from previous day.
runonday	Total infiltration to soil in second step of flow routing.
inflow0	Inflow to last active grid cell in basin in second step of flow routing.
totout2	Runoff from grid cell at basin outflow.
outflow0	Outflow from last active grid cell in basin in second step of flow routing.
swgainday	Net surface-water gain (inflow minus outflow) within the basin for the day.
it	Number of iterations in second step of the flow routing.
discharge0	Outflow from last active grid cell in basin in second step of flow routing, in cubic meters of water.
discharge1	Runoff at basin outflow cell, in cubic meters of water.
discharge2	Outflow from last active grid cell in basin, in cubic meters of water.
g-day-balance	Mass-balance check for each daily time step.

Table 1-8. Definitions for column headings printed to the monthly and annual output files for all grid cells.

[Water-budget terms are in millimeters unless otherwise noted]

Column heading	Definition
year	Year.
mo	Month.
md	Day of month.
yd	Day of year.
nd	Sequential day number in simulation.
precip	Total precipitation.
rain	Total precipitation as rain.
snow	Total precipitation as snow.
snowpack	Total water-equivalent depth of snow cover.
snowmelt	Total snowmelt.
sublimation	Total sublimation.
pet3	Approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Total unadjusted potential evapotranspiration for the month or year.
pet0	Total potential evapotranspiration adjusted for cloudy days for the month or year.
pet	Total potential evapotranspiration adjusted for cloudy days and sublimation for the month or year.
et	Total actual evapotranspiration from soil zone for the month or year.
delta-storage	Total change in water content for all six layers of model cell in first step of flow routing for the month or year.
net-infil1	Total net infiltration in first step of flow routing.
net-infil2	Total net infiltration in second step of flow routing.
net-infil3	Total net infiltration.
runoff	Total runoff during first step of flow routing.
run-infil	Total infiltrated run-on from previous day.
outflow	Total flow at outflow cell of basin.
mass-bal	Total mass-balance error for the year (not printed for the monthly output).

Table 1-9. Definitions of variables printed to the average annual output file for each grid cell.

[Water-budget terms are in millimeters per year unless otherwise noted]

Column heading	Definition
cellcode	Grid-cell (node) number.
easting	Grid-cell east-west coordinate.
northing	Grid-cell north-south coordinate.
ndays	Number of days in averaging period.
elev	Land-surface elevation.
temp	Average annual air temperature.
swinflow	Average annual surface-water inflow from upstream basins.
precip	Average annual precipitation.
rain	Average annual precipitation as rain.
snowfall	Average annual precipitation as snow.
snowcover	Average annual water-equivalent depth of snow cover.
snowmelt	Average annual snowmelt.
sublimation	Average annual sublimation.
pet3	Average annual approximate potential evapotranspiration estimated on the basis of vegetation cover, bare-soil area, and Priestley-Taylor α coefficients.
pet2	Average annual unadjusted potential evapotranspiration.
pet	Average annual potential evapotranspiration adjusted for cloudy days and sublimation.
et	Average annual total actual evapotranspiration from soil zone.
delta-storage1	Average annual change in water content for all six soil layers of model cell in first step of flow routing.
delta-storage2	Average annual change in water content for all six soil layers of model cell in second step of flow routing.
runoff	Average annual runoff during first step of flow routing.
net-infil1	Average annual net infiltration in first step of flow routing.
net-infil2	Average annual net infiltration in second step of flow routing.
net-infil3	Average annual total net infiltration.
runon-infil1	Average annual water-content change caused by infiltration of run-on for all six layers.
sw-inflow	Average annual run-on.
sw-outflow	Average annual runoff during second step of flow routing.
total-outflow	Average annual total runoff.
run-on(cfs)	Average annual runoff for second step of flow routing, in cubic feet per second.
run-on(cmd)	Average annual runoff for second step of flow routing, in cubic meters per day.
c-run-balance	Average annual mass-balance check for each grid cell.

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This appendix provides brief descriptions of each of the major components of the INFIL3.0 code, as well as definitions of the major program variables used in each program component. INFIL3.0 is written in the FORTRAN-90 computer-programming language.

MODULE INFIL_DECL

Module INFIL_DECL is used to declare variables and parameters that are shared among the MAIN program and subroutines. Several parameters that are declared in this module are defined in table 2-1. The remaining variables in the module are defined in the sections below for the MAIN program and each of the subroutines.

Table 2-1. Parameters declared in module INFIL_DECL.

Variable name	Size	Description
mxcells	60,005	Maximum number of grid cells in a simulation.
mxgridind	3,350	Maximum number of row or column grid indices in a simulation.
mxdays	40,000	Maximum number of days in a simulation.
mxprop	800	Maximum number of rock or soil types in a simulation.
mxstations	250	Maximum number of climate stations in a simulation.
vegcode1b	-10,000	Lower bound on vegetation code indice.
vegcodeub	10,000	Upper bound on vegetation code indice.
dr	scalar	Degrees to radians conversion; set to 0.0174533.
rd	scalar	Radians to degrees conversion; set to 57.29579.
pi	scalar	The number pi; set to 3.141592654.
gr	scalar	Gravitational acceleration; set to 9.8 meters per second squared.
wd	scalar	Water-density factor (water mass to volume conversion); set to 1,000 kilograms per cubic meter.

MAIN PROGRAM

The MAIN program controls the order in which the subroutines are executed, as well as processing and writing of simulation results. Miscellaneous variables used in the MAIN program are defined in table 2-2, whereas water-budget terms are defined in tables 2-3 through 2-9.

Table 2-2. Miscellaneous variables used in MAIN program.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
nr	scalar	Counter for number of simulations.
nruns	scalar	Total number of simulations.
ndayscrash	scalar	Last day of successful simulation in a previous simulation.
initopt	scalar	Flag that determines how initial soil-water content conditions will be set.
ndavg	scalar	Number of days in averaging period.
nall, ndays2, ndays3, ndays4, ndays5, nyears	scalar	Counters used for averaging period.
j	scalar	Time step counter.
yrstart	scalar	Simulation start year.
mostart	scalar	Simulation start month.
dystart	scalar	Simulation start day.
yrend	scalar	Simulation end year.
moend	scalar	Simulation end month.
dyend	scalar	Simulation end day.
istart	scalar	Sequential day number of simulation start time.
iend	scalar	Sequential day number of simulation end time.
yrstart1	scalar	Simulation start year for calculation of simulation averages.
mostart1	scalar	Simulation start month for calculation of simulation averages.
dystart1	scalar	Simulation start day for calculation of simulation averages.
yrend1	scalar	Simulation end year for calculation of simulation averages.
moend1	scalar	Simulation end month for calculation of simulation averages.
dyend1	scalar	Simulation end day for calculation of simulation averages.
istart1	scalar	Sequential day number of simulation start time for calculation of simulation averages.
iend1	scalar	Sequential day number of simulation end time for calculation of simulation averages.
ia	scalar	Grid-cell counter.
nloc	scalar	Total number of grid cells.
iwat	mxcells	Downstream grid identifier to which runoff is directed from current cell (iwat = -3 indicates the outflow cell from the basin).
monthold	scalar	Current month of simulation.
nupstream	scalar	Number of upstream basins contributing surface-water inflow. A maximum of 5 upstream basins can be specified.
iupstream	5	Last value of cellcode that is read from each upgeoinp file. All values in the iupstream array should be equal; otherwise, the program will stop.
cellcode	mxcells	Location identifier for each grid cell.

Table 2-2. Miscellaneous variables used in MAIN program.—Continued[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
easting	mxcells	East-west (easting) coordinate of the centroid of the grid cell, in meters.
northing	mxcells	North-south (northing) coordinate of the centroid of the grid cell, in meters.
row	mxcells	Row assignment for each grid cell.
col	mxcells	Cell assignment for each grid cell.
elev	mxgridind, mxgridind	Elevation of the centroid of each grid cell, in meters.
ja	scalar	Model layer counter.
averaging-StartDay, averaging-StartMonth, averaging-StartYear	scalar	Day, month, and year of averaging start date.
output-Interval	scalar	Interval, in years, for which annual or average annual output will be printed.
TextExt	C*4	Suffix to name of output file for mass-balance terms for annual totals or multiyear averages by grid cell.
noutyr	scalar	Counter for current year of output for annual or multiyear mass-balance totals.
iptval	scalar	Flag that specifies whether precipitation will be a constant value.
pptval	scalar	Constant precipitation value, in millimeters.
pptfact	scalar	Precipitation scaling factor, dimensionless.
iairval	scalar	Flag that specifies whether air temperature will be a constant value.
airval	scalar	Constant air-temperature value, in degrees Celsius.
ietval	scalar	Flag that specifies whether evapotranspiration will be a constant value.
etval	scalar	Constant evapotranspiration value, in millimeters.
etfact	scalar	Evapotranspiration scaling factor, dimensionless.
soilet2	scalar	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration.
barsoil2	scalar	Variable α in the modified Priestley-Taylor equation used for defining evaporation as a function of bare-soil water content and potential evapotranspiration.
petadj	scalar	An empirical adjustment factor to the calculated potential evapotranspiration to account for cloud cover (precipitation), dimensionless.
isnow	scalar	Flag that specifies whether or not snow accumulation, melting, and sublimation will be simulated.
optmassb	scalar	Flag that specifies whether or not routing of runoff will be stopped on the last day of simulation.
yr	mxdays	Calendar year (for example, 1900).
month	mxdays	Calendar month (1 for January, 2 for February, and so forth).
monday	mxdays	Day of month.

Table 2-3. Variables related to volumetric balances in MAIN program.

Variable name	Size	Description
inflow0	scalar	Daily inflow to last active grid cell in basin due to second step of flow routing, in millimeters of water over the basin.
outflow0	scalar	Daily outflow from last active grid cell in basin due to second step of flow routing, in millimeters of water over the basin.
outflow2	scalar	Total daily outflow from last active grid cell in basin, in millimeters of water over the basin.
swgainday	scalar	Net surface-water gain within the basin for the day, in millimeters.
swin	mxcells	Total surface-water inflow to basin from upstream sources, in millimeters.
swinflow	mxdays, 5	Surface-water flow value from upstream basin, in millimeters.
flowout	0:mxgridind, 0:mxgridind	Runoff from each grid cell for first step of flow routing, in millimeters.
totout	0:mxgridind, 0:mxgridind	Total runoff from each grid cell for second step of flow routing, in millimeters.
dsnowcv	scalar	Daily change in water-equivalent depth of snow for current cell, in millimeters.
melt	scalar	Snowmelt for each cell, in millimeters.
totout2	scalar	Runoff from grid cell at basin outflow, in millimeters.
totout3	scalar	Runoff from grid cell at basin outflow divided by number of grid cells, in millimeters.
vegcover0	vegcode1b: vegcodeub	Vegetation cover for vegetation type vegmap (specified as a percentage, such as 50.0).
avglaythck	10	Average layer thickness for each of the six model layers, in meters.
cdepth	6, mxcells	Layer thickness for layers 1 through 6, in meters.
discharge0	scalar	Daily outflow from last active grid cell in basin due to second step of flow routing, in cubic meters of water.
discharge1	scalar	Daily runoff from grid cell at basin outflow, in cubic meters of water.
discharge2	scalar	Daily outflow from last active grid cell in basin, in cubic meters of water.
iter	scalar	Counter for number of iterations of the second step of the flow-routing algorithm.
rzwater1	mxcells	Total water content for all six soil layers after the first step of flow routing for each cell, in millimeters.
rzwater2	mxcells	Total water content for all six soil layers after the second step of flow routing for each cell, in millimeters.
totoutflow	mxcells	Total runoff from each grid cell for both steps of the flow-routing algorithm, in millimeters.
runmassb1	mxcells	Mass-balance error term for net infiltration equation that includes changes in water content of soil zone for second step of the flow-routing algorithm, in millimeters.
totupflow	scalar	Total surface-water flow from upstream basins, in millimeters.
pptloc	mxcells	Precipitation for each cell, in millimeters.
pptloc00	scalar	Precipitation for each cell, in millimeters.
rain	mxcells	Precipitation as rain for each cell, in millimeters.
snowfall	mxcells	Precipitation as snow for each cell, in millimeters.
snowmm	mxcells	Water-equivalent depth of snow for each cell, in millimeters.
meltmm	mxcells	Snowmelt for each cell, in millimeters.
sublim	mxcells	Sublimation for each cell, in millimeters.
avgairt	mxcells	Average air temperature for each cell, in degrees Celsius.
dsoilmm1	mxcells	Change in water content for all six soil layers due to first step of flow routing for each cell, in millimeters.

Table 2-3. Variables related to volumetric balances in MAIN program.—Continued

Variable name	Size	Description
dsoilmm2	mxcells	Change in water content for all six soil layers due to second step of flow routing for each cell, in millimeters.
dsoilmm3	scalar	Total change in water content for all six soil layers due to flow routing, in millimeters.
tpet	mxcells	Potential evapotranspiration adusted for cloudy days for each cell, in millimeters.
tet0	mxcells	Total actual evapotranspiration from soil zone for each cell, in millimeters.
tpet0	scalar	Total unadjusted potential evapotranspiration for daily time step, in millimeters.
tpet2	mxcells	Total unadjusted potential evapotranspiration for daily time step for each cell, in millimeters.
tpet3	mxcells	An approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor α coefficients.
petrs	mxcells	Potential evapotranspiration adjusted for cloudy days and sublimation for each cell, in millimeters.
petrs2	scalar	Temporary variable used for potential evapotranspiration adjusted for cloudy days and sublimation for each cell, in millimeters.
soilmm	5, mxcells	Soil water content for each soil layer for each cell, in millimeters.
rockmm	mxcells	Rock water content for each cell, in millimeters.
flux	6, mxcells	Flow from one layer to the underlying layer in first step of flow routing for each cell, in millimeters.
fluxr0	6, mxcells	Flow from one layer to the underlying layer in second step of flow routing for each cell, in millimeters.
et	6, mxcells	Evapotranspiration for each soil layer for each cell, in millimeters.
runoffmm	mxcells	Runoff generated for first step of flow routing for each cell, in millimeters.
rinfmm0	mxcells	Change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
rinfmm1	mxcells	Change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
rinfmm2	mxcells	Net infiltration due to second step of flow routing for each cell, in millimeters.
infilmm1	mxcells	Net infiltration due to first step of flow routing for each cell, in millimeters.
infilmm2	mxcells	Net infiltration due to second step of flow routing for each cell, in millimeters.
infilmm3	scalar	Total net infiltration due to flow routing, in millimeters.
flowin0	mxcells	Infiltration across the air-soil interface, in millimeters.
vwcl1, ..., vwcl6	scalar	Dimensionless volumetric soil-water content for each layer.
cDay-Balance	scalar	Mass-balance check for each cell, in millimeters.

Table 2-4. Variables related to daily volumetric balances in postprocessing phase of MAIN program.

Variable name	Size	Description
upflwday	scalar	Daily total surface-water flow from upstream basins, in millimeters.
pptday	scalar	Daily precipitation for all cells, in millimeters.
rainday	scalar	Daily precipitation as rain for all cells, in millimeters.
snowday	scalar	Daily precipitation as snow for all cells, in millimeters.
sncvday	scalar	Daily water-equivalent depth of snow for all cells, in millimeters.
meltday	scalar	Daily snowmelt for all cells, in millimeters.
sublday	scalar	Daily sublimation for all cells, in millimeters.
atday	scalar	Daily air temperature for all cells, in degrees Celsius.
petday	scalar	Daily potential evapotranspiration adjusted for cloudy days for all cells, in millimeters.
pet2day	scalar	Daily unadjusted potential evapotranspiration for daily time step for all cells, in millimeters.
pet3day	scalar	Daily approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients for all cells, in millimeters.
petrsday	scalar	Daily potential evapotranspiration adjusted for cloudy days and sublimation for all cells, in millimeters.
tetday	scalar	Total daily actual evapotranspiration from soil zone, in millimeters.
tetday0	scalar	Daily total actual evapotranspiration from soil zone for all cells, in millimeters.
soilday1	scalar	Daily change in water content for all six model layers due to first step of flow routing for all cells, in millimeters.
soilday2	scalar	Daily change in water content for all six model layers due to second step of flow routing for all cells, in millimeters.
soilday3	scalar	Total daily change in water content for all six model layers for all cells, in millimeters.
l1mmday, ..., l5mmday	scalar	Daily soil water content for each soil layer for all cells, in millimeters.
l6mmday	scalar	Daily rock water content for all cells, in millimeters.
l1wcday, ..., l6wcday	scalar	Daily water content for each soil or rock layer divided by the average soil-layer thickness for all cells, dimensionless.
l1drnday, ..., l6drnday	scalar	Daily flow from one layer to the underlying layer in first step of flow routing for all cells, in millimeters.
l1etday, ..., l6etday	scalar	Daily evapotranspiration for each soil layer for all cells, in millimeters.
l1rundrn, ..., l6rundrn	scalar	Daily flow from one layer to the underlying layer in second step of flow routing for all cells, in millimeters.
runday	scalar	Daily runoff generated for first step of flow routing for all cells, in millimeters.
rinfday	scalar	Daily change in water content for all six layers due to infiltration of run-on for all cells, in millimeters.
rinfday2	scalar	Infiltrated run-on from previous day, in millimeters.
infrday	scalar	Daily net infiltration due to second step of flow routing for all cells, in millimeters.
inf1day	scalar	Daily net infiltration due to first step of flow routing for all cells, in millimeters.
inf2day	scalar	Daily net infiltration due to second step of flow routing for all cells, in millimeters.
inf3day	scalar	Total daily net infiltration for all cells, in millimeters.
runonday	scalar	Daily infiltration across air-soil interface for second step of flow-routing algorithm, in millimeters.
totout4	scalar	Daily flow at outflow cell of basin, in millimeters of water over the entire basin.
cfsday	scalar	Daily flow at outflow cell of basin, in cubic feet per second from the entire basin.
gDay-Balance	scalar	Mass-balance check for each daily time step, in millimeters.

Table 2-5. Variables related to total monthly volumetric balances in postprocessing phase of MAIN program.

Variable name	Size	Description
pptmo	scalar	Total precipitation for all cells for the month, in millimeters.
rainmo	scalar	Total precipitation as rain for all cells for the month, in millimeters.
snowmo	scalar	Total precipitation as snow for all cells for the month, in millimeters.
sncvmo	scalar	Total water-equivalent depth of snow for all cells for the month, in millimeters.
meltmo	scalar	Total snowmelt for all cells for the month, in millimeters.
sublmo	scalar	Total sublimation for all cells for the month, in millimeters.
atmo	scalar	Total air temperature for all cells for the month, in degrees Celsius.
petmo	scalar	Total potential evapotranspiration adjusted for cloudy days for all cells for the month, in millimeters.
pet2mo	scalar	Total unadjusted potential evapotranspiration for daily time step for all cells for the month, in millimeters.
pet3mo	scalar	Total approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients for all cells for the month, in millimeters.
petrsmo	scalar	Total potential evapotranspiration adjusted for cloudy days and sublimation for all cells for the month, in millimeters.
tetmo	scalar	Total actual evapotranspiration from soil zone for the month, in millimeters.
dswmo1	scalar	Total change in water content for all six model layers due to first step of flow routing for all cells for the month, in millimeters.
dswmo2	scalar	Total change in water content for all six model layers due to second step of flow routing for all cells for the month, in millimeters.
inf1mo	scalar	Total net infiltration due to first step of flow routing for all cells for the month, in millimeters.
inf2mo	scalar	Total net infiltration due to second step of flow routing for all cells for the month, in millimeters.
inf3mo	scalar	Total daily net infiltration for all cells for the month, in millimeters.
rinfmo	scalar	Total infiltrated run-on from previous day for the month, in millimeters.
runmo	scalar	Total runoff generated for first step of flow routing for all cells for the month, in millimeters.
outmo	scalar	Total flow at outflow cell of basin for the month, in millimeters of water over the entire basin.

Table 2-6. Variables related to total annual volumetric balances in postprocessing phase of MAIN program.

Variable name	Size	Description
pptyr	scalar	Total precipitation for all cells for the year, in millimeters.
rainyr	scalar	Total precipitation as rain for all cells for the year, in millimeters.
snowyr	scalar	Total precipitation as snow for all cells for the year, in millimeters.
sncvyr	scalar	Total water-equivalent depth of snow for all cells for the year, in millimeters.
meltyr	scalar	Total snowmelt for all cells for the year, in millimeters.
sublyr	scalar	Total sublimation for all cells for the year, in millimeters.
atyr	scalar	Total air temperature for all cells for the year, in degrees Celsius.
petyr	scalar	Total potential evapotranspiration adjusted for cloudy days for all cells for the year, in millimeters.
pet2yr	scalar	Total unadjusted potential evapotranspiration for daily time step for all cells for the year, in millimeters.
pet3yr	scalar	Total approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients for all cells for the year, in millimeters.
petsyr	scalar	Total potential evapotranspiration adjusted for cloudy days and sublimation for all cells for the year, in millimeters.
tetyr	scalar	Total actual evapotranspiration from soil zone for the year, in millimeters.
dswyr1	scalar	Total change in water content for all six model layers due to first step of flow routing for all cells for the year, in millimeters.
dswyr2	scalar	Total change in water content for all six model layers due to second step of flow routing for all cells for the year, in millimeters.
inflyr	scalar	Total net infiltration due to first step of flow routing for all cells for the year, in millimeters.
inf2yr	scalar	Total net infiltration due to second step of flow routing for all cells for the year, in millimeters.
inf3yr	scalar	Total daily net infiltration for all cells for the year, in millimeters.
rinfy	scalar	Total infiltrated run-on from previous day for the year, in millimeters.
runyr	scalar	Total runoff generated for first step of flow routing for all cells for the year, in millimeters.
outyr	scalar	Total flow at outflow cell of basin for the year, in millimeters of water over the entire basin.
soutyr	scalar	Annual surface-water outflow, in millimeters.
soutfl2yr	scalar	Annual surface-water outflow, in millimeters.

Table 2-7. Variables related to average annual volumetric balances for each cell in postprocessing phase of MAIN program.

Variable name	Size	Description
yearat	mxcells	Average annual air temperature for each cell, in degrees Celsius.
yearrun	mxcells	Average annual runoff for second step of flow-routing algorithm for each cell, in millimeters.
yearinfr	mxcells	Average annual change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
yearswin	mxcells	Average annual surface-water inflow to basin from upstream sources, in millimeters.
yearppt	mxcells	Average annual precipitation for each cell, in millimeters.
yearrain	mxcells	Average annual precipitation as rain for each cell, in millimeters.
yearsnow	mxcells	Average annual precipitation as snow for each cell, in millimeters.
yearsncv	mxcells	Average annual water-equivalent depth of snow for each cell, in millimeters.
yearmelt	mxcells	Average annual snowmelt for each cell, in millimeters.
yearsubl	mxcells	Average annual sublimation for each cell, in millimeters.
yearpet	mxcells	Average annual potential evapotranspiration adjusted for cloudy days and sublimation for each cell, in millimeters.
yearpet2	mxcells	Average annual unadjusted potential evapotranspiration for each cell, in millimeters.
yearpet3	mxcells	Average annual approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients for each cell, in millimeters.
yeartet	mxcells	Average annual total evapotranspiration from soil zone for each cell, in millimeters.
yeardsw1	mxcells	Average annual change in water content for all six soil layers due to first step of flow routing for each cell, in millimeters.
yeardsw2	mxcells	Average annual change in water content for all six soil layers due to second step of flow routing for each cell, in millimeters.
yearinf1	mxcells	Average annual net infiltration due to first step of flow routing for each cell, in millimeters.
yearinf2	mxcells	Average annual net infiltration due to second step of flow routing for each cell, in millimeters.
yearinf3	mxcells	Total average annual net infiltration for each cell, in millimeters.
yearoff	mxcells	Average annual runoff generated for first step of flow routing for each cell, in millimeters.
yearrunon	mxcells	Average annual infiltration across air-soil interface for second step of flow-routing algorithm, in millimeters.
yearbal	mxcells	Average annual mass-balance error for net infiltration for each cell, in millimeters.
totbal	scalar	Average annual mass-balance error for all cells, in millimeters.

Table 2-8. Variables related to long-term average annual volumetric balances for each location during averaging period of MAIN program.

Variable name	Size	Description
aaifr	mxcells	Average annual change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
aaat	mxcells	Average annual air temperature for each cell, in degrees Celsius.
aaupflw	mxcells	Average annual surface-water inflow to basin from upstream sources, in millimeters.
aaopt	mxcells	Average annual precipitation for each cell, in millimeters.
aarain	mxcells	Average annual precipitation as rain for each cell, in millimeters.
aaasnow	mxcells	Average annual precipitation as snow for each cell, in millimeters.
aaasncv	mxcells	Average annual water-equivalent depth of snow for each cell, in millimeters.
aaamelt	mxcells	Average annual snowmelt for each cell, in millimeters.
aaasubl	mxcells	Average annual sublimation for each cell, in millimeters.
aaatet	mxcells	Average annual total evapotranspiration from soil zone for each cell, in millimeters.
aaadsw1	mxcells	Average annual change in water content for all six soil layers due to first step of flow routing for each cell, in millimeters.
aaadsw2	mxcells	Average annual change in water content for all six soil layers due to second step of flow routing for each cell, in millimeters.
aaapet	mxcells	Average annual potential evapotranspiration adjusted for cloudy days and sublimation for each cell, in millimeters.
aaapet2	mxcells	Average annual unadjusted potential evapotranspiration for daily time step for each cell, in millimeters.
aaapet3	mxcells	Average annual approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients for each cell, in millimeters.
aaainf1	mxcells	Average annual net infiltration due to first step of flow routing for each cell, in millimeters.
aaainf2	mxcells	Average annual net infiltration due to second step of flow routing for each cell, in millimeters.
aaainf3	scalar	Average annual net infiltration for each cell, in millimeters.
aaaoft	mxcells	Average annual runoff generated for first step of flow routing for each cell, in millimeters.
aaarunon	mxcells	Average annual infiltration across air-soil interface for second step of flow-routing algorithm to each cell, in millimeters.
aaatotout	mxcells	Average annual total runoff for each cell, in millimeters.
aaarun	mxcells	Average annual runoff for second step of flow routing for each cell, in millimeters.
aaacfs	mxcells	Average annual runoff for second step of flow routing for each cell, in cubic feet per second.
aaacmd	mxcells	Average annual runoff for second step of flow routing for each cell, in cubic meters per day.
aaRun-Balance	scalar	Average annual mass-balance check for each cell, in millimeters.

Table 2-9. Variables related to global average annual volumetric balances for all cells in the simulation domain during averaging period of MAIN program.

Variable name	Size	Description
gaainfr	mxcells	Average annual change in water content for all six layers due to infiltration of run-on, in millimeters per year.
gaaat	mxcells	Average annual air temperature, in degrees Celsius.
gaaupflw	mxcells	Average annual surface-water inflow to basin from upstream sources, in millimeters per year.
gaappt	mxcells	Average annual precipitation, in millimeters per year.
gaarain	mxcells	Average annual precipitation as rain, in millimeters per year.
gaasnow	mxcells	Average annual precipitation as snow, in millimeters per year.
gaasncv	mxcells	Average annual water-equivalent depth of snow, in millimeters per year.
gaamelt	mxcells	Average annual snowmelt, in millimeters per year.
gaasubl	mxcells	Average annual sublimation, in millimeters per year.
gaatet	mxcells	Average annual total actual evapotranspiration from soil zone, in millimeters per year.
gaadsw1	mxcells	Average annual change in water content for all six soil layers due to first step of flow routing, in millimeters per year.
gaadsw2	mxcells	Average annual change in water content for all six soil layers due to second step of flow routing, in millimeters per year.
gaapet	mxcells	Average annual potential evapotranspiration adjusted for cloudy days and sublimation, in millimeters per year.
gaapet2	mxcells	Average annual unadjusted potential evapotranspiration, in millimeters per year.
gaapet3	mxcells	Average annual approximation of potential evapotranspiration using vegetation cover, bare-soil area, and user-specified Priestley-Taylor coefficient α coefficients, in millimeters per year.
gaainf1	mxcells	Average annual net infiltration due to first step of flow routing, in millimeters per year.
gaainf2	mxcells	Average annual net infiltration due to second step of flow routing, in millimeters per year.
gaainf3	scalar	Average annual total net infiltration, in millimeters per year.
gaaoff	mxcells	Average annual runoff generated for first step of flow routing, in millimeters per year.
gaarunon	mxcells	Average annual infiltration across air-soil interface for second step of flow-routing algorithm, in millimeters per year.
gaarun	mxcells	Average annual runoff for second step of flow routing, in millimeters per year.
gaamb3	scalar	Average annual maximum daily error, in millimeters per day.
gaaoutf2	scalar	Average annual surface-water outflow, in millimeters per year.
soilStorage-Change	scalar	Average annual total storage change, in millimeters per year.
gRun-Balance	scalar	Average annual global mass balance, in millimeters per year.

SUBROUTINE RUNSRP

Subroutine RUNSRP reads the total number of simulations to be made by INFIL3.0 and the names of the Simulation-Control Files for each simulation from the batch-control file named *infil3.ctl*. Variables used in the subroutine are defined in table 2-10.

Table 2-10. Variables in subroutine RUNSRP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the set of simulations.
nruns	scalar	Total number of simulations to be made. A maximum of 100 simulations is allowed.
runfile	C*30	Name of simulation. A maximum of 100 names is allowed.

SUBROUTINE CTRLP

Subroutine CTRLP reads data from the Simulation-Control, Soil-Properties, Bedrock-Properties, Vegetation-Properties, and Monthly Atmospheric-Parameters Files. Variables used in the subroutine are defined in tables 2-11 through 2-15.

Table 2-11. Variables in subroutine CTRLP read from the Simulation-Control File.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
title	C*250	Title for the simulation (up to 250 characters).
irout	scalar	Flag that specifies the type of flow routing to be simulated.
petadj	scalar	An empirical adjustment factor to the calculated potential evapotranspiration to account for cloud cover (precipitation), dimensionless.
isnow	scalar	Flag that specifies whether or not snow accumulation, melting, and sublimation will be simulated.
meltime	scalar	Duration of the daily snowmelt period, in hours.
snoday1	scalar	Starting Julian day for the timing of the early spring snowmelt period.
snopar1	scalar	Snowmelt rate that corresponds to the early spring snowmelt period, in millimeters per day.
snoday2	scalar	Starting Julian day for the timing of the late spring snowmelt period.
snopar2	scalar	Snowmelt rate that corresponds to the late spring snowmelt period, in millimeters per day.
isublim	scalar	Flag that specifies whether or not sublimation will be simulated.
subpar1	scalar	Sublimation factor if air temperature is less than or equal to 0 degrees Celsius, dimensionless.
subpar2	scalar	Sublimation factor if air temperature is greater than 0 degrees Celsius, dimensionless.
ipptval	scalar	Flag that specifies whether precipitation will be a constant value.
pptval	scalar	Constant precipitation value to use throughout the simulation period, in millimeters.
iairval	scalar	Flag that specifies whether air temperature will be a constant value.
airval	scalar	Constant air-temperature value to use throughout the simulation period, in 0 degrees Celsius.
ietval	scalar	Flag that specifies whether evapotranspiration will be a constant value.
etval	scalar	Constant evapotranspiration rate, in millimeters.
isdepthval	scalar	Flag to specify whether a constant soil depth will be used for all grid cells.
sdepthval	scalar	Constant soil depth for all grid cells, in meters.
isksval	scalar	Flag that specifies whether soil saturated hydraulic conductivity will be a constant value.
sksval	scalar	Constant soil saturated vertical hydraulic conductivity value, in millimeters per day.

Table 2-11. Variables in subroutine CTRLP read from the Simulation-Control File.—Continued[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
iimbval	scalar	Flag that specifies whether bedrock unsaturated and saturated hydraulic conductivities will be a constant value.
imbval	scalar	Constant bedrock unsaturated and saturated hydraulic conductivities, in millimeters per day.
celsize	scalar	Length of each side of each model grid cell, in meters.
nupstream	scalar	Number of upstream basins contributing surface-water inflow.
ioptupflow	5	Flag that specifies a constant rate of inflow for all days.
upconst	5	Constant rate of inflow specified for upstream basin, in millimeters.
upfile	5	Name of file containing daily upstream flow values.
upgeoinp	5	Name of file containing upstream cellcode identifiers for cells contributing inflow.
header	C*250	Header line in file upgeoinp .
cellcodeval	scalar	Location identifier for each grid cell.
iupstream	5	Last value of cellcode that is read from each upgeoinp file. All values in the iupstream array should be equal; otherwise, the program will stop.
monthwy, mondaywy	scalar	Month and day for which annual and average annual output will be calculated.
yrstart, mostart, dystart	scalar	Year, month, and day of simulation start time.
yrend, moend, dyend	scalar	Year, month, and day of simulation end time.
yrstart1, mostart1, dystart1	scalar	Year, month, and day of starting date to calculate simulation output flow averages.
yrend1, moend1, dyend1	scalar	Year, month, and day of ending date to calculate simulation output flow averages.
output-Interval	scalar	Interval, in years, for which annual or average annual output will be printed.
sdfact	scalar	Soil-depth scaling factor.
pptfact	scalar	Precipitation scaling factor.
effact	scalar	Evapotranspiration scaling factor.
imbfact	scalar	Bedrock unsaturated and saturated hydraulic conductivities scaling factor.
sksfact	scalar	Soil saturated vertical hydraulic conductivity factor.
ivegc	scalar	Flag for specifying vegetative-cover values.
fvegc	scalar	Constant vegetation-cover value, in decimal percent.
ichanmod	scalar	Flag for specifying how the wetted-flow area for each grid cell will be specified.
chan1	scalar	Surface-water minimum effective wetted-flow area, in decimal percent.
chan2	scalar	Surface-water wetted-flow area factor, dimensionless.
chan3	scalar	Surface-water maximum headwater wetted-flow area, dimensionless.
chan4	scalar	Surface-water maximum stream-channel wetted-flow area, dimensionless.
ikschnmod	scalar	Flag for specifying how soil saturated vertical hydraulic conductivity will be modified for stream-channel locations.
kschn1	scalar	Minimum number of upstream cells for adjusting the soil saturated vertical hydraulic conductivity, dimensionless.
kschn2	scalar	Scaling factor for adjusting soil saturated vertical hydraulic conductivity in channels, dimensionless.
kschn3	scalar	Maximum adjustment factor to the soil saturated vertical hydraulic conductivity in channels, dimensionless.

Table 2-11. Variables in subroutine CTRLRP read from the Simulation-Control File.—Continued

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
barsoil1	scalar	Variable β in the modified Priestley-Taylor equation used for defining evaporation as a function of bare-soil water content and potential evapotranspiration, dimensionless.
barsoil2	scalar	Variable α in the modified Priestley-Taylor equation used for defining evaporation as a function of bare-soil water content and potential evapotranspiration, dimensionless.
barsoilf	scalar	An adjustment factor that can be used to modify the value of barsoil1 for layer 2 of the model, dimensionless.
rocket1	scalar	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.
rocket2	scalar	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.
soilet1	scalar	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of soil water content and potential evapotranspiration, dimensionless.
soilet2	scalar	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of soil water content and potential evapotranspiration, dimensionless.
hstep	scalar	Time-step length used for calculating total daily evapotranspiration, in hours.
dysumbeg, dysumend	scalar	Beginning and ending Julian day number for summer storms.
stormsum, stormwin	scalar	Duration of summer and winter storms, in hours.
daystations	C*30	Name of climate-stations information file.
monthmod	C*30	Name of monthly climate-regression models data file.
daypptinput	C*30	Name of daily precipitation data file.
tunit	scalar	Flag to convert from degrees Fahrenheit to degrees Celsius.
daytmax-input	C*30	Name of daily maximum air-temperature data file.
daytmin-input	C*30	Name of daily minimum air-temperature data file.
soilprop	C*30	Name of soils-properties data file.
rockprop	C*30	Name of bedrock-properties data file.
atmosinput	C*30	Name of monthly atmospheric-parameters data file.
vegprop	C*30	Name of vegetation-properties data file.
initopt	scalar	Flag for determining how initial soil-water content conditions will be set.
vwfact	scalar	Multiplication factor for setting initial soil-water content for each of the 5 soil layers.
restartfile	C*30	Name of file with several mass-balance terms for each grid cell for the last successful day of a previous simulation.
ndayscrash	scalar	Last day of successful simulation in a previous simulation that corresponds to data in file restartfile .
infile	C*30	Name of Geospatial Watershed-Characteristics data file.
crashfile	C*30	Name of program crash file to hold several mass-balance terms for each grid cell for the last successful day of a simulation.
dayall	C*30	Name of file for output of spatially averaged output terms for all grid cell locations for each successive day of a simulation.
ndaymap	scalar	Number of daily output files of mass-balance results for each grid cell.
irday, nyrou	100	Sequential number of day (irday) and the year (nyrou) to write daily mass-balance results to a corresponding daymap file.
daymap	C*30	Name of file for output of daily mass-balance terms for each grid cell for specific days identified by irday and nyrou . A maximum of 100 files may be listed.

Table 2-11. Variables in subroutine CTRLRP read from the Simulation-Control File.—Continued[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
pointfile(1)	C*30	Name of file for output of daily mass-balance terms corresponding to the last active grid cell in the model area (that is, the cell immediately above the outflow cell).
ipointfile	scalar	Number of additional output files of daily mass-balance terms at specific grid cells.
xpoint, ypoint	20	East-west (easting; xpoint) and north-south (northing; ypoint) coordinates of grid cell for output file of daily mass-balance terms.
pointfile	C*30	Name of file for output of daily mass-balance terms corresponding to current xpoint, ypoint . A maximum of 20 files may be listed.
outfile	C*30	Name of output file with summary information for the simulation, as well as summary statistics for the entire simulation.
flxfile	C*30	Name of output file with average annual mass-balance terms during averaging period for each grid cell.
spatialout	C*30	Name of output file to which summary information about spatial properties for each grid cell is written.
outyear1	C*26	Prefix of the name of the output file for mass-balance terms for annual totals or multiyear averages by grid cell.
outannual	C*30	Name of file to hold total annual flow terms for the entire grid.
outmonth	C*30	Name of file to hold total monthly flow terms for the entire grid.

Soil properties are read from file **soilprop**, which is defined for each simulation in the Simulation-Control File. Variables that are read from this file are defined in table 2-12.

Table 2-12. Variables read from Soil-Properties File.[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the file.
nsoilid	scalar	Number of soil types to be entered.
soilid	scalar	Integer variable used to identify the soil-type number.
soilmu	C*12	Name of the soil type.
soilporo	mxprop	Soil porosity, dimensionless.
fieldcap	mxprop	Soil field capacity, dimensionless.
soilresid	mxprop	Residual soil-water content for plant transpiration, which is also referred to as the wilting point, dimensionless.
soilb	mxprop	Soil drainage function coefficient, dimensionless.
soilks1	scalar	Saturated vertical hydraulic conductivity of the soil, in millimeters per day.
isksval	scalar	Flag that specifies whether soil saturated vertical hydraulic conductivity will be a constant value.
sksval	scalar	Constant soil saturated vertical hydraulic conductivity value, in millimeters per day.
soilks	mxprop	Saturated vertical hydraulic conductivity of the soil, in millimeters per day.
soilet1	scalar	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration, dimensionless.
soilet2	scalar	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration, dimensionless.
soilalpha	mxprop	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration, dimensionless.
soilbeta	mxprop	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of soil-water content and potential evapotranspiration, dimensionless.

Bedrock and deep alluvium properties are read from file **rockprop**, which is defined for each simulation in the Simulation-Control file. Variables that are read from this file are defined in table 2-13.

Table 2-13. Variables read from Rock-Properties File.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the file, or other descriptive information.
nrockid	scalar	Number of bedrock types to be entered.
rockid	scalar	Integer variable used to identify the bedrock-type number (or map-unit identifier).
rockname2	C*52	A character description of the rock type.
rockporo	0:mxprop	Bedrock porosity (effective root-zone porosity for bedrock layer).
imbibe	0:mxprop	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock vertical hydraulic conductivity), in millimeters per day.
imbibe2	0:mxprop	Effective saturated hydraulic conductivity for the bedrock layer (used to define the upper bedrock and deep-alluvium vertical hydraulic conductivity), in millimeters per day.
iimbval	scalar	Flag that specifies whether bedrock unsaturated and saturated vertical hydraulic conductivities will be a constant value.
imbval	scalar	Constant bedrock unsaturated and saturated vertical hydraulic conductivities, in millimeters per day.
rockalbeta	0:mxprop	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.
rocktalpha	0:mxprop	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.
rocket1	scalar	Variable β in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.
rocket2	scalar	Variable α in the modified Priestley-Taylor equation used for defining transpiration as a function of rock-matrix water content and potential evapotranspiration, dimensionless.

Vegetation properties are read from file **vegprop**, which is defined for each simulation in the Simulation-Control File. Variables that are read from this file are defined in table 2-14.

Table 2-14. Variables read from Vegetation-Properties File.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	Four records, each a character variable that can be used for a title for the file.
vegname1	C*28	Name of the vegetation type.
vegmap	scalar	Map-unit code of the vegetation type (integer value).
vegcode	vegcode1b:vegcodeub	Vegetation-code number for vegetation type (integer value).
vegcover0	vegcode1b:vegcodeub	Vegetation land-surface cover for vegetation type (specified as a percentage, such as 50.0).
vegname2	C*30	Second name of the vegetation type (currently not used in INFIL3).
vegcover	vegcode1b:vegcodeub, 7	Percent vegetation cover for each of the six layers of the model.
rzdepth	vegcode1b:vegcodeub, 7	Root-zone depths for vegetation type for layers 1 through 5, and root-zone thickness for layer 6 (meters).
rzdepthf	vegcode1b:vegcodeub	Root-zone depth factor used in soil-layer thickness determinations.

Monthly atmospheric variables are read from file **atmosinput**, which is defined for each simulation in the Simulation-Control File. Records are read for each of the 12 months of the year. Variables that are read from this file are defined in table 2-15.

Table 2-15. Variables read from Monthly Atmospheric-Parameters File.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	Four records, each a character variable that can be used for a title for the file.
iii	scalar	Month number, 1 for January, 2 for February, and so forth.
ozone	12	Ozone-layer thickness for month, in centimeters.
wp	12	Precipitable water in the atmosphere for month, in centimeters.
beta	12	Mean atmospheric turbidity for month, dimensionless.
csr	12	Circumsolar radiation for month, dimensionless.
pg	12	Surface reflectivity for month, dimensionless.

SUBROUTINE STATIONSRP

Subroutine STATIONSRP reads information about the climate stations that provide climate data for a simulation. Information for the subroutine is read from file **daystations**, which is defined for each simulation in the Simulation-Control File. Variables used in the subroutine are defined in table 2-16.

Table 2-16. Variables in subroutine STATIONSRP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*256	A character variable that can be used for a title for the dataset.
name	C*28, mxstations	Name of each climate station.
statid	mxstations	An integer-variable code for each climate station.
eutm	mxstations	East-west coordinate (easting) of each climate station, in meters.
nutm	mxstations	North-south coordinate (northing) of each climate station, in meters.
statelev	mxstations	Elevation of each climate station, in meters.

SUBROUTINE MMPARAMRP

Subroutine MMPARAMRP reads information about the data from the monthly climate-regression models and calculates estimated monthly climate variables (precipitation and maximum and minimum air temperature) for the climate stations. Information for the subroutine is read from file **monthmod**, which is defined for a specific simulation in the Simulation-Control File. Variables used in the subroutine are defined in table 2-17.

Table 2-17. Variables in subroutine MMPARAMRP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the dataset.
imonth	scalar	Number of month (1 for January, 2 for February, and so forth).
pptmod	13	Integer variable equal to the regression model being used: 1 for linear, 3 for quadratic.
ppta	13	Regression-model coefficient A for the precipitation-elevation model.
pptb	13	Regression-model coefficient B for the precipitation-elevation model.
pptc	13	Regression-model coefficient C for the precipitation-elevation model.
tmaxmod	13	Integer variable equal to the regression model being used: 1 for linear, 3 for quadratic.
tmaxa	13	Regression-model coefficient A for the maximum air-temperature/elevation model.
tmaxb	13	Regression-model coefficient B for the maximum air-temperature/elevation model.
tmaxc	13	Regression-model coefficient C for the maximum air-temperature/elevation model.
tminmod	13	Integer variable equal to the regression model being used: 1 for linear, 3 for quadratic.
tmina	13	Regression-model coefficient A for the minimum air-temperature/elevation model.
tminb	13	Regression-model coefficient B for the minimum air-temperature/elevation model.
tminc	13	Regression-model coefficient C for the minimum air-temperature/elevation model.
nstations	scalar	Total number of climate stations.
statelev	mxstations	Elevation of climate station.
epptmon	nstations, 12	Estimated monthly precipitation variable for each climate station.
etmaxmon	nstations, 12	Estimated maximum monthly air-temperature variable for each climate station.
etminmon	nstations, 12	Estimated minimum monthly air-temperature variable for each climate station.
tunit	scalar	Flag to switch from degrees Fahrenheit to degrees Celsius.

SUBROUTINE CLIMATEDATARP

Subroutine CLIMATEDATARP reads daily precipitation and maximum and minimum air-temperature values for each climate station. Climate data are read from files **daypptinput**, **daytmaxinput**, and **daytmininput**. The subroutine also is used to set starting and ending dates for the model simulation. Variables used in the subroutine are defined in table 2-18.

Table 2-18. Variables in subroutine CLIMATEDATARP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the dataset.
nstations	scalar	Total number of climate stations.
dyn	scalar	Sequential day number (time step).
yr	mxdays	Calendar year (for example, 1900).
month	mxdays	Calendar month (1 for January, 2 for February, and so forth).
monday	mxdays	Day of month.
yearday	mxdays	Sequential day of the year (from 1 to 365 except for leap years).
iday	scalar	Current day of month.
imonth	scalar	Current month.
iyear	scalar	Current year.
ppt	mxdays,mxstations	Daily precipitation value at each climate station, in millimeters.
maxairt	mxdays,mxstations	Daily maximum air temperature at each climate station, in degrees Celsius.
minairt	mxdays,mxstations	Daily minimum air temperature at each climate station, in degrees Celsius.
ndays	scalar	Total number of days (time steps) in the simulation.
ndpptdat	scalar	Total number of days in which precipitation has been recorded for at least one climate station.
npptdat	scalar	Total number of days with measured/reported precipitation data.
years	scalar	Total number of years of the simulation.
sppt	scalar	Total precipitation for simulation.
avgppt	scalar	Average annual precipitation for the modeled area, in millimeters per year.
maxppt	scalar	Maximum daily precipitation recorded at any climate station, in millimeters.
yrstart	scalar	Simulation start year.
mostart	scalar	Simulation start month.
dystart	scalar	Simulation start day.
yrend	scalar	Simulation end year.
moend	scalar	Simulation end month.
dyend	scalar	Simulation end day.
istart	scalar	Sequential day number of simulation start time.
iend	scalar	Sequential day number of simulation end time.
yrstart1	scalar	Simulation start year for calculation of simulation-output flow averages.
mostart1	scalar	Simulation start month for calculation of simulation-output flow averages.
dystart1	scalar	Simulation start day for calculation of simulation-output flow averages.
yrend1	scalar	Simulation end year for calculation of simulation-output flow averages.
moend1	scalar	Simulation end month for calculation of simulation-output flow averages.
dyend1	scalar	Simulation end day for calculation of simulation-output flow averages.
istart1	scalar	Sequential day number of simulation start time for calculation of simulation-output flow averages.
iend1	scalar	Sequential day number of simulation end time for calculation of simulation-output flow averages.

SUBROUTINE UPSTREAMRP

Subroutine UPSTREAMRP reads daily surface-water inflows for each subbasin that contributes flow to the simulated basin. Surface-water inflows are read for each subbasin from file **upfile**. The contents of **upfile** are the same as the contents of the **pointfile** that is generated as part of the INFIL simulation output for subbasins. The only values from **upfile** that are actually used by INFIL are those for variables **dyn** and **upinput(51)**, which are the simulation time step and surface-water-inflow value, respectively. Variable **upinput(51)** is made equal to variable **swinflow(mxdays,5)**, which is defined with the other variables for the subroutine in table 2-19.

Table 2-19. Variables in subroutine UPSTREAMRP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*256	A character variable that can be used for a title for the dataset.
dyn	scalar	Sequential day number (time step).
upinput	53	Array of flow and storage terms from upstream basin; the only variable of interest to the subroutine is upinput(51) , which is the surface-water-inflow value.
ioptupflow	5	Flag that specifies a constant rate of inflow for all days.
upconst	5	Constant rate of inflow specified for upstream basin, in millimeters.
upfile	5	Name of file containing daily upstream flow values.
swinflow	mxdays, 5	Surface-water-flow value from upstream basin, in millimeters.

SUBROUTINE GEOSPATIALRP

Subroutine GEOSPATIALRP reads spatial coordinates and other watershed information about each grid cell, calculates average watershed characteristics for the modeled area, and calculates layer thicknesses for each grid cell. Information for the subroutine is read from file **infile**, which is defined for each simulation in the Simulation-Control File. Variables used in the subroutine are defined in table 2-20.

Table 2-20. Variables in subroutine GEOSPATIALRP.

[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
header	C*250	A character variable that can be used for a title for the dataset.
nloc	scalar	Total number of grid cells.
ncell	scalar	Total number of active grid cells (those with variable iwat not equal to -3).
ssl	scalar	Total slope of all active grid cells, degrees.
avgsl	scalar	Average slope of all active grid cells, degrees.
maxsl	scalar	Maximum slope of all active grid cells, degrees.
selev	scalar	Total elevation of all active grid cells, in meters.
avelev	scalar	Average elevation of all active grid cells, in meters.
maxelev	scalar	Maximum elevation of all active grid cells, in meters.
minelev	scalar	Minimum elevation of all active grid cells, in meters.
locid	mxcells	Location identifier for each grid cell.
cellcode	mxcells	Integer variable equal to the grid-cell (node) number.
easting	mxcells	East-west (easting) coordinate of the centroid of the grid cell, in meters.
northing	mxcells	North-south (northing) coordinate of the centroid of the grid cell, in meters.

Table 2-20. Variables in subroutine GEOSPATIALRP.—Continued[C*n in size column indicates a character variable of *n* characters]

Variable name	Size	Description
lat	mxcells	Latitude of the centroid of each grid cell.
lon	mxcells	Longitude of the centroid of each grid cell.
row	mxcells	Row assignment for each grid cell.
col	mxcells	Cell assignment for each grid cell.
iwat	mxcells	Integer variable equal to the downstream location identifier to which runoff is directed from the current cell (iwat = -3 indicates the outflow cell of the basin).
elev	mxgridind, mxgridind	Land-surface elevation of the centroid of each grid cell, in meters.
sl	mxcells	Land-surface slope of the centroid of each grid cell, degrees.
asp	mxcells	Land-surface aspect of the centroid of each grid cell, degrees azimuth relative to north.
upcells	mxcells	Total number of upstream cells that contribute flow to the current grid cell.
soiltype	mxcells	Integer code for the soil type of each grid cell.
depth	mxcells	Total soil depth for each grid cell, in meters.
rocktype	mxcells	Integer code for the bedrock type of each grid cell.
vegtype	mxcells	Integer code for the vegetation type of each grid cell.
skyview	mxcells	Total fraction of viewable sky, as fraction of hemisphere, dimensionless.
ridge	mxcells, 36	Blocking ridge angles (36) for each grid cell.
isdepthval	scalar	Flag to specify whether a constant soil depth will be used for all grid cells.
sdepthval	scalar	Constant soil depth for all grid cells, in meters.
sdfact	scalar	Soil-depth scaling factor.
imbibe	0:mxprop	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock hydraulic conductivity).
imbibe2	0:mxprop	Effective saturated vertical hydraulic conductivity for the bedrock layer (used to define the upper bedrock and deep-alluvium vertical hydraulic conductivity).
rzdpth	vegcode1b: vegcodeub, 7	Root-zone depths for vegetation type for layers 1 through 5, and root-zone thickness for layer 6, in meters.
rzdpthf	vegcode1b: vegcodeub	Root-zone depth factor used in soil-layer thickness determinations.
rdepth1, ..., rdepth6	scalar	Root-zone depth for layers 1 through layer 5 and root-zone thickness for layer 6, in meters.
rdepthf	scalar	Root-zone depth factor used in soil-layer thickness determinations.
cdepth	6, mxcells	Layer thickness for layers 1 through 6, in meters.
xcfs	scalar	East-west coordinate of basin outflow cell (iwat = -3 cell), in meters.
ycfs	scalar	North-south coordinate of basin outflow cell (iwat = -3 cell), in meters.
xpoint(1)	20	East-west coordinate of basin outflow cell (iwat = -3 cell), in meters.
ypoint(1)	20	North-south coordinate of basin outflow cell (iwat = -3 cell), in meters.
avgdepth	scalar	Average soil depth of all active grid cells, in meters.
avglaythck	10	Average layer thickness for each of the six model layers for all grid cells, in meters.
avgimbibe	scalar	Average unsaturated (lower) vertical hydraulic conductivity of bedrock for all grid cells, in millimeters per day.
avgimbibe2	scalar	Average saturated (higher) hydraulic conductivity of bedrock for all grid cells, in millimeters per day.

SUBROUTINE ATMOS

Subroutine ATMOS calculates daily atmospheric variables that are subsequently used in subroutine POTEVAP for solar-radiation calculations. The calculations for each of the daily atmospheric terms are based on a linear interpolation of values between the middle of each successive month. For example, the daily values for January 15 are equal to the monthly value for January and values for dates between January 1 and 14 are weighted between values for January and December. Variables used in the subroutine are defined in table 2-21.

Table 2-21. Variables in subroutine ATMOS.

Variable name	Size	Description
ozone	12	Ozone-layer thickness for month, in centimeters.
wp	12	Precipitable water in the atmosphere for month, in centimeters.
beta	12	Mean atmospheric turbidity for month, dimensionless.
csr	12	Circumsolar radiation for month, dimensionless.
pg	12	Surface reflectivity for month, dimensionless.
ozone0	366	Daily ozone-layer thickness, in centimeters.
wp0	366	Daily precipitable water in the atmosphere, in centimeters.
beta0	366	Daily mean atmospheric turbidity, dimensionless.
csr0	366	Daily circumsolar radiation, dimensionless.
pg0	366	Daily surface reflectivity, dimensionless.

SUBROUTINES SPDATAINIT and OUTPUTINIT

Subroutines SPDATAINIT and OUTPUTINIT are used to initialize several of the water-budget variables that are used in INFIL computations. Most of the variables that are initialized in these subroutines are defined in tables 2-2 through 2-9, 2-11 and 2-12, or 2-20, and their definitions can be found in those tables. Variables that are not defined previously are defined in table 2-22.

Table 2-22. Variables in subroutines SPDATAINIT and OUTPUTINIT not defined previously.

Variable name	Size	Description
scapmm1, ..., scapmm5	scalar	Initial storage capacity of each soil layer of the grid cell, in millimeters.
rkmm	scalar	Initial storage capacity of the bedrock layer, in millimeters.
scapmmt	scalar	Total initial storage capacity for all six model layers, in millimeters.
soilvwc	mxcells	Initial soil-water contents for the five soil layers, dimensionless.
skmm	scalar	Saturated vertical hydraulic conductivity of the soil, in millimeters per day.
imb0	scalar	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock vertical hydraulic conductivity), in millimeters per day.
imb2	scalar	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock vertical hydraulic conductivity), in millimeters per year.
tet	scalar	Total evapotranspiration, in millimeters.

SUBROUTINE DAYDIST

Subroutine DAYDIST distributes daily precipitation and air-temperature data across the model domain by monthly precipitation-elevation and air temperature-elevation regression models combined with an inverse-distance-squared interpolation algorithm. The subroutine calculates for each grid cell daily precipitation, maximum and minimum daily air temperatures, and average daily air temperature. Variables used in the subroutine are defined in table 2-23.

Table 2-23. Variables in subroutine DAYDIST.

Variable name	Size	Description
j	scalar	Current daily time step.
ia	scalar	Current grid location.
nstations	scalar	Total number of climate stations.
k	scalar	Counter for climate stations.
dist	mxstations	Distance between grid location ia and climate station k .
delx2	scalar	East-west distance squared from current grid location to station location, in meters.
dely2	scalar	North-south distance squared from current grid location to station location, in meters.
ppt	mxdays,mxstations	Daily precipitation value at each climate station, in millimeters.
maxairt	mxdays,mxstations	Daily maximum air temperature at each climate station, in degrees Celsius.
minairt	mxdays,mxstations	Daily minimum air temperature at each climate station, in degrees Celsius.
eutm	mxstations	East-west coordinate (easting) of each climate station, in meters.
nutm	mxstations	North-south coordinate (northing) of each climate station, in meters.
statelev	mxstations	Elevation of each climate station, in meters.
easting	mxcells	East-west (easting) coordinate of the centroid of the grid cell, in meters.
northing	mxcells	North-south (northing) coordinate of the centroid of the grid cell, in meters.
month	mxdays	Month of current time step.
row	mxcells	Row assignment for each grid cell.
col	mxcells	Cell assignment for each grid cell.
elev	mxgridind, mxgridind	Land-surface elevation of the centroid of each grid cell, in meters.
pptmod	13	Integer variable equal to the spatial-distribution model being used: 0 for inverse-distance-squared model; 1 for linear-regression model; 3 for quadratic-regression model.
ppta	13	Regression-model coefficient A for the precipitation-elevation model.
pptb	13	Regression-model coefficient B for the precipitation-elevation model.
pptc	13	Regression-model coefficient C for the precipitation-elevation model.
tmaxmod	13	Integer variable equal to the spatial-distribution model being used: 0 for inverse-distance-squared model; 1 for linear-regression model; 3 for quadratic-regression model.
tmaxa	13	Regression-model coefficient A for the maximum air-temperature/elevation model.
tmaxb	13	Regression-model coefficient B for the maximum air-temperature/elevation model.
tmaxc	13	Regression-model coefficient C for the maximum air-temperature/elevation model.
tminmod	13	Integer variable equal to the spatial-distribution model being used: 0 for inverse-distance-squared model; 1 for linear-regression model; 3 for quadratic-regression model.
tmina	13	Regression-model coefficient A for the minimum air-temperature/elevation model.
tminb	13	Regression-model coefficient B for the minimum air-temperature/elevation model.
tminc	13	Regression-model coefficient C for the minimum air-temperature/elevation model.
epptmon	nstations, 12	Estimated monthly precipitation variable for each climate station.

Table 2-23. Variables in subroutine DAYDIST.—Continued

Variable name	Size	Description
etmaxmon	nstations, 12	Estimated maximum monthly air temperature variable for each climate station.
etminmon	nstations, 12	Estimated minimum monthly air temperature variable for each climate station.
tunit	scalar	Flag to switch from degrees Fahrenheit to degrees Celsius.
sdistppt, sdisttmax, sdisttmin	scalar	Sum of the distances between grid location ia and each of the climate stations that have values for precipitation (sdistppt), maximum air temperature (sdisttmax), and minimum air temperature (sdisttmin).
eppt1	scalar	Estimated precipitation for grid cell, in millimeters.
etmax	scalar	Estimated maximum air temperature for grid cell, in degrees Celsius.
etmin	scalar	Estimated minimum air temperature for grid cell, in degrees Celsius.
pptloc00	scalar	Estimated precipitation for grid cell, in millimeters.
avgairt00	scalar	Estimated average air temperature for grid cell, in degrees Celsius.
maxairt00	scalar	Estimated maximum air temperature for grid cell, in degrees Celsius.

SUBROUTINE POTEVAP

Subroutine POTEVAP calculates daily solar radiation, net radiation, and potential evapotranspiration for each grid cell for each day. The primary output of the subroutine is a value of the daily potential evapotranspiration (variable **tpet0**) for a cell. Variables used in the subroutine are defined in table 2-24.

Table 2-24. Variables in subroutine POTEVAP.

Variable name	Size	Description
j	scalar	Current daily time step.
ia	scalar	Current grid location.
yearday	mxdays	Sequential day of the year (from 1 to 365 except for leap years).
lat	mxcells	Latitude of the centroid of each grid cell.
lon	mxcells	Longitude of the centroid of each grid cell.
elev	mxgridind, mxgridind	Land-surface elevation of the centroid of each grid cell, in meters.
sl	mxcells	Slope of the centroid of each grid cell, degrees.
row	mxcells	Row assignment for each grid cell.
col	mxcells	Cell assignment for each grid cell.
asp	mxcells	Aspect of the centroid of each grid cell, degrees azimuth relative to north.
skyview	mxcells	Total fraction of viewable sky, as fraction of hemisphere, dimensionless.
ozone0	366	Daily ozone layer thickness, in centimeters.
wp0	366	Daily precipitable water in the atmosphere, in centimeters.
beta0	366	Daily mean atmospheric turbidity, dimensionless.
csr0	366	Daily circumsolar radiation, dimensionless.
pg0	366	Daily surface reflectivity (albedo of ground or ground cover), dimensionless.
airtemp	scalar	Average air temperature for grid cell, in degrees Celsius.
ydn	scalar	Sequential day of the year (from 1 to 365 except for leap years).
std	scalar	Standard meridian of the site, in degrees.
lat2	mxcells	Latitude of the centroid of each grid cell in radians.

Table 2-24. Variables in subroutine POTEVAP.—Continued

Variable name	Size	Description
sl2	mxcells	Slope of the centroid of each grid cell, degrees.
viewfactor	scalar	Total fraction of viewable sky, as fraction of hemisphere, for current grid cell, dimensionless.
dnn2	scalar	Sequential day of the year in real-number format.
Solar-position routine		
ta	scalar	Air temperature in degrees Kelvin as a function of Julian day number.
tau	scalar	Day angle, in radians.
dec	scalar	Solar declination, in radians.
et	scalar	Equation of solar time, in minutes.
hasr	scalar	Hour angle of the sun at sunrise, in radians.
hass	scalar	Hour angle of the sun at sunset, in radians.
cf	scalar	Correction factor for standard time at local longitude, in hours.
h1	scalar	Starting time for the daily simulation (sunrise), in hours.
h2	scalar	Ending time for the daily simulation (sunset), in hours.
hstep	scalar	Time step used for simulating potential evapotranspiration, in hours. The variable hstp can range from 1.0 to 4.0, and values of either 1.0 or 2.0 are recommended.
lst	scalar	Time-step counter, in hours.
t	scalar	Local apparent time, in hours.
ha	scalar	Hour angle of the sun, in radians.
alt	scalar	Elevation of the sun at hour angle ha , first in radians, then converted to degrees.
az	scalar	Azimuth of the sun at hour angle ha , first in radians, then converted to degrees.
zenith	scalar	Zenith angle of the sun with respect to the vertical, in degrees.
sunaz	scalar	Azimuth of the sun, in degrees.
theta	scalar	Solar angle of incidence, in degrees.
Net-radiation routine (based on Flint and Childs, 1987, and Iqbal, 1983)		
alpha	scalar	Wavelength exponent to Angstrom's turbidity equation, dimensionless; set to 1.
isc	scalar	Solar constant; set to 1367 watts per square meter.
po	scalar	Standard atmospheric pressure at sea level; set to 1013.25 millibars.
p	scalar	Atmospheric pressure at grid cell, in millibars.
wo	scalar	Fraction of energy scattered to attenuation by aerosols, dimensionless.
amsp	scalar	Air mass at standard pressure (10132.5 millibars), dimensionless.
ma	scalar	Air mass at actual pressure, dimensionless.
w	scalar	Precipitable water, in centimeters.
u1	scalar	Total pressure-corrected relative optical-path length for water vapor, in centimeters.
u3	scalar	Total optical-path length for ozone, in centimeters.
eo	scalar	Eccentricity correction factor.
trr	scalar	Fraction of incident radiation transmitted by air molecules, dimensionless.
tro	scalar	Fraction of incident radiation transmitted by ozone, dimensionless.
trg	scalar	Fraction of incident radiation transmitted after absorption by mixed gases, dimensionless.
trw	scalar	Fraction of incident radiation transmitted by water vapor, dimensionless.
tra	scalar	Fraction of incident radiation transmitted by aerosols, dimensionless.
traa	scalar	Fraction of incident radiation transmitted after absorption by aerosols, dimensionless.
idr	scalar	Rayleigh scattered radiation, in watts per square meter.
tras	scalar	Fraction of incident energy transmitted after scatter by aerosols, dimensionless.
fc	scalar	Fraction of forward scatter to total scatter, dimensionless; set to 0.84.

Table 2-24. Variables in subroutine POTEVAP.—Continued

Variable name	Size	Description
ida	scalar	Aerosol scattered radiation, in watts per square meter.
pap	scalar	Albedo of cloudless-sky atmosphere, dimensionless.
inn	scalar	Direct normal irradiance, in watts per square meter.
ib	scalar	Direct beam radiation on a horizontal surface, in watts per square meter.
idm	scalar	Multiple reflected (diffuse) radiation, in watts per square meter.
id	scalar	Total diffuse irradiance on a horizontal surface, in watts per square meter.
ir	scalar	Ground-reflected diffuse radiation incident on an inclined surface, in watts per square meter.
iss	scalar	Diffuse sky radiation that is not blocked by surrounding topography, in joules per square meter.
idhoirz	scalar	Diffuse sky radiation on a horizontal surface, in watts per square meter.
idslope	scalar	Diffuse sky radiation on a sloping surface, in watts per square meter.
ibhoriz	scalar	Direct beam radiation (solar disk only) on a horizontal surface, in watts per square meter.
ibslope	scalar	Direct beam radiation (solar disk only) on a sloping surface, in watts per square meter.
rnhoriz	scalar	Net radiation on a horizontal surface (long and short wave), in watts per square meter.
rnslope	scalar	Net radiation on a sloping surface (long and short wave), in watts per square meter.
rad	scalar	Total radiation for hourly time step, in joules per square meter.
tr	scalar	Total radiation for daily time step, in joules per square meter.
drad	scalar	Total radiation for daily time step, in joules per square meter.
emmis	scalar	Clear-sky emissivity, dimensionless.
netlong	scalar	Net long-wave radiation, in joules per square meter.
netshort	scalar	Net short-wave radiation, in joules per square meter.
rn	scalar	Net short-wave radiation, in joules per square meter.
gh	scalar	Soil heat flux, in joules per square meter.
ssg	scalar	Term related to the slope of the saturation vapor-pressure/temperature curve and psychrometric constant in the Priestley-Taylor equation.
pet	scalar	Potential evapotranspiration for hourly time step.
tpet0	scalar	Total potential evapotranspiration for daily time step.

SUBROUTINE SNOW

Subroutine SNOW calculates daily snowfall (or rain), water-equivalent depth of snow, snowmelt, and sublimation for each grid cell for each day. Variables used in the subroutine are defined in table 2-25.

Table 2-25. Variables in subroutine SNOW.

Variable name	Size	Description
j	scalar	Current daily time step.
ia	scalar	Current grid location.
yearday	mxdays	Sequential day of the year (from 1 to 365 except for leap years).
yn	scalar	Sequential day of the year (from 1 to 365 except for leap years).
airtemp	scalar	Average air temperature, in degrees Celsius.
maxairt00	scalar	Estimated maximum air temperature for grid cell, in degrees Celsius.
pptloc	mxcells	Precipitation, in millimeters.
rain	mxcells	Precipitation as rain, in millimeters.
snowfall	mxcells	Precipitation as snow, in millimeters.
snowmm	mscells	Water-equivalent depth of snow, in millimeters.
snoday1	scalar	Starting (Julian) day for the timing of the early-spring snowmelt period.
snoday2	scalar	Starting (Julian) day for the timing of the late-spring snowmelt period.
melt	scalar	Amount of snowmelt, in millimeters.
snopar1	scalar	Snowmelt-rate variable that corresponds to the early-spring snowmelt period.
snopar2	scalar	Snowmelt-rate variable that corresponds to the late-spring snowmelt period.
isublim	scalar	Flag that specifies whether or not sublimation will be simulated: isublim = 1 indicates that sublimation will be calculated.
petrs	mxcells	Adjusted potential evapotranspiration, in millimeters.
subpar1	scalar	Sublimation variable 1, for temperatures less than or equal to freezing (dimensionless).
subpar2	scalar	Sublimation variable 2, for temperatures greater than freezing (dimensionless).
sublim	mxcells	Sublimation, in millimeters.
dsnowcv	scalar	Change in water-equivalent depth of snow, in millimeters.

SUBROUTINE ETINFIL

Subroutine ETINFIL is the primary subroutine that calculates root-zone water balance. The subroutine has four primary functions: (1) calculation of infiltration to the root zone from rain and snowmelt and an initial calculation of runoff equal to rain and snowmelt in excess of the infiltration capacity of the soil or bedrock; (2) redistribution of infiltration by downward drainage through all layers of the root zone and an initial calculation of the change in soil-water storage in each layer of the root zone; (3) calculation of evapotranspiration from each layer of the root zone; and (4) final calculations of infiltration below the root zone, change in soil-water storage in each layer of the root zone, and runoff from the grid cell. As part of the fourth function, ETINFIL is the first step in the two-step flow-routing algorithm of INFIL3.0. Variables used in the subroutine are defined in table 2-26.

Table 2-26. Variables in subroutine ETINFIL.

Variable name	Size	Description
j	scalar	Current daily time step.
ia	scalar	Current grid location.
yearday	mxdays	Sequential day of the year (from 1 to 365 except for leap years).
yd	scalar	Sequential day of the year (from 1 to 365 except for leap years).
drmm1, ..., drmm6	scalar	Total drainage for layers 1 (drmm1) through 6 (drmm6) for cell, in millimeters.
ivegc	scalar	Flag for specifying vegetative-cover values.
vegco	scalar	Vegetation land-surface cover for vegetation type (specified as a percentage, such as 50.0).
vegcl, ..., vegc6	scalar	Percent vegetation cover for each of the six layers of the model.
fveg	scalar	Constant vegetation-cover value, in decimal percent.
a	scalar	Variable α in the modified Priestley-Taylor equation used for defining evapotranspiration as a function of soil-water content and potential evapotranspiration.
b	scalar	Variable β in the modified Priestley-Taylor equation used for defining evapotranspiration as a function of soil water content and potential evapotranspiration.
a3	scalar	Variable α in the modified Priestley-Taylor equation used for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration, for rock type rockid .
b3	scalar	Variable β in the modified Priestley-Taylor equation used for defining evapotranspiration as a function of rock-matrix water content and potential evapotranspiration, for rock type rockid .
a2	scalar	Variable α in the modified Priestley-Taylor equation used for defining evaporation as a function of bare-soil water content and potential evapotranspiration.
b2	scalar	Variable β in the modified Priestley-Taylor equation used for defining evaporation as a function of bare-soil water content and potential evapotranspiration.
imb	scalar	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock vertical hydraulic conductivity), in millimeters per day.
imb2	scalar	Effective saturated vertical hydraulic conductivity for the bedrock layer (used to define the upper bedrock and deep-alluvium vertical hydraulic conductivity), in millimeters per day.
skmm	scalar	Vertical hydraulic conductivity of the soil, in millimeters per day.
dysumbeg	scalar	Beginning Julian day number for summer storms.
dysumend	scalar	Ending Julian day number for summer storms.
skmmp	scalar	Modified saturated vertical hydraulic conductivity (rain infiltration capacity) of the soil to account for storm duration, in millimeters per day.
stormsum	scalar	Duration of summer storms, in hours.
imbp	scalar	Modified saturated vertical hydraulic conductivity (rain infiltration capacity) of the bedrock to account for storm duration, in millimeters per day.
stormwin	scalar	Duration of winter storms, in hours.
skmelt	scalar	Modified saturated vertical hydraulic conductivity (snowmelt infiltration capacity) of the soil to account for a snowmelt event, in millimeters per day.

Table 2-26. Variables in subroutine ETINFIL.—Continued

Variable name	Size	Description
rkmelt	scalar	Modified saturated vertical hydraulic conductivity (snowmelt infiltration capacity) of the combined rock matrix and fractures to account for a snowmelt event, in millimeters per day.
melttime	scalar	Duration of the daily snowmelt period, in hours.
fieldcp	scalar	Soil field capacity, dimensionless.
fcmm1, ..., fcmm6	scalar	Equivalent depth of field capacity for each layer, in millimeters.
cdepth	6, mxcells	Layer thickness for layers 1 through 6, in meters.
rkmm	scalar	Equivalent depth of rock porosity, in millimeters.
rkpor	scalar	Porosity of rock, dimensionless.
spor	scalar	Porosity of soil, dimensionless.
sresid	scalar	Residual soil-water content for cell, dimensionless.
epor	scalar	Effective porosity, which is the difference between the porosity and residual water content of the soil, dimensionless.
pormm1, ..., pormm5	scalar	Equivalent depth of porosity for each layer, in millimeters. These values are also the maximum storage limit for each soil layer.
totmm	scalar	Total equivalent depth of porosity for all six model layers, in millimeters.
resmm1, ..., resmm6	scalar	Equivalent depth of residual soil-water content for each layer, in millimeters.
infilmm1	mxcells	Infiltration below root zone for current cell, in millimeters.
runoffmm	mxcells	Runoff for current cell, in millimeters.
initmm	scalar	Initial water content of all six soil layers of model cell, in millimeters.
rinfmm1	mxcells	Change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
finalmm	scalar	Final water content of all six soil layers of model cell, in millimeters.
dsoilmm1	mxcells	Difference between final and initial water content of all six soil layers of model cell, in millimeters.
totalpet	scalar	Adjusted rate of potential evapotranspiration accounting for days on which there is precipitation, in millimeters.
flowout2	scalar	Sum of excess rain and snowmelt that is not infiltrated to soil, in millimeters.
soildepth	scalar	Total depth of the five soil layers, in meters.
flux	6, mxcells	Flow from one layer to the underlying layer, in millimeters.
rainin	scalar	Precipitation as rain, in millimeters.
rainout	scalar	Precipitation in excess of rain infiltration capacity of soil, in millimeters.
meltin	scalar	Amount of snowmelt, in millimeters.
meltout	scalar	Snowmelt in excess of snowmelt infiltration capacity, in millimeters.
soilinf	scalar	Sum of infiltrated rain and snowmelt into soil, in millimeters.
soilb	mxprop	Soil drainage function coefficient.
gn	scalar	Modified soil drainage function coefficient.
gb	scalar	Inverse of modified soil drainage function coefficient.
drmm	scalar	Total drainage for current layer, in millimeters.
vwc1, ..., vwc5	scalar	Dimensionless volumetric soil-water content for each layer, equal to soil-water content (in millimeters) divided by thickness of layer (in meters) and by the conversion factor 1,000 millimeters per meter.
relsat1, ..., relsat5	scalar	Relative saturation for each layer, dimensionless.
soilmm	5, mxcells	Soil water content for each soil layer, in millimeters.

Table 2-26. Variables in subroutine ETINFIL.—Continued

Variable name	Size	Description
soilmm1, ..., soilmm5	scalar	Soil water content for each soil layer, in millimeters.
rockmm	mxcells	Rock water content, in millimeters.
rockmm1	scalar	Rock water content, in millimeters.
ga1, ..., ga5	scalar	Coefficients for layers 1 (ga1) through 5 (ga5) in the empirical drainage function.
gc1, ..., gc5	scalar	Coefficients for layers 1 (gc1) through 5 (gc5) in the empirical drainage function.
gt	scalar	Coefficient in the empirical drainage function.
vwc11, ..., vwc51,	scalar	Coefficients for layers 1 (vwc11) through 5 (vwc51) in the empirical drainage function.
vwc12, ..., vwc52,	scalar	Coefficients for layers 1 (vwc12) through 5 (vwc52) in the empirical drainage function.
vwc13, ..., vwc53,	scalar	Coefficients for layers 1 (vwc13) through 5 (vwc53) in the empirical drainage function.
rockinf	scalar	Infiltration into bedrock, in millimeters.
petrs2	mxcells	Potential evapotranspiration adjusted for cloudy days and sublimation for each cell, in millimeters.
pevap	scalar	Adjusted rate of potential evapotranspiration accounting for vegetation cover.
e1, e2	scalar	Bare-soil evaporation for layers 1 (e1) and 2 (e2), in millimeters.
petrs3	scalar	Updated potential evapotranspiration, in millimeters. This potential evaporation is equal to the adjusted rate of potential evapotranspiration accounting for days on which there is precipitation minus sublimation and minus the total amount of evaporation and transpiration that occurs from all model layers in the subroutine.
barsoilf	scalar	An adjustment factor that can be used to modify the value of b2 used for layer 1.
totsat	scalar	Total relative saturation of all six layers, dimensionless.
wgt1, ..., wgt2	scalar	Weighting functions for each model layer for use in modified Priestley-Taylor equation.
et1, ..., et6	scalar	Transpiration from each of the six model layers, in millimeters.
et	(6, mxcells)	Actual evapotranspiration from each model layer, in millimeters.
ptrans	scalar	Potential evapotranspiration adjusted for vegetation cover, in millimeters.
tet	scalar	Total amount of evapotranspiration from all six model layers, in millimeters.

SUBROUTINE SWINFIL

Subroutine SWINFIL is the second step of the flow-routing algorithm. In this step, runoff is routed to downstream cells as surface-water run-on. Run-on can infiltrate back into the root zone and contribute to the total daily net-infiltration rate. Variables used in the subroutine are defined in table 2-27.

Table 2-27. Variables in subroutine SWINFIL.

Variable name	Size	Description
j	scalar	Current daily time step.
yearday	mxdays	Sequential day of the year (from 1 to 365 except for leap years).
ydn	scalar	Sequential day of the year (from 1 to 365 except for leap years).
iter	scalar	Counter for number of iterations of the flow-routing algorithm.
nrun, nrun2, nrun3, irun	scalar	Counters related to number of iterations of the flow-routing algorithm.
xcfs	scalar	East-west coordinate of basin outflow cell (iwat = -3 cell), in meters.
ycfs	scalar	North-south coordinate of basin outflow cell (iwat = -3 cell), in meters.
easting	mxcells	East-west (easting) coordinate for each grid cell, in meters.
northing	mxcells	North-south (northing) coordinate for each grid cell, in meters.
run2	mxcells	Initial runoff from each grid cell at start of routing algorithm, in millimeters.
flowout	0:mxgridind, 0:mxgridind	Runoff from each grid cell for current iteration, in millimeters.
totout	0:mxgridind, 0:mxgridind	Total runoff from each grid cell, in millimeters.
nloc	scalar	Total number of grid cells.
locid	mxcells	Location identifier for each grid cell.
iwat	mxcells	Integer variable equal to the downstream location identifier to which runoff is directed from the current cell (iwat = -3 indicates the outflow cell of the basin).
nupstream	scalar	Number of upstream basins contributing surface-water inflow. A maximum of 5 upstream basins can be specified.
cellcode	mxcells	Integer variable equal to the grid-cell (node) number.
iupstream	5	Last value of cellcode that is read from each upgeoinp file. All values in the iupstream array should be equal; otherwise, the program will stop.
swinflw	mxdays, 5	Surface-water flow value from upstream basin, in millimeters.
flowin	-3:500000	Run-on to downstream cells, in millimeters.
totupflow	scalar	Total surface-water flow from upstream basins, in millimeters.
flarea	scalar	Fraction of grid cell that is wetted by surface-water run-on.
ichanmod	scalar	Flag for specifying how the wetted-flow area for each grid cell will be specified.
chan1	scalar	Surface-water minimum effective wetted-flow area.
chan2	scalar	Surface-water wetted-flow area factor.
chan3	scalar	Surface-water maximum headwater wetted-flow area.
chan4	scalar	Surface-water maximum stream-channel wetted-flow area.
sl2	scalar	Slope of grid cell.
upcells	mxcells	Total number of upstream cells that contribute flow to the current grid cell.
imb	scalar	Effective unsaturated vertical hydraulic conductivity for the bedrock layer (used to define the lower bedrock vertical hydraulic conductivity), in millimeters per day.
imb2	scalar	Effective saturated vertical hydraulic conductivity for the bedrock layer (used to define the upper bedrock and deep-alluvium vertical hydraulic conductivity), in millimeters per day.
skmm	scalar	Vertical hydraulic conductivity of the soil, in millimeters per day.
sksfact	scalar	Scaling (multiplication) factor for soil vertical hydraulic conductivity, dimensionless.

Table 2-27. Variables in subroutine SWINFIL.—Continued

Variable name	Size	Description
imbfact	scalar	Scaling (multiplication) factor for bedrock vertical hydraulic conductivity, dimensionless.
kschn	scalar	Scaling factor for soil saturated vertical hydraulic conductivity for stream-channel locations.
ikschnmod	scalar	Flag for specifying how soil saturated vertical hydraulic conductivity will be modified for stream-channel locations. Options: ikschnmod = 0, use equation 101 in the text; ikschnmod not equal 0, use equation 102 in the text.
kschn1	scalar	Minimum number of upstream cells for using kschn2 .
kschn2	scalar	Scaling factor for adjusting soil saturated vertical hydraulic conductivity in channels.
kschn3	scalar	Maximum adjustment factor to the soil saturated vertical hydraulic conductivity in channels.
dysumbeg	scalar	Beginning Julian day number for summer storms.
dysumend	scalar	Ending Julian day number for summer storms.
skmmp	scalar	Modified saturated vertical hydraulic conductivity (rain infiltration capacity) of the soil to account for storm duration, in millimeters per day.
stormsum	scalar	Duration of summer storms, in hours.
imbp	scalar	Modified saturated vertical hydraulic conductivity (rain infiltration capacity) of the bedrock to account for storm duration, in millimeters per day.
stormwin	scalar	Duration of winter storms, in hours.
soilthick	scalar	Total thickness of soil zone, in meters.
imbtop	scalar	Modified saturated vertical hydraulic conductivity (rain infiltration capacity) of the bedrock to account for storm duration, in millimeters per day.
stormm1, ..., stormm5	scalar	Difference between porosity and soil water content for each soil layer, in millimeters.
drmm	scalar	Current flow from one layer to the underlying layer, in millimeters.
fluxr	6, mxcells	Flow from one layer to the underlying layer, in millimeters.
flowin00	scalar	Infiltration across the air-soil interface, in millimeters.
cdepth	6, mxcells	Layer thickness for layers 1 through 6, in meters.
stormm	scalar	Total difference between porosity and soil water content for all five layers, in millimeters.
soilmm1, ..., soilmm5	scalar	Soil water content for each soil layer, in millimeters.
soilmm	5, mxcells	Soil water content for each soil layer, in millimeters.
rockmm	mxcells	Rock water content, in millimeters.
pormm1, ..., pormm5	scalar	Equivalent depth of porosity for each layer, in millimeters. These values are also the maximum storage limit for each soil layer.
rkmm	scalar	Equivalent depth of rock porosity, in millimeters.
drmm1, ..., drmm6	scalar	Total drainage for layers 1 (drmm1) through 6 (drmm6) for cell, in millimeters.
runmm2	scalar	Excess water from root zone that becomes downstream runoff, in millimeters.
initmm	scalar	Initial water content of all six soil layers of model cell, in millimeters.
finalmm	scalar	Final water content of all six soil layers of model cell, in millimeters.
flowin0	mxcells	Infiltration across the air-soil interface, in millimeters.
fluxr0	6, mxcells	Flow from one layer to the underlying layer, in millimeters.
outflow0	scalar	Runoff from grid cell at basin outflow, in millimeters.
inflow0	scalar	Infiltration across the air-soil interface at basin outflow, in millimeters.
outflow2	scalar	Initial runoff plus updated runoff from grid cell at basin outflow, in millimeters.
totout2	scalar	Runoff from grid cell at basin outflow, in millimeters.
rinfmm1	mxcells	Change in water content for all six layers due to infiltration of run-on for each cell, in millimeters.
rinfmm2	mxcells	Net infiltration due to second step of flow routing for each cell, in millimeters.

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