

PART E

FUNCTIONAL DESCRIPTION

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Functional Description

GENERAL COMMENTS

For a discussion on how this part of the documentation is organized, refer to Section 4 in Part B "General Principles".

1.0 MAIN Program

The MAIN program calls, directly or indirectly, all the other modules in the system. The functions performed are:

1. Preprocess the Users Control Input (UCI). Subroutine USRRDR transfers the UCI to memory, sets up a pointer system to non-comment lines, and recognizes input set headings and delimiters: RUN, END RUN.
2. If a RUN input set has been found, call subroutine INTERP to interpret it and then call OSUPER to supervise execution of it.

2.0 Manage the Time Series Store (Omitted)

3.0 Interpret a RUN Data Set in the User's Control Input (Module INTERP)

General Description of Module INTERP

This module, known as the Run Interpreter, translates a RUN data set in the User's Control Input (documented in Section 4 of Part F) into many elementary instructions, for later use by other parts of the system, when the time series are operated on. To do this, the Run Interpreter performs such tasks as:

1. Check and augment the data supplied by the user.
2. Decide which time series will be required and produced by each operation, based on the user's data and built-in tables which contain information on the various operations.
3. Allocate INPAD rows to the various time series.
4. Read the control data, parameters, and initial conditions supplied for each operation, convert them to internal units, and supply default values where required.

The output of the Run Interpreter is stored in memory arrays containing instructions to be read by the Operations Supervisor, TSGET and TSPUT (Figure 3.0-1). The instruction arrays contain the following information:

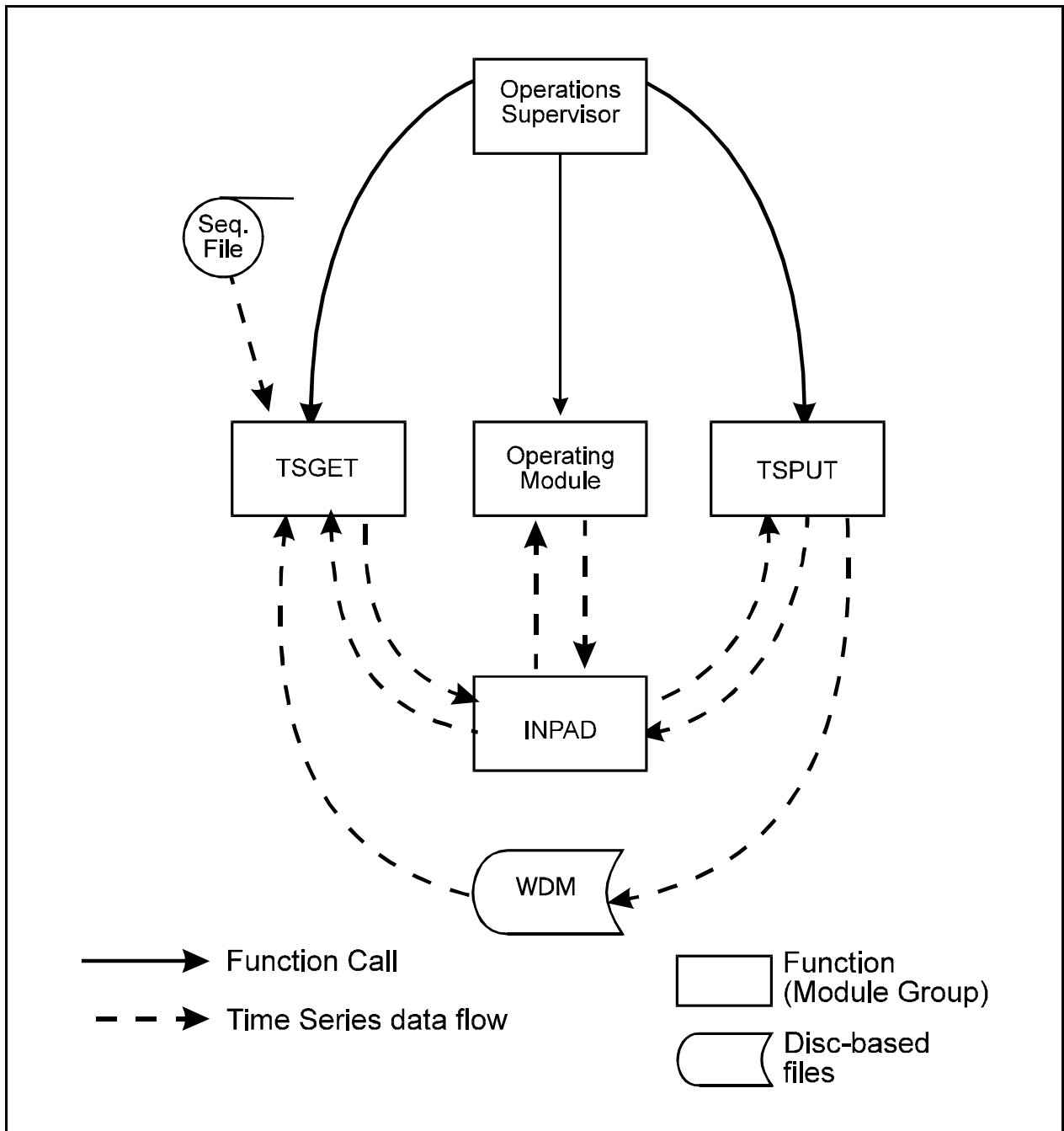


Figure 3.0-1 Functions and data transfers involved in the operations portion of HSPF

1. The Operations Supervisor Instructions Array. This array contains instructions which the Operations Supervisor reads to manage the operations in a run. This includes information on:
 - a) the configuration of the scratch pads (time intervals and widths)
 - b) the configuration of the INGROUPs, such as the number of INGROUPs, operations in each INGROUP, etc.
2. The Operation Status Vector Array. The operations in a run are interrupted every time an INPAD span is completed (Part B, Section 3.2). To save computer memory, the system is designed so that the various operations all use the same area of memory. This requires that upon interruption of an operation, all information necessary to restart an operation be stored in a disk file or another memory area. The data, called the "Operation Status Vector" (OSV), reside in a string of contiguous locations in memory and have a structure specified in the Programmer's Supplement (Johanson, et al., 1979). The array OSVMEM contains an exact copy of the OSV for each operation. It is used to restore the OSV in the common memory area when the operation is resumed after interruption.
3. The Input Time Series Instruction Array (TSGETM) and the Output Time Series Instruction Array (TSPUTM). These arrays contain instructions which govern the transfer of pieces of time series into and out of the INPAD, respectively. Each instruction enables module TSGET to retrieve a specified piece of time series from one of the source volumes (Figure 3.0-1), transform it to the interval and form required for the INPAD, and insert it in the desired row of the INPAD. In the case of TSPUTM, the sequence is the reverse of that just described.

Each operation has its own set of instructions in TSGETM and TSPUTM which are read whenever modules TSGET and TSPUT are called upon to service that operation (every INSPAN).
4. The Special Action Instruction Array (SPACM). Each record of this array contains a single special action instruction, which specifies the action required to be taken in a given operation at a specific time, e.g., report operation state, modify a state variable.

4.0 Supervise and Perform Operations (module OSUPER)

Function of Operations Group

The Operations group of modules handles all the manipulations of time series and thus, performs most of the work in a run. Subroutine OSUPER controls the group. It performs some of the tasks itself, but it invokes subordinate modules to do other tasks.

General Description of Subroutine OSUPER

The primary tasks of subroutine OSUPER are to ensure that the various operations in the run are called in the correct sequence and that the associated time series and OSVs are input and/or output at the required junctures (see Part B, Section 3.2). OSUPER uses a nest of DO-loops to control the sequencing. The instruction array OSUPM specifies the ranges of the loops and supplies information ("keys") which enable OSUPER, TSGET and TSPUT to correctly access the other instruction arrays. OSUPER reads an instruction each time an operation starts a new INSPAN. Using this information, it then:

1. calls TSGET, to supply the required input time series
2. reads the OSV from disk or memory storage
3. calls the operating module

When the INSPAN is over, OSUPER:

1. writes the OSV to disk or memory storage
2. calls TSPUT, to output time series

4.03 Perform Special Actions (Subroutine SPECL)

HSPF permits the user to perform certain "Special Actions" during the course of a run. A special action instruction specifies the following:

1. The operation on which the action is to be performed (e.g., PERLND 10)
2. The date/time at which the action is to be taken.
3. The variable name and element (if the variable is an array) or the type and location within COMMON block SCRTCH of the data item to be updated.
4. The action to be performed. Two choices are available:
 - a) Reset the variable to a specified value
 - b) Increment the variable by a specified value

The special action facility is used to accommodate things such as:

1. Human intervention in a watershed. Events such as plowing, cultivation, fertilizer and pesticide application, and harvesting are simulated in this way.

2. Changes to parameters. For example, a user may wish to alter the value of a parameter for which 12 monthly values cannot be supplied. This can be done by specifying a special action for that variable. The parameter could be reset to its original value by specifying another special action, to be taken at a later time.

Special Actions can be performed on variables in the PERLND, IMPLND, RCHRES, COPY, PLTGEN, and GENER modules. The input is documented in Section 4.10 of Part F.

4.1 Get Required Input Time Series (module TSGET)

The task of this module is to insert in the INPAD all input time series required by an operation. OSUPER calls it each time an operation is to commence an INSPAN, passing to it the keys of the first and last records in the TSGET instruction array which must be read and acted upon. Each instruction causes a row of the INPAD to be filled. TSGET can draw its input time series from any of the following source "volumes": WDM file, DSS file, sequential file and INPAD (Figure 3.0-1).

TSGET will, if necessary, automatically transform the time interval and "kind" (Appendix V) of the time series, as it is transferred from the source location to the INPAD (target). TSGET can also perform a linear transformation on the values in a time series; for example, if the source contains temperatures in degrees C and the INPAD needs them in degrees F.

4.2 Perform an Operation

Function of an Operating Module

An operating module is at the center of every operation (Part B, Section 2.1). When the Operations Supervisor calls an operating module the time series which it requires are already in the INPAD. The task of the operating module is to operate on these input time series. The results of this work are:

1. updated state variables. The operating module constantly updates any state variables. These are located in the OSV. Thus, when the operating module returns control to the Operations Supervisor, which copies the OSV to disk or memory storage area, the latest values of all state variables are automatically preserved.
2. printed output. The operating module accumulates values, formats them and routes these data to the line printer.
3. output time series. The operating module places these in the INPAD, but is not concerned with their ultimate disposition; this is handled by module TSPUT.

Note that all time series simultaneously present in an INPAD have the same constant time interval. This implies that, internally, all time series involved in an operation have the same time interval. Externally, the time series may have differing time intervals. Part of the function of modules TSGET and TSPUT is to convert time series from external to internal time intervals and vice versa.

Sub-divisions in an Operating Module

An operating module may be divided into several distinct sections, each of which may be selectively activated in a given run, under the user's control, e.g., the Pervious Land-segment module (PERLND) contains twelve sections, the first being air temperature correction, and the last is tracer (conservative substance) simulation. The operating procedure is as follows: in each time interval of the INSPAN, the operating module calls each of its active sections in the order in which they are built into the code (the sequence can not be altered by the user). When the INSPAN has been covered, the operating module returns control to OSUPER which determines the next action to be taken. This procedure implies that an operating module must be arranged so that a section is called after any others from which it requires information. For example, in the Pervious Land-segment module, the sediment calculation section may use data computed by the snow and water balance sections, but not by sections listed after sediment. This kind of information flow is called an inter-section data transfer (ISDT).

Partitioning of an Operation

A user may activate one group of module sections in an initial run and other groups in subsequent runs. Thus, it is possible to "partition" an operation. For example, it is possible to calibrate the hydraulic response of a set of river reaches before moving on to simulate the behavior of constituents contained in the water. If this type of work involves ISDT's between the sections handled in different runs, it follows that:

1. The time series involved in the ISDT's must be stored between runs, probably in the WDM file.
2. In the second run the system will expect the user to specify external sources for all of these time series.

Some users will be confused by the rules for partitioning operations, but our experience indicates this will be outweighed by the flexibility which it brings.

Numbering of Operating Modules

In principle, there is no limit to the number of operating modules which the system can accommodate. Ultimately, we expect a large number of modules ranging from very simple utility modules (e.g., COPY) to very complex simulation algorithms (e.g., PERLND). Although the size and complexity of the modules vary greatly, they all are, logically, of equal rank (Figure 2-3, Part B). The adopted numbering system reflects this. Every operating module is identified by the number 4.2 and is distinguished from the others only by a subscript. For example, the Pervious Land-segment Module is 4.2(1) and the Reach/Mixed Reservoir Module 4.2(3).

Inserting Additional Operating Modules

A programmer may insert additional modules. This requires the following tasks:

1. Write or adapt the operating module. This includes restructuring the data into an OSV which conforms with the requirements of the HSPF system.
2. Add a section of code to the Run Interpreter to interpret the UCI for the new module.
3. Add data to the message/information file (HSPFMSG.WDM).
4. Make minor changes to subroutines OPNBLK and OSUPER.

Types of Operating Modules

There are two types of operating modules; utility modules and application modules. Utility modules perform any operations involving time series which are essentially auxiliary to application operations, e.g., input time series data from ASCII formatted files to the WDM file using COPY, multiply two time series together to obtain a third one, plot several time series on the same graph. Application (simulation) modules represent processes, or groups of processes, which occur in the real world.

4.2(1) Simulate a Pervious Land Segment (Module PERLND)

A land segment is a subdivision of the simulated watershed. The boundaries are established according to the user's needs, but generally, a segment is defined as an area with similar hydrologic characteristics. For modeling purposes, water, sediment, and water quality constituents leaving the watershed move laterally to a downslope segment or to a reach/reservoir. A segment of land which has the capacity to allow enough infiltration to influence the water budget is considered pervious. In HSPF, PERLND is the module that simulates the water quality and quantity processes which occur on a pervious land segment.

The primary module sections in PERLND simulate snow accumulation and melt (Section SNOW), the water budget (section PWATER), sediment produced by land surface erosion (section SEDMNT), and water quality constituents by various methods (section PQUAL and the agri-chemical sections). Other sections perform the auxiliary functions of correcting air temperature (section ATEMP) for use in snowmelt and soil temperature calculations, producing soil temperatures (section PSTEMP) for estimating the outflow temperatures and influencing reaction rates in the agri-chemical sections, and determining outflow temperatures which influence the solubility of oxygen and carbon dioxide. The structure chart for the PERLND module (Figure 4.2(1)-1) shows these sections and their relationships to each other and to PPTOT, PBAROT, and PPRINT. These last three sections manipulate the data produced. Section PPTOT places state variables (point values) and PBAROT places flux variables which are actually averages over the interval (mean values) into the INPAD. PPRINT produces the printable results in the quantity and frequency that the user specifies. The sections in the structure chart are executed from left to right.

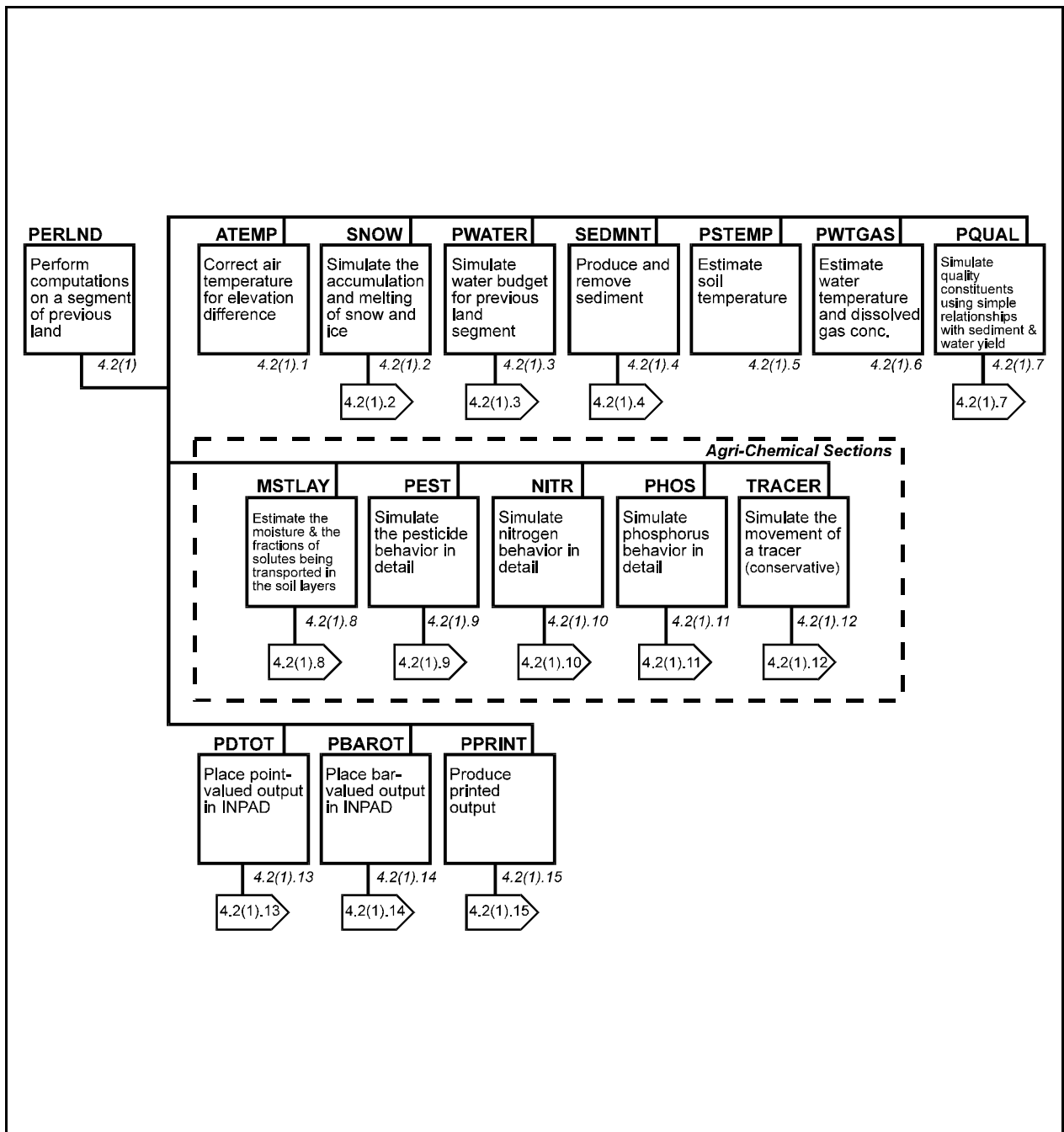


Figure 4.2(1)-1 Structure chart for PERLND Module

4.2(1).1 Correct Air Temperature for Elevation Difference (Section ATEMP of Modules PERLND and IMPLND)

Purpose

The purpose of ATEMP is to modify the input air temperature to represent the mean air temperature over the land segment. This module section is used by both PERLND and IMPLND. Air temperature correction is needed when the elevation of the land segment is significantly different than the elevation at the temperature gage. If no correction for elevation is needed, this module section can be skipped.

Method

The lapse rate for air temperature is dependent upon precipitation during the time interval. If precipitation occurs, a wet lapse rate of 0.0035 degrees F per foot difference in elevation is assumed. Otherwise, a dry lapse rate, that varies with the time of day, is used. A table of 24 hourly dry lapse rates varying between 0.0035 to 0.005 is built into the system. A different, user-defined lapse rate may be implemented by modifying the HSPF message/information file (HSPFMSG.WDM). The corrected air temperature is:

$$\text{AIRTMP} = \text{GATMP} - \text{LAPS} * \text{ELDAT} \quad (1)$$

where:

AIRTMP = corrected air temperature (degrees F)
 GATMP = air temperature at gage (degrees F)
 LAPS = lapse rate (degrees F/ft)
 ELDAT = elevation difference between the land segment and the
 gage (ft)

4.2(1).2 Simulate Accumulation and Melting of Snow and Ice (section SNOW of modules PERLND and IMPLND)

Purpose

SNOW deals with the runoff derived from the fall, accumulation, and melt of snow. This is a necessary part of any complete hydrologic package since much of the runoff, especially in the northern half of the United States, is derived from snow conditions.

Approach

Figure 4.2(1).2-1 illustrates the processes involved in snow accumulation and melt on a land segment. The algorithms used are based on the work by the Corps of Engineers (1956), Anderson and Crawford (1964), and Anderson (1968). Empirical relationships are employed when physical ones are not well known. The snow algorithms use meteorologic data to determine whether precipitation is rain or snow, to simulate an energy balance for the snowpack, and to determine the effect of the heat fluxes on the snowpack.

Five meteorologic time series are required by SNOW for each land segment simulated. They are:

- precipitation
- air temperature
- solar radiation
- dewpoint
- wind velocity

A value from each of these time series is input to SNOW at the start of each simulation interval. However, some of the meteorological time series are only used intermittently for calculating rates, such as in the calculation of the potential rate of evaporation from the snowpack.

Air temperature is used to determine when snow is falling. Once snow begins to accumulate on the ground, the snowpack accumulation and melt calculations take place. Five sources of heat which influence the melting of the snowpack are simulated:

1. net radiation heat (RADHT), both longwave and shortwave
2. convection of sensible heat from the air (CONVHT)
3. latent heat transfer by condensation of moist air on the snowpack (CONDHT)
4. heat from rain, sensible heat from rain falling (RNSHT) and latent heat from rain freezing on the snowpack
5. conduction of heat from the underlying ground to the snowpack (GMELTR)

Other heat exchange processes such as latent heat from evaporation are considered less significant and are not simulated.

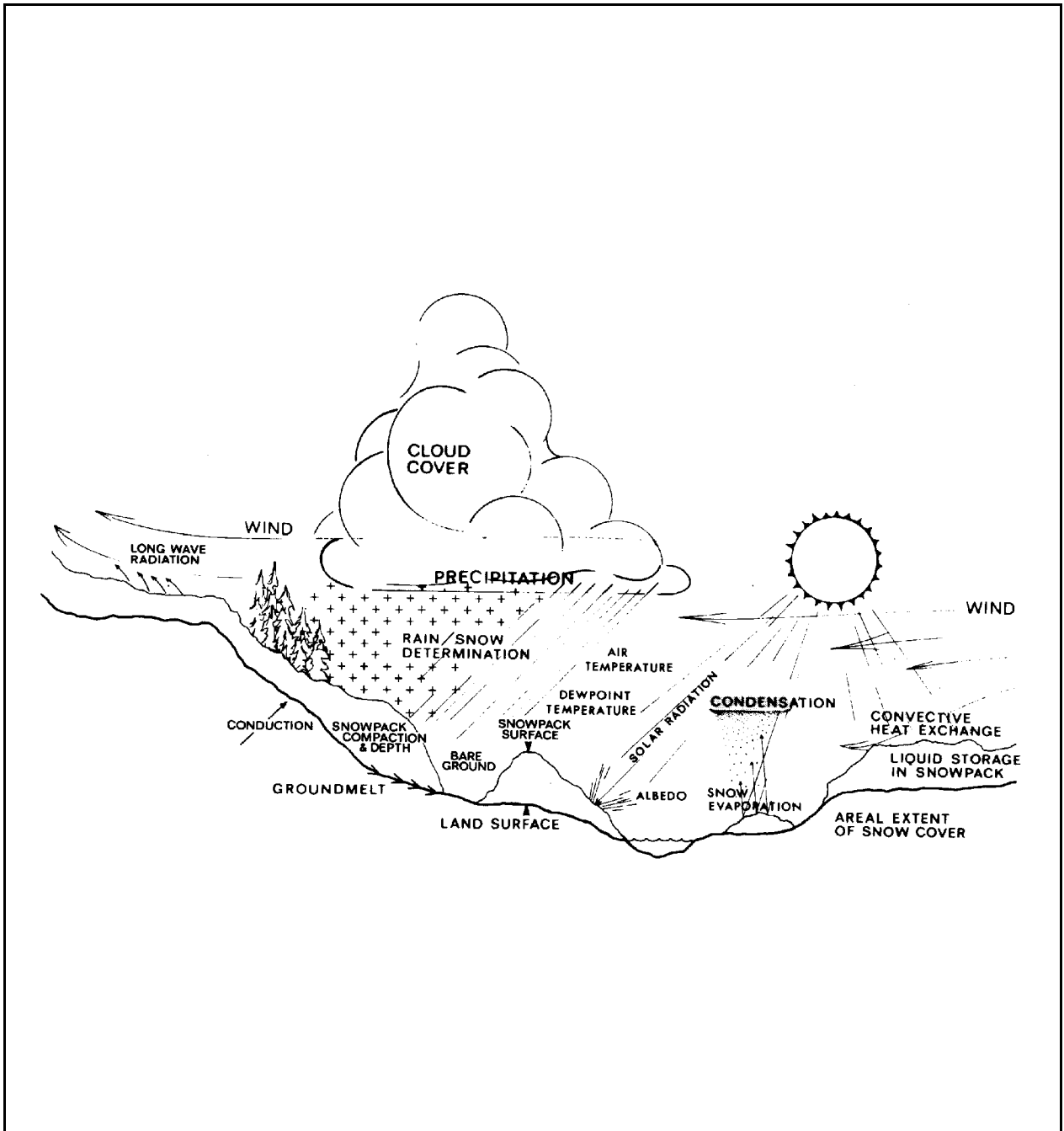


Figure 4.2(1).2-1 Snow accumulation and melt processes

The energy calculations for RADHT, CONVHT, and CONDHT are performed by subroutine HEXCHR while GMELTR is calculated in subroutine GMELT. Latent heat from rain freezing is considered in subroutine WARMUP. RNSHT is computed in the parent subroutine SNOW. For uniformity and accounting, energy values are calculated in terms of the water equivalent which they could melt. It takes 202.4 calories per square cm on the surface to melt one inch water equivalent of snow at 32 degrees F. All the sources of heat including RNSHT are considered to be positive (incoming to the pack) or zero, except RADHT which can also be negative (leaving the pack).

Net incoming heat from the atmosphere (the sum of RADHT, CONVHT, CONDHT, and RNSHT) is used to warm the snowpack. The snowpack can be further warmed by the latent heat released upon rain freezing. Any excess heat above that required to warm the snowpack to 32 degrees F is used to melt the pack. Likewise, net loss of heat is used to cool the snowpack producing a negative heat storage. Furthermore, incoming heat from the ground melts the snowpack from the bottom independent of the atmospheric heat sources except that the rate depends on the temperature of the snowpack.

Figure 4.2(1).2.2 gives a schematic view of the moisture related processes modeled in section SNOW. Precipitation may fall as rain or snow on the snowpack or the ground. Evaporation only occurs from the frozen portion of the pack (PACKF). The frozen portion of the pack is composed of snow and ice. The ice portion of PACKF is considered to be in the lower part of the snowpack, so it is the first to melt when heat is conducted from the ground. Similarly, the snow portion of PACKF is the first to melt when atmospheric heat increases. Melted PACKF and rain falling on the snowpack produce the water portion of the total snowpack which may overflow the capacity of the pack. The water yield and rain on the bare ground becomes input to module section PWATER or IWATER. These moisture related processes as well as the heat exchange processes are discussed later in more detail.

Heat transfer from incoming rain (RNSHT) to the snowpack is calculated in the parent subroutine SNOW (Section 4.2(1).2). The following physically based equation is used:

$$RNSHT = (AIRTMP - 32.0) * RAINF / 144.0 \quad (2)$$

where:

AIRTMP = temperature of the air (degrees F)
 RAINF = rainfall (inches)
 144.0 = factor to convert to equivalent depth of melt
 32.0 = freezing point (degrees F)

Other characteristics of the snowpack are also determined in the main subroutine SNOW. The fraction of the land segment covered by the snowpack is estimated by merely dividing the depth of the snowpack by a cover index (COVINX) which is a function of the parameter COVIND and the history of the pack as explained in subroutine EFFPRC. The temperature of the snowpack is estimated by:

$$PAKTMP = 32.0 - NEGHTS / (0.00695 * PACKF) \quad (3)$$

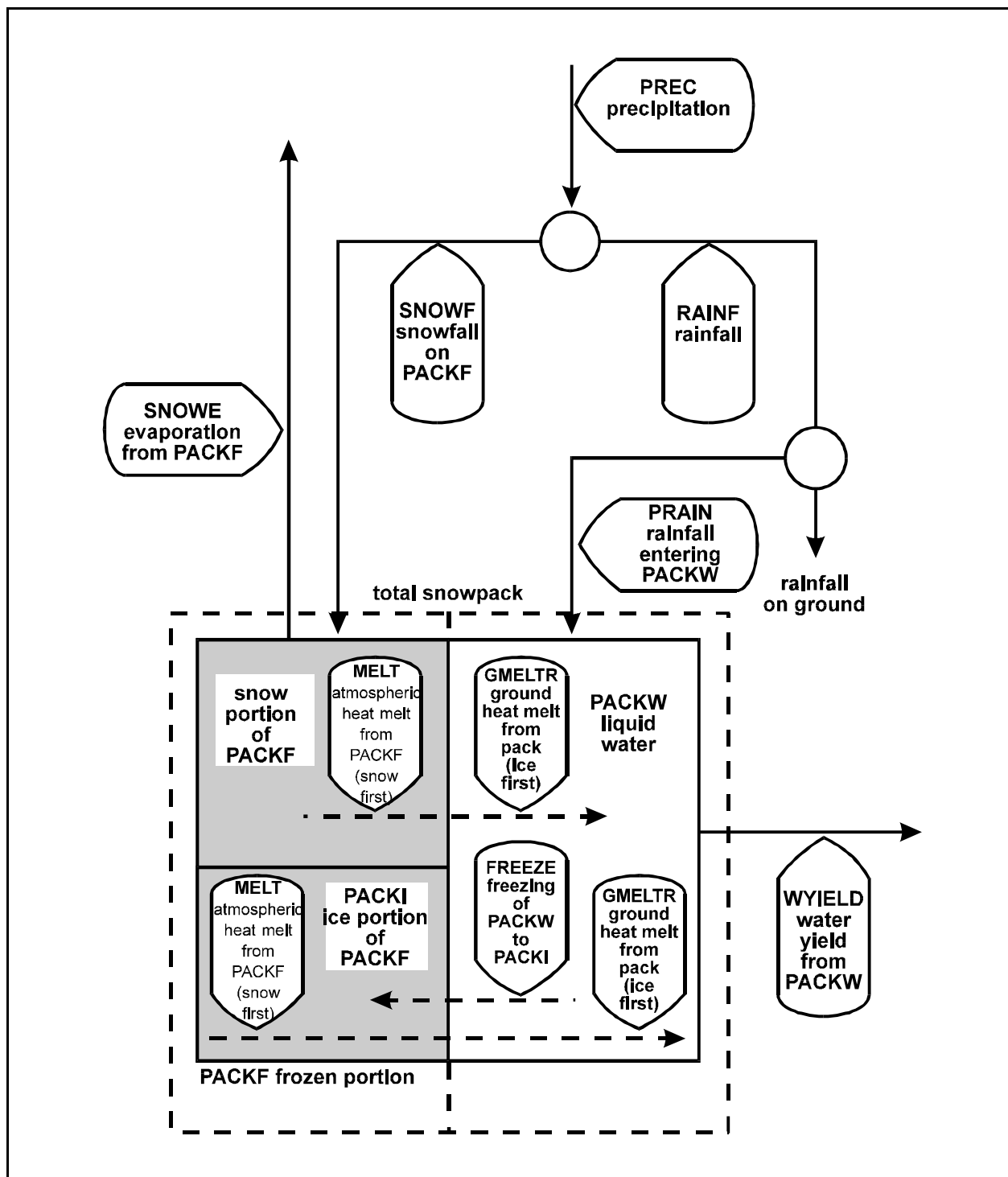


Figure 4.2(1).2-2 Flow diagram of water movement, storages, and phase changes modeled in the SNOW section of the PERLND and IMPLND Application Modules

where:

PAKTMP = mean temperature of the snowpack (degrees F)
 NEGHTS = negative heat storage (inches of water equivalent)
 PACKF = frozen contents of the snowpack (inches of water equivalent)
 0.00695 = physically based conversion factor

4.2(1).2.1 Estimate Meteorological Conditions (subroutine METEOR)

Purpose

Subroutine METEOR estimates the effects of certain meteorological conditions on specific snow-related processes by the use of empirical equations. It determines whether precipitation is falling as snow or rain. The form of precipitation is critical to the reliable simulation of runoff and snowmelt. When snow is falling, the density is calculated in order to estimate the depth of the new snowpack. The fraction of the sky which is clear is also estimated for use in the radiation algorithms, and the gage dewpoint temperature is corrected if it is warmer than air temperature.

Method

The following expression is used to calculate hourly the effective air temperature below which snowfall occurs:

$$\text{SNOTMP} = \text{TSNOW} + (\text{AIRTMP} - \text{DEWTMP}) * (0.12 + 0.008 * \text{AIRTMP}) \quad (4)$$

where:

SNOTMP = air temperature below which snowfall occurs (degrees F)
 TSNOW = parameter (degrees F)
 AIRTMP = air temperature (degrees F)
 DEWTMP = dewpoint (degrees F)

SNOTMP is allowed to vary in this calculation by a maximum of one degree F from TSNOW. When AIRTMP is equal to or greater than SNOTMP, precipitation is assumed to be rain.

When snowfall occurs, its density is estimated as a function of air temperature according to:

$$\text{RDNSN} = \text{RDCSN} + (\text{AIRTMP}/100.0)**2 \quad (5)$$

where:

RDNSN = density of new snowfall (at zero degrees F or greater)
 relative to liquid water
 RDCSN = parameter designating density of new snow at an air temperature
 of zero degrees F and lower, relative to liquid water

RDNSN is used in subroutine EFFPRC to calculate the new depth of the snowpack resulting from the addition of the snow. This and all other snow density terms are in water equivalent (inches) per depth of the snowpack (inches).

The fraction of the sky which is clear (SKYCLR) is needed for the calculation of the longwave back radiation to the snowpack from the clouds (done in subroutine HEXCHR). SKYCLR is set to the minimum value of 0.15 when precipitation occurs. Otherwise, it is increased each simulation time interval as follows:

$$\text{SKYCLR} = \text{SKYCLR} + (0.0004 * \text{DELT}) \quad (6)$$

where:

DELT = simulation time interval (min)

SKYCLR increases until either it reaches unity or precipitation causes it to be reset.

A gage dewpoint higher than air temperature is not physically possible and will give erroneous results in the calculation of snowpack evaporation. Therefore, dewpoint is set equal to the air temperature when this situation occurs. Otherwise, the gage dewpoint is used.

4.2(1).2.2 Determine the Effect of Precipitation on the Pack (subroutine EFFPRC)

Purpose

The purpose of this subroutine is to add the falling snow to the pack, determine the amount of rain falling on the snowpack, and adjust the snowpack dullness to take into account new snow.

Method

The amount of precipitation falling as snow or rain is determined in subroutine METEOR. Subroutine EFFPRC accounts for the influence that snowfall and rain have on the land segment. The subroutine begins by increasing the snowpack depth by the amount of snow falling on the pack divided by its density.

The fraction of the land segment which is covered by the snowpack (SNOCOV) is determined by re-evaluating the index to areal coverage (COVINX). When the frozen contents of the pack (PACKF) exceeds the value of the parameter describing the maximum PACKF required to insure complete areal coverage by snow cover (COVIND), then COVINX is set equal to COVIND. Otherwise, COVINX is equal to the largest previous value of PACKF. SNOCOV is PACKF/COVINX if PACKF < COVINX. The amount of rain falling on the snowpack is that fraction of the precipitation which falls as rain multiplied by the SNOCOV. Rain falling on the snowpack will either freeze, adding to the frozen portion of the pack and produce heat used to warm the pack (see subroutine WARMUP), or it will increase the liquid water content of the pack (see subroutine LIQUID). Any rain not falling on the pack is assumed to land on bare ground.

When snowfall occurs, the index to the dullness of the snowpack (DULL) is decreased by one thousand times the snowfall for that interval. However, if one thousand times the snowfall is greater than the previous value for DULL, then DULL is set to zero to account for a new layer of perfectly reflectable snow. Otherwise, when snowfall does not occur, DULL is increased by one index unit per hour up to a maximum of 800. Since DULL is an empirical term used as an index, it has no physical units. DULL is used to determine the albedo of the snowpack, which in turn is used in the shortwave energy calculations in subroutine HEXCHR.

4.2(1).2.3 Compact the Pack (subroutine COMPAC)

Purpose

The addition of new snow will reduce the density as well as increase the depth of the snowpack as in subroutine EFFPRC. The pack will tend to compact with age until a maximum density is reached. The purpose of subroutine COMPAC is to determine the rate of compaction and calculate the actual change in the depth due to compaction.

Method

When the relative density is less than 55 percent, compaction is assumed to occur. The rate of compaction is computed according to the empirical expression:

$$\text{COMPCT} = 1.0 - (0.00002 * \text{DELT60} * \text{PDEPTH} * (0.55 - \text{RDENPF})) \quad (7)$$

where:

COMPCT = unit rate of compaction of the snowpack per interval
 DELT60 = number of hours in an interval
 PDEPTH = depth of the snowpack in inches of total snowpack
 RDENPF = density of the pack relative to liquid water

The new value for PDEPTH is COMPCT times PDEPTH. PDEPTH is used to calculate the relative density of the snowpack which affects the liquid water holding capacity as determined in subroutine LIQUID.

4.2(1).2.4 Simulate Evaporation from the Pack (subroutine SNOWEV)

Purpose

The SNOWEV subroutine estimates evaporation from the snowpack (sublimation).

Method

Evaporation from the snowpack will occur only when the vapor pressure of the air is less than that of the snow surface, that is, only when the air vapor pressure is less than 6.108 mbar, which is the maximum vapor pressure that the thin surface film of air over the snowpack can attain. When this condition is met the evaporation is computed by the empirical relationship:

$$\text{SNOWEP} = \text{SNOEVP} * 0.0002 * \text{WINMOV} * (\text{SATVAP} - \text{VAP}) * \text{SNOCOV} \quad (8)$$

where:

SNOWEP = potential rate of evaporation from the frozen part of the snowpack (inches of water equivalent/interval)
 SNOEVP = parameter used to adjust the calculation to field conditions
 WINMOV = wind movement (miles/interval)
 SATVAP = saturated vapor pressure of the air at the current air temperature (mbar)
 VAP = vapor pressure of the air at the current air temp (mbar)
 SNOCOV = fraction of the land segment covered by the snowpack

The potential (SNOWEP) will be fulfilled if there is sufficient snowpack. Otherwise, only the remaining pack will evaporate. For either case, evaporation occurs only from the frozen content of the snowpack (PACKF).

4.2(1).2.5 Estimate Heat Exchange Rates (except ground melt and rain heat) (subroutine HEXCHR)

Purpose

The purpose of this subroutine is to estimate the heat exchange from the atmosphere due to condensation, convection, and radiation. All heat exchanges are calculated in terms of equivalent depth of melted or frozen water.

Method of Determining Heat Supplied by Condensation

Transfer of latent heat of condensation can be important when warm moist air masses travel over the snowpack. Condensation occurs when the air is moist enough to condense on the snowpack. That is, when the vapor pressure of the air is greater than 6.108 mbar. This physical process is the opposite of snow evaporation; the heat produced by it is calculated by another empirical relationship:

$$\text{CONDHT} = 8.59 * (\text{VAP} - 6.108) * \text{CCFACT} * 0.00026 * \text{WINMOV} \quad (9)$$

where:

CONDHT = condensation heat flux to the snowpack (inches of water equivalent/interval)
 VAP = vapor pressure of the air at the current air temp (mbar)
 CCFACT = parameter used to correct melt values to field conditions
 WINMOV = wind movement (miles/interval)

CONDHT can only be positive or zero, that is, incoming to the pack.

Method of Determining Heat Supplied by Convection

Heat supplied by turbulent exchange with the atmosphere can occur only when air temperatures are greater than freezing. This convection of heat is calculated by the empirical expression:

$$\text{CONVHT} = (\text{AIRTMP} - 32.0) * (1.0 - 0.3 * \text{MELEV} / 10000.0) * \text{CCFACT} * 0.00026 * \text{WINMOV} \quad (10)$$

where:

CONVHT = convective heat flux to the snowpack (inches of water equivalent/interval)
 AIRTMP = air temperature (degrees F)
 MELEV = mean elevation of the land segment above sea level (ft)

In the simulation, CONVHT also can only be positive or zero, that is, only incoming.

Method of Determining Heat Supplied by Radiation

Heat supplied by radiation is determined by:

$$\text{RADHT} = (\text{SHORT} + \text{LONG}) / 203.2 \quad (11)$$

where:

RADHT = radiation heat flux to the snowpack (inches of water equivalent/interval)
 SHORT = net solar or shortwave radiation (langleys/interval)
 LONG = net terrestrial or longwave radiation (langleys/interval)

The constant 203.2 is the number of langleys required to produce one inch of melt from snow at 32 degrees F. RADHT can be either positive or negative, that is, incoming or outgoing.

SHORT and LONG are calculated as follows. Solar radiation, a required time series, is modified by the albedo and the effect of shading. The albedo or reflectivity of the snowpack is a function of the dullness of the pack (see subroutine EFFPRC for a discussion of DULL) and the season. The equation for calculating albedo (ALBEDO) for the 6 summer months is:

$$\text{ALBEDO} = 0.80 - 0.10 * (\text{DULL} / 24.0) ** 0.5 \quad (12)$$

The corresponding equation for the winter months is:

$$\text{ALBEDO} = 0.85 - 0.07 * (\text{DULL} / 24.0) ** 0.5 \quad (13)$$

ALBEDO is allowed a minimum value of 0.45 for summer and 0.60 for winter. The hemispheric location of the land segment is taken into account for determining summer and winter in using the above equation. This is done through the use of the latitude parameter which is positive for the northern hemisphere.

Once the albedo of the pack is found then solar radiation (SHORT) is modified according to the equation:

$$\text{SHORT} = \text{SOLRAD} * (1.0 - \text{ALBEDO}) * (1.0 - \text{SHADE}) \quad (14)$$

where:

SOLRAD = solar radiation (langleys/interval)
 SHADE = parameter indicating the fraction of the land segment which is shaded

Unlike shortwave radiation which is more commonly measured, longwave radiation (LONG) is estimated from theoretical consideration of the emitting properties of the snowpack and its environment. The following equations are based on Stefan's law of black body radiation and are linear approximations of curves in Plate 5-3, Figure 6 in Snow Hydrology (Corps of Engineers, 1956). They vary only by the constants which depend on air temperature. For air temperatures above freezing:

$$\text{LONG} = \text{SHADE} * 0.26 * \text{RELTMP} + (1.0 - \text{SHADE}) * (0.2 * \text{RELTMP} - 6.6) \quad (15)$$

And for air temperatures at freezing and below:

$$\text{LONG} = \text{SHADE} * 0.20 * \text{RELTMP} + (1.0 - \text{SHADE}) * (0.17 * \text{RELTMP} - 6.6) \quad (16)$$

where:

RELTMP = air temperature minus 32 (degrees F)
 6.6 = average back radiation lost from the snowpack in open areas (langleys/hr)

Since the constants in these equations were originally based on hourly time steps, both calculated values are multiplied by DELT60, the number of hours per interval, so that they correspond to the simulation interval. In addition, LONG is multiplied by the fraction of clear sky (SKYCLR) when it is negative, to account for back radiation from clouds.

4.2(1).2.6 Simulate Loss of Heat from Pack (subroutine COOLER)

Purpose

The purpose of this code is to cool the snowpack whenever it is warmer than the ambient air and thus loses heat. This is accomplished by accumulating negative heat storage which increases the capacity of the pack to later absorb heat without melting as simulated in subroutine WARMUP.

Method

In every interval where there is heat loss to the atmosphere and the temperature of the snowpack is greater than the air temperature, the negative heat storage will increase; that is, the pack will cool. However, there is a maximum negative heat storage. The maximum negative heat storage that can exist at any time is found by assuming a linear temperature distribution from the air temperature which is considered to be above the pack to 32 degrees at the bottom of the snowpack. This maximum negative heat storage is calculated hourly as follows:

$$\text{MNEGHS} = 0.00695 * (\text{PACKF} / 2.0) * (-\text{RELTMP}) \quad (17)$$

where:

MNEGHS = maximum negative heat storage (inches of water equivalent)
 PACKF = water equivalent of the frozen contents of the snowpack (inches)
 RELTMP = air temperature above freezing (degrees F)

The accumulation of the negative heat storage is calculated hourly from the following empirical relationship:

$$\text{NEGHT} = 0.0007 * (\text{PAKTMP} - \text{AIRTMP}) * \text{DELT60} \quad (18)$$

where:

NEGHT = potential rate of cooling of the snowpack (inches of water equivalent per interval)
 PAKTMP = mean temperature of the snowpack (degrees F)
 AIRTMP = air temperature (degrees F)
 DELT60 = number of hours per interval

NEGHT is added to the negative heat storage (NEGHTS) every interval except when limited by MNEGHS. NEGHTS is used in the parent subroutine SNOW to calculate the temperature of the snowpack and in subroutine WARMUP to determine the extent that the pack must be warmed to reach 32 degrees F.

4.2(1).2.7 Warm the Snowpack if Possible (subroutine WARMUP)

Purpose

This subroutine warms the snowpack to as much as 32 degrees F when possible.

Method

When there is negative heat storage in the pack (see subroutine COOLER for a discussion of NEGHTS), and there is net incoming energy as calculated in previous subroutines, then NEGHTS will decrease resulting in a warmer snowpack and possible melt.

The calculations in this subroutine are merely accounting. They decrease NEGHTS to a minimum of zero by subtracting the net incoming heat. If any negative heat storage remains, then the latent heat released by the freezing of any incoming rain is added to the pack. Since NEGHTS and all other heat variables are in units of inches of melt, the inches of rain falling on the pack and freezing is subtracted from NEGHTS without any conversion.

4.2(1).2.8 Melt the Pack Using Any Remaining Heat (subroutine MELTER)

Purpose

MELTER simulates the actual melting of the pack with whatever incoming heat remains. Any heat which was not used to heat the snowpack in subroutine WARMUP can now be used to melt the snowpack.

Method

This subroutine is also merely an accounting subroutine. The net incoming heat has already been calculated in terms of water equivalents of melt. Hence, any remaining incoming heat is used directly to melt the snowpack either partially or entirely depending on the size of the snowpack.

4.2(1).2.9 Handle Liquid Water in the Pack (subroutine LIQUID)

Purpose

Subroutine LIQUID first determines the liquid storage capacity of the snowpack. It then determines how much liquid water is available to fill the storage capacity. Any liquid water above the capacity will leave the snowpack unless it freezes (see subroutine ICING).

Method

The liquid water holding capacity of the snowpack can be at the maximum as specified by the parameter MWATER, at zero, or somewhere in between depending on the density of the pack: the less dense the snowpack the greater the holding capacity. The following relationships define the capacity:

for $RDENPF > 0.91$,

$$PACKWC = 0.0 \quad (19)$$

for $0.6 < RDENPF < 0.91$,

$$PACKWC = MWATER * (3.0 - 3.33 * RDENPF) \quad (20)$$

for RDENPF < 0.61,

$$\text{PACKWC} = \text{MWATER} \quad (21)$$

where:

PACKWC = liquid water holding capacity of the snowpack (in/in)

MWATER = parameter specifying the maximum liquid water content of the snowpack (in/in)

RDENPF = density of the snowpack relative to liquid water

MWATER is a function of the mass of ice layers, the size, the shape, and spacing of snow crystals and the degree of channelization and honeycombing of the snowpack.

Once PACKWC is calculated, it is compared to the available liquid water in the pack PWSUPY. PWSUPY is calculated by summing any storage remaining at the start of the interval, any melt, and any rain that fell on the pack which did not freeze. If PWSUPY is more than PACKWC, then water is yielded to the land surface from the snowpack.

4.2(1).2.10 Simulate Occurrence of Ice in the Pack (subroutine ICING)

Purpose

The purpose of subroutine ICING is to simulate the possible freezing of water which would otherwise leave the snowpack. This freezing in turn produces ice or frozen ground at the bottom of the snowpack. In this subroutine, the ice can be considered to be at the bottom of the pack or frozen in the ground below the snow portion of the pack thus extending the total pack into the soil. This subroutine may only be applicable in certain areas; therefore, it is optional.

Method

The freezing of the water yield of the snowpack depends on the capacity of the environment to freeze it. Every day at approximately 6 a.m. the capacity is reassessed. A new value is estimated in terms of inches of melt by multiplying the Fahrenheit degrees of the air temperature below 32.0 by 0.01. This estimate is compared with the freezing capacity if any which remains from the previous 24-hr period. If it is greater, then the new estimated capacity replaces the old, else the old value remains as the potential. Any water yield that occurs freezes and is added to the ice portion of the snowpack until the capacity is met. Any subsequent water yield is released from the snowpack.

4.2(1).2.11 Melt the Pack Using Heat from the Ground (subroutine GMELT)

Purpose

The purpose of the GMELT subroutine is to simulate the melt caused by heat conducted from the surface underlying the snowpack. This ground heat melts the pack only from below. Therefore, melt from this process is considered independent of other previously calculated heat influences except for an indirect effect via the temperature of the snowpack. Unlike the other melt processes, ground heat melts the ice portion of the snowpack first since ice is considered to be located at the lower depths of the pack.

Method

The potential rate of ground melt is calculated hourly as a function of snowpack temperature (PAKTMP) and a lumped parameter (MGMELT). MGMELT is the maximum rate of melt in water equivalent caused by heat from the ground at a PAKTMP of 32 degrees F. MGMELT would depend upon the thermal conductivity of the soil and the normal depth of soil freezing. The potential ground melt is reduced below MGMELT by 3 percent for each degree that PAKTMP is below 32 degrees F to a minimum of 19 percent of MGMELT at 5 degrees F or lower. As long as a snowpack is present, ground melt occurs at this potential rate.

4.2(1).2.12 Reset State Variables When Snowpack Disappears (subroutine NOPACK)

Purpose

This code resets the state variables (for example, SNOCOV) when the snowpack completely disappears.

Method

The frozen contents of the snowpack required for complete areal cover of snow (COVINX) is set to a tenth of the maximum value (COVIND). All other variables are either set to zero or the "undefined" value of -1.0E30.

4.2(1).3 Simulate Water Budget for a Pervious Land Segment (Section PWATER of Module PERLND)

Purpose

PWATER is used to calculate the components of the water budget, primarily to predict the total runoff from a pervious area. PWATER is the key component of module PERLND; subsequent major sections of PERLND (eg. SEDMNT) depend on the outputs of this section.

Background

The hydrologic processes that are modeled by PWATER are illustrated in Figure 4.2(1).3-1. The algorithms used to simulate these land related processes are the product of over 15 years of research and testing. They are based on the original research for the LANDS subprogram of the Stanford Watershed Model IV (Crawford and Linsley, 1966). LANDS has been incorporated into many models and used to successfully simulate the hydrologic responses of widely varying watersheds. The equations used in module section PWATER are nearly identical to the ones in the current version of LANDS in the PTR Model (Crawford and Donigian, 1973), HSP (Hydrocomp, 1976), and the ARM and NPS Models (Donigian and Crawford, 1976 a,b). However, some changes have been made to LANDS to make the algorithms internally more amenable to a range of calculation time steps. Also, many of the parameter names have been changed to make them more descriptive, and some can be input on a monthly basis to allow for seasonal variation.

Data Requirements and Manipulation

The number of time series required by module section PWATER depends on whether snow accumulation and melt are considered. When such conditions are not considered, only potential evapotranspiration and precipitation are required. However, when snow conditions are considered, air temperature, rainfall, snow cover, water yield, and ice content of the snowpack are also required. Also, the evaporation data are adjusted when snow is considered. The input evaporation values are reduced to account for the fraction of the land segment covered by the snowpack (determined from the generated time series for snow cover), with an allowance for the fraction of area covered by coniferous forest which, it is assumed, can transpire through any snow cover. Furthermore, PET is reduced to zero when air temperature is below the parameter PETMIN. If air temperature is below PETMAX but above PETMIN, PET will be reduced to 50% of the input value, unless the first adjustment already reduced it to less than this amount.

The estimated potential evapotranspiration (PET) is used to calculate actual ET in subroutine group EVAPT.

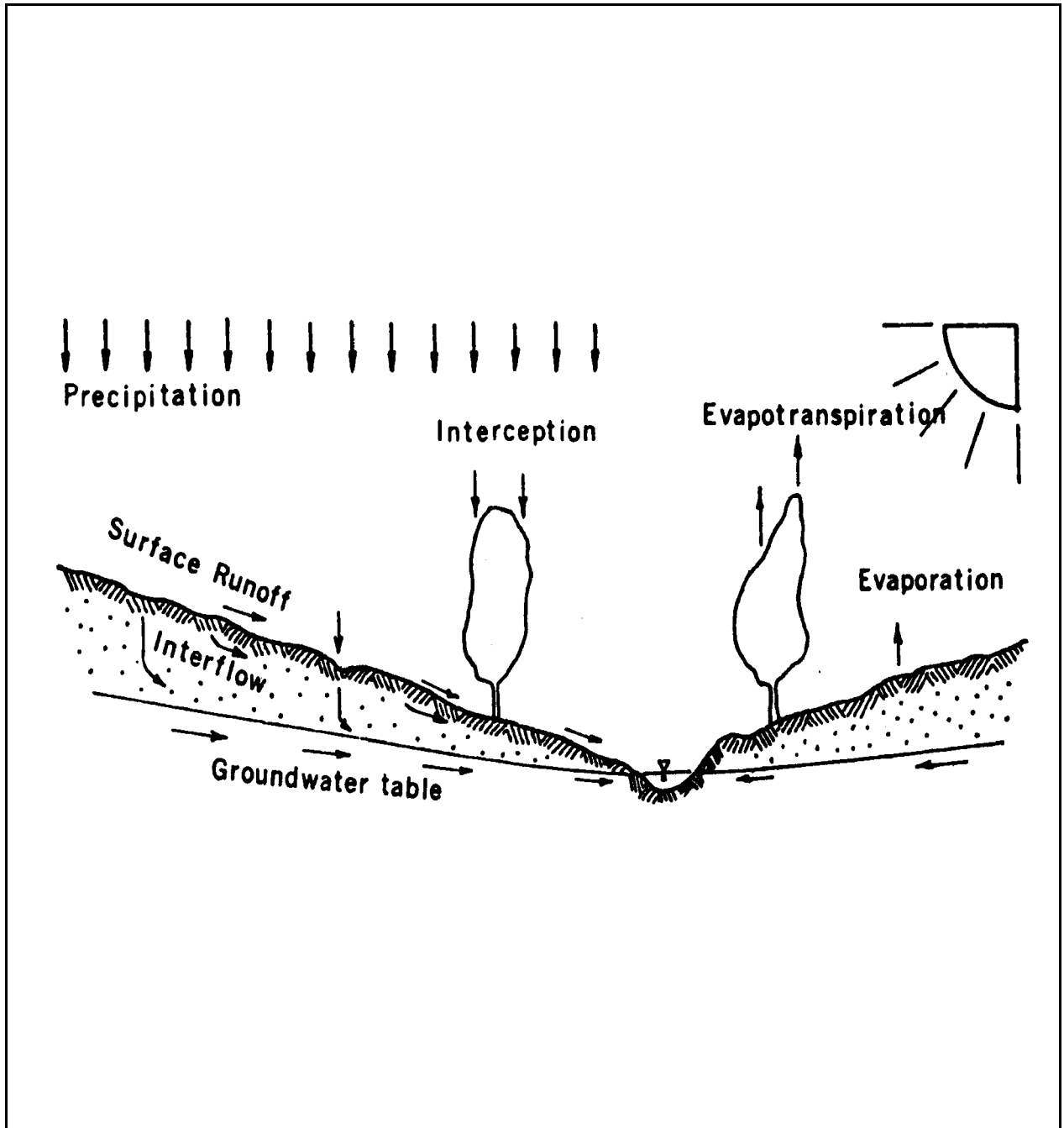


Figure 4.2(1).3-1 Hydrologic cycle

Approach

Figure 4.2(1).3-2 represents the fluxes and storages simulated in module section PWATER. The time series SUPY representing moisture supplied to the land segment includes rain, and when snow conditions are considered, rain plus water from the snowpack. SUPY is then available for interception. Interception storage is water retained by any storage above the overland flow plane. For pervious areas, interception storage is mostly on vegetation. Any overflow from interception storage is added to the optionally supplied time series of surface external lateral inflow to produce the total inflow into the surface detention storage.

Inflow to the surface detention storage is added to existing storage to make up the water available for infiltration and runoff. Moisture which directly infiltrates moves to the lower zone and groundwater storages. Other water may go to the upper zone storage, may be routed as runoff from surface detention or interflow storage, or may stay on the overland flow plane, from which it runs off or infiltrates at a later time.

The processes of infiltration and overland flow interact and occur simultaneously in nature. Surface conditions such as heavy turf on mild slopes restrict the velocity of overland flow and reduce the total quantity of runoff by allowing more time for infiltration. Increased soil moisture due to prolonged infiltration will in time reduce the infiltration rate producing more overland flow. Surface detention will modify flow. For example, high intensity rainfall is attenuated by storage and the maximum outflow rate is reduced. The water in the surface detention may also later infiltrate reoccurring as interflow, or it can be contained in upper zone storage.

Water infiltrating through the surface and percolating from the upper zone storage to the lower zone storage may flow to active groundwater storage or may be lost by deep percolation. Active groundwater eventually reappears as baseflow, but deep percolation is considered lost from the simulated system.

Lateral external inflows to interflow and active groundwater storages are also possible in section PWATER. One may wish to use this option if an upslope land segment is significantly different to merit separating it from a downslope land segment and no channel exists between them.

Not only are flows important in the simulation of the water budget, but so are storages. As stated, soil storage affects infiltration. The water holding capacity of the two soil storages, upper zone and lower zone, in module section PERLND is defined in terms of nominal capacities. Nominal, rather than absolute capacities, serve the purpose of smoothing any abrupt change that would occur if an absolute capacity is reached. Such capacities permit a smooth transition in hydrologic performance as the water content fluctuates.

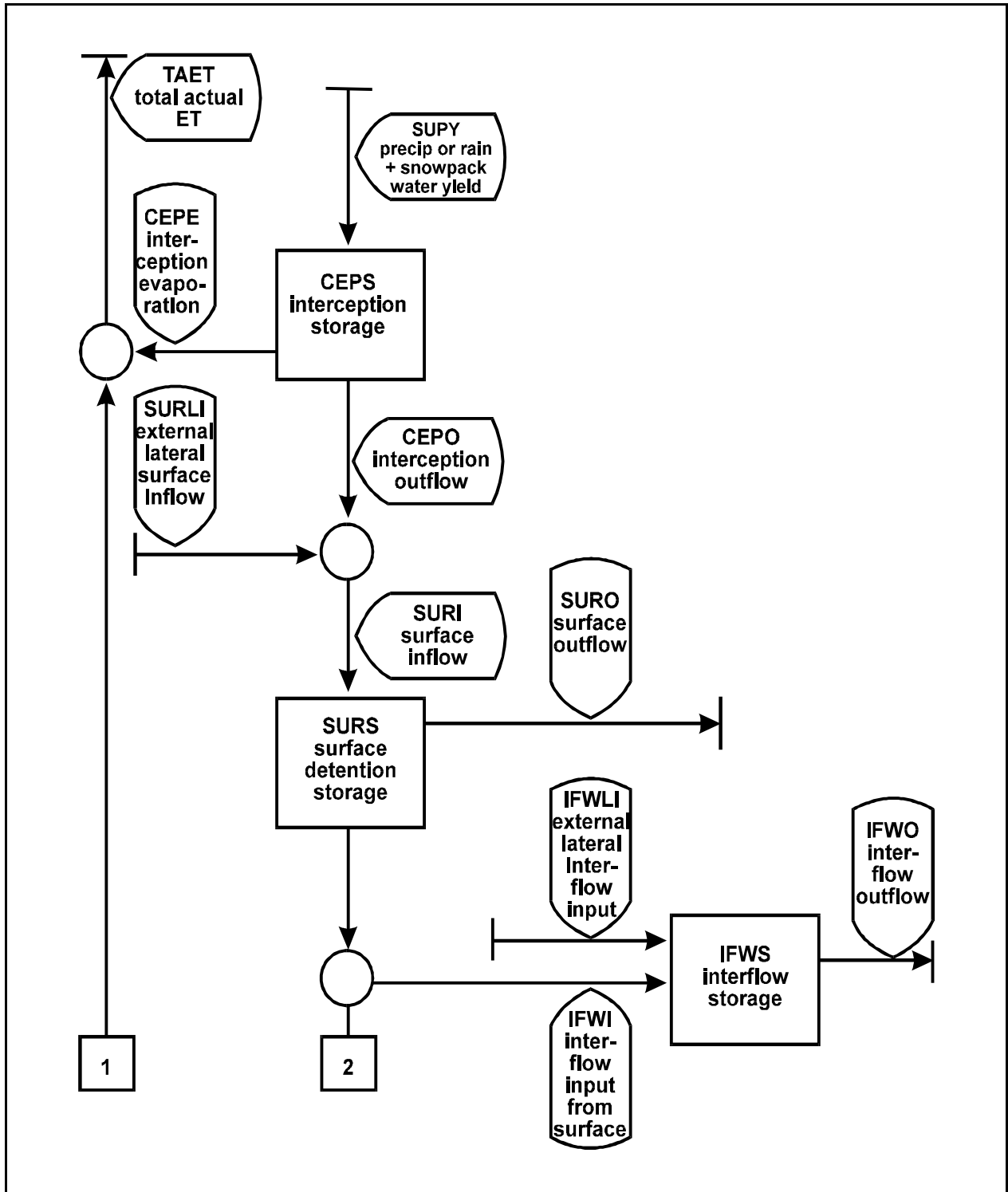


Figure 4.2(1).3-2 Flow diagram of water movement and storages modeled in the PWATER section of the PERLND Application Module

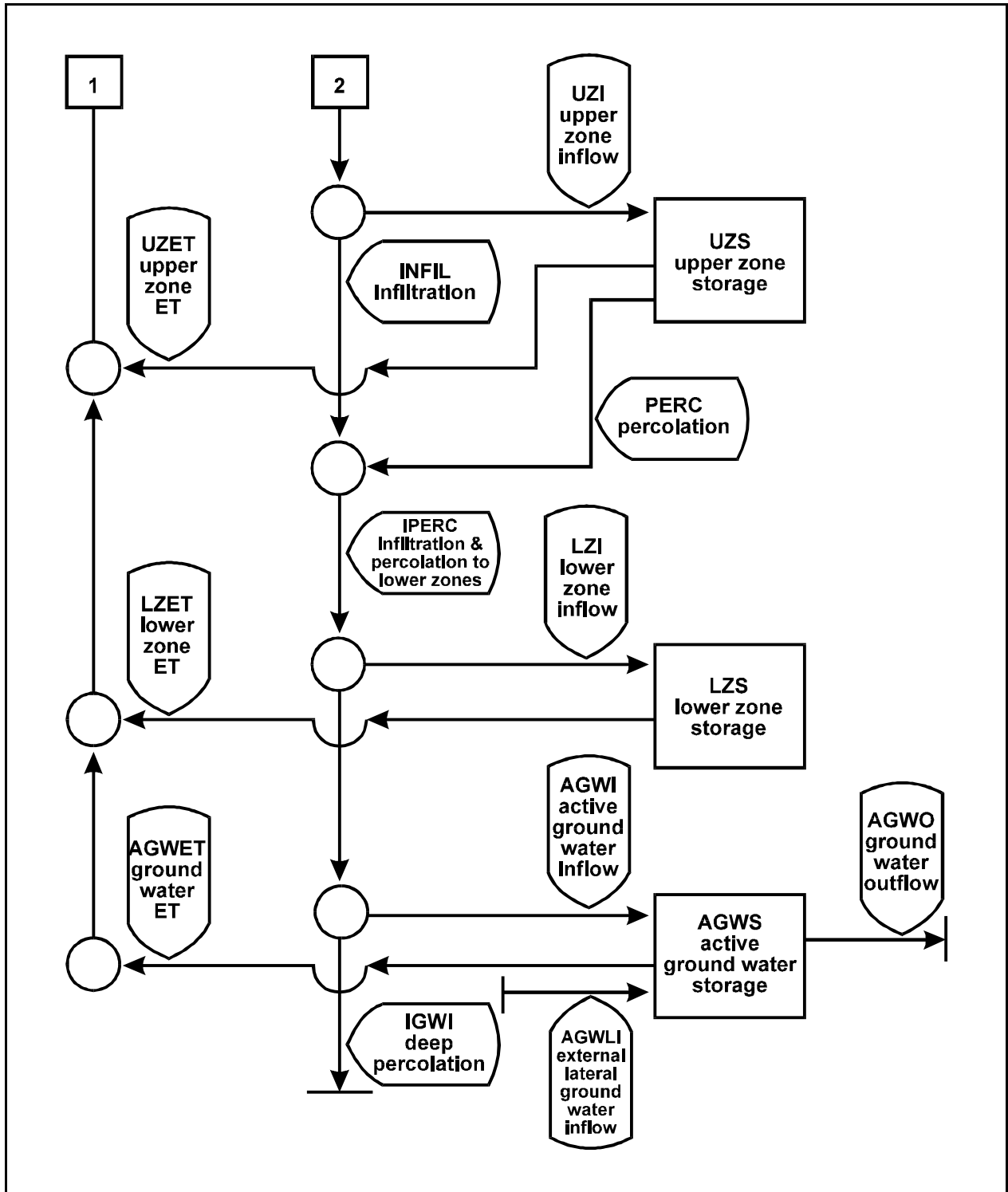


Figure 4.2(1).3-2 Flow diagram of water movement and storages modeled in the PWATER section of the PERLND Application Module (continued)

Storages also affect evapotranspiration loss. Evapotranspiration can be simulated from interception storage, upper and lower zone storages, active groundwater storage, and directly from baseflow.

Storages and flows can also be instrumental in the transformation and movement of chemicals simulated in the agri-chemical module sections. Soil moisture levels affect the adsorption and transformations of pesticides and nutrients. Soil moisture contents may vary greatly over a land segment. Therefore, a more detailed representation of the moisture contents and fluxes may be needed to simulate the transport and reaction of agricultural chemicals.

The following subroutine descriptions explain the algorithms of the PWATER module section in more detail. Further detail can be found in the reports cited above.

4.2(1).3.1 Simulate Interception (subroutine ICEPT)

Purpose

The purpose of this code is to simulate the interception of moisture by vegetal or other ground cover. Moisture is supplied by precipitation, or under snow conditions, it is supplied by the rain not falling on the snowpack plus the water yielded by the snowpack.

Method

The user may supply the interception capacity on a monthly basis to account for seasonal variations, or may supply one value designating a fixed capacity. The interception capacity parameter can be used to designate any retention of moisture which does not infiltrate or reach the overland flow plane. Typically for pervious areas this capacity represents storage on grass blades, leaves, branches, trunks, and stems of vegetation.

Moisture exceeding the interception capacity overflows the storage and is ready for either infiltration or runoff as determined by subroutine group SURFAC. Water held in interception storage is removed by evaporation; the amount is determined in subroutine EVICEP.

4.2(1).3.2 Distribute the Water Available for Infiltration and Runoff (subroutine SURFAC)

Purpose

Subroutine SURFAC determines what happens to the moisture on the surface of the land. It may infiltrate, go to the upper zone storage or interflow storage, remain in surface detention storage, or run off.

Method

The algorithms which simulate infiltration represent both the continuous variation of infiltration rate with time as a function of soil moisture and the areal variation of infiltration over the land segment. The equations representing the dependence of infiltration on soil moisture are based on the work of Philip (1957) and are derived in detail in the previously cited reports.

The infiltration capacity, the maximum rate at which soil will accept infiltration, is a function of both the fixed and variable characteristics of the watershed. Fixed characteristics include primarily soil permeability and land slopes, while variables are soil surface conditions and soil moisture content. Fixed and variable characteristics vary spatially over the land segment. A linear probability density function is used to account for areal variation. Figure 4.2(1).3-3 represents the infiltration/interflow/surface runoff distribution function of section PWATER. Careful attention to this figure and Figure 4.2(1).3-2 will facilitate understanding of subroutine SURFAC and the subordinate subroutines DISPOS, DIVISN, UZINF, and PROUTE.

The infiltration distribution represented by Figure 4.2(1).3-3 is focused around the two lines which separate the moisture available to the land surface (MSUPY) into what infiltrates and what goes to interflow. A number of the variables that are used to determine the location of lines I and II are calculated in subroutine SURFAC. They are calculated by the following relationships:

$$IBAR = (INFILT/(LZS/LZSN)**INFEXP)*INFFAC \quad (1)$$

$$IMAX = INFILD*IBAR \quad (2)$$

$$IMIN = IBAR - (IMAX - IBAR) \quad (3)$$

$$RATIO = INTFW*(2.0**(LZS/LZSN)) \quad (4)$$

where:

IBAR = mean infiltration capacity over the land segment (in/interval)

INFILT = infiltration parameter (in/interval)

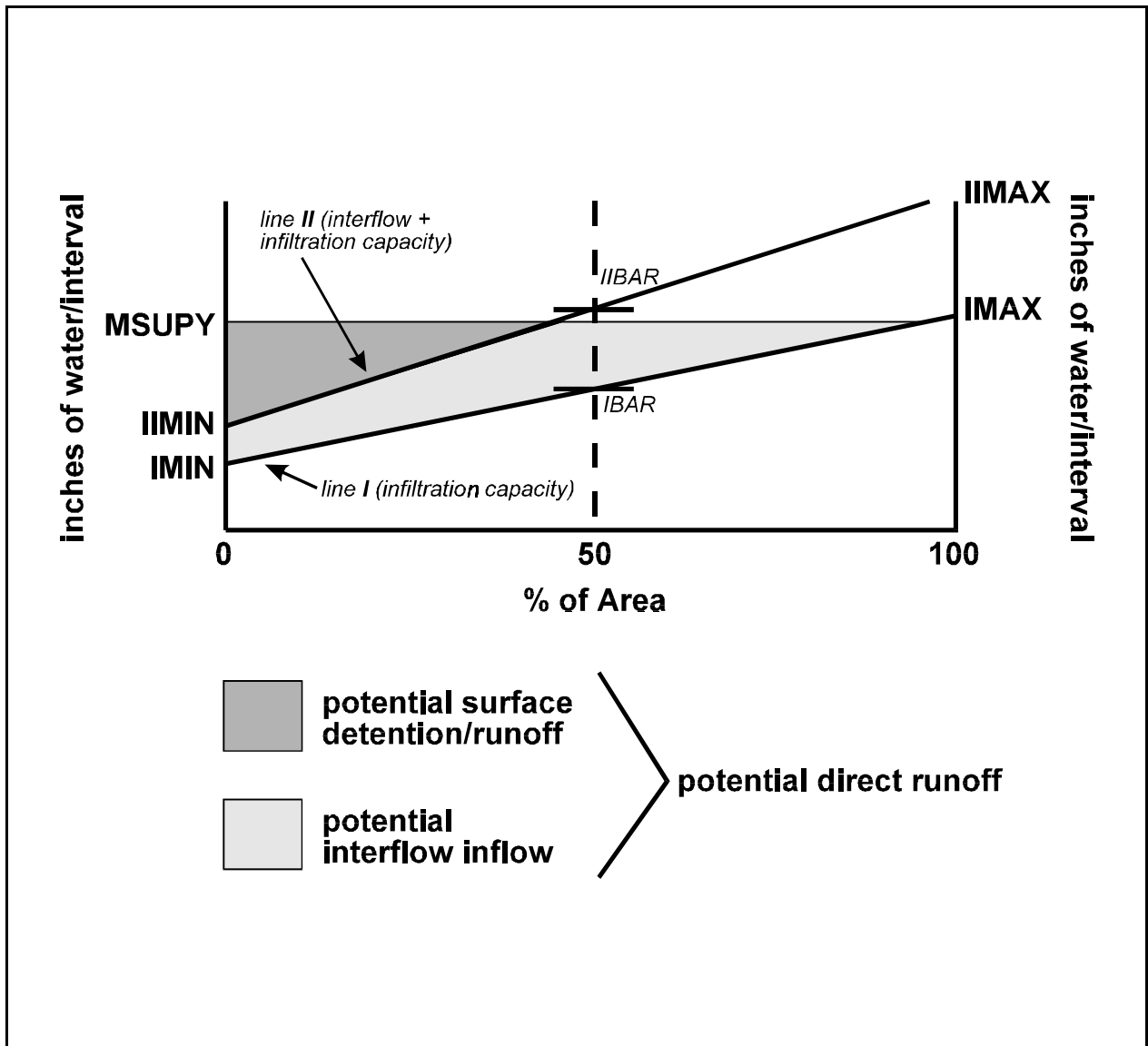


Figure 4.2(1).3-3 Determination of infiltration and interflow inflow

LZS = lower zone storage (inches)
 LZSN = parameter for lower zone nominal storage (inches)
 INFEXP = exponent parameter greater than one
 INFFAC = factor to account for frozen ground effects, if applicable
 IMAX = maximum infiltration capacity (in/interval)
 INFILD = parameter giving the ratio of maximum to mean infiltration capacity over the land segment
 IMIN = minimum infiltration capacity (in/interval)
 RATIO = ratio of the ordinates of line II to line I
 INTFW = interflow inflow parameter

The parameter INTFW can be input on a monthly basis to allow for variation throughout the year.

The factor that reduces infiltration (and also upper zone percolation) to account for the freezing of the ground surface (INFFAC) is calculated in one of two ways. In the first method, it is derived from the water equivalent of ice in the snowpack according to the equation:

$$\text{INFFAC} = 1.0 - \text{FZG} * \text{PACKI}$$

where:

FZG = parameter indicating how much icing reduces infiltration (/inches)
 PACKI = water equivalent of ice in snowpack (inches)

In this method, INFFAC is subject to a minimum, supplied as the dimensionless parameter FZGL.

The second method determines INFFAC according to the soil temperature in the lower layer. If this temperature is less than 0 degrees C, then INFFAC is set to the parameter FZGL; otherwise it is set to 1.0. This method can only be used if section PSTEMP is active.

4.2(1)3.2.1 Dispose of Moisture Supply (subroutine DISPOS)

Purpose

Subroutine DISPOS determines what happens to the moisture supply (MSUPY) on the land segment.

Method

This subroutine calls subordinate routines DIVISN, UZINF, and PROUTE. DIVISN is called to determine how much of MSUPY falls above and below line I in Figure 4.2(1).3-3. The quantity under this line is considered to be infiltrated. The amount over the line but under the MSUPY line (the entire shaded portion) is the potential direct runoff (PDRO), which is the combined increment to interflow, and upper zone storage plus the quantities which will stay on the surface and run off. PDRO is subdivided by line II. The ordinates of line II are found by multiplying the ordinates of line I by RATIO (see subroutine SURFAC for definition). The

quantity underneath both line II and the MSUPY line but above line I is called potential interflow inflow. This consists of actual interflow plus an increment to upper zone storage. Any amount above line II but below the MSUPY (potential surface detention/runoff) is that portion of the moisture supply which stays on the surface and is available for overland flow routing, plus a further increment to upper zone storage. The fractions of the potential interflow inflow and potential surface detention/runoff which are combined to compose the upper zone inflow are determined in subroutine UZINF.

4.2(1).3.2.1.2 Compute Inflow to Upper Zone (subroutines UZINF1 and UZINF2)

Purpose

The purpose of this code is to compute the inflow to the upper zone when there is some potential direct runoff (PDRO). PDRO, which is determined in subroutine DISPOS, will either enter the upper zone storage or be available for either interflow or overland flow. This subroutine determines what amount, if any, will go to the upper zone storage.

Method

The fraction of the potential direct runoff which becomes inflow to the upper zone storage is a function of the ratio (UZRAT) of the storage to the nominal capacity. Figure 4.2(1).3-4 diagrams this relationship. The equations used to define this curve follow:

$$\text{FRAC} = 1 - (\text{UZRAT}/2) * (1/(4 - \text{UZRAT})) ** (3 - \text{UZRAT}) \quad (7)$$

for UZRAT less than or equal to two. For UZRAT greater than two,

$$\text{FRAC} = (0.5/(\text{UZRAT}-1)) ** (2*\text{UZRAT}-3) \quad (8)$$

where:

FRAC = fraction of PDRO retained by the upper zone storage
UZRAT = UZS/UZSN

Since UZS and FRAC are dynamically affected by the inflow process it becomes desirable when using particularly large time steps to integrate over the interval to find the inflow to the upper zone. This is done in subroutine UZINF1. The solution is simplified by assuming that inflow to and outflow from the upper zone are handled separately. Considering inflow, the following differential equation results:

$$d(\text{UZS})/dt = (d(\text{UZRAT})/dt) * \text{UZSN} = \text{PDRO} * \text{FRAC} \quad (9)$$

Thus

$$d(\text{UZRAT})/\text{FRAC} = (\text{PDRO}/\text{UZSN}) * dt \quad (10)$$

Now taking the definite integral of both sides of the equation:

$$\text{INTGRL} = \int_{\text{UZRAT}_{t1}}^{\text{UZRAT}_{t2}} \frac{d(\text{UZRAT})}{\text{FRAC}} = (\text{PDRO}/\text{UZSN})(t2-t1) \quad (11)$$

where:

t1 = time at start of interval

t2 = time at end of interval

The integral on the left side must be evaluated numerically. Subroutine UZINF1 uses tabulated corresponding values of INTGRL and UZRAT to evaluate it. This relationship, plus Equations 9 and 11, enable one to find the change in UZRAT over the interval, and hence, the quantity of inflow.

Subroutine UZINF2, which is an alternative to UZINF1, uses the algorithm used in the predecessor models HSP, ARM and NPS. That is, Equations 7 and 8 are used directly to estimate the fraction of PDRO retained by the upper zone. Only the value of UZRAT at the start of the simulation interval is used; thus, no account is taken of the possible steady reduction in inflow to the upper zone within a single time step, due to its being filled (Figure 4.2(1).3-4).

4.2(1).3.2.1.3 Determine Surface Runoff (subroutine PROUTE)

Purpose

The purpose of subroutine PROUTE is to determine how much potential surface detention runs off in one simulation interval.

Method of Routing

Overland flow is treated as a turbulent flow process. It is simulated using the Chezy-Manning equation and an empirical expression which relates outflow depth to detention storage. A more detailed explanation and derivation can be found in the reports cited in the initial background discussion. The rate of overland flow discharge is determined by the equations:

for SURSM < SURSE

$$\text{SURO} = \text{DELT60} * \text{SRC} * (\text{SURSM} * (1.0 + 0.6(\text{SURSM}/\text{SURSE})^{**3})^{**1.67} \quad (12)$$

for SURSM >= SURSE

$$\text{SURO} = \text{DELT60} * \text{SRC} * (\text{SURSM} * 1.6)^{**1.67}$$

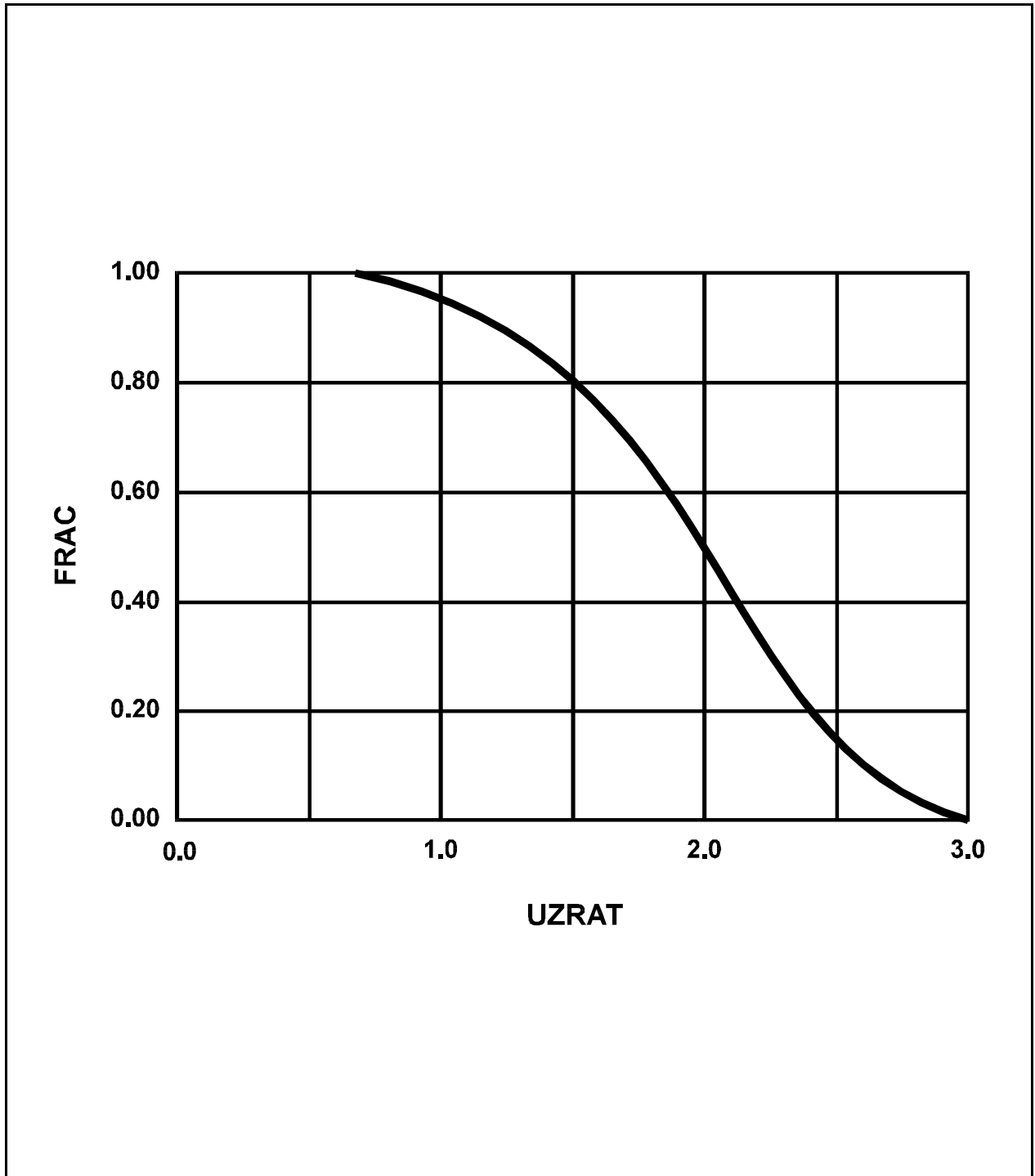


Figure 4.2(1).3-4 Fraction of the potential direct runoff retained by the upper zone (FRAC) as a function of the upper zone soil moisture ratio (UZRAT)

where:

SURO = surface outflow (in/interval)
 DELT60 = DELT/60.0 (hr/interval)
 SRC = routing variable, described below
 SURSM = mean surface detention storage over the time interval (in)
 SURSE = equilibrium surface detention storage (inches) for current supply rate

DELT60 makes the equations applicable to a range of time steps (DELT). The first equation represents the case where the overland flow rate is increasing, and the second case where the surface is at equilibrium or receding. Equilibrium surface detention storage is calculated by:

$$\text{SURSE} = \text{DEC} * \text{SSUPR} ** 0.6 \quad (13)$$

where:

DEC = calculated routing variable, described below
 SSUPR = rate of moisture supply to the overland flow surface

There are two optional ways of determining SSUPR and SURSM. One option - the same method used in the predecessor models - HSP, ARM, and NPS - estimates SSUPR by subtracting the surface storage at the start of the interval (SURS) from the potential surface detention (PSUR) which was determined in subroutine DISPOS. The units of SSUPR are inches per interval. SURSM is estimated as the mean of SURS and PSUR. The other option estimates SSUPR by the same method except that the result is divided by DELT60 to obtain a value with units of inches per hour. SURSM is set equal to SURS. This option is dimensionally consistent for any time step.

The variables DEC and SRC are calculated daily in subroutine SURFAC, but their equations will be given here since they pertain to routing. They are:

$$\text{DEC} = 0.00982 * (\text{NSUR} * \text{LSUR} / \text{SQRT}(\text{SLSUR})) ** 0.6 \quad (14)$$

$$\text{SRC} = 1020.0 * (\text{SQRT}(\text{SLSUR}) / (\text{NSUR} * \text{LSUR})) \quad (15)$$

where:

NSUR = Manning's n for the overland flow plane
 LSUR = length of the overland flow plane (ft)
 SLSUR = slope of the overland flow plane (ft/ft)

NSUR can be input on a monthly basis to allow for variations in roughness of the overland flow plane throughout the year.

4.2(1).3.3 Simulate Interflow (subroutine INTFLW)

Purpose

Interflow can have an important influence on storm hydrographs particularly when vertical percolation is retarded by a shallow, less permeable soil layer. Additions to the interflow component are retained in storage or routed as outflow from the land segment. Inflows to the interflow component may occur from the surface or from upslope external lateral flows. The purpose of this subroutine is to determine the amount of interflow and to update the storage.

Method of Determining Interflow

The calculation of interflow outflow assumes a linear relationship to storage. Thus outflow is a function of a recession parameter, inflow, and storage. Moisture that remains will occupy interflow storage. Interflow discharge is calculated by:

$$IFWO = (IFWK1*INFLO) + (IFWK2*IFWS) \quad (16)$$

where:

IFWO = interflow outflow (in/interval)
 INFLO = inflow into interflow storage (in/interval)
 IFWS = interflow storage at the start of the interval (inches)

IFWK1 and IFWK2 are variables determined by:

$$IFWK1 = 1.0 - (IFWK2/KIFW) \quad (17)$$

$$IFWK2 = 1.0 - \text{EXP}(-KIFW) \quad (18)$$

and

$$KIFW = -\text{ALOG}(\text{IRC}) * \text{DELT60} / 24.0 \quad (19)$$

where:

IRC = interflow recession parameter (per day)
 DELT60 = number of hr per interval
 24.0 = number of hours per day
 EXP = exponential function
 ALOG = natural logarithm function

IRC is the ratio of the present rate of interflow outflow to the value 24 hours earlier, if there was no inflow. IRC can be input on a monthly basis to allow for variation in soil properties throughout the year.

4.2(1).3.4 Simulate Upper Zone Behavior (subroutine UZONE)

Purpose

This subroutine and the subsidiary subroutine UZONES are used to calculate the water percolating from the upper zone. Water not percolated remains in upper zone storage available for evapotranspiration in subroutine ETUZON.

Method of Determining Percolation

The upper zone inflow calculated in DISPOS is first added to the upper zone storage at the start of the interval to obtain the total water available for percolation from the upper zone.

Percolation only occurs when UZRAT minus LZRAT is greater than 0.01. When this happens, percolation from the upper zone storage is calculated by the empirical expression:

$$\text{PERC} = 0.1 * \text{INFILT} * \text{INFFAC} * \text{UZSN} * (\text{UZRAT} - \text{LZRAT}) ** 3 \quad (20)$$

where:

PERC = percolation from the upper zone (in/interval)
 INFILT = infiltration parameter (in/interval)
 INFFAC = factor to account for frozen ground, if any
 UZSN = parameter for upper zone nominal storage (inches)
 UZRAT = ratio of upper zone storage to UZSN
 LZRAT = ratio of lower zone storage to lower zone nominal storage (LZSN)

The upper zone nominal capacity can be input on a monthly basis to allow for variations throughout the year. The monthly values are interpolated to obtain daily values.

4.2(1).3.5 Simulate Lower Zone Behavior (subroutine LZONE)

Purpose

This subroutine determines the quantity of infiltrated and percolated water which enters the lower zone. The infiltrated moisture supply is determined in subroutine DISPOS. The percolated moisture from the upper zone is found in subroutine UZONE.

Method

The fraction of the direct infiltration plus percolation that enters the lower zone storage (LZS) is based on the lower zone storage ratio of LZS/LZSN where LZSN is the lower zone nominal capacity. The inflowing fraction is determined empirically by:

$$\text{LZFRAC} = 1.0 - \text{LZRAT} * (1.0 / (1.0 + \text{INDX})) ** \text{INDX} \quad (21)$$

when LZRAT is less than 1.0, and by

$$\text{LZFRAC} = (1.0 / (1.0 + \text{INDX})) ** \text{INDX} \quad (22)$$

when LZRAT is greater than 1.0. INDX is defined by:

$$\text{INDX} = 1.5 * \text{ABS}(\text{LZRAT} - 1.0) + 1.0 \quad (23)$$

where:

LZFRAC = fraction of infiltration plus percolation entering LZS

LZRAT = LZS/LZSN

ABS = function for determining absolute value

These relationships are plotted in Figure 4.2(1).3-5. The fraction of the moisture supply remaining after the surface, upper zone, and lower zone components are subtracted is added to the groundwater storages.

4.2(1).3.6 Simulate Groundwater Behavior (subroutine GWATER)

Purpose

The purpose of this subroutine is to determine the amount of the inflow to groundwater that is lost to deep or inactive groundwater and to determine the amount of active groundwater outflow. These two fluxes will in turn affect the active groundwater storage.

Method of Determining Groundwater Fluxes

The quantity of direct infiltration plus percolation from the upper zone which does not go to the lower zone (determined in subroutine LZONE) will be inflow to either inactive or active groundwater. The distribution to active and inactive groundwater is user designated by parameter DEEPFR. DEEPFR is that fraction of the groundwater inflow which goes to inactive groundwater. The remaining portion of the percolating water and all external lateral inflow if any make up the total inflow to the active groundwater storage.

The outflow from active groundwater storage is based on a simplified model. It assumes that the discharge of an aquifer is proportional to the product of the cross-sectional area and the energy gradient of the flow. Further, a representative cross-sectional area of flow is assumed to be related to the groundwater storage level at the start of the interval. The energy gradient is estimated as a basic gradient plus a variable gradient that depends on past active groundwater accretion.

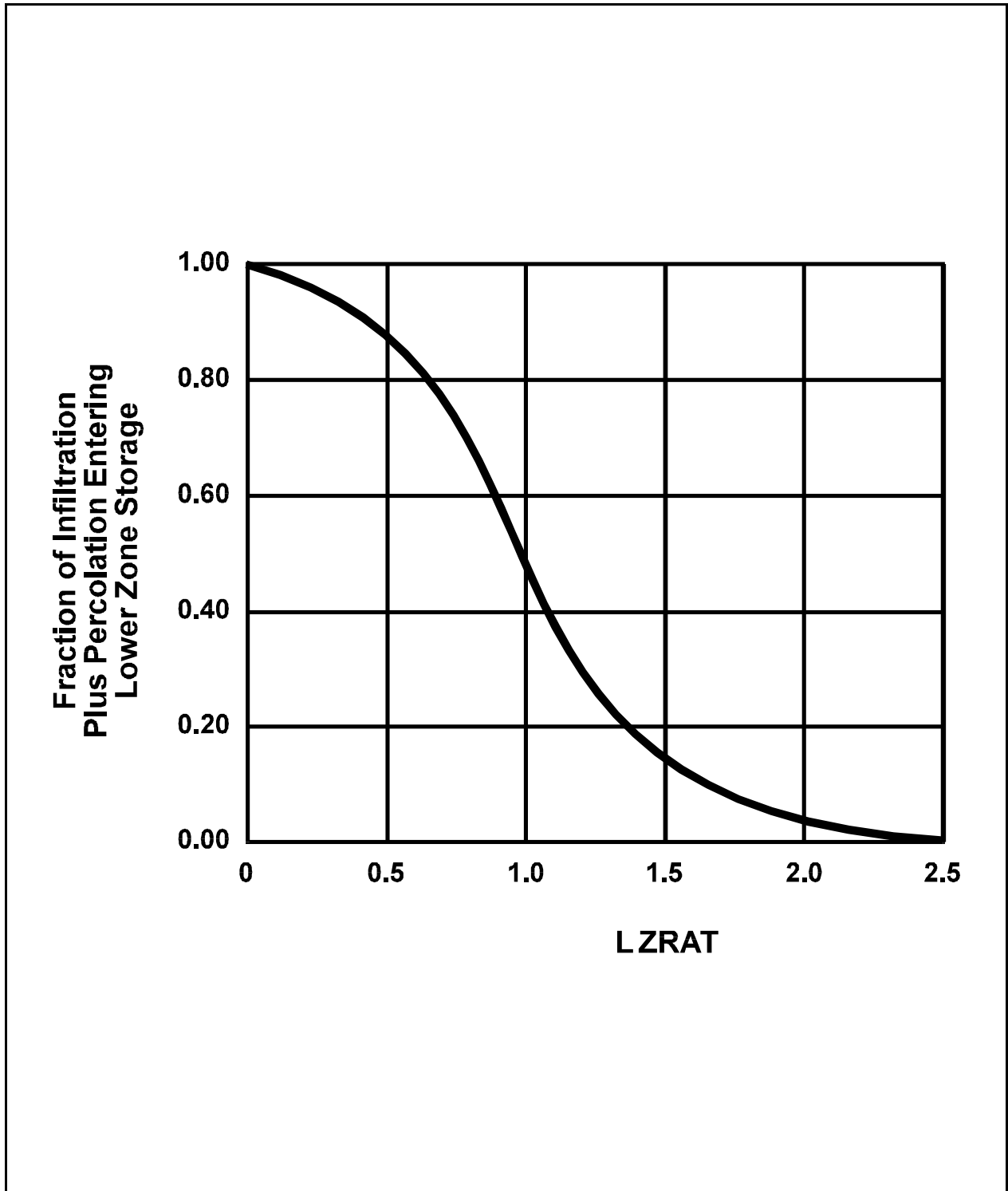


Figure 4.2(1).3-5 Fraction of infiltration plus percolation entering lower zone storage

Thus, the groundwater outflow is estimated by:

$$AGWO = KGW * (1.0 + KVAR * GWVS) * AGWS \quad (24)$$

where:

AGWO = active groundwater outflow (in/interval)
 KGW = groundwater outflow recession parameter (/interval)
 KVAR = parameter which can make active groundwater storage to outflow
 relation nonlinear (/inches)
 GWVS = index to groundwater slope (inches)
 AGWS = active groundwater storage at the start of the interval (inches)

GWVS is increased each interval by the inflow to active groundwater but is also decreased by 3 percent once a day. It is a measure of antecedent active groundwater inflow. KVAR is introduced to allow variable groundwater recession rates. When KVAR is nonzero, a semilog plot of discharge versus time is nonlinear. This parameter adds flexibility in groundwater outflow simulation which is useful in simulating many watersheds.

The parameter KGW is calculated by the Run Interpreter using the relationship:

$$KGW = 1.0 - (AGWRC) ** (DELT60 / 24.0) \quad (25)$$

where:

AGWRC = daily recession constant of groundwater flow if KVAR or GWVS = 0.0
 That is, the ratio of current groundwater discharge
 to groundwater discharge 24-hr earlier
 DELT60 = hr/interval

4.2(1).3.7 Simulate Evapotranspiration (subroutine EVAPT)

Purpose

The purpose of EVAPT and its subordinate subroutines is to simulate evaporation and evapotranspiration fluxes from all zones of the pervious land segment. Since in most hydrologic regimes the volume of water that leaves a watershed as evapotranspiration exceeds the total volume of streamflow, this is an important aspect of the water budget.

Method of Determining Actual Evapotranspiration

There are two separate issues involved in estimating evapotranspiration (ET). First, potential ET must be estimated. ET potential or demand is supplied as an input times series, typically using U.S. Weather Bureau Class A pan records plus an adjustment factor. The data are further adjusted for cover in the parent subroutine PWATER. Second, actual ET must be calculated, usually as a function of moisture storages and the potential. The actual ET is estimated by trying to meet the demand from five sources in the order described below. The sum of the ET from these five sources is the total actual evapotranspiration from the land segment.

Subroutine ETBASE

The first source from which ET can be taken is the active groundwater outflow or baseflow. This simulates effects such as ET from riparian vegetation in which groundwater is withdrawn as it enters the stream. The user may specify by the parameter BASETP the fraction, if any, of the potential ET that can be sought from the baseflow. That portion can only be fulfilled if outflow exists. Any remaining potential not met by actual baseflow evaporation will try next to be satisfied in subroutine EVICEP.

Subroutine EVICEP

Remaining potential ET exerts its demand on the water in interception storage. Unlike baseflow, there is no parameter regulating the rate of ET from interception storage. The demand will draw upon all of the interception storage unless the demand is less than the storage. When the demand is greater than the storage, the remaining demand will try to be satisfied in subroutine ETUZON.

Subroutine ETUZON

There are no special ET parameters for the upper zone, but rather ET is based on the moisture in storage in relation to its nominal capacity. Actual evapotranspiration will occur from the upper zone storage at the remaining potential demand if the ratio of UZS/UZSN, upper zone storage to nominal capacity, is greater than 2.0. Otherwise the remaining potential ET demand on the upper zone storage is reduced; the adjusted value depends on UZS/UZSN. Subroutine ETAGW will attempt to satisfy any remaining demand.

Subroutine ETAGW

Like ET from baseflow, actual evapotranspiration from active groundwater is regulated by a parameter. The parameter AGWETP is the fraction of the remaining potential ET that can be sought from the active groundwater storage. That portion of the ET demand can be met only if there is enough active groundwater storage to satisfy it. Any remaining potential will try to be met in subroutine ETLZON.

Subroutine ETLZON

The lower zone is the last storage from which ET is drawn. Evapotranspiration from the lower zone is more involved than that from the other storages. ET from the lower zone depends upon vegetation transpiration. Evapotranspiration opportunity will vary with the vegetation type, the depth of rooting, density of the vegetation cover, and the stage of plant growth along with the moisture characteristics of the soil zone. These influences on the ET opportunity are lumped into the LZETP parameter. Unlike the other ET parameters LZETP can be input on a monthly basis to account for temporal changes in the above characteristics.

If the LZETP parameter is at its maximum value of one, representing near complete areal coverage of deep rooted vegetation, then the potential ET for the lower zone is equal to the demand that remains. However, this is normally not the case. Usually vegetation type and/or rooting depths will vary over the land segment. To simulate this, a linear probability density function for ET opportunity is assumed (Figure 4.2(1).3-6). This approach is similar to that used to handle areal variations in infiltration/percolation capacity.

The variable RPARM, the index to maximum ET opportunity, is estimated by:

$$\text{RPARM} = (0.25 / (1.0 - \text{LZETP})) * (\text{LZS} / \text{LZSN}) * \text{DELT60} / 24.0 \quad (26)$$

where:

RPARM = maximum ET opportunity (in/interval)
 LZETP = lower zone ET parameter
 LZS = current lower zone storage (inches)
 LZSN = lower zone nominal storage parameter (inches)
 DELT60 = hr/interval

The quantity of water lost by ET from the lower zone storage, when remaining potential ET (REMPET) is less than RPARM, is given by the cross-hatched area of Figure 4.2(1).3-6. When REMPET is more than RPARM the lower zone ET is equal to the entire area under the triangle, RPARM/2.

ET from the lower zone storage is further reduced when LZETP is less than 0.5 by multiplying by LZETP*2.0. This is designed to account for the fraction of the land segment devoid of any vegetation that can draw from the lower zone.

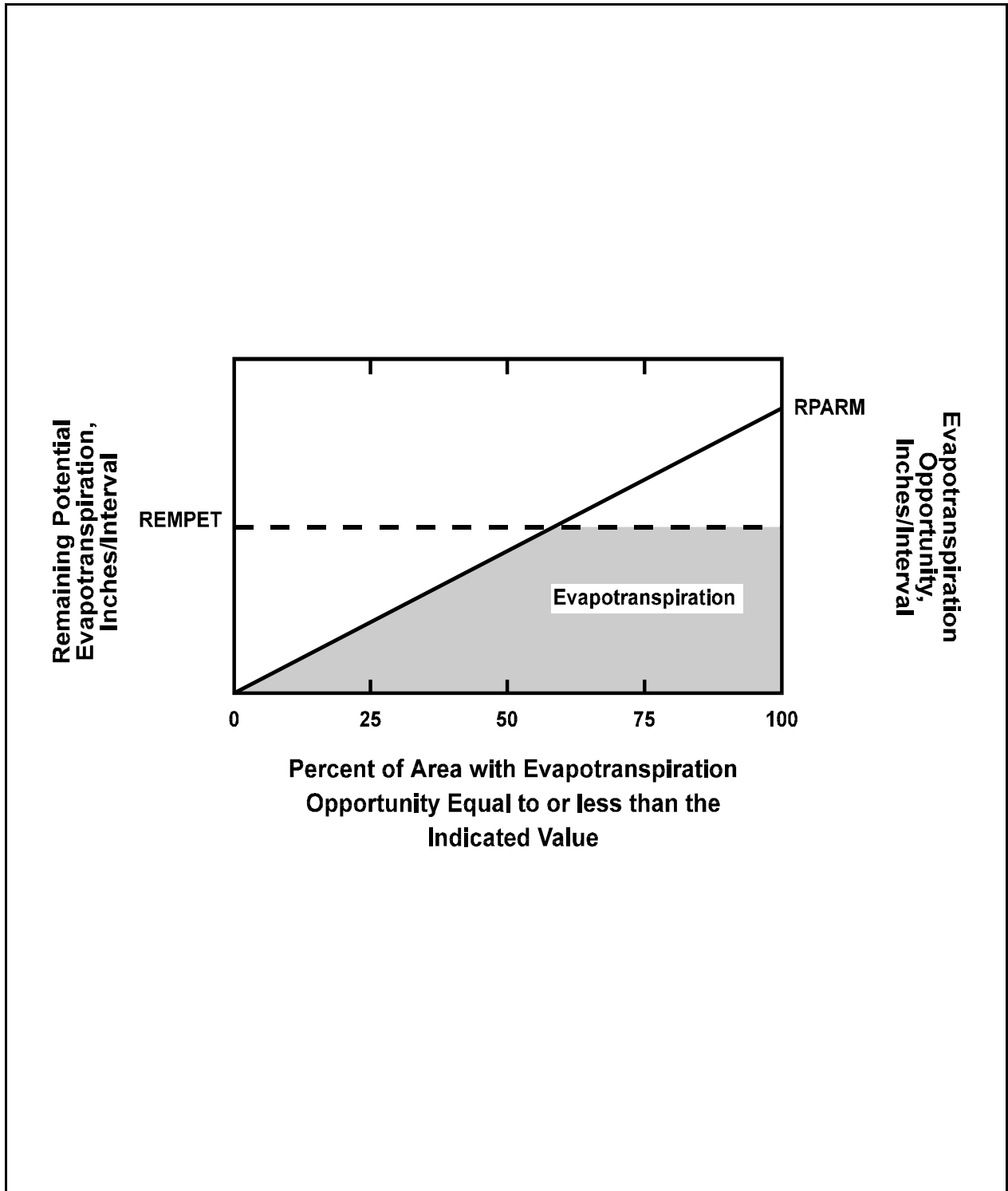


Figure 4.2(1).3-6 Potential and actual evapotranspiration from the lower zone

4.2(1).4 Simulate Production and Removal of Sediment (Section SEDMNT of Module PERLND)

Purpose

Module section SEDMNT simulates the production and removal of sediment from a pervious land segment. Sediment can be considered to be inorganic, organic, or both; the definition is up to the user.

Sediment from the land surface is one of the most common pollutants of waters from urban, agricultural, and forested lands. It muddies waters, covers fish eggs, and limits the capacity of reservoirs. Nutrients and toxic chemicals are carried by it.

Approach

The equations used to produce and remove sediment are based on the predecessor models ARM and NPS (Donigian and Crawford, 1976 a,b). The algorithms representing land surface erosion in these models were derived from a sediment model developed by Moshe Negev (1967) and influenced by Meyer and Wischmeier (1969) and Onstad and Foster (1975). The supporting management practice factor which has been added to the soil detachment by rainfall equation was based on the "P" factor in the Universal Soil Loss Equation (Wischmeier and Smith, 1965). It was introduced in order to better evaluate agricultural conservation practices. The equation that represents scouring of the matrix soil (which was not included in ARM or NPS) was derived from Negev's method for simulating gully erosion.

Figure 4.2(1).4-1 shows the detachment, attachment, and removal involved in the erosion processes on the pervious land surface, while Figure 4.2(1).4-2 schematically represents the fluxes and storages used to simulate these processes. Two of the sediment fluxes, SLSED and NSVI, are added directly to the detached sediment storage variable DETS in the parent routine SEDMNT while the other fluxes are computed in subordinate routines. SLSED represents external lateral input from an upslope land segment. It is a time series which the user may optionally specify. NVSI is a parameter that represents any net external additions or removals of sediment caused by human activities or wind.

Removal of sediment by water is simulated as washoff of detached sediment in storage (WSSD) and scour of matrix soil (SCRSD). The washoff process involves two parts: the detachment/attachment of sediment from/to the soil matrix and the transport of this sediment. Detachment (DET) occurs by rainfall. Attachment occurs only on days without rainfall; the rate of attachment is specified by parameter AFFIX. Transport of detached sediment is by overland flow. The scouring of the matrix soil includes both pick-up and transport by overland flow combined into one process.

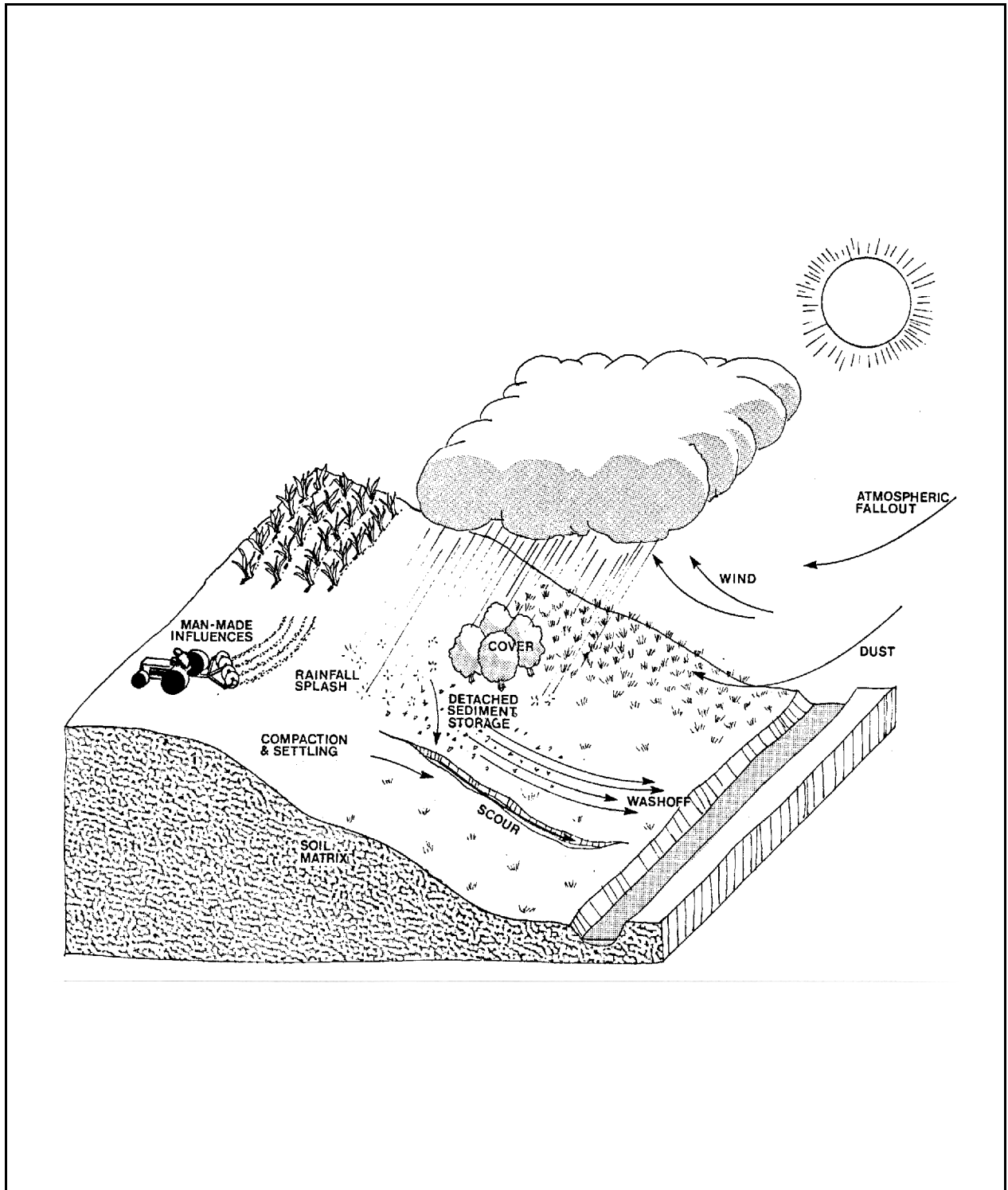


Figure 4.2(1).4-1 Erosion processes

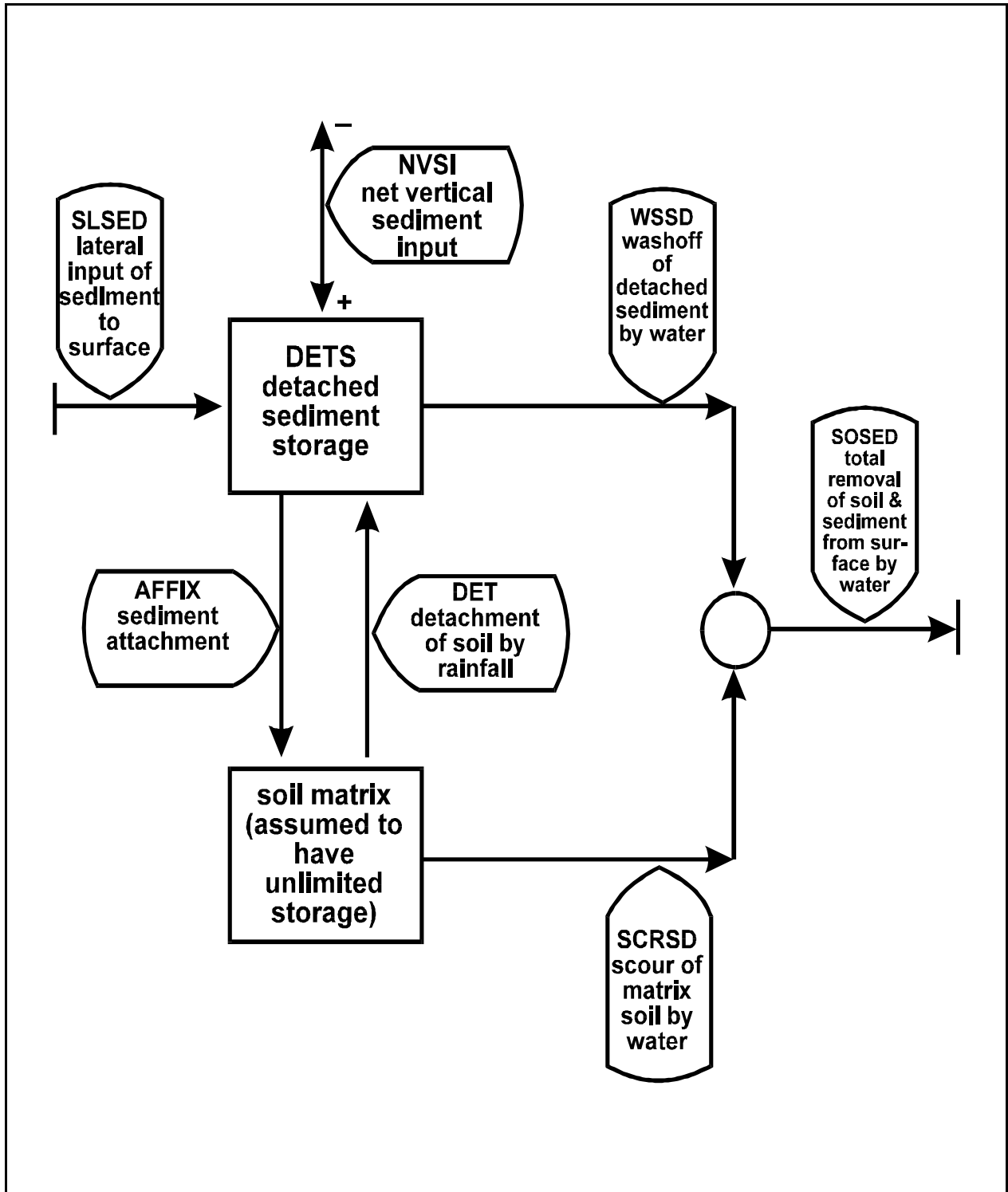


Figure 4.2(1).4-2 Flow diagram for SEDMNT section of PERLND Application Module

Module section SEDMNT has two options for simulating washoff of detached sediment and scour of soil. One uses subroutine SOSED1 which is identical to the method used in the ARM and the NPS Models. However, some equations used in this method are dimensionally nonhomogeneous, and were designed for 15- and 5-min intervals. The results obtained are probably highly dependent on the simulation time step. The other option uses subroutine SOSED2, which is dimensionally homogeneous and is, generally less dependent on the time step.

4.2(1).4.1 Detach Soil By Rainfall (subroutine DETACH)

Purpose

The purpose of DETACH is to simulate the splash detachment of the soil matrix caused by impact of rain.

Method of Detaching Soil by Rainfall

Kinetic energy from rain falling on the soil detaches particles which are then available to be transported by overland flow. The equation that simulates detachment is:

$$DET = DELT60 * (1.0 - CR) * SMPF * KRER * (RAIN / DELT60) ** JRER \quad (1)$$

where:

DET = sediment detached from the soil matrix by rainfall
(tons/ac/interval)
DELT60 = number of hours/interval
CR = fraction of the land covered by snow and other cover
SMPF = supporting management practice factor
KRER = detachment coefficient dependent on soil properties
RAIN = rainfall (in/interval)
JRER = detachment exponent dependent on soil properties

The variable CR is the sum of the fraction of the area covered by the snowpack (SNOCOV), if any, and the fraction that is covered by anything else but snow (COVER). SNOCOV is computed by section SNOW. COVER is a parameter which for pervious areas will typically be the fraction of the area covered by vegetation and mulch. It can be input on a monthly basis.

4.2(1).4.2 Remove by Surface Flow Using Method 1 (subroutine SOSED1)

Purpose

Subroutines SOSED1 and SOSED2 perform the same task but by different methods. They simulate the washoff of the detached sediment and the scouring of the soil matrix.

Method

When simulating the washoff of detached sediment, the transport capacity of the overland flow is estimated and compared to the amount of detached sediment available. The transport capacity is calculated by the equation:

$$STCAP = DELT60 * KSER * ((SURS + SURO) / DELT60) ** JSER \quad (2)$$

where:

STCAP = capacity for removing detached sediment (tons/ac/interval)
 DELT60 = hr/interval
 KSER = coefficient for transport of detached sediment
 SURS = surface water storage (inches)
 SURO = surface outflow of water (in/interval)
 JSER = exponent for transport of detached sediment

When STCAP is greater than the amount of detached sediment in storage, washoff is calculated by:

$$WSSD = DETS * SURO / (SURS + SURO) \quad (3)$$

If the storage is sufficient to fulfill the transport capacity, then the following relationship is used:

$$WSSD = STCAP * SURO / (SURS + SURO) \quad (4)$$

where:

WSSD = washoff of detached sediment (tons/ac/interval)
 DETS = detached sediment storage (tons/ac)

WSSD is then subtracted from DETS.

Transport and detachment of soil particles from the soil matrix is simulated with the following equation:

$$SCRSD = SURO / (SURS + SURO) * DELT60 * KGER * ((SURS + SURO) / DELT60) ** JGER \quad (5)$$

where:

SCRSD = scour of matrix soil (tons/ac/interval)
 KGER = coefficient for scour of the matrix soil
 JGER = exponent for scour of the matrix soil

The sum of the two fluxes, WSSD and SCRSD, represents the total sediment outflow from the land segment.

Subroutine SOSED1 differs from SOSED2 in that it uses the dimensionally nonhomogeneous term $(SURS + SURO) / DELT60$ in the above equations, while SOSED2 uses the homogeneous term $SURO / DELT60$.

4.2(1).4.3 Remove by Surface Flow Using Method 2 (subroutine SOSED2)

Purpose

The purpose of this subroutine is the same as SOSED1. It only differs in method.

Method of Determining Removal

This method of determining sediment removal makes use of the dimensionally homogeneous term $SURO/DELT60$ instead of $(SURO+SURS)/DELT60$.

The capacity of the overland flow to transport detached sediment is determined in this subroutine by:

$$STCAP = DELT60 * KSER * (SURO/DELT60) ** JSER \quad (6)$$

When STCAP is more than the amount of detached sediment in storage, the flow washes off all of the detached sediment storage (DETS). However, when STCAP is less than the amount of detached sediment in storage, the situation is transport limiting, so WSSD is equal to STCAP.

Direct detachment and transport of the soil matrix by scouring (e.g., gullyng) is simulated with the equation:

$$SCRSD = DELT60 * KGER * (SURO/DELT60) ** JGER \quad (7)$$

Definitions of the above terms can be found in subroutine SOSED2. The coefficients and exponents will have different values than in subroutine SOSED1 because they modify different variables.

4.2(1).4.4 Simulate Re-attachment of Detached Sediment (subroutine ATTACH)

Purpose

Subroutine ATTACH simulates the re-attachment of detached sediment (DETS) on the surface (soil compaction).

Method

Attachment to the soil matrix is simulated by merely reducing DETS. Since the soil matrix is considered to be unlimited, no addition to the soil matrix is necessary when this occurs. DETS is diminished at the start of each day that follows a day with no precipitation by multiplying it by $(1.0 - AFFIX)$, where AFFIX is a parameter. This represents a first-order rate of reduction of the detached soil storage.

4.2(1).5 Estimate Soil Temperatures (Section PSTEMP of Module PERLND)

Purpose

PSTEMP simulates soil temperatures for the surface, upper, and lower/groundwater layers of a land segment for use in module section PWTGAS and the agri-chemical sections. Good estimates of soil temperatures are particularly important for simulating first-order transformations in the agri-chemical sections.

Method

The two methods used for estimating soil temperatures are based on the regression equation approach in the ARM Model (Donigian, et al., 1977) and the smoothing factor approach used in HSP QUALITY (Hydrocomp, 1977) to simulate the temperatures of subsurface flows.

Simulation of soil temperatures is done by layers which correspond to those specified in the agri-chemical sections. The surface layer is the portion of the land segment that affects overland flow water quality characteristics. The subsurface layers are upper, lower, and groundwater. The upper layer affects interflow quality characteristics while the lower layer is a transition zone to groundwater. The temperature of the groundwater layer affects groundwater quality transformations and outflow characteristics. Lower layer and groundwater temperatures are considered approximately equal; a single value is estimated for both layers.

Surface layer soil temperatures are estimated by the following regression equation:

$$SLTMP = ASLT + BSLT \cdot AIRT C \quad (1)$$

where:

SLTMP = surface layer temperature (degrees C)

ASLT = Y-intercept

BSLT = slope

AIRT C = air temperature (degrees C)

Temperatures of the other layers are simulated by one of two methods. If TSOPFG is set equal to 1 in the User's Control Input, the upper layer soil temperature is estimated by a regression equation as a function of air temperature (similar to equation above), and the lower layer/groundwater layer temperature is specified by a parameter which can vary monthly. This method is similar to that used in the ARM Model except that ARM relates the upper layer temperature to the computed soil surface temperature instead of directly to air temperature.

If TSOPFG is set equal to zero, both the upper layer and the lower layer/groundwater layer temperatures are computed by using a mean departure from air temperature plus a smoothing factor. The same basic equation is used with separate state variables and parameters for each layer:

$$TMP = TMPS + SMO \cdot (AIRTCS + TDIF - TMPS) \quad (2)$$

where:

TMP = layer temperature at the end of the current interval (degrees C)
SMO = smoothing factor (parameter)
AIRTCS = air temperature at the start of the current interval (degrees C)
TDIF = parameter which specifies the difference between the mean air
temperature and the mean temperature of the soil layer (degrees C)
TMPS = layer temperature at the start of the current interval (degrees C)

If TSOPFG is set to 2, then the method is identical to the above, except that the lower layer/groundwater layer temperature is estimated from the upper layer temperature (ULTMP), instead of directly from the air temperature.

The values of the parameters for any of the layer computations can be linearly interpolated from monthly input values to obtain daily variations throughout the year. If this variation is not desired, the user may supply yearly (constant) values.

4.2(1).6 Estimate Water Temperature and Dissolved Gas Concentrations (Section PWTGAS of Module PERLND)

Purpose

PWTGAS estimates water temperature and concentrations of dissolved oxygen and carbon dioxide in surface, interflow, and groundwater outflows from a land segment.

Method

The temperature of each outflow is considered to be the same as the soil temperature of the layer from which the flow originates, except that water temperature can not be less than freezing. Soil temperatures must either be computed in module section PSTEMP or supplied directly as an input time series. The temperature of the surface outflow is equal to the surface layer soil temperature, the temperature of interflow to the upper layer soil temperature, and the temperature of the active groundwater outflow equals the lower layer and groundwater layer soil temperature.

The dissolved oxygen and carbon dioxide concentrations of the overland flow are assumed to be at saturation and are calculated as direct functions of water temperature. PWTGAS uses the following empirical nonlinear equation to relate dissolved oxygen at saturation to water temperature (Committee on Sanitary Engineering Research, 1960):

$$\text{SODOX} = (14.652 + \text{SOTMP} * (-0.41022 + \text{SOTMP} * (0.007991 - 0.000077774 * \text{SOTMP}))) * \text{ELEVGC} \quad (1)$$

where:

SODOX = concentration of dissolved oxygen in surface outflow (mg/l)
 SOTMP = surface outflow temperature (degrees C)
 ELEVGC = correction factor for elevation above sea level
 (ELEVGC is calculated by the Run Interpreter dependent upon mean elevation of the segment)

The empirical equation for dissolved carbon dioxide concentration of the overland flow (Harnard and Davis, 1943) is:

$$\text{SOCO2} = (10 ** (2385.73 / \text{ABSTMP} - 14.0184 + 0.0152642 * \text{ABSTMP})) * 0.000316 * \text{ELEVGC} * 12000.0 \quad (2)$$

where:

SOCO2 = concentration of dissolved carbon dioxide in surface outflow (mg C/l)
 ABSTMP = temperature of surface outflow (degrees K)

The concentrations of dissolved oxygen and carbon dioxide in the interflow and the active groundwater flow cannot be assumed to be at saturation. Values for these concentrations are provided by the user. They may be specified as constant values or 12 monthly values. If monthly values are provided, daily variation in values will automatically be obtained by linear interpolation between the monthly values.

4.2(1).7 Simulate Quality Constituents Using Simple Relationships with Sediment and Water Yield (Section PQUAL of Module PERLND)

Purpose

The PQUAL module section simulates water quality constituents or pollutants in the outflows from a pervious land segment using simple relationships with water and/or sediment yield. Any constituent can be simulated by this module section. The user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation. However, more detailed methods of simulating sediment, heat, dissolved oxygen, dissolved carbon dioxide, nitrogen, phosphorus, soluble tracers, and pesticide removal from a pervious land segment are available, in other module sections.

Approach

The basic algorithms used to simulate quality constituents are a synthesis of those used in the NPS Model (Donigian and Crawford, 1976b) and HSP QUALITY (Hydrocomp, 1977). However, some options and combinations are unique to HSPF.

Figure 4.2(1).7-1 shows schematically the fluxes and storages represented in module section PQUAL. The occurrence of a water quality constituent in both surface and subsurface outflow can be simulated. The behavior of a constituent in surface outflow is considered more complex and dynamic than the behavior in subsurface flow. A constituent on the surface can be affected greatly by adhesion to the soil and by temperature, light, wind, atmospheric deposition, and direct human influences. Section PQUAL is able to represent these processes in a general fashion. It allows quantities in the surface outflow to be simulated by two methods. One approach is to simulate the constituent by association with sediment removal. The other approach is to simulate it using atmospheric deposition and/or basic accumulation and depletion rates together with depletion by washoff; that is, constituent outflow from the surface is a function of the water flow and the constituent in storage. A combination of the two methods may be used in which the individual outfluxes are added to obtain the total surface outflow. These approaches will be discussed further in the descriptions of the corresponding subroutines. Concentrations of quality constituents in the subsurface flows of interflow and active groundwater are specified by the user. The concentration may be linearly interpolated to obtain daily values from input monthly values.

The user has the option of simulating the constituents by any combination of these surface and subsurface outflow pathways. The outflux from the combination of the pathways simulated will be the total outflow from the land segment. In addition, the user is able to select the units to be associated with the fluxes. These options provide considerable flexibility. For example, a user may wish to simulate coliforms in units of organisms/ac by association with sediment in the surface runoff and use a concentration in the groundwater which varies seasonally. Or a user may want to simulate total dissolved salts in pounds per acre by direct association with overland flow and a constant concentration in interflow and groundwater flow.

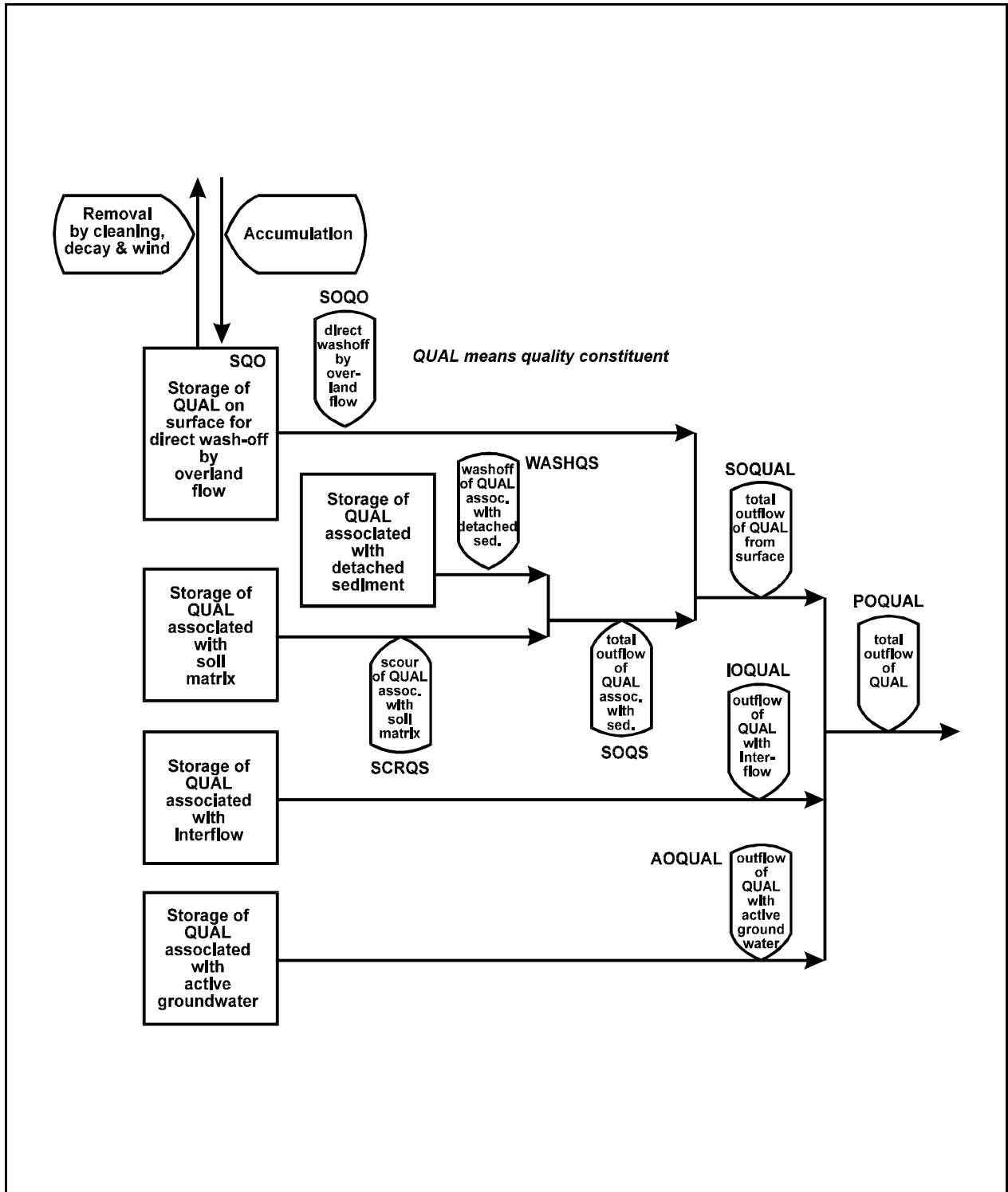


Figure 4.2(1).7-1 Flow diagram for PQUAL section of the PERLND Application Module

PQUAL allows the user to simulate up to 10 quality constituents at a time. Each of the 10 constituents may be defined as one or a combination of the following types: QUALSD, QUALOF, QUALIF, and/or QUALGW. If a constituent is considered to be associated with sediment, it is called a QUALSD. The corresponding terms for constituents associated with overland flow, interflow, and groundwater flow are QUALOF, QUALIF, and QUALGW, respectively. Note that only a QUALOF may receive atmospheric deposition, since it is the only type to maintain a storage. However, no more than seven of any one of the constituent types (QUALSD, QUALOF, QUALIF, or QUALGW) may be simulated in one operation. The program uses a set of flag pointers to keep track of these associations. For example, QSDFP(3) = 0 means that the third constituent is not associated with sediment, whereas QSDFP(6) = 4 means that the sixth constituent is the fourth sediment associated constituent (QUALSD). Similar flag pointer arrays are used to indicate whether or not a quality constituent is a QUALOF, QUALIF, or QUALGW.

4.2(1).7.1 Remove by Association with Sediment (subroutine QUALSD)

Purpose

QUALSD simulates the removal of a quality constituent from a pervious land surface by association with the sediment removal determined in module section SEDMNT.

Method

This approach assumes that the particular quality constituent removed from the land surface is in proportion to the sediment removal. The relation is specified with user-input "potency factors." Potency factors indicate the constituent strength relative to the sediment removed from the surface. Various quality constituents such as iron, lead, and strongly adsorbed toxicants are actually attached to the sediment being removed from the land surface. Some other pollutants such as ammonia, organics, pathogens, and BOD may not be extensively adsorbed, but can be considered highly correlated to sediment yield.

For each quality constituent associated with sediment, the user supplies separate potency factors for association with washed off and scoured sediment (WSSD and SCRSD). Typically, the washoff potency factor would be larger than the scour potency factor because washed off sediment is usually finer than the scoured material and thus has a higher adsorption capacity. Organic nitrogen would be a common example of such a constituent. The user is also able to supply monthly potency factors for constituents that vary somewhat consistently during the year. For instance, constituents that are associated with spring and fall fertilization may require such monthly input values.

Removal of the sediment associated constituent by detached sediment washoff is simulated by:

$$\text{WASHQS} = \text{WSSD} * \text{POTFW} \quad (1)$$

where:

WASHQS = flux of quality constituent associated with
detached sediment washoff (quantity/ac per interval)
WSSD = washoff of detached sediment (tons/ac per interval)
POTFW = washoff potency factor (quantity/ton)

Removal of constituents by scouring of the soil matrix is similar:

$$\text{SCRQS} = \text{SCRSD} * \text{POTFS} \quad (2)$$

where:

SCRQS = flux of quality constituent associated with scouring
of the matrix soil (quantity/ac per interval)
SCRSD = scour of matrix soil (tons/ac per interval)
POTFS = scour potency factor (quantity/ton)

WASHQS and SCRQS are combined to give the total sediment associated flux of the constituent from the land segment, SOQS.

The unit "quantity" refers to mass units (pounds or tons in the English system) or some other quantity, such as number of organisms for coliforms. The unit is user-specified.

4.2(1).7.2 Accumulate and Remove by a Constant Unit Rate and by Overland Flow (subroutine QUALOF)

Purpose

QUALOF simulates the accumulation of a quality constituent on the pervious land surface and its removal by a constant unit rate and by overland flow.

Method

This subroutine differs from the others in module section PQUAL in that the storage of the quality constituent on the land surface is simulated. The constituent can be accumulated and removed by processes which are independent of storm events such as cleaning, decay, and wind erosion and deposition, or it can be washed off by overland flow. The accumulation and removal rates can have monthly values to account for seasonal fluctuations. A pollution indicator such as fecal coliform from range land is an example of a constituent with accumulation and removal rates which may need to vary throughout the year. The concentration of the coliform in the surface runoff may fluctuate with the seasonal grazing density, and the weather.

The constituent may, alternatively or additionally, receive atmospheric deposition. Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time

series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

If atmospheric deposition data are input to the model, the storage of qual is updated as follows:

$$SQO = SQO + ADFX + PREC*ADCN \quad (3)$$

where:

SQO = storage of available quality constituent on the surface (mass/area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition (mass/volume)

When there is surface outflow and some quality constituent is in storage, washoff is simulated using the commonly used relationship:

$$SQOQ = SQO*(1.0 - EXP(-SURO*WSFAC)) \quad (4)$$

where:

SQOQ = washoff of the quality constituent from the land
 surface (quantity/ac per interval)
 SQO = storage of available quality constituent on the surface (quantity/ac)
 SURO = surface outflow of water (in/interval)
 WSFAC = susceptibility of the quality constituent to washoff (/in)
 EXP = exponential function

The storage is updated once a day to account for accumulation and removal which occurs independent of runoff by the equation:

$$SQO = ACQOP + SQOS*(1.0 - REMQOP) \quad (5)$$

where:

ACQOP = accumulation rate of the constituent (quantity/ac per day)
 SQOS = SQO at the start of the interval
 REMQOP = unit removal rate of the stored constituent (per day)

The Run Interpreter computes REMQOP and WSFAC for this subroutine according to:

$$REMQOP = ACQOP/SQOLIM \quad (6)$$

where:

SQOLIM = asymptotic limit for SQO as time approaches infinity
 (quantity/ac), if no washoff occurs

and

$$WSFAC = 2.30/WSQOP \quad (7)$$

where:

WSQOP = rate of surface runoff that results in 90 percent washoff in
one hour (in/hr)

Since the unit removal rate of the stored constituent (REMQOP) is computed from two other parameters, it does not have to be supplied by the user.

4.2(1).7.3 Simulate by Association with Interflow Outflow (subroutine QUALIF)

Purpose

QUALIF is designed to permit the user to simulate the occurrence of a constituent in interflow.

Method

The user specifies a concentration for each constituent which is a QUALIF. Optionally, one can specify 12 monthly values, to account for seasonal variation. In this case, the system interpolates a new value each day.

4.2(1).7.4 Simulate by Association with Active Groundwater Outflow (subroutine QUALGW)

Purpose

QUALGW is designed to permit the user to simulate the occurrence of a constituent in groundwater outflow.

Method

The method is identical to that for QUALIF.

Introduction to the Agri-Chemical Sections

Introduction to the Agri-chemical Sections

The introduction of agricultural chemicals into streams, lakes, and groundwater from agricultural land may be detrimental. For example, persistent fat soluble pesticides, such as DDT, have been known to concentrate in the fatty tissue of animals causing toxic effects. Nitrogen and phosphorus are essential plant nutrients which when introduced into certain surface waters will increase productivity. This may or may not be desirable depending upon management objectives. Significant productivity results in algal blooms, but some increase in productivity will increase fish production. Drinking water containing high nitrate concentrations may cause methomoglobinemia in small children.

Pesticide, nitrogen, and phosphorus compounds are important to agricultural production, but prediction of their removal from the field is necessary for wise management of both land and water resources. HSPF can be used to predict such outflows. The agri-chemical sections of the PERLND module of HSPF simulate in detail nutrient and pesticide processes, both biological and chemical, and the movement of any nonreactive tracer in a land segment. These chemicals can also be simulated in module section PQUAL, but in a simplified manner. The dynamic and continuous processes that affect the storages and outflow of pesticides and of nutrients from fertilized fields should be simulated in detail to fully analyze agricultural runoff. If the situation does not require full representation of these processes, or if data are not available, the PQUAL subroutines could be used.

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for module PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

An additional use of the atmospheric deposition time series is specifying inputs of agricultural chemicals and fertilizers instead of changing soil storages in the SPEC-ACTIONS block. For this purpose, deposition to the upper soil layer in addition to the surface soil layer has been provided for in sections NITR, PHOS, and TRACER. (Section PEST has time series only for the surface layer, since pesticides are not normally incorporated into the soil as are fertilizers.) Depending on the complexity of the agricultural practices being modeled, the user should decide whether the SPEC-ACTIONS block or the time series is simpler to construct.

The basic algorithms in the agri-chemical sections of HSPF were originally developed for use on agricultural lands, but can be used on other pervious areas where pesticides and plant nutrients occur, for example, orchards, nursery land, parks, golf courses, and forests. All pervious land contains nitrogen and phosphorus in the soil; it is possible to use this module to simulate the behavior of agricultural chemicals in any such area.

Introduction to the Agri-Chemical Sections

Comparison of HSPF and ARM

The methods used to simulate pesticide processes in the agri-chemical sections were developed originally for the Pesticide Transport and Runoff (PTR) Model (Crawford and Donigian, 1973), then expanded to include nutrients in the Agricultural Runoff Management (ARM) Model (Donigian and Crawford, 1976) and tested and modified in ARM Version II (Donigian, et al., 1977). In HSPF the ARM Version II algorithms were recreated with some additional options. (For more detail on the basic methods, refer to the above reports.)

The differences between HSPF and ARM Model Version II should, however, be discussed. The biggest difference is the availability of new options to simulate soil nutrient and pesticide adsorption and desorption. Ammonium and phosphate adsorption/desorption in HSPF can be accomplished by using Freundlich isotherms as well as by first-order kinetics. Pesticides can be adsorbed and desorbed by the two Freundlich methods used in the ARM Model or by first-order kinetics. In addition, the pesticide parameter values are now input for each separate soil layer instead of inputting one parameter set for all the layers. HSPF also allows the user to simulate more than one pesticide in a run. (The ARM Model only simulates one per run). In addition to the percolation factors which can still be used to retard any solute leaching from the upper layer and lower layer, a multiplication factor has been introduced that can reduce leaching from the surface layer. Also, in HSPF, nitrogen and phosphorus chemical and biochemical transformations can each be simulated at different time steps to save computer time. Plant uptake of ammonium is also available in HSPF.

Units

The fluxes and storages of chemicals modeled in these module sections are in mass per area units. The user must supply the input in appropriate units; kg/ha for the Metric system, and lb/ac for the English system. Internally, most of the code does not differentiate between the unit systems. Fluxes are determined by either proportionality constants, fractions of chemicals in storage, or unitless concentrations. First-order kinetics makes use of proportionality constants for determining reaction fluxes. Chemicals are transported based on the fractions of that compound in storage. Freundlich adsorption/desorption is based on ppm concentrations.

Module Sections

There are five agri-chemical module sections. They are shown in the structure chart of PERLND (Figure 4.2(1)-1). Module section MSTLAY manipulates water storages and fluxes calculated in module section PWATER. This section must be run before the following sections can be run, since it supplies them with data for simulating the storage and movement of solutes. Module section PEST simulates pesticide behavior while NITR and PHOS simulate the plant nutrients of nitrogen and phosphorus. Simulation of a nonreactive solute is accomplished in module section TRACER.

4.2(1).8 Estimate Moisture Content of Soil Layers and Fractional Fluxes (Section MSTLAY of Module PERLND)

Purpose

This module section estimates the storages of moisture in the four soil layers with which the agricultural chemical sections deal (Figure 4.2(1).8-1); and the fluxes of moisture between the storages. MSTLAY is required because the moisture storages and fluxes computed by module section PWATER can not be directly used to simulate solute transport through the soil. For example, in PWATER, some moisture which infiltrates can reach the groundwater in a single time step (Figure 4.2(1).3-2). While this phenomenon does not have any serious effect in simulating the hydrologic response of a land segment, it does seriously affect the simulation of solute transport.

Thus, MSTLAY takes the fluxes and storages computed in PWATER and adapts them to fit the storage/flow path picture in Figure 4.2(1).8-1. The revised storages, in inches of water, are also expressed in mass/area units (that is, lb/ac or kg/ha) for use in the adsorption/desorption calculations.

Method

Figure 4.2(1).8-1 schematically diagrams the moisture storages and fluxes used in subroutine MSTLAY. Note that the fluxes are represented in terms of both quantity (e.g., IFWI, in inches/interval) and as a fraction of the contributing storage (e.g., FII, as a fraction of UMST/interval). The reader should also refer to Figure 4.2(1).3-2 in module section PWATER when studying this diagram and the following discussion.

For the agri-chemical sections the moisture storages (the variables in Figure 4.2(1).8-1 ending in MST) are calculated by the general equation:

$$\text{MST} = \text{WSTOR} + \text{WFLUX} \quad (1)$$

The variable WSTOR is the related storage calculated in module section PWATER (Figure 4.2(1).3-2). For example, in the calculation of the lower layer moisture storage (LMST), WSTOR is the lower zone storage (LZS). The variable WFLUX generally corresponds to the flux of moisture through the soil layer. For the computation of LMST, WFLUX is the sum of water percolating from the lower zone to the inactive (IGWI) and active groundwater (AGWI) as determined in section PWATER. Note that these equations are dimensionally non-homogeneous, because storages (inches) and fluxes (inches/interval) are added together. Thus, the results given are likely to be highly dependent on the simulation time step. The ARM Model, from which the equations come, uses a time step of 5 minutes. Caution should be exercised if the agricultural chemical sections (including MSTLAY) are run with any other time step.

The upper layer has been subdivided into two storages, principal and transitory. The transitory (interflow) storage is used to transport chemicals from the upper layer to interflow outflow. The chemicals in it do not undergo any reactions. However, reactions do occur in the principal storage.

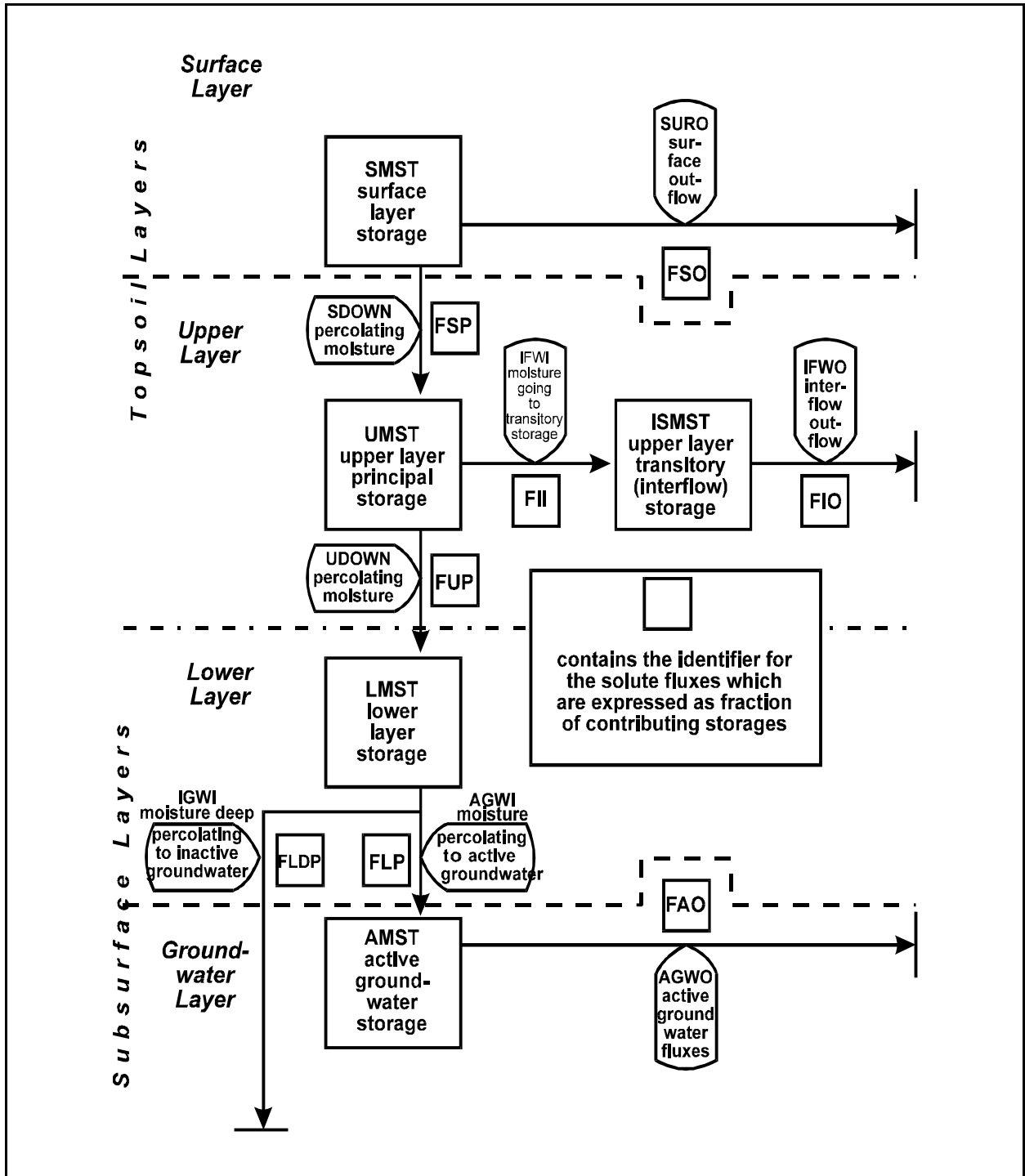


Figure 4.2(1).8-1 Flow diagram showing transport of moisture and solutes as estimated in the MSTLAY section of the PERLND Application Module

The fluxes shown in Figure 4.2(1).8-1 are the same as those in Figure 4.2(1).3-2 with the exceptions of SDOWN and UDOWN. SDOWN encompasses all the water that moves downward from the surface layer storage. It is the combination of the water infiltrating from the surface detention storage directly to the lower zone (INFIL), the inflow to the upper zone (UZI), and the water flowing into interflow storage (IFWI). UDOWN is all the water percolating through the upper layer. It is INFIL plus the percolation from the upper zone storage to the lower zone storage (PERC).

Each fractional solute flux is the appropriate moisture flux divided by the contributing storage. For example, the fraction of chemical in solution that is transported overland from the surface layer storage (FSO) is the surface moisture outflow (SURO) divided by the surface layer moisture storage (SMST).

The above estimates are based on the assumption that the concentration of the solute being transported is the same as that in storage. They also assume uniform flow through the layers and continuous mixing of the solutes. However, these assumptions may need to be revised or implemented differently for some of the transport. Past testing has shown that the above method leads to excessive leaching of solutes (Donigian, et al., 1977). Factors that retard solute leaching were added in the ARM Model Version II to remedy this problem. For the surface layer, the percolation factor (SLMPF) affects the solute fraction percolating (FSP) by the relationship:

$$FSP = SLMPF * SDOWN / SMST \quad (2)$$

The variables SDOWN and SMST are defined in Figure 4.2(1).8-1. FSP will typically be between 0 and 1.

For the upper or lower layer percolating fraction (FUP, FLDP, or FLP), the retardation factor only has an influence when the ratio of the respective zone storage to the nominal storage times the factor ($ZS / (ZSN * LPF)$) is less than one. The relationship under this condition is:

$$F = (ZS / (ZSN * LPF)) * (PFLUX / MST) \quad (3)$$

where:

F = layer solute percolating fraction
 ZS = zone moisture storage, either UZS or LZS
 ZSN = zone nominal moisture storage, either UZSN or LZSN
 LPF = factor which retards solute leaching for the layer, either ULPF or LLPF
 PFLUX = percolation flux, either UDOWN, IGWI, or AGWI
 MST = layer moisture storage, either UMST or LMST

4.2(1).9 Simulate Pesticide Behavior in Detail (Section PEST of Module PERLND)

Purpose

Because of the complexity of pesticide behavior on the land, simulation of the processes frequently requires considerable detail. Pesticide applications vary in amount and time during the year. Various pesticides adsorb and degrade differently. Some, like paraquat, attach themselves strongly to the soil, thereby appearing in low concentrations in water but in high concentrations on soil particles. Others, like atrazine, undergo complex interactions with the soil and are found in higher concentrations in the runoff water than on the eroded sediment.

Section PEST models pesticide behavior by simulating the processes of degradation and adsorption as well as transport. The pesticides are simulated in the soil and runoff in three forms: dissolved, adsorbed, and crystallized. These phases in the soil affect the forms and amounts in the runoff.

Method

Pesticides are simulated by using the time series generated by other PERLND module sections to transport and influence the adsorption and degradation processes. Pesticides move with water flow or by association with the sediment. They also may be adsorbed to the soil in varying degree as a function of the chemical characteristics of the toxicant and the exchange capacity of the soil layer. Pesticide degradation occurs to varying degrees depending upon the susceptibility of the compound to volatilization and breakdown by light, heat, microorganisms and chemical processes. The subroutines in module section PEST consider these transport and reaction processes.

All the subroutines described in this module section except NONSV and DEGRAS are accessed by other agri-chemical module sections because many of the basic transport and reaction processes are similar. The subroutines are described here because they are physically located in this subroutine group. Subroutine AGRGET is first to be called. This subroutine has no computing function; it obtains any required time series (that is not already available) from the INPAD.

Inputs of pesticide to the surface soil layer may be simulated using either or both of two methods: 1) as changes to storage variables in the SPEC-ACTIONS block or 2) as atmospheric deposition. However, atmospheric deposition affects only the surface layer, so if a pesticide is incorporated into the upper soil layer, special actions must be used.

Atmospheric deposition inputs of pesticide can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of

monthly values that is used for each year of the simulation. The specific pesticide atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

If atmospheric deposition data are input to the model, the surface storage is updated for each of the three forms of each pesticide using the formula:

$$SPS = SPS + ADFX + PREC*ADCN \quad (1)$$

where:

SPS = storage of pesticide form on the surface (mass/area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition (mass/volume)

Subroutine SDFRAC determines the fraction of the surface layer soil that has eroded. The amount eroded is the total sediment removed by scour and washoff as determined in module section SEDMNT. The mass of soil in the surface layer is a parameter value which does not vary even when material is removed. The chemical which is associated with the sediment is assumed to be removed from the surface layer storage in the same proportion that the layer has eroded. Chemical removal is simulated in subroutine SEDMOV. A sediment associated chemical is one that may be attached to the eroding soil or one which may move with the soil. With pesticides the adsorbed form will be attached to the soil particle, while the crystalline form will move with the soil particle being eroded but will not be attached to it. Both forms are taken from their respective surface layer storages in proportion to the fraction of the surface soil layer removed by overland flow.

Subroutines TOPMOV and SUBMOV perform a function similar to SEDMOV except they move the solutes. Chemicals in solution move to and from the storages according to the fractions calculated in section MSTLAY. Figure 4.2(1).9-1 schematically illustrates the fluxes and storages used in these subroutines. The fractions (variables beginning with the letter "F") of the storages are used to compute the solute fluxes. The equations used to compute the solute transport fluxes from the fractions and storages are given in the figure. Subroutine TOPMOV performs the calculations of the fluxes and the resulting changes in storage for the topsoil layers (surface and upper), while SUBMOV performs them for the subsurface layers (lower and active groundwater).

Biological and chemical reactions are performed on the pesticides (and other chemicals) in each layer storage. Chemicals in the upper layer principal storage undergo reactions while those in the transitory (interflow) storage do not. The upper layer transitory storage is a temporary storage of chemicals on their way to interflow outflow. Subroutine PSTRXN is called to perform reactions on the pesticide in each layer.

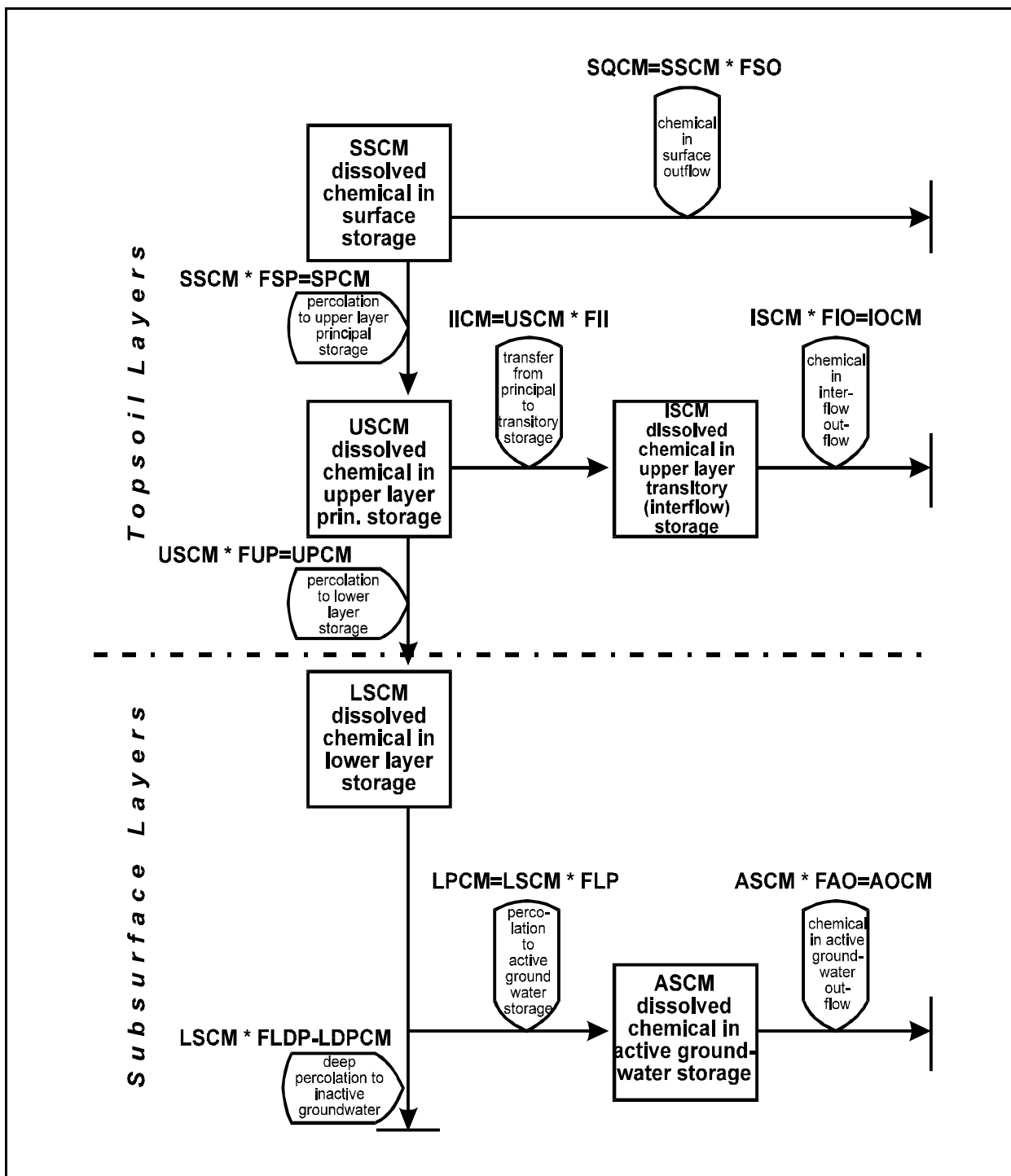


Figure 4.2(1).9-1 Flow diagram showing modeled movement of chemicals in solution

4.2(1).9.5 Perform Reactions on Pesticides
(subroutine PSTRXN)

Purpose

This code simulates the degradation and adsorption/desorption of pesticides. This subroutine is called for each of the four soil layers and each pesticide.

Method of Reacting Pesticides

The user has the option of adsorbing/desorbing the pesticide by one of three methods. The first method is by first-order kinetics. This method assumes that the pesticide adsorbs and desorbs at a rate based on the amount in soil solution and on the amount on the soil particle. It makes use of a proportionality constant and is independent of the concentration. The second method is by use of the single value Freundlich isotherm. This method makes use of a single adsorption/desorption curve for determining the concentration on the soil and in solution. The third method is by use of multiple curves based on a varying Freundlich K value. Further details of these methods can be found in the discussion of the individual subroutines that follows and in documentation of the ARM Model (Donigian and Crawford, 1976; Donigian, et al., 1977).

Degradation is performed once a day in each of the four layers that contain pesticide. The amount degraded is determined simply by multiplying a decay rate parameter specified for each soil layer by each of the three forms (adsorbed, solution, and crystalline) of pesticide in storage. The degraded amounts are then subtracted from their respective storages. This method of simulating degradation lumps complex processes in a simple parameter.

4.2(1).9.5.1 Adsorb/Desorb Using First-Order Kinetics (subroutine FIRORD)

Purpose

The purpose of this subroutine is to calculate the adsorption and desorption reaction fluxes of chemicals using temperature dependent first-order kinetics. These fluxes are calculated every simulation interval when the subroutine is called by section PEST, but they are determined only at the designated chemical reaction frequency when called by sections NITR and PHOS.

Method

The calculation of adsorption and desorption reaction fluxes by first-order kinetics for soil layer temperatures less than 35 degrees C takes the form:

$$DES = CMAD * KDS * THKDS ** (TMP - 35.0) \quad (1)$$

$$ADS = CMSU * KAD * THKAD ** (TMP - 35.0) \quad (2)$$

where:

DES = current desorption flux of chemical (mass/area per interval)
 CMAD = storage of adsorbed chemical (mass/area)
 KDS = first-order desorption rate parameter (per interval)
 THKDS = temperature correction parameter for desorption
 TMP = soil layer temperature (degrees C)
 ADS = current adsorption flux of chemical (mass/area per interval)
 CMSU = storage of chemical in solution (mass/area)
 KAD = first-order adsorption rate parameter (per interval)
 THKAD = temperature correction parameter for adsorption
 THKDS and THKAD are typically about 1.06

All of the variables except the temperature coefficients may vary with the layer of the soil being simulated. The soil temperatures are time series which may be input (e.g., using field data) or simulated in module section PSTEMP. The temperature correction of the reaction rate parameter is based on the Arrhenius equation. At temperatures of 35 degrees C or above, no correction is made. When the temperature is at 0 degrees C or below or the soil layer is dry, no adsorption and desorption occurs.

The storage of the solution chemical is updated every simulation interval in the calling subroutine, that is, in PSTRXN, NITRXN, or PHORXN, by adding DES minus ADS. Likewise, the storage of the adsorbed chemical is updated there also by adding ADS minus DES. An adjustment is made in the calling subroutine if any of the fluxes would cause a storage to go negative. When this happens a warning message is produced and fluxes are adjusted so that no storage goes negative. This usually occurs when large time steps are used in conjunction with large KAD and KDS values.

4.2(1).9.5.2 Adsorb/Desorb Using the Single Value Freundlich Method (subroutine SV)

Purpose

Subroutine SV calculates the adsorption and desorption and the resulting new storages of a chemical using the single value Freundlich method.

Method

The Freundlich isotherm methods, unlike first-order kinetics, assume instantaneous equilibrium. That is, no matter how much chemical is added to a particular phase, equilibrium is assumed to be established between the solution and adsorbed phase of the chemical. These methods also assume that for any given amount of chemical in the soil, the equilibrium distribution of the chemical between the soil solution and on the soil particle can be found from an isotherm. Figure 4.2(1).9-2 illustrates such an isotherm.

Three phases of the chemical are actually possible; crystalline, adsorbed, and solution. The crystalline form is assumed to occur only when the soil layer is dry, or when there is more chemical in the layer than the combined capacity to adsorb and hold in solution. When the soil is dry, all the chemical is considered to be crystalline salt. When there is more total chemical in the soil layer than the soil adsorption sites can contain and more than that saturated in solution, then the chemical content which exceeds these capacities is considered to be crystalline salt. Module section PEST considers crystalline phase storage, but module sections NITR and PHOS do not. Instead, any crystalline phosphate or ammonium predicted by an isotherm is added to the adsorbed phase storage.

The adsorbed and solution phases of the chemical are determined in this subroutine by the standard Freundlich equation as plotted by curve 1 in Figure 4.2(1).9-2. When the amount of chemical is less than the capacity of the soil particle lattice to permanently bind the chemical (XFIX), then all the material is considered fixed. All the fixed chemical is contained in the adsorbed phase of the layer storage. Otherwise, the Freundlich equation for curve 1 is used to determine the partitioning of the chemical into the adsorbed and solution phases:

$$X = KF1 * C^{(1/N1)} + XFIX \quad (3)$$

where:

X = chemical adsorbed on soil (ppm of soil)
 KF1 = single value Freundlich K coefficient
 C = equilibrium chemical concentration in solution (ppm of solution)
 N1 = single value Freundlich exponent
 XFIX = chemical which is permanently fixed (ppm of soil)

The above equation is solved in subroutine ITER by an iteration technique. The parameters used in the computation can differ for each layer of the soil.

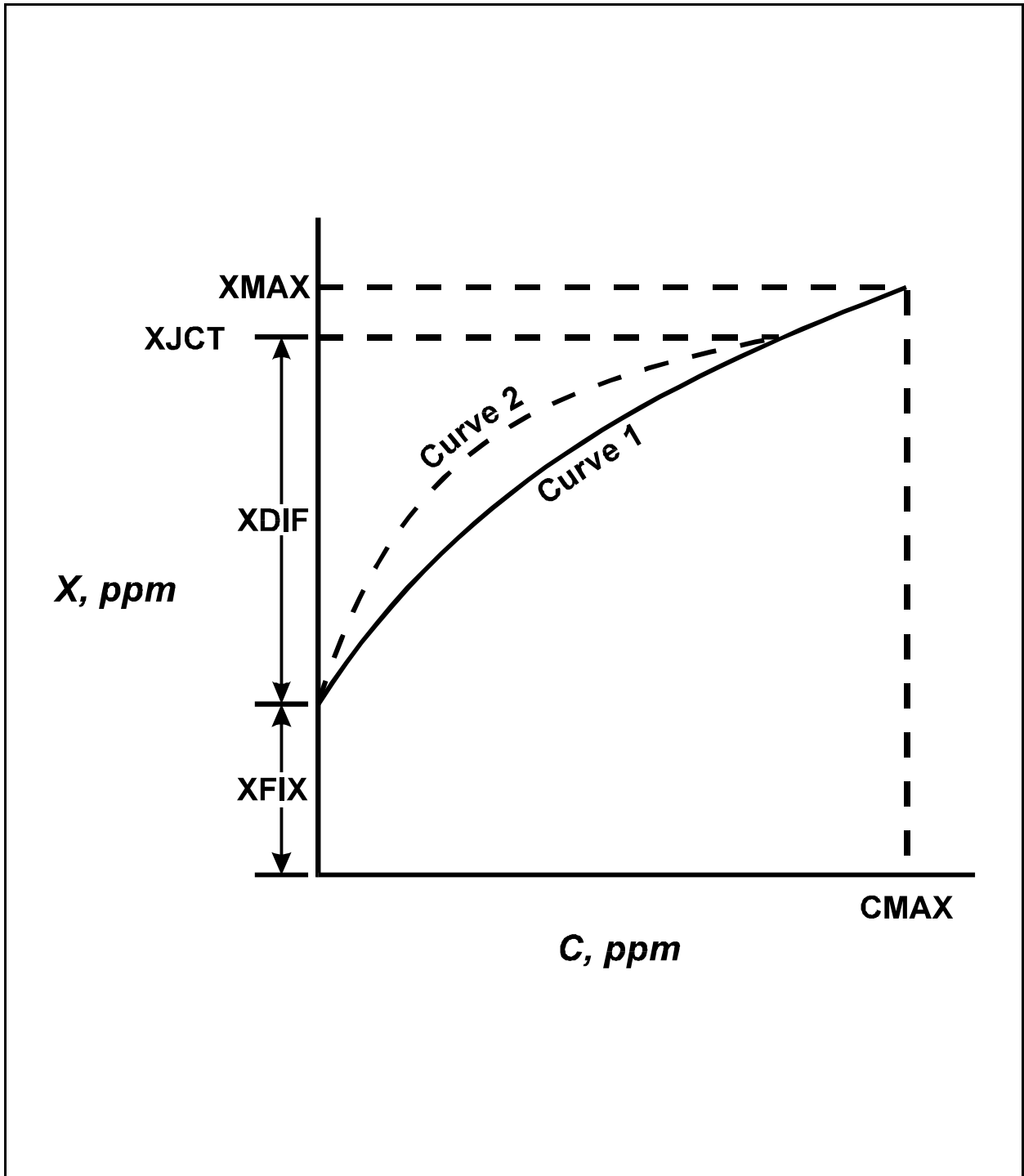


Figure 4.2(1).9-2 Freundlich isotherm calculations

4.2(1).9.5.3 Adsorb/Desorb Using the Non-single Value Freundlich Method (subroutine NONSV)

Purpose

The purpose of this subroutine is to calculate the adsorption/desorption of a chemical by the nonsingle value Freundlich method. The single value Freundlich method was found to inadequately represent the division of some pesticides between the soil particle and solution phases, so this method was developed as an option in the ARM Model (Donigian and Crawford, 1976). This routine is only available for use by the PEST module section.

Method

The approach in this code uses the same algorithms and solution technique as subroutine SV for determining curve 1 in Figure 4.2(1).9-2. However, curve 1 is used solely for adsorption. That is, only when the concentration of the adsorbed chemical is increasing. When desorption occurs a new curve (curve 2) is used:

$$X = KF2 * C^{1/N2} + XFIX \quad (4)$$

$$KF2 = (KF1/XDIF)^{N1/N2} * XDIF \quad (5)$$

where:

KF2 = nonsingle value Freundlich coefficient
 N2 = nonsingle value Freundlich exponent parameter
 XDIF = XJCT - XFIX
 XJCT = the adsorbed concentration where curve 1 joins curve 2
 (i.e., where desorption started)
 as shown in Figure 4.2(1).9-2 (ppm of soil)

The other variables are as defined for subroutine SV.

Once curve 2 is used, both desorption and adsorption follow it until the adsorbed concentration is less than or equal to XFIX or until it reaches XJCT. Then, adsorption will again take place following curve 1 until desorption reoccurs, following a newly calculated curve 2. The solution of the Freundlich equations for curves 1 and 2 utilizes the same iteration technique introduced in subroutine SV (subroutine ITER).

4.2(1).10 Simulate Nitrogen Behavior in Detail (section NITR of module PERLND)

Purpose

NITR, like section PEST, simulates the behavior of chemicals in the soil profile of a land segment. Section NITR handles the nitrogen species of nitrate, ammonia, and organic nitrogen. This involves simulating nitrogen transport and soil reactions. Nitrogen, like phosphorus, may be a limiting nutrient in the eutrophication process in lakes and streams. Nitrates in high concentrations may also pose a health hazard to infants.

Method

Nitrogen species are transported by the same methods used for the pesticide forms. The subroutines that are called to transport nitrogen are located in and described with the PEST module section. Adsorbed ammonium and two forms of particulate organic nitrogen (labile and refractory) are removed from the surface layer storage by association with sediment. These processes are handled by subroutines SDFRAC and SEDMOV. Nitrate, ammonium, and two forms of dissolved organic nitrogen (labile and refractory) in the soil water are transported using the subroutines TOPMOV and SUBMOV. Nitrogen reactions are simulated separately for each of the soil layers. The methods are described below, in the discussion of subroutine NITRXN, and are shown schematically in Figure 4.2(1).10-1.

Inputs of nitrogen to the soil

Natural and agricultural inputs of nitrogen to the surface and upper soil layers can be simulated using either or both of two methods: 1) as changes to storage variables in the SPEC-ACTIONS block, or 2) as atmospheric deposition inputs. Atmospheric deposition inputs are implemented for three species: nitrate, ammonium, and particulate labile organic nitrogen.

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

If atmospheric deposition data are input to the model, the soil storage is updated for each of the three species of nitrogen in each soil layer (surface and upper) using the general formula:

$$\text{NSTOR} = \text{NSTOR} + \text{ADFX} + \text{PREC} * \text{ADCN} \quad (1)$$

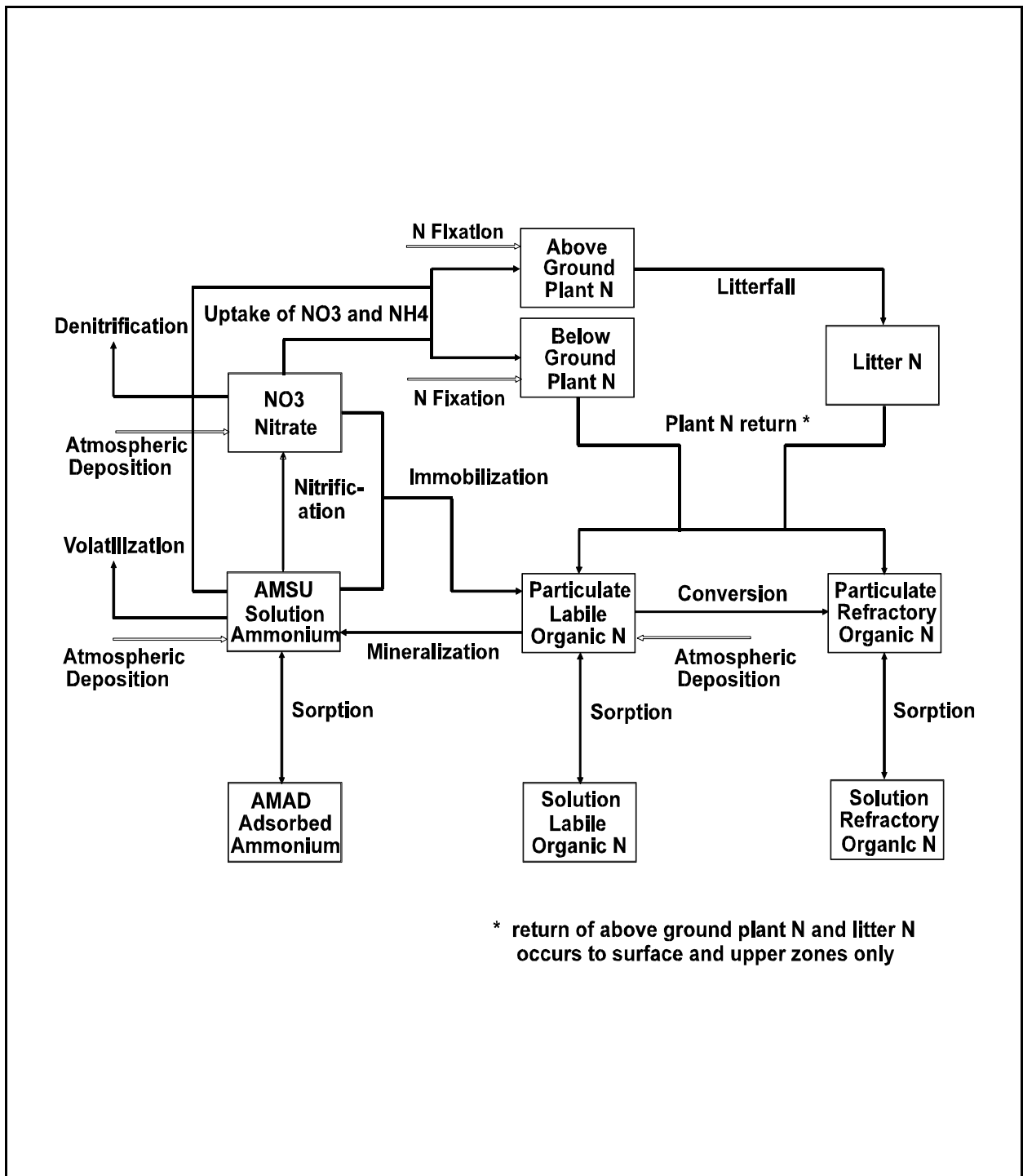


Figure 4.2(1).10-1 Flow diagram for nitrogen reactions

where:

NSTOR = storage of nitrogen species in the soil layer (mass/area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation (depth per interval)
 ADCN = concentration of nitrogen species in rainfall (mass/volume) 4.2(1).10.1

Perform Reactions on Nitrogen Forms (subroutine NITRXN)

Purpose

The purpose of NITRXN is to simulate soil nitrogen transformations. This includes plant uptake of nitrate and ammonium, return of plant nitrogen to organic nitrogen, denitrification or reduction of nitrate-nitrite, immobilization of nitrate-nitrite and ammonium, mineralization of organic nitrogen, fixation of atmospheric nitrogen, volatilization of ammonium, adsorption/desorption of ammonium, and partitioning of two types of organic nitrogen between solution and particulate forms.

Method of Nitrogen Transformations

Adsorption/desorption of ammonium

Nitrogen reactions can be divided between those that are chemical in nature and those that are a combination of chemical and biological reactions. The adsorption and desorption of ammonium is a chemical process. The user has the option of simulating ammonium adsorption and desorption by first-order kinetics with subroutine FIRORD or by the Freundlich isotherm method with subroutine SV. These subroutines are described in the PEST module section.

The user has the option of specifying how often the adsorption and desorption rates are calculated. When adsorption/desorption is simulated by the Freundlich method, the solution and adsorbed storages of ammonium are determined instantaneously at the specified frequency of reaction. However, when the first-order method is used, the temperature-corrected reaction fluxes (Figure 4.2(1).10-1) are recomputed intermittently, but the storages are updated every simulation interval.

Organic Nitrogen Partitioning

Organic nitrogen is assumed to exist in the following four forms in each soil layer.

Particulate labile
 Solution labile
 Particulate refractory
 Solution refractory

The particulate labile species is the default form of organic N in the model; if default values of organic N-related sorption parameters and reaction rates are used, only this form will exist. This species is formed by immobilization of nitrate and ammonia, and is converted back to ammonia by mineralization in the

soil. It also is transported on the surface by association with sediment. However, if the user inputs non-zero values of the parameters, it can undergo conversion by first-order rate to the particulate refractory form, and it can also desorb to the solution labile form. The particulate refractory species can also desorb to the solution refractory form. The two solution species are available for transport with surface runoff and within the soil profile, and the particulate refractory form can be transported on the surface with sediment.

The organic nitrogen partitioning reactions (sorption-desorption) are described by equilibrium isotherms as shown in the following equations:

$$\begin{aligned} \text{KLON} &= \text{PLON}/\text{SLON} \\ \text{KRON} &= \text{PRON}/\text{SRON} \end{aligned} \quad (2)$$

where:

KLON and KRON = partition coefficients for the labile and refractory organic nitrogen, respectively (-)
 PLON = particulate labile organic N (lb N/ac or kg N/ha)
 SLON = solution labile organic N (lb N/ac or kg N/ha)
 PRON = particulate refractory organic N (lb N/ac or kg N/ha)
 SRON = solution refractory organic N (lb N/ac or kg N/ha)

The four organic nitrogen forms and their assorted reactions are illustrated in Figure 4.2(1).10-1. Note that the storages and transformations in this figure are generally repeated in each soil layer except for the aboveground plant N and the litter compartments.

Note that the three new organic nitrogen state variables described above are always present in the NITR module, i.e., they are not optional. However, in order to make the program compatible with previous versions, the default inputs result in the three new forms maintaining zero concentrations; therefore, there should be no impact on the simulation results of existing applications when using the current version of HSPF.

Other Nitrogen Transformations

The other reactions are a combination of biological and chemical transformations. All of these reactions can be modeled using first-order kinetics; optional algorithms can be used for plant uptake of N and immobilization of organic N. The optimum first-order kinetic rate parameter is corrected for soil temperatures below 35 degrees C by the generalized equation:

$$\text{KK} = \text{K} * \text{TH}^{**}(\text{TMP} - 35.0) \quad (3)$$

where:

KK = temperature-corrected first-order reaction rate (/interval)
 K = optimum first-order reaction rate at 35 degrees C (/interval)
 TH = temperature correction coefficient for reaction (typically about 1.06)
 TMP = soil layer temperature (degrees C)

When temperatures are greater than 35 degrees C, the rate is considered optimum, that is, KK is set equal to K . When the temperature of the soil layer is below 4 degrees C or the layer is dry, no biochemical transformations occur.

The corrected reaction rate parameters are determined every biochemical reaction interval and multiplied by the respective storages as shown in Figure 4.2(1).10-1 to obtain the reaction fluxes. Plant uptake can vary monthly and can be distributed between nitrate and ammonium by the parameters $NO3UTF$ and $NH4UTF$. These parameters are intended to designate the fraction of plant uptake from each species of N; the sum of $NO3UTF$ and $NH4UTF$ should be 1.0.

The biochemical reaction rate fluxes that are shown in Figure 4.2(1).10-1 are coupled, that is, added to and subtracted from the storages simultaneously. The coupling of the fluxes is efficient in use of computer time, but has a tendency to produce unrealistic negative storages when large reaction intervals and large reaction rates are used jointly. A method is used which modifies the reaction fluxes so that they do not produce negative storages. A warning message is issued when this modification occurs.

Immobilization of nitrate and ammonia (conversion to particulate labile organic N) can be simulated using either first-order kinetics as described above, or a saturation kinetics (Michaelis-Menten) method. The saturation kinetics option is intended primarily for forests, and is activated when $NUPTFG = 2$ or -2 . Details of this option are presented below, under plant uptake optional methods.

Ammonia Volatilization

Ammonia volatilization is included as an optional ($AMVOFG = 1$) first-order reaction in order to allow large concentrations of ammonia in the soil, resulting from animal waste and fertilizer applications, to be attenuated by losses to the atmosphere. The original formulation by Reddy et al., (1979) included adjustment for variable soil cation exchange capacity (CEC) and wind speed, and it could be "turned off" after seven days. In HSPF, it is assumed that: (1) the CEC factor can be incorporated into the first-order rate constant by the user, and (2) the wind (air flow) is always high enough to result in maximum loss; Reddy's original method reduced the volatilization rate only when wind speed was less than 1.4 km/day. Downward adjustment of the rate, after an initial period of high losses, requires use of the Special Actions capability.

The temperature correction for volatilization of ammonia is slightly different than the standard method used for the other reactions. The reference temperature is user-specified, instead of 35 degrees C, since rates in the literature are often given at a temperature of 20 degrees C. Also, instead of attaining a maximum value at the reference temperature, the volatilization rate is adjusted upwards when the soil temperature exceeds the reference temperature.

Plant nitrogen

The user can select between two optional scenarios for simulating plant nitrogen. If $ALPNFG = 0$, plant N is simulated in each of the four standard soil layers (i.e., surface, upper, lower, and active groundwater). If $ALPNFG = 1$, plant N is also simulated in above-ground and litter compartments, in addition to the standard

below-ground layers. Plant N simulation involves uptake of ammonium and nitrate by the plant, and "return" of plant N to organic N in the soil. Above-ground plant N returns to the litter compartment, and litter plant N returns to the particulate organic N compartments in the surface and upper soil layers. These return "reactions" from above-ground plant N to litter and from litter to surface/upper organic N are simulated using first-order kinetics. No other reactions affect these nitrogen storages except for plant uptake to the above-ground compartment.

Return of plant N to particulate organic N is divided into labile and refractory fractions. By using default values of the return parameters, all plant return becomes labile organic N.

Optional Methods for Modeling Plant Uptake of Nitrogen

There are three optional methods for simulating plant uptake, including the default, first-order method described above. These options are selected using the input flag NUPTFG.

The second method for simulating plant uptake is to use a yield-based algorithm (NUPTFG = 1). This approach is a modification of the algorithm used in the Nitrate Leaching and Economic Analysis Package (NLEAP model) (Shaffer et al, 1991). It is designed to be less sensitive to soil nutrient levels and nutrient application rates than the first-order rate approach (NUPTFG = 0); thus, it allows crop needs to be satisfied, subject to nutrient and moisture availability, without being calculated as a direct function of the soil nutrient level. This approach allows a better representation of nutrient management practices, since uptake levels will not change dramatically with changes in application rates.

In this method, a total annual target, NUPTGT, is specified by the user, and is then divided into monthly targets during the crop growing season; the target is further divided into the four soil layers. The monthly target for each soil layer is calculated as:

$$\text{MONTGT} = \text{NUPTGT} * \text{NUPTFM}(\text{MON}) * \text{NUPTM}(\text{MON}) * \text{CRPFRC}(\text{MON}, \text{ICROP}) \quad (4)$$

where:

MONTGT= monthly plant uptake target for current crop (lb N/ac or kg N/ha)

NUPTGT= total annual uptake target (lb N/ac or kg N/ha)

NUPTFM= monthly fraction of total annual uptake target (-)

NUPTM = soil layer fraction of monthly uptake target (-)

CRPFRC= fraction of monthly uptake target for current crop (-)

This is 1.0 unless the month contains parts of two or more crop seasons, in which case the monthly uptake target is divided among the crops according to the number of days of the month belonging to each season.

MON = current month

ICROP = index for current crop

Planting and harvesting dates can be specified for up to three separate crops during the year. Plant uptake is assumed to occur only during a growing season, defined as the time period between planting and harvest. When portions of two

growing seasons are contained within one month, the total monthly target is divided between the two crops in proportion to the number of days in each season in that month. The daily target is calculated by starting at zero at the beginning of a crop season and using a trapezoidal rule to solve for monthly boundaries; linear interpolation is used to solve for daily values between the monthly boundaries, and between a monthly boundary and a planting or harvest date.

Yield-based plant uptake only occurs when the soil moisture is above the wilting point, which is specified by the user for each soil layer. No temperature rate adjustment is performed, but all uptake is stopped when soil temperature is below 4 degrees C. If the uptake target is not met during a given interval, whether from nutrient, temperature, or moisture stress, then an uptake deficit is accumulated, and applied to the next interval's target. When uptake later becomes possible, the program will attempt to make up the deficit by taking up nitrogen at a rate higher than the normal daily target, up to a user-specified maximum defined as a multiple of the target rate. The deficit is tracked for each soil layer, and is reset to zero at harvest, i.e. it does not carry over from one crop season to the next.

When using the yield-based plant uptake option, it is also possible to represent leguminous plants (e.g. soybeans) that will fix nitrogen from the atmosphere. The algorithm is designed to allow N fixation only to make up any shortfall in soil nitrogen, i.e., fixation is only allowed if the available soil nitrogen (nitrate and solution ammonium) is insufficient to satisfy the target uptake. The maximum daily nitrogen fixation rate is subject to the same limits as the uptake under deficit conditions noted above.

The third option for simulating plant uptake is to use a Michaelis-Menten or saturation kinetics method. This algorithm is included in HSPF primarily for simulating forested areas, and whenever it is selected, the same method is also used to simulate immobilization of ammonium and nitrate. Saturation kinetics is activated for both uptake and immobilization by setting NUPTFG to 2 or -2.

The user specifies a maximum rate and a half-saturation constant for each of the four processes (uptake of nitrate and ammonia, and immobilization of nitrate and ammonia). The input maximum rates can vary monthly. The corresponding reaction fluxes are computed using the general equation:

$$FLUX = KK * CONC / (CS + CONC) \quad (5)$$

where:

FLUX = amount of flux (mg/l/interval)
 KK = temperature corrected maximum rate (mg/l/interval)
 CONC = concentration of nitrogen species in soil layer (mg/l)
 CS = half-saturation constant (mg/l)

The flux is then converted to units of mass per interval.

Regardless of the option used to simulate plant uptake, if the above-ground and litter compartments are being simulated, then the user can specify the fraction of uptake from each layer that goes to the above-ground plant N storage. The remainder is assumed to become plant N within that soil layer.

4.2(1).11 Simulate Phosphorous Behavior in Detail (Section PHOS of Module PERLND)

Purpose

Module section PHOS simulates the behavior of phosphorus in a pervious land segment. This involves modeling the transport, plant uptake, adsorption/desorption, immobilization, and mineralization of the various forms of phosphorus. Because phosphorus is readily tied to soil and sediment, it is usually scarce in streams and lakes. In fact, in many cases it is the limiting nutrient in the eutrophication process. Because of its scarcity, accurate simulation is particularly important.

Method

The method used to transport and react phosphorus is the same as that used for nitrogen in module section NITR. The subroutines used to transport phosphorus are described in module section PEST. Organic phosphorus and adsorbed phosphate are removed with sediment by calling subroutine SEDMOV. Phosphate in solution is transported in the moving water using subroutines TOPMOV and SUBMOV. Phosphorus reactions are simulated in the soil by subroutine PHORXN.

Inputs of the two species of phosphorus to the surface and upper soil layers, natural or agricultural, can be simulated using either or both of two methods: 1) as changes to storage variables in the SPEC-ACTIONS block, or 2) as atmospheric deposition.

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

If atmospheric deposition data are input to the model, the soil storage is updated for each of the two species of phosphorus for both affected soil layers using the formula:

$$P = P + ADFX + PREC*ADCN \quad (1)$$

where:

P = storage of phosphorus species in the soil layer (mass/area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition (mass/volume)

In subroutine PHORXN, phosphate is adsorbed and desorbed by either first-order kinetics or by the Freundlich method. The mechanics of these methods are described in module section PEST. As with the simulation of ammonium adsorption/desorption, the frequency of this chemical reaction for phosphate can also be specified. Unlike ammonium, typically phosphate includes a large portion which is not attached to the soil particle but is combined with cations. This is because phosphate is much less soluble with the ions found in soils than ammonium.

Other reactions performed by subroutine PHORXN include mineralization, immobilization, and plant uptake. These are accomplished using temperature dependent, first-order kinetics; the same method used for the nitrogen reactions. As for nitrogen, a yield-based plant uptake option is available for phosphorus and is activated with PUPTFG = 1. The saturation-kinetics option for uptake and immobilization, however, is not available for phosphorus. The only other difference between nitrogen and phosphorus plant uptake is that only solution phosphate can be taken up by the plant and no fixation process is modeled. The general description of these processes is in module section NITR. Figure 4.2(1).11-1 shows the parameters and equations used to calculate the reaction fluxes for phosphorus. Reactions are simulated for each of the four soil layers using separate parameter sets for each layer. As with nitrogen, the biochemical phosphate reaction fluxes of mineralization, immobilization, and plant uptake can be determined at an interval less frequent than the basic simulation interval.

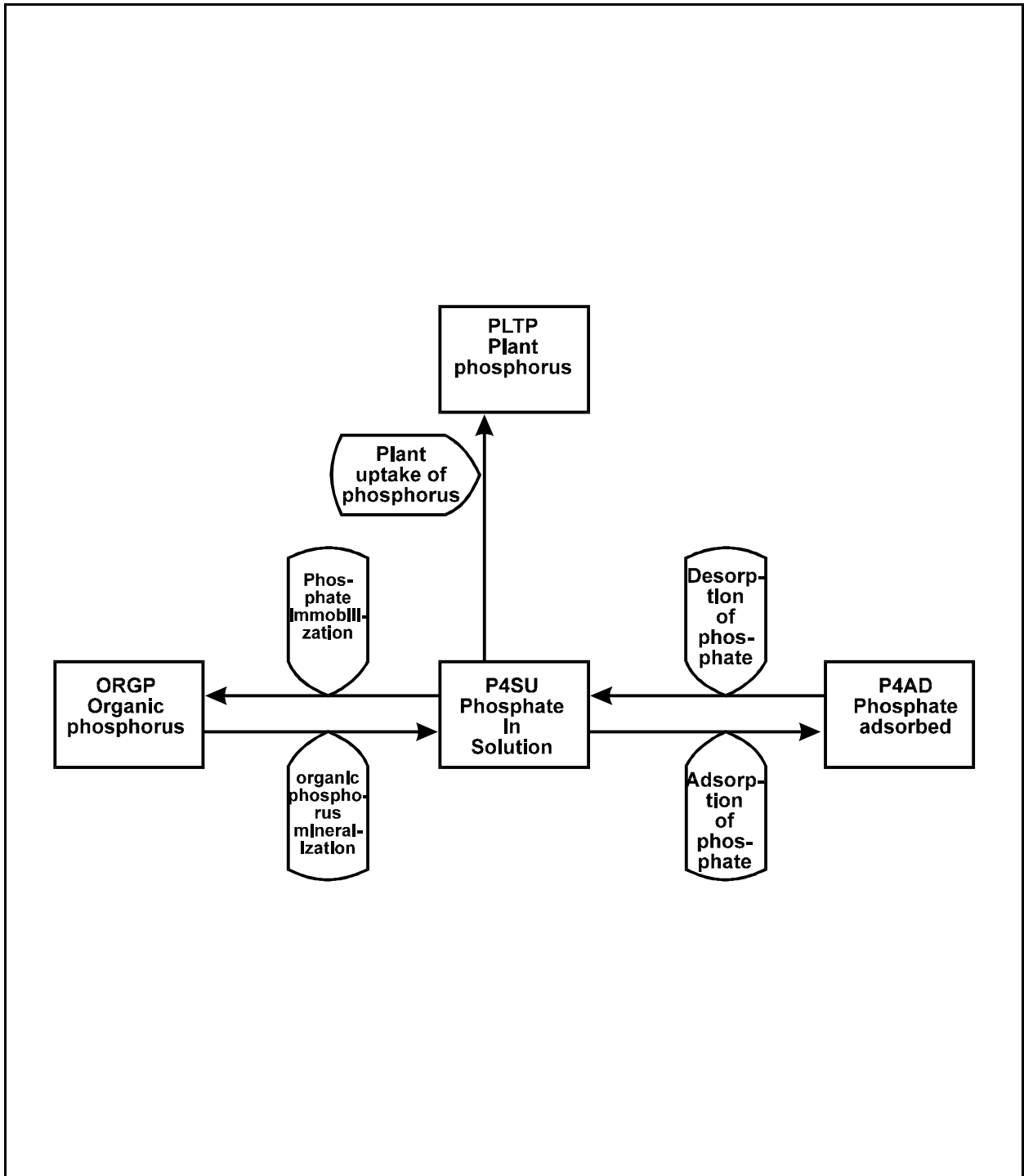


Figure 4.2(1).11-1 Flow diagram for phosphorus reactions

4.2(1).12 Simulate Movement of a Tracer (Section TRACER of Module PERLND)

Purpose

The purpose of this code is to simulate the movement of any nonreactive tracer (conservative) in a pervious land segment. Chloride, bromide, and dyes are commonly used tracers which can be simulated by section TRACER. Also, total dissolved salts could possibly be modeled by this section. Typically, this code is applied to chloride to calibrate solute movement through the soil profile. This involves adjustment of the percolation retardation factors (see section MSTLAY) until good agreement with observed chloride concentrations has been obtained. Once these factors have been calibrated, they are used to simulate the transport of other solutes, such as nitrate.

Method of Simulating Tracer Transport

Tracer simulation uses the agri-chemical solute transport subroutines TOPMOV and SUBMOV which are described in section PEST. No reactions are modeled.

Inputs of the tracer substance to the surface and upper soil layers can be simulated using either or both of two methods: 1) as changes to storage variables in the SPEC-ACTIONS block, or 2) as atmospheric deposition.

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If the deposition is in the form of a concentration in rainfall, then it is considered "wet deposition", and the program automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The specific atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for PERLND, and are specified in the EXT SOURCES block of the UCI. The monthly values are input in the MONTH-DATA block in the UCI.

If atmospheric deposition data are input to the model, then the soil storage of tracer is updated for both affected soil layers using the formula:

$$T = T + ADFX + PREC*ADCN \quad (1)$$

where:

T = storage of tracer in the soil layer (mass/area)
 ADFX = dry or total atmospheric deposition flux (mass/area per interval)
 PREC = precipitation depth
 ADCN = concentration for wet atmospheric deposition (mass/volume)

4.2(2) Simulate an Impervious Land Segment (Module IMPLND)

In an impervious land segment, little or no infiltration occurs. However, land surface processes do occur as illustrated in Figure 4.2(2)-1. Snow may accumulate and melt, and water may be stored or may evaporate. Various water quality constituents accumulate and are removed. Water, solids, and various pollutants flow from the segments by moving laterally to a downslope segment or to a reach/reservoir.

Module IMPLND simulates these processes. The sections of IMPLND and their functions are given in the structure chart shown in Figure 4.2(2)-2. They are executed from left to right. Many of them are similar to the corresponding sections in the PERLND module. In fact, since sections SNOW and ATEMP perform functions that can be applied to pervious or impervious segments, they are shared by both modules. IWATER is analogous to PWATER in module PERLND; SOLIDS is analogous to SEDMNT; IWTGAS is analogous to PWTGAS; and IQUAL is analogous to PQUAL. However, the IMPLND sections are simpler since they contain no infiltration function and consequently no subsurface flows.

4.2(2).3 Simulate the Water Budget for an Impervious Land Segment
(Section IWATER of Module IMPLND)

Purpose

Section IWATER simulates the retention, routing, and evaporation of water from an impervious land segment.

Method

Section IWATER is similar to section PWATER of the PERLND module. However, IWATER is simpler because there is no infiltration and consequently no subsurface processes. IWATER is composed of the parent subroutine plus three subordinate subroutines: RETN, IROUTE, and EVRETN. RETN is analogous to ICEPT, IROUTE is analogous to PROUTE, and EVRETN is analogous to EVICEP in module section PWATER. The time series requirements are the same as for section PWATER.

Figure 4.2(2).3-1 schematically represents the fluxes and storages simulated in module section IWATER. Moisture (SUPY) is supplied by precipitation, or under snow conditions, it is supplied by the rain not falling on the snowpack plus the water yielded by the snowpack. This moisture is available for retention; subroutine RETN performs the retention functions. Lateral surface inflow (SURLI) may also be retained if the user so specifies by setting the flag parameter RTLIFG=1. Otherwise, retention inflow (RETI) equals SUPY. Moisture exceeding the retention capacity overflows the storage and is available for runoff.

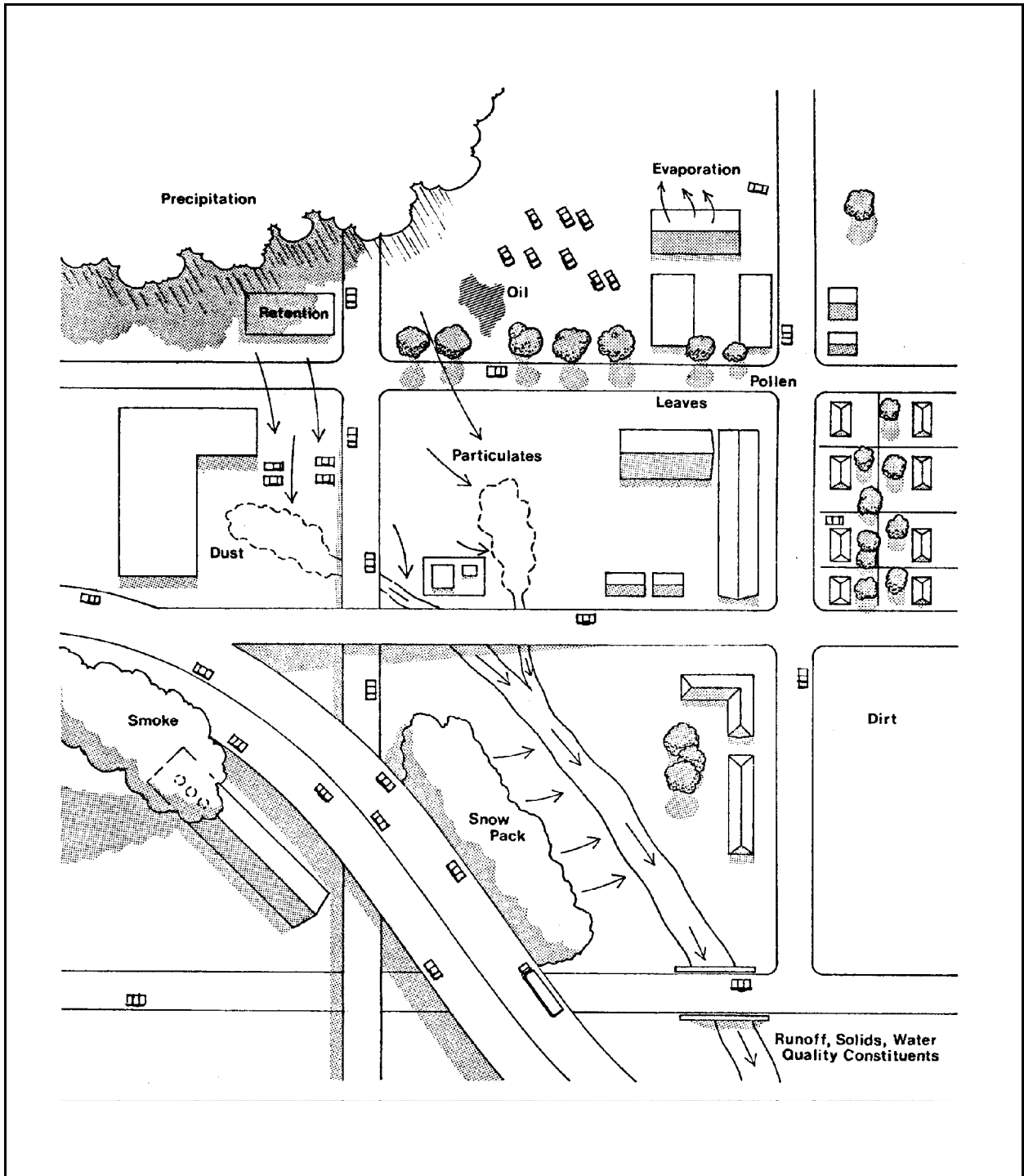


Figure 4.2(2)-1 Impervious land segment processes

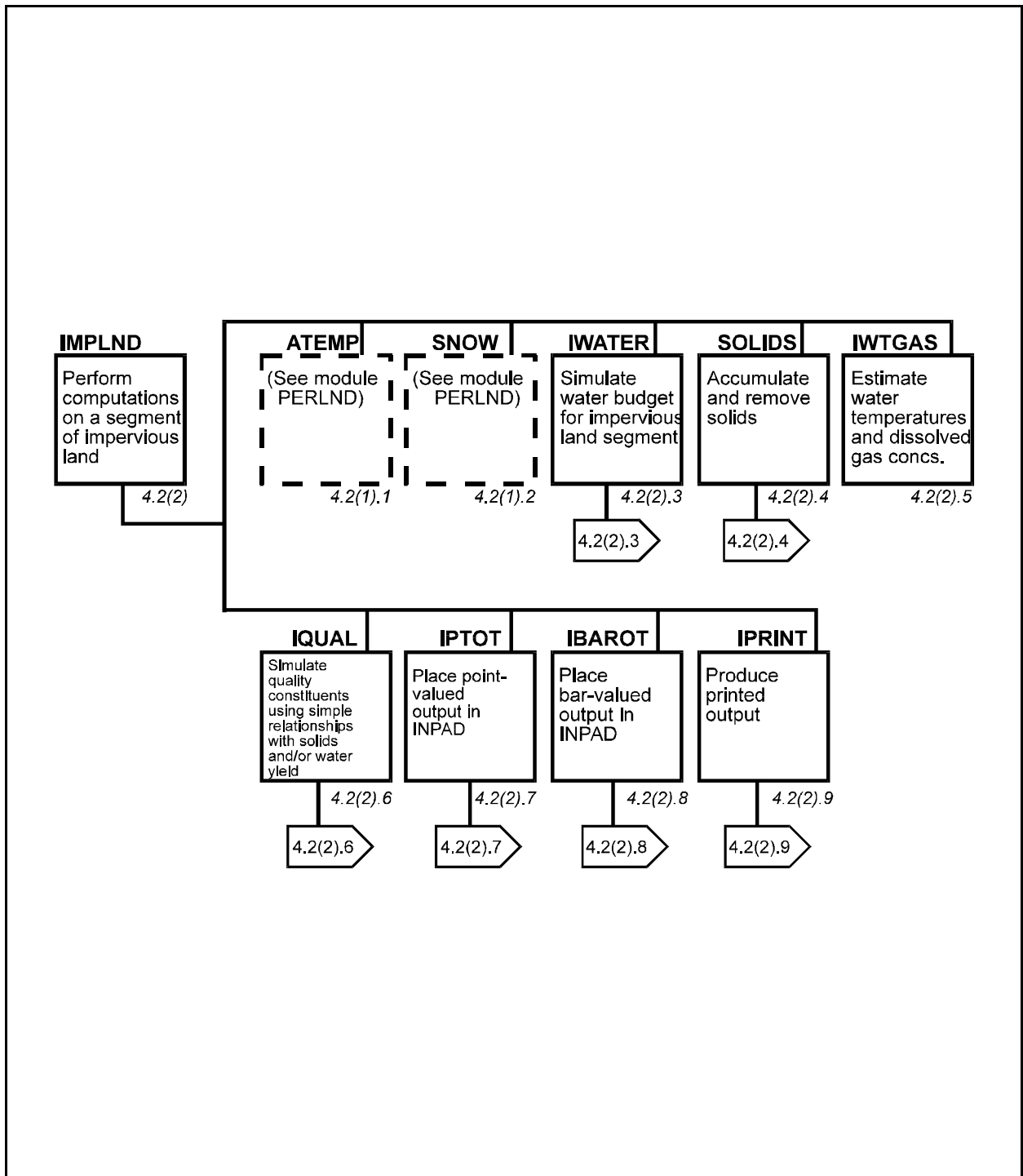


Figure 4.2(2)-2 Structure chart for IMPLND Module

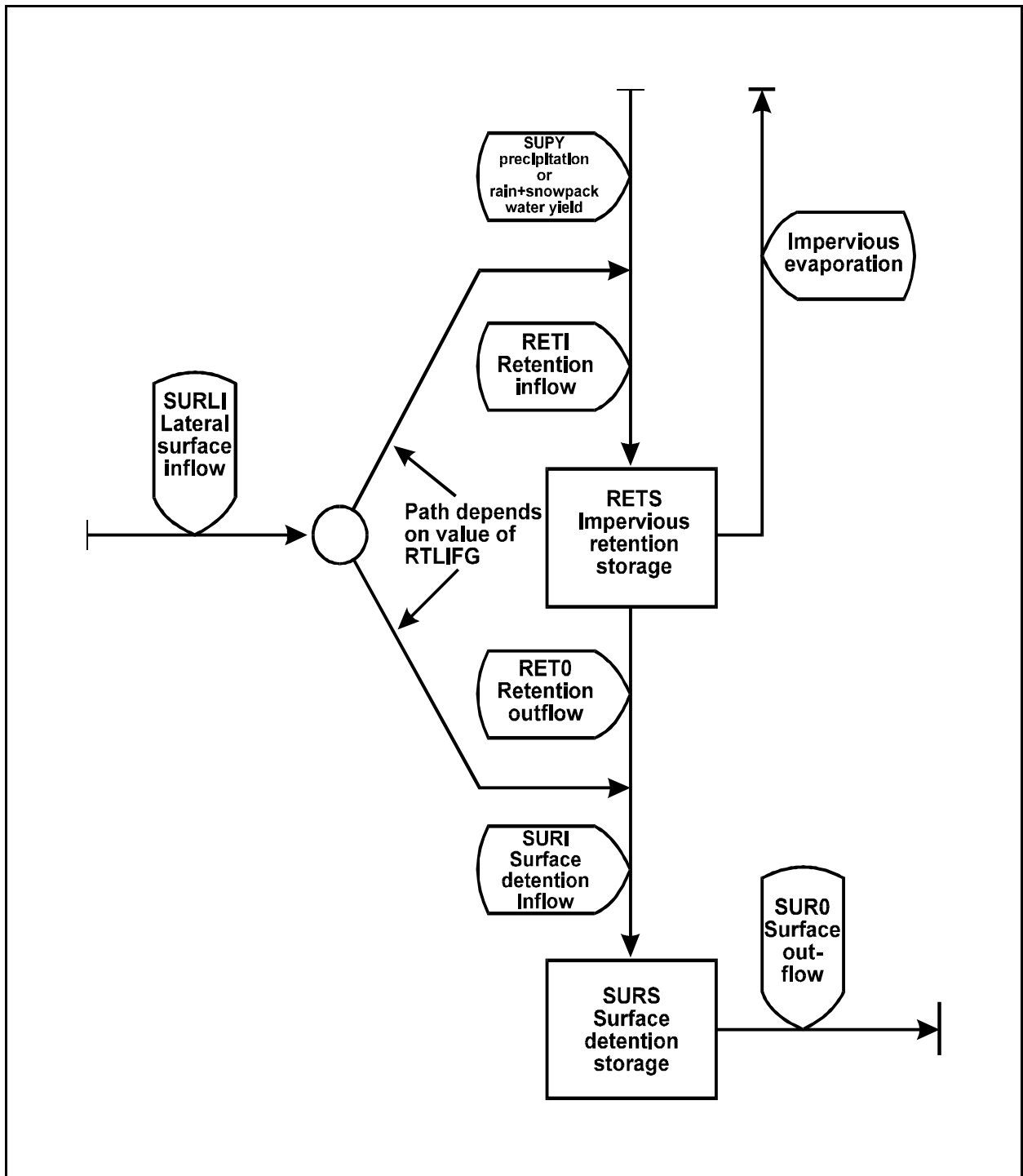


Figure 4.2(2).3-1 Hydrologic Processes

The retention capacity, defined by the parameter RETSC, can be used to designate any retention of moisture which does not reach the overland flow plane. RETSC may be used to represent roof top catchments, asphalt wetting, urban vegetation, improper drainage, or any other containment of water that will never flow from the land segment. The user may supply the retention capacity on a monthly basis to account for seasonal variations, or may supply one value designating a fixed capacity.

Water held in retention storage is removed by evaporation (IMPEV). The amount evaporated is determined in subroutine EVRETN. Potential evaporation is an input time series.

Retention outflow (RETO) is combined with any lateral inflow when RTLIFG=0 producing the total inflow to the detention storage (SURI). Water remaining in the detention storage plus any inflow is considered the moisture supply. The moisture supply is routed from the land surface in subroutine IROUTE.

4.2(2).3.2 Determine How Much of the Moisture Supply Runs Off (subroutine IROUTE)

Purpose

The purpose of subroutine IROUTE is to determine how much of the moisture supply runs off the impervious surface in one simulation interval.

Method of Routing

A method similar to that used in module PERLND (Section 4.2(1).3.2.1.3) is employed to route overland flow.

4.2(2).4 Simulate Accumulation and Removal of Solids (Section SOLIDS of Module IMPLND)

Purpose

Module section SOLIDS simulates the accumulation and removal of solids by runoff and other means from the impervious land segment. The solids outflow may be used in section IQUAL to simulate quality constituents associated with particulates.

Method

The equations used in this section are based on those in the NPS Model (Donigian and Crawford, 1976b). Figure 4.2(2).4-1 schematically represents the fluxes and storages simulated by section SOLIDS. Lateral input of solids by water flow is a user designated option. Washoff of solids may be simulated by one of two ways. One subroutine is similar to the method used in the NPS Model. However, this method is dimensionally nonhomogeneous. That is, a flux and a storage are added making the answer more interval dependent. This technique was designed for 15-min intervals. The other subroutine is dimensionally homogenous, since only a flux term is used in the solution.

The accumulation and removal of solids which occurs independently of runoff (e.g., by atmospheric fallout, street cleaning) is handled in subroutine ACCUM.

4.2(2).4.1 Washoff Solids Using Method 1 (subroutine SOSLD1)

Purpose

Subroutines SOSLD1 and SOSLD2 perform the same task, but by different methods. They simulate the washoff of solids from an impervious land segment.

Method

When simulating the washoff of solids, the transport capacity of the overland flow is estimated and compared to the amount of solids available. The transport capacity is calculated by the equation:

$$STCAP = DELT60 * KEIM * ((SURS + SURO) / DELT60) ** JEIM \quad (1)$$

where:

STCAP = capacity for removing solids (tons/ac per interval)
 DELT60 = hours per interval
 KEIM = coefficient for transport of solids
 SURS = surface water storage (inches)
 SURO = surface outflow of water (in/interval)
 JEIM = exponent for transport of solids

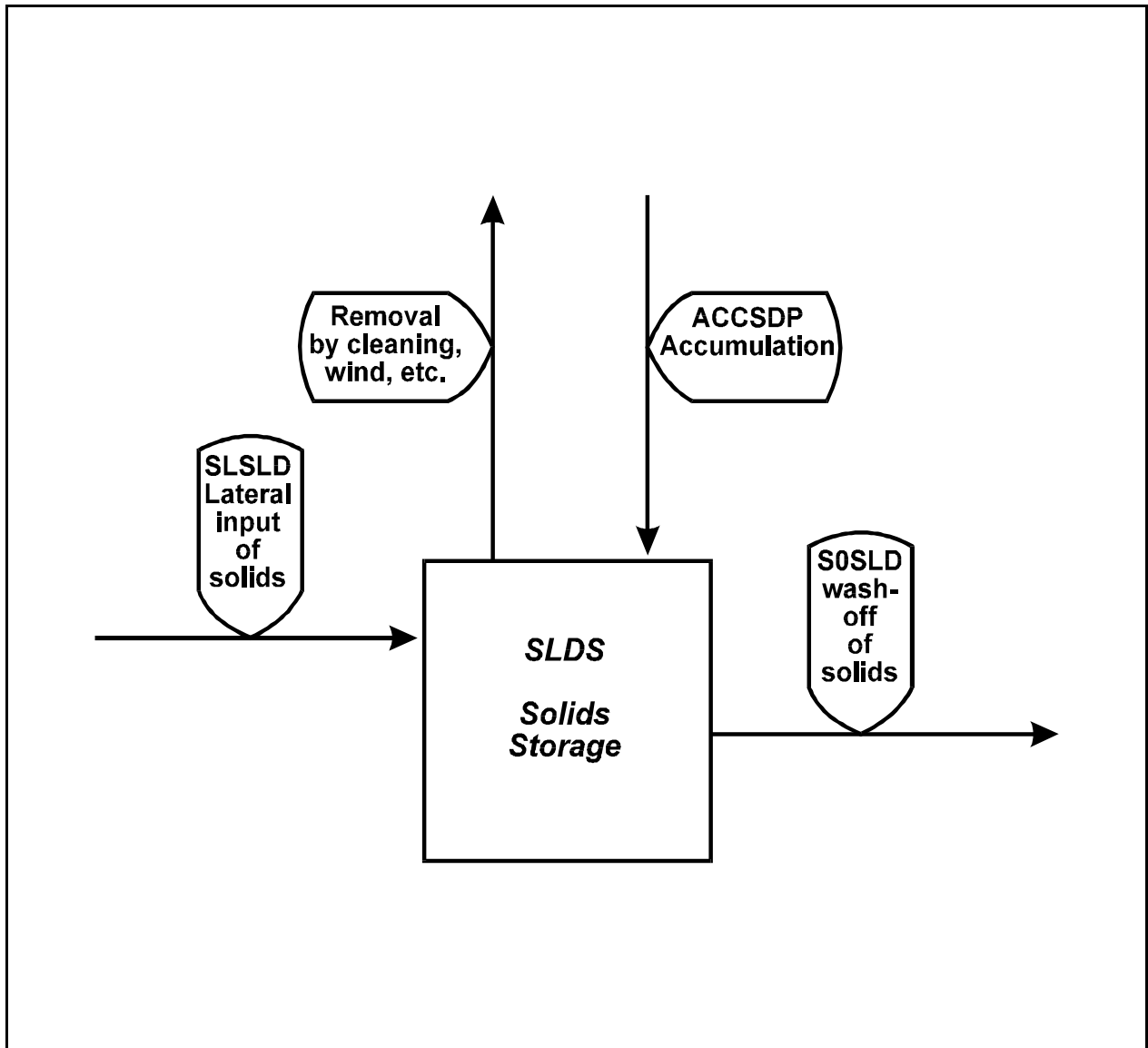


Figure 4.2(2).4-1 Flow diagram of the SOLIDS section of the IMPLND Application Module

When STCAP is greater than the amount of solids in storage, washoff is calculated by:

$$\text{SOSLD} = \text{SLDS} * \text{SURO} / (\text{SURS} + \text{SURO}) \quad (2)$$

If the storage is sufficient to fulfill the transport capacity, then the following relationship is used:

$$\text{SOSLD} = \text{STCAP} * \text{SURO} / (\text{SURS} + \text{SURO}) \quad (3)$$

where:

SOSLD = washoff of solids (tons/ac per interval)

SLDS = solids storage (tons/ac)

SOSLD is then subtracted from SLDS.

Subroutine SOSLD1 differs from SOSLD2 in that it uses the dimensionally nonhomogeneous term $(\text{SURS} + \text{SURO})/\text{DELT60}$ in the above equations, while SOSLD2 uses the homogeneous term $\text{SURO}/\text{DELT60}$.

4.2(2).4.2 Washoff Solids Using Method 2 (subroutine SOSLD2)

Purpose

The purpose of this subroutine is the same as SOSLD1. It only differs in method.

Method of Determining Removal

Unlike subroutine SOSLD1, this method of determining sediment removal makes use of the dimensionally homogeneous term $\text{SURO}/\text{DELT60}$ instead of $(\text{SURO} + \text{SURS})/\text{DELT60}$ in the following equation.

$$\text{STCAP} = \text{DELT60} * \text{KEIM} * (\text{SURO}/\text{DELT60}) ** \text{JEIM} \quad (4)$$

When STCAP is more than the amount of solids in storage, the flow washes off all of the solids storage (SLDS). However, when STCAP is less than the amount of solids in storage, the situation is transport limiting, so SOSLD is equal to STCAP.

4.2(2).4.3 Accumulate and Remove Solids Independently of Runoff (subroutine ACCUM)

Purpose

Subroutine ACCUM simulates the accumulation and removal of solids independently of runoff; for example, atmospheric fallout and street cleaning.

Method

The storage is updated once a day, on those days when precipitation did not occur during the previous day, using the equation:

$$SLDS = ACCSDP + SLDSS*(1.0 - REMSDP) \quad (5)$$

where:

ACCSDP = accumulation rate of the solids storage (tons/ac per day)
 SLDS = solids in storage at end of day (tons/ac)
 SLDSS = solids in storage at start of day (tons/ac)
 REMSDP = unit removal rate of solids in storage
 (i.e., fraction removed per day)

ACCSDP and REMSDP may be input on a monthly basis to account for seasonal variations.

Note: if no runoff occurs, Equation 5 will cause the solids storage to asymptotically approach a limiting value. The limit, found by setting SLDS and SLDSS to the same value (SLDSL), is:

$$SLDSL = ACCSDP/REMSDP \quad (6)$$

4.2(2).5 Estimate Water Temperature and Dissolved Gas Concentrations (Section IWTGAS of Module IMPLND)

Purpose

IWTGAS estimates the water temperature and concentrations of dissolved oxygen and carbon dioxide in the outflow from the impervious land segment.

Method

Outflow temperature is estimated by the following regression equation:

$$\text{SOTMP} = \text{AWTF} + \text{BWTF} * \text{AIRT C} \quad (1)$$

where:

SOTMP = impervious surface runoff temperature (degrees C)
 AWTF = Y-intercept
 BWTF = slope
 AIRT C = air temperature (degrees C)

The parameters AWTF and BWTF may be input on a monthly basis. When snowmelt contributes to the outflow, SOTMP is set equal to 0.5.

The dissolved oxygen and carbon dioxide concentrations of the overland flow are assumed to be at saturation and are calculated as direct functions of water temperature. IWTGAS uses the following empirical nonlinear equation to relate dissolved oxygen at saturation to water temperature (Committee on Sanitary Engineering Research, 1960):

$$\text{SODOX} = (14.652 + \text{SOTMP} * (-0.41022 + \text{SOTMP} * (0.007991 - 0.000077774 * \text{SOTMP}))) * \text{ELEVGC} \quad (2)$$

where:

SODOX = concentration of dissolved oxygen in surface outflow (mg/l)
 SOTMP = surface outflow temperature (degrees C)
 ELEVGC = correction factor for elevation above sea level
 (ELEVGC is calculated by the Run Interpreter dependent upon mean elevation of the segment)

The empirical equation for dissolved carbon dioxide concentration of the overland flow (Harnard and Davis, 1943) is:

$$\text{SOCO2} = (10 ** (2385.73 / \text{ABSTMP} - 14.0184 + 0.0152642 * \text{ABSTMP})) * 0.000316 * \text{ELEVGC} * 12000.0 \quad (3)$$

where:

SOCO2 = concentration of dissolved carbon dioxide in surface outflow (mg C/l)
 ABSTMP = absolute temperature of surface outflow (degrees K)

4.2(2).6 Simulate Washoff of Quality Constituents Using Simple Relationships with Solids and Water Yield (Section IQUAL of Module IMPLND)

Purpose

The IQUAL module section simulates water quality constituents or pollutants in the outflows from an impervious land segment using simple relationships with water yield and/or solids. Any constituent can be simulated by this module section. The user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation. Note that more detailed methods of simulating solids, heat, dissolved oxygen, and dissolved carbon dioxide removal from the impervious land segment are available in other sections of IMPLND.

Approach

The basic algorithms used to simulate quality constituents are a synthesis of those used in the NPS Model (Donigian and Crawford, 1976b) and HSP QUALITY (Hydrocomp, 1977). However, some options and combinations are unique to HSPF.

Figure 4.2(2).6-1 shows schematically the fluxes and storages represented in module section IQUAL. A quality constituent may be simulated by two methods. One approach is to simulate the constituent by association with solids removal. The other approach is to simulate it by using atmospheric deposition and/or basic accumulation and depletion rates together with depletion by washoff; that is, constituent outflow from the surface is a function of the water flow and the constituent in storage. A combination of the two methods may be used in which the individual fluxes are added to obtain the total surface outflow. These approaches will be discussed further in the descriptions of the corresponding subroutines.

IQUAL allows the user to simulate up to 10 quality constituents at a time. If a constituent is considered to be associated with solids, it is called a QUALSD. The corresponding term for constituents associated directly with overland flow is QUALOF. Each of the 10 constituents may be defined as either a QUALSD or a QUALOF or both. Note that only a QUALOF may receive atmospheric deposition, since it is the only type to maintain a storage. However, no more than seven of any one of the constituent types (QUALSD or QUALOF) may be simulated in one operation. The program uses a set of flag pointers to keep track of these associations. For example, QSDFP(3)=0 means that the third constituent is not associated with solids, whereas QSDFP(6)=4 means that the sixth constituent is the fourth solids associated constituent (QUALSD). Similar flag pointer arrays are used to indicate whether or not a quality constituent is a QUALOF.

4.2(2).6.1 Remove by Association with Solids (subroutine WASHSD)

Purpose

WASHSD simulates the removal of a quality constituent from the impervious land surface by association with the solids removal determined in section SOLIDS.

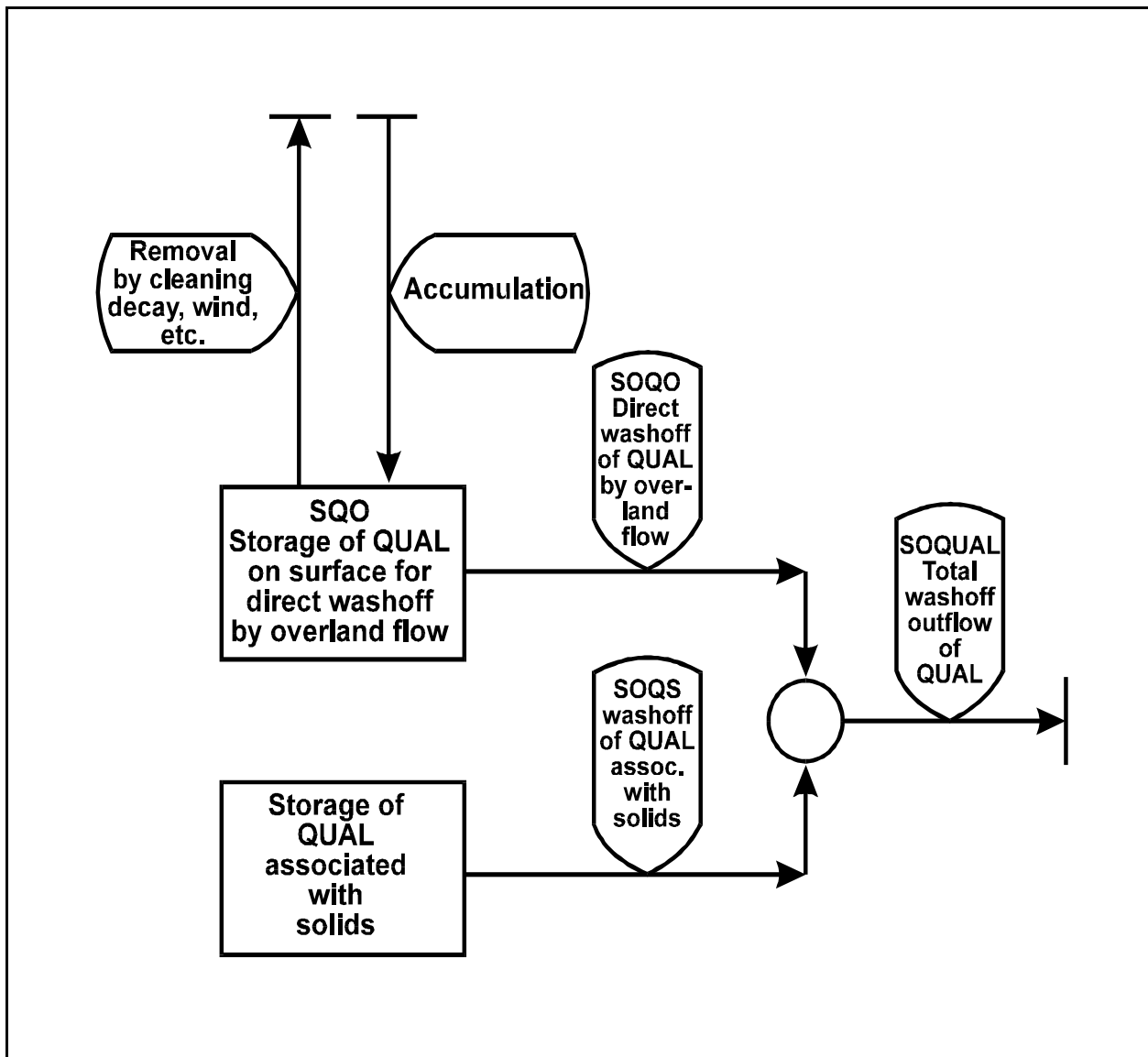


Figure 4.2(2).6-1 Flow diagram for IQUAL section of IMPLND Application Module

Method

This approach assumes that the particular quality constituent removed from the land surface is in proportion to the solids removal. The relation is specified by user-input "potency factors." Potency factors indicate the constituent strength relative to the solids removal from the surface. For each quality constituent associated with solids, the user supplies separate potency factors. The user is also able to supply monthly potency factors for constituents that vary somewhat consistently throughout the year.

Removal of the solids associated constituent by solids washoff is simulated by:

$$SOQS = SOSLD * POTFW \quad (1)$$

where:

SOQS = flux of constituent associated with solids washoff
(quantity/ac per interval)

SOSLD = washoff of detached solids (tons/ac per interval)

POTFW = washoff potency factor (quantity/ton)

The unit "quantity" refers to mass units (pounds or tons in the English system) or some other quantity, such as number of organisms for coliforms. The user specifies the units of "quantity."

4.2(2).6.2 Accumulate and Remove by a Constant Unit Rate and by Overland Flow (subroutine WASHOF)

Purpose

WASHOF simulates the accumulation of a quality constituent on the impervious land surface and its removal by a constant unit rate and by overland flow.

Method

This subroutine differs from subroutine WASHSD in that the storage of the quality constituent is simulated. The stored constituent can be accumulated and removed by processes which are independent of storm events, such as cleaning, decay, and wind deposition, and it is washed off by overland flow. The accumulation and removal rates can have monthly values to account for seasonal fluctuations. The constituent may, alternatively or additionally, receive atmospheric deposition.

Atmospheric deposition inputs can be specified in two possible ways depending on the form of the available data. If the deposition is in the form of a flux (mass per area per time), then it is considered "dry deposition". If it is in the form of a concentration in rainfall, then it is considered "wet deposition", and HSPF automatically combines it with the input rainfall time series to compute the resulting flux. Either type of deposition data can be input as a time series, which covers the entire simulation period, or as a set of monthly values that is used for each year of the simulation. The atmospheric deposition time series are documented in the EXTNL table of the Time Series Catalog for IMPLND, and are input in the EXT SOURCES block. The monthly values are input in the MONTH-DATA block.

If atmospheric deposition data are input, the surface storage is updated:

$$SQO = SQO + ADFX + PREC*ADCN \quad (1)$$

where:

SQO = storage of available quality constituent on the surface
(mass/area)
ADFX = dry or total atmospheric deposition flux (mass/area per interval)
PREC = precipitation depth
ADCN = concentration for wet atmospheric deposition (mass/volume)

When there is surface outflow and some quality constituent is in storage, then washoff is simulated using the commonly used relationship:

$$SQOQ = SQO*(1.0 - EXP(-SURO*WSFAC)) \quad (2)$$

where:

SQOQ = washoff of the quality constituent from the land
surface (quantity/ac per interval)
SQO = storage of the quality constituent on the surface (quantity/ac)
SURO = surface outflow of water (in/interval)
WSFAC = susceptibility of the quality constituent to washoff (/inch)
EXP = exponential function

The storage is updated once a day to account for accumulation and removal which occurs independent of runoff by the equation:

$$SQO = ACQOP + SQOS*(1.0 - REMQOP) \quad (3)$$

where:

ACQOP = accumulation rate of the constituent (quantity/ac per day)
SQOS = SQO at the start of the interval
REMQOP = unit removal rate of the stored constituent (per day)

The Run Interpreter computes REMQOP and WSFAC for this subroutine according to:

$$REMQOP = ACQOP/SQOLIM \quad (4)$$

where:

SQOLIM = asymptotic limit for SQO as time approaches infinity,
if no washoff occurs (quantity/ac),

and

$$WSFAC = 2.30/WSQOP \quad (5)$$

where:

WSQOP = rate of surface runoff that results in 90% washoff in 1 hour (in/hr)

Since the unit removal rate (REMQOP) is computed from two other parameters, it is not supplied directly by the user.