RAMCC HPM Design Document

3 Mar 2005

Objective

The objective is to replace AFSIRS because of several deficiencies in AFSIRS (See HPM subteam notes 17Dec04). However, we want to maintain the simplicity the afsirs provides and maintain most of AFSIRS functionality for calculating irrigation requirements while fixing the soil water budget for non-optimal irrigation. The revised afsirs will be written in C++ and written to be compatible with RSM. The processes to be included in ramcc.cc are presented below.

Background

The AFSIRS.FOR model is a simple daily irrigation requirement estimation model. It has a simple water budget model that accounts for evapotranspiration losses and irrigation. It was designed to estimate long-term irrigation requirements for a variety of crops using daily climatic data. The AFSIRS model was constructed with two soil water zones: irrigated and non-irrigated and roots could obtain water from both zones. Although that works reasonably well for estimating optimal irrigation requirements for well-irrigated crops in soils with well-behaved water tables, it does not work well where the water table rises frequently into the root zone. It also does not work well for non-optimally irrigated crops. For this improvement of AFSIRS the two-compartment soils will be replaced with a 4-compartment soil. This should resolve water redistribution problems created by the equalization redistribution process in the current AFSIRS model.

Afsirs Water Budget Processes

To better reflect the hydrologic processes on irrigated agricultural and urban land, including golf courses, water storage has been divided into four soil water storage zones and surface water interception storage (Fig. 1). Although all four soil water storage zones occur in most agricultural land, there are several instances where the not all zones exist. For example, in irrigated pasture and golf courses the entire land is irrigated and there is no zone c or d. In vegetables that are grown under plastic mulch and container nurseries, there is no zone c. The soil water storages are listed below and the hydrologic processes of each zone are presented:

Interception – surface water storage
Zone a – irrigated root zone
Zone b – non-irrigated root zone below Zone a
- neceives water from Zone a by percolation

Zone c – non-irrigated root zone adjacent to Zone a & b
- water can redistribute laterally into zone a & b. In mulched vegetables there may not be any zone c (ie, a = 0.4 b = 0.4 c=0 d=0.6)

Zone d – non-irrigated non-root zone adjacent to Zone c
- this zone disappears with full irrigation by flood, seepage or sprinkler.

Watertable – a watertable is maintained under the soil to provide for upflux, seepage irrigation and field drainage
- the water table is necessary to reflect the effect of the regional heads on agriculture and maintain an accurate water balance.

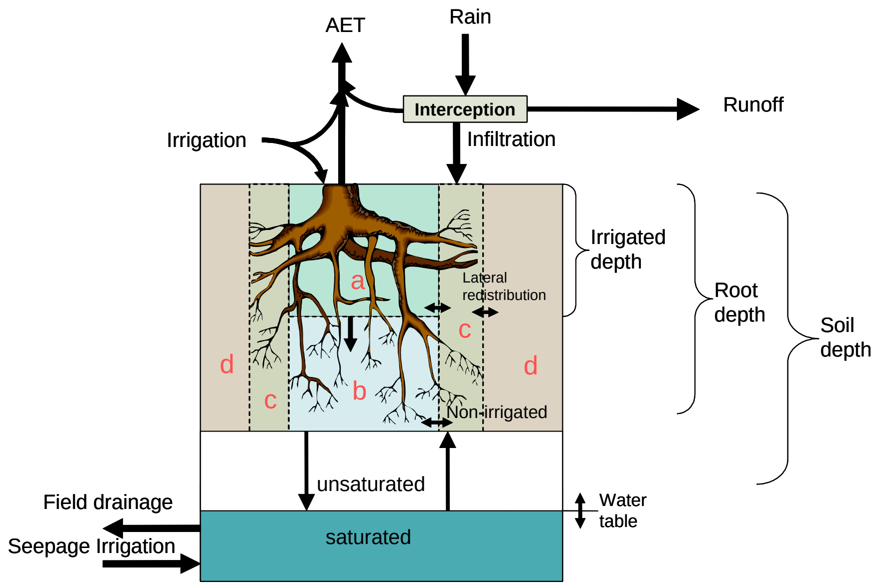

Figure 1. Soil water storages and hydrologic processes for afsirs.cc

Interception

Surface zone processes describe the interaction between rain and irrigation and infiltration (Fig. 2). In AFSIRS daily rain and irrigation were applied directly to the soil water budget. In the revised ramcc.cc rain is partitioned into interception, runoff and infiltration. A small interception storage (interception needs to be handled as a storage, it may hold water from day to day and it is necessary for rice irrigation) must be filled before rain can infiltrate the soil. The interception storage is emptied by evaporation that reduces the amount of water available for evapotranspiration from the soil through the plants. Rain can produce runoff if the infiltration capacity of the soil is exceeded. Although the native infiltration capacity of the sandy soils commonly found in South Florida exceed 40 cm/hr, the maximum infiltration rate for soil on managed land is reduced by compaction and mixing with subsoil. Therefore, there will be a maximum infiltration rate assigned by major landuse type that if exceeded will produce runoff. (In the first implementation this will be set as a constant for all applications.) Runoff may also occur as a result of the water table reaching the ground surface.

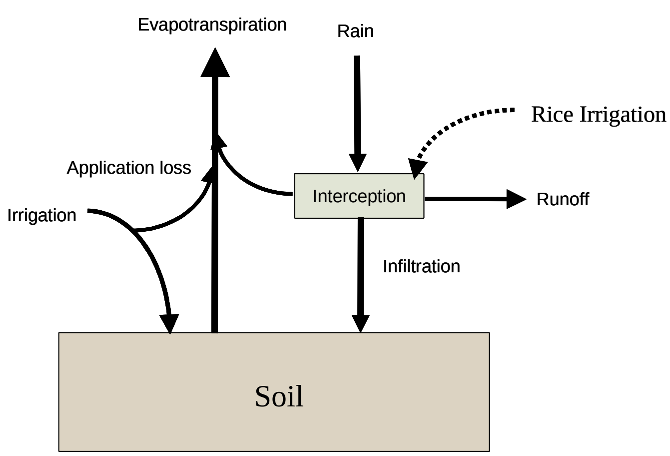

Figure 2. Zone “0”: Surface hydrologic processes

Soil Zone A

This zone is the irrigated soil that contains most of the plant roots. The water budget for Soil zone A is provided in Figure 3. Zone A receives water from infiltration, irrigation, lateral redistribution from adjacent soil. When the water table is near the surface, Zone A can receive water by upflux from the water table. Losses from Zone A include evapotranspiration, percolation and lateral redistribution to zone C.

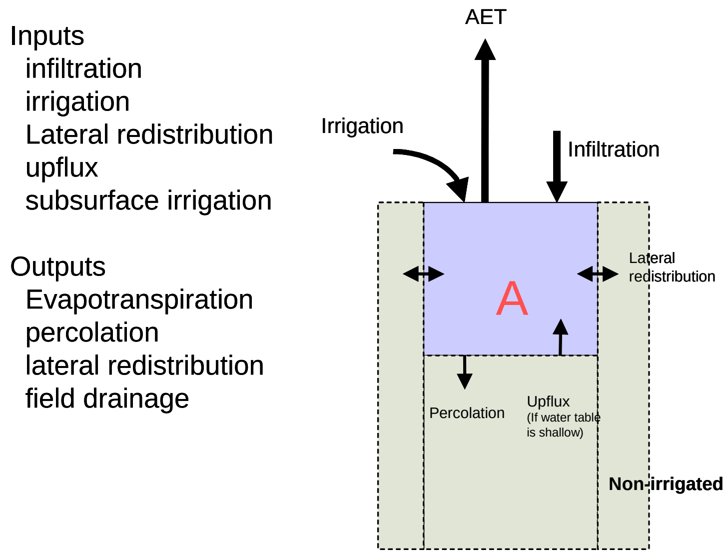

Figure 3. Zone “a”: irrigated, rooted soil

Soil Zone B

This is the root zone below the irrigated soil depth (Fig. 4). This zone receives water by percolation from irrigated root zone (a) as well as upflux from the water table and lateral redistribution from adjacent soil. The upflux component show be a major source of water on high water table soils. The difference between upflux and direct seepage irrigation will depend of the location of the water table. It is assumed that the water table will limit the rooting depth and the only water available for plant use will occur from upflux. If the water table is too shallow the available soil water can become very low. The redistribution exchange should be predominantly away from zone B to zone C, because the percolation of infiltration from the irrigated soil above.

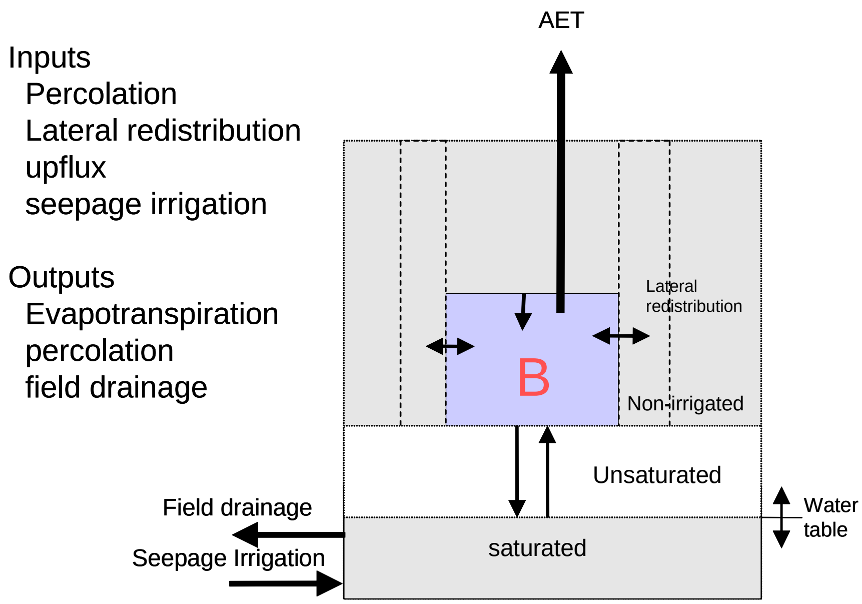

Figure 4. Zone “b”: non-irrigated rooted, subsoil

Soil Zone C

The zone C soil is adjacent to the irrigated zone and has roots (Fig. 5). This zone is primarily rain fed and can be an important source of water if the irrigation system is undersized or during periods when the farmer wants to cut back on irrigation water use. This zone may become zero in plastic mulch bedded vegetables where the roots are constrained to live in the irrigated zone under the mulch.

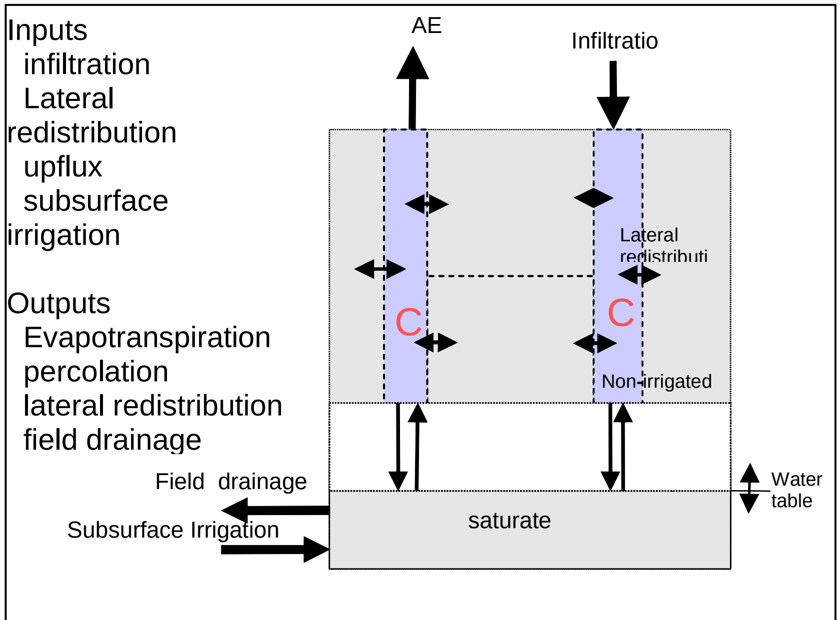

Figure 5. Zone “c”: rooted, non-irrigated

Soil Zone D

This is the soil that is not directly irrigated and does not have roots (Fig. 6). This zone goes to zero for full field crops such as turf, rice and some tree crops, and irrigation methods that irrigate the entire field. This soil is subject to infiltration, evaporation, percolation, upflux, lateral redistribution, field drainage and seepage irrigation. The evaporation will occur as bare soil.

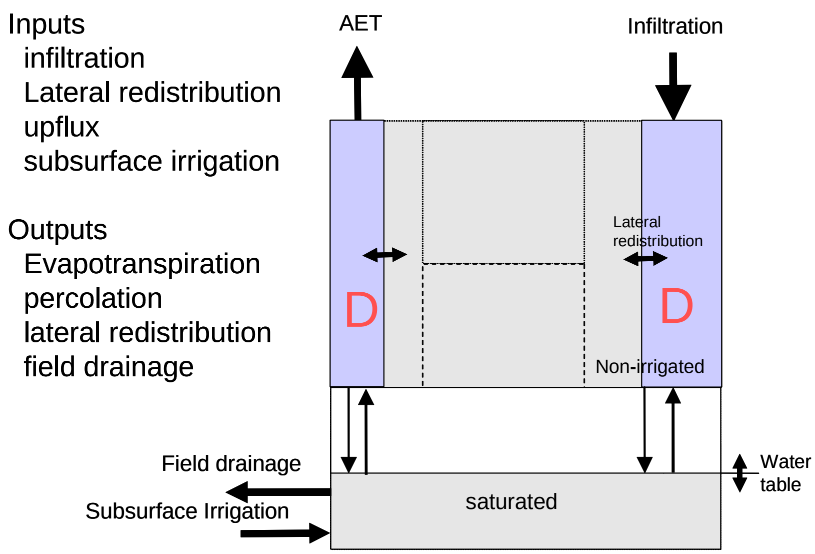

Figure 6. Zone "d": non-rooted, non-irrigated soil

Soil depth

Typically, the soil is deeper than the typical root depth for the selected crop. However, there are soils that are shallow over rock. For those soils, zone b disappears and zone a interacts directly with the water table.

Hydrologic Processes

The sequence and timing of hydrologic processes is likely to affect runoff hydrographs and the partitioning of water losses among evapotranspiration, runoff, percolation and field drainage. The processes simulated in afsirs.cc are presented below in the order in which they are calculated in the model. At each timestep, calculate each process (1-11) in order: soil zone a, zone b, zone c and zone d. Lateral redistribution is calculated sequentially for the following interactions: zone a-c, zone b-c and zone c-d. It is necessary to calculate the redistribution sequence once to avoid oscillations.

1) Obtain regional solution changes from RSM
2) Calculate initial soil water content
3) Upflux [all day – slow process]
4) Percolation [all day – slow process]
5) Field drainage/ subsurface irrigation [all day – slow process]

6)	Redistribution	[all day – slow process]
7)	Infiltration/Interception	[all day – slow process]
8)	Irrigation	[6am-1200pm]
9)	Evapotranspiration	[sinewave]
10)	Rain	[2pm-6pm]
11)	Runoff	[all day – as occurs]

Regional Solution

The first step in modeling the soil hydrologic balance is to set the water table from the previous time step. The ramcc HPM is a semi-coupled with RSM; the water balance in the PseudoCell is matched with the water balance in the associated mesh cell such that the head in the cell is the same as the HPM water table elevation minus the water stored in the HPM (unsaturated soil, interception, detention). This is unlike other HPMs that are fully coupled; the HPM water table is set to the mesh cell head at the beginning of each time step. The change in the mesh cell water content [AdjustPsudoCell/CellDelta] as a result of the regional (matrix) solution is added to the ramcc water table at the beginning of each time step. This adjusts the local water table for any changes that result from regional groundwater flow.

Initial Water Content

The water content for each of the storages is calculated based on the results of the processes occurring at the previous time step. This includes calculating the maximum available soil water content for each zone, which is determined by the amount of rainfall on previous days, the rooting depth and location of the water table. The location of the bottom of zone b, c and d may be affected by the location of the water table.

Upflux

This is the upward movement of water from the water table by capillary movement. It is based on the information in Obreza and Pitts (2002). Upflux occurs in soil zones b, c and d when the water table is in the root zone. It may occur in zone a if the water table is really shallow.

Percolation

When soil water content exceeds the maximum soil water content, water will percolate from the soil zone. Water from Zone a will percolate into zone b. Water from zone b, c and d will percolate to the water table. This is a slow process that will occur during the entire day when RSM is run on a sub-daily time step. The volume of redistribution that occurs at the various timesteps is equivalent to the redictribution that occurs at a single daily time step.

Field Drainage and Subsurface Irrigation

In several crops we want to maintain the water table at a specific depth by controlling field drainage and subsurface irrigation. Input to afsirs or the HUB will include detailed information about the field ditches or secondary canals as appropriate.

We will use Hooghoudt’s equation to calculate the flow to the field drains or off-site canals. This will require adding code to the RSM to accommodate additional input parameters.

A preliminary kluge will be simple darcian flow between the pseudo cell and the external field drain water level.

Subsurface irrigation occurs when the water table falls below a specified depth. The volume of water necessary to bring the water table back to the selected depth is calculated and requested from the appropriate water source. Once the water table is set there can be upflux into the soil above the water tables.

Rainfall Redistribution

(see soil moisture)

Lateral Redistribution

Lateral redistribution takes place as a result of the soil water potential gradients that occur following rainfall and irrigation events. In AFSIRS soil water redistributes evenly between the irrigated and non-irrigated soil at the end of each day. This accounts for loss of water from the irrigated soil to both soil below the root zone (zone b) and soil without roots (zones c and d). The water lost to the non-rooted soil is lost from the soil water accounting. This provides for increased available soil water storage in the irrigated zone. In the revised ramcc there will be water redistribution between the adjacent lateral soil zones. The amount of lateral redistribution will be an exponential decay function based on the difference in soil water content between the zones from zone of high water content to the zone of low water content. Vertical redistribution will be handled with a new water percolation process.

Infiltration

Typically infiltration into sandy soils of South Florida is not soil limited. Infiltration rates may exceed 40 cm/hr. In a daily timestep all rain will infiltrate into the soil. There are a few hydrophobic soils where rain water will pond, however there are no spatial coverages documenting those soils. The revised model does account for interception storage which can be used for ponded storage. If necessary, an infiltration function can be added to the model in the future.

Irrigation

The AFSIRS model was developed to calculate the irrigation requirement for user selected crops, soils and irrigation systems. The strength of the AFSIRS model was the completeness of the irrigation module. It includes irrigation application methods and management, the effect of different systems and different irrigation rates. The irrigation module calculates gross irrigation as well as the net irrigation rate. AFSIRS has been most commonly used to estimate the irrigation requirement for optimum irrigation; the available soil water content does not drop far below the maximum soil water deficit and the water table does not inhibit root growth. This is important in south Florida where the water table is frequently in the root zone.

In the revised ramcc module, the irrigation process is essentially the same with a few modifications. First, the gross irrigation is applied to the field and a portion of the irrigation water is lost to the atmosphere, reducing the crop potential evapotranspiration.

Irrigation Methods

There are several parameters that describe crop irrigation. These include the following: 1) irrigated area (azir), 2) amount of water the plant extracts from the irrigated area (exir), 3) irrigation efficiency (eff), 4) the irrigation method either optimal [0], fixed depth[1] or fix percent of field capacity [2] (trigcode), the volume of irrigation [fix] and depth to the water table (dwt)

Seepage and Flood Irrigation

<u>Rice</u>

Rice is typically grown with 3 inches of flooded water on the field. With saturated soil afsirs does not calculate soil water storage, only interception storage. The interception storage volume is set to 3 inches and the crop coefficient for rice is set at 1.0, driven primarily by the evaporation from the ponded water. The input for rice irrigation is allowable decrease in water depth before irrigation.

<u>Crown Flood and Seepage Irrigation</u>

For these irrigation systems the root depth is assumed to be 18 inches unless otherwise specified. The soil is irrigated to maintain the water table at 18 inches. In this system, there is a zone a soil but no soil zone b. The roots get water a upflux into zone a from the water table. At the beginning of each time step water is removed from the water table and placed in zone a by upflux. The soil is irrigated to bring the water table back to the required depth filling the drainable porosity.

Crown flood irrigation is similar to other irrigation except that it requires three days for crown flood irrigation to fill the field and three days to drain, so irrigation of five days amount of irrigation has to be applied every six days during periods without rain.

<u>Sprinkler Irrigated Container Nurseries</u>

Container nurseries are a special case in that the irrigation requirement is estimated based on the needs of the plants grown in the buckets. The rooting depth is shallow and there is limited interaction between zone a and zone b. There is no zone c (roots with no irrigation). However, in this special case zone d receives irrigation at the following rate:

$$zone\_d\_irr = (1.0 - ARZI)/ARZI * NIR$$

where NIR is the irrigation requirement for the containered nursery plants.
There is no upflux from zone b or lateral redistribution with zone d to zone a because water can not effectively reach the plant root from outside the containers. Zone b, however, receives percolation from zone a, and there is lateral redistribution between zone b and d. The soil water of zone b and d are important to track because this affects runoff and drainage.

Evapotranspiration

Evapotranspiration is the combination of evaporation from the intercepted rainfall, evaporation from applied irrigation water and crop transpiration. The maximum amount of ET is determined by the potential evapotranspiration, which is the atmospherically defined limit for evaporation for that day. The PET is first met by evaporating any intercepted rainfall:

PET1 = PET – interception storage

Second, PET is reduced by the loss of irrigation water from inefficient application of irrigation water. The amount of water lost to the atmosphere depends on the irrigation method and the assigned efficiency is an input to afsirs.

PET2 = PET1 – net irrigation(1/efficiency -1)

The crop PET is calculated from the remaining available PET2:

PET3 = Kc * PET2

The actual ET is limited by the available soil water content. In AFSIRS it was assumed that 70 percent of the ET was extracted from the irrigated soil and the remaining from the non-irrigated root zone below the irrigated soil and adjacent to the irrigated soil. In the revised afsirs.cc the first 70 percent of PET3 is extracted from the irrigated soil at the rate Kc if the soil water content is greater than 50 percent of available soil water content and at a linearly decreasing rate from 50 percent down to 33 percent of available soil water content. Below 33 percent ET is zero. The remaining amount of PET3 is extracted first from zone c, adjacent surface soil, and then from zone b, rooted subsoil. This approach approximates the pattern of ET that occurs in the field for citrus (Obreza and Pitts, 2002). For other crops, such as vegetables grown with plastic mulch, the soil water extraction would naturally come from the rooted subsoil before adjacent soil, but it is expected that in those soils zone c is likely to go to zero.

It has been observed (Smajstrla, 1990; Jacobs, 2005) that following a significant rain event the evapotranspiration reaches PET as a result of saturate surface soil. As a result, the crop correction coefficients are increased to 1.0 for a few days following a rain that exceeds the maximum soil water content. The number of days is determined by the rooting depth and the magnitude of the rainfall. The Kc is reduced to 1.0 on rain days. The Kc could be higher than 1.0 if ponded or soil crops have AET greater than the reference crop. This is reducing AET during days of rain due to cloud cover.

Multiple Cropping

With annual crops there are several combinations of cropping patterns. Double cropping with a spring crop and a fall crop is common and there may be more than two distinct crops with different irrigation practices. In addition to the crops there are periods of fallow between crops and periods when there is a cover crop. The period of fallow occurs between the fall crop and the spring crop. Water loss is limited to evaporation from bare ground as described below in Soil zone d evaporation. Water loss during the cover crop period is calculated as crop ET from a zone c soil (rooted without irrigation) with a constant Kc = 0.40.

Soil Zone d Evaporation

The water loss from zone d is by evaporation from bare ground. Water loss from soil zone d is different from ET loss from zones a and c. Typically in annual crops zone d is most likely to be bare ground. In perennial crops with full irrigation there is no zone d. In perennial crops with low-volume irrigation systems there is a zone d where there may be bare ground or a weedy cover. However, the crop coefficient for the crop includes the water losses from the entire agricultural field, so the water loss from the zone d land is accounted for in the water loss from zone a and c. The available water for Evaporation from zone d should be limited to the available soil water in the top 4 inches. Thus, the amount of water available for ET loss is a fraction of the zone d water content:

$$\text{Limit of Evaporation loss} = AWC_d * (4/depth_d)$$

Evaporation of soil water from zone d occurs computationally after ET from the other zones.

Rain

In AFSIRS rain is added directly to the soil water budget and made available to the plants before estimating evapotranspiration. In the revised ramcc, rain will satisfy interception storage before estimating infiltration. Infiltration will occur when the maximum infiltration rate is not exceeded and the water table is not near the land surface. Rain will be applied at the end of the time step, after irrigation and calculation of evapotranspiration. For sub-daily time steps, rain will be applied uniformly during the period 2pm to 8pm, but the actual time of application will depend on the actual time step selected.

Soil Water Processes

Redistribution to Field Capacity

The maximum available soil water content is an input property of the soil. The soil is assume to have a uniform maximum available soil water content with depth. This is a amount of soil water above wilting point and below field capacity. It is a constant value for irrigated soil. However, the maximum available soil water content increases following rainfall in excess of field capacity. The experience of Smajstrla (1990) and others (Jacobs, 2005) has been that there is a spike in ET following rainfall events indicating that there is both an increase in the crop coefficient and an increase in available water following a rain. This reflected the ability of soils to hold additional water in perched water tables due to different properties of the soil horizons. In AFSIRS, the maximum content was increased the volume of two to seven days of ET based on the volume of rain and the rooting depth of the crop. This water is withheld from percolation and redistribution. The increased volume is reset following each rain. The increased available soil water content should be a function of soil type, but as a first approximation we will use the current version of enhanced soil water storage as a function of crop type (ie number of days of redistribution * PET).

RSM Coupling

The afsirs HPM is coupled to the RSM model through a standard interface. On the input side, rainfall and PET values are passed through RSM to afsirs. On the output side, afsirs can only connect to HSE through water supply, runoff and recharge. Water supply and runoff can be directed to the homecell (the mesh cell immediately below the HPM) or a single specified cell or segment. There is a little flexibility in that the water supply and runoff values can be set to a positive or a negative value, thus the runoff location can be turned into an alternative source. This is appropriate for field drainage and seepage irrigation. Recharge is always directed to the homecell. Recharge can be positive, adding water to the homecell, or negative, withdrawling water from the homecell. Each of the processes from afsirs can only interact with these sources and sinks. The difference in the processes affects the timing of the interaction.

The ramcc HPM is designed to use the same input information as the Afsirs.f code. As such there are no changes in the XML inputs or outputs from the model.

Scheduler

The scheduling of annual crops when there is multiple crops per year in not effectively addressed in this version of afsirs. In different regions of the SFRSM domain there are different growing seasons for different crops and different crops can be planted in the same HPM during the same year. The seasons in the different regions are not the same. Although it was possible to include multiple cropping in afsirs.cc it was decided that this capability was best developed outside of afsirs.cc in a new Scheduler object in HSE. The Scheduler would provide the ability to start and stop various management activities within SFRSM. This applies to HPMs as well as seasonal structure flows. The Scheduler will be developed at some time in the future. As a short-term solution, multiple crops will be handled as a sequence of the following crops: spring crop, summer grass cover crop, fall crop and winter bare soil. The dates of the crops can be adjusted to account for the different region in the SFRSM domain.