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FIELD AND POND HYDROLOGIC ANALYSES WITH THE *SPAW* MODEL

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Abstract. The *SPAW* (Soil-Plant-Air-Water) computer model simulates the daily hydrology of agricultural fields and ponds including wetlands, lagoons and reservoirs. Field hydrology is represented by daily climatic descriptions of rainfall, temperature and evaporation; a layered soil profile with automated water characteristics; annual crop growth; and management with crop rotation and irrigation. Pond, lagoon, and wetland simulations which have agricultural watershed fields or producer operations as their water source provide daily inundation levels as controlled by multiple input and depletion processes. Data input and file selection are by graphical screens. Simulation results are both tabular and graphical. Typical applications include analyses of crop water status, deep seepage, wetland inundation duration and frequency, lagoon designs, and water supply reservoir reliability. The program and descriptions are publicly available.

Keywords. Agricultural, Hydrology, Soil Water, Crop Water, Ponds, Wetlands, Reservoirs, Lagoons

FIELD AND POND HYDROLOGIC ANALYSES WITH THE *SPAW* MODEL

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Introduction

The SPAW (**S**oil-**P**lant-**A**ir-**W**ater) computer model simulates the daily hydrologic water budgets of agricultural landscapes by two connected routines, one for farm fields and a second for impoundments such as wetland ponds, lagoons or reservoirs. Climate, soil and vegetation data files for field and pond projects are selected from those prepared and stored with a system of interactive screens. Various combinations of the data files readily represent multiple landscape and ponding variations.

Field hydrology is represented by: 1.) daily climatic descriptions of rainfall, temperature and evaporation; 2.) a soil profile of interacting layers each with unique water holding characteristics; 3.) annual crop growth with management options for rotations, irrigation and fertilization. The simulation estimates a daily vertical, one-dimensional water budget depth of all major hydrologic processes such as runoff, infiltration, evapotranspiration, soil water profiles and percolation. Water volumes are estimated by budget depths times the associated field area.

Pond hydrology simulations provide water budgets by multiple input and depletion processes for impoundments which have agricultural fields or operations as their water source. Data input and selection of previously defined data files are by graphical screens with both tabular and graphical results. Typical applications include analyses of wetland inundation duration and frequency, wastewater storage designs, and reliability of water supply reservoirs.

The objective of the SPAW model was to understand and predict agricultural hydrology and its interactions with soils and crop production without undue burden of computation time or input details. Over the development period, both the model and the method of data input with system descriptors have evolved for improved accuracy, extended applications, and ease of use. The program documentation includes theory, data requirements, example applications, and operational details. The model results have been corroborated through research data, workshops and application evaluations.

The SPAW-Field model is a daily vertical water budget of an agricultural field, with a field to be considered, for practical purposes, spatially uniform in soil, crop and climate. These considerations will limit the definition of a "field" depending on the local conditions and the intended simulation accuracy. For many cases, the simulation will represent a typical farm field of tens to a few hundred acres growing a single crop with insignificant variations of soil water characteristics or field management. In other cases, a single farm field may need to be divided into separate simulation regions because of distinct and significant differences of soil or crop characteristics. These definitions and divisions will depend on the accuracy required, however users soon gain enough experience through alternative solutions to guide these choices.

Since the field model has no infiltration time distribution less than daily and no flow routing, it is generally not applicable for large watershed hydrologic analyses. However, it can be utilized for water budgets of agricultural watersheds composed of multiple farm fields, each simulated separately and the results combined. The combined field concept to represent a watershed is used as an input source for the pond simulations. With no streamflow routing there are no channel descriptors required. Daily runoff is estimated as an equivalent depth over the simulation field by the USDA/SCS Curve Number method.

The SPAW-Pond model simulates the water budget of an inundated depression or constructed impoundment. The water supply to the inundated area is estimated runoff from one or more previously simulated fields, plus, if

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applicable, that from external sources such as an off-site pump or flush water from an animal housing facility. Pond climatic data are provided from that input to the watershed field simulation. Additional features are included such as outlet pipe discharge, drawdown pumps, irrigation supply demands and water tables to allow for a wide variety of pond situations described as wetlands, small ponds, water supply reservoirs, lagoons or seasonal waterfowl ponds.

Basic interactions of soil chemicals such as nitrogen and salinity with soil water and crop production are included. The chemistry is represented as a daily budget without interactions and minor processes. These budgets are useful to estimate potential effects and hazards related to the chemical inputs and dispositions for situations often encountered in agricultural hydrologic analyses.

Example Applications

The SPAW water budget model can be adapted to a wide variety of hydrologic analyses within the constraints of the programmed processes and data available. Some example applications for agricultural fields and ponds would be:

- Evaluate the daily status of available crop water and plant water stress under rainfall or irrigation regimes.
- Estimate runoff and seepage from agricultural fields.
- Schedule irrigation or defining irrigation requirements.
- Assess deep seepage of field water and chemicals which may contribute to water and nutrient losses.
- Define depths, frequency and durations of agricultural wetland inundations.
- Design and performance evaluation of agricultural ponds, lagoons and reservoirs for water supply, waste management and water management.
- Estimate soil nitrogen or salinity budgets and concentrations for crop production and salinity hazard.

Hydrologic Systems and Processes

Simulating the hydrologic budget of an agricultural field or pond requires defining the hydrologic system and associated processes. The field budget utilizes a one-dimensional vertical system beginning above the plant canopy and proceeding downward through the soil profile a depth sufficient to represent the complete root penetration and subsurface hydrologic processes (lateral soil water flow is not simulated). The pond hydrologic system is an impoundment with external inputs from a watershed or supplemental water sources and outflow by spillways, pumps and seepage.

The principle hydrologic processes in the SPAW-Field model are depicted in Figure 1 by a schematic of the vertical budget of an agricultural field. They include: precipitation, runoff, infiltration, evapotranspiration, soil water redistribution, percolation and deep drainage, chemical applications and redistributions.

The evapotranspiration estimates include combined daily estimates of plant transpiration, direct soil surface evaporation and interception evaporation estimated from a daily atmospheric potential evaporation reduced by the plant and soil water status. The potential evaporation input data may be estimated by one of several methods such as the Penman and/or Monteith equation, daily pan evaporation, temperature or radiation methods, or mean annual evaporation distributed by months and monthly mean daily.

Soil water redistribution within the soil profile and percolation are estimated by a Darcy tension-conductivity method to provide both downward and upward flow estimates. Soil water holding characteristics of tension and conductivity are estimated from soil textures and organic matter and adjusted for density, gravel or salinity as described later.

The principle hydrologic processes of the SPAW-Pond model are depicted in Figure 2 by a schematic of the inflows, withdrawals and losses. A depth-area table describes the ponded volume plus specific depths above the pond bottom for inlets and outlets. Each of these depths provides operational limits of the various budgeting processes such as the pumps, pipe outlet, or irrigation water. These processes include: watershed surface and subsurface inflow; sequential pond inflow; side slope runoff; external inflows; surface rainfall and evaporation; bottom infiltration, seepage and water table; outlet pipe and spillway overflow; water supply and drawdown pumps.

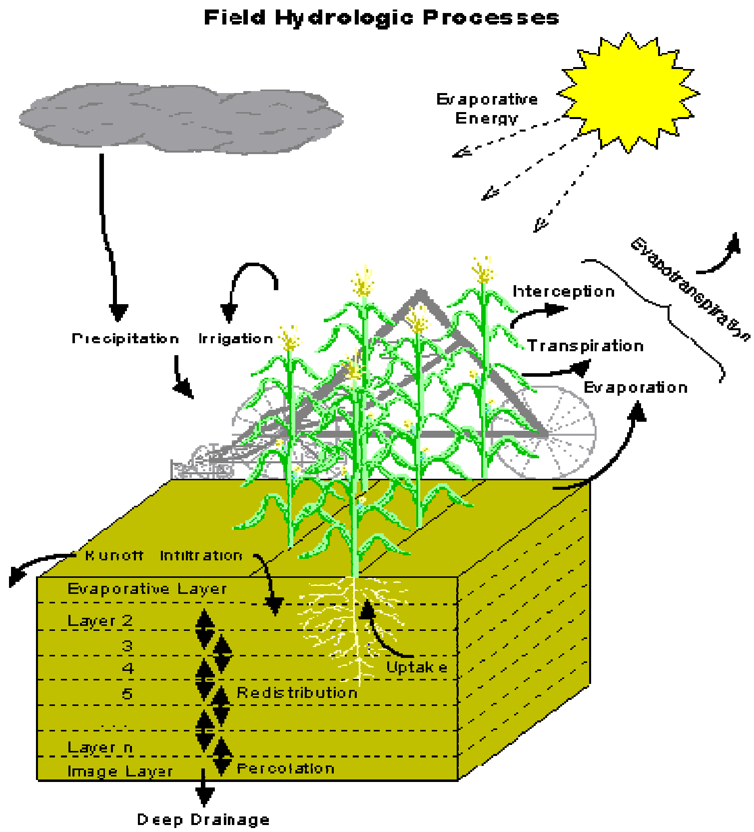

Figure 1: Hydrologic processes within the SPAW-Field system of an agricultural field.

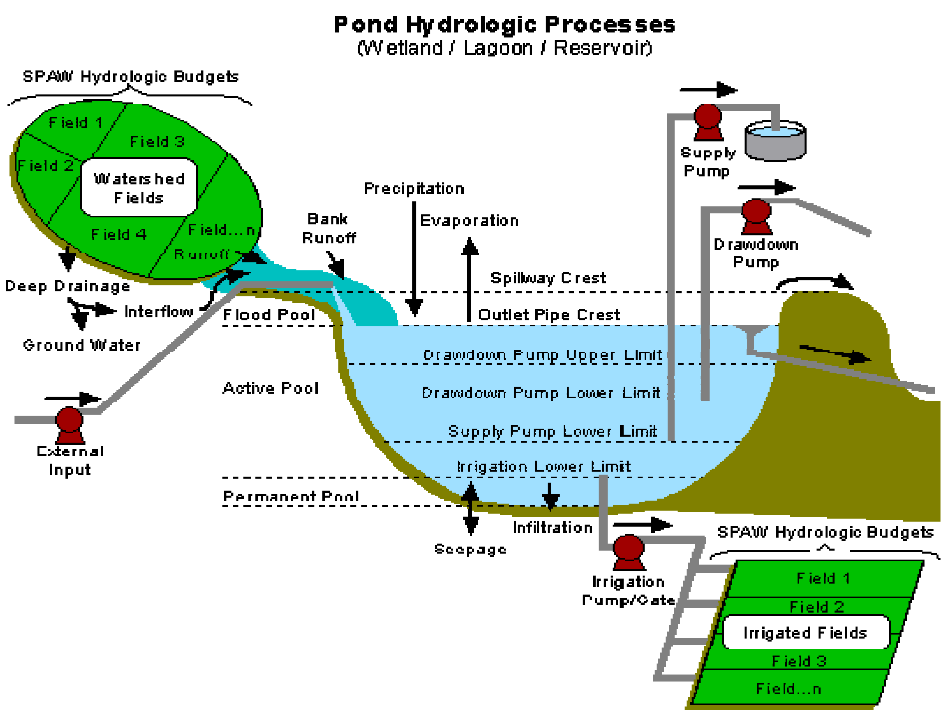

Figure 2: Hydrologic processes within the SPAW-Pond system of an agricultural impoundment.

Field Methods

The major hydrologic processes within the vertical field water budget are represented by interconnected routines, rates and volumes. The following summarizes those processes most influential in the daily budgets. Detailed equations and variables are generally not included here, but the program contains several additional documents in the HELP menu which provide detail and references.

Runoff
The USDA/SCS Runoff Curve Number (SCS-CN) method is used to estimate the percentage of precipitation which becomes runoff, or conversely that which infiltrates. Average annual curve numbers are determined by the model from tabulated values of the SCS-CN method using entries of land use, treatment, hydrologic conditions (crop condition) and hydrologic soil class (Rawls et al., 1992; Heggen, 1996; USDA-NRCS, 1997). The applied curve numbers for a field can also be manually specified which provides an option to modify the estimated runoff and infiltration volumes. With only daily precipitation and infiltration, there is no sub-daily time distribution of runoff for short-term hydrographs or stream routing.

Infiltration
Daily infiltration is estimated as precipitation minus runoff, with runoff estimated either by the SCS-CN routine, or by observed runoff values if provided. While the estimated infiltration is not given a time distribution less then daily, it is computationally divided into sub-daily time steps used for the water profile redistribution and cascaded to successive deeper layers until adequate storage is achieved. All further redistribution is by the Darcian soil moisture redistribution routine. Should the entire profile reach 90 % saturation due to exceptional rains or restrictive soil layers, additional runoff is estimated.

Potential ET
The concept and definition of potential evapotranspiration (PET) is not universal among hydrologists and other scientists. However, most agree that the maximum, or potential, largely depends upon the energy available for the liquid-to-vapor phase change, and that this energy source is primarily solar radiation supplemented by wind travel and vapor pressure deficit. PET for irrigation-related estimates are often defined as that water lost from a well-watered reference crop such as grass or alfalfa. However practical, this partially confounds the values with local plant and surface characteristics. Methods based on radiation or radiation plus air properties have been the most widely used for short-term estimates such as Penman or Jensen-Haise (Saxton, 1971; Shuttleworth, 1992). These are largely defined by atmospheric variables with minimal surface influence, but are often not readily available.

Pan evaporation is an indirect, standardized, method of estimating potential ET (PET) with appropriate coefficients. It is generally available for most regions either as daily measurements or monthly and annual means. Large body lake evaporation is a similar approach with minimal coefficient requirements to estimate PET. PET may be externally obtained from any one of the several meteorological methods with appropriate coefficients.

Actual ET
The vapor transport of water back into the atmosphere by actual evapotranspiration (AET) is estimated by beginning with daily atmospheric PET, then estimating and combining the major AET components: interception evaporation, soil water evaporation and plant transpiration. This approach assumes that the PET is primarily an atmospheric determined value which provides evaporative energy, either radiated or conducted, to a partially wetted surface. The challenge is to evaluate the opportunity of this energy to interact with the various surfaces depending on their current status of wetness and resistance of water to their surface. Energy not utilized in the process of evaporation is available for other uses, largely heating of the near-surface air mass.

Interception water is free water on plant and soil surfaces which readily evaporates with minimal surface interaction or vapor resistance. Therefore, the PET value is reduced by the amount of interception evaporation before plant and soil water evaporation are computed. Interception is specified as a storage depth with a constant maximum capacity which represents a potential interception. This storage is filled by precipitation and sprinkler irrigation, and depleted by PET. Defining a potential interception is not obvious. Few data are available and the concept is somewhat nebulous but obviously a factor. Each plant canopy has some ability to intercept water and prevent that portion of the precipitation from becoming infiltration or runoff. Surface residues and the uppermost soil surface similarly will wet and dry (not to be confused with depressional storage or soil water evaporation).

Well-watered, vigorous crops will transpire at nearly the rate demanded by the atmospheric conditions (PET), but as their water supply becomes limited, physical and biological resistances begin to limit the rate of transpiration. It is apparent that plant transpiration is a function of both atmospheric evaporative demand and plant available soil water. Plants have unique abilities to control water flow rates within their vascular system and through stomatal action. They make soil water available by root extension and by creating competitive water pressure within their membranes to cause gradients and water flow. A simplified approach based on atmospheric demand and plant available water has been programmed.

The curves of Figure 3 provide a relationship between plant available soil water, defined by the range from wilting point to field capacity, and the ratio of actual transpiration to potential transpiration. The general shape of the curves are based on those derived by Denmead and Shaw (1960, 1962) in controlled small lysimeter studies of corn. These curves express the effect that actual plant transpiration will decrease from potential transpiration in a quite non-linear pattern as plant available water is decreased. The curves representing different levels of daily PET indicate that for a given level of plant available water, the plant will transpire a greater percentage of PET when PET is low than when PET is high. The curves are applied independently to each defined soil layer in proportion to the percent roots present, thus plant transpiration is estimated as the combined effect of PET, root density distribution, and soil water content and profile distribution.

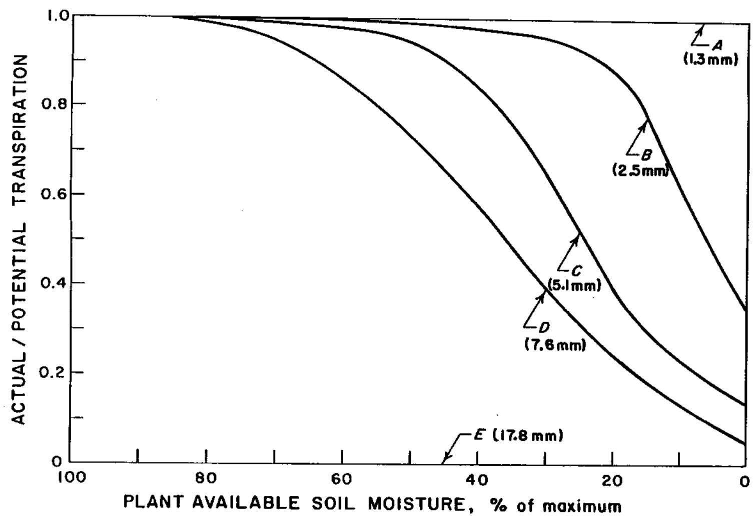

Figure 3: Actual over potential transpiration as a function of plant available water and daily PET.

Soil Water Redistribution

Soil water is continuously moving in response to pressure gradients caused by capillary and gravimetric forces unique to each soil element according to its pore structure, water content, chemicals, and other minor effects. This water redistribution within the soil profile plays a significant role in the water profile status, vertical conductivity and plant water abstraction. It is a very necessary process to be estimated for realistic simulations of AET and soil water, although one of the more difficult processes to represent because of the data requirements and mathematical solutions.

A finite difference form of the Darcy equation for vertical water conductivity (up or down) between the specified soil layers is used. While many solutions are available for the Darcy equation (or Richards equation) which use sophisticated numerical analysis techniques, a simpler and more direct method of forward differencing was programmed. Variable time steps are defined according to a maximum allowed change of soil water tension per time step. The objective was to minimize the computations, yet provide reasonable redistribution estimates and computational stability over long simulation periods and over the full range of soil water content of agricultural soils.

Field Data

Each major hydrologic process in the field and pond environment is simulated individually, then combined to develop daily water budgets for the system components. Each process requires specific descriptions of the physical parameters and influencing variables followed by appropriate fixed and dynamic data inputs. This approach is similar to that first outlined by Saxton et al., 1974a, 1974b and similar to that of other models (Feddes et al., 1980; Malone et al., 2001). More details can be found in Saxton and Willey (2006) and in the HELP menu items included with the model. The following summarizes the major data requirements.

Field input data are in three general categories of climate, soils and crops. The climatic data are those from a climatic data and regional estimates. Soils data are interpretations from soil profile descriptions of those typical of the simulated field. Crop data are annual descriptions of locally observed crop growth parameters. The crop data are supplemented by management options such as rotations, irrigation and nitrogen fertilizer chemicals.

The data input files are compiled and assembled via a series of data input screens with the exception of observed climatic data files which are manually copied from a climatic data base to a directory. Each screen saves a unique data file in the computer directory such as daily climate, soil profiles and individual crop growth parameters which then become selectable for subsequent simulations. These saved data files provide the user an opportunity to describe data unique to the study region for individual crops, soils and climates, then accessed in various combinations as fields and pond descriptions require, thus minimizing input duplication. New files can be created by copying and modifying existing files.

Climatic Data

Field water budgets are significantly dependent on the climatic inputs of precipitation and potential evaporation which control water input and evapotranspiration, ET, the largest depletion process. Climatic data are input in three categories: 1) historic measured climatic data for the local region, 2) default daily potential evaporation values by monthly estimates, and 3) selected data pertinent to a specific location. The historic climatic data files are copied into a SPAW directory from external sources such as from the NOAA National Climatic Data Center or the USDA/NRCS Water and Climate Center, while the default and location files are created by input screens.

Soil Profile

The soil profile is described by incremented layers and water characteristic curves for each layer. Except for the upper and lower boundary, the layers should reflect the soil profile changes plus provide an incremented soil water profile to allow appropriate calculations and definitions. Usually, smaller increments (4 to 8 inches) are used in the first 2 or 3 feet below the surface, then 12 to 18-inch increments thereafter. Thinner layers are not warranted and cause excessive computations while large layers provide excessively broad averages.

The pressure and conductivity relationships as a function of moisture content are the most difficult to obtain and input into the model for the redistribution solutions. Measured values of these relationships are very seldom available for hydrologic study sites, yet it is important to use curves that approximate the water holding characteristics of the soil layers. There are numerous estimating methods in literature for various curve parameters, but many require at least some field or laboratory data (Rawls et al., 1992; Hillel, 1998).

An estimating method for soil water holding characteristics has been developed and included. The technique is a set of generalized equations which describe soil tension and conductivity relationships versus moisture content as a function of sand and clay textures and organic matter (Rawls et al., 1982; 1992; 1998; Saxton et al., 1986; Saxton and Rawls, 2006). The soil water characteristic equations are valid within a range of soil textures approximately 0-60% clay content and 0-95% sand content. Adjustments to the solutions have been added to include the effects of bulk density, gravel and salinity (Tanji, 1990). A programmed texture triangle as an input screen, Figure 4, provides ready solutions to the equations and values for the layer definitions of the soil profile. This methodology is incorporated in the model and is also available as a stand-alone program.

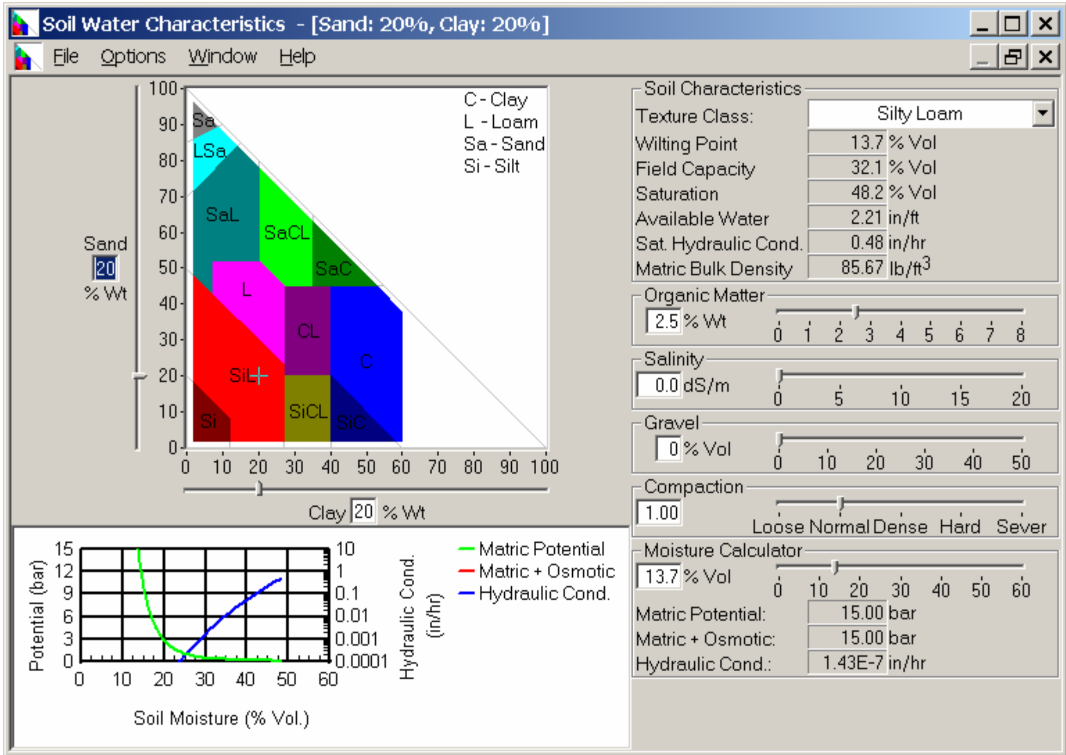

Figure 4: Texture triangle data screen to estimate soil water characteristics.

Crop Growth

Plant growth is a very important contributor to hydrologic budgeting through the evapotranspiration effects. Manual descriptions are input for the plant growth based on local knowledge of average growth descriptions for major crops (Wild, 1988). Methods used by other models such as "crop coefficient curves" or plant growth estimation routines based on plant and environment parameters are generally less accurate or more difficult to define. This approach has proven easy to apply, and sufficiently accurate to achieve expected hydrologic accuracies.

The annual crop growth is described by three annual distributions of plant canopy, greenness, and rooting depth. A fourth curve, yield susceptibility, defines the relative impact of accumulative crop water stress on grain yields when correlated with observed grain yields. For simulations involving nitrogen budgets, the annual nitrogen uptake distribution is included in the crop definitions. Crops growing over the end of the calendar year require two years of definitions. Multiple year crop rotations are developed by selecting a cropping sequence in the “management” screen.

It is useful to coordinate all of the crop descriptive graphs on the same time axes to assure they correspond at selected dates such as planting and harvest. An input screen provides this graph as data are entered as shown in Figure 5.

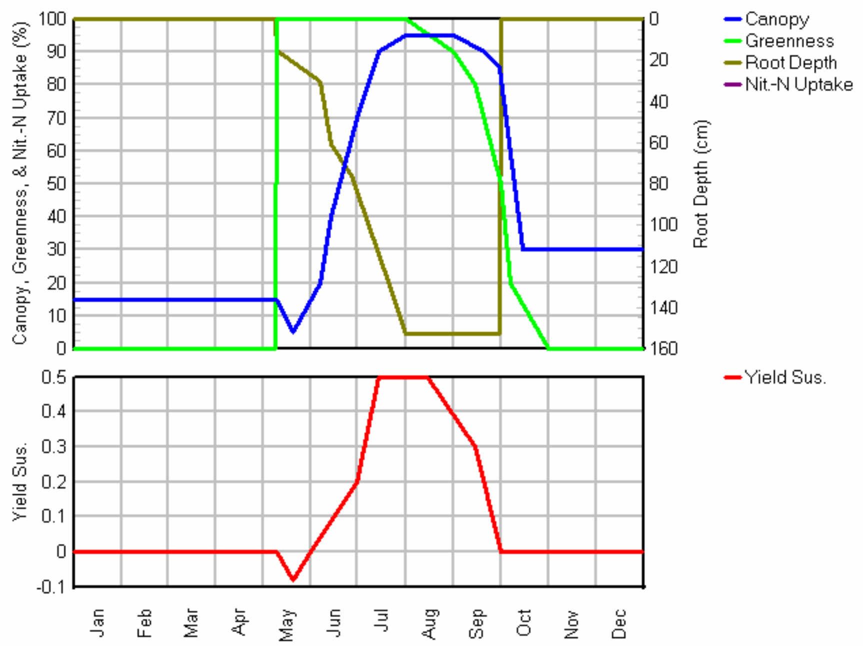

Figure 5: Example corn (maize) crop description curves for a calendar year.

Percent crop canopy cover represents that portion of the daily potential ET effectively impinging on the plant and not on the soil. An annual distribution is described by date-percentage data points throughout the calendar year for daily linear interpolation. Residue, green crop or some combination are included in the canopy percentage. Greenness accounts for the plant capability to maintain transpiration, for example as the plant declines during maturation representing a mixture of residue and green growth. Rooting depth represents the maximum rooting penetration depth and is used for a triangular root density from the soil surface downward.

Crop Management

Management of typical agricultural crops affecting water budgeting most often involve crop rotations. Irrigation and fertilizer application may be options. Crop rotations for a field are selected to be in a fixed rotation listed in an annual order and selected from the crop files previously defined. Crop growth characteristics for each selected crop will have been previously described and filed by the crop input screen. Multi-year simulations require each crop to be described for the complete calendar year. Crop rotations are cycled in the order selected and repeated as needed to complete the full simulation period.

Daily irrigation water is budgeted very similar to precipitation. The inputs are either of known irrigation amounts and dates or criteria are provided for the model to determine the time and amount of irrigation water. The irrigation options include ten methods to determine when to irrigate and six to determine how much water to apply. Fertilization is an important part of modern crop production and often poses questions related to water and chemical management, thus daily nitrogen budgeting is included as an option. While not a fully rigorous treatment of chemical budgeting, methods are included to provide nitrogen and salinity budgets within the soil-plant system and interactions with the simulated water budget and transport. The methods are similar to those described by Saxton et al. (1977, 1992b), Burwell et al. (1976), and Malone et al. (2001).

Fertilizer applications for each of the crops in the rotation are listed by date of application, amount and type. The chemical budgets are for nitrogen fertilizers of nitrate or ammonia form. Release of NO_3 nitrogen from decaying organic matter and residues is estimated, denitrification is not. The salinity budgets provide estimated chemical quantities, profile distributions and leaching. This method focuses on water interactions and does not include chemical-soil solute exchanges.

Observed data
It is often useful to include initial or measured data for the simulated variables such as runoff, soil water, or one of the chemical species. These optional input data by soil profile layers include: soil water, runoff, salinity, nitrate-N, ammonium-N, and negative ion chemical tracer (like nitrate without plant uptake, eg. Cl, Br). The simulation output includes these observed data used as either a comparison with simulated values or to reset the simulation to be equal to the input data such as for initialization. Standard tabled curve numbers for daily runoff estimates are estimated based on the selected soil and crop parameters, but alternative curve numbers can be manually entered.

Pond Data and Methods

Water budgets for various types of impoundments can be simulated by using appropriate descriptors and data. The schematic of figure 2 indicates the various processes and options, not all of which need to be represented in each pond case. Three types of inundated areas are typical examples. The hydrology of wetland impoundments whose inputs are largely from agricultural landscapes, constructed lagoons for storing runoff and waste from confined animal feedlots and housing, and small ponds or reservoirs used for water storage.

Description
A Pond Project requires describing the physical and hydrologic parameters of the impoundment on the input screen such as depths, depth-area, seepage rate and outlet pipe rating. An infiltration amount into the dry pond bottom is estimated based on soil characteristics. This water depth must be satisfied before any inundation will occur, thus prevents ponding with small events. A constant seepage rate below the saturated ponded soil is specified based on the soil and geologic setting. The infiltration and seepage areas vary as the impoundment fills or empties. No evapotranspiration is estimated for the fringe area of the wetted perimeter.

The physical size and shape of the impoundment is defined by depth-area values incremented from the pond bottom to above the maximum spillway. Depths are specified with reference to the bottom. These values for natural ponds or wetlands can be estimated from topographic elevation maps while constructed ponds have more uniform and known dimensions.

An outlet pipe may be specified at an elevation less than the uppermost spillway outlet by a crest elevation and a stage-discharge flow rate above that depth. This outlet pipe could be one of many configurations from typical outlet weirs with pipes through the dam fill material, simple outflow drop box control structures and tile drains from wetlands. The crest elevation can be changed over a calendar year to accommodate situations such as variable drop box board changes to create seasonal ponding control.

Sinks and Sources
The pond watershed is represented by one to several previously simulated Field Projects with an associated size and deep drainage (interflow) percentage captured by the pond. Direct precipitation and evaporation of the pond surface are transferred from the last watershed field selected. Runoff from the exposed pond banks is added.

An external water supply option may represent a variety of inputs ranging from an offsite supply pump to wash water from animal housing or product processing. This daily influx is specified for selected periods and rates. The inflow can be program controlled with specified upper and lower depth limits to estimate water inputs required to maintain the set water volumes.

Irrigated fields may be considered for water withdrawal with an outlet or pump having a specified inlet depth. The amount and schedule of these withdrawals depends on the irrigated field having been previously simulated as a field with an irrigation schedule option. A field size and irrigation efficiency are specified. Irrigation water is removed from the impoundment if available above the outlet depth, and any lack of required water is documented as an irrigation deficit.

Several pumping options may be selected to remove ponded water. A supply pump will remove water for daily applications such as stock water supply by specifying an inlet depth, operation periods and rates. Any specified pumping not met due to low water levels is documented as a deficit to evaluate the reliability for the intended purpose.

A drawdown pump may be specified for water level control in systems such as wastewater storage lagoons. By defined intake elevation, operational periods and discharge rates, the water is removed to an external site such as an irrigated disposal field. An option of program-determined pond level control can be set such that pumping begins at a set upper level and stops at a lower level. Both manual and automatic pumping options assist with the selection of pump size and operation periods to meet water level requirements.

Water may influx from external ground water such as a nearby seasonal river rise. Groundwater levels relative to the pond bottom determined from an external data source are input to estimate upward seepage into the pond at the specified pond seepage rate until the pond and water table depths are equal. As the ground water levels go below the pond elevation, seepage out of the pond resumes. The rate of seepage is controlled by the specified pond seepage rate.

Impoundments may occur in a sequence with those downstream receiving water from those upstream such as sequential settling and storage ponds. These inputs are made with sequential simulations beginning with the one uppermost. A percent of each upstream outflow is specified as inflow to allow for flow losses or divisions.

Simulation Results

Simulations for either a Field or Pond Project begins by selecting either an existing project file or creating a new file from the Project menu. Projects are filed by Location/Field or Location/Pond to provide a readily accessible directory. Each Field project file is completed by selecting previously defined location climate, field management and soil data files appropriate to that field. Optional observed data are entered, the runoff curve numbers reviewed or changed, output files selected and simulation dates specified within those of available climatic data.

New or existing Pond Project files are defined from selected tabs of the input screen appropriate to the current impoundment. At least one previously simulated Field must be selected to provide watershed runoff and climatic data. Minimum inputs are depths and depth-area values, the simulation period within the dates of the watershed data and selected output files.

Each Field or Pond simulation generates a set of selected output files available directly after the simulation under the View menu. These can also be re-opened at any later time by again selecting the Project Field or Pond screen. Each field output file is labeled with user information, simulation dates and complete file descriptions followed by labeled variables. Pond output tables provide user information, simulation dates, file information plus the descriptive data of the simulated impoundment.

Budget summaries for time periods of annual, monthly and daily are provided. Average data for each time period (annual, monthly or daily) are shown at the end of each summary table. Each output table is compatible with word processing or spread sheet programs (tab delineated) to be viewed, edited, printed or analyzed.

For wetland hydrologic analyses, results are a summary of inundation periods, defined as individual periods when separated by one or more days of dry pond. A statistical summary of the inundation periods for the entire simulated period is provided at the end of the report. This shows the percentage of years the inundation periods met the criteria of wetland hydrology by each 10% of the maximum pond depth. Pond summaries also include depth durations as the number of days the pond depths equaled or exceeded the indicated depths in 10% increments of the maximum depth.

An optional detailed field hydrology report contains one of three levels of budgeting output which can be selected for simulation accuracy assurance or error analyses. The "Minimum" level shows only daily totals, "Medium" provides budgets for each soil layer, and "Maximum" provides soil water movement each delta time increment for each soil layer. These "detailed" files should be selected with caution since they can become very large for long simulation periods.

A graph routine is provided to visually view daily hydrologic values within the field and pond budgets. Daily and accumulative values for most variables are selectable. Soil water and chemical values are graphed by total profile, each soil layer or a combined graph of all layers under the label "Stack". The pond graph is similar to that of the field with both daily and accumulative variable values over each calendar year. The time period of the graph is selectable by months (1-24) and years. The graphs can be saved using the "File/Save As" option.

Calibration and Sensitivity

Simulation results are achieved by combining the products of several hydrologic processes, each of which has been developed from research results and physical understanding. Thus, calibrating the model consists of identifying the appropriate parameters and coefficients for each of these processes. Each input has a method to estimate values based on experience and data to assure a solution within expected hydrologic accuracy.

For those cases when results need to be altered to better represent measured data or experienced estimates, calibrations can be accomplished by identifying which of the several hydrologic processes will impact the values being evaluated. An overview of the input screens provides a suite of the parameter and data choices which might be altered. Field examples would be the evaporation pan coefficients, runoff curve numbers, soil water holding characteristics, and crop growth descriptors and those for a pond such as seepage and dry bottom infiltration are variable.

Precipitation and evaporation data and parameters have the most influence on water balance computations with variations caused by location, elevation or local anomalies. Adjustment factors are available to modify observed precipitation, temperature and evaporation data. Evaporation coefficients are generally more stable over time and space than other climatic data.

Runoff estimates by the curve number method is one of the more empirical process representations. Standard tabled estimates of the curve number values are derived, but these can be replaced by manual estimates. Even after calibration, significant deviations of daily runoff and infiltration from actual values can be expected, but averages over longer periods are generally adequate.

The impact of soil and plant descriptors and parameters are less sensitive than those climactically related. While both soil and plant impacts are very important, their representation is often easier to document, thus, with less sensitivity, also less likely to require significant calibration for broad scale water budgets. An exception would be those analyses focused on crop production in which both soil water and crop parameters become increasingly important.

Simulation Corroboration

Establishing the utility and accuracy of a hydrologic model varies with the focus of the model and the analytical intent. The SPAW model is most useful for those water budgets involving agricultural soils and crops, thus significant effort has been given to these descriptions and representations. Most analyses using the model would include field runoff, soil water and pond budgets, thus assurances of these estimates becomes important.

Estimating runoff by the USDA/SCS curve number method is based on the long term data sets used in its derivation, thus it is best representative of annual streamflow volumes. The original data sets were from the Great Plains region of central US, thus it best represents summer convective rainfall events. A transect study from Western Kansas to Eastern Missouri (Saxton and Bluhm, 1982) showed reasonably good agreement of the estimated annual runoff for regions with annual precipitation ranging from some 10 to 40 inches.

Of particular importance are the soil water profile dynamics over time because much of the precipitation is generally infiltrated to profile. Simulated soil water has been extensively compared with measured data in a wide range of climate, soil and crop combinations. Most of the soil moisture measurements have been by the neutron probe method supplemented by surface samples. The model has been extensively tested on agricultural crops such as corn, soybeans, brome grass, and wheat (Sudar et. al 1981; DeJong and Zentner, 1985; Saxton, 1985, 1989; Saxton and Bluhm, 1982; Saxton et al. 1974a, 1974b, 1992a, 1992b). Several studies for irrigated conditions showed good agreement of measured and estimated soil moisture for scheduling and economic analyses with varying crops and soil types (Field et al., 1988; Bernardo et al., 1988a; 1988b). Some calibration is recommended wherever possible.

Applications of the POND model have ranged from determining wetland inundation frequencies, sizing stock watering ponds for minimal deficiencies, sizing waste water lagoons and associated pumping capacities, and the long-term levels of wildlife ponds (Saxton and Willey, 1999; 2004). With the many operational inputs included in the pond model, simulations can be achieved for many pond types and best understood by analyzing pond states and processes over times of days and years. The tabled and graphical outputs provide many analytical opportunities. Recent evaluations of pond budgets for waste water storage pond design was presented by Moffit et al. (2003) and Moffit and Wilson (2004).

Conclusions

The agricultural hydrology model, SPAW, consists of two linked routines, a daily vertical water budget of an agricultural field and a daily impoundment water budget. The field model input includes daily climate data, annual crop definitions, and a layered soil profile with individual tension-conductivity soil water characteristics. The ponding routine utilizes the climatic data and runoff estimates from one or more previously simulated farm fields, physical descriptions of depth-area, pipe and pump flow rates and process parameters. The pond simulations may be applied to shallow wetlands, small ponds, or constructed lagoons and reservoirs. Outputs include annual, monthly or daily hydrologic budgets, graphics and wetland statistics. The SPAW model and documentation is publicly available by contacting the authors or their associated agencies. General information about the SPAW model and latest versions can be found at the following Web Page: (http:// http://hydrolab.arsusda.gov/SPAW/Index.htm).

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