	Texas A & M University and U.S. Bureau of Reclamation **REVISION FOR** **US BUREAU OF RECLAMATION** **2008 MODELING INVENTORY**
Short Name:	SPAW Field and Pond Hydrology
Model Type:	SPAW is a daily water budget model of the soil-plant-air-water (SPAW) system for an agricultural field/watershed plus a wetland/pond/reservoir model. The SPAW model simulates a daily hydrologic budget for agricultural fields with a moderate level of complexity to account for the most important hydrologic processes that will be impacted by the field characteristics. The model inputs describe the climate, soils and crops of a specific farm field in the one-dimensional vertical plane. The climatic variables are daily rainfall and potential evaporation with optional air temperature for cold climate hydrology. The soils and crop descriptions determine the daily disposition of this water into and out of the soil-plant-air-water (SPAW) system. The basic hydrologic budgeting by SPAW has been enhanced by the addition of a soil water characteristics model, an irrigation field budget (scheduling) and an inundated pond (wetland/lagoon/pond/reservoir) budget.
Model Objectives:	The objective of the SPAW model research was to provide a model of mid-range technical complexity to achieve understanding and predictions of agricultural hydrology and its interactions with crop production without undue burden of computation time or input details. The SPAW model is generally applicable to soil water hydrologic analyses on a unit of land with a unique and spatially uniform set of climate, soil and plant characteristics, often designated as a farm field. The POND simulation can represent any number of various inundated surfaces such as small wetlands, farm ponds, storage lagoons for animal waste, or water supply reservoirs. Watershed flow routing beyond the daily budget is not included, thus hydrograph analyses are not possible.
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Model Structure:	SPAW field model hydrologic processes which represent the vertical water movement in a farm field: <u>Rainfall</u>: daily totals, although snow accumulation and melt is considered when air

	temperature is included. Runoff: Computed by the USDA/SCS curve number method, which considers the soil, vegetation and surface conditions. Frozen soil effects are included if air temperature data is included. No stream routing is provided. Infiltration: A daily amount based on the difference of rainfall and runoff as determined with the USDA/SCS curve number routine. Redistribution within the soil profile: Infiltrated and existing soil water is moved between assigned soil layers by a Darcy tension-conductivity procedure providing both downward and upward flow components. Evapotranspiration: Daily estimates of plant transpiration, direct soil surface evaporation and surface interception are driven by a daily potential evaporation and controlled by the plant and soil water status. The potential evaporation may be derived externally by any one of several methods such as the Penman and/or Monteith method, daily pan evaporation, and temperature or radiation methods. A method based on mean annual evaporation distributed as mean daily varied by months is included in the model. Percolation: Daily water leaving the bottom of the described soil profile, which will contribute, to local ground water or horizontal inter-flow. The POND model hydrologic processes which represent the inflows, withdrawals and losses are: Runoff: Daily water supplied to the pond by watershed runoff (comprised of one or more fields which have had runoff estimated by a SPAW field simulation). Inter-flow: Daily water supplied to the pond by watershed field deep percolation from one or more fields which have had runoff estimated by a SPAW field simulation. Input Pump: A pump bringing water from elsewhere such as an off-stream source or an animal housing flush system. Rainfall: That falling directly on the pond surface. Evaporation: Taken as the potential daily evaporation of the climate data. Infiltration: An amount infiltrating into the pond bottom as it is initially inundated. Seepage: A constant daily seepage rate to the local groundwater beneath the inundated area. Pipe outlet: A daily flow of a pipe outlet system having a defined stage-discharge relationship. Spillway overflow: An uncontrolled daily flow from the uppermost spillway or outlet. Output pump #1: A daily pumped amount from the pond for designated rates and periods with a specified inlet pond depth, e.g. to an animal water tank. Output pump #2: A daily pumped amount from the pond for designated rates and periods with a specified inlet pond depth, e.g. to remove lagoon water to a disposal field. Irrigation: A daily amount to one or more fields to supply an irrigation amount previously defined by a SPAW field simulation for each irrigated field.
Model	Data and parameters are input via daily climatic data files supplemented with data

Parameters:	from a set of monitor screens to describe soil profiles, annual crop growth, crop management, irrigation and fertilization. The inundated ponded area is described in terms of a depth-area relationship, spillway height, the discharge pipe inlet height and its depth-discharge relationship, and heights above the pond bottom to various pump inlets.
Spatial Scale:	The SPAW model is a field scale vertical water budget, given that the field can 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 likely represent a typical farm field of tens to a few hundred acres growing a single crop with only moderate soil characteristic variations. 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. The SPAW model may be extended to represent small watersheds composed of multiple farm fields, each simulated separately and the results combined. This concept is used as the input source for the inundation simulations of wetlands and ponds. No streamflow routing or channel descriptors are included and daily runoff is estimated as an equivalent depth over the simulation field. The POND simulation can represent any number of various inundated surfaces such as small wetlands and ponds, storage lagoons for animal waste, or water supply reservoirs. Since no detailed routing beyond the daily budget is provided, hydrograph analyses are not included. A daily inundated wetland or pond budget can be simulated subsequent to one or more SPAW field simulations to provide an estimate of contributing watershed runoff into the pond as surface or subsurface flow.
Temporal Scale:	The SPAW model is a daily simulation of all hydrologic processes for a portion of a calendar year or multiple years. The exception is the water movement within the soil profile, which is simulated by a Darcy solution with a time element selected by the model of a portion of a day or hour depending on the potential for water conductivity.
Input Requirements:	Climatic Data: The appropriate weather files of precipitation, evaporation and air temperature which best describe the simulation field location are entered from external weather data sources. Daily precipitation is required while daily evaporation and daily air temperatures are optional. Average annual pan or lake evaporation is entered from map references or local knowledge. Mean daily values for each month are computed from a default annual distribution, but these can be manually edited. Monthly Pan/PET coefficients are provided from a default distribution, but these can be manually edited. Other PET options are possible. Soil Profile Characteristics:

The typical soil profile for the soil of the field to be simulated is represented by a series of layers, each described by thickness and water holding and transmission characteristics. Soil texture of each major profile layer is the first important variable to determine water holding characteristics, and average relationships determined from a very large laboratory data set are included. Other variables such as bulk density, organic matter, salinity and density are included in this estimating routine. Graphical analyses are shown for these effects as well as their effect on computed water simulations.

Crop Characteristics:
Crop characteristics are described for a full calendar year period and include both growing and non-growing periods. Multiple crops during any one year would be described as one data set; for over-winter crops such as winter wheat, two calendar years would be required for one crop. The crops are defined with four annual curves representing: 1) canopy cover, 2) greenness of the canopy, 3) root depth and 4) grain yield water stress sensitivity. Given familiarity with the common crops in the region, the crop characteristic curves can usually be sketched to sufficient accuracy to provide an adequate crop impact on the soil water hydrology.

Field Management:
Fields management with various crop rotations, irrigations and fertilization and inputs over multiple years can be represented. To define crop rotations, the previously defined annual crop data sets are selected and assigned a rotation year. If irrigation is involved, an irrigation scheduling routine may be selected with multiple choices for the time, depth and method of irrigation. Several parameters are associated with each of the irrigation options. Fertilizer values of amount, type and application dates are input if this option is used.

Runoff: Curve numbers for the USDA/SCS procedure are estimated from data specified in the CROP and SOIL data screens. Given this is an empirical approximation, the user may find it desirable to modify these first estimates to better represent the simulation. Two numbers may be entered on the main SPAW field screen, one for a fallow soil, and a second for the “seasonal average” of a cropped soil.

Ponding Inputs:
The inundated ponded area is described in terms of a depth-area relationship, spillway height, the discharge pipe inlet height and its depth-discharge relationship, and heights above the pond bottom to various pump inlets. The pump intake pool depths provide a depth below which no outputs can be supplied to water needs, but seepage and evaporation will continue such that any remaining water will be depleted. If a pipe outlet is involved, the depth above the pond bottom to the inlet is specified and spillage begins anytime the water depth exceeds this level at a rate specified by a depth-rate table for the particular output device, the depth being the water depth above the intake. A maximum pond depth is specified at which spillway

	overflow occurs at an unrestricted rate if the water depth exceeds this level. Lastly, an initial depth is specified.
Computer Requirements:	Computer requirements are such that the typical PC computer will readily install and operate this model in the DOS environment. Memory should be least 565 KB of conventional RAM memory plus 4-6 MB of hard disk space available. The current version of SPAW is programmed for the "Windows" environment in Visual Basic. A mouse screen pointer is most convenient to quickly operate the screens, although keyboard control is available for most functions.
Model Output:	The simulation results can be reviewed in either tabular (screen or printed) or graphic form. Tabled values show major hydrologic budget values for periods of annual, monthly, or daily and the averages for each selected period. The graph menu shows the daily and accumulative values for most of the major hydrologic processes plus a "stack chart" and/or a bar chart of the soil water by layers as defined by the simulation. The graphs or tables can be readily printed. The daily pond simulations provide an annual distribution of ponded depths. Each inundation period is defined by the day filling begins and the last day water depth is present. These periods are analyzed according to wetland definitions depending on the time of year, duration of inundation and frequency of occurrence.
Parameter Estimation, Calibration:	See data input for crop and soil parameter estimation. Model calibration is typically with observed soil water profiles if that is the primary interest. Pond/inundation areas are calibrated with observed runoff/depth data. Primary variables for calibration would be USDA/SCS curve number for runoff estimation, soil profile lower boundary parameters, and pond seepage rate.
Model Testing, Verification:	The SPAW model has been developed and applied extensively to hydrologic simulations for both research and design. The original model was focused on plant available soil water under rain-fed conditions (Saxton, 1980, 1981, 1985; Saxton et al., 1974; Saxton and McGuinness, 1982; Sudar et al., 1981). Since there have been significant model additions, alterations, added capability and numerous applications related to agricultural field hydrology (Saxton et al., 1992; Saxton and Bluhm, 1982; Rao and Saxton, 1995; DeJong and Zentner, 1985). The enhancement of soil water characteristic estimates was particularly useful to make the model field applicable (Rawls, et al., 1982; Saxton et al., 1986; Saxton and Rawls, 2006). The pond model has been verified by multiple field sites of wetland and lagoons (Saxton and Willey, 1999; Saxton et al., 2006).
Model Sensitivity:	The model is most sensitive to climatic data and less sensitive to crop and soil descriptions. Hydrologic budgets are largely driven by the climatic inputs of precipitation and evaporation potential, thus these values are the first most sensitive for accurate simulations. We have chosen daily values as appropriate input for the SPAW model for a daily time-step hydrologic simulation. While we often must use

	the available climatic data from a nearby local source, knowing that each day's values are important makes us alert to review these data carefully for obvious errors and missing values, particularly for precipitation. Often the available data are not at the simulation site, thus the impact of spatial variation must be assessed and recognized in evaluating the simulation results. Evaporation and air temperature data are not as spatially or time variable as that of precipitation and are less critical to accurate simulation than precipitation, thus they often can be transferred some distance or estimated by time-averaged values of weeks or months and yet provide reasonable results The inundation model is most sensitive to estimated initial soil infiltration over the inundated region and the seepage of the inundated area.
Model Reliability:	The model has been extensively tested and evaluated such that hydrologic budgets are accurate and reliable. No major mathematical errors have been detected in numerous recent simulations. Data errors or extreme conditions such as very sandy soils may cause computational errors. Error detection routines are included with appropriate alerts.
Model Application:	Some common uses for hydrologic budgeting on agricultural fields and ponds would be: 1. Evaluating the status of available crop water from either natural rainfall or as augmented by irrigation. 2. The scheduling of supplemental irrigation or assessment of irrigation efficiencies of known irrigation regimes. 3. Assessing the deep seepage of particular field water regimes that may be contributing to deep percolation contamination. 4. Assessing the frequency and duration of wetland inundation being supplied by surface runoff or inter-flow from up-slope agricultural fields comprising the watershed. 5. Designing ponds for water supply which are supplied by watershed runoff or pumps in nearby streams. 6. Designing storage lagoons that capture field runoff and wash-water for remedial treatment. 7. Designing irrigation supply reservoirs that are supplied by watershed runoff. 8. Also see references cited under "Model testing and verification".
Documentation:	The model and all documentation may be accessed from the following WEB site: http://hydrolab.arsusda.gov/SPAW/Index.htm. The graphical and interactive method of relating soil texture to soil water holding characteristics utilized in the SPAW model can also be obtained as a "stand-alone" program from the same site. A five hour SPAW model training DVD is available from: http://cru84.cahe.wsu.edu/cgi-bin/pubs/DVD0001.html Three manuals are included with the model distribution and accessed by the HELP menu. An "Operational Manual" assists with run-time questions, a "Users Manual" is an introduction to the SPAW model and its typical applications, and a "Reference Manual" includes details about the internal model methods, assumptions and

	calculations.
Other Comments:	References: 1. DeJong, R. and Zentner R. P. 1985. Assessment of the SPAW model for semi-arid growing conditions with minimal local calibration. Agric. Water Mgt., 10(1985):31-46. 2. Rao, A. S. and Saxton, K. E. 1995. Analysis of soil water and water stress for pearl millet in an Indian arid region using the SPAW model. Indian J. of Arid Environments 29:155-167. 3. Rawls, W. I., Brakensiek, D. L. and Saxton, K. E. l982. Soil water characteristics. Trans. ASAE 25(5):13l6-1328. 4. Saxton, K. E. 1980. Agricultural drought assessment by daily soil moisture predictions. Proc. of Climate and Risk Symposium, Washington, D. C., May, l980. 22 pp. 5. Saxton, K. E. l98l. Mathematical modeling of evapotranspiration on agricultural watersheds. In Modeling Components of Hydrologic Cycle, a part of the Proc. Inter. Symp. on rainfall-Runoff Modeling, Miss. State Univ., May l8-2l, l98l. pp. 183-203. 6. Saxton, K. E. l985. Soil water hydrology: Simulation for water balance computations. Proc. Int. Asoc. Hydro. Sciences General Assembly. IUGG, Hamburg, West Germany, Aug., l983. IAHS Pub. No. l48, pp. 47-59. 7. Saxton, K. E. and Bluhm G. C. l982. Regional prediction of crop water stress by soil water budgets and climatic demand. Trans. ASAE. 25(l):105-ll5. 8. Saxton, K. E. and McGuinness, J. L. l982. Chapter 6--Evapotranspiration. In C. T. Haan, H. P. Johnson, and D. L. Brakensiek (eds) Hydrologic Modeling of Small Watersheds, Am. Soc. Agric. Eng. Monograph No. 5, pp. 229-273, 9. Saxton, K. E., Johnson, H. P. and Shaw, R. H. l974. Modeling evapotranspiration and soil moisture. Trans. ASAE l7(4):673-677. 10. Saxton, K. E., Rawls, W. J., Romberger, J. S. and Papendick, R. I. 1986. Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036. 11. Saxton, K. E., Porter, M. A. and McMahon, T. A. 1992. Climatic impacts on dryland winter wheat yields by daily soil water and crop stress simulations. Agric. and Forest Meteor. 58(1992):177-192. 12. Saxton, K. E. and P. Willey. 1999. Agricultural wetland and pond dydrologic calcualations using the SPAW mode. Proc. Paper 992030, Amer. Soc. Agric. Engr. 1999 annual meeting, Toronto, ON, July 18-21, 1999. 13. Sudar, R. A., Saxton, K. E. and Spomer, R. G. l98l. A predictive model of water stress in corn and soybeans. Trans. ASAE. 24(l):97-102. 14. Saxton, K.E. and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Sci. Soc. Am. J. 70:1569-1578. 15. Saxton, K.E., P.H. Willey and W.J. Rawls. 2006. Field and Pond Hydrologic Analyses with the SPAW Model. Proceed. Paper No. 062108, Annual Inter. Meeting, Amer. Soc. Agric. and Biol. Engr., July 9-12, 2006, Portland, OR. 16. Saxton, K. E. and P. H. Willey. 2006. The SPAW Model for Agricultural Field and Pond Hydrologic Simulation. Chapter 17 in: Mathematical Modeling of

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