Agricultural and watershed modeling with EPIC, APEX, and SWAT: Computational tools for investigating, planning, and understanding the future

June WOLFE1, Jaehak JEONG2, Kara PAULK3, and Ashley FARLEY4

1 Associate Research Scientist, Texas A&M AgriLife Research, Water Science Laboratory
    (720 East Blackland Road, Temple, Texas 76502, USA)
    E-mail:jwolfe@brc.tamus.edu
2 Associate Professor, Texas A&M AgriLife Research, Department Biological and Agricultural Engineering
    (720 East Blackland Road, Temple, Texas 76502, USA)
    E-mail:jjeong@tamu.edu
3,4 Student Intern, Temple BioScience Center - Temple College
    (5701 Airport Road, Temple, Texas 76502, USA)
    E-mail:tbitemple@templejc.edu

Scientists from Texas A&M AgriLife Research and the United States Department of Agriculture – Agricultural Research Service have worked together at the Blackland Research Center (BRC) in Temple, Texas for more than 80 years. Since the mid-1960’s, computer models describing agricultural, environmental, and hydrological processes have been developed by scientists at BRC. Today BRC scientists continue to refine and support numerous modeling products that are used world-wide by researchers, environmental managers, and government policy makers. The Environmental Policy and Integrated Climate (EPIC) model, the Agricultural Policy and Environmental eXtender (APEX) model, and the Soil and Water Assessment Tool (SWAT) are the most prominent and heavily used. This paper briefly describes their history, general organization, usage tools, support and availability, and three example uses.

In the first example, the EPIC model was used to evaluate irrigation control methods on an urban landscape. The uncalibrated results suggested that scheduled irrigation was more efficient than sensor-based. This was unexpected but explained by poor plant growth under water-saturated soil conditions. In another example, a calibrated SWAT model was used to determine sediment sources and evaluate a detention pond management strategy in a heavily developed urban watershed. Stream channel erosion was found to be higher than upland erosion and the implementation of a sediment detention pond showed that sediment exports could be reduced by up to 14%. Finally, the APEX model was used to examine two irrigation strategies in cascading rice paddy fields. Data from Okayama, Japan was used to develop a terraced hydrology model and predict irrigation management practice effects on water usage and soil and nitrogen exports to downstream waterbodies. The uncalibrated model showed that constant flooding irrigation produced higher crop yields but also increased sediment exports. Cycled flooding however showed reduced nitrogen exports. Determining the optimal management strategy depends upon user goals.

Key Words: modeling, agriculture, environmental, hydrological, EPIC, APEX, SWAT

1. INTRODUCTION

Agricultural, municipal, industrial, and private users all compete for limited water resources. Negative effects resulting from the use of these resources must be minimized through efficient management decisions in order to provide both water quality and quantity for future generations. The computational tools developed at the Blackland Research Center (BRC) in Temple, Texas provide scientifically credible and economically viable means to investigate and test management strategies without risking time and expense. The intent of this article is to introduce the models, describe their basic configuration and operation, and demonstrate their utility through example studies.
2. TEMPLE MODEL DESCRIPTIONS

(1) Overview

Scientists working for the U.S. Department of Agriculture - Agricultural Research Service and Texas A&M AgriLife Research are co-located at the Blackland Research Center (BRC) in Temple, Texas where they have developed a set of comprehensive hydrologic land management models over the past 40 years. Computer modelling at BRC began in the mid-1960s with the development of single-event models which served as the building blocks for today's comprehensive models. Early focus was on surface water hydrology and sediment yield.

The most popular models currently in use include the Environmental Policy Integrated Climate (EPIC) model, the Agricultural Policy and Environmental eXtender (APEX) model, and the Soil and Water Assessment Tool (SWAT). They are continuous, process-based models that simulate spatial scales ranging from individual fields to large river basins and temporal scales from minutes to thousands of years.

The BRC models have been used in projects worldwide involving soil and water resource and environmental management. The University of Iowa currently maintains a web-hosted database containing nearly 1700 peer-reviewed articles describing developments, applications, and studies attributed to the BRC family of models.

(2) Environmental Policy Integrated Climate (EPIC) model

Originally known as the Erosion Productivity and Impact Calculator, EPIC was a plant growth model initially developed in the early 1980s to estimate soil productivity affected by erosion. Since then, it has been extensively modified and expanded. Today EPIC has been renamed the Environmental Policy Integrated Climate model. It is a process-based model that simulates physio-chemical processes occurring in soil and water environments under agricultural management. The model is organized into components describing weather, hydrology, erosion, nutrients, soils, plant growth, tillage, and economic budgets. It is designed to simulate a field, farm, or small watershed that is homogenous with respect to climate, soil, landuse, and topography. This is called a hydrologic landuse unit (HLU). EPIC operates on a continuous daily time-step. It can perform long-term simulations of hundreds and even thousands of years in length. Output from the model is in the form of text files listing the water, nutrient, and pesticide flux in the HLU at time scales from daily to annual. A wide range of crop rotations and vegetative systems can be simulated with the model’s generic crop growth routine. Many management practices such as irrigation, drainage, fertilization, grazing, terracing, and tillage can be simulated.

(3) Agricultural Policy and Environmental eXtender (APEX)

The APEX model was developed for use in non-homogenous, whole farm watershed simulations. It is built upon and similar to EPIC. APEX can be used to evaluate land management strategies regarding sustainability, soil erosion, economics, water supply and quality, soil quality, plant competition, weather and pests. Management capabilities include irrigation, drainage, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage.

In addition to farm management functions, APEX can be adapted to study environmental problems. The model typically uses a daily time step, however some processes may be simulated with hourly or smaller time steps, and can simulate hundreds of years. Farms may be subdivided into fields, soil types, landscape positions, or other desirable configurations. The ability to route individual HLU results to downstream HLUs distinguish APEX from EPIC.

(4) Soil and Water Assessment Tool (SWAT)

SWAT incorporates features of several Temple models and is the result of 30+ years of non-point source modeling. SWAT is a river basin, or watershed, scale model developed to quantify and predict the impacts of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. Basins of several thousand square miles can be studied, but must be divided to account for the difference in soils, land use, crops, topography, and weather.

SWAT accepts outputs from APEX as well as other measured and point-source data. Watersheds with no monitoring data can be modeled and management or climate changes can be simulated for “what if” studies.

3. GENERAL MODEL STRUCTURE, FILE ORGANIZATION, AND USAGE

(1) General model structure

The Temple models are made up of thousands of equations describing different physical, chemical, and biological processes and their interactions. The
equations are coded in the FORTRAN computer language and require a set of text files containing the input parameters. The input (and output) files have specific row and column formats.

A typical model is comprised of approximately 30 to 50 text files contained in a single working directory and can be managed by hand. For large projects with numerous test scenarios there are provisions to create batch jobs that automate the handling of thousands of input/output files organized in hundreds of directories. The great strength of the Temple models is their flexibility. Application is limited only by the skill and imagination of the user.

(2) Model input/output tools and support

The inputs and outputs from the FORTRAN code take the form of text files. For small simulations, the data files comprising a model are easily modified using simple text editing programs. Researchers at BRC have also developed tools that make the task easier and more manageable. Editors for EPIC and APEX have been built based on the Microsoft Excel spreadsheet program and a dedicated editor has been developed for SWAT. There are additional tools that allow the use of GIS software to generate the input files.

The output from a model run also takes the form of a text file, often containing several thousand lines of information. This file may be examined with a text editor but portions of interest are more often copied and pasted into a spreadsheet program such as Excel for plotting and visualization. A number of specialized tools for editing, displaying, model calibration, and scenario evaluation have been developed for EPIC, APEX, and SWAT.

These public domain models are constantly updated and supported. They are freely available for download on the internet. Theoretical documentation, user guides, and tools are also available. Numerous workshops are held around the world every year to assist users with learning and applying the models.

4. EXAMPLE MODEL APPLICATIONS

(1) Examining urban irrigation with EPIC

Residential landscape irrigation in the U.S. often uses more than 50% of total household potable water. The EPIC model was used to compare grass water use under two kinds of irrigation control (schedule vs sensor) in a homogenous urban landscape. Grass water stress was used to evaluate grass health and biomass was used to estimate aesthetic quality.

Both irrigation types showed an increase in plant water stress as irrigation amounts were decreased. Although higher water stress was observed in schedule-based irrigation it used less water while producing higher amounts of biomass and superior aesthetics (Fig. 1, circled point). Sensor-based irrigation control was expected to outperform schedule-based irrigation. Overwatering creating saturated soil conditions and poor growth (high stress, low biomass) may explain the results.

(2) Urban erosion investigation using SWAT

The SWAT model was used to examine sediment exports from a highly urbanized and environmentally sensitive watershed in San Marcos, Texas. Storm discharge and associated sediment loads were monitored for 18 months. A high-resolution (spatial and temporal) SWAT model was created to represent the large range of slopes and complex land use in the watershed. Monitoring data were used to calibrate the SWAT model so that erosion could be predicted and management practices could be tested before committing to the actual installation.

High impervious cover (buildings, parking lots, etc.) combined with steep slopes caused rapid runoff and high erosive shear leading to higher erosion in stream channels than upland areas (Fig. 2).
The model was also used to test the efficiency of constructing a detention pond. Results showed a detention pond would flatten peak storm flows (Fig. 3) thereby reducing sediment suspension and entrainment. This could potentially lower sediment export up to 14%. These results helped city managers with resource allocation and planning.

(3) Simulating Japanese cascading rice paddy water use and pollutant export with APEX

Rice is an important crop around the world. Its cultivation can stress water resources in terms of water use and water pollution. Efficient management is needed to sustain future production while protecting downstream environmental resources.

An APEX model was constructed to estimate water use, crop yield, sediment export, and nitrogen export of a 5-field, terraced, rice paddy system in Misaki Town, Okayama, Japan. Two irrigation methods were compared (constant vs cycled flooding) at four irrigation levels (50, 60, 75, 100 mm) to optimize irrigation combinations yielding maximum crop production with minimum water use and sediment and nitrogen exports.

Constant flooding irrigation produced the highest grain yield with the lowest water use at all irrigation levels (Fig. 4). Constant flooding however exhibited more sediment loss than cycle flooding and may contribute to downstream sediment pollution. Conversely, cycle flooding showed lower nitrogen export and may help reduce downstream nutrient pollution. Determining which irrigation type and is optimal depends upon local management goals.

5. CITATION AND REFERENCE LIST

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