CHAPTER 9

Development and Application of the Automated Geospatial Watershed Assessment Tool

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INTRODUCTION

The emphasis in natural resource management is shifting from inventory and exploitation to an integrated, broad-scale approach with the goals of maintaining diversity, balance, and long-term productivity of the environment. Accomplishing this requires an understanding of spatio-temporal processes on a detailed, integrated, and formalized level. The advent of remotely sensed and other forms of

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geospatial data has facilitated the study of large-scale, complex spatio-temporal processes. The need to assimilate this wealth of information when making decisions is increasing the demand for integrated computer-based tools capable of storing, manipulating, and analyzing environmental data. This chapter describes in detail the Automated Geospatial Watershed Assessment (AGWA) tool, which is an integrated hydrologic modeling toolkit developed by the USDA-ARS-Southwest Watershed Research Center in cooperation with the USEPA-National Exposure Research Laboratory-Landscape Science Program. AGWA was designed to perform watershed assessment across multiple spatial and temporal scales to facilitate scientific study and resource management. This chapter presents a detailed description of AGWA and two case studies illustrating the application of the tool. The case studies include (1) assessing the impact of land-cover and land-use change on water quantity and quality and (2) investigating the hydrologic impacts likely to result from a variety of forecasted population growth and development scenarios (alternative futures) for a semi-arid basin on the U.S.-Mexico border.

Most management decisions concerning the environment affect and are affected by the landscape. City and county planning authorities make decisions about land use and infrastructure that directly affect the landscape. Farmers make decisions about what to grow and how to grow it that affect and are affected by the landscape. Individual homeowners and business make decisions about their own behavior that affect and are affected by the landscape. Therefore, understanding and modeling the spatial patterns of landscape processes and changes over time at several different scales is critical to effective environmental management. In recognition of this, we need to develop a deeper understanding of the complex spatial and temporal linkages between and among ecological, hydrological, geomorphologic, and economic systems on the landscape and to use that understanding to develop effective and adaptive policies.

Central to environmental and ecological continua is water, which may occur as surface water, subsurface water, or groundwater. When assembled, these three types of water constitute the water continuum. The quantity and quality of these types and their variations in time and space constitute the necessary input to the integrated development and management of water resources. Integrated water management involves technology-based management and non-technology-based management. The core of technology-based management is watershed hydrology modeling (Singh, 1995).

Inherent to integrated resource management is the concept of total watershed management that is being increasingly accepted as an approach for environmental protection in general, and water resources (both quantity and quality) protection in particular. Watershed management links human activities (such as land use) within the watershed with hydrologic process and response, most commonly through the use of hydrologic models. One important outcome of this approach is that it provides a reasonable estimate of the expected water quality in the receiving stream. In other words, integrated modeling entails linking watershed conditions with water quantity and quality of the receiving body (Mankin et al., 1999).

For the decision maker, implementing simulation models and interpreting their output is complicated by the complexity of the models and by the nature of natural resource decisions that often involve conflicting objectives. Although complex simulation models aid the decision maker by predicting the outcome of particular management practice or system of practices, the abundance of information provided complicates the ability of decision makers to analyze the information and come to a decision that satisfies more than one objective. A framework that facilitates the efficient transfer of technology to user groups is thus necessary, and gives the decision maker the ability to apply the technology easily and in a repeatable and scientifically defensible manner.

In recognition of this, in June 1997, the United States Environmental Protection Agency (USEPA), National Exposure Research Laboratory (NERL), Landscape Science Program and the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) entered into an Interagency Agreement for the purpose of improving ecosystem risk assessment via characterization research, process modeling, and long-term monitoring studies.

At the outset of the project, a detailed evaluation of existing hydrological models was conducted to select suitable models for multi-scale watershed assessments. It was concluded that for multi-scale modeling, it was necessary to select two models that perform successfully at small and large space-time scales. For studies to be conducted at the basin scale, the Soil Water Assessment Tool (SWAT, Arnold et al., 1994) model was selected, and for studies at the watershed or subwatershed scale, the Kinematic Runoff and Erosion Model (KINEROS2, Smith et al., 1995) model was chosen. The extensive data requirements and the difficult task of building input parameter files have long represented an obstacle to the timely and cost-effective use of such complex models by resource managers. For this reason, an intuitive GIS-based interface was developed to take advantage of the now widely available digital elevation, land-use/cover and soils datasets for the automated development of model input parameters. This interface, the Automated Geospatial Watershed Assessment tool (AGWA), was released in August 2002 (Miller et al., 2002a).

OVERVIEW OF THE AGWA TOOL

This section describes the main components of the AGWA tool, including its strengths and limitations. AGWA is an extension for the ArcView versions 3.X (ESRI, 2001). The GIS framework is ideally suited for watershed-based analysis, which relies heavily on landscape information for both deriving model input and presenting model results. AGWA is distributed freely via the Internet as a modular, open-source suite of programs and associated documentation (www.tucson.ars.ag.gov/agwa).

AGWA provides the functionality to conduct all phases of a watershed assessment for two widely used watershed hydrologic models: the Soil Water Assessment Tool (SWAT) and a customized version of the KINEmatic Runoff and erOSion model (KINEROS2). SWAT is a continuous simulation model for use in large (river-basin scale) watersheds. KINEROS2 is an event-driven model designed for small arid, semi-arid, and urban watersheds. The AGWA tool contains these models in an intuitive interface for performing multi-scale change assessment, and provides the user with consistent, reproducible results. Data requirements include elevation, land -cover, soils, and precipitation data, all of which are typically available at no cost over the internet. Model input parameters are derived directly from these data using optimized look-up tables that are provided with the tool.

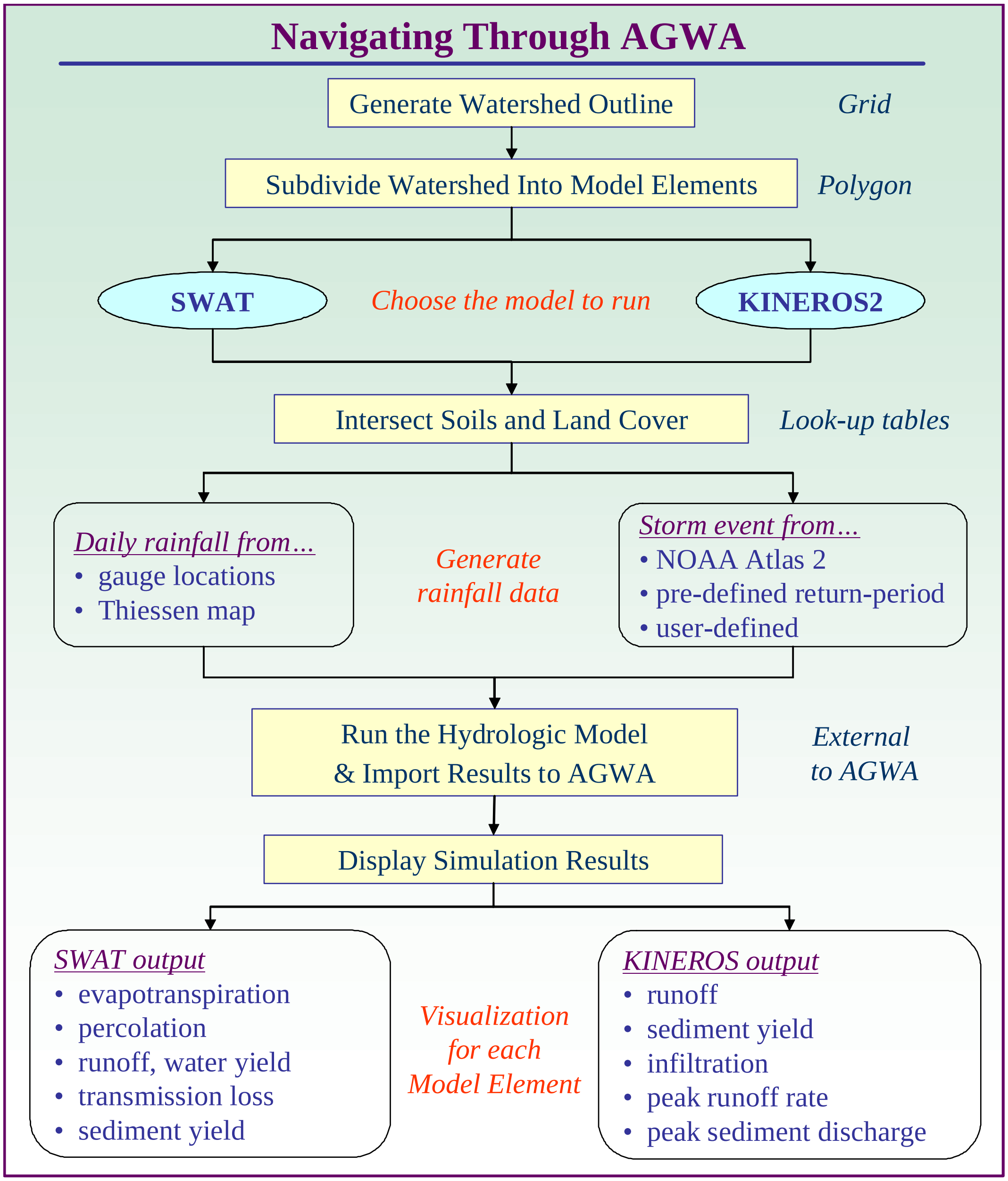


Fig. 9-1. Sequence of steps in the use of AGWA for hydrologic modeling.

The conceptual design of AGWA is presented in Fig. 9-1. A fundamental assumption of AGWA is that the user has previously compiled the necessary GIS data layers, all of which are easily obtained for the conterminous United States. The AGWA extension for ArcView adds the 'AGWA Tools' menu to the View window and must be run from an active view. Pre-processing of the DEM to ensure hydrologic connectivity within the study area is required, and tools are provided in AGWA to aid in this task. Once the user has compiled all relevant GIS data and initiated an AGWA session, the program is designed to lead the user in a stepwise fashion through the transformation of GIS data into simulation results. The AGWA Tools menu is designed to reflect the order of tasks necessary to conduct a watershed assessment, which is broken out into five major steps: (1) location identification and watershed delineation; (2) watershed subdivision; (3) land-cover and soils parameterization; (4) preparation of parameter and rainfall input files; and (5) model execution and visualization and comparison of results.

Step 1: The user first creates a watershed outline, which is a grid based on the designated outlet (pour point) of the study area. If a GIS coverage of the outlet location exists (such as would be the case for a runoff gauging station), it can be used to designate the drainage outlet. Alternatively, the user has the option of using a mouse to click on the watershed outlet. If internal gauging stations exist as a separate GIS coverage, AGWA will use them as internal drainage pour points and generate output at each of the stations. This option is particularly useful for calibration and validation of model results.

Step 2: A polygon shapefile is built from the watershed outline grid created in Step 1. The user specifies the threshold of contributing area for the establishment of stream channels, and the watershed is divided into model elements required by the model of choice. From this point onward, tasks are specific to the model that will be used (KINEROS2 or SWAT), but the same general process is followed independent of model choice.

Step 3: The watershed created in Step 2 is intersected with soil and land-cover data, and parameters necessary for the hydrologic model runs are determined through a series of GIS analyses and look-up tables. The hydrologic parameters are added to the polygon and stream channel tables to facilitate the generation of input parameter files. At this point, the user can manually alter parameters for each model element if additional information is available to guide the estimation of those values.

Step 4: Rainfall input files are built at this stage. For SWAT, the user must provide daily rainfall values for rainfall gauges within and near the watershed. If multiple gauges are present, AGWA will build a Thiessen polygon map and create an area-weighted rainfall file. For KINEROS2, the user can select from a series of pre-defined rainfall events dependent on the geographic location, choose to build his/her own rainfall file through an AGWA module, or use NOAA Atlas II return period rainfall depth grids distributed with AGWA (NOAA, 1973). Precipitation files may be created for uniform (single-gauge) or distributed (multiple-gauge) rainfall data.

Step 5: After Step 4, all necessary input data have been prepared: the watershed has been subdivided into model elements; hydrologic parameters have been determined for each element; and rainfall files have been created. The user can proceed to run the hydrologic model of choice. AGWA will automatically import the model results and add them to the polygon and stream map tables for display. A separate module controls the visualization of model results. The user can toggle among viewing various model outputs for both upland and channel elements, enabling the problem areas to be identified visually. If multiple land-cover scenes exist, the user can parameterize either or both of the two models and attach the results to a given watershed. Results can then be compared on either an absolute or percent change basis for each model element. Model results can also be overlaid with other digital data layers to further prioritize management activities.

Hydrologic Models

Key components of AGWA are the hydrological models used to evaluate the effects of land cover and land use on watershed response. In this section, a description of the basic structure of each model is provided as well as the model's simplifying assumptions, strengths, and weaknesses. Additionally, guidelines are provided for correctly applying the hydrological models to capture the spatial heterogeneities of the watershed to represent the dominant processes at different scales. The KINEROS2 and SWAT models are able to process complex watershed representations in order to explicitly account for spatial variability of soils, rainfall distribution patterns, and vegetation.

KINEROS2

KINEROS2 is an event-oriented, physically based model describing the processes of interception, infiltration, surface runoff, and erosion from small agricultural and urban watersheds (Smith et al., 1995). In this model, watersheds are represented by subdividing contributing areas into a cascade of one-dimensional overland flow and channel elements using topographic information. The infiltration component is based on the simplification of the Richard's equation posed by (Smith and Parlange, 1978).

$$f_c = K_s \frac{e^{F/B}}{\left(e^{F/B} - 1\right)} \qquad [1]$$

$$B = G \cdot \varepsilon \cdot \left(S_{\max} - SI\right) \qquad [2]$$

where f_c is the infiltration capacity (L/T), K_s is the saturated hydraulic conductivity (L/T), F is the infiltrated water (L), B is the saturation deficit (L), G is the effective net capillary drive (L), ε is the porosity, $S_{\max}$ is the maximum relative fillable porosity, and SI is the initial relative soil saturation. Runoff generated by infiltration excess is routed interactively using the kinematic wave equations for the overland flow and channel flow, respectively stated as:

$$\frac{\partial h}{\partial t} + \frac{\partial \alpha \cdot h^m}{\partial x} = r_i(t) - f_i(x,t) \qquad [3]$$

$$\frac{\partial A}{\partial t} + \frac{\partial Q(A)}{\partial x} = q_l(t) - f_{c_i}(x,t) \qquad [4]$$

where h is the mean overland flow depth (L), t is the time (T), x is the distance along the slope (L), α is the 1.49 $S^{1/2}/n$, S is the slope, n is the Manning's roughness coefficient, m is 5/3, $r_i(t)$ is the rainfall rate (L/T), $f_c(x, t)$ is the overland infiltration rate (L/T), A is the channel cross-sectional area of flow (L^2), $Q(A)$ is the channel discharge as a function of area (L^3/T), $q_l(t)$ is the net lateral inflow per unit length of channel (L^2/T), and $f_{c_i}(x, t)$ is the net channel infiltration per unit length of channel (L^2/T). These equations, and those for erosion and sediment transport, are solved using a four-point implicit finite difference method (Smith et al., 1995). Unlike excess routing, interactive routing implies that infiltration and runoff are computed at each finite difference node using rainfall, upstream inflow, and the current degree of soil saturation. This feature is particularly important for accurate treatment of transmission losses with flow down dry channels. To explicitly account for space-time variations in rainfall patterns the model computes, for each overland flow element, the rainfall intensities at the element centroid are computed as a linear combination of intensities at the three nearest gauges forming a piece-wise planar approximation of the rainfall field over the watershed (Goodrich, 1991). The interpolated intensity at the centroid is applied uniformly over the individual model element.

Application of KINEROS2

In numerous modeling studies, KINEROS2 has been applied to the Walnut Gulch Experimental Watershed administrated by the USDA, Agricultural Research Service (Renard et al., 1993). This is a semi-arid watershed, with 11 nested subwatersheds that range in area from 2.3 to 148 km^2, and an additional 13 small watershed areas ranging from 0.004 to 0.89 km^2. Spatial variabiliy in rainfall is assessed using a network of 85 gauges. At a small scale, Goodrich et al. (1995) and Faures et al. (1995) applied KINEROS2 to the 4.4-ha Lucky Hills LH-104 subwatershed to examine the importance of different antecedent soil moisture estimates and the effects of wind and rainfall pattern on the predicted discharges. At this scale, both studies conclude that an adequate representation of the rainfall pattern is crucial to achieve accurate runoff prediction in this environment. Goodrich et al. (1994) also looked at the sensitivity of runoff production to pattern of initial water content at the larger scale of the WG-11 subwatershed (6.31 km^2). They suggested that a simple basin average of initial moisture content will normally prove adequate and that, again, knowledge of the rainfall patterns is far more important. Michaud and Sorooshian (1994) compared three different models at the scale of the whole watershed: a lumped curve number model, a simple distributed curve number model, and the more complex distributed KINEROS2 model. The modeled events were 24 severe thunderstorms with a raingauge density of one per 20 km^2. Their results suggested that none of the models could adequately predict peak discharge and runoff volumes, but that the distributed models did somewhat better in predicting time to runoff initiation and time to peak. The lumped model was, in this case, the least successful.

According to Syed (1999), modeling a medium-size watershed (~150 km^2) using the kinematic wave approximation, along with a coarse resolution DEM of the order of 80 m with vertical accuracy of tens of meter, is acceptable. For watersheds of this size, this implies that USGS level I, 30-m DEM data available throughout the continental United States is adequate. For smaller watersheds of the order of several hectares, better vertical accuracy is desired especially when using high horizontal resolution (small grid spacing) DEMs.

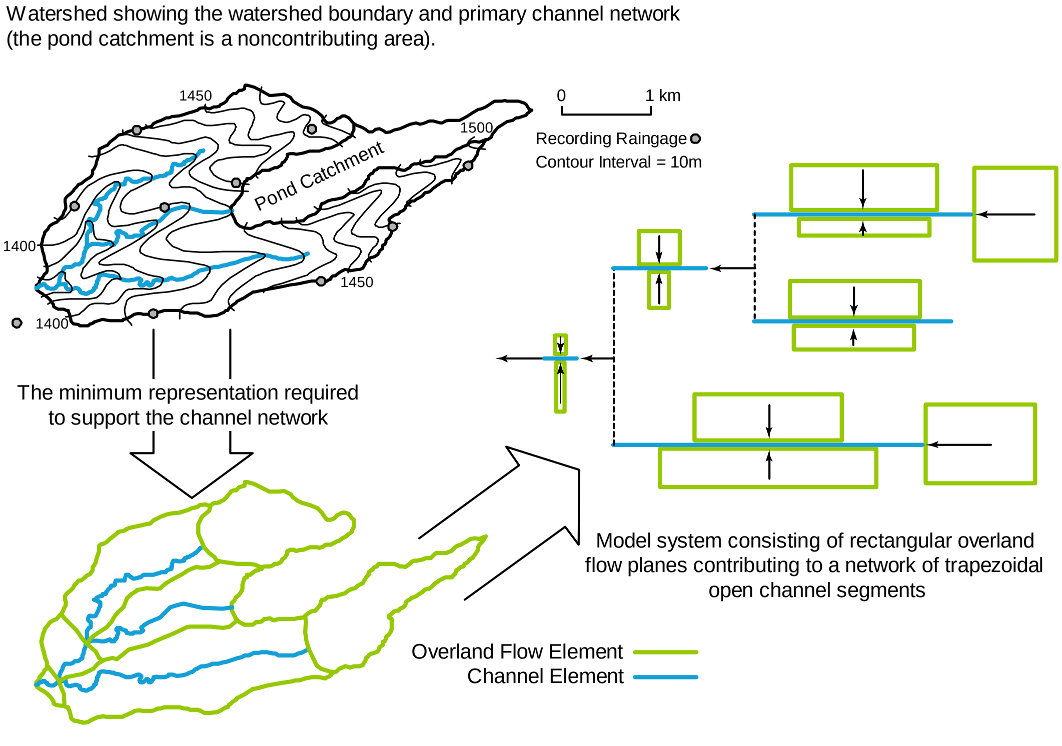


Fig. 9-2. Delineation of overland flow and channel elements in AGWA for KINEROS2 hydrologic modeling.

Limitations of the kinematic wave approximation

There is one important limitation of using the kinematic approximation to the fully dynamic flow equation; the kinematic wave equation assumes a free-overfall downstream boundary condition. Essentially the effects of any disturbance to the flow will generate a kinematic wave, but the equation can only predict the downstream movement of these waves. Thus, a kinematic wave description cannot predict the backwater effects of an obstruction to the flow for a surface flow (Beven, 2000).

Basin representation with kinematic wave elements

The contribution to the flood hydrograph from pervious and impervious areas within a single watershed is modeled in the kinematic wave method by using different types of elements as shown in Fig. 9-2. The kinematic wave elements shown are overland flow planes and a main channel. In general, watershed runoff is modeled with kinematic wave elements by taking an idealized view of the basin. Rather than trying to represent every overland flow contributing area and every possible channel, watersheds are depicted with overland flow planes and channels that represent the average conditions of the basin. Various levels of complexity can be obtained by combining different elements to represent a watershed. The simplest combination of elements that could be used to represent a watershed is two overland flow planes and a main channel. The overland flow planes can be used to separately model the overland flow from pervious and impervious surfaces to the main channel. Flow from the overland flow planes is input to the main channel as a uniform lateral inflow. The complexity of a watershed can be modeled by combining various levels of channel elements.

The procedure for representing a watershed using overland flow and channel elements is shown in Fig. 9-2. Using topographic maps and other geographic information, a watershed is configured into an interconnected system of stream network components. The watershed is subdivided into a number of subwatersheds in order to configure the stream network. In performing the subdivision, the following are taken into account: (1) the study purpose and (2) the spatial variability of precipitation and runoff response characteristics. The purpose of the study serves to pinpoint the areas of interest and, therefore, the location of watershed boundaries. The spatial variability aids in the selection of the number of subwatersheds. Each subwatershed is intended to represent an area of the basin that, on the average, has the same hydraulic and hydrologic properties. Usually, the assumption of uniform precipitation and infiltration over a subwatershed becomes less accurate as the subwatershed size increases.

SWAT

SWAT is a river-basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields on large, complex watersheds with varying soils, land-use, and management conditions over long periods of time (Arnold et al., 1994). The model combines empirical and physically based equations, uses readily available inputs, and enables users to study long-term impacts.

The hydrology model is based on the water balance equation

$$SW_t = SW + \sum_{i=1}^{t} \left(R_i - Q_i - ET_i - P_i - QR_i \right)$$

[5]

where *SW* is the soil water content minus the 15-bar water content, *t* is the time in days, and *R*, *Q*, *ET*, *P*, and *QR* are the daily amounts of precipitation, runoff, evapotranspiration, percolation, and return flow, respectively; all the units are in mm. Since the model maintains a continuous water balance, complex basins are subdivided to reflect differences in *ET* for various crops, soils, etc. Thus, runoff is predicted separately for each sub-area and routed to obtain the total runoff for the basin. This increases accuracy and gives a better physical description of the water balance.

Surface runoff is estimated with a modification of the SCS curve number method (USDA, 1986).

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S} \qquad R > 0.2S$$

[6]

$$Q = 0 \qquad R <= 0.2S$$

where Q is the daily surface runoff (mm), R is the daily rainfall (mm), and S is the retention parameter. The retention parameter, S, varies (1) among watersheds because of changes in soils, land-use, and slope and (2) with time because of changes in soil water content. The parameter S is related to curve number (CN) by the SCS equation (USDA, 1986).

$$S = 254\left(\frac{100}{CN} - 1\right)$$

[7]

The constant 254 in Eq. [7] gives S in mm. The curve number varies non-linearly from 1, dry condition at wilting point, to the wet condition at field capacity and approaches 100 at saturation.

Application of the SWAT model

SWAT is currently being utilized in several large basin projects. SWAT provides the modeling capabilities of the HUMUS (Hydrologic Unit Model of the United States) project (Srinivasan et al., 1993). The HUMUS project simulates the hydrologic budget and sediment movement for the approximately 2100 hydrologic unit areas that have been delineated by the USGS. Findings of the project are being utilized in the Resource Conservation Act (RCA) appraisal conducted by the NRCS. Scenarios include projected agricultural and municipal water use, tillage and cropping system trends, and fertilizer and animal waste use management options. The model is also being used by NOAA to estimate nonpoint source loadings into all U.S. coastal areas as part of the National Coastal Pollutant Discharge Inventory. The USEPA has incorporated SWAT into the Better Assessment Science Interacting Point and Nonpoint Sources (BASINS) interface for assessment of impaired water bodies.

Limitations of the Curve Number method

The curve number approach to predicting runoff generation has been the subject of a number of critical reviews (e.g., Hjelmfelt et al., 1982; Bales and Betson, 1982). Further work is required to clarify under what conditions the method gives satisfactory predictions. Mishra and Singh (1999) show that their generalized version of the method gives better results than the original formulation, as it should, since it has two additional fitting parameters. Hjelmfelt et al. (1982) suggest that the curve number, rather than being considered as a characteristic for a given soil-land-cover association, might better be considered as a stochastic variable. Their analysis of the annual maximum storms for two small catchments in Iowa suggested that the storage capacity parameter, Smax, derived for individual storms was approximately log normally distributed with a coefficient of variation on the order of 20%. The 10 and 90% quartiles of the distributions corresponded well to the modified curve numbers for dry and wet antecedent conditions, following the standard SCS procedure based on the preceding five-day rainfall. However, they found no strong correlation between curve number and antecedent condition for the individual storms, suggesting that interactions with individual storm characteristics, tillage, plant growth, and temperature were sufficient to mask the effect of antecedent rainfall alone.

Despite its limitations, the Curve Number method has been used quite widely since the tabulated curve number values provide a relatively easy way of moving from a GIS data set on soils and vegetation to a rainfall-runoff model.

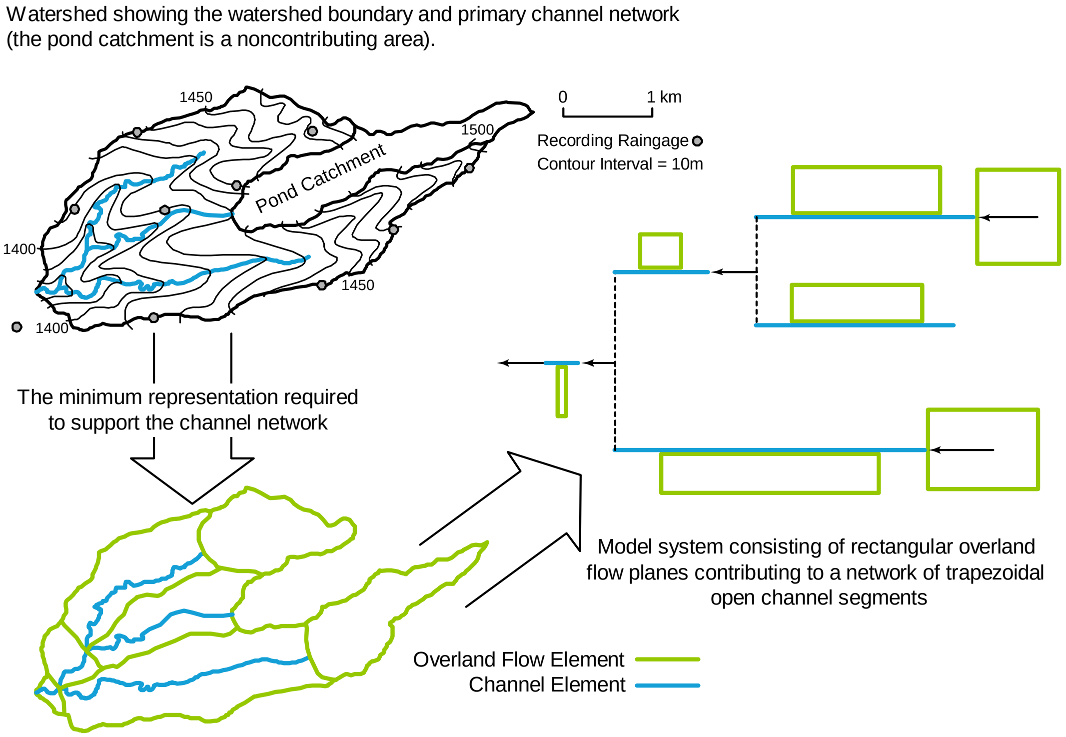


Fig. 9-3. Delineation of planes and channels in AGWA for SWAT hydrologic modeling.

Basin representation with SWAT

For modeling purposes, a watershed may be partitioned into a number of subwatersheds or subbasins. The use of subbasins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils characteristically different enough to impact hydrology. By partitioning the watershed into subwatersheds, the user is able to relate different areas of the watershed to one another spatially. The number of subwatersheds chosen depends on the size of the watershed, the spatial detail of available input data, and the amount of detail required to meet the goals of the project. Figure 9-3 illustrates a watershed delineation for Subwatershed 11 of the Walnut Gulch Experimental Watershed for SWAT. The flow routing structure is delineated by linking the channels with the surrounding uplands to define the individual subwatershed and channel elements. AGWA does not split the subwatershed elements into more than one unit for SWAT (e.g., there are no separate left and right hand contributing elements to the channel element as in KINEROS2, Fig. 9-2).

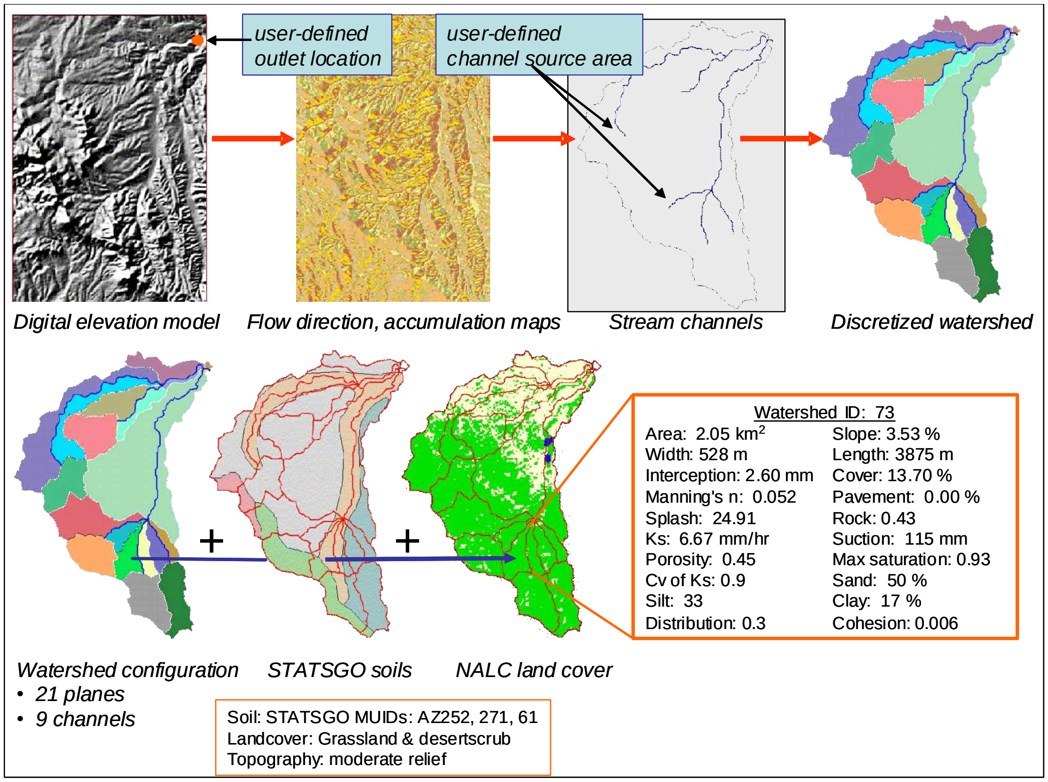


Fig. 9-4. The transformation of topography, soils, and land-cover GIS data into KINEROS2 input parameters. A DEM is used to subdivide the watershed into upland and channel model elements, each of which are parameterized according to their soil, topographic, and land-cover characteristics.

Data Inputs and Parameter Estimation

Watershed Discretization

The most widely used method, and that which is used in AGWA, for the extraction of stream networks is to compute the accumulated area upslope of each pixel through a network of cell-to-cell drainage paths. This flow accumulation grid is subsequently pruned by eliminating all cells for which the accumulated flow area is less than a user-defined threshold drainage area, called the Channel, or Contributing Source Area (CSA). The watershed is then further subdivided into upland and channel elements as a function of the stream network density. In this way, a user-defined CSA is used to define the locations and numbers of stream channels; since the watershed is subdivided into upland and channel elements as a function of the stream channels, the choice of CSA is the determining factor in the spatial complexity of the watershed discretization. This approach often creates a large number of spurious polygons and disconnected model elements due to inaccuracies in the underlying DEM. A suite of algorithms has been implemented in AGWA that refines the watershed elements by eliminating spurious elements and ensuring downstream connectivity.

Parameter Estimation

Each of the overland and channel elements delineated by AGWA is represented in either SWAT or KINEROS2 by a set of parameter values. These values are assumed to be uniform within a given element. There may be a large degree of spatial variability in the topographic, soil, and land-cover characteristics within the watershed, and AGWA uses an area-weighting scheme to determine an average value for each parameter within an overland flow model element abstracted to an overland flow plane (Goodrich et al., 2002). As shown in Fig. 9-4, the three GIS coverages are intersected with the subdivided watershed, and a series of look-up tables and spatial analyses are used to estimate parameter values for the unique combinations of land-cover and soils. SWAT and KINEROS2 require a host of parameter values, and estimating their values can be a tedious task; AGWA rapidly provides estimates based on an extensive literature review and calibration efforts. In the absence of observed data and performing a calibration exercise, these values should be used in comparative or relative assessments. Since AGWA is an open-source suite of programs, users can modify the values of the look-up tables or manually alter the parameters associated with each element.

Soil parameters for upland planes as required by KINEROS2 (such as percent rock, suction head, porosity, saturated hydraulic conductivity) are initially estimated from soil texture according to the State Soil Geographic (STATSGO) soil data following Woolhiser et al. (1990) and Rawls et al. (1982). Saturated hydraulic conductivity is reduced following Bouwer (1966) to account for air entrapment. Further adjustments are made following Stone et al. (1992) as a function of estimated canopy cover. Cover parameters, including interception, canopy cover, Manning's roughness, and percent paved area are estimated following expert opinion and previously published look-up tables (Woolhiser et al., 1990). Upland element slope is estimated as the average plane slope, while geometric characteristics such as plane width and length are a function of the plane shape assuming a rectangular shape, where the longest flow length is equal to element length. Stream channel geometric characteristics are parameterized following Miller et al. (1996), who found strong relationships between channel width and depth and watershed characteristics. Channel parameters relating to soil characteristics assume a sandy bed and all channels are assumed uniform. Channel slope is determined from a slope grid derived from the DEM.

Similar approaches are used to provide estimates for soil and land-cover parameters as required by SWAT. The most sensitive parameter of SWAT is the Curve Number, which is estimated as a function of hydrologic soil group, hydrologic condition, cover type, and antecedent moisture condition. STATSGO data provide information on soil hydrologic group, while cover type is determined from classified land-cover data. AGWA assumes a fair hydrologic condition, and antecedent moisture group II. Look-up tables following USDA-SCS (1986) recommendations are used to estimate Curve Number values for each unique combination of hydrologic group and land-cover type within a watershed element. Because the land-cover data are grids, this process occurs for each cell, and the results are area-weighted to produce a unique estimate of Curve Number for the overland flow plane.

Rainfall Input

A variety of methods are available in AGWA to create rainfall input files for KINEROS2 and SWAT. Each of these is described briefly in this section and organized according to the models for which they are designed.

KINEROS2: Either distributed or uniform precipitation input can be used with KINEROS2 and is provided in the form of storm hyetographs for one or more point locations. Data from multiple point locations are distributed across the watershed by KINEROS2 using a piecewise planar time-space interpolation technique (Goodrich, 1991). Since the spatial component of this process is computed by the model itself, it was deemed unnecessary to prepare distributed input files in AGWA. KINEROS2 rainfall input files created outside of AGWA (either uniform or distributed) can be used in AGWA without causing any problems. Methodologies for utilizing radar data to build distributed event rainfall files in AGWA are currently being investigated.

Uniform rainfall input files can be created in AGWA using one of two data sources provided with the tool or using data entered by the user. Uniform rainfall, although less appropriate for quantitative modeling of individual events, is particularly useful for relative assessment of land-cover change. Precipitation data that can be used to generate design storms in AGWA include the NOAA Atlas 2 Precipitation-Frequency Atlas of the Western United States (NOAA, 1973) and a database of return period storms from various locations. Both of these sources are provided with AGWA and are currently limited to 11 western states. Return period rainfall depths are converted to hyetographs using the USDA-SCS (1973) methodology and a type II distribution. The type II distribution is appropriate for deriving the time distribution of rainfall for most of the country, including all of the interior West. Although the NOAA Atlas 2 data can be used anywhere in the western U.S., the database can be easily edited to add data for areas where it is not provided and has the added advantage of the option to incorporate an area-reduction factor. The third option of using data entered by the user allows design storm data from any region to be used. User-defined storms are entered in the form of a hyetograph, thus providing additional flexibility in defining the time-distribution of rainfall.

SWAT: AGWA can generate either uniform or distributed rainfall input files for SWAT. The option to create distributed rainfall files uses Thiessen precipitation weighting to compute the weighted rainfall depth falling on each subwatershed for each day in the simulation period. The user is automatically routed to the dialog for creating either the uniform or distributed rainfall input based on the number of raingauges with data in a raingauge point theme that is designated by the user. If there are two or fewer gauges, Thiessen polygons cannot be generated, and a uniform rainfall input file will be created (using the gauge closest to the watershed centroid if there are two). When there are more than two gauges, a distributed input file will be written.

Although any gauge data can be used, National Weather Service gauge data are the most widely available. A point theme of raingauge locations and an unweighted daily precipitation database file are necessary to generate the input file. Missing data can be accommodated through a weighting scheme that dynamically adjusts the gauge weights according to those gauges that do have data for that day.

EXAMPLES OF AGWA APPLICATIONS

As indicated earlier, the hydrologic models in the AGWA tool have been applied on various watersheds across the United Sates. Sizes of these watersheds are in the range of 0.012 – 7000 square kilometers. In this section, however, we focus on two examples from the San Pedro River Basin, which traverses the U.S.-Mexico border between Arizona and Sonora. The first one involved integrating landscape assessment and hydrologic modeling for land-cover change analysis. In this case, the AGWA tool was employed to evaluate the effects of historic land-cover change on watershed response by applying the SWAT model on the Upper San Pedro Basin to the Charleston USGS stream flow gauge and the KINEROS2 model on a small contributing subwatershed in the San Pedro River Basin. Miller et al. (2002b) demonstrated the utility of AGWA to conduct a landscape assessment analysis of the spatial distribution of land-cover changes using classified satellite imagery. Simulated watershed response in the form of runoff volume, peak runoff rate, and total sediment yield were used as indicators of watershed condition. The second example presents a scenario-based approach to regional land-use planning. This approach is particularly useful for shaping future use of land and water resources and has been used in a wide variety of geographic settings to assist stakeholders and policy makers in environmental decision-making (Schwartz 1996; Steinitz 1990). Kepner et al. (2004) demonstrated the utility of AGWA for this purpose by evaluating the spatial distribution of impacts to the hydrologic regime resulting from different land-use/cover scenarios for the Upper San Pedro River basin.

Description of the Study Area and Data Sources

The San Pedro River flows north from Sonora, Mexico, into southeastern Arizona (Fig 9- 5). With a wide variety of topographic, hydrologic, cultural, and political characteristics, the basin is a prime example of desert biodiversity in the semi-arid Southwest and an exceptional study area for addressing a range of scientific and management issues. It is also a region in socioeconomic transition, as the previously dominant rural ranching economy is shifting to irrigated agriculture and urban development (Tellman et al., 1997; CEC, 1998).

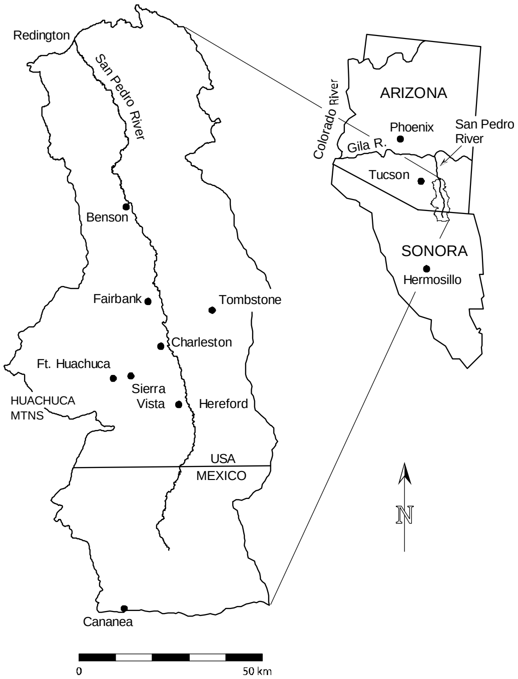


Fig. 9-5. Location of study area.

The area is a transition zone between the Chihuahuan and Sonoran deserts and has a highly variable climate with significant biodiversity. The tested watershed is approximately 7598 km^2 and is dominated by desert shrub-steppe, riparian, grasslands, agriculture, oak and mesquite woodlands, and at higher elevations, pine forest (Kepner et al., 2000). The basin supports among the highest number of mammal species in the world and the riparian corridor provides nesting and migration habitat for more than 400 bird species. The San Pedro River is the only unimpounded river in Arizona, and all municipal and most agricultural water is derived from groundwater sources.

For the purpose of modeling runoff from the Upper San Pedro Basin, a number of geospatial data sets were compiled that describe the landscape characteristics of the basin and are required by AGWA for modeling with KINEROS2 and SWAT. The basic input data were a USGS 30-m digital elevation model, STATSGO soil, and North American Landscape Characterization (NALC) classified satellite imagery for land-cover (Fig. 9-6a).

Standard USGS DEM data were mosaicked together, and the results were filtered using a low-pass filter to remove topographic anomalies and then filled to create a "hydrologically correct" surface, where all locations within the study area were connected to the outlet and a minimum of sinks were present. Some larger sinks within the Basin are real features, and these were retained (Fig. 9-6b).

It is recognized that STATSGO soils are overly generalized for small-scale application of rainfall-runoff modeling (Fig. 9-6c). Unfortunately, more detailed geospatial soil data are not available for the research.

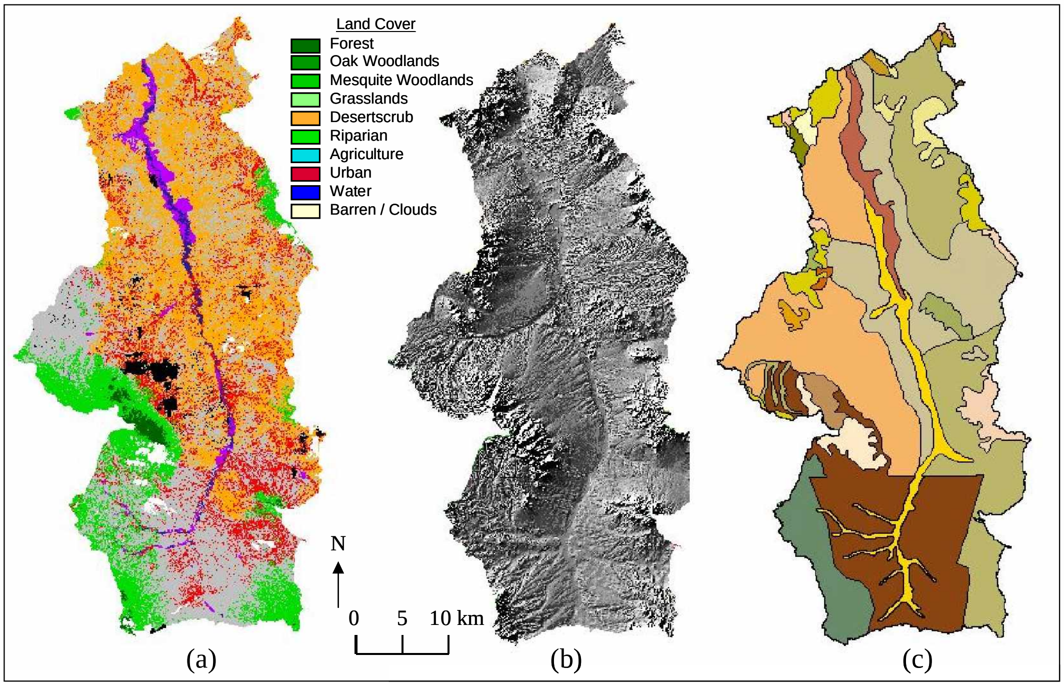


Fig. 9-6. GIS data sets for the Upper San Pedro Basin. (a) Land cover from the 1992 NALC classification, (b) topography relief map based on USGS 30m DEM data, and (c) soils data from the USDA-NRCS STATSGO.

Remote imagery was derived from the Landsat Multi-spectral Scanner (MSS) and Landsat Thematic Mapper (TM) earth observing satellites (path/row 35/38 and 35/39) (Kepner et al., 2000). Landsat-MSS satellite scenes were selected from the North American Landscape Characterization (NALC) project (USEPA, 1993). The scenes available in the NALC database (1973-92) and Landsat TM (1997) are from four pre-monsoon dates for a period approximately 25 yr (i.e., 5 June 1973, 10 June 1986, 2 June 1992, and 8 June 1997). All imagery in the database is coregistered and georeferenced to a 60 x 60 m Universal Transverse Mercator (UTM) ground coordinate grid with a nominal geometric precision of 1-1.5 pixels (60-90 m). Digital land-cover maps were developed separately for each year using 10 classes: Forest, Oak Woodland, Mesquite Woodland, Grassland, Desertscrub, Riparian, Agriculture, Urban, Water, and Barren (Fig. 9-6a) (Kepner et al., 2000).

Using AGWA for Land-Cover Change Analysis

Introduction

Hydrologic response is an integrated indicator of watershed condition, and changes in land cover may affect the overall health and function of a watershed. Such changes vary spatially and occur at different rates through time. Miller et al. (2002b) evaluated the hydrologic change both spatially, using distributed hydrologic models, and temporally, using satellite imagery acquired over 25 years. The main objective of this study was to evaluate the effects of historic land-cover change on watershed response by applying the SWAT model on the San Pedro River Basin at the Charleston USGS stream flow gauge, and the KINEROS2 model on a small contributing watershed in the San Pedro Basin. Simulated watershed response in the form of runoff volume, peak runoff rate, and total sediment yield were used as indicators of watershed condition.

Methods

The general approach used in this study was to acquire geospatial information relating to land cover, topography, and soils for the two study areas; assess the overall land-cover trends of the past quarter-century; and analyze the consequent impacts on simulated runoff.

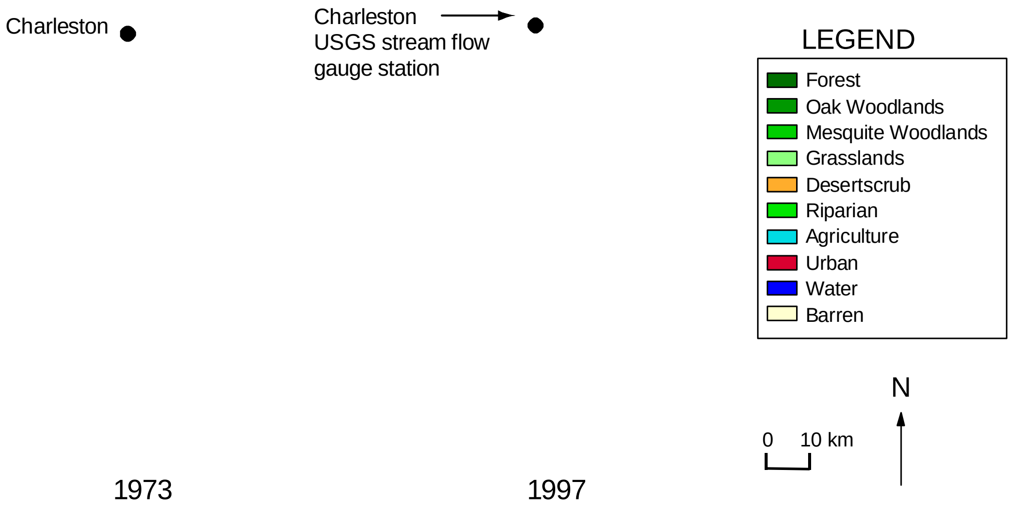
Input parameters required by SWAT and KINEROS2 were estimated by AGWA as a function of the topographic, soil, and cover characteristics of the individual watershed response units. Look-up tables relating soil and land-cover associations to relevant hydrologic parameters (e.g., curve number, saturated hydraulic conductivity, surface roughness) were defined through literature review and calibration exercises. Hernandez et al. (2000) describe the derivation of input parameters for KINERSO2 and SWAT used in this approach.

Since KINEROS2 is an event-based model, a series of synthetic hyetographs were used as input to the model. Previously published work using long-term rainfall measurements on the Walnut Gulch Experimental Watershed were used to estimate return-period design storms as a function of watershed scale. Osborn et al. (1980) provided estimates of the 5-, 10-, and 100-yr events for both 30- and 60-min durations. These six design events provide estimates of rainfall intensity throughout the event. These estimates were determined for small watersheds, so an adjustment was made for watershed size. It has been well demonstrated that return period-duration rainfall depths decrease as a function of watershed scale (Osborn et al., 1985).

Runoff-producing rainfall in the San Pedro Basin is dominated by summer convective thunderstorms that are locally intense and highly constrained in space. Winter rains are generally frontal and widespread with lower intensities. Runoff is produced through infiltration-excess overland flow, and winter rainfall intensities are often too low to overcome the high infiltration rates of soils within the basin. Thus, on small watersheds, the larger design storms will be driven by localized convection storms. Since these storms are localized, an adjustment factor has to be used to prevent a gross over-estimation of rainfall and the associated runoff. All six design storms were input to each of the subdivided watersheds to assess the impact of rainfall on simulation results.

In this study, the variability in rainfall through time serves as a confounding variable in the interpretation of the impacts of cover transition on hydrologic response, so it was necessary to apply the same rainfall data to each parameter set associated with different land-cover scenes. Since rainfall is held constant for each model run, changes in model results are due solely to changes in input parameters affected by land-cover change.

The SWAT model uses daily rainfall input data for multi-year simulation. Multi-year rainfall was extracted from long-term National Weather Service records and input to the SWAT model. These rainfall records represent periods in which a minimum of data were missing from the long-term records. For this effort, nine gauges that record rainfall in the San Pedro Basin contain long-term historical data for input to SWAT. A 14-yr period of record was extracted for this area.



Results

As illustrated in Fig. 9-7, signifi

cant land-cover change occurred within the San Pedro Basin between 1973 and 1997. A matrix illustrating the relative change within each cover class for the different scenes (1973 and 1997) is presented as Table 9-1.

Fig. 9-7. Land-cover change within the Upper San Pedro Basin for the area drained at the Charleston USGS stream flow gauge.

Table 9-1. Percent relative land-cover change for the Upper San Pedro Watershed. A positive value in a difference column indicates an increase in area between dates (Miller et al., 2002b).

Land Cover	1973 to 1986	1986 to 1992	1992 to 1997	1973 to 1997
Forest	-0.12	-5.27	0.37	-5.04
Oak Woodland	-0.16	-4.89	1.55	-3.57
Mesquite	413.75	-1.66	-3.41	387.98
Grassland	-14.55	-0.78	-0.68	-15.80
Desertscrub	-17.83	-3.29	-2.35	-22.40
Riparian	2.16	0.42	3.70	6.38
Agriculture	31.13	29.13	-2.21	65.58
Urban	212.07	25.71	31.18	414.63
Water	11.36	14.63	23.15	57.20
Barren	62.77	-0.10	-0.34	62.05

The most significant changes were large increases in urbanized areas, mesquite woodlands, and agricultural communities and commensurate decreases in grasslands and desertscrub. This overall shift indicates an increasing reliance on ground water (due to increased municipal water consumption and agriculture) and potential for localized large–scale runoff and erosion events (due to the decreased infiltration capacities and roughness associated with the land-cover transition). The Sierra Vista subwatershed experienced significant land-cover change between 1973 and 1997, with the dominant transitions within this watershed being the declines in grasslands and desertscrub and increases in urban areas and mesquite woodlands (Table 9-2).

Table 9-2. Percent relative land-cover change for the Sierra Vista Subwatershed. A positive value in a difference column indicates an increase in area between dates (Miller et al., 2002b).

Land-cover	1973 to 1986	1986 to 1992	1992 to 1997	1973 to 1997
Forest	0	0	0	0
Oak Woodland	-0.48	-1.17	-1.47	-3.09
Mesquite	306.25	-5.98	-12.67	233.57
Grassland	-34.65	0	-9.01	-40.54
Desertscrub	-36.67	-5.38	-7.09	-44.32
Urban	302.78	19.62	36.34	556.89

Runoff was simulated with the SWAT model from the San Pedro Basin using a 14-yr continuous rainfall period with input data corresponding to the four classified satellite scenes. In general, the total annual runoff volume increased as a function of land-cover change within the basin (Fig. 9-8). The graph shows the deviation in total annual runoff results from the 1973 land-cover results. These results do not necessarily reflect observed changes in runoff volume for the time periods simulated in this study but are illustrative of the effects on hydrologic response of the transition the basin has undergone over the past quarter-century. Given that the 1973 scene serves as the base image from which landscape change is derived, annual runoff results are presented in Fig. 9-8 as the percent change from the 1973 runoff results.

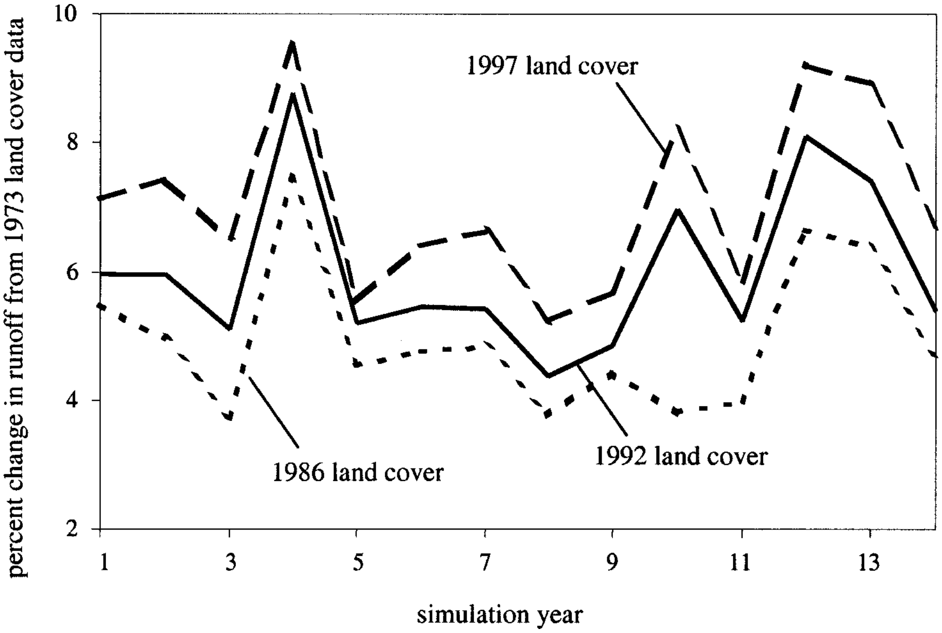


Fig. 9-8. SWAT simulation results for the Upper San Pedro Basin (Miller et al., 2002b).

Simulated runoff results show an increase in annual runoff over time commensurate with increasing urbanization and woody plant invasion. Considerable spatial variability in the observed land-cover change has implications for hydrologic modeling and assessment (Fig. 9-7, and Table 9-1).

Simulated annual runoff from the Sierra Vista subwatershed increased significantly, so the KINEROS2 model was used to investigate this area in more detail. In this approach, KINEROS2 is used to focus both temporally and spatially. SWAT is used to locate subwatersheds that are responding strongly to change over long time periods, while KINEROS2 provides more detail and analysis for return period rainfall events.

For this smaller subwatershed within the San Pedro Basin, KINEROS2 was used to simulate runoff and sediment yield for six design storms using watershed data from the classified satellite imagery, resulting in a suite of 24 simulation runs. Results for the simulation runs are given in Table 9-3, and Fig. 9-9 shows hydrographs from the two endpoint design storms, the 5-yr, 30-min event and the 100-yr, 60-min event. Note the disparity in the hydrographs resulting from the smaller event and their similarities for the larger event. The differences in simulated results decrease with increasing storm size and duration. This trend toward convergence is due to the increasing importance of storm characteristics over watershed characteristics as storm size increases. For smaller storms, changes in the watershed, especially those due to land-cover change, may radically alter the hydrologic response. However, the hydrologic response for very large storms is driven by the characteristics of the rainfall, and management may have little improvement effect. As would be expected with design storms, runoff volume and peak runoff rates increased directly with the size of the modeled events. Since erosion and sediment yield are

Table 9-3. Runoff simulation results using design rainfall events and KINEROS2 for the Sierra Vista Subwatershed (Miller et al., 2002b).

Rainfall Event	Rainfall (mm)	Runoff (mm)				Percent Change 1973 to 1997
		1973	1986	1992	1997	
5 yr, 30min	17.35	0.057	0.144	0.134	0.158	177.2
5 yr, 60min	21.08	0.185	0.339	0.367	0.498	169.2

10 yr, 30 min	**22.74**	**1.25**	**1.64**	**1.72**	**1.95**	**56.0**
10 yr, 60 min	**26.44**	**2.07**	**2.47**	**2.55**	**2.79**	**34.8**
100 yr, 30 min	**31.79**	**7.02**	**7.55**	**7.65**	**7.95**	**13.2**
100 yr, 60 min	**38.33**	**10.2**	**10.7**	**10.8**	**11.0**	**7.8**

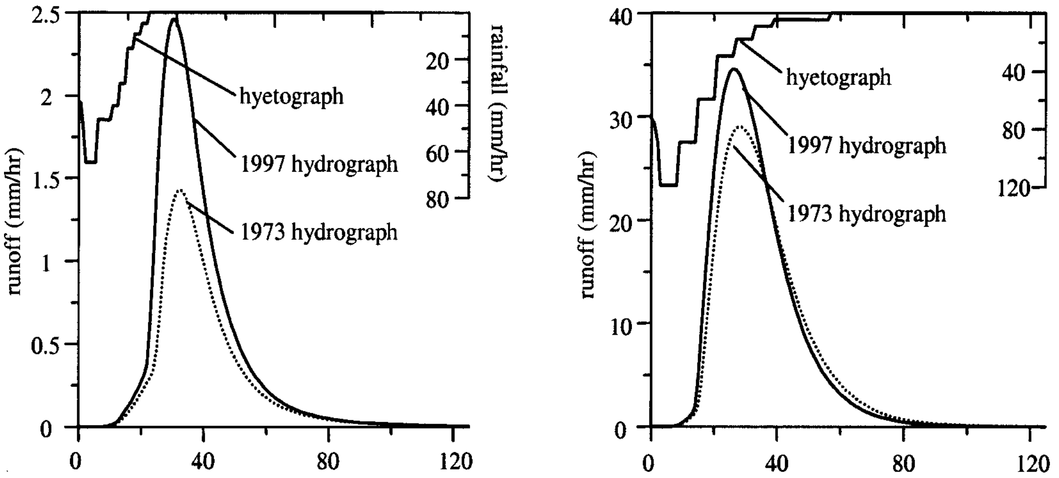


Fig. 9-9. Runoff hydrographs simulated using KINEROS2 for the Sierra Vista Subwatershed (Miller et al., 2002b).

tied closely to the energy of a given runoff event, they are subsequently determined by runoff rates and therefore increase greatly with storm size and duration. In all cases, the hydrographs produced with the 1986, 1992, and 1997 classification data were significantly larger than those produced using the 1973 data. The dominant land-cover transitions within this small watershed were from grassland and desertscrub to mesquite woodlands and urban. These transitions provide lower surface roughness values, decreased infiltration rates, and less cover, thereby reducing interceptions and exposing the surface to raindrop splash, all of which contribute to increased runoff and erosion.

The sediment yield data depicted in Table 9-4 reveal a similar response to urbanization within the watershed. Given that erosion and sediment yield are directly related to runoff velocity and volume, as runoff rates increase, the sediment likewise increases. The percent increases in sediment yield from 1973 to 1997 do not equal the percent increases in runoff for the same time periods. This apparent dissimilarity can be explained by the complexity of the spatially distributed changes within the watershed. As urbanization increases, so does the percent of impervious and paved area, which is treated in the model with a factor that reduces the erosion on those impervious areas.

Table 9-4. Sediment yield results using design rainfall events and KINEROS2 for the Sierra Vista Subwatershed (Miller et al., 2002b).

Rainfall Event	**Rainfall (mm)**	**Sediment yield (ton)**				**Percent Change 1973 to 1997**
		1973	**1986**	**1992**	**1997**	
5 yr, 30 min	**17.35**	**2.02**	**18**	**15.2**	**19.2**	**851**
5 yr, 60 min	**21.08**	**20.8**	**21.9**	**24.1**	**26.9**	**29.3**
10 yr, 30 min	**22.74**	**212**	**208**	**248**	**295**	**39.2**
10 yr, 60 min	**26.44**	**283**	**423**	**427**	**449**	**58.7**
100 yr, 30 min	**31.79**	**1803**	**2070**	**2180**	**2420**	**34.2**
100 yr, 60 min	**38.33**	**2580**	**2550**	**2890**	**3090**	**19.8**

In general, simulation results indicate that land-cover changes within the Sierra Vista watershed have altered its hydrologic response. These localized changes were associated with vegetation transition and urbanization. Reduced estimates of infiltration, percent vegetated cover, and surface roughness in conjunction with increased impervious surfaces resulted in increased simulated runoff from a variety of rainfall events.

Discussion

The Upper San Pedro River Basin has undergone a profound transition over the past several decades from a rural watershed to one with significant urban and agricultural regions. The Sierra Vista subwatershed within the Upper San Pedro Basin was chosen for more intensive research since it has undergone significant land-cover change implicated in increased runoff volumes and rates accompanied by decreased water quality due to erosion and sedimentation. These results follow the conclusions of Kepner et al. (2000), who showed that rapid urbanization in the towns within the San Pedro watershed over the past 20 years has become an important factor in altering land-cover composition and patterns.

Hydrologic modeling results indicated that watershed hydrologic response in the Upper San Pedro Basin has been altered to favor increased average annual runoff due to land-cover change during the period from 1973 to 1997, and consequently it is at risk for decreased water quality and related impacts to the local ecology. The Sierra Vista watershed within the San Pedro was modeled using design rainfall events, and the hydrographs resulting from these events showed dramatic increases in runoff volume, runoff rate, and soil loss.

Using AGWA for Land-Use Planning

Introduction

Today's environmental managers, urban planners, and decision-makers are increasingly expected to examine environmental and economic problems in a larger geographic context. To accomplish this, it is necessary to 1) understand the scale at which specific management actions are needed; 2) conceptualize environmental management strategies; 3) formulate sets of alternatives to reduce environmental and economic vulnerability and uncertainty in their evaluation analyses; and 4) prioritize, conserve, or restore valued natural resources, especially those which provide important economic goods and services.

A scenario-based approach to regional land planning offers an organizational basis to explore decision analysis and opportunities for public resources. This approach is particularly useful for shaping future use of land and water resources, and has been used in a wide variety of geographic settings to assist stakeholders and policy makers in environmental decision-making (Schwartz 1996, Steinitz 1990). The GIS framework and automated procedures in AGWA are designed to facilitate this type of scenario-based analysis by enabling users to rapidly conduct replicate simulations for different land-use/cover scenarios and to directly compare the results of any two simulations. Kepner et al. (2004) demonstrated the utility of AGWA for this purpose by evaluating the spatial distribution of impacts to the hydrologic regime resulting from different land-use/cover scenarios for the Upper San Pedro River basin along the U.S.-Mexico border.

Methods

Baseline digital data for the year 2000 were obtained from the San Pedro River Geo-Data Browser (Kepner et al., 2003). Future scenarios were derived from Steinitz et al. (2003), who developed a series of land-use/cover maps for the year 2020 based on current land management and projected census growth. For the purpose of this study, three of the 2020 scenarios were selected that reflected important contradictions in desired future policy based on stakeholder input. These scenarios are described in Table 9-5 and shown in Fig. 9-10, and basically reflect changes in population within the watershed, patterns of growth, and development practices and constraints. The Constrained scenario is the most conservation oriented, the Plans scenario reflects the most likely census predictions with zoning options designed to accommodate growth, and the Open scenario is the least conservation and most development positioned option. The Open scenario also assumes a greater than predicted population with few constraints on land development.

Table 9-5. Scenarios for future urbanization of the upper San Pedro River Basin in the year 2020.

CONSTRAINED	**Assumes lower population (78,500) than presently forecast for 2020. Development is concentrated in mostly existing developed areas (i.e., 90% urban). Removes all irrigated agriculture within the river basin.**
PLANS	**Assumes population increase as forecast for 2020 (95,000). Development is in mostly existing developed areas (i.e., 80% urban and 15% suburban). Removes irrigated agriculture within a 1-mi buffer zone of the river.**
OPEN	**Assumes population increase is more than the current 2020 forecast (111,500). Most constraints on land development are removed. Development occurs mostly into rural areas (60%) and less in existing urban areas (15%). Irrigated agriculture remains unchanged from current policy except for prohibiting new expansion near the river.**

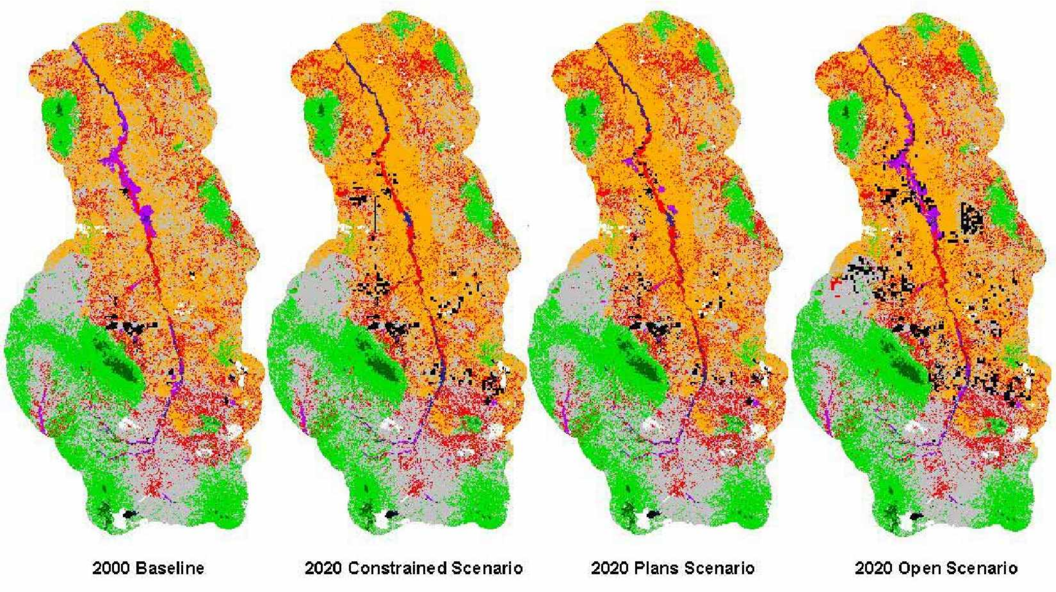


Fig. 9-10. Land-use/cover maps for the 2000 baseline and three 2020 future scenarios.

Our modeling approach involved first running SWAT using the 2000 baseline land cover to parameterize the model to determine reference condition. SWAT was run using 13 yr of continuous daily rainfall and temperature data (1960 – 1972) from a single gauge in the center of the basin. The same simulation was then performed using each of the three 2020 land-cover scenarios to develop parameter inputs. Average annual outputs from the three alternative futures were then differenced from the baseline values to compute percent change in average daily values over the 20-yr period. Output parameters compared in the analyses included surface runoff, channel discharge, percolation, and sediment yield. It is important to note that the purpose of this study was to demonstrate the utility of AGWA in alternative futures analysis. All results are presented relative to the 2000 baseline, but the model was not calibrated to permit quantitative comparisons of the hydrologic impacts. Our analyses thus focus on the relative magnitude and spatial distribution of the computed changes.

Results

A summary of the simulation results for each of the alternative futures is given in Table 9-6 and presented graphically using subwatersheds as the comparative unit in Fig. 9-11, 9-12, 9-13, and 9-14. The figures show relative departure, in percent, from the year 2000 baseline and illustrate the spatial variability of impacts on the surface water hydrology. Since soil and precipitation are held constant, differences in model output are exclusively associated with changes in land use/cover, primarily increasing urbanization and variable amounts of irrigated agriculture.

Table 9-6. Simulated average daily surface runoff, percolation, and sediment yield at the watershed outlet for the 2000 baseline conditions and predicted relative change for each of the three development scenarios from Kepner et al. (2004). Current and predicted daily groundwater overdraft for the three development scenarios from Steiniz et al. (2003).

	Baseline 2000	**Simulated Percent Relative Change 2000 – 2020**		
		Constrained 2020	**Plans 2020**	**Open 2020**
Surface runoff (m^3/day)	**186,538**	**4.3**	**3.7**	**6.9**
Percolation (m^3/day)	**42,760**	**-2.7**	**-3.0**	**-4.6**
Sediment yield (t/day)	**1,042**	**4.4**	**3.7**	**7.0**
Groundwater overdraft (m^3/day)	**131,494**	**-57.6**	**-42.1**	**8.1**

In the case of surface runoff, the simulations show average increases over the 20-yr period commensurate with increases in urbanization, although there is considerable spatial variability of simulated hydrologic response (Fig. 9-11).

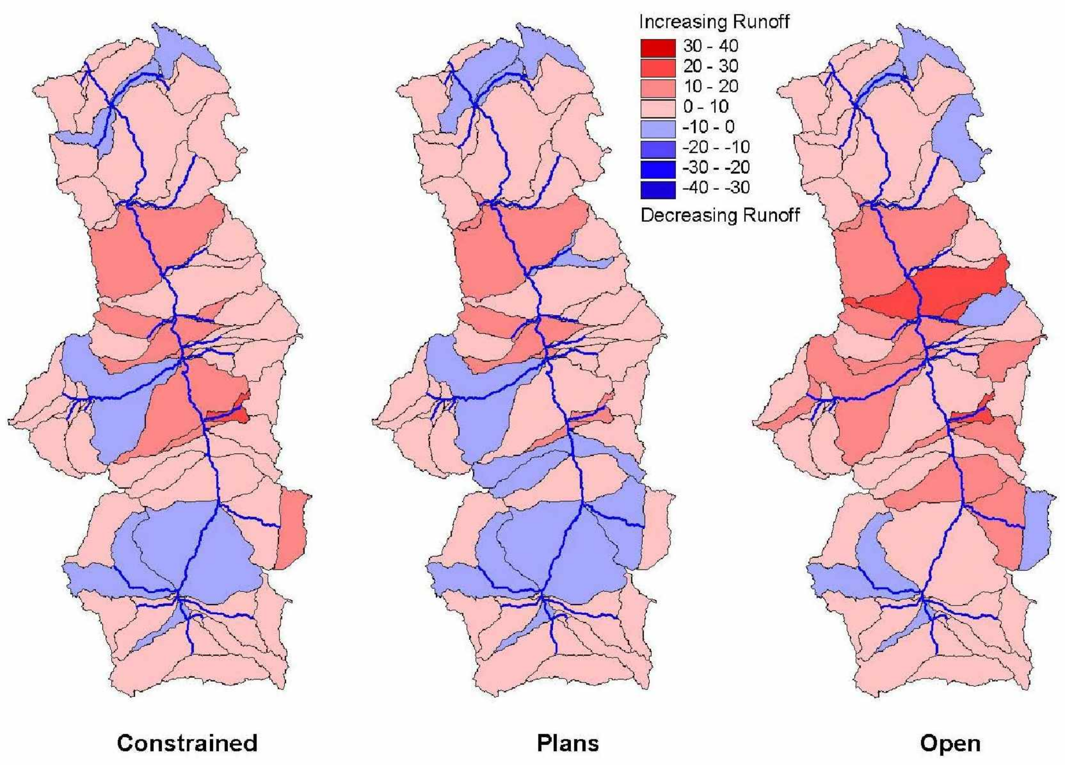


Fig. 9-11. Percent change in surface runoff, 2000 – 2020.

Most subwatersheds exhibit negative impacts (reds), but some areas do show improvement (blue), and there is substantial variation in the specific hydrologic response. The greatest change was simulated for the Open scenario with an average increase almost 7% over the 2000 baseline (Table 9-6). Simulated increases in surface runoff predominantly occur within subwatersheds located in the central portion of the watershed where the greatest development is anticipated (see Fig. 9-10).

Percent change in simulated channel discharge agrees closely with results for surface runoff. Figure 9-12 shows change in simulated mean daily channel discharge relative to the 2000 baseline for each of the three development scenarios. By mapping this model output for each reach in the model area, it is possible to visually identify reaches that are anticipated to experience the greatest changes in their hydrologic regime as a result of the land-cover/use change. Important changes in the magnitude and frequency of flooding increase the likelihood of channel scour and associated negative impacts on riparian vegetation. As such, the simulated changes to the hydrologic regime mapped in Fig. 9-12 can also be viewed as an index of riparian vulnerability to the unmitigated future development. As in the previous example, channel discharge increased most under the Open scenario, and although the results are spatially variable, the greatest impact seems to be concentrated in the subwatersheds in the central portion of the San Pedro, where most development is forecast.

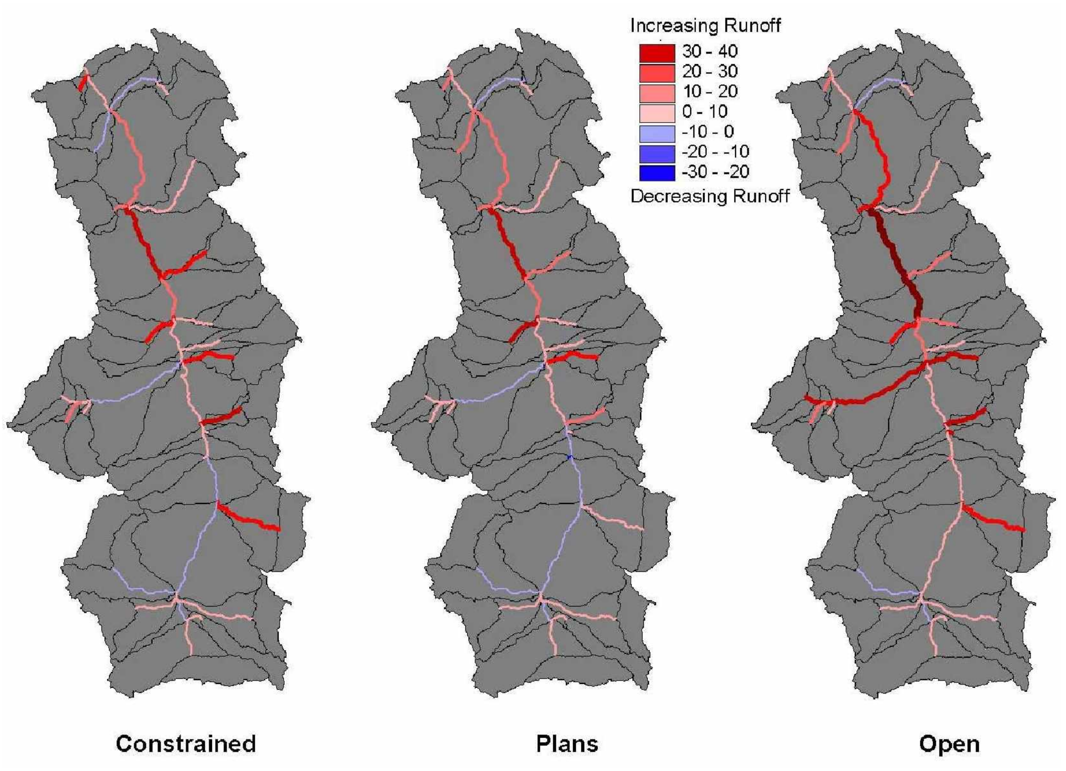


Fig. 9-12. Percent change in channel discharge, 2000 – 2020.

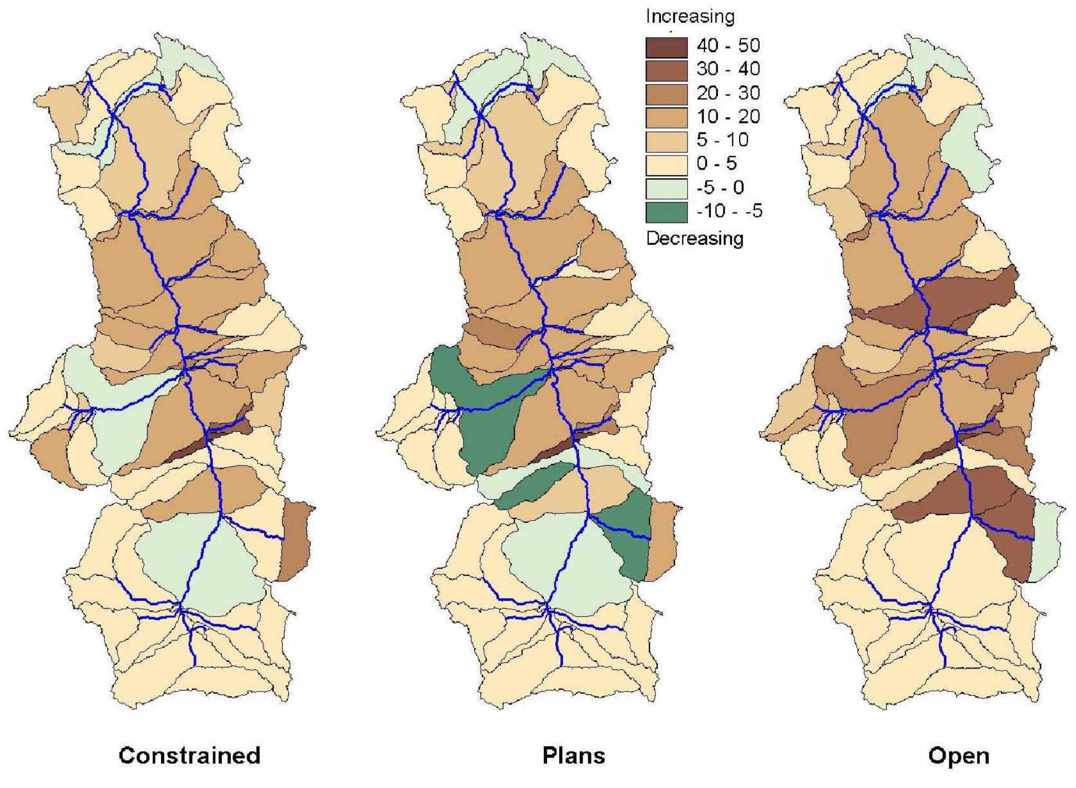


Fig. 9-13. Percent change

in sediment yield, 2000 – 2020.

Sediment yield and erosion are directly related to runoff volume and velocity, and subwatersheds with the greatest increase in sediment yield (Fig. 9-13) correlate tightly with those exhibiting the greatest change in surface runoff. The Open scenario is thus expected to produce the highest sediment yields and the largest increase (7%) over the baseline conditions.

Percolation is a hydrologic measure of the water volume that is able to infiltrate into the soil past the root zone to recharge the shallow and/or deepwater aquifers. Figure 9-14 shows that although the model does predict some improvement in the watershed headwaters where human occupation is most dispersed, overall percolation is expected to decrease in all options as urban impervious surfaces are expanded. This is most apparent for the Open scenario, for which percolation is predicted to decline by 4.6% (Table 9-6), although the daily volume this would represent is trivial in comparison to the groundwater overdraft

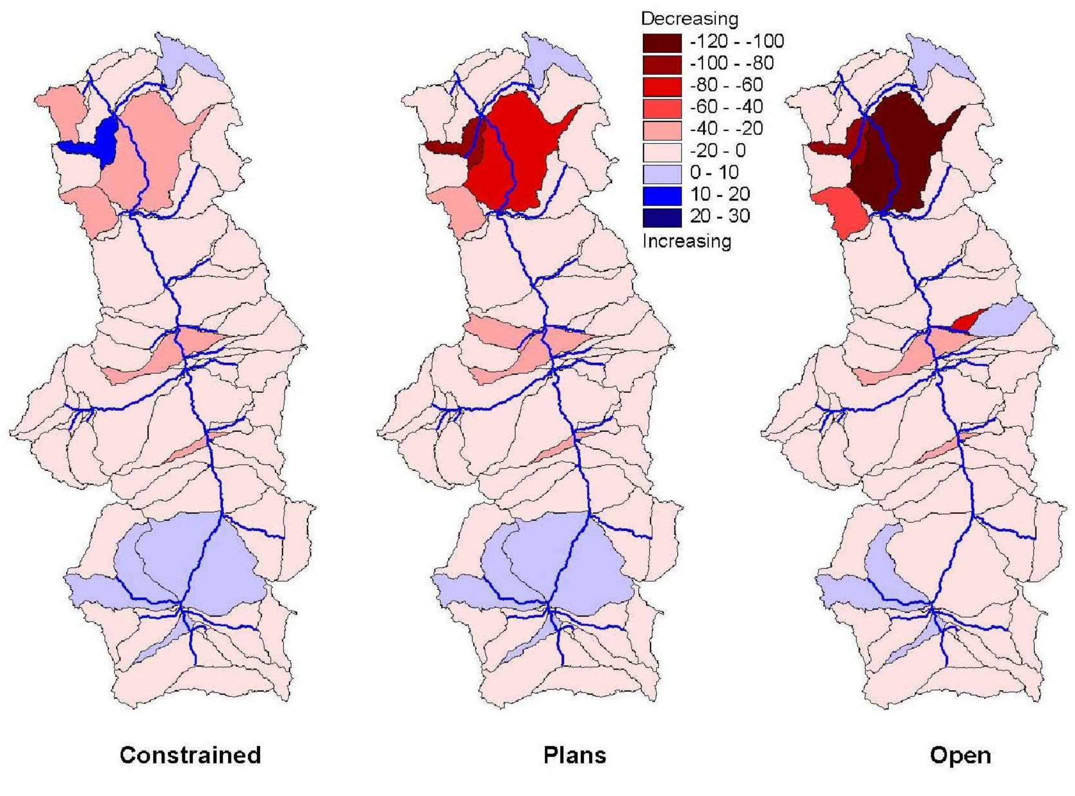


Fig. 9-14. Percent change in percolation, 2000 – 2020.

In general, under a future urbanizing environment, the model results appear to indicate that important impacts to the watershed hydrology can be expected. The most notable changes are likely to be increases in runoff, channel discharge, and sediment yield, and a reduction of surface water access to the groundwater table. This appears to agree with the results reported by Steinitz et al. (2003) who predicted changes in groundwater storage for the three 2020 scenarios (Table 9-6). In this study, the largest groundwater overdraft (10,608 m^3/day above the 2000 baseline) was predicted for the Open Scenario.

Discussion

The hydrologic responses resulting from three development scenarios for the upper San Pedro River Basin were evaluated using AGWA to demonstrate its utility in alternative futures analysis. Alternative futures research has traditionally neglected the spatially-variable impact of land-cover/use change on the surface-water hydrologic regime. With this type of assessment, however, it is possible to rapidly evaluate likely changes in surface runoff throughout a basin, as well as the cumulative downstream change as widely distributed tributary impacts are felt in the main channel. In this fashion, it is possible to assess the vulnerability of potentially sensitive areas to basin-wide development alternatives.

For the purpose of this study, negative impacts are considered to be any increase in surface runoff, channel discharge, sediment yield, and/or declines in groundwater percolation. In general, the Open scenario has the greatest negative impact on surface water hydrology and results in greater simulated surface runoff, channel discharge, and sediment yield than the other options, especially in the downstream reaches near Benson, Arizona. Additionally, percolation and thus groundwater recharge are most reduced under this option. This scenario favors development and allows for the largest future population increase within the watershed.

The Constrained and Plans alternatives have less significant impacts to the surface-water hydrology due to the concentration of development in existing urban areas and the significant reductions in irrigated agriculture. The simulation results from these two scenarios are very similar, with most of the differences resulting from the presence or absence of agriculture in the basin. Under the Constrained alternative, the elimination of all irrigated agriculture causes the biggest reduction in groundwater pumping, but it also has the effect of producing slightly higher surface runoff and erosion than when it is present in the Plans alternative. Results thus suggest that the increased runoff resulting from additional suburban development in the Plans scenario (15% vs. 0% in Constrained scenario) is offset by the presence of agriculture, which is generally characterized by higher infiltration rates than the native desert scrub.

Areas within the San Pedro Basin are valued both for development and for conservation purposes, and this sometimes brings human values into direct conflict. Clearly policy decisions regarding both population growth and irrigated agriculture will have important impact on future water use and conservation. Scenario analyses such as this one improve our ability to make informed decisions regarding land and water resource management. By integrating spatial data and distributed modeling in natural resources management, AGWA allows stakeholders and decision-makers to assess the relative impacts of several alternative sets of options and thus provides an important tool to help make better informed choices for an improved future.

SUMMARY AND CONCLUSIONS

A GIS-based hydrologic modeling toolkit called the Automated Geospatial Watershed Assessment (AGWA) tool has been developed for use in watershed analysis. This tool has been released as an open-source suite of programs and is fully modular and customizable. AGWA automates the process of converting commonly available GIS data to input parameter files for the SWAT and KINEROS2 hydrologic models. Rainfall files for both models can be prepared within AGWA, depending on the availability of rainfall data. Results from these models, such as runoff, peak discharge, and sediment yield for each model element, are imported into AGWA and can be investigated using AGWA's visualization tools. Since the models operate at different spatial and temporal scales, they provide the ability to perform a range of analyses as tailored to specific research or management objectives.

In the absence of a calibration/validation exercise, AGWA model results are best suited for relative analysis. Given repeat classified remote sensing imagery, AGWA provides the capability to assess the spatial distribution of the impacts of land-cover change on watershed hydrologic response. In the absence of repeat imagery, AGWA may be used to identify portions of a study area that are most susceptible to change, or high-priority management zones.

The modeling capability of the AGWA tool was demonstrated by presenting two case studies. The first case study consisted in evaluating the hydrologic response of the Upper San Pedro Basin to land-cover change over several decades using the SWAT and KINEROS2 models. These models significantly differ in their representation of hydrologic processes and operate at different temporal and spatial scales. Input parameters for these models were obtained using AGWA in conjunction with readily available topographic and soil data and a series of classified satellite images detailing land cover over the study area. The results indicate that watershed hydrologic response in the basin has been altered to favor increased average annual runoff due to land-cover change during the period from 1973 to 1997, and consequently it is at risk for decreased water quality and related impacts to the local ecology. The Sierra Vista watershed within the San Pedro was modeled using design rainfall events, and the hydrographs resulting from these events showed dramatic increases in runoff volume, runoff rate, and sediment yield. The second case study illustrated the application of the AGWA tool to evaluate the response of the San Pedro River basin to possible future urbanization scenarios in the year 2020. In general, the results appear to indicate that important impacts to the watershed hydrology can be expected. The most notable changes are likely to be increases in runoff, channel discharge, and sediment yield, and a reduction of surface water access to the groundwater table.

This chapter illustrated how the AGWA tool provides a formal specification for well-integrated, repeatable analyses that provide consistent landscape/hydrologic evaluations over time and space. Therefore, AGWA represents a powerful and flexible tool for managing resources and understanding and predicting complex and changing systems.

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