

Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual

Version 1.5

S.N. Scott, I.S. Burns, L. Levick, M. Hernandez, and D.C. Goodrich
USDA - ARS
Southwest Watershed Research Center
Tucson, Arizona
ARIS Log # 137460

Semmens, D.J., W.G. Kepner
US - EPA
Office of Research and Development
Las Vegas, Nevada
EPA Clearance # EPA/600/C-06/001

Miller, S.N.
University of Wyoming
Rangeland Ecology and Watershed Management
PO BOX 3354, 14 Agriculture C
Laramie, Wyoming 82071-3354



Contents

Abstract

Disclaimer

Acknowledgments

Introduction

Watershed Modeling

- Process Description
- Spatial Scale
- Temporal Scale
- Land Use
- Effects of aggregation of landscape attributes on watershed response
- Integration of geographic information systems and remote sensing in hydrologic modeling
- Kinematic Runoff and Erosion Modeling – KINEROS
- Soil Water Assessment Tool – SWAT

AGWA Tool Overview

- Changes for AGWA 1.5

Set-up and Installation

- Hardware and Software Requirements
- Installation

File Management

- Required Files and Datasets
- Moving Spatial Data

Watershed Delineation and Discretization

- Basic Concepts
 - Stream map
 - Watershed Outline
 - Contributing Source Area (CSA)
 - KINEROS Flow Length
 - Hydraulic Geometry Relationships
 - Watershed and Stream parameters
- Watershed Delineation
 - Create a new watershed
 - Create a nested watershed
 - Create a watershed group
 - Multiple outlet locations
 - Area of Interest outlet location
 - Edit a watershed group
 - Append watersheds
 - Extract watersheds
 - Remove watersheds
 - Use existing watershed delineation(s)
 - Select a subwatershed from a SWAT watershed
 - Apply channel buffers to a KINEROS watershed
- Watershed Discretion
 - Individual watersheds
 - CSA Enforcement
 - Multiple or Nested Watersheds
 - Internal Breakpoints
 - Internal Gages
 - KINEROS Ponds
 - SWAT Reservoirs
 - Non-releasing ponds

- Setting the hydraulic geometry relationship

Landcover and Soils Parameterization

- Landcover
 - KINEROS
 - SWAT
 - Hydrologic Response Units (HRU)
 - Default CROP values
 - Custom Lookup tables
- Soils
 - Soil Datasets
 - STATSGO
 - SSURGO
 - FAO
 - KINEROS
 - SWAT
- Parameterization
 - Parameterizing an individual watershed
 - Parameterizing a buffered watershed
 - Parameterizing a watershed group

KINEROS

- Generating precipitation files
 - Uniform Inputs
 - Precipitation-Frequency Maps
 - AGWA Design Storm Database
 - Manual Inputs
 - Enter event
 - Single return-period depth
 - Multiple Gage Inputs
 - Setting the saturation index
- Inputs and Execution
 - Writing the parameter file
 - Hydrograph Output
 - Using multipliers
 - Running KINEROS with a watershed group

SWAT

- Generating precipitation files
 - Uniform Precipitation
 - Distributed Precipitation
 - Elevation Bands
- Inputs and Execution
 - Selecting the weather generator file
 - Advanced Options
 - Rainfall adjustment factors
 - Groundwater
 - Nitrogen/Phosphorus modeling
 - Running SWAT with a watershed group

Results

- Setting and using the breakpoints
- Simulation totals
- KINEROS Time Series
- SWAT Time Series
- Unbuffered vs. Buffered Comparisons
- Differencing

Rerunning Simulations

- KINEROS
- SWAT

Metadata

- Metadata structure
- View watershed metadata
- Add user comments
- View simulation metadata

Managing AGWA Datasets

- Package a watershed for export
- Import an AGWA watershed

Advanced Options

- Landcover Modification Tool
 - Change a user-specified area to a new landcover type using an interactively drawn polygon
 - Change a landcover type to a new landcover type
 - Change a user-specified area to a new landcover type using a polygon map
 - Change a user-specified area to multiple landcover types in a randomly spatially distributed pattern
 - Analyze an area using a burn severity map
- SSURGO Tool
 - Import SSURGO datasets
 - Merge SSURGO datasets
 - Correct internal voids
 - Extend SSURGO edges
- Hydraulic Geometry Relationships
- Preferences
 - KINEROS Baseflow
 - Warning messages
 - SWAT DAT Defaults
 - Setting the default DAT location
 - Editing Landcover Lookup Tables
 - KINEROS Flow Length
 - File Management

Troubleshooting

- Tips and Tricks
- Errors
- Additional Resources
 - AGWA Frequently Asked Questions
 - Technical Support

Appendix A: Obtaining Spatial Datasets

Appendix B: Analyzing watersheds with AGWA and ATtiLA

Appendix C: Landcover Modification Fractal Component

References

Abstract

Scott, S.N., I.S. Burns, D.J. Semmens, L. Levick, S.N. Miller, M. Hernandez, D.C. Goodrich, W.G. Kepner, 2006, Automated Geospatial Watershed Assessment (AGWA) – A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual; U.S. Department of Agriculture, Agricultural Research Service, ARS-1446.

Planning and assessment in land and water resource management are evolving from simple, local-scale problems toward complex, spatially explicit regional ones. Such problems have to be addressed with distributed models that can compute runoff and erosion at different spatial and temporal scales. The extensive data requirements and the difficult task of building input parameter files, however, have long represented an obstacle to the timely and cost-effective use of such complex models by resource managers.

The USDA-ARS Southwest Watershed Research Center, in cooperation with the U.S. EPA Office of Research and Development, has developed a GIS tool to facilitate this process. A geographic information system (GIS) provides the framework within which spatially-distributed data are collected and used to prepare model input files and evaluate model results for two watershed runoff and erosion models: KINEROS2 and SWAT.

AGWA is designed as a tool for performing relative assessment (change analysis) resulting from land cover/use change. Areas identified through large-scale assessment with SWAT as being most susceptible to change can be evaluated in more detail at smaller scales with KINEROS2. AGWA includes functions to assist in land cover/land use modification, in scenario development for individual watersheds and for areas of interest, and in best management practice and erosion management analyses. Results can be visualized as percent or absolute change for a variety of output and derived parameters. These features are intended to assist resource managers in identifying the most important areas for watershed restoration efforts and preventative measures.

Disclaimer

The development of this document and the AGWA tool has been funded by the U.S. Environmental Protection Agency and carried out by the U.S. Department of Agriculture's Agricultural Research Service. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Environmental Protection Agency or the Department of Agriculture. The Automated Geospatial Watershed Assessment (AGWA) tool described in this manual is applied at the user's own risk. Neither the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, nor the system authors can assume responsibility for system operation, output, interpretation, or use.

Acknowledgments

The Automated Geospatial Watershed Assessment (AGWA) tool was developed by the USDA-ARS Southwest Watershed Research Center in close collaboration with the US-EPA National Research Exposure Lab, Las Vegas, NV. The authors would like to thank several EPA colleagues who assisted in the development of this tool, especially Bruce Jones, Daniel Heggem, Megan Mehaffey, Kim Devonald, and Curt Edmonds. The authors benefited greatly from the thoughtful comments and reviews of ARS staff scientists, most notably Carl Unkrich, Ginger Paige, Jeff Stone, and Susan Moran.

The software extension and manual were reviewed by Lainie Levick, Mariano Hernandez and Shea Burns from the University of Arizona, Tucson, AZ. AGWA benefited greatly from their reviews and we thank them for their time and attention.

AGWA is based on two existing watershed runoff and erosion models, KINEROS and SWAT, and we would like to acknowledge the authors of those models for providing assistance with integrating the models. Carl Unkrich of the Southwest Watershed Research Center was kind enough to create an AGWA-specific KINEROS program. Thanks also to Jeff Arnold of the USDA-ARS Blackland Research Center, Temple, TX, for his assistance in developing the SWAT interface.

Introduction

The Automated Geospatial Watershed Assessment (AGWA) tool is a multipurpose hydrologic analysis system for use by watershed, water resource, land use, and biological resource managers and scientists in performing watershed- and basin-scale studies. It was developed by the U.S. Agricultural Research Service's Southwest Watershed Resource Center to address four objectives:

1. To provide a simple, direct, and repeatable method for hydrologic model parameterization
2. To use only basic, attainable GIS data
3. To be compatible with other geospatial watershed-based environmental analysis software
4. To be useful for scenario development and alternative futures simulation work at multiple scales.

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 the KINematic Runoff and EROSION model, KINEROS2. SWAT, developed by the U.S. Agricultural Research Service, is a long-term simulation model for use in large (river-basin scale) watersheds. KINEROS, also developed by the U.S. Agricultural Research Service, is an event driven model designed for small semi-arid watersheds. The AGWA tool has intuitive interfaces for both models that provide the user with consistent, reproducible results in a fraction of the time formerly required with the traditional approach to model parameterization.

Data used in AGWA include Digital Elevation Models (DEMs), land cover grids, soils data, and precipitation data. All are available at no cost over the internet for North America, and other areas around the world. A more detailed description of these data types can be found in the Data Requirements section.

AGWA is an extension for the Environmental Systems Research Institute's (ESRI's) ArcView versions 3.x, a widely used and relatively inexpensive geographic information system (GIS) software package. 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. In addition, AGWA shares the same ArcView GIS framework as the U.S. Environmental Protection Agency's Analytical Tool Interface for Landscape Assessment (ATtiLA), and Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). This facilitates comparative analyses of the results from multiple environmental assessments. In addition, output from one model may be used as input in others, which can be particularly valuable for scenario development and alternative futures simulation work.

Watershed Modeling

Since the development of the Stanford Watershed Model (Crawford and Linsley, 1966) numerous hydrologic models have been developed that use watersheds as the fundamental spatial unit to describe the various components of the hydrologic cycle. Watershed models have five basic components: watershed (hydrologic) processes and characteristics; input data; governing equations; initial and boundary conditions; and output (Singh, 1995). Despite their uniform general structure, however, various treatments of the five model components has resulted in a significant range of available model types. Distinguishing between these different model types is an important first step in selecting the appropriate model for a project.

Watershed models are generally classified according to the method they use to describe the hydrologic processes, the spatial and temporal scales for which they are designed, and any specific conditions or intended use for which they are designed. Some knowledge of these components is highly recommended when selecting the combination that is best suited to a specific watershed and task.

Process Description

Watershed models can be divided into two main types according to how they treat the spatial component of watershed hydrology (Figure 1). Lumped, or lumped-parameter models treat an entire watershed as one unit and take no account of the spatial variability in processes, input, boundary conditions, or the hydrologic properties of the watershed. In contrast, distributed models ideally account for all spatial variability in the watershed explicitly by solving the governing equations for each pixel in a grid. In reality, neither of these extremes are suitable for watershed modeling because a lumped framework is a gross oversimplification and a distributed framework requires enormous amounts of data that are not readily obtainable. As a result most models have combined aspects of both approaches and subdivide the watershed into smaller elements with similar hydrologic properties that can be described by lumped parameters. This model type is commonly referred to as partially distributed, or quasi-distributed.

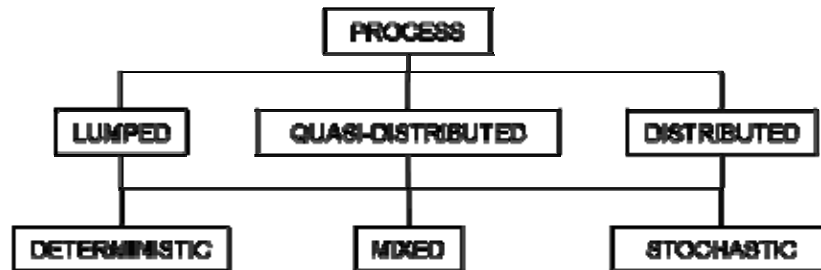


Figure 1. Process-based classification of watershed models, after Singh (1995).

The description of the hydrologic processes within a watershed model can be deterministic, stochastic, or some combination of the two. Deterministic models are models in which no random variables are used, i.e. for each unique set of input data the model will compute fixed, repeatable results (e.g. Law and Kelton, 1982). The governing equations describing the hydrologic and soil erosion processes in a deterministic model should be a major factor in selecting a model. Models with equations based on fundamental principles of physics or robust empirical methods are the most widely used in computing surface runoff and sediment yield. Stochastic models, in contrast, use distributions for each variable to generate random values for model input (e.g. Clarke, 1998). As a result, the output from a stochastic model is itself random, with its own distribution, and can thus be presented as a range of values with confidence limits.

The vast majority of watershed models are deterministic, including both KINEROS and SWAT. Fully stochastic models, in which all components of the model are stochastic, are virtually non-existent (Singh, 1995). Stochastic generation of input variables, however, is commonly used to optimize models, or determine model sensitivity to various input variables. If only parts of a model are described by the laws of probability then it is commonly referred to as quasi-deterministic, quasi-stochastic, or mixed.

Spatial Scale

A watershed can range from as little as one hectare to hundreds of thousands of square kilometers. The spatial scale for which a model is designed can play a significant role in how specific processes are treated. Runoff in large watersheds ($> 1000 \text{ km}^2$), for instance, is dominated by channel storage. In contrast, runoff from small watersheds ($< 100 \text{ km}^2$) is dominated by overland flow. For intermediate watersheds it is important to account for the essential concept of homogeneity and averaging of hydrologic process in the models.

Spatial scale is an important criterion in the selection of a model because the storage characteristics may vary at different watershed scales, that is, large watersheds have well developed channel networks and channel phase, and thus, channel storage is dominant. Such watersheds are less sensitive to short duration, high intensity rainfalls. On the other hand, small watersheds are dominated by the land phase and overland flow, have relatively less conspicuous channel phase, and are highly sensitive to high intensity, short duration rainfalls.

Temporal Scale

Hydrologic processes may occur at different time scales, therefore it is important to consider models that operate from event to daily to yearly time scales. At the event time scale, models typically do not compute inter-storm soil moisture conditions and therefore this information must be provided as an initial condition to initiate the model run. Event based models may be employed for storm events of relatively short duration or to finalize the design of technically complex structural and nonstructural management practices. On the other hand, continuous-time hydrologic models can simulate precipitation, available surface storage, snowmelt, evapotranspiration, soil moisture, and infiltration in a seasonal framework. These models typically operate on a time interval ranging from a fraction of an hour to a day. The principal advantage of continuous modeling is that it can provide long-term series of water and pollutants loadings.

Land Use

Many studies have shown that the land uses within a watershed can account for much of the variability in stream water quality (Omernick, 1987; Hunsaker et al., 1992; Charbonneau and Kondolf, 1993; Roth et al., 1996). Agriculture on slopes greater than three percent, for example, increases the risk of erosion (Wischmeier and Smith 1978). A drastic change in vegetation cover, such as clear cutting in the Pacific northwest, can produce 90% more runoff than in watersheds unaltered by human practices (Franklin, 1992). The linkage between intact riparian areas and water quality is well established (Karr and Schlosser, 1978; Lowrance et al., 1984). For example, riparian habitats function as "sponges", greatly reducing nutrient and sediment runoff into streams (Peterjohn and Correll, 1984).

The percentage and location of natural land cover influences the amount of energy that is available to move water and materials (Hunsaker and Levine, 1995). Forested watersheds dissipate energy associated with rainfall, whereas watersheds with bare ground and anthropogenic cover are less able to do so (Franklin, 1992). The percentage of the watershed surface that is impermeable, due to urban and road surfaces, influences the volume of water that runs and increases the amount of sediment that can be moved (Arnold and Gibbons, 1996). Watersheds with highly erodible soils tend to have greater potential for soil loss and sediment delivery to streams than watersheds with non-erodible soils.

Moreover, intense precipitation events may exceed the energy threshold and move large amounts of sediment across a degraded watershed (Junk et al., 1989; Sparks, 1995). It is during these events that human-induced landscape changes may manifest their greatest negative impact.

A direct and powerful link exists between vegetation and hydrological processes in semi-arid environments. Vegetation plays a pivotal role in determining the amount and timing of the runoff which ultimately supplies mass and energy for the operation of hydrologic and erosive processes (Graf, 1988). Most analyses that assess the variability of sediment yield demonstrate that at the lower end of the precipitation scale (representing semi-arid conditions), small changes in annual precipitation bring about major changes in vegetation communities and associated sediment yields (Graf, 1988). For example, for

a mean annual temperature of 10° C, the Langbein and Schumm (1958) curve reaches a peak at an effective precipitation of about 300 mm (Figure 2), trailing off at lower values because of lower runoff totals and at higher ones because an increasingly abundant vegetation cover affords better protection against erosion.

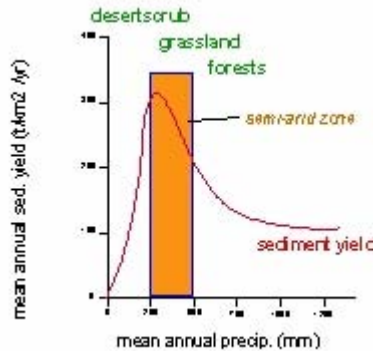


Figure 2. Erosion as a function of precipitation. After Langbein & Schumm (1958)

It should be clearly noted that methods for transforming various land cover and land use characteristics into distributed hydrologic model parameters are not well developed for a wide range of conditions. For management purposes, many approaches rely largely on empirical studies from large numbers of small plots and catchments to relate land cover and land use to effective hydrologic model parameters. The curve number method (Chow et al., 1988) and the USLE or RUSLE method for predicting soil erosion (Renard et al., 1997) are examples of this type of approach to relate land cover/land use to hydrologic model parameters. The transformation of land cover/land use conditions into meaningful hydrologic and erosion parameters, and quantifying the associated uncertainty is a major challenge in watershed modeling.

Effects of aggregation of landscape attributes on watershed response

Recent papers (e.g. Roth et al., 1996; Weller et al., 1996) suggest that the importance of landscape features may change in different environmental settings, or when moving from one spatial scale to another. Therefore, methods to analyze and interpret broad spatial scales are becoming increasingly important for hydrological and ecological studies. Parameters and processes important at one scale are frequently not important or predictive at another scale, and information is often lost as spatial data are considered at coarser scales of resolution (Meentemeyer and Box, 1987). Furthermore, hydrological problems may also require the extrapolation of fine-scale measurement for the analysis of broad-scale phenomena. Therefore, the development of methods that will preserve information across scales or quantify the loss of information with changing scales has become a critical task.

Wood et al. (1988) carried out an empirical averaging experiment to assess the impact of scale. They averaged runoff over small subwatersheds, aggregating the subwatersheds into larger watersheds, and repeating the averaging process. By plotting the mean runoff against mean subwatershed area, they noted that the variance decreased until it was rather negligible at a watershed scale of about 1 km². That analysis has been repeated for the runoff ratio (Wood, 1994) and evaporation (Famiglietti and Wood, 1995) using data from Kings Creek, which was part of the FIFE '87 experiment. Results from the experiment show that at small scales there is extensive variability in both runoff and evaporation. This variability appears to be controlled by variability in soils and topography whose correlation length scales are on the order of 10² - 10³m, typical of hillslopes. At an increased spatial scale, the increased sampling of hillslopes leads to a decrease in the difference between subwatershed responses. At some scale, the variance between hydrologic response for watersheds of the same scale should reach a minimum.

Integration of geographic information systems and remote sensing in hydrologic modeling

Spatially distributed models of watershed hydrological processes have been developed to incorporate the spatial patterns of terrain, soils, and vegetation as estimated with the use of remote sensing and

geographic information systems (GIS) (Band et al., 1991; 1993; Famiglietti and Wood, 1991; 1994; Moore and Grayson, 1991; Moore et al., 1993; Wigmosta et al., 1994; Star et al., 1997). This approach makes use of various algorithms to extract and represent watershed structure from digital elevation data. Land surface attributes are mapped into the watershed structure as estimated directly from remote sensing imagery (e.g. canopy leaf area index), digital terrain data (slope, aspect, contributing drainage area) or from digitized soil maps, such as soil texture or hydraulic conductivity assigned by soil series.

Over the past decade numerous approaches have been developed for automated extraction of watershed structure from grid digital elevation models (e.g. Mark et al., 1984; O'Callaghan and Mark, 1984; Band, 1986; Jenson and Dominique, 1988; Moore et al., 1988; Martz and Garbrecht, 1993; Garbrecht and Martz, 1993; 1995; 1996). O'Callaghan and Mark (1984) define a digital elevation model (DEM) as any numerical representation of the elevation of all or part of a planetary surface, given as a function of geographic location. The most widely used method for the extraction of stream networks that has emerged is to accumulate the contributing area upslope of each pixel through a tree or network of cell to cell drainage paths and then prune the tree to a finite extent based on a threshold drainage area required to define a channel or to seek local morphological evidence in the terrain model that a channel or valley exists (Band and Moore, 1995).

The techniques used for delineation of the drainage path network by surface routing of drainage area and local identification of valley forms are ultimately dependent on a topographic signal generated in a local neighborhood on the DEM. As the approach is used to extract watershed structure with increasingly lower resolution terrain data, higher frequency topographic information is lost as the larger sampling dimensions of the grids act as a filter. Therefore, if watershed structural information is used to drive the hydrological model, the scaling behavior and consistency of the derived stream network with grid dimension needs to be addressed. One of the primary questions dealing with automated extracted channel network is that of the appropriate drainage density. Some authors suggest criteria to find this appropriate scale. For example, Goodrich (1991) found a drainage density of approximately 0.65 to 1.52×10^{-3} m for watersheds greater than 1 hectare was adequate for kinematic runoff modeling in semi-arid regions. Similarly, La Barbera and Roth (1994) proposed a filtering procedure based on the identification of threshold value for the quantity Ask , where A is the contributing area, S the stream slope and $k = 2$. This procedure consists in the progressive removal from the drainage network of the first order stream which presents the minimum Ask value; the procedure is iterated up to a given target value for the area drained by first order streams. Calore et al. (1997) found that above a certain threshold, an increase in resolution in the spatial description of drainage networks obtained from a DEM cannot be directly linked to an increase of information. The criterion they used for assessing the amount of information contained in the drainage was based on the information entropy concept of Shannon (1948).

Land use is an important watershed surface characteristic that affects infiltration, erosion, and evapotranspiration. Thus, almost any physically based hydrologic model uses some form of land use data or parameters based on these data (Spanner et al., 1990; 1994; Nemani et al., 1993). Distributed models, in particular, need specific data on land use and their location within the basin. Some of the first research for adapting satellite derived land use data was done by Jackson et al. (1976) with the US Army Corps of Engineers STORM Model (US Army Corps of Engineers, 1976). However, most of the work on adapting remote sensing to hydrologic modeling has been with the Soil Conservation Service (SCS) runoff curve number model (US Department of Agriculture, 1972). The SCS model has been widely used in hydrology and water resources planning of agricultural areas. The model was originally developed for predicting runoff volumes from agricultural fields and small watersheds. However, it has been expanded for subsequent use in a wide variety of conditions at many basin sizes including urban and suburban areas. In early work with remotely sensed data, Jackson et al. (1977) demonstrated that land cover (particularly the percentage of impervious surface) could be used effectively in the STORM Model (US Army Corps of Engineers, 1976). In a study of the upper Anacostia River basin in Maryland, Ragan and Jackson (1980) demonstrated that Landsat-derived land use data could be used for calculating synthetic flood frequency relationships. Results can be erroneous if land use is mislabeled. A study by the US Army Corps of Engineers (Rango et al., 1983) estimated that any individual pixel may be incorrectly classified about one-third of the time. However, by aggregating land use over a significant area, the misclassification of land use can be reduced to about 2% (Engman and Gurney, 1991).

More recently, vegetation classification studies implementing digital satellite data have utilized higher spatial, spectral, and radiometric resolution Landsat Thematic Mapper (TM) data with much more powerful computer hardware and software. These studies have shown that the higher information content of TM data combined with the improvements in image processing power result in significant improvements in image processing power resulting in significant enhancement in classification accuracy for more distinctive classes (Congalton et al., 1998).

A detailed analysis of the effects of the thematic accuracy of land cover is necessary before any attempt on using the hydrologic modeling tool to determine the vulnerability of semi-arid landscapes to land cover changes. The accuracy of maps made from remotely sensed data is measured by two types of criteria (Congalton and Green, 1999): location accuracy and, classification or thematic accuracy. Location accuracy refers to how precisely map items are located relative to their true location on the ground. Thematic accuracy refers to the accuracy of the map label in describing a class or condition on the earth. For example, if the earth's surface was classified as forest, thematic map accuracy procedures will determine whether or not forest has been accurately labeled forest or inaccurately labeled as another class, such as water.

The widespread acceptance and use of remotely sensed data has been and will continue to be dependent on the quality of the map information derived from it. However, map inaccuracies or error can occur at many steps throughout any remote sensing project. According to Congalton and Green (1999), the purpose of quantitative accuracy assessment is the identification and measurement of map errors. Quantitative accuracy assessment involves the comparison of a site on a map against reference information for the same site. The reference data is assumed to be correct.

The history of accuracy assessment of remotely sensed data is relatively short, beginning around 1975. Researchers, notably Hord and Brooner (1976), van Genderen and Lock (1977), proposed criteria and techniques for testing map accuracy. In the early 1980s more in-depth studies were conducted and new techniques proposed (Rosenfield et al., 1982; Congalton et al., 1983; and Aronoff, 1985). Finally, from the late 1980s up to present time, a great deal of work has been conducted on accuracy assessment. An important contribution is the error matrix, which compares information from reference sites to information on the map for a number of sample areas. The matrix is a square array of numbers set out in rows and columns that express the labels of samples assigned to a particular category in one classification relative to the labels of samples assigned to a particular category in another classification. One of the classifications, usually the columns, is assumed to be correct and is termed the reference data. The rows usually are used to display the map labels or classified data generated from remotely sensed data. Error matrices are very effective representation of map accuracy, because the individual accuracy of each map category are plainly described along with both errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map (Congalton and Green, 1999). A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs. In addition to clearly showing errors of omission and commission, the error matrix can be used to compute overall accuracy.

Soils information derived from a GIS are generally gathered in a similar manner to vegetation, with the exception that remote sensing often cannot provide critical information about soil properties, especially if the soil is obscured by a vegetation canopy (Band and Moore, 1995). Substantial progress has been made in estimating near-surface and profile soil water content with active and passive microwave sensors and in the estimation of hydraulic properties by model inversion (e.g. Entekhabi et al., 1994). However, in general, soil spatial information is the least known of the land surface attributes relative to its well-known spatial variability that has been observed in many studies (Nielsen and Bouma, 1985).

Kinematic Runoff and Erosion Model - KINEROS

KINEROS utilizes a network of channels and planes to represent a watershed and the kinematic wave method to route water off the watershed (Figure 3). It is a physically-based model designed to simulate runoff and erosion for single storm events in small watersheds less than approximately 100 km². More detailed technical information about KINEROS can be found at <http://www.tucson.ars.ag.gov/kineros/>.

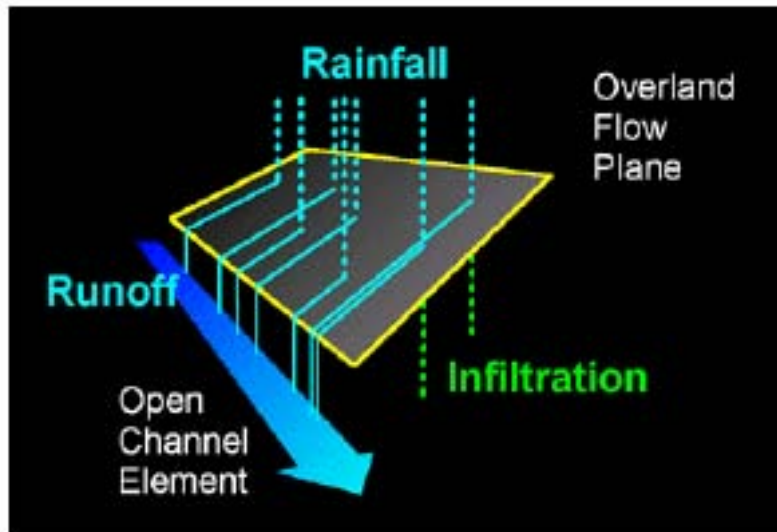


Figure 3. A schematic representation of the KINEROS program.

Soil Water Assessment Tool - SWAT

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1994) was developed to predict the effect of alternative management decisions on water, sediment, and chemical yields with reasonable accuracy for ungaged rural basins. It is a distributed lumped-parameter model developed at the USDA Agricultural Research Service (ARS) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large (basin scale) complex watersheds with varying soils, land use and management conditions over long periods of time (> 1 year). SWAT is a continuous-time model, i.e. a long-term yield model, using daily average input values, and is not designed to simulate detailed, single-event flood routing. Major components of the model include: hydrology, weather generator, sedimentation, soil temperature, crop growth, nutrients, pesticides, groundwater and lateral flow, and agricultural management. The Curve Number method is used to compute rainfall excess, and flow is routed through the channels using a variable storage coefficient method developed by Williams (1969). Additional information and the latest model updates can be found at <http://www.brc.tamus.edu/swat/>.

AGWA Tool Overview

The AGWA tool, packaged as an extension for the ESRI ArcView 3.x GIS software, uses geospatial data to parameterize two watershed runoff and erosion models: KINEROS, and SWAT. A schematic of the procedure for utilizing these models with AGWA is presented below in Figure 4. AGWA is a modular program that is designed to be run in a step-wise manner.

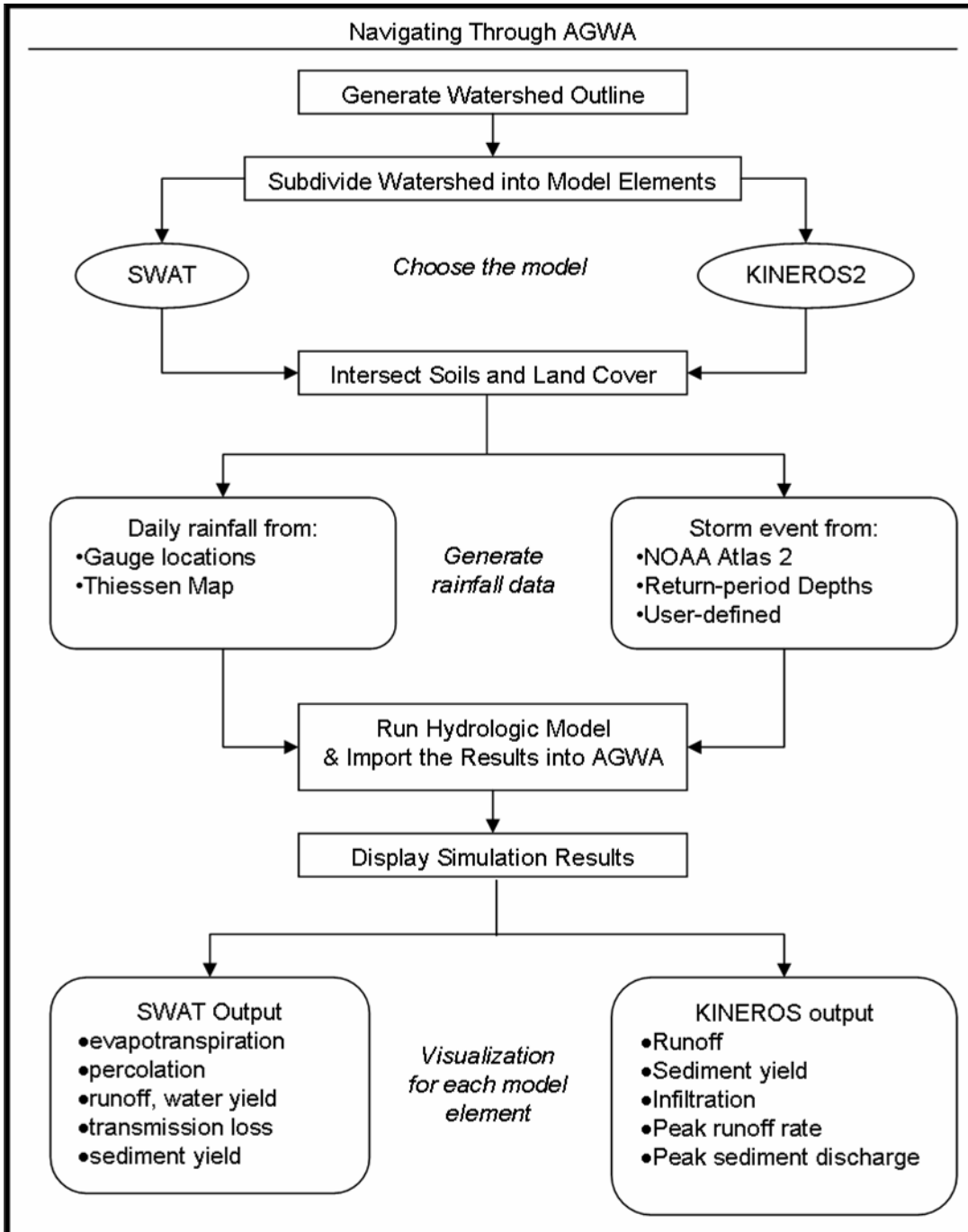
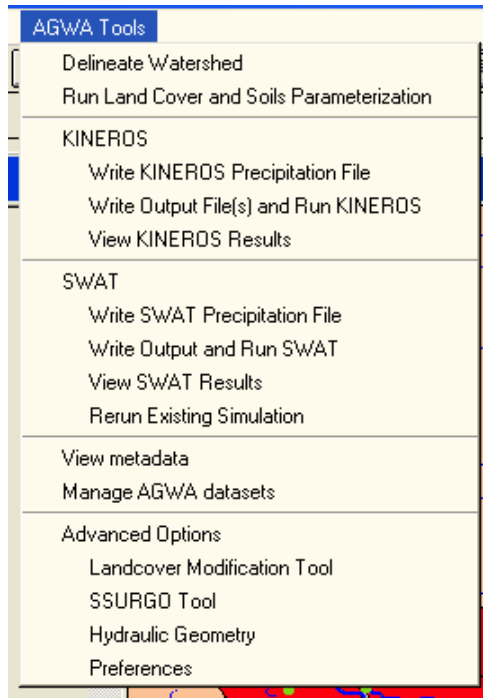


Figure 4. Basic processing steps for AGWA.



The AGWA extension for ArcView adds the **AGWA Tools** menu to the View window, and must be run from an active view. 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. Watershed delineation and discretization
2. Land cover and soils parameterization
3. Writing a precipitation file for model input
4. Writing parameter files and running the chosen model
5. Viewing results

In more detail...

Step 1. Watershed Delineation and Discretization: The user first creates a watershed outline, which is a grid based on the accumulated flow to the designated outlet (pour point) of the study area. A polygon shapefile is built from the watershed outline grid. The user then 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, the tasks are specific to the model that will be used, but both follow the same general process. If internal runoff gages for model validation or ponds/reservoirs are present in the discretization, they can be used to further subdivide the watershed.

Step 2. Land cover and soils parameterization: AGWA is predicated on the presence of both land cover and soil GIS coverages. In step 2, the watershed is intersected with these data and parameters necessary for the hydrologic model runs are determined through a series of look-up tables. The hydrologic parameters are added to the polygon and stream channel tables.

Step 3. Writing a precipitation file for model output: Rainfall input files are built. For SWAT, the user must provide daily rainfall values for rainfall gages within and near the watershed. If multiple gages are present, AGWA will build a Thiessen polygon map and create an area-weighted rainfall file. For KINEROS, the user can select from a series of pre-defined rainfall events or choose to build his/her own rainfall file through an AGWA module. Precipitation files for model input are written from uniform (single gage) rainfall or distributed (multiple gage) rainfall data.

Step 4. Writing parameter files and running the chosen model: At this point, all necessary input data have been prepared: the watershed has been subdivided into model elements; hydrologic parameters have been determined for each element; rainfall files have been prepared. The user can proceed to run the hydrologic model of choice.

Step 5. Viewing results: AGWA imports the model results and add them to the polygon and stream maps' tables for display. A separate module controls the visualization of model results. The user can toggle between viewing the total depth or accumulated volume of runoff, erosion, and infiltration output for both upland and channel elements. This enables problem areas to be identified visually so that limited resources can be focused for maximum effectiveness. Model results can also be overlaid with other digital data layers to further prioritize management activities.

Changes for AGWA 1.5

New to 1.5

Support for riparian buffer modeling with KINEROS, including the capability of comparing simulations between unbuffered and buffered watersheds

Support for spatially distributed precipitation files for KINEROS

Nitrogen and phosphorous modeling for SWAT
Hydrologic Response Unit simulation for SWAT
Support for GAP vegetation datasets
Support for landcover modification using a burn severity map with the Landcover Modification Tool
Support for watershed groups, including discretization and simulation of multiple watersheds as one unit either with multiple outlet locations or with the area of interest tool
Improved handling of SSURGO datasets, including correction of internal voids, extension of the dataset to correspond to watershed boundaries, spatial and tabular dataset merge tools, and tabular dataset import tools
Improved handling of contributing source areas for higher order planes with the CSA enforcement option
Support for KINEROS batch processing
Improved handling of AGWA datasets, including AGWA metadata and the ability to easily transfer watersheds and related datasets between projects and users
Additional simulation display options, including timestep sequencing for KINEROS and SWAT, the ability to standardize the classification scheme based on previous simulation results, and the inclusion of nitrogen and phosphorus outputs for SWAT and percent error for KINEROS
Addition of non-releasing ponds to exclude regions of a watershed from simulation
Support for nested watersheds
Addition of XY coordinate specification for watershed outlets
New selection option for weather generator files using a point theme
Support for adjustable stream grids for watershed outlet placement
User-specified DAT directory defaults for SWAT inputs files
Support for displaying KINEROS multipliers for any stored simulation
Landcover lookup table editing for SWAT HRU parameters (crop, urban simulation method, and urban landcover)

Changes from 1.4

Improved handling of internal breakpoints, including internal gages, ponds, and reservoirs
Improved KINEROS plane splitting
Improved flow length calculations for KINEROS
Improved error checking for watershed discretization
Improved handling of simulation results, including the capability to re-import deleted results tables
Improved handling of watershed delineation and discretization options
Improved handling of SWAT precipitation file generation
Improved handling of the SWAT subwatershed selection discretization option
Improved handling for rerunning SWAT simulations to retain original output files

Set-up and Installation

Hardware and Software Requirements

The AGWA tool is not a stand alone program. It requires the Environmental Systems Research Institute's (ESRI) ArcView 3.x software and the Spatial Analyst Extension for working with grid-based data. AGWA is available in two releases, as an extension for BASINS 3.1 (version 1.4) and as a stand alone extension (version 1.5), both requiring ESRI's ArcView software. The AGWA tool is designed to run on Microsoft Windows versions 95, 98, NT 4.0, 2000, ME, and XP. Processor speed does have a significant impact on the time required to perform the watershed delineation and other tasks in AGWA.

Installation

The AGWA tool comes as a collection of files that are necessary for its operation. These files are organized as follows in both agwa1_5.zip, and the AGWA CD:

- ArcView extension agwa1_5.avx
- datafiles* directory – database files and supplementary extensions (grid01.avx, and xtools.avx).
- models* directory – model executables and associated files
- gisdata* directory – example data
- documents* directory – presentations and example documents
- manual* directory – user manual and associated files

For users downloading the file agwa1_5.zip please unzip these files and directories to a directory named AGWA, e.g. C:\AGWA.

For users with an AGWA CD, please copy the entire AGWA directory to your computer, creating e.g. C:\AGWA. Once this directory has been established you will need to change the permissions for it (everything is converted to 'read only' when written to the CD).

For Windows 2000 and XP – Right click on the AGWA directory to view the directory Properties window and uncheck the “read only” box. When you click **OK** or **Apply**, the **Confirm Attribute Changes** window will pop up and prompt you to choose whether you would like to apply the change to just the specified AGWA directory, or to also include subfolders and files. Please select the

latter to ensure that “read-only” is unset for all files in the directory.

For Windows 95, 98 and NT – File permissions cannot be set recursively for subfolders and files through a folder properties window. Instead, select **Run** from the **Start Menu** to bring up the window shown on the right. Type "attrib -R C:\AGWA*.* /S" in the text

When the AGWA directory and its associated subdirectories have been created on your hard drive:

Drag or paste the extension file (agwa1_5.avx) into the \ESR\AV_GIS30\ARCVIEWEXT32\ directory. Two supplementary extensions (grid01.avx, and xtools.avx) can optionally be copied from the *datafiles* subdirectory to \ESR\AV_GIS30\ARCVIEWEXT32\. These two extensions provide the user with additional capabilities when preparing data for AGWA, and potentially for analyzing results within ArcView.

Open ArcView and select **Extensions** from the **File** menu. To activate the AGWA extension click the box next to its name in the Extensions window and then click **OK**. You are now ready to begin using AGWA, but be sure to read the **File Management** section first. If the two supplementary extensions will be used then they can be turned on at this time as well, but these can be turned on/off and used at any time.

To take full advantage of the AGWA extension, users should set the AGWA environmental variable. To set the variable, go to the **Environment Variables** tab in the **System** dialog. Add a new variable called “AGWA” and set the path to the main AGWA directory, for example, c:\agwa\. This variable should not be changed once set. Instructions for setting the environment variable:

For Windows 2000 and XP

1. From the **Start Menu** select **Settings>Control Panel**
2. Double click on the **System** icon

3. From the **System Properties** window select the **Advanced** tab, and then click the **Environment Variables** button.
4. For the user variables, click on the **New** button and set its name to "AGWA" (without the quotes), and its value to "C:\AGWA" or wherever you have established your AGWA directory. This will give AGWA a head start in locating files and save you time in the long run.

For Windows NT

1. From the **Start Menu**, select **Settings>Control Panel**
2. Double click on the **System** icon
3. From the **System Properties** window select the **Environment** tab, and then click the **Environment Variables** button.
4. For the user variables, click on the **New** button and set its name to "AGWA" (without the quotes), and its value to "C:\AGWA" or wherever you have established your AGWA directory. This will give AGWA a head start in locating files and save you time in the long run.

For Windows 95 & 98

1. Open the file c:\autoexec.bat in a text editor – this can be accomplished by right clicking on the file in the Explorer window and selecting **Edit**.
2. Add the following line to the autoexec.bat file:

```
set AGWA=agwadir
```

where "agwadir" is the folder that will contain all your AGWA-related files and directories, for example: C:\AGWA.

3. Restart your computer to activate the changes to autoexec.bat.

Important – Do not ever use spaces anywhere in the path to this directory (e.g. "C:\My Documents\AGWA") because ArcView has problems dealing with file and folder names that contain spaces.

File Management

File management in any ArcView-based application is extremely important. ArcView projects maintain references to many files that are generated or used, and moving or deleting these files incorrectly will cause problems. Since this happens frequently when working and data directories are not fixed (i.e. user-selected or default directories), the AGWA extension manages them for you. When the AGWA extension is loaded into a project it prompts the user to select a name for a new project directory. This directory is then created and the project is automatically saved to it. In addition, several additional subdirectories are created for writing various input and output files used by AGWA. This, in combination with the option to set a system environmental variable "AGWA", allows AGWA to locate many files without prompting the user, and in other instances when the user must select a file it opens the appropriate directory when asking the user to select a file.

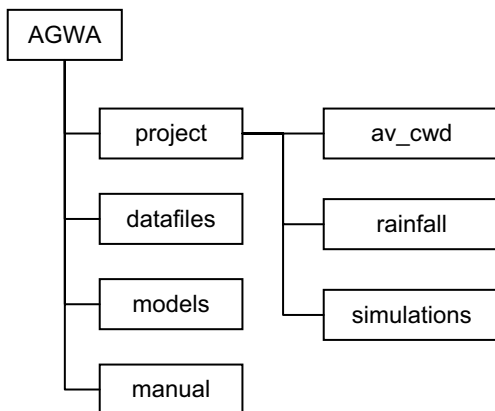


Figure 5. The AGWA file structure

The AGWA directory contains all projects and their associated datasets (Figure 5). The creation of this directory was described in **Set-up and Installation>Installation**. Each project directory contains three subdirectories:

- av_cwd*, which serves as the working directory for the project;
- rainfall*, which contains all precipitation files generated by AGWA; and,
- simulations*, which contains a simulation directory for each simulation, SWAT or KINEROS, performed within AGWA.

The handling of simulations, particularly KINEROS simulations, has been changed for version 1.5. Unlike earlier versions, where input files were stored in a *kin_sims* directory, KINEROS input files are now stored in a separate subdirectory in a manner similar to that of SWAT simulations. At no time should spaces be used in AGWA file names.

Users are encouraged to create a *datafiles* directory and a *gisdata* directory in the main AGWA directory. AGWA searches for required tabular datasets in the *datafiles* directory during a number of processing steps. These files include the *kin_lut.dbf*, the *wgnfiles.dbf*, all landcover lookup tables, and tabular datasets for soils.

The *datafiles* directory also contains several SWAT default data files, including the *crop2000.dat* and *urban2000.dat* files. Because these files can be modified to include user-defined landcover or urban landuse types, AGWA allows users to set the default directory location for all of the required DAT files. This directory can be changed at any time with **AGWA Tools>Preferences**. After AGWA creates the new project directory, it searches for the DAT files in the AGWA *datafiles* directory. If the files are not located there, AGWA prompts you to locate the *crop2000.dat* file to set the default location.

The *models* directory contains the executables for SWAT and KINEROS. It also contains the executable for the multifractal surface generator utilized by the Landcover Modification Tool (*lcmf.exe*).

The *manual* directory contains the dynamic help files accessed by AGWA through any **Help** button. If this directory (and the manual) are not located by AGWA, the manual cannot be accessed from an AGWA project.

Project information regarding the current state of AGWA preferences is stored in the *AGWA.odb* file in the project directory. This file should not be deleted.

All spatial data should be projected to a suitable projection with units in METERS. Failure to do so will result in unusable watersheds and erratic AGWA behavior. DO NOT set the View Projection.

It is the user's responsibility to provide correctly projected datasets. The View's Map Units must also be set to meters.

Required Files and Datasets

These files are either required for different AGWA components or created during processing. In many cases, the AGWA generated files are required for later processing steps. User-specified names are indicated by <name>, where name indicates the type of object the name refers to.

Watershed Raster Inputs

Digital elevation model (required): A raster dataset, supplied by the user, encompassing the study area. This file is used by AGWA in determining watershed boundaries and other model-specific parameters. If the user decides to fill any sinks in the raster (an option available through AGWA), this new dataset is located in the *av_cwd* directory.

Flow direction grid (optional): A raster dataset, specific to a given DEM, representing the direction of flow throughout a study area. This dataset can be created within AGWA (file located in the *av_cwd* directory) or can be generated outside of AGWA and added to the view before attempting to generate a watershed.

Flow accumulation grid (optional): A raster dataset, specific to a given DEM, representing the accumulation of runoff throughout a study area. This dataset can be created in AGWA (file located in the *av_cwd* directory) or can be generated outside of AGWA and added to the view before attempting to generate a watershed.

Stream map: A raster dataset representing the cells into which a specified number of cells flow. This grid is generated by AGWA; the threshold can be determined by a user based on DEM resolution and degree of network complexity required. The stream map is used for user-identified outlet location and, if using the area of interest watershed delineation method, for dynamically locating outlets.

Watershed Components

Outlet (optional): A point theme containing one or more outlet locations.

HGR.dbf (required): A table containing the hydraulic geometry relationships available for use during watershed discretization. This table is available for download from the AGWA website.

Watershed outline: A raster representing the total area draining to the specified outlet. This dataset is created by AGWA and can be found in the working directory. This grid must have a unique name within the project.

Watershed discretization: A polygon shapefile representing the subwatershed or plane elements at the specified contributing source area for a given watershed outline. This file must have a unique name within the project.

Stream Network: A polyline shapefile representing the stream elements at the specified contributing source area for a given watershed outline.

Area of interest boundary (optional): A polygon shapefile containing the boundary or boundaries for an area of interest to create a watershed group. This shapefile is only necessary to use this delineation/discretization option.

Metadata: An object database file (ODB) containing file creation, parameterization, and simulation information (as <watershed name>.odb). This file replaces the watershed and stream comments from earlier AGWA versions. This file is necessary to use a watershed in AGWA. A metadata file is also created for the watershed outline and must be present in the AGWA working directory to reuse the outline.

Landcover Components

Landcover (required): A raster dataset representing the distribution of landscape classes across a study area. Several datasets are supported by AGWA, including NALC, MRLC, and GAP landcovers. The landcover attribute table must contain a VALUE field and a NAME field. The surface should extend beyond the boundaries of the watershed for successful watershed parameterization.

Landcover lookup table (required): A dBASE formatted table containing parameter values by landcover class. Each record is identified by a unique key, identical to the values contained in the VALUE field of the landcover raster. Additional parameters include cover, interception, Manning's N, percent impervious and curve number values (A, B, C, and D). AGWA provides several lookup tables; custom tables, containing the parameters described above, can also be utilized for landcover parameterization.

<watershed>_HRUs.dbf: A table containing the areas of each landcover type found within a SWAT subwatershed. Required to simulate hydrologic response units.

Soil Components

Soils (required): A polygon shapefile or coverage representing the soil types across the study area. Supported soil classifications include STATSGO, SSURGO, and FAO. The dataset should extend beyond the watershed boundaries and not contain any internal voids for successful soils parameterization.

Soil tables (required): Each soil classification is associated with a tabular dataset. AGWA requires specific tables from each dataset to perform parameterization:

STATSGO: Required dataset includes the comp.dbf and layer.dbf tables. These are organized by state and are available from the AGWA website. The state directories should be located in the AGWA *datafiles* directory.

SSURGO: Required dataset includes the comp.txt, chorizon.txt, and chtexgrp.txt files. Although the SSURGO dataset is available as an Access database, this dataset cannot be utilized by AGWA. These files can be located anywhere on the computer but must be imported by AGWA before or during the parameterization process. Imported tables can be found in the *av_cwd* directory.

FAO: Required dataset includes the FAO_summ, FAO_world, FAO_Africa, and FAO_properties tables. These are available from the AGWA website and should be located in the *datafiles* directory.

temp_kin_soil_lut.dbf: Temporary soils table created during soils parameterization for KINEROS. It contains the depth-weighted averages for each soil classification within the watershed. This file is updated for each parameterization. The file is maintained to aid in error resolution.

<watershed name>_temp_swat_soil_lut.dbf: Temporary table containing hydraulic conductivity (KS) and hydrologic soil group averages (based on component percent) by soil classification.

<watershed name>_soil_lut.dbf: Required table containing the soil layers for each soil classification

within the watershed. This file is used during SWAT input file generation to describe the subwatersheds.

soil_output.dbf: Temporary table containing hydraulic conductivity and hydrologic soil group values area-weighted for each subwatershed. These values are based on the component averages found in the temp_swat_soil_lut.dbf table for the watershed. The averages are transferred to the watershed attribute table during the parameterization process.

Precipitation Components: KINEROS

Precipitation-frequency grid (optional): A grid representing the accumulated depth for an event of a given return period for a region.

dsgnstrm.dbf (optional): A table containing design storm parameters for southeastern Arizona. This table is used to generate precipitation files for the design storm option for KINEROS.

raingage point theme (optional): A shapefile containing raingage locations. This file is used if generating distributed precipitation files for KINEROS.

Precipitation event table (optional): A table containing precipitation information for each event. The file must correspond to a specific format (see **KINEROS>Generating precipitation files>Multiple Gage Inputs** for more information).

Precipitation file (.pre)*: This file contains time-depth or time-intensity pairs for one or more raingage locations. These files can be created in AGWA (located in the project's *rainfall* directory) or can be created outside of AGWA if the correct format is followed (see the KINEROS documentation at <http://tucson.ars.ag.gov/KINEROS> for more information).

Precipitation Components: SWAT

unweighted precipitation file: This file contains a record for every day to be used in generating the file. The table must be formatted properly (see **SWAT>Generating precipitation files** for more information) and must include fields for each gage.

Raingage point theme: A point theme for raingage locations. The attribute table must contain a gage identifier field with a field name other than ID and with values corresponding to those found in the unweighted precipitation file.

Thiessen polygons (optional): A polygon shapefile, generated by AGWA, containing the Thiessen polygons for a specific raingage theme.

Thiessen-Watershed intersection (optional): A shapefile generated by AGWA to calculate the weighted average precipitation for each subwatershed.

weights.dbf (optional): This file is created during the Thiessen polygon precipitation processing and can be found in the *av_cwd* directory. There is no need to modify this file.

Precipitation file (.pcp)*: A file containing the weighted average precipitation for each subwatershed or a uniform precipitation for the watershed for each day in the unweighted precipitation file.

Temperature file (.tmp)*: This file contains the maximum and minimum temperatures (in degrees Celsius) for each day in a given time period. This file is not created by AGWA and must be supplied, properly formatted, by the user. See the SWAT User's Manual for more information.

wgnfiles.dbf (required): A table containing the weather generator stations for the western United States. This table can be used to select the WGN file to use during SWAT simulation.

Wgnpoints.shp (optional): A point theme containing point locations for weather generator stations in the western United States. This dataset can be used to select the WGN file to use during SWAT simulation.

WGN files (.wgn)*: These files contain weather generator data for SWAT. The information includes statistics for a number of parameters that SWAT uses to estimate missing temperature data and other climate inputs. WGN files are provided for each state and can be found in the state subdirectories of the *datafiles* directory. For more information, see the SWAT User's Manual.

swatpfiles.dbf (required): This table maintains a record of SWAT precipitation files for each watershed. The table contains the full path to the precipitation file and the start and end dates of the files.

Simulation Output Components

Plane or subwatershed table: A dBASE file, named "p" + <simulation name>_<parameter file

basename>_<precipitation file basename>.dbf (KINEROS) or "p" + <simulation name>.dbf (SWAT), containing the simulation summary values. This table must be in the project to view the results of a simulation.

Channel table: A dBASE file, named "c" + <simulation name>_<parameter file basename>_<precipitation file basename>.dbf (KINEROS) or "c" + <simulation name>.dbf (SWAT), containing the simulation summary values. This table must be in the project to view the results of a simulation.

Hydrograph outputs (KINEROS): Two dBASE files, <watershed name>_plane_sim.dbf and (watershed name)_channel_sim.dbf, containing the plane and channel outputs for each timestep in the simulation. These can be viewed sequentially.

Subwatershed and Reach outputs (SWAT): Two text files (added to the project as tables), <sim name>_sbs.txt and <sim name>_rch.txt, containing the subwatershed and channel outputs for each timestep in the simulation. The timestep is based on the selected frequency, daily, monthly, or yearly, of the simulation. These can be viewed sequentially.

HRU outputs (SWAT): An additional table, <watershed name>_HRU_results.dbf, that contains subwatershed outputs for each HRU in each subwatershed for each time step. This table cannot be displayed through the GIS.

Moving spatial data

Spatial datasets should not be moved between directories using Microsoft Windows Explorer. These datasets generally consist of several files; if one of the files is omitted, the dataset is unusable. To transfer datasets, use the **Manage Data Sources** option from the View's **File** menu. This function can be used to move watersheds and stream networks; however, to ensure compatibility with other AGWA projects, the ODB file must also be moved to the same directory as the watershed. The watershed will not be available in AGWA if this file cannot be located. We recommend moving AGWA datasets with the **AGWA Datasets** option (**AGWA Tools>Manage AGWA Datasets**). This option provides import and export functionality for all AGWA watersheds.

Watershed Delineation and Discretization

Watershed delineation is the first step in the process of using the AGWA tool. To delineate or discretize a watershed, go to **AGWA Tools>Delineate watershed**. This is used for both KINEROS and SWAT. This step requires that you enter the basic data types (described in **File management>Required Files and Datasets**) that are required to compute the watershed boundary and then divide the watershed into a series of planes or subwatersheds.

Watershed information can be viewed at any time with **AGWA Tools>View metadata**. This information was previously (version 1.42c and earlier) stored in the watershed theme's comments.

Basic Concepts

Stream Map

The stream map is a theme containing all streams for a given DEM. It represents all cells in the DEM that receive runoff from a certain number of cells (Figure 6). This number is the threshold value for the map and represents the number of cells rather than an area or percent. The threshold for the stream map can be set to create a more or less complex network. The default value of 2500 is recommended for DEMs with a resolution of 30m; however, this default may be too coarse for higher resolution DEMs.

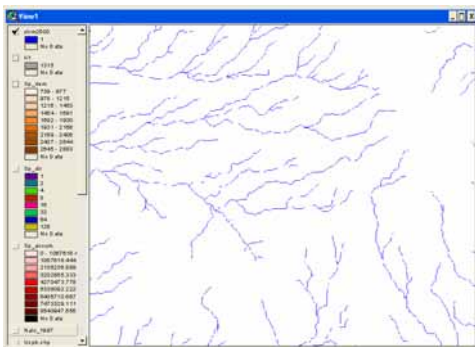


Figure 6. AGWA-generated stream map (threshold = 2500).

The stream map is used as a visual aid when locating outlet locations when creating an individual watershed (with the original AGWA process). It is also used by the area of interest delineation option to define the potential outlet

locations – any outlet must fall along the stream map.

Watershed Outline

A watershed outline is the result of the delineation process. The boundary represents all cells of a given DEM that drain to the specified outlet location. An outline can be used to create watersheds for each model and for different complexities. Figure 7 shows an example of a watershed outline.

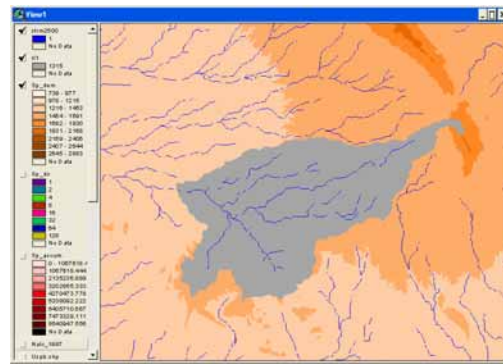


Figure 7. Example of a watershed outline.

Contributing Source Area (CSA)

This value determines the level of geometric complexity in the discretized watershed. It is the threshold at which flow becomes channelized. Lower CSAs produce more watershed elements; higher CSAs, fewer elements (Figure 8). The default value is 2.5%, which produced the best results during preliminary analysis.

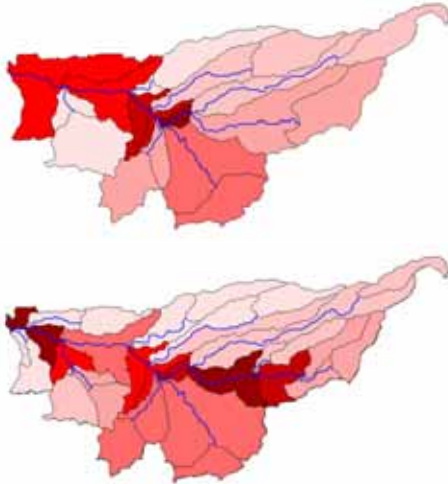


Figure 8. Differences in watershed complexity based on contributing source area. (Top) CSA = 5%; (bottom) CSA = 2.5%.

KINEROS Flow Length

Flow length is length of the path from a source to a channel, as indicated by flow direction. AGWA offers two methods for calculating flow length of lateral planes in KINEROS. The default method assumes a geometric abstraction, where the plane is considered a rectangle with a length equal to the channel length of the associated stream and the width (or flow length) equal to the plane area divided by the channel length. This method must be used to add riparian buffers to a KINEROS watershed.

The second method calculates the mean flow length of the plane element. Flow length is based on the following:

$$L = 2 * \frac{\sum D_i * a_i}{\sum a_i}$$

where L is the flow length, D is the flow length from cell i , and a is the area of cell i (Syed, 1999).

The flow length of the source planes (any plane element ending with 1) is calculated the same for both methods. This calculation considers the source plane as a triangular abstraction, where flow length is 3/2 the distance between the plane centroid and the upstream node of the associated channel. Length is equal to the plane area divided by the flow length. See Figure 9.

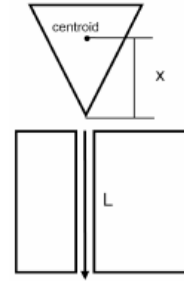


Figure 9. Geometric abstractions of KINEROS plane elements.

The flow length method can be changed in **AGWA Tools>Preferences**.

Hydraulic Geometry Relationships

These relationships refer to bankfull hydraulic geometry relationships and they define the bankfull channel width and depth based on watershed size. Bankfull relationships are useful in that they define channel topography with minimal input and effort by the user; however, there are some drawbacks. The relationships are designed to be applied to very specific physiographic regions and outside of these regions the performance of the relationships in accurately depicting the channel geometries severely declines. Also, deriving relationships for specific regions is very labor intensive, requiring field work and analysis. At this time, only two relationships are defined: Walnut Gulch Experimental Watershed in southeastern Arizona (Miller, 1995) and the Coastal Plain of North Carolina (Sweet and Geratz, 2003). These relationships are provided in the HGR.dbf table as part of the AGWA *datafiles* download. See **Advanced Options>Hydraulic Geometry** for more information.

Watershed and Stream parameters

KINEROS Watershed

WS# (WS_): watershed number

Area: the area of the plane element in internal map units

Slope: the zonal mean slope of the plane element in percent rise

X Centroid: the X coordinate of the plane element's centroid

Y Centroid: the Y coordinate of the plane element's centroid

Width: the flow length of the plane element, based on a geometric abstraction or the mean flow length to the channel element

Length: the length of the plane element, parallel to the channel

KINEROS Stream

Stream# (Stream_): stream number
Cont_chan: contributing element to the given stream (WS# or Stream#)
Length: length of the channel element (in map units)
Order: stream order of the channel element (1 = first order, 99 = higher order)
Slope: channel slope derived from elevation of end nodes (percent rise)
Down_width: downstream width of channel element (map units)
Up_width: upstream width of channel elements (map units)
Down_depth: downstream depth of channel element (map units)
Up_depth: upstream depth of channel element (map units)
Man: Manning roughness coefficient (0-1)
SS1: bank slope side
SS2: bank slope side
Wool: indicates use of wetted perimeter function
CV: coefficient of variation of Ksat
Ksat: saturated hydraulic conductivity (mm/hr)
G: mean capillary drive (mm)
Dist: pore size distribution index
Por: porosity (cm³/cm³)
Rock: volumetric rock fraction
Pct_clay: fractional clay content (0-1)
Pct_silt: fractional silt content (0-1)
Pct_sand: fractional sand content (0-1)
SP: rainsplash coefficient
COH: soil cohesion coefficient
Sequence: integer values indicating channel sequence
Area: upland and lateral areas contributing directly to the channel element (m²)
Cum_area: sum of all upland and lateral elements contributing to the channel (m²)

SWAT Watershed

WS# (WS_): watershed number
Area: area of the subwatershed (map units)
Slope: zonal mean slope of the subwatershed (percent rise)
Max_FlwLength: maximum flow length of the subwatershed (map units)

SWAT Stream

Stream# (Stream_): stream number
Cont_chan: contributing element of the channel element (WS# or Stream#)
Length: length of the channel element (map units)
Order: stream order of the channel (1 = first order; 99 = higher orders)

Slope: channel slope derived from elevation of end nodes (percent rise)
Sequence: integer values indicating channel sequence
Area: upland area contributing directly to the channel (map units)
Cum_area: sum of all areas contributing directly to the channel
Swat_id: integer values for SWAT routing
Storage_Loc: storage location number used in SWAT routing

Watershed Delineation

Several options are available for watershed delineation and discretization with AGWA. These options include:

- Create a new watershed
- Create a nested watershed
- Create a watershed group
 - Multiple Outlet Locations
 - Area of Interest Delineation
- Edit a watershed group
 - Append watersheds
 - Extract watersheds
 - Remove watersheds
- Use existing watershed delineation(s)
- Select subwatersheds from a SWAT watershed
- Apply channel buffers to a KINEROS watershed

To access these options, select **AGWA Tools>Delineate watershed**. In the Watershed Options dialog (figure 10), select the option that best suits your needs and click **Continue**. To use an existing watershed outline or create multiple watersheds, also select one of the two available choices. The relevant dialog is opened based on your selection.

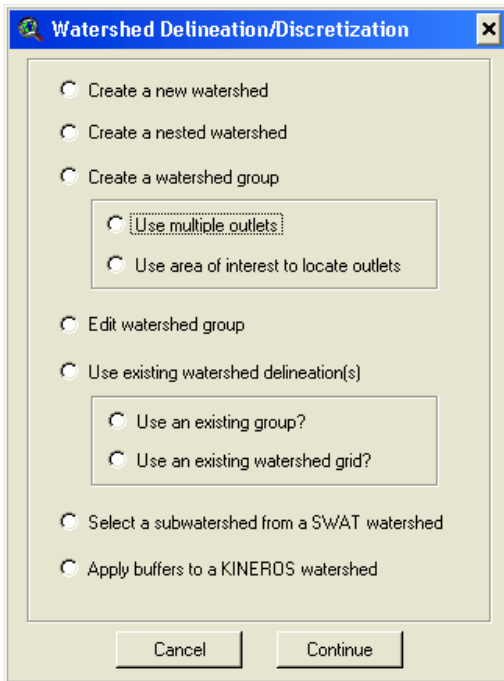


Figure 10. Watershed Delineation and Discretization Options dialog.

Create a new watershed

This option generates a new watershed from a user-specified outlet and is divided into two steps – watershed delineation and watershed discretization. Before proceeding to the delineation process, the user must identify the raster surfaces to be utilized. These surfaces include a digital elevation model (DEM), a flow direction grid (FDG) and a flow accumulation grid (FACG). An additional surface, a stream map, is generated following the selection of these inputs to facilitate outlet location. The stream map represents all streams for a specific DEM. In previous versions of AGWA (1.4X and earlier), the threshold for these streams was set to a default of 2500, where all cells receiving runoff from at least 2500 cells are identified as streams. AGWA 1.5 allows users to adjust this threshold as the default threshold may not produce detailed enough networks for high-resolution DEMs. Users can also select an existing stream map to use during outlet identification. See Figure 11.

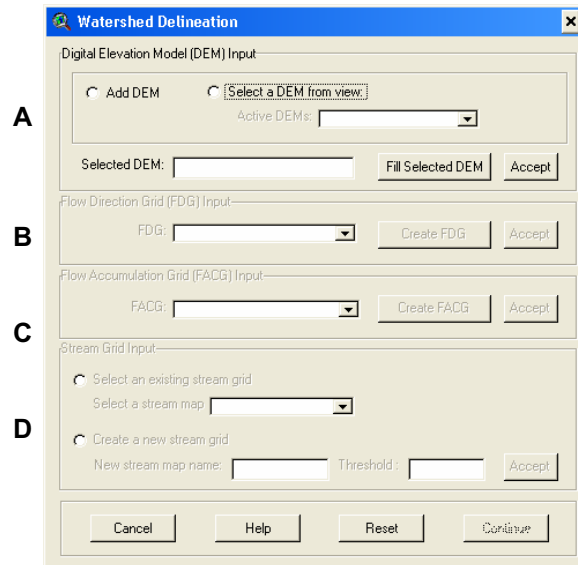


Figure 11. Watershed Delineation dialog. A) DEM Selection panel; B) Flow Direction Creation and Selection Panel; C) Flow Accumulation Creation and Selection panel; D) Stream Map Creation and Selection panel.

First, select the DEM in the DEM Selection panel. If you have not already added a DEM to the view, you are given the option to do so here; otherwise, select the DEM from the combobox. Once a DEM is selected (it must be actively selected from the combobox), you are given the option of filling sinks with the **Fill Selected DEM** button. Sinks are isolated depressions in the elevation surface that can cause flow routing problems, and are common in USGS DEMs that have not been corrected. Click **Accept** to proceed.

Then, select a flow direction (FDG) grid in the Flow Direction Creation and Selection panel. If an FDG for the selected DEM has not already been generated and added to the view, you must click the **Create FDG** button. Otherwise, select an FDG from the combobox (new FDG grids are added to the combobox upon successful generation). Click **Accept** to proceed.

Select a flow accumulation (FACG) grid in the Flow Accumulation Creation and Selection panel. If an FACG for the DEM has not already been generated and added to the view, you must click the **Create FACG** button. Otherwise, select an FACG from the combobox (new FACG grids are added to the combobox upon successful generation). Click **Accept** to proceed.

Finally, select a stream grid in the Stream Map Creation and Selection panel. If you wish to use an existing stream map, select the **Select an existing stream grid** radio button. Select the stream map from the combobox and click **Accept** to proceed. If you wish to generate a new stream map, select the radio button for **Create a new stream grid**. The default value is set to 2500 cells, which is appropriate for 30m DEMs. Enter a new name for the stream map (8 character limit) and enter a threshold. Threshold values are based on the number of cells contributing runoff to a given cell. Click **Accept** to proceed.

Once all of the selections have been made, click **Continue**.

AGWA then directs you to the Watershed Outline dialog (figure 12). This dialog allows you to select a point location for the watershed outlet. (NOTE: to use multiple outlets, return to the Watershed Options dialog and select **Create a watershed group>Multiple outlet locations**.) Enter a name for the watershed outline to be created in the Watershed Outline Name panel and select a method for identifying the outlet in the Outlet Type Selection panel. (C) User-defined Outlet panel; D) Point Location Selection panel; E) XY Coordinate Entry panel.

Select a point from an existing theme – select a point theme in the view. Using the selection tool, select a point (User-defined Outlet panel).

Interactively identify a point – using the click tool, click a location on the DEM to use as an outlet. Try to click near a stream (on the stream map). The location may be adjusted based on the point of highest flow accumulation within the specified radius (Point Location Selection panel).

Provide XY coordinates – type in an X and Y coordinate pair to serve as the outlet. These values must be in the same coordinate system as the input grids and must intersect the selected DEM. It is the user's responsibility to provide appropriate XY coordinates. Click **Go** to continue (XY Coordinate Entry panel).

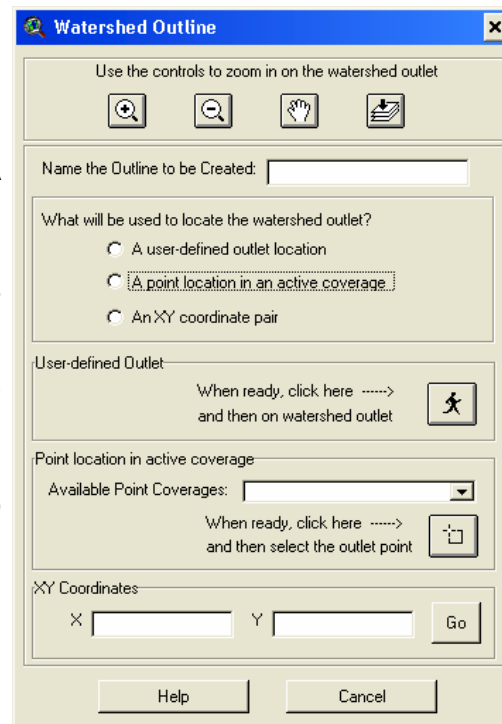


Figure 12. Watershed Outline dialog. A) Watershed Outline Name panel; B) Outlet Type Selection panel; C) User-defined Outlet panel; D) Point Location Selection panel; E) XY Coordinate Entry panel.

Once you've located the outlet, AGWA will generate a watershed outline. AGWA determines the outlet based on the intersection of the specified point and the stream map and the available outlet locations within a given radius. Outlet locations that do not intersect the stream map may be moved to a suitable location on the stream map before watershed discretization occurs. The new outlets are generally at the lowest point within a radius of 2.5 times the DEM cellsize of the specified outlet. Outlets that intersect the stream map will not be adjusted. If, at this time, the outline looks incorrect, you can cancel the process. If the outline is acceptable, AGWA proceeds to the Watershed Discretization dialog.

Create a nested watershed

A nested watershed contains regions of different complexity. These regions are identified by locating additional outlets upstream of the main watershed outlet and specifying different CSA values for each region. AGWA automatically identifies the main watershed outlet and any upstream breakpoints; the user only needs to provide a point theme containing all of the points with each point identified with an integer ID in the

attribute table. Figure 13 shows an example of a nested watershed.

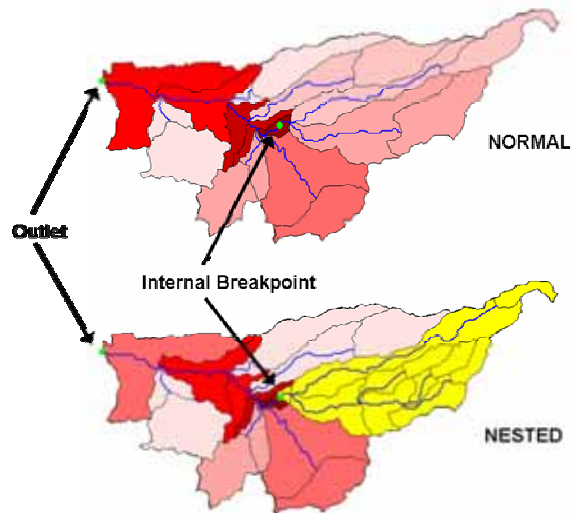


Figure 13. A nested watershed. The highlighted planes reflect the increased complexity of the region upstream of the internal breakpoint.

The process for creating these watersheds begins in the same way as the process for creating a new watershed, with selecting the raster surfaces from the Watershed Delineation dialog. Once **Continue** is clicked, however, the user is directed to the Nested Watershed Delineation dialog to select the watershed outlet and internal breakpoints to be used during discretization.

In the Nested Watershed Delineation dialog (Figure 14), select the point theme containing the outlet locations in the Outlet Selection panel. This theme does not have to contain any attributes to characterize an outlet as upstream to another – AGWA automatically identifies and processes those points. The point theme must contain an ID field, containing integer identifiers for each point. Select both the main outlet location and any internal (upstream) points to be used during delineation and discretization. Nested watersheds cannot be part of a watershed group; AGWA will terminate the processing if another source outlet is identified. To correctly generate the nested watershed, AGWA must delineate a watershed outline for each outlet. To retain these outlines for use later, check the **Save datasets** option and enter a name for the watershed outlines in the Save Dataset panel. This shapefile can be used to create another nested watershed or a watershed group of overlapping watersheds. Click **Continue**. If the delineation process is successful, AGWA

opens the Multiple Watershed Discretization dialog. If the watersheds do not look correct, the process can be halted at this time.

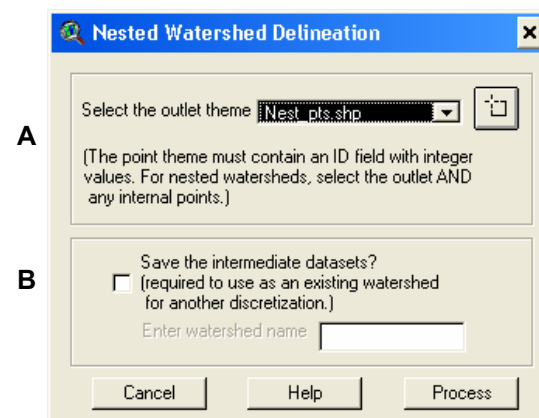


Figure 14. Nested Watershed Delineation dialog. A) Outlet Selection panel; B) Save Dataset panel.

Create a Watershed Group

A watershed group is a collection of AGWA watersheds, for either KINEROS or SWAT, that are discretized, parameterized and simulated as a unit. Each watershed in the group is numbered and parameterized as a normal AGWA watershed but is identified by a GROUP number to separate each watershed and by a GROUPID number to uniquely identify each element.

Multiple outlet locations

This option allows you to select two or more outlets from an existing point theme. First, select the point theme containing the outlets from the combobox on the Outlet Selection panel (Figure 15). Use the selection tool to select the points to use. When selecting multiple points, it may be necessary to click on the selection tool more than once, especially if using the Shift key. To save the watershed outlines to reuse at a later time, check the **Save datasets** option and enter a name for the watershed outlines in the Save Dataset panel. Click **Continue**. If the delineation process is successful, AGWA opens the Multiple Watershed Discretization dialog. If the watersheds do not look correct, the process can be halted at this time.

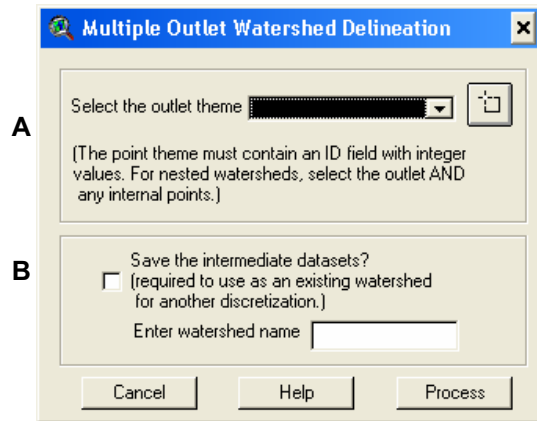


Figure 15. Multiple Outlet Watershed Delineation dialog. A) Outlet Selection panel; B) Save Dataset panel.

Area of Interest outlet locations

This option dynamically locates outlets based on an area of interest boundary so that the boundary is completely covered by watersheds. This can be used to delineate watersheds for parks, ranches, urban developments, islands, etc. (Scott, 2005).

To use this option, you must create a polygon shapefile containing at least one boundary region. From the Area of Interest Delineation dialog (Figure 16), select the boundary theme in the Boundary Layer Selection panel. If the shapefile contains more than one polygon, use the selection tool to select the boundary of interest. Only one boundary can be used at a time. Next, define the analysis extent in the Analysis Extent Definition panel. This polygon limits the area within which AGWA will search for outlets. This is used both to reduce the potential size of the final watersheds as well as to exclude any regions that you do not wish to use during the process. See Figure 17 for an example of the boundary and analysis extent polygons.

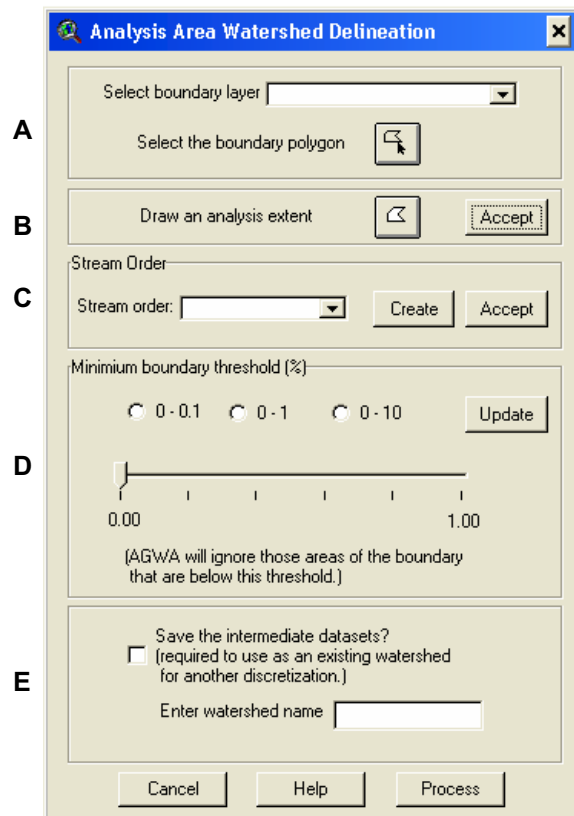


Figure 16. Area of Interest Watershed Delineation dialog. A) Boundary Layer Selection panel; B) Analysis Extent definition panel; C) Stream Order grid Creation and Selection panel; D) Minimum Boundary Threshold Selection panel; E) Save Dataset panel.

AGWA uses stream order to assist in the outlet location process. The stream order grid can be reused for other boundaries, so, in a method similar to that of the flow direction and flow accumulation grids, the stream order grid can be selected from existing grids in the view or created from the selected flow direction and flow accumulation grids in the Stream Order grid Creation and Selection panel.

In some instances, the watersheds created to completely cover the watershed may not contribute significantly to the water balance of the area of interest. These watersheds may occupy only a small fraction of the boundary; the inclusion of these watersheds requires additional processing time that may not be beneficial. To exclude small watersheds, set the minimum area slider to a value greater than zero on the Minimum Boundary Threshold Selection panel. Setting this slider to zero will include all watersheds that intersect the

area of interest and have a valid outlet within the analysis extent. Any other value will ignore those watersheds that occupy less than the minimum size. First, select a range of percents, 0-0.1, 0-1, 0-10 (all values in percent), and click **Update**. Drag the slider to the desired percent.

To reuse the watershed outlines, check the **Save datasets** checkbox and enter a name for the outlines in the Save Dataset panel. Click **Continue**.

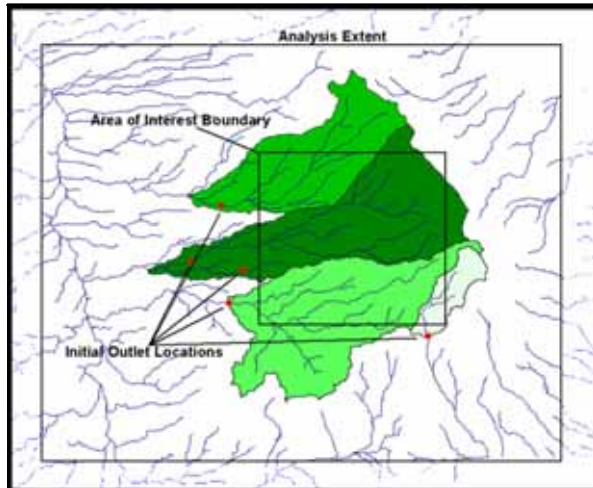


Figure 17. Area of Interest Watershed Delineation results with a minimum area threshold of 0.2%. Several regions of the boundary were excluded from the delineation process due to this threshold. Note the placement of the original outlet locations and the final outlet locations.

The process begins by locating potential outlets at the intersection of the boundary polygon and the stream network. Outlets are rejected if the stream flows into the boundary – these streams will be captured by another outlet, or if another outlet is identified downstream. Outlets are located at 75% of the distance from the start of the stream segment; if this falls within the boundary and another stream segment is not available downstream, the process fails. To avoid this, adjust the boundary.

These initial outlets are adjusted based on the stream network. The next downstream segment is tested against the current outlet location – if it captures more streams that flow from the boundary, the current outlet is replaced and the next potential outlet is tested. The goal of this step is to locate outlets so that all of the streams within the boundary are accounted for with the fewest

number of outlets possible given the constraints of the boundary and analysis extent.

Once the outlets have been located, watersheds are delineated for each point. The union of these watersheds is compared against the boundary polygon. If gaps in the coverage exist, further processing is necessary. This processing involves moving outlets downstream one segment and testing that delineation, unioned with the existing delineations, against the boundary. If a stream segment is not found downstream or AGWA determines that the next downstream segment is a much larger tributary, a new outlet is located along the flow path from the midpoint between the two watersheds. If an area is smaller than the minimum threshold, the gap is ignored.

If the watershed delineation looks correct, proceed to the Multiple Watershed Discretization dialog.

Edit a watershed group

Individual watersheds can be appended to an existing group, removed from a group or extracted from the group to be processed separately. Extracting a watershed does not affect the watershed group; it simply copies the selected watershed to a new shapefile to be modeled independently from the group.

Parameterization information is discarded when a watershed is extracted or added to a group. The modified group or extracted watershed must be reparameterized before performing any simulations.

Append watersheds

To append a watershed, select the watershed group to be modified in the Group Selection panel (Figure 18). Only individual watersheds discretized for the same model and, if KINEROS, the same flow length method as the group can be appended. Select one or more individual watersheds to append from the Available Watershed List. Click

the button to add the selected watershed to the Selected Watershed List. To remove a watershed from the Selected Watershed List,

select the watershed and click . The removed watershed will be added back in the available watershed list. Click **Continue** when satisfied with the selections. The selected watersheds will be added to the group and the metadata updated to reflect the modification. This option can also be

used to create a watershed group from existing watersheds.

If appending a watershed to a KINEROS group or creating a new KINEROS group, the flow length method utilized during watershed discretization must be identical for all selected watersheds. This value can be checked with **AGWA Tools>View Metadata** under the “Flow length” parameter.

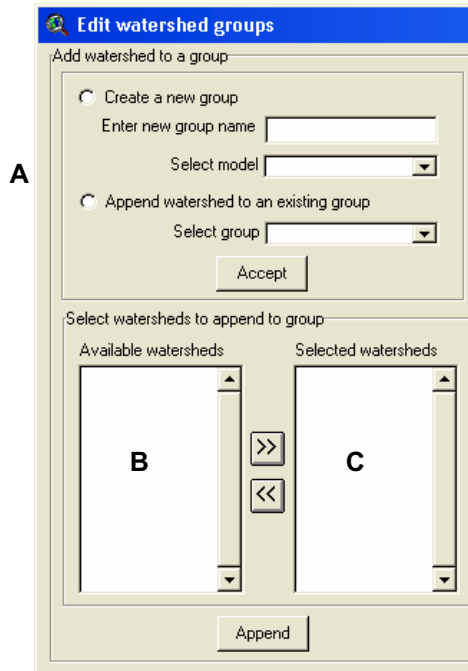


Figure 18. Edit Watershed Groups dialog, Append Watershed Panel. A) Group Selection panel; B) Available Watershed List; C) Selected Watershed List.

Remove watersheds

To remove a watershed, select the watershed group (Figure 19). Select the group number and click **Remove**. The selected watershed will be deleted from the group's watershed and stream themes and the metadata updated. This option cannot be reversed.

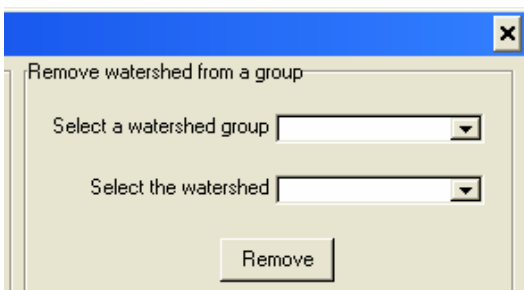


Figure 19. Edit Watershed Groups dialog, Remove Watershed panel.

Extract watersheds

To extract a watershed, select the watershed group (Figure 20). Select a group number from the combobox. Enter a name for the new watershed. Click **Extract**. The selected watershed will be copied into a new watershed; the associated stream network will also be copied. This watershed can then be simulated independently of the watershed group. It does not modify the original watershed group.

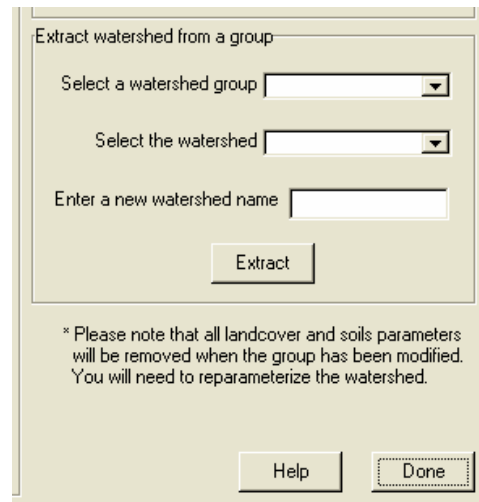


Figure 20. Edit Watershed Groups dialog, Extract Watershed panel.

Use existing watershed delineation(s)

Watersheds can be re-discretized using an existing watershed outline or, in the case of a group, a set of watershed outlines. A watershed outline created in AGWA 1.5 has metadata, in the form of an ODB file, associated with it. This metadata contains the name of the DEM, flow direction, flow accumulation and stream grids used to create the file. These inputs should be located in the view but do not need to be selected again. The presence of this file is required to reuse an outline.

First, select the type of outline you wish to use. **Use an existing watershed grid** is identical to the **Use existing** option from previous versions of AGWA. Click **Continue** to proceed to the Watershed Discretization dialog. When asked, select the watershed grid you wish to use. AGWA only considers watershed grids created with the provided delineator as valid watershed delineations.

Use an existing watershed group allows you to reuse the delineated watersheds from a watershed group or nested watershed.

Delineations for a nested watershed can be used to discretize a watershed group or a nested watershed. To rediscretize a nested watershed, click **Yes** when queried; to discretize a watershed group from a nested watershed delineation, click **No**. This selection will not affect later discretizations. Click **Continue** to proceed to the Multiple Watershed Discretization dialog.

Select a subwatershed from a SWAT watershed

This option allows you to select a SWAT subwatershed to act as a watershed outline. In many cases, SWAT watersheds are used to identify problem areas on a watershed that can then be simulated at a more detailed level with KINEROS. This option is best suited to larger SWAT subwatersheds.

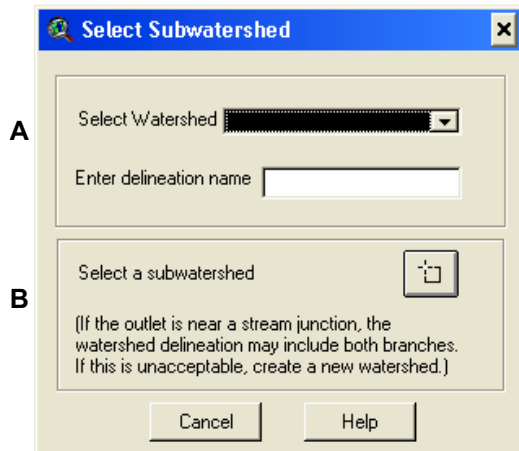


Figure 21. Select a SWAT Subwatershed dialog. A) Watershed Selection and Name panel; B) SWAT Subwatershed Selection panel.

To create a new watershed from a SWAT watershed, you must first create the SWAT watershed. Select the watershed from the combobox on the Watershed Selection and Name panel (Figure 21). Enter a name for the watershed outline. As before, this outline can be reused to create watersheds of different complexity. Using the select tool on the Subwatershed Selection panel, select one subwatershed from the watershed. The tool automatically extracts the appropriate outlet and creates a new watershed outline.

Once the outline is created, AGWA proceeds to the watershed discretization dialog. Select the watershed options and contributing source area and click **Continue**. See Figure 22 for an example.

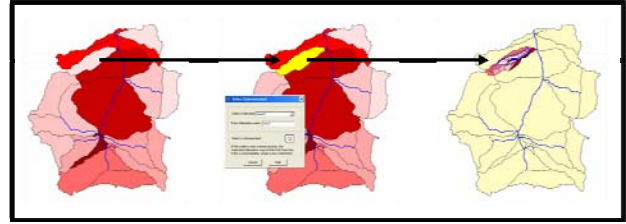


Figure 22. Creating a watershed from a SWAT subwatershed. (left) The original SWAT watershed; (center) the selected SWAT subwatershed; and (right) the new KINEROS watershed.

In some cases, the selected SWAT subwatershed does not produce a valid watershed configuration. Potential issues include failure to identify the outlet of the stream network (i.e. the network terminates at the junction of two channels), the inclusion of very small plane or channel elements that interfere with numbering or routing algorithms, and other numbering errors. These errors, particularly the outlet identification error, cannot be resolved by adjusting the CSA.

Apply channel buffers to a KINEROS watershed

This option allows you to install channel buffer elements on an existing KINEROS watershed. Buffers can be added to any channel segment and can be one of three types:

- a buffer extending the length of the entire channel;
- a buffer extending from one endpoint of the channel to an internal breakpoint;
- and, a buffer falling between two internal breakpoints.

The endpoints of the buffer element are identified by the user, as is the buffer width. Both lateral elements can be buffered; however, both sides must share the same endpoints (Scott, 2005).

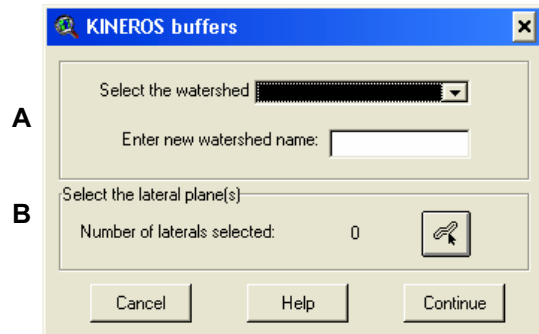


Figure 23. Apply Riparian Buffers to a KINEROS Watershed dialog. A) Watershed Selection and Name panel; B) Lateral Element Selection panel.

Select the watershed to be buffered on the Watershed Selection and Name panel (Figure 23). Using the selection tool on the Lateral Element Selection panel, select one or more plane elements to buffer. Any plane that is not a zero order upland can be selected. Click **Continue** to proceed to the buffer geometry definition. The selection process is shown in Figure 24.

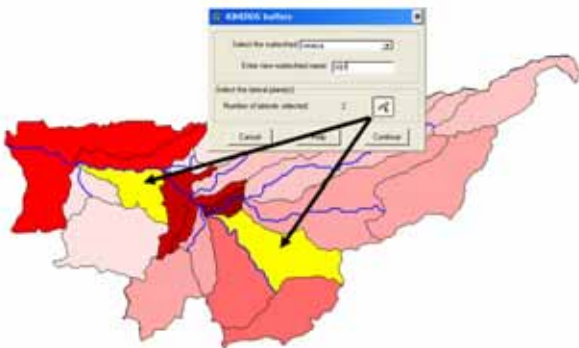


Figure 24. Lateral element selection process. The buffer is defined for the channel associated for the selected element and will fall to the left or right of the channel depending on which lateral element is selected.

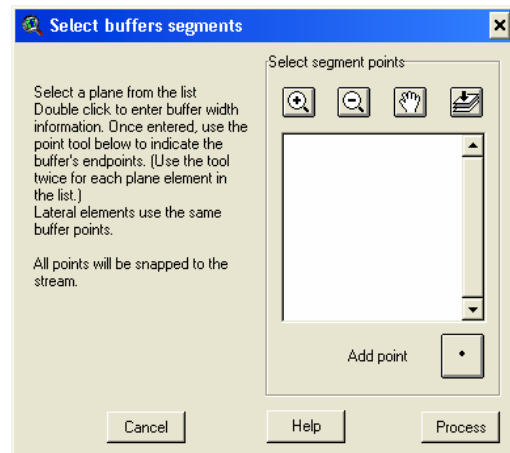


Figure 25. Buffer Geometry Specification dialog.

Each selected plane element is listed in the table (Figure 25). Select a plane number to highlight the plane in the view. Double-click to enter a buffer width (Figure 26). The minimum buffer width is determined by the DEM resolution. If both lateral elements are selected, AGWA will ask twice for the buffer width, once for each lateral. These values do not have to be the same. The width will be added to the table.



Figure 26. Buffer width specification. The width is set for the selected lateral element

After setting the width, use the point tool to add the first endpoint. Clicking near the channel endpoint will set the buffer endpoint to the channel endpoint. Use the click tool again to set the other point. To buffer the entire segment, locate both points near the channel endpoints. Endpoints only have to be set once for each lateral pair. See Figure 27. Buffer endpoints do not have to fall directly on the stream; however, care should be taken to place the locations as close as possible. Again, endpoints within 10% of the length of the channel will be moved to the channel endpoint. Repeat for each selected plane (unless its lateral has already been set). Click **Continue** to create

the buffered watershed. Figure 28 shows the results of the buffering process.

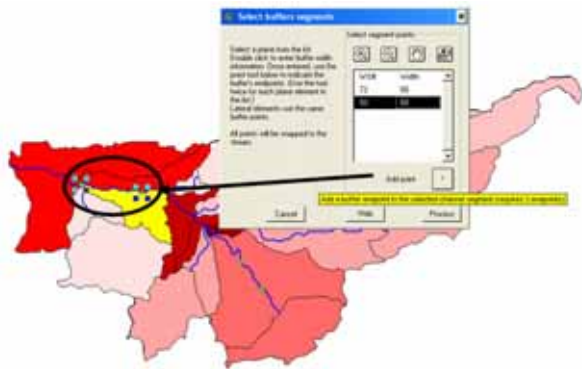


Figure 27. Buffer length specification. Using the point tool, click along the channel of the highlighted lateral element to place a buffer endpoint. This step must be performed twice for each lateral plane to be buffered.

not affect the watershed or stream numbering other than the assignment of a watershed number to the buffer element. If the plane must be rediscritized, the most upstream elements retain the original plane and channel numbers while the new elements are numbered based on the next available value (Figure 29). Buffers are numbered according to their upland and stream elements. If the upland plane number is odd, the buffer number ends in 5; if even, it ends in 6. These values are reserved for buffer elements. Plane and channel parameters are recalculated following successful buffer creation.

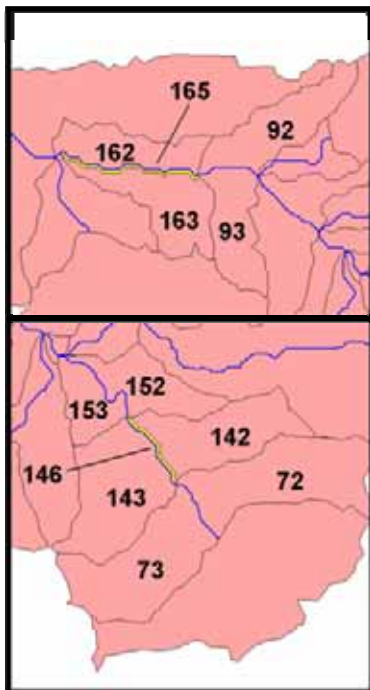


Figure 28. The new buffer elements. Note the increased complexity for the affected lateral planes.

To create the buffer, AGWA performs one of two processes: for whole channel buffers, AGWA simply splits the lateral element to achieve the desired buffer width; for any buffer with one or more internal breakpoint, AGWA must rediscritize that plane element and its lateral so that the proper routing can occur. Whole channel length buffers do

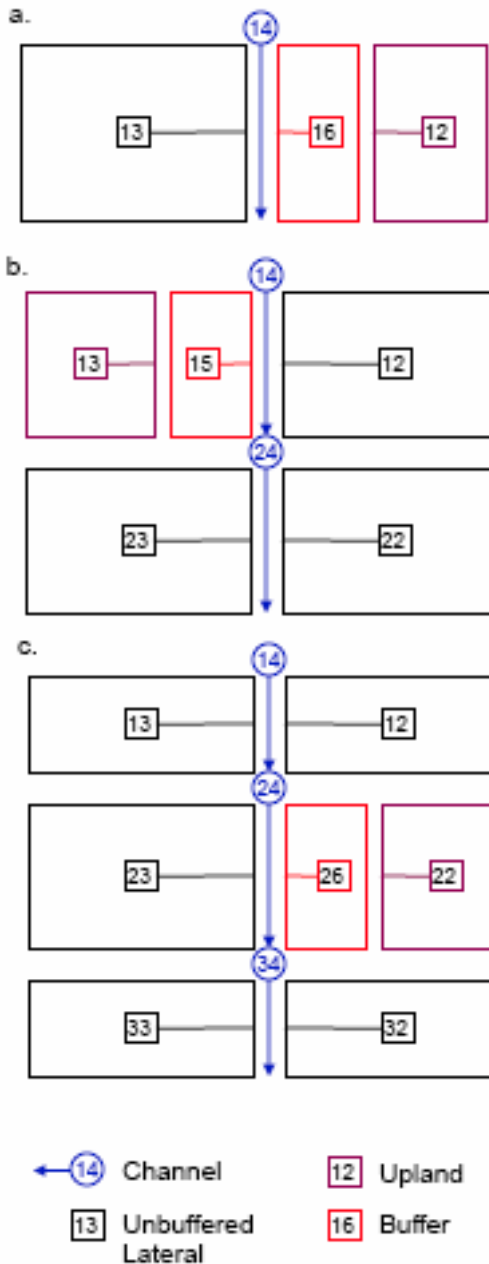


Figure 29. Buffer numbering schematic for lateral watersheds 12 and 13. (a) Entire reach buffer (buffer = 16); (b) Buffer a reach segment terminating at a reach endpoint (buffer = 15); and (c) Buffer an interior reach segment (buffer = 26).

In some cases, AGWA cannot create buffers at the specified locations. Failures can be due to ArcView issues, including errors converting the new watershed grid or errors generating the watershed grid. Should this occur, it is unlikely that adjusting the buffer endpoints for that channel will resolve the issue; however, whole channel length buffers can always be created for those plane

elements. Other errors generally involve splitting or numbering errors. These errors may be resolved by relocating the endpoints. Again, whole channel length buffers can always be generated. Analysis of these errors indicates that, in general, buffer creation fails approximately 8% of the time, with 50% of those errors related to ArcView issues (Scott, 2005).

Flow length must be adjusted to reflect the new configuration of the selected plane element. Adjustments are based on the proportion of the new element to the original plane and assumes a rectangular abstraction of the planes (Woolhiser et al., 1990). For planes not flowing directly onto a buffer, the new width is

$$W = \frac{(A * \%P_n)}{FL_{orig}}$$

where W is the width, A is the area, $\%P_n$ the percent of the original plane area occupied by the new plane, and FL_{orig} is the original flow length. The new flow length is

$$FL = FL_{orig}$$

For upland planes (flowing directly onto a buffer element), the new width is

$$W = \frac{A * (\%P_{up} + \%B)}{FL_{orig}}$$

where $\%P_{up}$ is the percent of the original plane area occupied by the upland plane and $\%B$ is the percent of the original plane occupied by the buffer element. The flow length for upland planes

$$FL = \frac{A * \%P_{up}}{W}$$

The buffer flow length is always set to the specified buffer width.

Watershed Discretization

Individual watersheds

Discretization options for individual watersheds can be found on the Watershed Discretization dialog (Figure 30). The user can choose from a number of options to modify the internal watershed boundaries. These options incorporate different

kinds of internal breakpoints to split planes and channels in specific locations. Available options include internal gages, ponds or reservoirs, non-releasing ponds and no breakpoints. If the option involves using internal breakpoints, AGWA will open the Point Selection dialog (see **Watershed Discretization>Internal Breakpoints: Gages, Ponds and Reservoirs** for more information).



Figure 30. Individual Watershed Discretization dialog. A) Watershed Name panel; B) Model Selection panel; C) Contributing Source Area Selection panel; D) Internal Breakpoint Selection panel; E) CSA Enforcement Selection panel.

Enter a watershed name in the Watershed Name panel. This name is limited to 4 characters in length. Two new shapefiles will be created for the watershed – a stream network named “s” + the entered name and a discretized watershed named “w” + the entered name. Click **Accept** to continue.

Select a model for the discretized watershed in the Model Selection panel. KINEROS and SWAT require different parameters and routing conditions, so watersheds discretized for one model cannot be used for the other.

Enter a contributing source area value as either a contributing area (in acres or hectares, depending on the selected units) or as a percent of the watershed in the Contributing Source Area Selection panel. Changes to one value will automatically update the other. Click **Accept**.

Select an internal breakpoint option from the Internal Breakpoint Selection panel. To not use internal breakpoints, select **None**. To discretize the watershed with internal gages, select **Use internal gages**. To use either KINEROS ponds or SWAT

reservoirs, select **Use ponds (releasing)**. To use non-releasing ponds to exclude regions of the watershed, select **Use ponds (non-releasing)**. See **Watershed Discretization>Internal Breakpoints: Gages, Ponds, and Reservoirs** for more information. Users can also choose to enforce the specified CSA for lateral elements in the watershed using the checkbox on the CSA Enforcement Selection panel. See **Watershed Discretization>CSA Enforcement** for more information. Click **Continue** to discretize the watershed.

CSA Enforcement

In some instances, ArcView may discretize subwatersheds that exceed the specified CSA value. The Enforce CSA option allows users to automatically place internal breakpoints to split any lateral elements that exceed the specified CSA (this option only affects planes with an area greater than 1.85 the specified CSA). When this occurs, AGWA will determine new breakpoints within that element based on the flow accumulation and the specified CSA. Processing begins at the upstream node of the channel and proceeds downstream. No breakpoints are added within 10% of the channel length of the downstream node. The breakpoints cannot be modified by the user during processing. Figure 31 compares a SWAT watershed before and after discretization with the CSA Enforcement option.

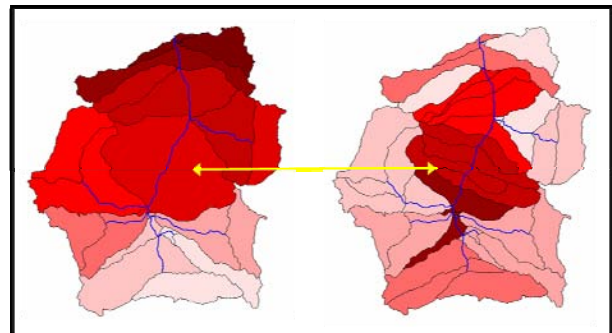


Figure 31. Results of CSA enforcement. (left) SWAT watershed discretized with 3.2% CSA; (right) SWAT watershed discretized with 3.2% CSA and with CSA Enforcement. Note the increased complexity in the center of the watershed.

Multiple or nested watersheds

Watershed discretization for watershed groups or nested watersheds is similar to that for individual watersheds. It does not, however, support internal breakpoints for either watershed type. Please note that due to the delineation process, the boundaries

for both the delineation and the internal plane elements will be slightly different from those generated if using the same outlet for an individual watershed. Watershed parameters will also be slightly different. AGWA provides a tool to extract an individual watershed from a group should further analysis of an individual watershed be warranted.

The discretization process is the same for watershed groups created with area of interest boundaries or with multiple outlet locations. AGWA displays each watershed in the listbox (Contributing Source Area Entry panel) by a unique identifier in the Multiple Watershed Discretization dialog (Figure 32). To locate a watershed in the view, select a record in the listbox. The selected watershed will be highlighted. To set the CSA for that watershed, double-click in either the **Contributing Area** column or the **% of Watershed** column to enter a value. CSA can be set for either a percent of the watershed or a contributing area (with area in the selected units). The other value is automatically calculated. Because the watershed delineations can vary greatly in size, a CSA must be entered for each watershed.

The **Nested** column contains information regarding the type of outlet used to delineate each watershed in the group. If Nested is FALSE, the watershed used a main outlet and does not represent an upstream region of another outlet. If Nested is TRUE, the selected watershed represents an upstream region of a main outlet. This parameter cannot be modified.

Select a model for all of the watersheds in the group from the Model Selection panel.

Finally, enter a name for the watershed group on the Watershed Name panel. Click **Continue** to discretize the group.

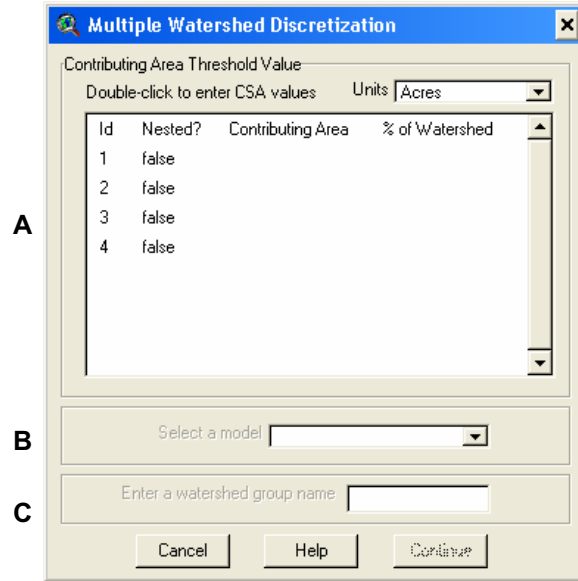


Figure 32. Multiple Watershed Discretization dialog. A) Contributing Source Area Entry panel; B) Model Selection panel; C) Watershed Name panel.

Temporary watershed and stream network shapefiles are created for each watershed in the group. These are parameterized separately and merged into one watershed network and one stream network shapefile once the parameterization has been completed successfully for all watersheds in the group. To avoid any attribution errors in other AGWA processes, the group contains two additional identifiers for both watershed and stream – a GROUP number that identifies which group the element belongs to, and a GROUPID number that serves as a unique ID. The GROUP number is also used to identify the watershed metadata for each watershed in the group. The GROUPID is used to associate landcover and soils tables as well as results tables to the watershed and stream network. Figure 33 shows an example of a discretized watershed group.

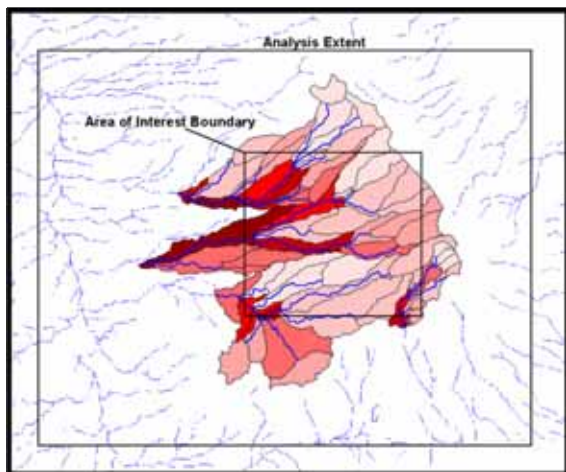


Figure 33. Discretized watersheds for a watershed group.

Nested watersheds not part of a group are numbered and parameterized as an individual watershed. These datasets will not contain GROUP or GROUPID values.

Internal Breakpoints: Gages, Ponds, and Reservoirs

AGWA provides several options for defining internal breakpoints in a watershed. These options include internal gages, KINEROS ponds, SWAT reservoirs and non-releasing ponds. Internal gages are used to split planes at specific locations to compare model estimates with observed discharge values. KINEROS ponds and SWAT reservoirs are water storage elements. Non-releasing ponds indicate regions of the watershed that will be excluded from the simulation process.

The selection process for the breakpoints is the same for each option. In the Point Selection dialog (Figure 34), select the point theme from the Point Theme Selection panel. Use the selection tool on the Point Selection panel to select the points to be used. If the selected option is KINEROS ponds, SWAT reservoirs, or non-releasing ponds, select the point theme ID field from the list provided. This value will be used to identify pond locations for data input during later processing steps. Click **OK** to continue.

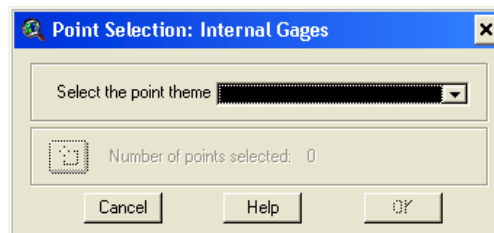


Figure 34. Point Selection dialog. A) Point Theme Selection panel; B) Point Selection panel.

Internal breakpoints increase the potential for error during watershed discretization. To reduce this potential, make sure that the point theme is in the same projection as the input grids and that the points are not in close proximity with each other or stream junctions (ponds or reservoirs close to the junctions are not used to modify the watershed configuration). Adjusting the point location and the CSA may resolve the errors.

Internal Gages

Internal gages are used to split the watershed and stream network at specific locations. This makes it possible to compare measured and estimated runoff at a point or series of points.

Points should be located within 100 meters of the stream network to ensure successful snapping. The points cannot be located within 10% of the channel length of a junction or within 5 cells (based on the DEM resolution) of each other. If AGWA detects points within these tolerances, they will be ignored.

Note that the presence of gages can result in improper watershed configurations, including unsplit KINEROS planes, misnumbered planes and orphaned stream segments. AGWA contains several checks for various errors but the user should inspect the final watershed carefully before proceeding.

KINEROS Ponds

Ponds are created in a manner similar to that of internal gages; however, if a pond is too close to a junction, the proper location is assumed to be the junction and the correct routing should occur.

Additional parameters are required when simulating ponds in KINEROS. AGWA will prompt you to locate this file during parameter file generation. These parameters should be contained in a comma-delimited text file that describes the rating curve for the pond. The file may contain

parameters for more than one pond, and must have the following formatting:

```
ID, STOR, NUM
Volume, Discharge, Surface Area
...
...
Volume, Discharge, Surface Area
ID, STOR, NUM
Volume, Discharge, Surface Area
...
...
Volume, Discharge, Surface Area
```

Example:

```
1, 0, 4 <-----ID, STOR, NUM
0.00, 0.00, 24959.11
3833.24, 0.49, 25345.83
...
...
28090.92, 1.31, 277728.55
2, 0, 8 <-----ID, STOR, NUM
0.00, 0.00, 24959.11
3833.24, 0.49, 25345.83
...
...
28090.92, 1.31, 27728.55
```

with NUM number of lines per each pond ID containing volume in m³, pond outflow discharge in m³/s, and pond surface area at each volume in m². STOR is the initial pond storage volume in m³. Each ID from the pond point theme used during the delineation process must have a set of entries in the text file. The formatting requirements are very specific, so the user should make an effort to follow the above format as closely as possible.

Note that it is possible for pond elements to be overwhelmed. This occurs when rainfall and runoff entering the pond element exceeds the volume and capacity of the pond element, as specified in the pond input file. This error may be hard to detect, because it may appear that KINEROS runs to completion when, in reality, it failed on the pond element. If AGWA does not regain control after a KINEROS run using ponds or if results are not properly imported, KINEROS failed. To fix this problem, increase the rating table for the pond by adding more values to the pond input text file.

SWAT Reservoirs

A SWAT reservoir is similar to a KINEROS pond in that the reservoir lies on a channel segment. A second water storage element is available in SWAT, ponds, but these are not

supported by AGWA. Ponds are water storage locations within a subwatershed and do not affect watershed discretization. Reservoirs are created in a manner similar to that of internal gages; however, if a reservoir is too close to a junction, the proper location is assumed to be the junction and the correct routing should occur. A channel can only contain one reservoir in AGWA due to the discretization process.

Reservoir input files are defined through the SWAT Reservoir Input dialog (Figure 35). Once the watershed has been successfully discretized AGWA will display the dialog. Locate the main input data file using the **Browse** button on the Input File Selection panel. Click **Accept** to continue.

Select an Outflow Simulation Code from the Outflow Simulation Code Selection panel. Each code requires a specific input format as outlined below. Click **Process** to parameterize the reservoirs.

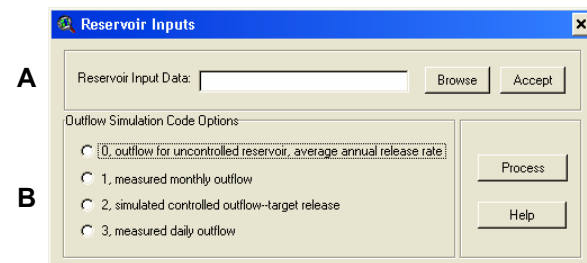


Figure 35. SWAT Reservoir Input dialog. A) Input File Selection panel; B) Outflow Simulation Option Selection panel.

The input files regardless of the Outflow Simulation Code must contain the following values in this order on ONE line:

```
ID, MORES, IYRES, ESA, EVOL, PSA, PVOL,
VOL, SED, NSED, K, FLOWMX1, FLOWMX2,
FLOWMX3, FLOWMX4, FLOWMX5,
FLOWMX6, FLOWMX7, FLOWMX8,
FLOWMX9, FLOWMX10, FLOWMX11,
FLOWMX12, FLWOMN1, FLOWMN2,
FLOWMN3, FLOWMN4, FLOWMN5,
FLOWMN6, FLOWMN7, FLOWMN8,
FLOWMN9, FLOWMN10, FLOWMN11,
FLOWMN12
```

where ID is the point theme identifier; MORES is the month the reservoir became operational; IYRES is the year the reservoir became operational (if either MORES or IYRES is 0, SWAT

Manual for more information regarding required inputs and formats for the reservoir data files.

Non-releasing Ponds

Non-releasing ponds do not allow any discharge from any upstream element to flow past that point. All upstream elements are removed from the watershed. No additional information is required.

Setting the hydraulic geometry relationship

If the default hydraulic geometry has not been set (see **Advanced Options>Hydraulic Geometry**), AGWA will ask the user to select from two options. The first option uses the AGWA default hydraulic geometry relationship for Walnut Gulch; the other allows users to select from a different relationship in the HGR.dbf or define a new relationship. The second option should only be used by those familiar with the watershed to be modeled.

Landcover and Soils Parameterization

Before running KINEROS or SWAT simulations for your watershed, hydrologic parameters must be derived from the landcover and soils data. Each model requires a different set of parameters. Landcover datasets must be in raster format; soil datasets must be in vector format.

KINEROS Parameters

Int: interception depth (mm)
 Cover: fraction of surface covered by intercepting cover – the rainfall intensity is reduced by this fraction until the specified interception depth has been accumulated (0-1)
 Mann_n: Manning roughness coefficient (0-1)
 Pave: fraction of surface covered by erosion pavement (0-1)
 Splash: Rainsplash coefficient (0-1)
 Rock: Volumetric rock fraction, if any. If Ksat is estimated based on textural class, it should be multiplied by (1- rock) to reflect this rock volume.
 Ks: Saturated hydraulic conductivity (mm/hr)
 G: mean capillary drive – a zero value sets the infiltration at a constant value of Ks (mm)
 Por: porosity (cm³/cm³)
 Smax: maximum relative saturation (0-1)
 Cv: coefficient of variation of Ks
 Fract_sand: fractional sand content (0-1)
 Fract_silt: fractional silt content (0-1)
 Fract_clay: fractional clay content (0-1)
 Dist: pore size distribution index. Used for redistribution of soil moisture during unponded intervals
 Coh: Soil cohesion coefficients
 Ks_final: area-weighted Ks value
 Pct_imperv: percent of watershed covered by impervious materials

SWAT Parameters

CN: area-weighted curve number based on soil type and landcover
 Cover: fraction of surface covered by intercepting cover – rainfall intensity is reduced by this fraction until the specified interception depth has been accumulated (0-1)
 HydValue: weighted hydrologic group value used to determine curve number
 Ks: saturated hydraulic conductivity (mm/hr)
 Soil_id: value of the soil ID field (MUID, MUKEY or SNUM) of the dominant soil type

Additional soil parameters are included in the <watershed name>_soil_lut.dbf. This table contains values for each layer in each soil component found in the watershed.

The parameterization process requires the provided kin_lut.dbf table (Figure 36). These parameters were derived from the KINEROS manual (1990) and Rawls et al. (1982). The table is used to obtain the necessary soil parameters not found in the soils databases. Several soil parameters are modified by AGWA to avoid errors or improve estimates.

The textures listed in the table refer to soil textures found in STATSGO and SSURGO soil components (U.S.D.A., 1994; U.S.D.A., 1995). Several additional textures were added to accommodate the FAO soils dataset. The soil parameters include

KS: Saturated hydraulic conductivity (mm/hr)
 G: Net capillary drive (mm)
 Por: porosity (cm³/cm³)
 Smax: Maximum relative soil saturation (0-1)
 Cv: Coefficient of variation of KS
 Sand: Fractional sand content (0-1)
 Silt: Fractional silt content (0-1)
 Clay: Fractional clay content (0-1)
 Dist: Pore size distribution index
 Kff: soil erodibility factor (0-1).

Texture	Ks	G	Por	Smax	Cv	Sand	Silt	Clay	Dist	Kff
C	0.690	407.0	0.475	0.910	0.500	27.00	23.00	50.00	0.160	0.340
CBV	210.000	46.0	0.437	0.950	0.690	91.00	1.00	8.00	0.690	0.050
CFM	0.000	0.0	0.000	0.000	0.000	0.00	0.00	0.00	0.000	0.280
CIND	210.000	46.0	0.437	0.950	0.690	91.00	1.00	8.00	0.690	0.020
CL	2.300	259.0	0.464	0.940	0.940	32.00	34.00	34.00	0.240	0.290
CLIS	210.000	46.0	0.437	0.950	0.690	91.00	1.00	8.00	0.690	0.150
CDSL	26.000	127.0	0.453	0.910	1.300	65.00	23.00	12.00	0.380	0.240
FB	0.690	407.0	0.475	0.910	0.500	27.00	23.00	50.00	0.160	0.050
FRIAG	210.000	46.0	0.437	0.950	0.690	91.00	1.00	8.00	0.690	0.050
FS	210.000	46.0	0.437	0.950	0.690	91.00	1.00	8.00	0.690	0.200
FSL	26.000	127.0	0.453	0.910	1.300	65.00	23.00	12.00	0.380	0.250
G	210.000	46.0	0.437	0.950	0.690	27.00	23.00	50.00	0.160	0.150
GYP	0.000	0.0	0.000	0.000	0.000	0.00	0.00	0.00	0.000	0.050

Figure 36. The kin_lut.dbf.

Landcover

Weighted hydrologic parameters are derived from landcover data in conjunction with a lookup table. Each lookup table is related to a specific type of landcover through the landcover classification number (the value of the grid cell). AGWA provides several lookup tables, including NALC, MRLC, SWGAP, NY, and MRLC_FIRE. All values found in

the landcover raster must be found in the selected lookup table.

The SWGAP land cover map uses a more detailed classification system than the other land cover maps used in AGWA. Since hydrological properties are not available for these detailed classes, whenever possible, each SWGAP land cover type was given a value matching a land cover type from the National Land Cover Data (NLCD) set to obtain the hydrologic properties for the models. The remaining SWGAP land cover types were given a NLCD value based on the larger ecological system they were in.

AGWA provides fire assessment capabilities using the Burn Severity option in the Landcover Modification Tool and the provided MRLC_FIRE landcover lookup table. The table contains MRLC parameters modified to reflect field observations for three classifications (Canfield and Goodrich, 2005). See **Advanced Options>Landcover Modification Tool>Analyze an area with a burn severity map** for more information.

Landcover parameters are area-weighted averages based on the landcover types within each plane or subwatershed. Using the ArcView TabulateArea feature, AGWA calculates the proportion of each landcover type within a plane. These values are then used with the relevant parameter from the selected lookup table to determine the average value for the plane or subwatershed.

In some cases, a landcover surface will contain values that do not correspond to a recognized landcover, such as "Clouds" or "Water". This classification indicates an area with no landcover data and is usually accompanied by a corresponding record in the landcover lookup table with all hydrologic soil group (A, B, C, D) values set to zero or to 100. Any landcover with all parameters set to zero or with all hydrologic soil group values to 100 will be excluded from the normal area-weighting process and from the HRU parameterization process.

KINEROS

Landcover parameters for KINEROS are area-weighted averages based on the intersection of the watershed with the landcover raster. Four parameters are required: cover, interception, Manning's N, and percent impervious. The averages are written to the watershed attribute table.

SWAT

Landcover parameters for SWAT are based on the landcover intersection and the average hydrologic soil group as determined by soils parameterization. Derived parameters include hydrologic soil group and KS. KS is based on the soil texture of the first soil layer and the kin_lut table values. The parameters are written to the watershed attribute table.

Hydrologic Response Units

AGWA 1.5 supports SWAT hydrologic response units (HRU). An HRU is a region within a subwatershed that, as defined by AGWA, has unique landcover attributes. HRUs are not identified spatially within the watershed nor do the HRU elements interact during simulation. Each HRU is simulated independently before estimates are summed for the subwatershed. See the SWAT User's Manual for more information.

To use HRUs, users must include a CROP, URBAN, and URBANLU field in the landcover lookup table. CROP contains the class code (the integer value preceding the name) from the crop2000.dat file. See **Advanced Options>Preferences>SWAT DAT Defaults** for more information regarding the default crop2000.dat file. URBAN contains the urban simulation code used in the HRU file. The value must correspond to one of the following values:

- 0: no urban sections in the HRU
- 1: urban sections in the HRU simulated using USGS regression equations
- 2: urban sections in the HRU simulated using build up/wash off algorithms

The URBANLU field contains the urban land use identification number from the urban2000.dat file. If the URBAN value is greater than 0, the URBANLU value must also be specified. Urban processes override plant growth processes in an HRU, so the CROP value is not utilized if URBAN is greater than 0.

The HRU process creates a second landcover table called <watershed name>_HRUs.dbf. This table contains the areas of each landcover class found in each subwatershed. The table is required to use HRUs for a given watershed in a SWAT simulation. See **SWAT>Inputs and Execution** for information regarding HRU simulation.

The CROP, URBAN, and URBANLU values can be edited using the SWAT DAT preferences. Go to

Advanced Options>Preferences to edit any landcover table based on values in the default DAT files. These values can be added to the tables or existing values can be modified.

Default CROP values

This option allows users to specify CROP values for each landcover class in the landcover lookup table. These values should be set based on the default CROP file. If the user wishes to use default crop values, all affected parameters will be set using the Range Brush (16) crop type; otherwise the values will be based on the CROP values set in the lookup table. The CROP value for the subwatershed is set to the CROP value of the dominant landcover within the subwatershed. These values can be modified during the SWAT initialization process if Nitrogen and Phosphorus Modeling is selected (this step does not require additional information).

See **Advanced Options>Preferences>SWAT DAT Defaults** or **SWAT>Inputs and Execution>Nitrogen and Phosphorus Modeling** for more information.

Custom Lookup Tables

Any landcover classification can be used with AGWA if the user supplies the properly formatted lookup table. The lookup table must be keyed to the landcover raster by a CLASS field with a record for each value in the landcover raster. To use the Landcover Modification Tool (see **Advanced Options>Landcover Modification Tool**) or to use with a buffered watershed, the table must also have a NAME field. Other required fields include Percent Cover, Interception, Manning's N, Percent Impervious, and curve numbers for hydrologic groups A, B, C, and D. Figure 37 shows an example lookup table.

Class	Name	A	B	C	D	Cover	Int	N	Impervious
11	Open Water	100	100	100	100	0	0.00	0.000	0.00
12	Perennial Ice/Snow	90	90	90	90	0	0.00	0.000	0.00
21	Low Intensity Residential	77	95	90	92	15	0.10	0.150	0.40
22	High Intensity Residential	81	88	81	83	10	0.08	0.120	0.75
23	Commercial/Industrial/Traffic	89	92	94	95	2	0.05	0.010	0.80
31	Bare Rock/Sand/Clay	96	96	96	96	2	0.00	0.010	0.00
32	Gravel/Strip Mines/Gravel Pit	78	95	90	92	2	0.00	0.010	0.00
33	Transitional	72	82	87	90	20	0.00	0.010	0.00
41	Deciduous Forest	55	55	75	80	50	1.15	0.015	0.00
42	Evergreen Forest	55	55	70	77	50	1.15	0.015	0.00

Figure 37. Example landcover lookup table for the MRLC classification scheme.

Soils

AGWA supports three soils datasets – STATSGO, SSURGO, and FAO. Example datasets for each soil type are provided in the AGWA *gisdata* and *datafiles* download.

Soils Datasets

STATSGO

STATSGO datasets are identified by the MUID field in the soil theme's attribute table. Datasets will not be recognized by AGWA without this field.

STATSGO soil types are identified by an MUID (map unit ID) field. For each MUID, there are predefined components that describe the spatial variation within a particular soil type. For instance, there may be three components associated with MUID AZ061 (see Figure 38). Each component occupies a certain percentage of the larger soil type (MUID); the component percentages must sum to 1. Component information is stored in a file called comp.dbf for each state in the United States. A component is composed of different layers. Layer information is stored in the layer.dbf file for each state.

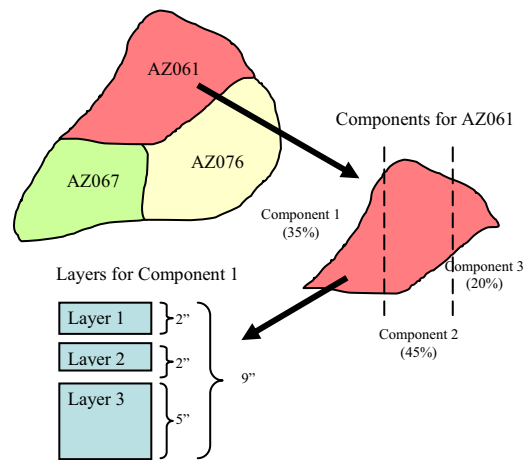


Figure 38. STATSGO structure.

SSURGO

SSURGO datasets are identified by the MUKEY field in the soil theme's attribute table. Datasets will not be recognized by AGWA without this field.

Like the STATSGO dataset, the SSURGO dataset is composed of components and horizons (i.e. layers). See Figure 39. A similar weighting process is used for this dataset.

The FAO datasets and tables were obtained either from the Food and Agriculture Organization of the United Nations (FAO/UNESCO, 2003) Soil Map of the World CD-ROM, or from C.A. Reynolds research (Reynolds et al., 1999).

To use FAO soils in AGWA, several modifications were made. FAO soils are classified into three broad soil texture categories: coarse, medium, and fine; however, the kin_lut.dbf uses textures based on the USDA soil texture triangle. All FAO soil units in the tables were assigned one of the twelve texture classes from the soils triangle. For those FAO soil mapping units that did not have any associated soil-units or soil properties, textures were assigned based on the most similar texture in the table. These units include “dunes/shifting sands”, “salt”, “rock”, “glaciers”, “water” and “No Data”. For example, “salt” is given the same values as “gypsum”, while “rock” is given values from “unweathered bedrock”.

FAO soil classes are composed of multiple components. The components do not have multiple layers (Figure 40).

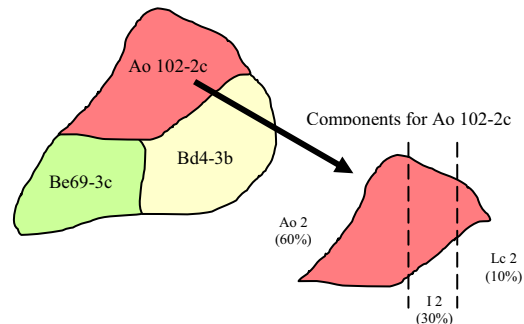


Figure 40. FAO Structure.

Occasionally, a soil-unit is not found in the tables, so texture is determined based on the soil-unit name. FAO textures are “coarse”, “medium”, or “fine”, and are designated with a “1” (coarse), “2” (medium), or “3” (fine) following the soil-unit symbol (i.e. AF 2). These textures are defined in the FAO documentation based on the soil texture classes from the USDA Soil texture triangle (FAO/UNESCO, 2003). These three soil textures (coarse, medium, and fine) were added to the kin_lut.dbf and their soil properties created from weighted averages of values in the kin_lut.dbf. For example, “coarse” soil, defined as “Sand, Loamy sand, and Sandy loam soils when clay is less than 18% and sand is greater than 65%” (FAO/UNESCO, 2003), uses the weighted average of these three soil textures (see Figure 41).

Figure 39. SSURGO Structure.

In some cases, the SSURGO tables will not correspond to the correct formatting required by AGWA. If an error occurs, double-check the formatting of the SSURGO dataset being used. The correct formatting can be found in the SSURGO Access database (version 2000) provided in the AGWA *gisdata\ssurgo_tables* directory. The fields in the component, chorizon, and chtexgroup tables in the user-provided SSURGO database should correspond to those in the provided AGWA database. The number and order of the fields must match those in the provided SSURGO database for soil processing to be successfully performed.

It is important that the SSURGO dataset extends beyond the watershed boundary. Voids in this coverage can lead to failure during parameterization or during SWAT simulation of the watershed. Previously this condition halted the parameterization process and required manipulation of the spatial dataset to correct. Now, a dedicated SSURGO tool is included with AGWA that allows users to remove internal voids, to extend the dataset beyond a given watershed and to merge spatial and tabular datasets (see **Advanced Options>SSURGO Tool**). Users are strongly encouraged to use the provided tool when editing SSURGO datasets.

FAO

FAO datasets are identified by the SNUM field in the soil theme's attribute table. Datasets will not be recognized by AGWA without this field. To use the dataset, first reproject the dataset to a geographic projection with decimal degrees and then to UTM or some other projection with units in meters.

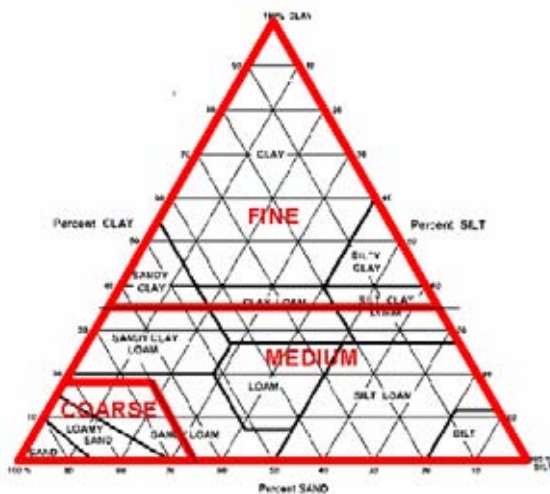


Figure 41. USDA Soil Texture Triangle with FAO soil textures outlined.

When retrieving parameters for use as inputs to the models, parameters were first obtained from the FAO data if available (FAO_world.dbf and FAO_Africa.dbf), then from the Reynolds data (FAO_Summ.dbf), and finally from the AGWA kin_lut.dbf table if not found in any other source.

The hydrologic soil group (HSG) is not given in the FAO documentation. It was determined using the soil texture classes, the USDA soil texture triangle, and the FAO documentation on soil texture classes (FAO/UNESCO, 2003). General definitions for the hydrologic soil groups for use in verifying the relationship between texture and HSG were taken from Engel et al. (2004) and Jarrel and Bundy (2002).

KINEROS

Soil parameters for KINEROS are area-weighted averages of the top 9 inches of the soil stratum. First, AGWA performs any depth-weighting necessary based on the depth of the layers for each component within the plane. The depth-weighted values are then used during the area-weighting process to derive the final parameters. Weights are determined through the intersection of the watershed with the soils dataset.

Parameters are added to the watershed attribute table once weighting is complete.

Clay, silt, and sand fractions should sum to 1 for each plane element after area-weighting is complete. If the sums exceed the specified ranges, parameterization fails. This can be caused by missing data in a plane element or incorrect

watershed intersections. Correct any problems before attempting to run KINEROS.

In some cases, a plane element may fall completely within a soil type, such as water, that cannot be averaged. In earlier versions of AGWA, the soil parameters for these elements were assigned a value of -99; however, because these elements do not contribute runoff to the watershed, AGWA now provides the option to remove these elements from the watershed to allow users to continue the simulation process.

If soil parameters for a plane element cannot be averaged, AGWA informs the user and asks if processing should continue without the affected elements. If the user declines, soil parameterization ceases and the watershed should not be used for simulation with the selected soil theme. If the user accepts, the affected plane elements are removed from the watershed and any affected parameters updated (cumulative area, and contributing element). Please note that this situation could be an indication of errors within the soils dataset or the intersection theme. If this is the case, removing the planes will result in misleading runoff estimates. It is the user's responsibility to examine the watershed and soils theme before undertaking this option.

SWAT

Unlike KINEROS, SWAT soil parameters are not area-weighted by subwatershed. Instead, these values are based on the dominant soil type found in the subwatershed.

Soil parameters are stored in a table, <watershed name>_soil_lut.dbf, with a record for each layer of each component in the watershed. The watershed attribute is modified to include a SOIL_ID field containing the dominant soil identifier. This table is required for SWAT simulation.

Parameterization

Parameterizing an individual watershed

Before parameterizing a watershed, add any soil and landcover datasets that will be used. Also, add the landcover lookup tables for the landcover datasets.

To parameterize a watershed, select **AGWA Tools>Landcover and soils parameterization** (Figure 42). Select the watershed from the Watershed Selection panel. If the watershed was

discretized for SWAT, users can select to use the default CROP value (16) or to parameterize for HRUs based on landcover. HRUs must be defined in this step to be simulated later. These options are not available for KINEROS.

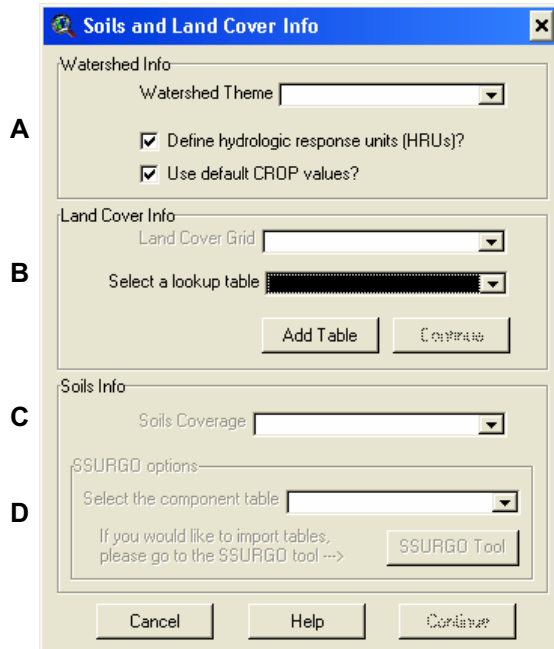


Figure 42. Soils and Landcover Parameterization dialog. A) Watershed Selection panel; B) Landcover Selection panel; C) Soils Selection panel; D) SSURGO Options panel.

Select a landcover raster from the combobox on the Landcover Selection panel. Only rasters loaded into the view will be available for use. Select a landcover lookup table. All available tables in the project can be found in the combobox. Tables must have the minimum landcover fields to be used (Class, Name, A, B, C, D, Cover, Int, N, Imperv). If the desired landcover lookup table is not found in the combobox, it can be added to the project using the **Add table** button. Navigate to the table to add it to the project. Select the added table. Click **Continue** to proceed to the soils dataset section.

Select a soil spatial dataset from the Soils Selection panel. If the selected dataset is a SSURGO soil theme, the SSURGO Options panel will be activated. If a tabular dataset has already been imported for the selected spatial dataset, select the associated COMP table from the combobox. Tabular datasets can be reused for spatial datasets that were corrected using the AGWA SSURGO Tool. If the combobox is left empty, i.e. no selection is made, AGWA will search

for tables with the soil dataset name followed by `_comp`, `_hor`, or `_tex`. If those files are not located in the project, AGWA will import those files from the formatted text files. If the soil dataset was merged, a tabular dataset must be selected from the combobox unless the merged tables conform to the above naming convention. Users should not attempt to merge datasets outside of the SSURGO Tool as testing indicates that those datasets have a very high failure rate.

During the initialization process, the soils dataset is compared to the watershed to ensure that the two datasets fully overlap – the soils dataset must extend beyond the edges of the watershed and must not contain any internal voids or gaps. The user can choose to continue with the parameterization if either of those situations are found with a KINEROS watershed; however, the soils dataset must be corrected before parameterizing a SWAT watershed. If the internal void error occurs, AGWA will automatically fill the voids and create a new soil dataset with a temporary file name of “soil” and a number. If the watershed edge extends beyond the soils dataset with a SSURGO dataset, the user must use the SSURGO tool to correct the soils theme.

Parameterizing a buffered watershed

Watersheds with riparian buffer elements can be parameterized based on the watershed configuration before buffer installation and after buffer installation (Figure 43). Affected parameters include cover, interception, roughness, percent impervious and slope. Both conditions require the presence of the original, unbuffered watershed in the view for successful parameterization.

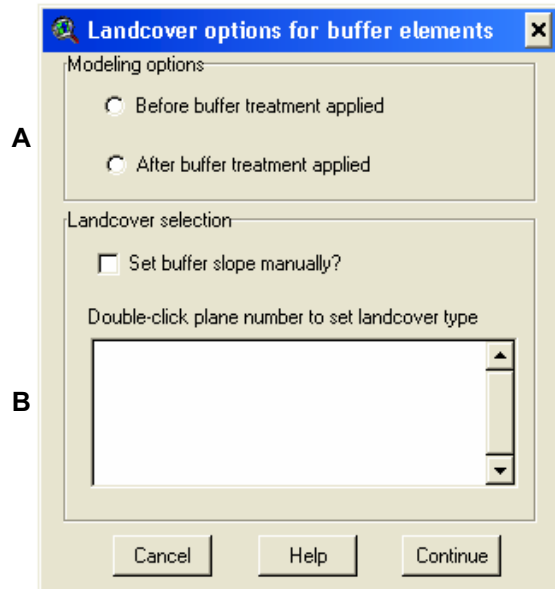


Figure 43. KINEROS Buffers Landcover Options dialog. A) Treatment Options panel; (B) Post-treatment Landcover Selection panel.

Because the watershed configuration of the buffered watershed is altered by the buffering process, the original watershed is parameterized. The planes of the buffered watershed receive the parameter values from the original watershed; elements created during the buffering process receive the parameters of the plane element the buffered elements replaced. This is true for both landcover and soil parameters. For the pre-treatment option, all buffered elements receive the same values, including slope, to approximate the uniform surface of the original plane. To parameterize for pre-treatment conditions, select **Before buffer treatment applied** on the Treatment Options panel and click **Continue**.

Table 1. Post-treatment parameter estimates (buffer = WS# 146).

WS#	SLOPE	INT	COVER	KS
72	6.5543	2.60	24.35	8.38
73	6.5007	2.83	24.70	8.15
142	6.5543	2.60	24.35	8.38
143	6.5007	2.83	24.70	8.15
146	6.9557	1.15	70.00	13.53
152	6.5543	2.60	24.35	8.38
153	6.5007	2.83	24.70	8.15

For the post-treatment option, all affected planes excluding the buffer element are set to the original plane parameters; the buffer element parameters are selected by the user (see Table 1).

The user can opt at this time to manually set the slope of the buffer element or to automatically recalculate the slope. To manually set the slope, check the **Set buffer slope manually?** option on the Post-treatment Landcover Selection panel. Select a buffer element from the list provided. Double-click the **Landcover** cell to select a landcover type for the selected buffer element (Figure 44). Any landcover type found in the landcover lookup table selected in the main landcover and soils dialog can be applied to the buffer. Double-click the **Slope** cell to enter a slope value for the buffer. Slope values should be between 0 and 25%. (Slopes vary based on the conditions and management options for a given region. Users are encouraged to consult the literature for appropriate buffer design specifications for their region or management needs.) Click **Continue** to complete the parameterization process.



Figure 44. Post-treatment buffer parameterization landcover selection.

Parameterizing a watershed group

The process as described for an individual watershed also applies to a watershed group with one difference – the temporary tables are keyed to the GROUPID field instead of the WS# field. The same issues involving soils and landcover dataset extents apply to watershed groups. It is the user's responsibility to provide datasets encompassing the study area. Processing times are longer due to the increased number of plane elements in a watershed group.

KINEROS

Generating Precipitation Files

Several options are available for generating properly formatted KINEROS precipitation files. The files can be multiple gage or single gage events; however, creating files for multiple gages requires very specific inputs that may not be widely available. All precipitation files are written to the AGWA project's *rainfall* directory.

To generate precipitation files, go to **AGWA Tools>Write KINEROS precipitation file** (Figure 45).

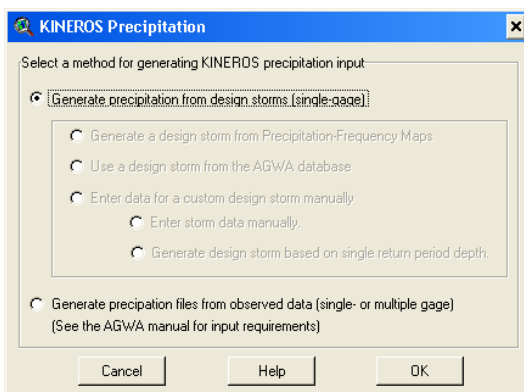


Figure 45. KINEROS Precipitation dialog.

Five options are presented in the window:

- Generate an event using a Precipitation-Frequency map
- Use an event from the AGWA design storm database
- Enter an event manually
- Generate an event from a single return-period depth
- Generate one or more events for one or more gages from observed data

Select a precipitation option and click **OK** to continue.

Uniform Inputs

Precipitation-Frequency Maps

Precipitation-frequency maps may be downloaded via NOAA's Precipitation Frequency Data Server (PFDS) (<http://hdsc.nws.noaa.gov/hdsc/pfds/> for the Western states and Ohio River Basin. For those states not covered by the NOAA dataset, we have

developed a temporary alternative by digitizing and interpolating NOAA TP 40 rainfall frequency atlas maps. These data are available for download at http://www.tucson.ars.ag.gov/agwa/rainfall_frequency.html until such time as the PFDS is complete. Multiple durations and frequencies are available, but users should note that durations exceeding 48 hours are not applicable in KINEROS. Releases prior to AGWA 1.4 also supported precipitation-frequency maps but in different units. AGWA 1.4X and 1.5 supports grids with units of 1000ths of inches, whereas prior releases supported grids with units of 100,000ths of inches. If grids measured in 100,000ths of inches are all that is available, a simple grid calculation will make the grids compatible.

Instructions for importing precipitation-frequency maps

From the NOAA Precipitation-Frequency Data Server

1. Go to <http://hdsc.nws.noaa.gov/hdsc/pfds/> in your web browser.
2. Click the desired state on the map.
3. Click on the **GRIDS** button in the top right quadrant of the map.
4. On the new page, scroll down until you see the first set of comboboxes. The appropriate region should already be selected in **Region**. Select the desired return period and duration of the storm. Choose ArcInfo ASCII Grid for the **Format** and Mean for the **Type**.
5. When the appropriate selections are made, click the **Click here to begin GIS data download** and save the grid to your hard drive.
6. Once the file is downloaded, it will need to be converted from an ASCII file to a grid. This can be accomplished in one of two ways, either through the **Import Data Source** option in ArcView or through the ArcInfo **GRID** command.
7. In ArcView, go to **File>Import Data Source**. Navigate to the ASCII grid file and import the grid.
8. In ArcInfo, use the ASCIIGRID command. Refer to the ArcInfo documentation for the required arguments.
9. The grid is downloaded in geographic coordinates (Decimal Degrees). It must be projected to match the rest of the project

- data. Use ArcInfo, ArcToolbox or the Reproject Grids extension (available from the ESRI website) to reproject the data.
10. Add the grid to the view (this can be done using the **Add data** button or with the **Add grid** option in the dialog).

From the USDA-ARS server

1. Go to http://www.tucson.ars.ag.gov/agwa/rainfall_frequency.html in your web browser.
2. Select the desired state from the **Location** combobox. Select the return period and duration.
3. Click the download button and save the grid to your hard drive (The grid does not need to be converted).
4. Reproject the grid from geographic coordinates (Decimal Degrees). It must be projected to match the rest of the project data. Use ArcInfo, ArcToolbox or the Reproject Grids extension (available from the ESRI website) to reproject the data.
5. Add the grid to the view (this can be done using the **Add data** button or with the **Add grid** option in the dialog).

Select the desired grid from the combobox on the Grid Selection panel (Figure 46). Select a watershed on the Watershed Selection panel. Enter a precipitation name and a saturation index. This is the initial soil saturation value for the event. (It is equivalent to the SA value in the parameter file.)

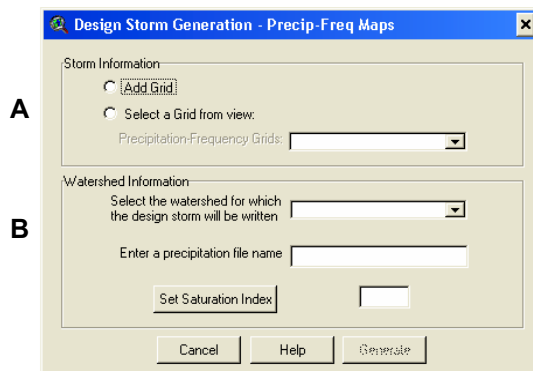


Figure 46. Precipitation-Frequency Precipitation File dialog. A) Grid Selection panel; B) Watershed Selection panel.

AGWA takes the watershed centroid and intersects it with the NOAA grid to determine the event's total depth value. The depth value is converted to a hyetograph using the SCS methodology (SCS, 1973) and a type II distribution.

The type II distribution and several others are shown in Figure 47 and is appropriate for deriving the time distribution of rainfall for most of the country.

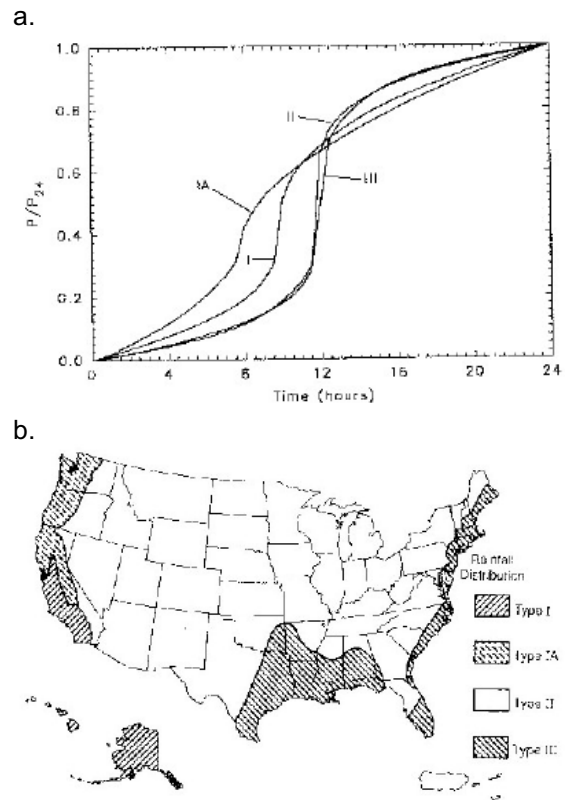


Figure 47. (a) SCS distributions. (b) Applicability of type II distribution.

AGWA Design Storm database

AGWA provides a number of design storms in the `dsgnstrm.dbf` (in the `datafiles` directory). This file contains return period depths and are available only for specific locations. Load this table into the project before creating a precipitation file. Select the location and frequency from the available choices. The events are generated using the SCS methodology for the type II method. (Area reduction can only be applied to events generated from the San Pedro data. The area reduction factor is computed using the Osborn et al. (1980) method for thunderstorms in the southwestern United States.)

The `dsgnstrm.dbf` can be modified by the user to include additional locations, durations, or return period depths (Figure 48). Open the table and select **Table>Start editing**. Add a new record with **Edit>Add record**. Modify the fields as necessary

and save the changes (**Table>Stop editing**; click **Yes** when ArcView asks to save changes).

Location	Frequency	Duration	Depth
ClarkCountyLV	100	1.00	2.06
ClarkCountyLV	100	2.00	2.30
ClarkCountyLV	100	3.00	2.48
ClarkCountyLV	100	6.00	2.77
ClarkCountyLV	100	24.00	2.96
San Pedro	5	0.50	0.69
San Pedro	5	1.00	1.07
San Pedro	10	0.50	1.18
San Pedro	10	1.00	1.35
San Pedro	100	0.50	1.71
San Pedro	100	1.00	2.04

Figure 48. The dsgnstrm table.

To generate the file, select the location and frequency-duration from the available choices (Figure 49). Select the watershed for which the event will be generated. Set the saturation index for the event (it is equivalent to the SA value in the parameter file). Enter a name for the precipitation file and click **Generate** to write the file.

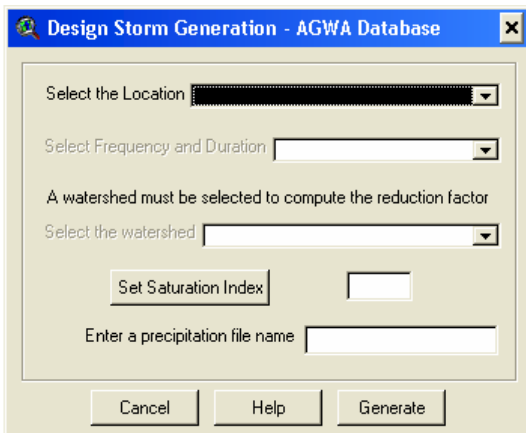


Figure 49. AGWA Design Storm dialog.

Manual Inputs

Enter Event

If the desired design storm is not found in the supplied database, the user can enter that event manually with the **Enter data for a custom design storm manually>Enter storm data manually** option (Figure 50). The user must supply each time-depth or time-intensity pair for the event duration. It is not recommended for events with long durations.

First, enter any comments to the precipitation file on the Basic Storm Information panel (optional). Set the saturation index (it is equivalent to the SA value in the parameter file). Select the

type of precipitation file to generate – time-depth pairs or time-intensity pairs. Enter the number of pairs that will be included and click **Proceed**. The Storm Entry panel is now active. Double-click in the **Time (min)** field to enter the time value (minutes); double-click in the **Depth (mm)** or **Intensity (mm/hr)** field to enter that value. Once all of the rows are completed, click **Generate** to write the precipitation file.

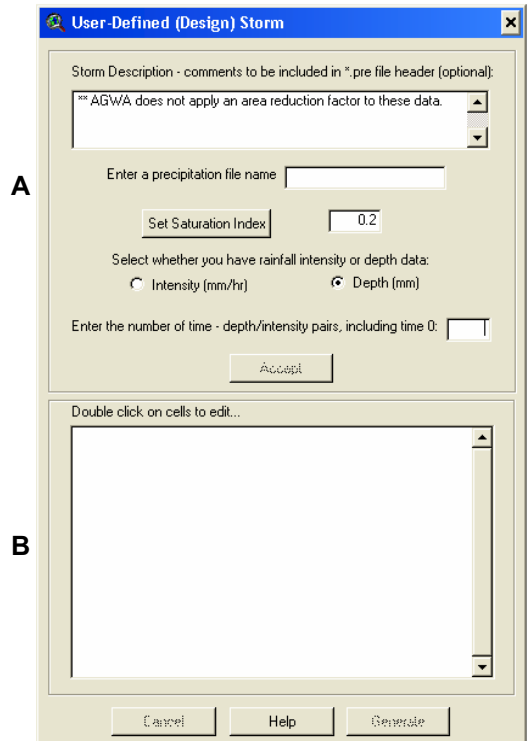


Figure 50. User-Defined Storm Dialog. A) Basic Storm Information panel; B) Storm Entry panel.

Single Return Period Depth

If the desired design storm is not found in the supplied database, the user can enter that event manually with the **Enter data for a custom design storm manually>Generate design storm based on single return period depth** option (Figure 51). This option converts the depth and duration into a hyetograph based on the SCS methodology for type II distributions.

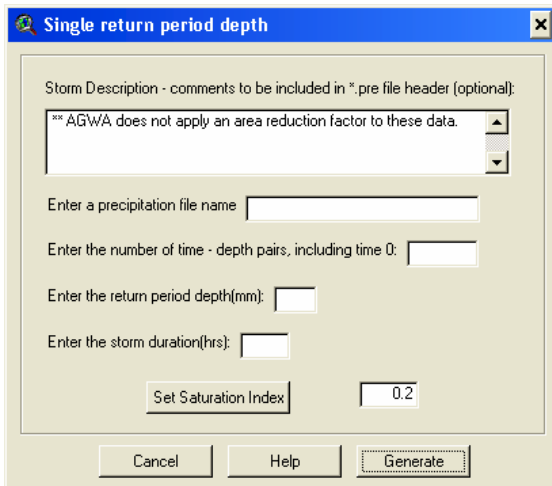


Figure 51. Single Return-period Depth Event dialog.

Enter any comments in the textbox (optional). Enter the number of time-depth pairs, including time zero, to be written to the file. Enter the return period depth (mm) and the duration of the event (hours). Select a saturation index (it is equivalent to the SA value in the parameter file). Click **Generate** to write the precipitation file.

Multiple Gage Inputs

This process is based on the Perl script previously available in the *datafiles* download from the AGWA website. The component simplifies several aspects of the original process, and reduces it to one step for the user. The component allows you to select the gages, to include gages with zero depths for more accurate interpolation by KINEROS, to set a minimum depth that the gages must exceed before creating a precipitation file, and to generate files for any events between a given range of dates.

The component uses breakpoint precipitation data (time-depth pairs) to generate precipitation files. Figure 52 shows an example of the type of raw data required by the tool, downloaded from the <http://www.tucson.ars.ag.gov/dap> website.

Event Report generated 2/15/2006 11:14:51 AM

Watershed 63 (Walnut Gulch)
 Gages: 23,26
 For the period 1/1/1961 to 12/31/1963
 For all months
 Breakpoint Data sorted by gage, depth in millimeters.

Gage Turned Off Turned Back On

Gage	Date	Start Time	Elapsed Time	Depth (mm)	Elapsed Time Estimated	Rainfall Rate (mm/hr)	Rainfall Estimated
23	1/27/1961	5:20	0	0	N	1.83	N
23	1/27/1961	5:20	50	1.5	N	0.42	N
23	1/27/1961	5:20	160	2.3	N	0	N
23	2/19/1961	15:50	0	0	N	9.14	N
23	2/19/1961	15:50	15	2.3	N	0	N

Figure 52. Breakpoint precipitation data for Walnut Gulch, AZ.

Once the precipitation data has been obtained, it must be formatted before use in the multiple gage file generator. The date must be separated into YEAR, MONTH, and DAY fields and the start time into HOUR and MINUTE fields. This can be done in Microsoft Excel using the YEAR(), MONTH(), DAY(), HOUR(), and MINUTE() functions. The start time should be based on 24-hour time. In addition, the formatted table must contain an ELAPSED field ("Elapsed Time" above) that contains the time, in minutes, from the start of the event, and a DEPTH_MM field that contains the recorded depth of the precipitation in millimeters at the current time step. The only other field required from the raw data file is the GAGE field, containing the numeric gage identification number. These numbers must correspond to the gage numbers found in the raingage point theme. Once the data is formatted, it must be exported as a DBF table (figure 53).

Gage	Elapsed	Depth_mm	Hour	Minute	Year	Month	Day
23	0	0.0	15	59	1991	7	6
23	25	2.5	15	59	1991	7	6
23	0	0.0	15	57	1991	7	19
23	3	1.5	15	57	1991	7	19
23	8	3.0	15	57	1991	7	19
23	66	3.3	15	57	1991	7	19
23	72	5.1	15	57	1991	7	19
23	0	0.0	15	26	1991	7	20
23	5	0.8	15	26	1991	7	20
23	7	1.5	15	26	1991	7	20
23	12	2.0	15	26	1991	7	20
23	27	2.5	15	26	1991	7	20
23	0	0.0	15	54	1991	7	23

Figure 53. Example precipitation input table.

Events are determined using the start time (HOUR and MINUTE), the elapsed time (ELAPSED), and the date. The end time of the event is based on the earliest start time for an event and the highest elapsed time. If the start time of a gage is later than the previous event's end time, AGWA assumes the observations are part of another event. The time breakpoints for all affected

gages are adjusted based on the earliest start time for the event.

Once the input table has been properly formatted, the multiple gage option can be used. Select the point theme containing the gage locations on the Raingage Selection panel (Figure 54). Select the gages to be included in the precipitation files. Hold down Shift to add or remove points from the selection. A maximum of one hundred gages can be selected; however, for larger events, this number should be reduced to ensure that the total number of time-depth pairs does not exceed 5000. Gages with no recorded rainfall can be included in the precipitation files by selecting **Include gages with no measured precipitation?** This will affect the KINEROS interpolation results.

Select the event table from the Event Information panel. Enter a range of dates to limit the event search. Each date should be formatted as MM/dd/yyyy. Enter a minimum depth. Events can be excluded if at least one gage included in the event does not exceed the specified minimum depth. The default value is zero to include all events.

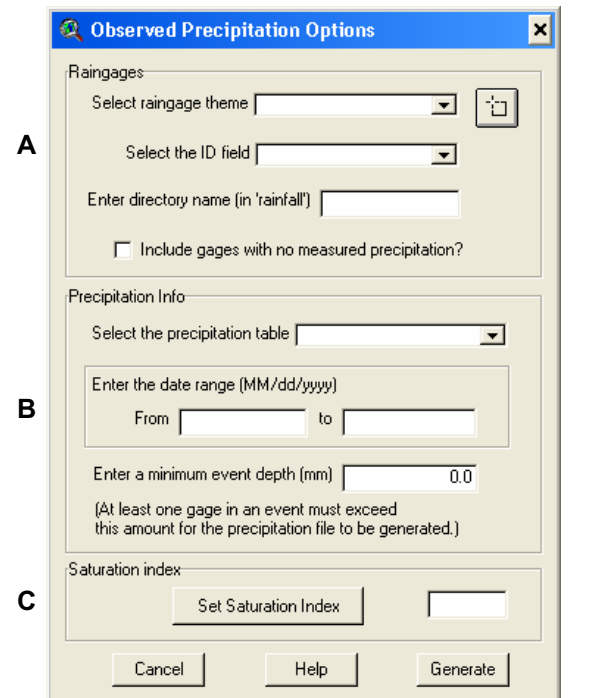


Figure 54. Multiple Gage Precipitation dialog. A) Raingage Selection panel; B) Event Information panel; C) Saturation Index panel.

Select an initial soil saturation value from the Saturation Index panel. This value will be used for every gage in every event generated in a given session. These values can be modified in a text editor before using in a simulation by resetting the SA value for any given gage. Click **Generate** to write the files.

A file for each event in the specified range will be written to the specified directory within the AGWA project's *rainfall* directory. If the subdirectory does not exist, AGWA will create it. Files are named with the following:

Year_month_day_event#

To avoid overwriting files, create a new subdirectory. The files will be available when creating a KINEROS simulation.

Setting the saturation index

The saturation index can be entered manually as a decimal value or can be selected using the slider (Figure 55).

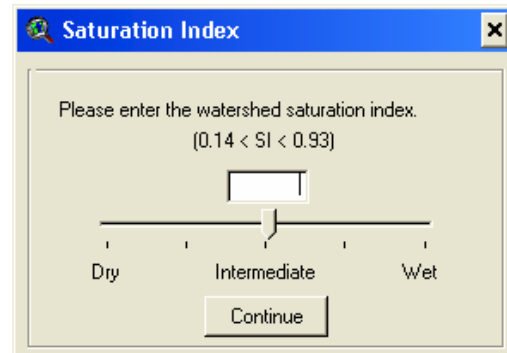


Figure 55. Saturation Index dialog.

Inputs and Execution

Once the watershed has been delineated, discretized, and parameterized, you can run KINEROS. The process includes writing the necessary input files to a KINEROS simulation directory (in the *simulations* directory of the current AGWA project), executing KINEROS, and importing the KINEROS output file into the project.

Three types of KINEROS simulations can be performed – an individual watershed with one parameter file and one precipitation file; a watershed group with multiple parameter files and one precipitation file; or a watershed or watersheds (not groups) with multiple parameter files and multiple precipitation files. The last two options are

examples of the new KINEROS batch simulation mode (all simulations use the same executable).

To run KINEROS, select **AGWA Tools>Write inputs and run KINEROS** (Figure 56). KINEROS can be run for multiple parameter file/precipitation file pairs. Parameter files can be reused as necessary, providing the simulation rerun option, and modified parameter files can be imported for use.

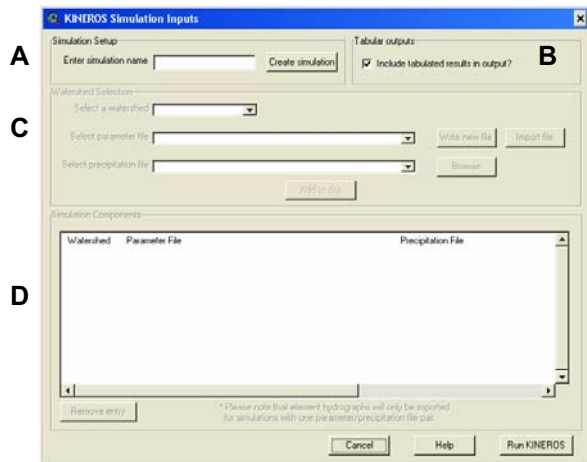


Figure 56. KINEROS Input dialog. A) Simulation Creation panel; B) Tabular Output panel; C) File Selection panel; D) Simulation Component panel.

First, create a new simulation directory on the Simulation Creation panel. This directory will contain all parameter files, precipitation files, and output files for the simulation. The directory will also contain the kin.fil file and a copy of the KINEROS executable. Enter a simulation name and click **Create simulation**. A new directory will be created in the current project's *simulations* directory.

Check the **Include tabulated results in output?** On the Tabular Output panel to include a tabular summary of the simulation at the end of the .OUT file (recommended). In some cases, writing this output can cause KINEROS to stall. Should this occur, do not select this option; however, results from the affected simulation can still be imported.

Select a watershed on the File Selection panel. A list of available parameter files for the watershed will be provided in the parameter file combobox. This list includes parameter files written or imported for any previous simulation. Parameter files can also be written or imported at this time (see **KINEROS>Inputs and Execution>Writing**

the parameter file). Click **Write new file** to generate a parameter file; click **Import file** to import an existing file into the simulation. The import option allows users to modify the parameter file in any text editor and reuse it in a simulation. The modified file should be located in an existing simulation directory for the selected watershed and must have a name unique to parameter files for the watershed (i.e., if a parameter file called kin1.par is found in sim1, the imported parameter file cannot be called kin1.par even if located in sim2). The new or imported parameter file will be added to the combobox. Select a file.

Select a precipitation file on the File Selection panel. The list in the combobox contains all precipitation files found in the *rainfall* directory of the current project. This list will also contain any precipitation files found within subdirectories of the *rainfall* directory (see **Multiple Gage Inputs**). If a precipitation file is located in another location, use the **Browse** button to navigate to the file.

Once all selections have been made, click **Add to simulation** to enter the parameter file/precipitation file pair to the simulation (Simulation Component panel). The filenames and watershed are added to the listbox. Repeat the above steps until the simulation inputs have been defined. Parameter file/precipitation file pairs cannot be repeated in a simulation. Parameter files written for different watersheds but used in one simulation also should not have the same name.

To utilize the hydrograph option, the parameter file must contain the appropriate output options and the parameter file/precipitation file pair must be the only pair in the simulation. The parameter file can be used in a batch simulation, but, because of potential conflicts with the hydrograph outputs, the files will not be imported or available for display.

Watershed groups also cannot be simulated in the multiple watershed/parameter file batch mode. AGWA will prevent users from adding additional parameter file/precipitation file pairs to the simulation. Groups make use of the batch simulation mode by pairing each parameter file for the group with the selected precipitation file and executing KINEROS.

A parameter file/precipitation file pair can be removed from the simulation by selecting the row and clicking **Remove entry**.

When satisfied with the simulation inputs, click **Run KINEROS** to begin the simulation process. Any parameter files not created specifically for this simulation will be copied to the simulation directory. Again, all parameter file names in the simulation must be unique or the simulation outputs could reflect the wrong parameter file inputs. Precipitation files are also copied to the simulation directory. AGWA will generate the kin.fil file (the KINEROS control file) in the following format (all entries on one line per pair):

parameter filename, precipitation filename, output filename, comments (optional), duration, timestep (1 minute default), use Courant criteria (Y/N), simulate sediment transport (Y/N), multipliers filename (not used), include tabular summary(Y/N), API initializing (Y/N)

The filenames in the kin.fil file (and the hydrograph outputs) are not the full path names, so KINEROS will only read or write files within the simulation directory. The output filename is a combination of the parameter file name and the precipitation file name. For example, the output file for kin1.par and event2.pre will be kin1_event2.out. AGWA defaults to use the Courant condition, to simulate sediment transport and not to initialize API. AGWA will then write a batch file (kin2.bat). This file will navigate to the simulation directory and initialize KINEROS (Figure 57).

```

C:\WINDOWS\system32\cmd.exe
C:\agwa\agwa_proj\simulations\test1
C:\agwa\agwa_proj\simulations\test1\kineros2_agwa < kin.fil
Processing Channel Elen. 94
Event Volume Summary:
      Rainfall      30.00000 mm      4227325. cu m
Plane infiltration 24.65240      3473791.
Channel infiltration 3.30722      464806.
      Interception  0.56983      80295.
      Storage      0.28026      39492.
      Outflow      0.96578      136117.
Error <Volume in - Volume out - Storage> < 1 percent
Time step was adjusted to meet Courant condition
Total watershed area = 14091.08 ha
Sediment yield = 489.6501 kg/ha
Sediment yield by particle class:
Particle size (mm)  0.250      0.033      0.004
Yield (kg/ha)      135.1981      301.9088      52.5432
C:\agwa\agwa_proj\simulations\test1

```

Figure 57. The KINEROS2 simulation (MS-DOS window).

AGWA does not automatically import simulation results. Files can be imported at any time through the View Results dialog.

Writing the parameter file

Parameter files are written when setting up a simulation. Any number of files can be written for a given watershed when in the KINEROS Simulation

Inputs dialog. The new file is written to the current simulation directory (created in Simulation Setup). Every precaution should be made to avoid naming a parameter file the same name as a parameter file in another simulation for the watershed. This is to avoid confusion when using multiple parameter files from different simulations in batch processing mode.

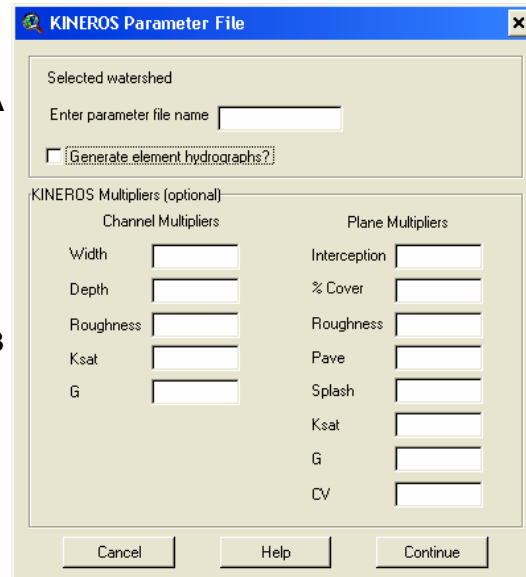


Figure 58. KINEROS Parameter File dialog. A) Parameter File Name panel; B) Multipliers panel.

Enter a name for the parameter file on the Watershed Name panel (Figure 58). The name of the selected watershed is displayed in the Parameter File Name panel. To view hydrograph results for each element, check the **Generate element hydrographs?** checkbox. See **KINEROS>Inputs and Execution>Hydrograph Output** for more information. Enter any multipliers for the provided parameters on the Multipliers panel. See **KINEROS>Inputs and Execution>Using multipliers** for more information. Click **Continue** to write the file and return to the KINEROS Simulation Inputs dialog.

If writing a parameter file for a watershed group, a parameter file will be written for each watershed in the group, with <parameter file name>_<group number>.par. These files are not available for individual simulation in AGWA. To perform an individual simulation with a watershed from a watershed group, first extract the watershed.

Hydrograph Output

The standard AGWA practice provides only the hydrograph information for the outlet channel. This file can be found in the simulation folder as <parameter file name>_<precipitation file name>.csv. However, hydrographs for each element in the watershed and stream network can be generated through KINEROS. With these files, users can take advantage of a new display option for KINEROS results – the time series view (see **Results>KINEROS Time Series**). Parameter files written with the hydrograph option can be used in any simulation; however, the time step view is only available for those simulations where the hydrograph parameter file is the only parameter file used.

The hydrograph outputs are written to two tables when AGWA imports simulation results, the <sim name>_plane_sim.dbf table and the <sim name>_channel_sim.dbf table. Each table contains the information for all plane elements or channel elements for each time step, in this case, the AGWA default of 1 minute.

Using multipliers

Multipliers are values used to adjust plane and channel parameters before KINEROS simulation, but do not modify the watershed or stream attribute tables. These values serve to calibrate the simulation. Multipliers range between -5 and 5, excluding zero. The multipliers are stored in the metadata file for the watershed and can be viewed with any of the simulation information buttons.

Running KINEROS with a watershed group

The batch processing method cannot be used when running a KINEROS watershed group (multiple parameter files cannot be added to the simulation). A watershed group automatically creates a parameter file for each watershed in the group; these files are stored in the simulation directory. The simulation takes advantage of the batch processing mode by simulating each watershed in the group with the specified precipitation file. A separate OUT file is written for each watershed.

Multiplier values are applied to all watersheds in the group.

SWAT

Generating precipitation files

AGWA provides two methods for generating precipitation files for SWAT – a single gage, uniform method and a multiple gage, distributed method. The multiple gage method utilizes Thiessen polygons to create an area-weighted precipitation file. Precipitation estimates (and temperature estimates) can be adjusted for topography with the SWAT elevation band component for individual watersheds.

To generate a precipitation file for SWAT, select **AGWA Tools>Write SWAT precipitation file**. This will open the SWAT Precipitation dialog (Figure 59).

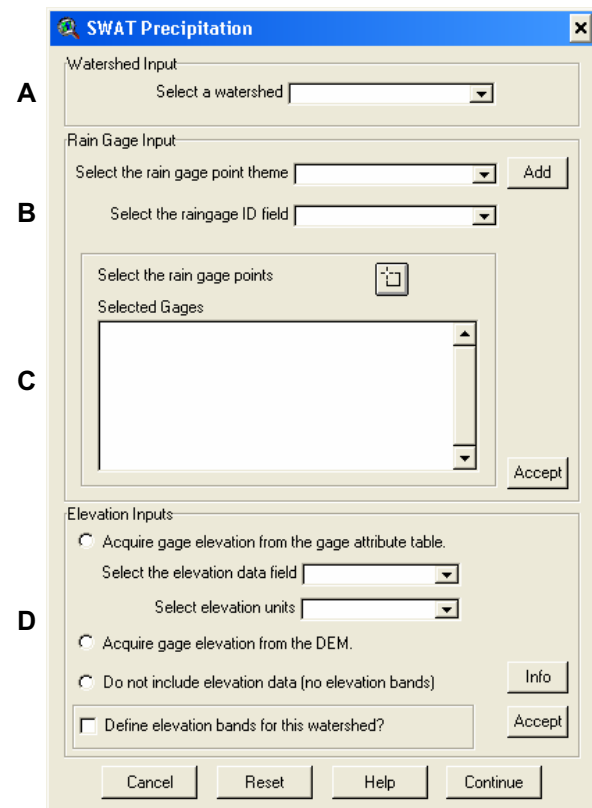


Figure 59. SWAT Precipitation dialog. A) Watershed Selection panel; B) Rain Gage Input Specification panel; C) Rain Gage Selection panel; and D) Elevation Input panel.

First, select a SWAT watershed from the combobox on the Watershed Selection panel. Select a point theme containing the raingage or gages to be used on the Rain Gage Input

Specification panel. Point themes can be added at this time with the **Add** button. Select the rain gage identifier field (this field cannot be called ID). The field values should correspond to the values found in the unweighted precipitation file, without the leading “G”. For example, Gage 24 from the GAGE_ID field in the attribute table will have precipitation values in the G24 field of the unweighted precipitation file.

Using the point selection tool on the Rain Gage Selection panel, select all raingages to be used. To create a uniform precipitation file, select 3 or fewer gages; to create a distributed precipitation file, select more. The identifiers will be displayed in the **Selected Gages** area. Click **Accept** to continue.

Elevation data is used by SWAT when adjusting precipitation and temperature estimates for orographic effects using the Elevation Bands option (see **SWAT>Generating precipitation files>Elevation Bands**). Two options are available for providing elevation data: extracting elevations from a DEM and extracting elevations from a field in the rain gage theme’s attribute table. If elevation data is not available for either of these options or if you do not wish to use elevation bands, you can generate files without elevation data. Elevation data cannot be added to an existing precipitation file. Elevation options are presented on the Elevation Input panel.

To use elevation data from the rain gage attribute table, select **Acquire gage elevation from the gage attribute table**. Select the elevation data field and units. If the units are not in meters or feet, you must provide the appropriate conversion value to convert your units to meters. AGWA will perform the conversion when calculating the mean elevation.

To use the elevation data from the DEM, first make sure that all of the selected points intersect the DEM. If any gage location falls outside the DEM, you must provide the elevation, in meters, at the AGWA prompt.

To exclude elevation data, select **Do not include elevation data (no elevation bands)**. You will not be able to define elevation bands with this precipitation file. When specifying inputs for a SWAT simulation, the elevation band option will

only be available for those watersheds that have bands defined and for precipitation files with elevation data defined.

To define elevation bands for the selected watershed, check the **Define elevation bands for this watershed?** box. This option is only available if elevation data is being provided. Once the precipitation inputs have been specified, AGWA will display the Elevation Bands dialog if this option is selected.

Click **Accept** when satisfied with the input selections. Click **Continue** to proceed to the Precipitation Weighting dialog. See **Uniform Precipitation** or **Distributed Precipitation**.

Both options require an unweighted precipitation file containing a minimum of three fields: YEAR, DAY, and a gage field. DAY refers to the Julian day of the year (1-366) with values repeating for each year in the record. The values in the gage fields must be in millimeters. Weighted averages will be adjusted for missing or negative precipitation values. See Figure 60 for an example of an unweighted precipitation file.

Year	Day	G20680	G20309	G27445	G22902	G
1960	1	7.4	6.4	190.5	0.0	
1960	2	0.3	0.5	1.3	0.0	
1960	3	0.0	0.0	0.0	0.0	
1960	4	0.0	0.0	0.5	0.0	
1960	5	0.0	0.0	0.0	0.0	
1960	6	0.0	0.0	0.0	0.0	
1960	7	0.0	0.0	0.0	0.0	
1960	8	0.0	0.0	0.0	0.0	
1960	9	0.0	0.0	0.0	0.0	
1960	10	0.0	2.5	7.4	24.1	
1960	11	15.8	15.8	19.8	0.0	

Figure 60. Example of an unweighted precipitation file.

AGWA tracks all generated precipitation files in the swatpfiles.dbf table. This table contains the watershed name, the precipitation file name, whether elevation data was included in the file, and the start and end dates of the file. Precipitation files are written to the project's *rainfall* directory. For watershed groups, a precipitation file is generated for each watershed in the group, indicated by the GROUP number at the end of the filename.

Uniform Precipitation

For this option, the user only needs to provide an unweighted precipitation file in addition to the rain gage information.

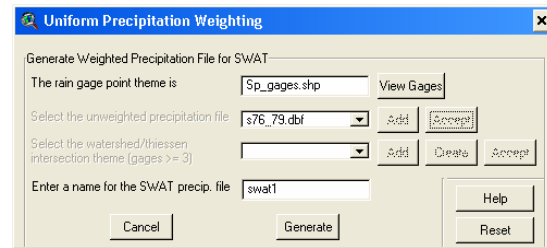


Figure 61. Uniform Precipitation Weighting dialog. (Note that the watershed/Thiessen intersection theme combobox and buttons are disabled. You do not need to provide this theme for uniform precipitation files.)

First, select the unweighted precipitation file (Figure 61). (The point theme and gage identifier field have already been selected.) The file can be added at this time by selecting **Browse**. Click **Accept** when satisfied with the selection. If any gage in the point theme selection is not found in the unweighted precipitation file, AGWA will terminate the process. If multiple gages (≤ 3) were selected, AGWA will use the values for the gage closest to the centroid of the watershed. Enter a name for the new precipitation file. Click **Generate** to generate the file.

Once the file has been successfully written, AGWA will continue to the elevation bands processing if that option was selected. This option is not available for watershed groups. See **SWAT>Generating precipitation files>Elevation Bands** for more information.

Distributed Precipitation

Distributed precipitation files use Thiessen polygons to calculate weighted averages for each subwatershed. Two additional steps are required before the precipitation file can be written. First, the Thiessen polygon theme must be created from the selected gages. Then, the Thiessen polygons must be intersected with the watershed theme to determine the weights. Thiessen polygon themes and Thiessen polygon-watershed intersection themes can be used more than once.

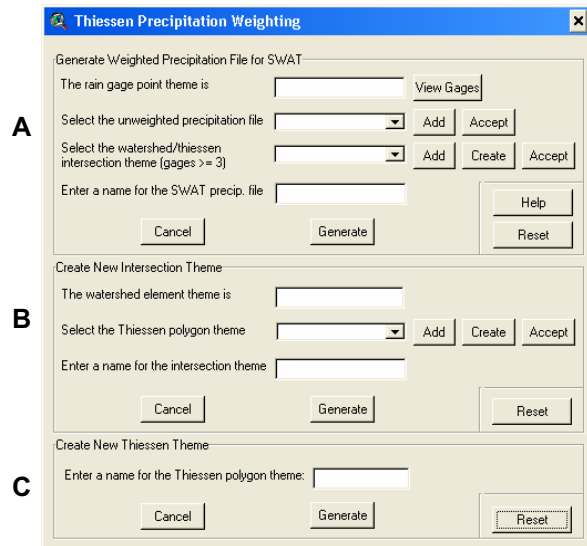


Figure 62. SWAT Thiessen Precipitation Weighting dialog. A) Precipitation Weighting panel; B) Intersection Theme Generation panel; C) Thiessen Polygon Theme Generation panel.

First, select the unweighted precipitation file from the Precipitation Weighting panel (Figure 62). The unweighted precipitation file must contain columns for each gage selected in the previous dialog (see Figure 63 for an example selection set). Again, a file can be added to the project at this time with the **Add** button. Click **Accept** to continue. If an intersection theme has been created, select it from the combobox. The user will need to identify the gage identifier field in the selected intersection theme. If the intersection does not exist, click **Create** to generate the shapefile. This activates the Intersection Theme Generation panel of the dialog.

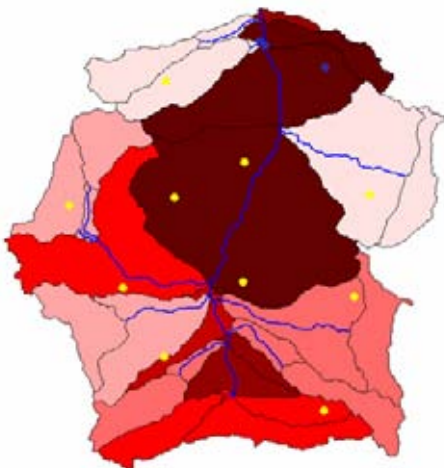


Figure 63. Rain Gage locations for a SWAT watershed.

If a Thiessen polygon theme has been generated for the selected raingage theme, select it from the combobox and click **Accept**. If a Thiessen polygon theme has not been created for the selected raingages, click **Create**. The Thiessen Polygon Theme Generation panel of the dialog is activated. In this section, enter a name for the new Thiessen polygon theme and click **Generate**. See Figure 64 for an example of a Thiessen polygon theme.

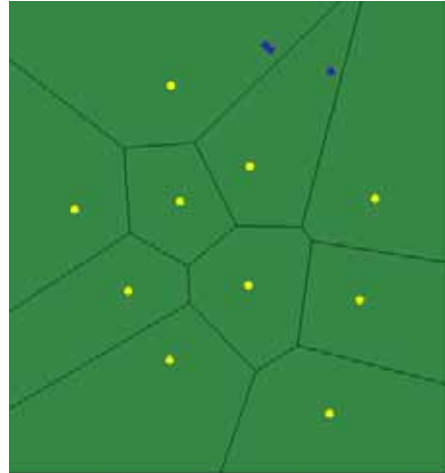


Figure 64. Thiessen polygon theme based on the selected rain gages.

Once the Thiessen polygon theme has been created, it is added to the Thiessen polygon combobox in the Intersection Theme Generation panel. Select the theme and click **Accept**. Enter a name for the new intersection theme and click **Generate**. The new intersection theme is then added to the intersection combobox in the original panel. Select the intersection theme and click **Accept**. Enter a name for the precipitation file and click **Generate** to create the file. See Figure 65 for an example of the Thiessen polygon/watershed intersection theme.



Figure 65. Thiessen polygon/watershed intersection theme.

If the gages in the intersection theme do not match the gages in the unweighted precipitation file, AGWA will display a message containing a list of gages that will not be used and a list of gages that will be used. This will not terminate the process.

The weighting scheme is modified to account for missing or negative precipitation values. The following outlines the weighting process:

- If all gages in a subwatershed have values then the weighted depth = weighted depth + (gage depth * gage weight)
- If all the gages in the watershed have zero values or no data then the weighted depth = 0.
- If one or more of the gages in the subwatershed have no data then
 - If all the gages for the subwatershed have no data, then set the weighted depth to the depth of the closest gage with a value unless there are more than one gage within the subwatershed, then the weighted depth is the depth of the gage closest to the subwatershed centroid
 - If some gages within a subwatershed have no data, then if the gage depth is negative the weighted depth is unaffected; otherwise the gage weight is adjusted as $(\text{gage weight} / (1 - \text{sum of the weights of the no data gages}))$.

The weighting process can take a considerable amount of time. Two factors affect the total processing time – the number of gages and the

length of the unweighted precipitation file. In both cases, processing times increase as the number of records increases. Processing times are also increased for watershed groups, increasing with the number of watersheds within the group. The AGWA Progress bar displays the number of days processed out of the total number of days to be processed. Once the file is written, AGWA will proceed to the elevation band processing if that option was selected. This option is not available for watershed groups. See **SWAT>Generating precipitation files>Elevation Bands** for more information.

Elevation Bands

Elevation bands allow users to adjust precipitation and temperature estimates based on orographic effects. These adjustments are made during the simulation process and do not affect the precipitation file generation. The process utilizes the elevation data acquired earlier in the precipitation file generation process as well as the mean elevation of the bands for each subwatershed.

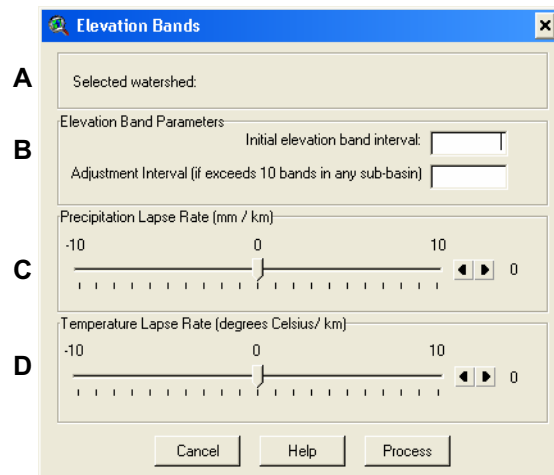


Figure 66. SWAT Elevation Bands dialog. A) Watershed Identification panel; B) Elevation Band Parameter Specification panel; C) Precipitation Lapse Rate Specification panel; D) Temperature Lapse Rate Specification panel.

On the Elevation Bands dialog (Figure 66), enter the band interval and interval adjustment values on the Elevation Band Parameter Specification panel. Specify the precipitation lapse rate (Precipitation Lapse Rate Specification panel) and the temperature lapse rate (Temperature Lapse Rate Specification panel). Click **Process** to generate the bands.

SWAT limits the number of bands for a given subwatershed to 10. To fall within this limitation, AGWA adjusts the elevation interval so that no subwatershed exceeds the 10 band limit. The elevation interval is the same across the watershed. The user enters the initial elevation interval (in meters) as well as an interval adjustment factor. This value is used to increment the initial interval value if necessary. For example, the initial interval is set to 30m with an adjustment factor of 10m. If one of the subwatersheds contains 11 bands, the initial interval is increased to 40m and new bands are generated. This process is repeated until all subwatersheds have 10 or fewer elevation bands. Figure 67 shows elevation bands defined for a SWAT subwatershed.

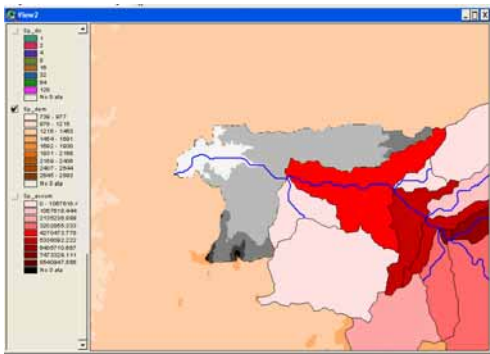


Figure 67. Discretization of elevation bands (gray regions).

Once the bands are determined, AGWA generates ELE data files. These files are placed in the *elev* directory within the project's *rainfall* directory. A file is created for each subwatershed, with <watershed name>_WS#.ele. Each file includes the following information:

- A comment indicating the subwatershed
- The precipitation lapse rate (if zero, SWAT will not adjust precipitation estimates)
- The temperature lapse rate (if zero, SWAT will not adjust temperature estimates)
- The mean elevation of the subwatershed
- The number of elevation bands, the midpoint elevation of each band, and the fraction of the watershed within each band (this information is written on one line per subwatershed)

These files are accessed when AGWA writes the subwatershed general input files (SUB). The user can also decide, when determining the inputs for a SWAT simulation, to use or not use the generated elevation bands.

Inputs and Execution

Once the watershed has been parameterized and a precipitation file generated, select **AGWA Tools>Write output and run SWAT** (Figure 68).

Figure 68. SWAT Input dialog. A) Watershed Selection panel; B) Precipitation File Selection panel; C) Simulation Length panel; D) Output Frequency panel; E) Temperature Selection panel; F) Directory Name panel; G) Advanced Options panel; H) Weather Generator Station Selection panel.

First, select the watershed on the Watershed Selection panel. If HRUs were generated for the selected watershed, this option can be simulated at this time.

Select a precipitation file for the selected watershed on the Precipitation File Selection panel. Only precipitation files found in the *swatpfiles.dbf* can be used for simulation. If elevation bands were generated for the watershed and elevation data used when generating the selected precipitation file, the **Use elevation bands?** option is activated. Check the box to use the elevation bands.

The beginning date of the simulation is based on the start date of the selected precipitation file. The date is entered as MMDDYYYY on the Simulation Length panel. This value can be changed if it does not reflect the desired start date. Enter the number of years to simulate. The precipitation file must contain all of the records necessary to simulate the time period from the specified start date to the end date indicated by the number of years.

Select the output frequency on the Output Frequency panel. Simulations can be run on a daily, monthly or yearly frequency. Please note that processing times increase for simulations run at the daily timestep.

Choose the type of temperature data to use during simulation on the Temperature Selection panel. Observed temperature data is the best option, but may not be available. If providing this type of file, refer to the included TMP file and the SWAT User's Manual for the data and formatting requirements.

Enter a simulation name on the Simulation Name panel. This name will be used to create a directory in the *simulations* directory. All input files for the simulation will be written to this directory. Simulation names are limited to 5 characters in length.

Determine which, if any, advanced options to use during the simulation from the Advanced Options panel (see **SWAT>Inputs and Execution>Advanced Inputs**). If HRUs were calculated for the watershed during the last parameterization, these can be used at this time. Other available options include groundwater simulation, rainfall adjustment factors and nitrogen and phosphorous simulation. To include any of these three options, check **Use advanced parameters**. Inputs for these options can be entered in the next dialog.

Select a weather generator file selection method on the Weather Generator Station Selection panel. See **SWAT>Inputs and Execution>Selecting the weather generator file** for more information.

Click **Continue** to proceed. If advanced parameters will be used, AGWA will proceed to the SWAT Advanced Inputs dialog; otherwise, AGWA generates the input files and initializes SWAT (Figure 69).

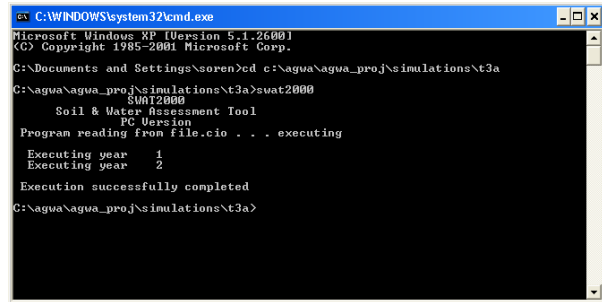


Figure 69. The SWAT Simulation (MS-DOS window).

Selecting the weather generator file

A weather generator file contains statistical data for a gage location that is used by SWAT to estimate daily maximum and minimum temperatures, rainfall, and other climate parameters required by SWAT. Select the station closest to the watershed. To aid in this process, a point theme of the available stations is provided in the *datafiles* download. These stations are the same as those found in the provided WGN table. Both options are available through the Weather Generator Station Selection dialog (Figure 70).

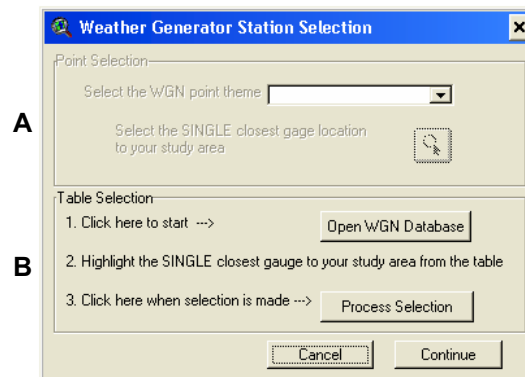


Figure 70. Weather Generator Station Selection dialog. A) Select by Point Theme panel; B) Select by Table panel.

If selecting from the table, click **Open WGN database** and select the record of the gage closest to the watershed. Return to the dialog and click **Process Selection** to return to the SWAT Inputs dialog.

If using the point selection option, select the point theme containing the stations. Use the point selection tool to select the ONE gage closest to the watershed. Click **Continue** to return to the SWAT Input dialog.

Advanced Inputs

Three options are provided by the SWAT Advanced Options Input dialog (Figure 71). Any or all of the options can be utilized in a simulation. If you do not wish to use one of the options, simply leave the default values provided by AGWA.

The image shows the 'SWAT Input Parameters' dialog box. It is divided into three main sections labeled A, B, and C. Section A, 'Monthly Rainfall adjustment factors (% change, integer values)', contains input fields for each month from Jan to Dec. Section B, 'Groundwater Input File (.gwi)*', contains input fields for parameters: SHALLST, DEEPST, GW_DELAY, ALPHA_BF, GWQMN, GW_REVAP, REVAFPMN, RCHRG_DP, and GW_SPLYD. Section C, 'N/P simulation', has a checkbox for 'Simulate N/P?' and a larger area with a checkbox 'Enter CROP values for each subwatershed?' and an 'Identify CROP' button. At the bottom are 'Help' and 'Continue' buttons.

Figure 71. SWAT Advanced Inputs dialog. A) Rainfall Adjustment Factors panel; B) Groundwater Input panel; C) Nitrogen and Phosphorus Simulation panel.

Rainfall Adjustment Factors

Rainfall adjustment factors modify the daily rainfall estimates for a given month. These values are given in percent on the Rainfall Adjustment Factors panel. For example, the rainfall adjustment factor for July is set to 12, so the daily estimates for July are adjusted to 112% of the original values. The factors are the same for all subwatersheds.

Groundwater

This option allows users to specify parameters for the groundwater files in SWAT on the Groundwater Input panel. SWAT simulates groundwater movement with two aquifer systems – a shallow, unconfined aquifer that contributes to the streams within the subwatershed and a deep, unconfined aquifer that contributes to streams outside the subwatershed. The specified values are used for all subwatersheds.

Nitrogen and Phosphorous Modeling

This provides basic water quality modeling through SWAT. This process can be undertaken with no additional information; however, the CROP

values for each subwatershed can be modified to reflect different management or landcover types.

To modify the CROP values, double-click the row for the subwatershed on the Nitrogen and Phosphorus Simulation panel. Select a new CROP type and click **Return**. The list will be modified to reflect the new CROP number. These will be used when parameterizing the current SWAT simulation. The CROP values in the watershed are not affected.

Additional parameters are included in the channel and subwatershed results tables and can be viewed with the Results viewer. See **Results** for more information regarding these parameters.

Running SWAT for a watershed group

This process is similar to that described above; however, within the created simulation directory, a subdirectory for each watershed in the group is created as <simulation name>_GROUP. Each watershed in the group is simulated separately, with different input files and output files.

Results

Simulation results must be imported following the successful execution of SWAT or KINEROS. Due to the nature of the various batch processing methods, automatic import is no longer feasible. By separating this functionality from the model simulation, simulation results can now be re-imported if accidentally removed from the project or otherwise corrupted.

KINEROS Plane Outputs

Infiltr_m: infiltration (mm)
Infiltr_e: infiltration (in)
Runoff_mm: runoff (mm)
Runoff_m3: runoff (m³)
Sed_out: sediment yield (kg)
Pflow_m3s: peakflow (m³/s)
Pflow_mmh: peakflow (mm/hr)
PSedQ_kgs: peak sediment discharge (kg/s)
Percent Error: mass balance error (%)

KINEROS Stream Outputs

Infiltr_m: infiltration (mm)
Infiltr_e: infiltration (in)
Runoff_mm: runoff (mm)
Runoff_m3: runoff (m³)
Sed_out: sediment yield (kg)
Pflow_m3s: peakflow (m³/s)
Pflow_mmh: peakflow (mm/hr)
PSedQ_kgs: peak sediment discharge (kg/s)
Z_change: channel scour (mm/m²)
Percent Error: mass balance error (%)

SWAT Subwatershed outputs

Precip_mm: total precipitation for the subwatershed for the given time period (mm)
ET_mm: estimated evapotranspiration (mm)
Perc_mm: estimated percolation for the subwatershed (mm)
Surq_mm: estimated surface runoff for the subwatershed (mm)
Tloss_mm: estimated transmission loss for the subwatershed (mm)
Watyld_mm: estimated water yield (mm)
SedYld_t_h: estimated sediment yield (t/ha)
OrgN_kg/ha: Organic Nitrogen contributed by the subwatershed to the channel (kg/ha)
OrgP_kg/ha: Organic Phosphorus contributed by the subwatershed to the channel (kg/ha)
SedP_kg/ha: Mineral Phosphorus attached to sediment contributed by the subwatershed to the channel (kg/ha)

SurN_kg/ha: NO₃ contributed by surface runoff from the subwatershed to the channel (kg/ha)
SolP_kg/ha: Soluble Phosphorus contributed by surface runoff from the subwatershed to the channel (kg/ha)


SWAT Stream Outputs

Watyld_mm: estimated water yield (mm)
Tloss_m3s: estimated transmission loss (m³/s)
SedYld_mtn: sediment yield (tons)
Q_cmd: channel runoff (m³/day)
SedCon_mg/kg: Sediment concentration (mg/kg)
OrgN_kg: Organic Nitrogen transported by water from the channel (kg)
OrgP_kg: Organic Phosphorus transported by water from the channel (kg)
NO3_kg: Nitrate transported by water from the channel (kg)
NH4_kg: Ammonium transported by water from the channel (kg)
NO2_kg: Nitrite transported by water from the channel (kg)
MinP_kg: Mineral Phosphorus transported by water from the channel (kg)

SWAT HRU outputs

Same as the subwatershed results but separated for each HRU in a subwatershed. These results cannot be displayed in the view.

Modifications for AGWA 1.5 allow results tables to be added back into a project without needing to rerun the simulation. Because the files end in ".dbf", these files can be added using the ArcView Tables **Add** functionality. The files can also be added using the Results dialog **Import** button.

To view results, go to **AGWA Tools>View KINEROS Results** or **View SWAT Results** (Figure 72). Select a watershed from Watershed Selection panel. Any previously imported simulations will be added to the simulations combobox on the Simulation Selection panel. If the combobox is empty or the simulation to be viewed is not listed, click the **Import** button (). Simulations can be imported at any time and can be reimported if deleted from the project. Select one or more simulations from the provided list to import. Once all of the files are imported, the simulation is added to the simulations combobox. Select a simulation.

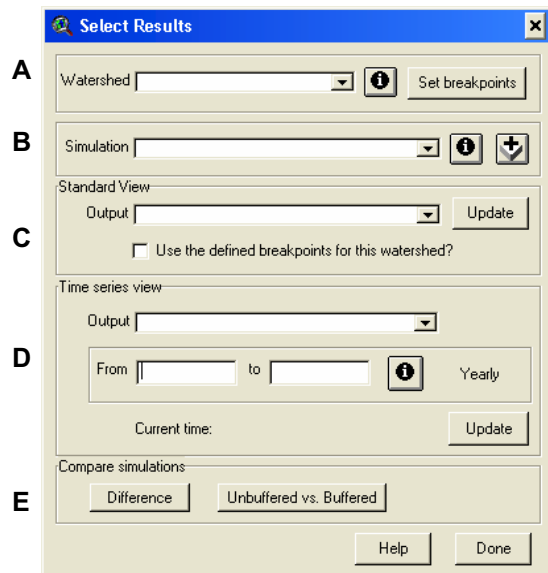


Figure 72. View Results dialog. A) Watershed Selection panel. B) Simulation Selection panel; C) Standard View panel; D) Time Series View panel; E) Simulation Comparison panel.

After selecting a watershed, the user can also use any previously imported simulations to set classification breakpoints. Click **Set breakpoints** and select from the list of simulations to determine the classification scheme for each output.

Several options are available for viewing the results. All simulations can be viewed with the standard outputs on the Standard View panel (Simulation Totals). Select an output type and click **Update** to view the simulation totals. If breakpoints have been defined, the derived classifications can be used by checking the **Use the defined breakpoints for this watershed** box.

If the simulation included KINEROS hydrographs or any SWAT output (excluding HRU simulations), the results can be viewed with the Time Series View option. Select an output in the Time Series output combobox. If SWAT, enter a date range based on the output frequency of the simulation. Acceptable formats can be viewed with the Identify button. Click **Update** to begin the time series display.

Simulations can also be compared with options on the Simulation Comparison panel. To compare a buffered watershed with the original, unbuffered watershed, use the **Unbuffered vs. Buffered** option. Otherwise use the **Difference** option.

Setting and using the breakpoints

This option allows users to display any imported results for a watershed with the same classification scheme. It is similar to applying a stored AVL legend for the watershed with two important differences – the breakpoints can be changed as necessary and the color schemes are identical to those used for the standard AGWA results display. These breakpoints are only used if the **Use the defined breakpoints for this watershed?** checkbox is checked; otherwise, the breakpoints are based on the selected simulation and output values.

To set the breakpoints, first select a watershed. Click **Set breakpoints**. Select any or all of the simulations listed in the provided listbox. Differenced results cannot be used to set the breakpoints to avoid misapplication of those values to a non-differenced simulation. AGWA will determine the maximum and minimum values for each output parameter from all of the selected simulations. The breakpoints are then calculated for each output parameter. The values are stored in the watershed metadata file for use in later AGWA sessions. Breakpoints can be reset as necessary by clicking the **Set breakpoints** button and selecting a different range. The simulations used to determine the breakpoints can be viewed with the watershed identification button.

Simulation Totals

This option displays the results, by element, for the simulation. For KINEROS, the simulation in this case refers to a single OUT file, so if the simulation contains multiple parameter file/precipitation file pairs, the outputs will be imported and displayed separately. For SWAT, the simulation totals refers to the average values for the simulation regardless of the output frequency. Results for a specific time period within a SWAT simulation can be viewed with the SWAT timestep option.

SWAT simulations using HRUs have an additional output table, <simulation name>_hru_results.dbf. This table contains the estimates for each HRU for each time step. The time step for monthly and yearly simulations are indicated by a “Y” (annual estimate), “M” (monthly estimate) or “S” (simulation estimate) before the number in the TIME field. The identifiers indicate which type of summary data is found within the record. These results cannot be displayed within AGWA as HRUs are not linked to a specific spatial component. The table is provided for analysis only.

See **Appendix B: Analyzing Watersheds with AGWA and ATtiLA**.

KINEROS Time Series

This option can only be used if hydrographs for each element are output by KINEROS (see **KINEROS>Inputs and Execution>Hydrograph Output**). These values are compiled into a SIM table for the watershed; one for the plane elements and one for the channel elements. The view is updated every 2-3 seconds for the duration of the simulation or until the selected output values are zero.

Select an output on the Time Series View panel. Click **Update** to display the results. The ranges cannot be modified for KINEROS. AGWA assumes the simulation timestep is one minute (the AGWA default). The current time is displayed next to the **Update** button.

SWAT Time Series

This option can be used for any frequency SWAT simulation. Like the KINEROS timestep option, the view is updated every 2-3 seconds for the duration of the event or for the selected range for the selected output. Simulations using HRUs cannot be displayed with this method.

Select an output on the Time Series View panel. Enter a range of dates. The simulation output frequency is indicated to the right of the range text boxes. Date ranges must be formatted based on the output frequency, with

- Daily = MM/dd/yyyy
- Monthly = MM/yyyy
- Yearly = yyyy

These formats can be displayed with the Information button. Click **Update** to display the results. The current time is displayed next to the **Update** button.

Unbuffered vs. Buffered comparison

This option allows users to compare the original, unbuffered watershed with the buffered watershed. Because the unbuffered and buffered watersheds are composed of a different number of elements, the differencing option is not available.

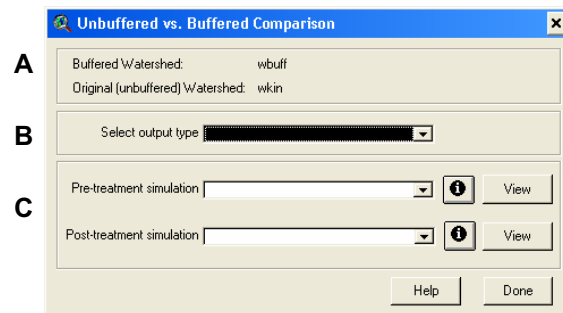


Figure 73. Unbuffered vs. Buffered Comparison dialog. A) Watershed Information panel; B) Output Selection panel; C) Simulation Selection panel.

The watersheds to be compared are identified in the Watershed Information panel (Figure 73). First, select an output type in the Output Selection panel. Then select the pre-treatment simulation (a simulation performed with the original watershed) on the Simulation Selection panel. To display this simulation, click **View**. To compare the buffered watershed, select a post-treatment simulation and click **View**. AGWA displays the post-treatment results using the classification scheme of the pre-treatment simulation. Click **Done** to return to the main Results dialog.

Differencing

This option generates new results tables containing the difference in output values between two simulations for a watershed. This can be used to analyze the impacts of different landcover types or events sizes. The difference can be expressed as absolute change or as percent change.

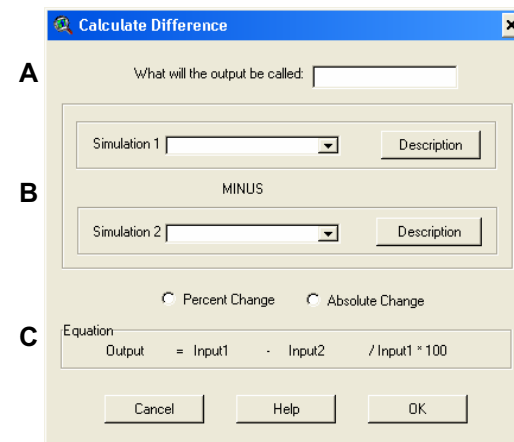


Figure 74. Difference dialog. A) Simulation Name panel; B) Simulation Selection panel; C) Equation panel.

Click the **Difference** button after selecting a watershed. (This option cannot be used to

compare buffered vs. unbuffered watersheds or with previously differenced results.) In the Calculate Difference dialog (Figure 74), enter a name for the new tables on the Simulation Name panel. Select the two input simulations on the Simulation Selection panel. Metadata for the simulations can be viewed by clicking the **Description** buttons. Select the type of output to calculate: percent change or absolute change. The equation used to determine the new outputs is displayed in the Equation panel. If satisfied, click **OK** to create the new tables. AGWA will return to the Results window with the new simulations results added to the simulations combobox. The results can then be displayed using the standard AGWA functionality.

Due to variations in SWAT outputs for different types of simulations, the differenced results contain only the estimates for outputs common to both simulations. For example, SIMA was performed with the Nitrogen and Phosphorus Simulation option but SIMB was not. The results specific to Nitrogen and Phosphorous modeling will not be included in the calculated differences. This also affects HRU outputs.

Rerunning Simulations

The tools described here are provided to enhance the functionality of AGWA. The capability to rerun existing simulations allows users to modify input values for calibration or, for SWAT, to include inputs not currently supported by AGWA while taking advantage of AGWA's results display options for visual analysis and comparison. AGWA assumes the modified input files will be correctly edited and formatted for the model.

KINEROS

To rerun a KINEROS simulation, select **AGWA Tools>Write output file and Run KINEROS**. Create a new simulation. Select the parameter file and precipitation file to run. AGWA will copy these files to a new simulation directory and run KINEROS. The original files remain in the original simulation directory; no output files are overwritten. Modified parameter files, saved under a different name, can be imported into the new simulation using the **Import** button. Any parameter files that are to be imported must be in an existing simulation directory for that watershed. The simulation metadata contains a list of all parameter files written or imported for a given watershed. This list can be viewed in the "SIMULATION" section of the metadata when viewed with the **AGWA Tools>View metadata** option. Parameter file names, even if written to different directories, cannot be the same for a watershed. For example, for two simulations, SIMA and SIMB, the parameter file name cannot be sim1.par even though the files are written to different directories. Imported file names also must not duplicate any existing file name for the watershed.

SWAT

Select **AGWA Tools>Rerun Existing Simulation** to view the Rerun Simulations dialog (Figure 75). Select the watershed and the simulation. AGWA will copy the contents of the original simulation to a new simulation folder, saving the original files, and rerun SWAT. The simulation metadata for the new simulation will indicate which simulation is being rerun. Bear in mind, the original simulation files and the new simulation files will be the same except for the outputs. To retain the original input files, copy the simulation directory to a new location before editing any files.

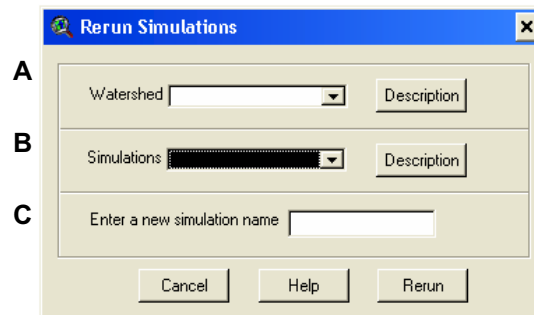


Figure 75. Rerun Simulation dialog. A) Watershed Selection panel; B) Simulation Selection panel; C) Simulation Name panel.

First, select the SWAT watershed on the Watershed Selection panel. The watershed metadata can be viewed by clicking the **Description** button. Then, choose the simulation on the Simulation Selection panel. The simulation metadata can be viewed using the **Description** button. Enter a new simulation name (maximum 5 characters) on the Simulation Name panel. Click **Rerun**.

Watershed group simulations can also be rerun using this option. As with individual watersheds, all required files are copied to the new simulation directory.

Rerun simulations contain two additional metadata properties – a parameter indicating that the simulation is not original and the name of the original simulation. In all other regards, AGWA treats the rerun simulation as a normal SWAT simulation.

Metadata

Metadata Structure

Watershed metadata is stored in an object database file (ODB). These files are created during the delineation and discretization process and are updated as necessary throughout the various AGWA processes. Stored information includes discretization inputs, current landcover and soils selections, simulation information, and breakpoint information if classifications were set when displaying results.

The watershed's metadata file is identified as <watershed name>.odb. It is located in the project's working directory (*av_cwd*). If the file is lost or corrupted, the watershed can no longer be used in AGWA.

For watershed outlines, including watershed group discretizations, the metadata includes the names of the input DEM, flow direction grid, flow accumulation grid, and stream map grid. The date the watershed was generated is also stored. The names of the input grids are accessed when reusing the outline(s); the specified files must be located in the active view.

For watershed discretizations, the metadata is separated into four sections: Delineation and Discretization, Parameterization, Results, and Breakpoints. The breakpoint information is not displayed in the AGWA Metadata viewer (Figure 76).

View watershed metadata

Watershed metadata can be viewed by going to **AGWA Tools>View metadata**. This opens the AGWA Metadata Viewer (Figure 76). Select a watershed outline or watershed discretization on the Watershed Selection panel to view the metadata in the Metadata panel. The metadata cannot be edited except for the user comments.

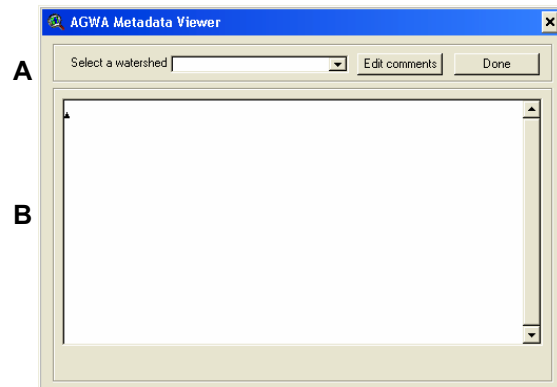


Figure 76. Metadata Display dialog. A) Watershed Selection panel; B) Metadata panel.

Delineation and discretization metadata includes the DEM name, flow direction name, flow accumulation name, the stream map, the DEM resolution, the date the watershed was created, the model the watershed was parameterized for, the CSA as area and percent, the units of the CSA area, the watershed area, the number of streams in the associated stream network, the hydraulic geometry relationship, if the watershed represents a watershed group, if the watershed contains channel buffers, if the watershed was created with ponds or reservoirs, the current landcover parameterization, the current soils parameterization, the selected KINEROS flow length method, if elevation bands exist and if HRUs exist. If the watershed is a watershed group, the CSA, area and stream number values are stored for each watershed in the group.

Results metadata includes the precipitation file used, the landcover and soils themes used and the date the simulation was created. Additional information is described in the **View simulation metadata** section.

KINEROS Results metadata includes a list of parameter files generated for the selected watershed. This list includes the full path name, the landcover and soils themes used, and the dates the files were created.


Add user comments

User comments can be added or edited from the Metadata dialog. Once a watershed has been selected, click **Edit comments**. Enter any comments in the provided text field (although the

field appears small, it can accommodate lengthy comments). Click **OK** when satisfied with the comments. To remove comments, delete all text from the field and click **Cancel**. The comments section will be automatically updated.

View simulation metadata

Simulation metadata can be viewed in either the Metadata Viewer described above or from any of the results dialogs (View Results, Differencing, or Unbuffered vs. Buffered Comparisons) or, for SWAT simulations, through the Rerun Simulations dialog. The option is presented as a **View** button,

Description button, or an **Identify** button () next to the simulation combobox. Only metadata for the selected simulation is displayed, including KINEROS multipliers.

Metadata for differenced results includes only the equation used (as shown in the Differencing dialog), the type of equation (absolute change or percent change), and the date the results were created. The simulations used to calculate the results can be found in the equation.

Metadata for KINEROS simulations includes the parameter file/precipitation file pair, the duration of the event, the landcover and soils themes used to generate the parameter file, the multipliers used when generating the parameter file, the date the parameter file was created and the date the simulation was created. A list of multipliers is provided for each parameter file.

Metadata for SWAT simulations includes the landcover and soils themes used, the precipitation file used, the number of years in the simulation, the start date of the simulation, the output frequency, if nitrogen and phosphorus simulation occurred, if HRUs were used, if elevation bands were used, if the simulation was rerun (and the original simulation), and the date the simulation was created.

Managing AGWA Datasets

AGWA watersheds have several files associated with them, including stream network, parameterization tables, simulation inputs and outputs and metadata. These files are stored in specific locations within an AGWA project directory. To transfer datasets from project to project or user to user, AGWA now provides an export/import tool (Figure 77) that can package all required watershed files. Use of this functionality is strongly encouraged if AGWA datasets are to be transferred.

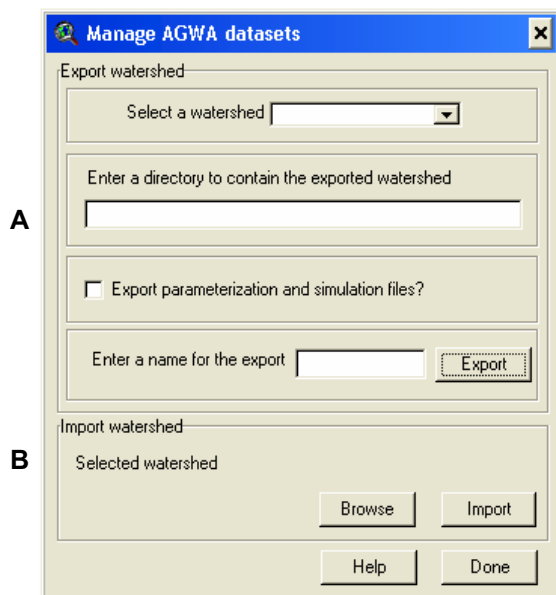


Figure 77. Manage AGWA Datasets dialog. A) Export Watershed panel; B) Import Watershed panel.

Package a watershed for export

To ensure that that a watershed moved from one project to another will be usable by AGWA, you must export it using the AGWA tool (Export Watershed panel). This option copies the watershed, stream and metadata files to an export directory to a user-specified location. This directory can then be transferred to another user, project directory or computer without losing any of the necessary files. We recommend compressing the export directory before sending the files as an email attachment to avoid file corruption.

Simulation and parameterization files can also be exported. The simulation files will be copied to a new directory in the specified location called

simulations/<simulation name>. If this option is not checked, all simulation and parameterization will be removed from the metadata.

Import an AGWA watershed

Because AGWA searches for the watershed components in specific places, exported files should be imported using the AGWA management tool (Import Watershed panel). This tool moves the exported files to the proper locations in the current AGWA project.

Use the **Browse** button to locate the watershed to import. The directory must be uncompressed before this step. The selected watershed will be displayed in the dialog. Click **Import** to transfer the files to the current project's directories. AGWA will place all files in the appropriate directories, including metadata and simulation files.

Advanced Options

The advanced options for AGWA include the Landcover Modification Tool, the SSURGO Tool, Hydraulic Geometry relationships and AGWA preferences. The Landcover Modification Tool allows users to modify an existing landcover surface to account for fire, urbanization, climate change or other natural or anthropogenic changes. The tool can be used with the supported AGWA datasets (MRLC, NALC, etc.) or with custom-defined landcovers, provided the custom lookup tables conform to the AGWA standard. The SSURGO Tool was designed to resolve certain issues with SSURGO datasets in AGWA as well as to improve the overall user experience. With the tool, users can merge spatial and tabular datasets, import SSURGO tables, and correct two errors in the spatial dataset that prevent AGWA from successfully parameterizing a watershed. Hydraulic geometry relationships can be defined and reset using this option. The AGWA preferences include the KINEROS baseflow option, model-specific warnings, the ability to change the DAT default files for SWAT, and the ability to select a flow length method for KINEROS. These options are described in more detail below.

Landcover Modification Tool

The Landcover Modification Tool (LCMT) was originally designed to be used as a separate extension to AGWA for ESRI's ArcView GIS software. The tool was combined with AGWA for version 1.4 as part of the Advanced Options component. The LCMT allows users to modify a landcover map and run AGWA to determine the hydrologic effects of the landcover change. The LCMT is accessed through **AGWA Tools>Advanced Options>Landcover Modification Tool**. See Figure 78 for the LCMT-AGWA workflow.

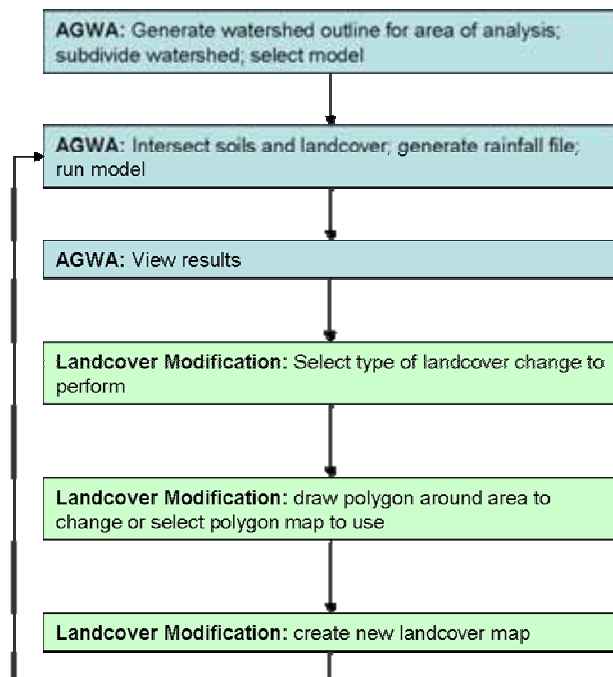


Figure 78. Landcover Modification workflow within AGWA.

Any landcover supported by AGWA can be modified with the tool, including custom landcovers. The classification choices for the modified surface are limited to those classifications found in the selected landcover lookup table; users can modify these tables or create new tables to include different classes and parameter values. An example of this type of modification can be found in the included MRLC_FIRE table.

The Landcover Modification Tool dialog offers five modification options:

- Change all of the landcover in an area to a new landcover type using an interactively drawn polygon
- Change one landcover type in an area to a new landcover type
- Change all of the landcover in an area to a new landcover type using a polygon map
- Change all of the landcover in an area to 2-3 new landcover types in a spatially distributed random pattern
- Analyze an area using a burn severity map

To proceed, zoom in on the area of interest, select which type of landcover modification you would like to perform, and click the **Continue** button (Figure 79).

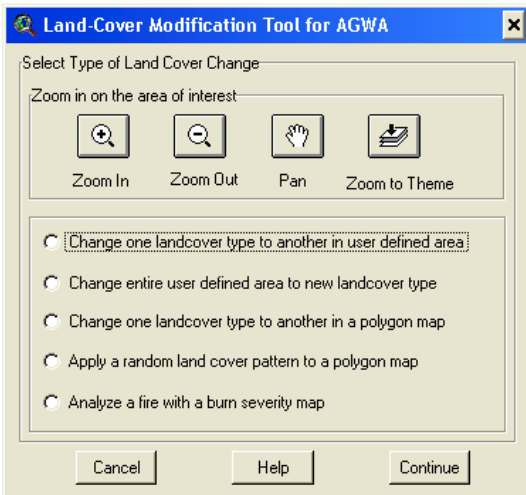


Figure 79. Landcover Modification Tool Selection dialog.

Change all of the landcover in an area to a new landcover type using an interactively drawn polygon

When this option is selected, the user is presented with the following screen (Figure 80):

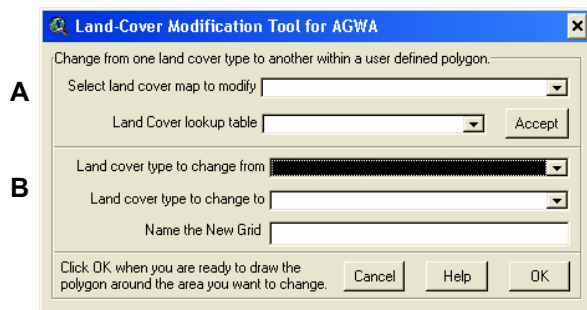


Figure 80. LCMT Change landcover based on interactively drawn polygon dialog. A) Landcover Selection panel; B) Landcover Change Information panel.

Select a landcover surface to modify in the first combobox on the Landcover Selection panel. Select the landcover classification of the selected surface (the lookup table for this classification should be loaded in the project before running the tool). Select the landcover type to change and the landcover type to replace it on the Landcover Change Information panel. Enter a name for the new surface. Click **OK** to begin drawing a polygon around the area you wish to analyze (Figure 81). Double-click to finish the polygon. The LCMT will

create a new landcover map with the landcover type specified. This map can then be used during landcover and soils parameterization.

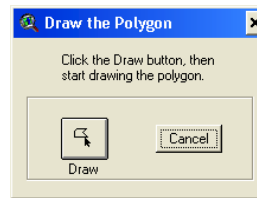


Figure 81. LCMT Draw polygon dialog.

Change one landcover type in an area to a new landcover type

When this option is selected, the user is presented with the following screen (Figure 82):

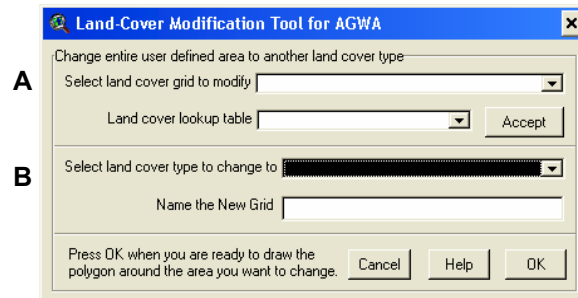


Figure 82. LCMT Change entire area dialog. A) Landcover Selection panel; B) Landcover Change Information panel.

Select the landcover grid to modify on the Landcover Selection panel. Select the landcover classification of the selected surface (the lookup table for this classification should be loaded in the project before running the tool). Select the new landcover type on the Landcover Change Information panel. Enter a name for the new surface. Click **OK** to begin drawing the polygon around the area you wish to analyze. The LCMT will create a new landcover map with the landcover type specified. This map can then be used during landcover and soils parameterization.

Change all of the landcover in an area to a new landcover type using a polygon map

When this option is selected, the user is presented with the following screen (Figure 83):

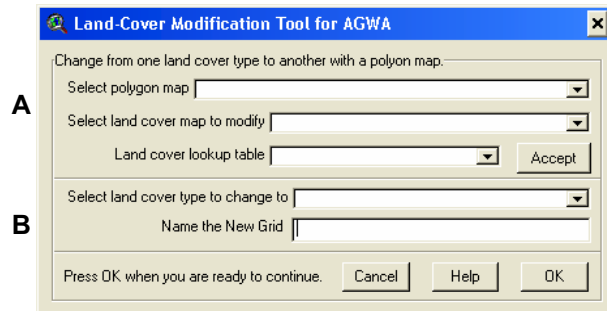


Figure 83. LCMT Change landcover based on polygon map dialog. A) Landcover and Polygon Map Selection panel; B) Landcover Change Information panel.

Select a polygon theme to define the modification area on the Landcover and Polygon Map Selection panel. Select the landcover map to modify. Select the landcover classification of the selected surface (the lookup table for this classification should be loaded in the project before running the tool). Select the new landcover type on the Landcover Change Information panel. Enter a name for the new surface. Click **OK** to create the new landcover map. The LCMT will create a new landcover map with the landcover type specified. This map can then be used during landcover and soils parameterization.

Change all of the landcover in an area to 2-3 new landcover types in a spatially distributed random pattern

This option provides two types of random distributions – completely spatially random surfaces and multifractal randomly distributed patchy surfaces. The multifractal surface is generated with the Landcover Modification Fractal executable (LCMF) that is provided on the AGWA website. See **Appendix C: Landcover Modification Fractal Component** for a description of the LCMF model.

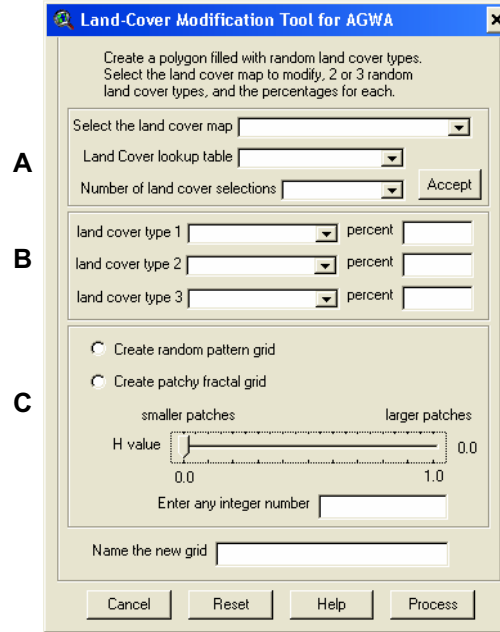


Figure 84. LCMT Random Pattern dialog. A) Landcover Selection panel; B) Landcover Change Selection panel; C) Random Parameter Selection panel.

First, select the landcover surface and classification on the Landcover Selection panel (Figure 84). Select the number of classes to use during modification on the Landcover Selection panel. Click **Accept** to enable the landcover type selection controls. Select the new landcover types and enter a percentage for each on the Landcover Change Selection panel. The combination of these values must sum to 100.

Select a random distribution on the Random Parameter Selection panel. **Random pattern** refers to the completely spatially random surface. This option does not require any additional inputs. **Patchy fractal** refers to the multifractal surface option. To use this option, select an *H* value using the slider. This value indicates the size of the patches in the final surface, where patch size increases as *H* increases. Enter any negative integer value to act as the random seed.

Enter a name for the new surface. Click **Process** to create the new surface.

Analyze an area using a burn severity map

This option modifies a landcover surface based on a burn severity map. The new landcover types are based on the combination of pre-fire conditions and the burn severity for each cell in the landcover grid.

Two additional inputs are required to use this option: a burn severity polygon theme (see Figure 85) with a GRID_CODE field containing unique integer identifiers and a CLASS field containing a string descriptor of the burn severity (i.e. low, medium, high, or unburned) and a change table describing the transition from the unburned type to the burned type. The change table (Figure 86) consists of three fields: PREBURN, POSTBURN, and SEVERITY. PREBURN and POSTBURN contain the integer identifiers found in the landcover lookup table; SEVERITY contains the string descriptors as found in the burn severity map. Both PREBURN and POSTBURN must have corresponding values in the associated landcover lookup table to be used within AGWA.

Shape	Grid code	Class	Count	S1
Polygon	-9999	Clouds	122	
Polygon	1	Unburned	113	
Polygon	2	low	123	
Polygon	3	moderate	366	
Polygon	4	high	114	

Figure 85. Modified MRLC table containing landcovers for fire.

PreBurn	Severity	PostBurn
41	low	410
42	low	420
43	low	430
51	low	510
41	moderate	411
42	moderate	421
43	moderate	431
51	moderate	511
41	high	412
42	high	422
43	high	432
51	high	512

Class	Name
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
51	Shrubland
410	Deciduous Forest, low severity burn
420	Evergreen Forest, low severity burn
430	Mixed Forest, low severity burn
510	Shrubland, low severity burn
411	Deciduous Forest, moderate severity
421	Evergreen Forest, moderate severity
431	Mixed Forest, moderate severity burn
511	Shrubland, moderate severity burn
412	Deciduous Forest, high severity burn
422	Evergreen Forest, high severity burn
432	Mixed Forest, high severity burn
512	Shrubland, high severity burn

Figure 86. Example of a change table (left) for the Burn Severity component and the corresponding values in the landcover lookup table (right).

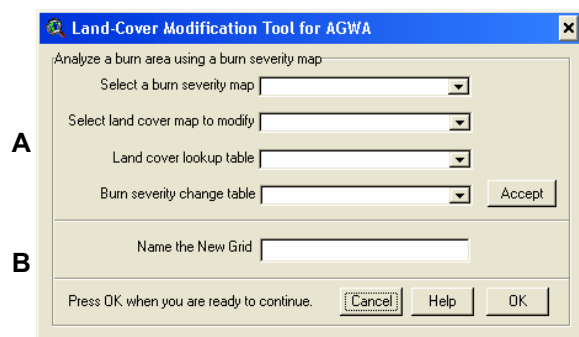


Figure 87. LCMT Burn Severity dialog. A) Burn Severity and Landcover Selection panel; B) Landcover Name panel.

First, select a burn severity map on the Burn Severity and Landcover Selection panel (Figure 87). Only polygon themes with the required fields will be available. Select a landcover modification grid, the associated landcover lookup table and the change table. When satisfied, click **Accept**. Enter a name for the new grid (8 character maximum) on the Landcover Name panel. Click **OK** to generate a new surface. The final map can then be used during landcover and soils parameterization.

SSURGO Tool

The SSURGO tool provides several different functions designed to facilitate the use of the dataset with AGWA. Users can import SSURGO tables independently of landcover and soils parameterization, merge spatial and tabular datasets, fill internal voids, and extend the edges of a spatial dataset beyond the boundary of a given watershed. The tool cannot resolve any errors within the datasets, particularly those involving the data tables. It is the user's responsibility to provide properly formatted files for use in AGWA. Go to **AGWA Tools>Advanced Options>SSURGO Tool** (Figure 88).

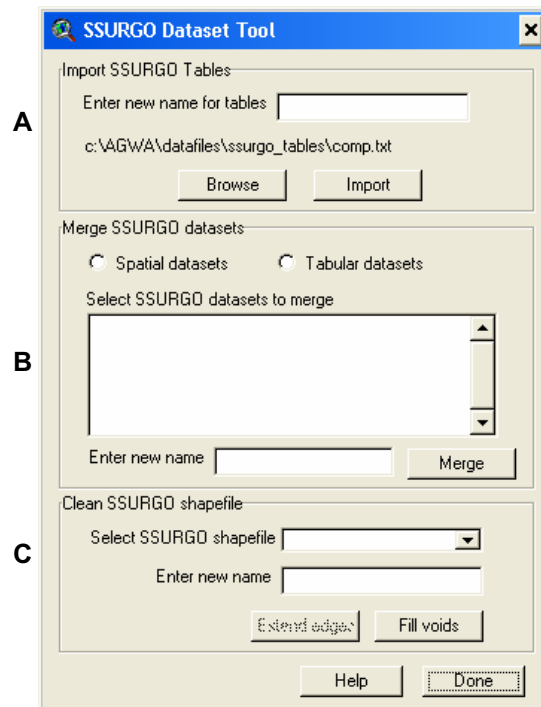


Figure 88. SSURGO Dataset Tool dialog. A) Import Tables panel; B) Merge Datasets panel; C) Clean Shapefiles panel.

Import SSURGO Datasets

To import SSURGO tables, enter a name for the set of tables (component.dbf, chorizon.txt, and

chtexgrp.txt) on the Import Tables panel. Click **Browse** and navigate to the component.txt file. AGWA assumes the other tables are located in that directory. The full path of the component.txt file is displayed in the dialog. Click **Import** to import the tables. This process is identical to that undertaken during landcover and soils processing. The imported tables are added as <new name>_comp, <new name>_hor and <new name>_tex and are ready to be used during parameterization.

Merge SSURGO Datasets

To merge spatial datasets, add all of the SSURGO shapefiles or coverages to the view. From the listbox (Merge Datasets panel), select two or more datasets (hold down Shift to select more than one). Enter a name for the new dataset and click **Merge**. The new shapefile will be added to the view. The attribute table will contain only the MUKEY field as this is the only attribute required by AGWA. The merge process may produce internal voids in the dataset; this can be resolved in the SSURGO tool or can be fixed during the parameterization process.

To merge tabular datasets, first import all of the table sets using the import option described above. This should help ensure that the tables are properly formatted for AGWA. Only the component tables are listed for clarity. Select two or more tables. Enter a name for the new table set and click **Merge**. The selected tables will be merged into one set as <new name>_comp, <new name>_hor, and <new name>_tex. These tables can now be used during parameterization.

Correct Internal Voids

Internal voids can be the result of dataset merging or lack of data. The presence of a void raises the same error as datasets that do not completely cover a watershed and must be fixed before parameterization can be successfully performed. Select the SSURGO dataset to test (Clean Shapefiles panel). Enter a name for the new dataset and click **Fill voids**. Any voids found within the dataset will be replaced by a new polygon. The MUKEY for this polygon will be set to the MUKEY of the existing SSURGO polygon with which it shares the longest edge. The repair process is shown in Figure 89.

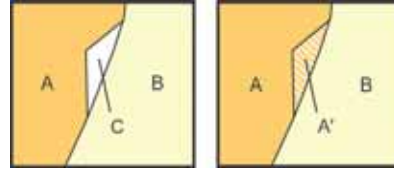


Figure 89. Internal void repair. A and B are original SSURGO polygons; C is the internal void and A' is the new polygon with the MUKEY from A.

Extend SSURGO Edges

This option ensures that the selected SSURGO dataset extends beyond the watershed boundary. The tool identifies the areas of the watershed not covered by the selected SSURGO theme. Using those areas, any SSURGO polygons that do not extend past the watershed boundary are identified. New SSURGO polygons are created to extend the affected polygons beyond the watershed boundary (the boundary is buffered to 100m). The new polygons are assigned a MUKEY based on the existing SSURGO polygon with which it shares the most edge. Figure 90 shows the edge extension process. The new SSURGO theme is specific to the selected watershed.

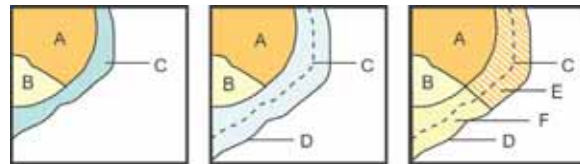


Figure 90. SSURGO extension process. A and B are original SSURGO polygons; C is the watershed boundary; D is the buffered watershed boundary and E and F are the new SSURGO polygons.

Select the SSURGO dataset to correct (Clean Shapefiles panel). Enter a name for the new dataset and click **Extend Edges**. When prompted, select the watershed to match the edge to.

Hydraulic Geometry Relationships

Hydraulic geometry relationships affect the width and depth of a watershed's stream network. This relationship should only be modified by those very familiar with their area of interest. This option allows users to set the default geometry, define a new hydraulic geometry, and modify geometries of existing watersheds (Figure 91).

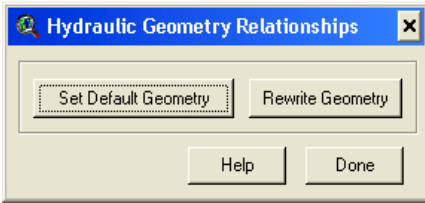


Figure 91. Hydraulic Geometry Relationships Preferences dialog.

The default geometry is set to the Walnut Gulch relationship until a new geometry is selected (Figure 92). Until the default relationship has been set, AGWA will query the user to select a relationship for each discretization. The default can be removed by clicking the **Cancel** button in the Hydraulic Geometry Relationship dialog.

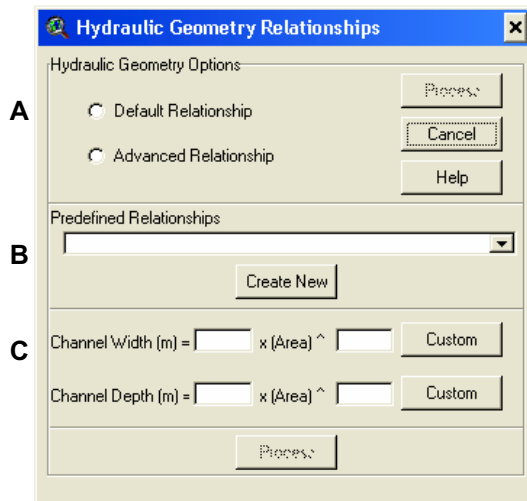


Figure 92. Hydraulic Geometry Relationships Options dialog. A) Default Relationship panel; B) Predefined Relationship Selection panel; C) New Relationship Definition panel.

To add a new relationship, select **Advanced Relationship**. The dialog will expand to reveal the Predefined Relationship Selection panel. Click **Create New** and enter width and depth coefficients and exponents in the New Relationship Definition panel. Click **Process** to store the relationship. The relationship will be saved in the HGR.dbf for future use. Also, should the user wish to modify an existing relationship for the current discretization only, this can be accomplished by clicking the **Custom** buttons to enter new coefficients and exponents.

Preferences

AGWA preferences include warning message reporting, KINEROS baseflow and SWAT CROP file defaults (Figure 93).

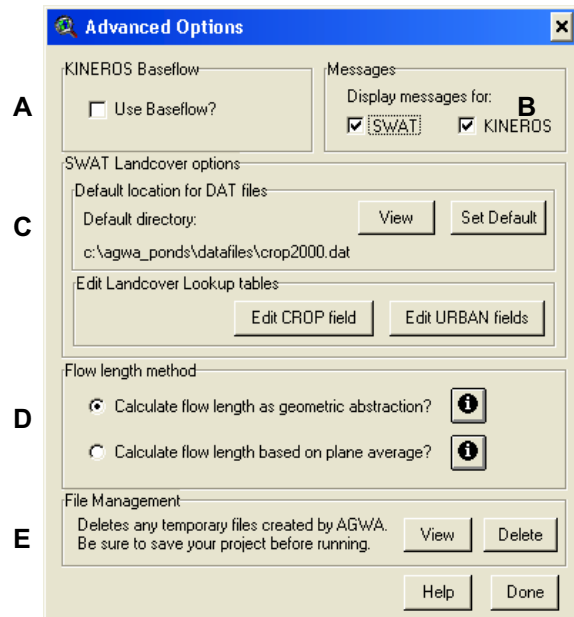


Figure 93. AGWA Preferences dialog. A) KINEROS Baseflow panel; B) Warning Messages panel; C) SWAT Landcover Options panel; D) KINEROS Flow Length Method Selection panel; E) File Management panel.

KINEROS Baseflow

This is an option for advanced users. This option deactivates channel infiltration for a given channel element. To use baseflow, you must first check the **Use baseflow?** On the KINEROS Baseflow panel. This option will remain activated until you uncheck the box. Additional information must then be added to the KINEROS stream attribute table. In this table, AGWA sets a default value of -999.00 for the QBASE field. For baseflow to be modeled, the checkbox must be selected and the QBASE field modified. To enable baseflow for a channel, change the default value based on the following ranges:

- Values < 0: baseflow is not written to the KINEROS parameter file for the current channel, infiltration is active in this channel.
- Values = 0: baseflow is written to the KINEROS parameter file with a value of 0 for the current channel, even though there is no contributing baseflow
- Values > 0: baseflow is written to the KINEROS parameter file with the values in the stream attribute table for the current channel, resulting in no infiltration in this channel and a flow (m³/s) equal to the value

in the stream attribute table being added to the channel.

Note that each record in the stream attribute table corresponds to a channel in the KINEROS parameter file. The entire reach is composed of all the channels in the stream attribute table, so a reach may have gaining (QBASE ≥ 0) or losing channels (QBASE < 0) if positive and negative values appear in the QBASE field for different records.

KINEROS applies an interpolation routine to the baseflow values by linearly interpolating between the value at the upstream node of the channel and the value of the next downstream element. If no baseflow (negative QBASE) is detected in the next downstream channel, baseflow is not interpolated and goes from the value in the upstream channel to zero abruptly. To avoid this, set the baseflow in the downstream channel to zero to enforce interpolation.

For more information regarding KINEROS baseflow, refer to the KINEROS website at <http://www.tucson.ars.ag.gov/kineros/>.

Warning Messages

These checkboxes allow users to turn off warnings and informational messages during AGWA processes. When checked, warnings may appear if the user is attempting to apply SWAT or KINEROS with inappropriate datasets. The warnings do not prevent the use of AGWA. Warnings include: creating KINEROS watersheds with areas greater than 100 km², extremely high or low channel or plane slope values in KINEROS, and soil or landcover datasets that do not completely contain the watershed. Check one or both of the options to turn on warning messages on the Warning Messages panel.

SWAT DAT Defaults

This option allows you to use modified DAT files when running SWAT with hydrologic response units or for water quality purposes. During those simulations, the default crop value and urban values can be modified based on landcover for each subwatershed or HRU. The default DAT files are provided by SWAT and can be found in the AGWA *datafiles* directory. These files should only be modified by those very familiar with the study area and the parameters involved. See the SWAT User's Manual for detailed information concerning the DAT files and their formats.

Setting the default DAT location

The default is set upon loading the AGWA extension to the crop2000.dat file found in the *datafiles* directory. To change the file, click **Set default** on the SWAT Landcover Options panel. Navigate to the new crop2000.dat file (even when modified, the file name should remain the same). The full path name is displayed below the buttons. AGWA assumes the other DAT files are located in the same directory as the crop2000.dat file.

Editing Landcover Lookup Tables

AGWA provides two tools to edit existing landcover tables to add or modify CROP, URBAN and URBANLU fields on the SWAT Landcover Options panel. Both tools utilize the default DAT file information.

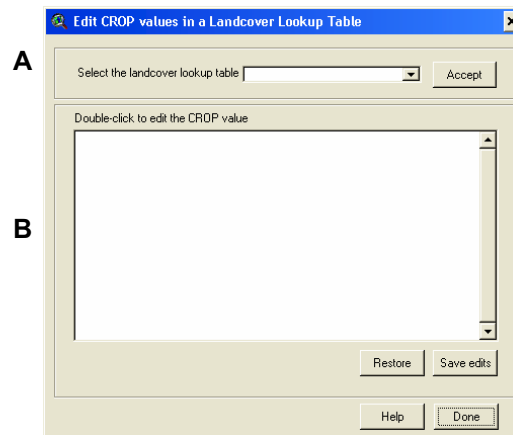


Figure 94. Edit CROP Field dialog. A) Landcover Lookup Table Selection panel; B) CROP Editing panel.

To add CROP values to a lookup table, click **Edit Crop** in the Preferences dialog. Select a lookup table from the provided list (only lookup tables found in the project can be modified) from the Landcover Lookup Table Selection panel (Figure 94). Click **Accept**. Double-click in a row to set the CROP for the landcover type on the CROP Editing panel. Select from the available choices. The CROP value will be added to the listbox. If satisfied with the edits, click **Save Edits** to update the lookup table. To restore the original values, click **Restore**. When finished, click **Done**.

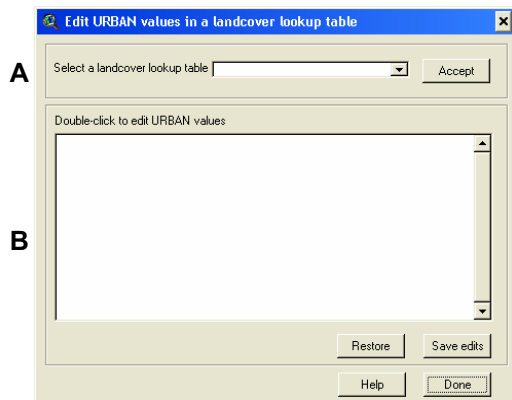


Figure 95. Edit URBAN and URBANLU Fields dialog. A) Landcover Lookup Table Selection panel; B) URBAN and URBANLU Editing panel.

A similar process occurs for the URBAN and URBANLU fields (Figure 95). If the URBAN value is 0, no additional information is required. Otherwise, the type of urban landuse type (URBANLU) must be selected. Double-click in the URBANLU cell to select an urban landuse type.

KINEROS Flow Length

AGWA provides two options for calculating flow length for lateral elements in KINEROS. The default method is a geometric abstraction of the elements. Initial testing indicates that the geometric abstraction provides better results for both unbuffered and buffered AGWA watersheds. This method must be used for any KINEROS watershed to be buffered. The second method calculates the mean flow length of each lateral element. Previous studies have shown this method of calculating the mean flow length for each lateral element to perform better than other mean flow length options, excluding the geometric abstraction method (Syed, 1999). The original AGWA flow length method is not available in AGWA 1.5. See a detailed description of the flow length methods in

Watershed Delineation and Discretization>Basic Concepts>Flow Length.

To change the default flow length method, select one of the provided flow length methods on the KINEROS Flow Length Method Selection panel. This method will be used until the selection changes. To view the flow length method used to calculate values for a specific watershed, view the watershed's metadata using **AGWA Tools>View metadata**. The options are identified as "Geometric abstraction" for the default method and "Mean flow length" for the calculated average. The flow length method cannot be changed once a watershed has been successfully created.

File Management

AGWA generates a number of temporary files during the various processing steps. These files are deleted from the project, but remain in the working directory following the completion of the given process. To avoid any confusion when clearing out the working directory, AGWA provides a file management option to delete these files from the working directory. First, save the AGWA project. The names of the temporary files can be viewed by clicking **View** on the File Management panel. Click the **Delete** button to remove any temporary files that were created during the current AGWA session. Only those files that can be deleted will be (for instance, if the file is in use by the current project, it will not be deleted). The temporary files are retained until the **Delete** button is clicked.

Troubleshooting

Tips and Tricks

Download the most up-to-date version of AGWA from <http://www.tucson.ars.ag.gov/AGWA>. This can resolve many errors.

Carefully inspect the watershed and stream shapefiles before continuing with any other AGWA steps. Watersheds with internal planes missing or with misnumbered elements will not provide acceptable results even if parameterization and simulation proceeds normally. It is absolutely necessary to project all input datasets to a suitable projection with units in METERS. In most cases, creating flow direction and flow accumulation grids in AGWA with the properly projected DEM grid is necessary.

DEM handling

In many situations, a watershed will fall across more than one DEM. These grids must be mosaiced before the watershed can be delineated. An ArcView extension, Grid Utilities by Min-Lang Huang (huang@dprc.ncku.edu.tw), provides the necessary functionality to mosaic DEMs. The extension, `grid01.avx`, and its documentation are available for download from the AGWA website and through the ESRI support website (<http://support.esri.com>).

Clipping the DEM, and other input grids, to a small buffer around the watershed will reduce processing times. Care should be taken if clipping the DEM prior to delineation to avoid inadvertently excluding some areas of the watershed. The Grid Utilities tool described above can be used to clip grids.

Flow direction and flow accumulation grids generated from AGWA can be used more than once. Avoid generating these files more than once to save hard drive space.

Naming Files

File names should not contain any spaces. This includes anywhere within the full path name.

Try to minimize name lengths. Certain situations require short file names. This is particularly true for SWAT.

AGWA provides several datasets. The names of these datasets, particularly dBASE tables,

should not be used. They include: `tarea`, `delta`, `ints`, `calcws`, `dsgnstrm.dbf`, `kin_lut.dbf`, `swatpfiles.dbf`, and `wgnfiles.dbf`.

Managing Themes

Grids and coverages – These files should not be moved using Windows Explorer unless the entire directory containing the grid or coverage and the INFO file is moved or copied. If you must move a grid or coverage, use the **Manage Data Sources** option under **File** from an active view. Failure to do so will render the dataset unusable by ArcView.

Shapefiles – If moving an AGWA watershed (and its associated stream network and metadata), use the provided **Manage AGWA datasets** option. This exports and imports AGWA watersheds and places the files in the correct locations for use in AGWA. If moving other shapefiles, be aware that shapefiles consist of five data files – `*.shx`, `*.shp`, `*.sbn`, `*.sbx`, and `*.dbf`. All of the files must be copied, moved, or deleted as a unit.

SWAT Precipitation Files

These files contain the average latitude, longitude and elevation of the watershed. The average elevation is derived from the DEM, and the precipitation values are adjusted for elevation in subwatersheds where elevation bands are defined. The latitude and longitude values are not used by the model. Due to the difficulty of converting projected data to geographic coordinates in ArcView, AGWA uses fixed values in the precipitation file. These values do not reflect the true location of the selected watershed.

Data projections

One of the problems with downloading spatial data from different sources is that the data is not always in a common projection. The NLCD dataset, for example, comes as either Interrupted Goode Homolosine or Lambert Azimuthal Equal Area projection while the STATSGO data are in Albers Equal Area. AGWA assumes the user has a working knowledge of data projections. It is crucial that all spatial data share a common projection and that the projection units are in meters. Failure to properly project data will result in unusable watersheds.

Very Small Watersheds or Subwatersheds

These watersheds are difficult to delineate in AGWA. This is due, in part, to the high threshold of the stream network grid default. This value can be set during the delineation process to a lower value.

Small subwatersheds, due to a small CSA, increases the potential for discretization and parameterization errors. Discretization errors include improper watershed configurations, misnumbered elements and sequencing errors.

No Data in Results

In certain rare situations for specific CSA values there can be errors in the watershed configuration that prevents KINEROS from running to completion. Rediscretize the watershed with a different CSA until the error is resolved.

Errors

Error messages are indicated in blue.

Landcover grid cellsize is too large for the subdivided watershed.

This error message appears when the CSA is very small compared to the resolution of the landcover grid. This interferes with AGWA's ability to determine the element averages. Two options are available for resolving this error:

1. Rediscretize the watershed with a CSA such that no individual plane is smaller than the landcover resolution.
2. Resample the landcover grid to a higher resolution (smaller cellsize). This does not 'improve' the dataset or otherwise affect the parameterization algorithms. If the Grid Utilities extension has been added to the project, select the landcover grid in the table of contents and then go to **Grid>Change Cell Size** to enter a new value. (This can also be done with the functionality available through Spatial Analyst by setting the **Analysis>Properties** cell size to the desired values and generating a new grid with the Map Calculator.)

Error calling unlink for <filename>: Returned Error Code 13.

The errors occur when an error occurs during an AGWA process, which terminates before file cleanup can occur. First, make note of the filename indicated by the error message. Check the watershed and stream attribute tables for joins and

remove any if found. Save the project and try again. If the error still occurs, quit ArcView and navigate to the directory indicated by the filename. In many cases, this will be the working directory of the project. Delete any files with names beginning with "delta" or the specified filename. Doing so does not damage the project. Restart the project.

There was an error running KINEROS. Please try again.

This is most likely due to ill-defined topography and channel routing for the watershed. This occurs with very linear stream networks or where the topography is relatively flat. Indications can include plane elements that remain unsplit or the channel routing is incorrect. The problem can be fixed by rediscretizing the watershed at a higher CSA.

AGWA has detected an error with the sand, silt and clay fractions not summing to one.

This error can occur when DEM and soil datasets are improperly projected, causing errors during intersection or when the soils dataset is missing data related to the soil fractions. During soils and landcover parameterization, this can cause the sand, silt and clay fractions to exceed the specified limits (fractions should be between 0.7 and 1.3, where 1 is ideal). While KINEROS will run these watersheds, the results will not be valid. Check the temporary soils tables created by AGWA as well as the intersection theme ("ints" + number) for potential errors. If you have modified the soils tables in any way, for example to use existing STATSGO components for a custom soils theme, make sure that the sum of the soil component percentages approaches 1.

The watershed does not lie entirely within the soil theme.

This error can be caused by one of two situations – the soil theme contains voids between polygons or the soil theme does not extend beyond the boundaries of the selected watershed. This causes the parameterization to have missing or zero values, which results in inaccurate parameterizations. In rare instances, this can cause AGWA to crash. The problem is most critical when parameterizing a SWAT watershed with a SSURGO dataset. If the error occurs in this situation, the user can resolve most issues by taking advantage of the provided SSURGO Tool. This tool can fill internal voids, extend the edges of the SSURGO dataset beyond the boundary of a selected watershed, and merge multiple SSURGO datasets. These steps should not be performed manually due to inconsistencies in the spatial and

tabular dataset formatting. The DEM can also be clipped to a size smaller than the soils dataset before delineating and discretizing the watershed should that be desired.

Invalid AGWA metadata

Some required component in the watershed's ODB file is missing or corrupt. This cannot be corrected. A new watershed must be discretized.

Error generating valid name

An error occurred when checking for illegal characters or file name length. Try entering a new name string in the textbox.

Could not locate <name>. The specified file could not be located.

In most cases, the file should be added to the project. If the missing file is an AGWA metadata file, the watershed cannot be used until the correct file is placed in the current working directory (*av_cwd*). The watershed cannot be used again if the ODB file no longer exists.

If this error refers to the *_SWAT.exe*, AGWA will be unable to store the location of the SWAT executable. Save and restart the project. You should be able to run SWAT once the project has reopened.

GRID ERROR - Unable to set analysis window

This error can occur after a processing step in AGWA fails and refers to an issue with the Spatial Analyst settings. To resolve this issue, first save the project. Restart and try to repeat the error. If it occurs again, it is necessary to delete the view and its contents, save the project and reopen it.

Watershed Discretization Errors

Despite efforts by the AGWA developers, some errors are not captured. In most cases, these errors are first noticed when running KINEROS or SWAT with the affected watershed. The first indication is typically an error message when running the model or the inclusion of NODATA values in the simulation results. Because the errors are due to invalid watershed configurations that cannot be easily corrected manually, the best solution is to discretize the watershed with a different CSA until achieving an appropriate configuration.

Large Watershed Warning

This occurs when discretizing a watershed with an area greater than 100 km² for KINEROS. It does not prevent the user from discretizing the

watershed but serves as a warning that KINEROS was not designed to be applied to watersheds larger than the given area.

DEM Resolution Warning

This warning occurs when the DEM resolution exceeds 30 meters. This is not an error, rather it is an indication that the selected DEM may not generate usable watersheds and stream networks. Coarse DEMs can cause problems during discretization for both SWAT and KINEROS that may later cause the parameterization or the simulation to fail. AGWA has been successfully tested with DEMs with a resolution of 30m or less, where smaller cellsize indicates higher resolution. This resolution is recommended.

Low Elevation Warning

This warning occurs when the selected DEM contains elevations at or below sea level. AGWA has difficulty filling, delineating or discretizing DEMs with low elevations or low slopes. Also, the kinematic wave equation used in KINEROS is not applicable in low slope situations or in coastal regions.

Questions or comments regarding other program errors can be directed to:

AGWA Help at agwa@tucson.ars.ag.gov

Please include the circumstances in which the error occurred.

Additional Resources

AGWA Frequently Asked Questions (FAQ)

In many cases, AGWA errors can be resolved by downloading the most recent release of the extension from the website (<http://www.tucson.ars.ag.gov/AGWA>).

What does it mean if the error message says scripts are missing from a dialog?

The extension is corrupt or otherwise unusable. Download a new version from the AGWA website.

What if AGWA doesn't recognize my watershed?

First, make sure the metadata information exists. The project's working directory (*av_cwd*) should contain a file called *<watershed_name>.odb*. If this file is missing, the watershed is unusable and must be rebuilt.

If this occurs in a previous version of AGWA (1.42c or earlier), the theme comments have been lost. The best solution is to rebuild the watershed. Remember, watershed and stream themes cannot be added into a project once they've been deleted and still be used by these earlier versions of AGWA. To create portable watersheds, update to AGWA 1.5 or AGWA2.

[What if some comboboxes are empty?](#)

If a combobox is empty and you are sure that the appropriate data themes are in your project, try selecting an object from the previous dialog. In many cases, the choices you make affect the available choices later on. If you have selected an item in a combobox, then valid data themes for that option were not found in your view. Add the datasets and try again.

[What do I do if the landcover and soils parameterization stalls?](#)

If, during soils parameterization, the progress dialog remains open but there is no activity in the ArcView status bar (bottom of the application), the parameterization has failed. Double-check the tables to ensure there are no empty records, no duplicates, and that all of the columns have been written correctly. If it's a SSURGO dataset, use the provided SSURGO tool to import, merge and clean the datasets.

In some cases, processing could stall due to overly large working directories. ArcView recommends working directory size limits of 100 MB; however, that limit is not absolute. Delete temporary files from the working directory by going to **AGWA Tools>Preferences**. In the File Management panel, click **Delete** to remove any temporary files. Or, use the **Manage Data Sources** in the ArcView **File** menu to delete unnecessary files (especially files beginning with "intsec" or "ints").

[I would like to buffer my KINEROS watershed but it is not listed in the watershed selection combobox.](#)

To create riparian buffers, watersheds must first be created for the KINEROS model. In addition, these watersheds must have been parameterized with the geometric flow length method. To determine which method your watershed uses, view the metadata for that watershed. If the flow length method parameter is "Mean", you cannot use the watershed to create buffers. The flow length method must be set to "Geometric". To set

the default flow length method, go to **AGWA Tools>Preferences** and select the desired flow length method.

[I modified a KINEROS parameter file. Can I still use it in AGWA?](#)

KINEROS parameter files can be modified in any text editor (be sure to retain the .PAR extension). Simply save the parameter file with a different name in an existing simulation directory for the given watershed. In the Run KINEROS dialog, click **Import file** and select the modified parameter file. Once imported, the file will always be available in the parameter file combobox for selection. If you don't see your file in the list, make sure the modified file is in a simulation directory for the watershed (go to **AGWA Tools>View metadata** to view the list of simulations for the watershed).

Parameter files for watershed groups follow specific naming conventions. When modifying these files, in order to ensure correct processing of the simulation and its results, it is best NOT to rename the files. Rather, a duplicate set of files should be copied to another location on your machine. Bear in mind that those files will only be available from within the original simulation directory and cannot be imported.

[What is an ODB file?](#)

These files contain metadata information regarding the watershed, watershed delineation, or AGWA project. The AGWA.odb file contains information regarding the preferences set for a given project (a new AGWA.odb file is created for each project directory). This allows the user to store preferences from one AGWA session to the next. Other ODB files (<watershed name>.odb) contain information regarding watershed attributes. These attributes include discretization parameters, current landcover and soils selections, and simulation details. The file is required for AGWA to recognize the watershed. Attribute values can be viewed in the Metadata viewer (**AGWA Tools>View metadata**). The watershed ODB files should not be deleted unless the watershed is being deleted. They cannot be rebuilt for an existing watershed.

[I'm using a SSURGO theme for parameterization, but get an error containing "Got a\(n\) Nil, expected a\(n\) Field".](#)

First, make sure you have the latest AGWA extension. SSURGO datasets are available in 2 versions—your version may be in the version that

is not supported by earlier AGWA versions (before 1.42c). If the problem still occurs, check the SSURGO tables that were imported into AGWA. To aid in tracking down the problem, try running the provided SSURGO dataset with the San Pedro dataset. Compare the Access database files, the provided text files and, finally, the imported tables.

[I get an error during the landcover and soils parameterization that says “Unable to continue”.](#)

If this error occurs during the landcover parameterization process (AGWA Progress Bar says “Intersecting the Land Cover with the watershed”), the landcover grid is too large for ArcView to process. If the grid extends a considerable distance beyond the watershed boundary, clip the grid to a size just large enough to fully contain the watershed. Next, reset the cellsize of the grid. Use the provided Grid Utilities extension (go to **Grid>Change Cell Size**) and create a new grid with a larger cellsize. Landcover with a resolution of 60m or higher generally work better. This error is most likely to occur with watershed groups.

[I've created a lot of watersheds. Is there any way to remove the files AGWA no longer needs?](#)

Yes. Any temporary files created during AGWA processes can be deleted during an AGWA session by going to **AGWA Tools>Preferences**. A **Delete** button is located on the File Management panel. Clicking this button will delete any files created to that point that can be deleted (if a dataset is loaded into the project, it will not be deleted). Temporary files are deleted at the end of each AGWA session, as the project terminates.

[I'm trying to create a KINEROS watershed using a SWAT subwatershed but AGWA crashes.](#)

Some SWAT subwatersheds cannot be used to create a new watershed. In some cases, this is caused by the outlet location; in others, the size of the watershed results in incorrect channel formation. Adjusting the CSA with these errors probably will not resolve the problem. The best option is to simply use the SWAT subwatersheds to identify outlet locations and create a new watershed.

[My watershed is incorrect—it appears rectangular and does not include the outlet location. How can I fix this?](#)

Some processes, particularly watershed discretization, make use of the Analysis mask

feature. Unfortunately, the mask cannot always be reset due to a known error in ArcView. The best option is to remove the mask from the view by going to **Analysis>Properties** and setting the extent to the extent of the View (or any theme that would completely encompass the watershed) and resetting the mask to “No mask set”.

[When discretizing watersheds, I get an error saying “Invalid stream network” accompanied by a list of numbers. What's wrong with my watershed?](#)

An invalid stream network basically contains more than one branch. The numbers refer to the ARCID of the unconnected streams. In some cases, two separate branches exit the watershed close to the specified outlet location but never connect. The only solution is to adjust the outlet location and redelineate the watershed. If the error occurs when using a SWAT subwatershed, the best option is to use the subwatershed to identify the outlet and use that to create a new watershed from a point location.

This error can also occur when creating nested or multiple watersheds, but, in this case, the error is not related to the outlet. The error here is generally along the edge of the watershed where two or more streams end at the boundary without connecting. Sometimes, the error can be corrected by increasing the CSA (usually significantly); however, this often does not adequately resolve the problem, as the discretization may contain other fatal errors that had not yet been identified. You can discretize the problem watershed separately from the watershed group (with that group rediscritized without the problem watershed) and append the new watershed to the group with the **Edit watershed group** option.

[My watershed has “holes” \(or missing plane elements\) in it. Can I still use it?](#)

A watershed with missing elements should not be used for parameterizing or simulation. (The error does not refer to watersheds created with non-releasing ponds.) This error is most likely due to a projection conflict that ArcView is unable to resolve or due to the use of input rasters that use a geographic projection. A clear indication of this is if the outlet used to delineate the suspect watershed falls well within the watershed outline instead of at the most downstream point.

To correct the problem, reproject the DEM to an appropriate projection. Then, recreate the filled DEM, flow direction grid and flow accumulation

grids based on the projected DEM in AGWA. If the flow direction grid or flow accumulation grid is not recognized by AGWA (it is not found in the appropriate combobox), the selected projection is still in error. Reproject all other inputs to the new projection before using them in AGWA.

I've received an error saying "Shapefile has error. Unable to open" that interferes with the current AGWA process.

This error can occur when AGWA deletes temporary files from the working directory that are still present in a view or in the Table view. First, make sure that all data sources for themes within the view are still available (to see the pathname for a theme, go to **Theme>Properties**). If the data source is no longer available, remove the theme and its attribute table from the project. Save the project and close ArcView. The error should be resolved when ArcView reloads the project.

When opening my AGWA project, ArcView asks me to locate a GRID file and then, when opening a View, displays an error message stating the MASK file cannot be located.

Running AGWA after receiving this error will produce unusable watersheds and inputs. To resolve this error, go to **Analysis>Properties**. Reset the Analysis Extent to be "Same as View", the cell size to be the same as the DEM, and reselect "No Mask Set". Close the window. If the processing step fails, close the project and reopen. You may have to reset the Analysis Properties again.

When running AGWA, I received an error message not described here or in the help files. How do I resolve the issue?

First, make sure that any tables involved in the process, including the watershed and stream attribute tables, contain the correct values (i.e., no null records, WS# or STREAM# = 0, improper stream sequencing, etc.). If you locate an error in an AGWA-generated table, try rebuilding the table by either recreating the watershed or performing the task again. In some instances, it might be necessary to completely rebuild the project to

correct a corrupted ArcView project. If the error continues to occur, contact AGWA technical support (agwa@tucson.ars.ag.gov). Please provide the following information: the exact error message received, the task being performed, the type of watershed (KINEROS, SWAT, buffered, etc.), the type of inputs used and any other relevant information that could aid in the timely resolution of the problem. Please do not send datasets unless asked to do so.

AGWA Technical Support

For problems or errors not described in this manual or in the AGWA support FAQ, email AGWA technical support (agwa@tucson.ars.ag.gov). Before doing so, make sure you are using the newest version of AGWA – many problems can be resolved by updating the extension. If this does not resolve the problem, provide technical support with the following information:

- The version of AGWA being used (1.5, 1.42c, BASINS-AGWA)
- the exact error message displayed,
- the task being performed (i.e. Watershed delineation, landcover and soils parameterization, etc.),
- the type of watershed being used (KINEROS, SWAT, buffered, etc.),
- the type of inputs used, and
- any other relevant information that could aid in the timely resolution of the problem.

Please do not send datasets unless asked to do so.

Third Party Support

For questions regarding model specifications or general ArcView problems, refer to the associated website.

ArcView: <http://support.esri.com/>

SWAT: <http://www3.baylor.edu/cagsr/swat/>

KINEROS: <http://www.tucson.ars.ag.gov/KINEROS>

Appendix A: Obtaining Spatial Datasets

The AGWA tool is designed to be used with geospatially referenced data, which includes most data types supported by ArcView. These include: coverages, shapefiles, and grids. Images can be used for reference within a view, but are not used directly by the AGWA tool. Specific data requirements for each of the model components are outlined below, and are described in more detail in the sections describing each component.

Watershed Delineation

USGS Digital Elevation Model (DEM) – available at multiple sites

<http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>

<http://edcsns17.cr.usgs.gov/EarthExplorer/>

<http://seamless.usgs.gov/> (easiest download site)

<http://datagateway.nrcs.usda.gov/>

Point coverage or shapefile of gauging station location(s) (optional)

Land Cover grid

North American Land Cover Characterization (NALC)

<http://www.epa.gov/owow/watershed/landcover/lulcny.html>

Multi-Resolution Land Characteristics (MRLC) Consortium – National Land Cover Data (NLCD)

<http://www.epa.gov/mrlc/nlcd.html>

<http://seamless.usgs.gov/> (easiest download site)

<http://datagateway.nrcs.usda.gov/>

New York – state-specific classification scheme

<http://www.epa.gov/owow/watershed/landcover/lulcny.html>

User-Defined - this can cover any other classification scheme

Soil Polygon Map

State Soil Geographic Database (STATSGO) soils coverage/shapefile

<http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/data/index.html> (by state)

<http://water.usgs.gov/lookup/getspatial?ussoils> (by basin)

Soil Survey Geographic (SSURGO) Database – higher resolution soils coverage/shapefile.

<http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/data/index.html>

<http://datagateway.nrcs.usda.gov/>

Food and Agriculture Organization of the United Nations (FAO) Digital Soil Map of the World – Low resolution global soils classification.

http://www.tucson.ars.ag.gov/agwa/fao_soils.html

http://www.fao.org/icatalog/search/dett.asp?aries_id=103540

KINEROS Precipitation Data (one of the following)

Uniform, single gage

National Weather Service

Precipitation Frequency Data Server <http://hdsc.nws.noaa.gov/hdsc/pfds/>

NOAA Atlas 2 <http://www.nws.noaa.gov/oh/hdsc/noaaatlas2.htm>

TP-40 Precipitation Frequency Grids http://www.tucson.ars.ag.gov/agwa/rainfall_frequency.html

AGWA design storm database, dsgnstrm.dbf – this is provided with AGWA, and should be located in the *datafiles* directory

Uniform or Distributed Gages

National Weather Service

National Climatic Data Center <http://www.ncdc.noaa.gov/>

Western Regional Center <http://www.wrcc.dri.edu/>

SWAT Precipitation Data (one of the following)

National Weather Service

National Climatic Data Center <http://www.ncdc.noaa.gov/>

NNDC Climate Data Online <http://cdo.ncdc.noaa.gov/CDO/cdo>
Western Regional Center <http://www.wrcc.dri.edu/>

Appendix B: Analyzing watersheds with AGWA and ATtILA

The watershed assessment tools provided by AGWA can be utilized in conjunction with the Analytical Tools Interface for Landscape Assessment (ATtILA) (Ebert et al., 2004) to integrate Landscape Ecology theory with hydrologic modeling. ATtILA was developed by the U.S. EPA Landscape Ecology Branch (<http://www.epa.gov/esd/land-sci/attila/index.htm>) as an ArcView 3.x extension. It calculates many commonly used landscape metrics and can accommodate spatial data from a variety of sources. Four metric groups are currently included in ATtILA: landscape characteristics, riparian characteristics, human stressors, and physical characteristics. ATtILA is suitable across all landscapes, from deserts to rain forests to urban areas.

The integrated approach to conducting watershed assessment analyses with AGWA and ATtILA is depicted in Figure B1 and consists of three elements: hydrologic simulation, landscape analysis, and assessment. The hydrologic simulation element is performed using the AGWA SWAT interface and hydrologic response units to evaluate the impact of landcover/land use on water yield and erosion (see **Landcover and Soils Parameterization>Landcover>SWAT>Hydrologic Response Units (HRUs) and SWAT>Inputs and Execution**). Landscape analyses are then performed using ATtILA to calculate landscape characteristic metrics, e.g. number and size of grassland patches, for each subwatershed. The assessment element integrates outputs from both previous processes, AGWA-SWAT hydrologic modeling and ATtILA landscape assessment. This step is carried out outside of the AGWA and ATtILA environments. Different analyses can be performed based on the user's stated objectives at the start of the assessment process by extracting select results from the generated outputs.

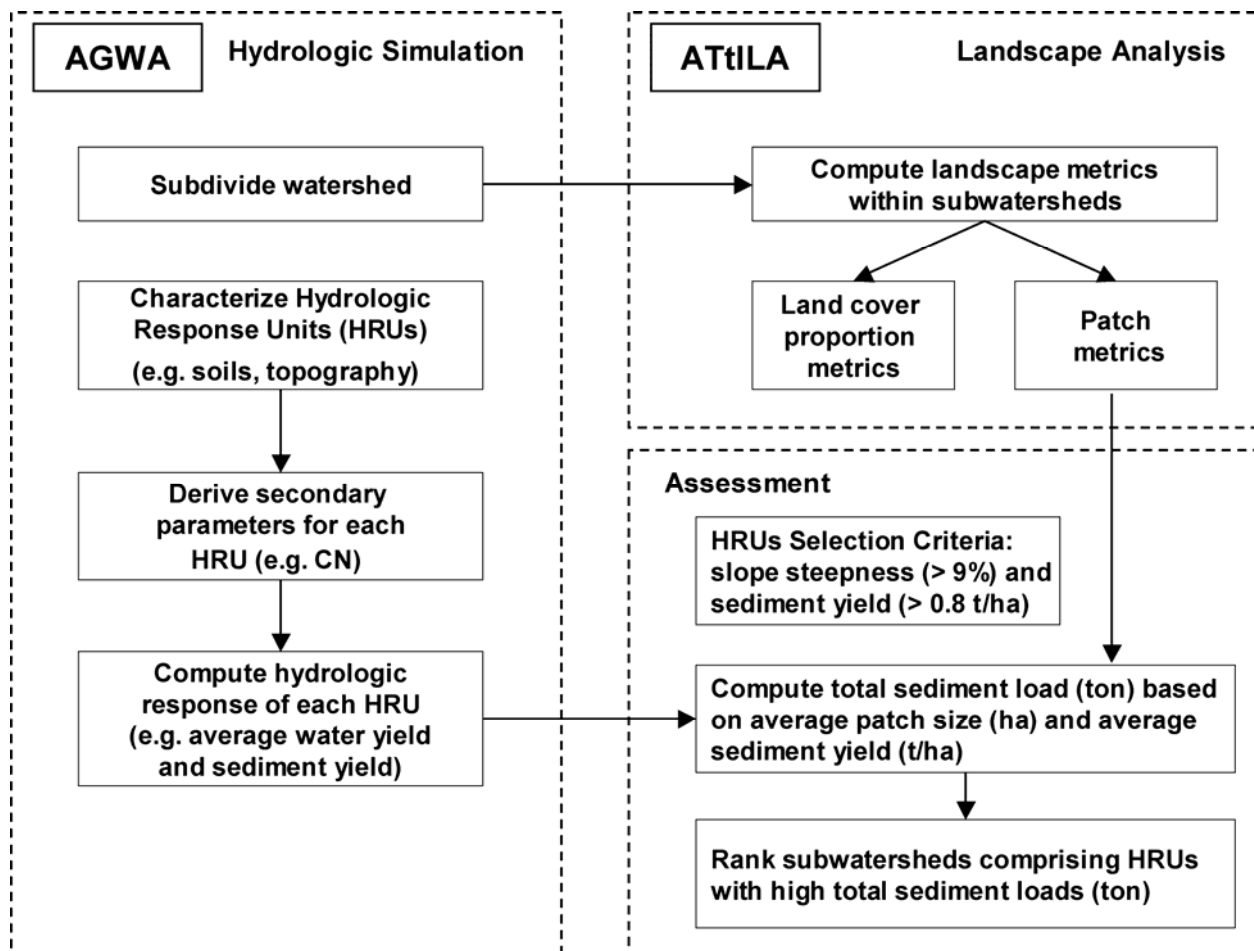


Figure B1. Integrated approach for conducting watershed assessment analyses with AGWA and ATtILA.

The approach shown in Figure B1 was formulated to identify and rank subwatersheds containing HRUs with high total sediment loads. This is accomplished by identifying all HRUs with average slope steepness greater than 9% and average sediment yields greater than 0.8 ton/ha; these values can be extracted from the watershed attribute table and SWAT subwatershed output table (or SBS file). The number and average patch size on each subwatershed for each landcover class are extracted from the ATtiLA attribute table. Average sediment yield is then computed based on the average patch size and the sediment yield. The subwatershed ranking by sediment load is a function of landcover type, slope steepness, and average patch size and is carried out by sorting sediment load values. This approach has been applied to the Upper San Pedro Basin in Southeastern Arizona to identify the main landcover classes contributing to soil erosion and high sediment loads (Hernandez et al., 2003).

Appendix C: Landcover Modification Fractal Component

The Landcover Modification Fractal (LCMF) component generates a multifractal surface with multiple landcover types. The result is a surface consisting of spatially randomly distributed patches within any polygon area defined by the user (Figure C1). This option was previously available through the Landcover Modification Tool as an ArcView algorithm. The conversion to a Fortran 90 executable greatly improves its performance and allows for the generation of larger surfaces. This component was specifically written to be used in AGWA and the Landcover Modification Tool.

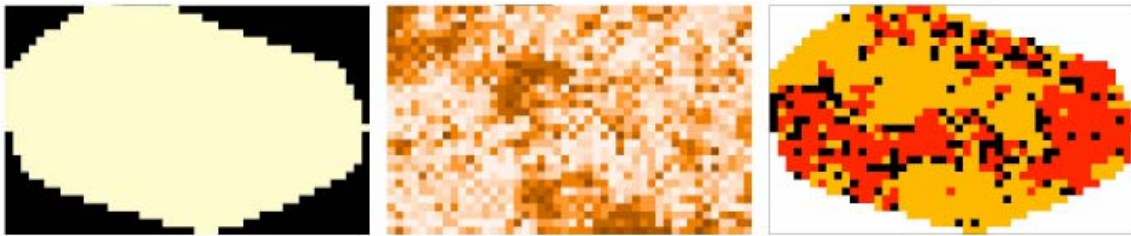


Figure C1. The LCMF process. (left) The input mask grid (black = NODATA); (center) the multifractal surface; and (right) the final surface (Scott, 2005).

The multifractal algorithm is based on the two-dimensional midpoint displacement algorithm described by Saupe and Peitgen (1988). The algorithm combines a displacement process with successive random additions, based on average cell values of the surrounding cells and modified by a Gaussian random number. The displacement, in effect, rotates the surface 45° for each processing step. Patchiness is determined by the fractal dimension D , where $D = 3 - H$. Patch size increases as H approaches 1. Low H values, however, do not produce completely spatially random surfaces – the multifractal surface always displays some clustering tendency. The algorithm is restricted to squares with dimensions based on 2^x , where x is the number of recursions in the fractal process.

The LCMF requires four basic inputs to create a surface – a mask of the irregular polygon, the new landcover types (as integer codes), the proportion of each type, and the level of patchiness. The number of recursions is determined by the size of the input mask, which calculates the x value based on the maximum number of rows or columns. The model constructs an array with the calculated dimensions, populates the array with random numbers based on the Bays and Durham generator (Press, 1996) and performs the multifractal displacement. Once the calculations are complete, breakpoints based on the proportions are calculated for the area described by the mask. The array values are replaced by integer values based on the input landcover types using the derived breakpoints. All other areas are set to 9999 (NODATA). The integer array is written to a new ASCII file with the same dimensions as the original input mask. In general, proportions of the final surface are within 1-2% of the specified values.

The executable can be run outside of AGWA to generate surfaces with more than three landcover types. The required inputs are listed in the patch.fil file in the following order:

- Line 1 mask file name (full pathname)
- Line 2 new grid name (no extension or path)
- Line 3 working directory (location of the output ASCII)
- Line 4 number of vegetation types
- Line 5 integer values of vegetation types*
- Line 6 integer values of percentages (percentages are the running total)*
- Line 7 integer seed value (positive)
- Line 8 H value (0.01-0.99)

*Lines 5 and 6 are fixed width inputs where vegetation types are 4 digit integers and percentages are 3 digit integers followed by a blank space.

If either value contains fewer digits, those digits should be represented by blank spaces preceding numerical value.

Ex. We would like an output grid of 30% vegetation 34 and 70% vegetation 75.

The corresponding input lines would be

```
  34  75
```

```
30 100
```

(represents one blank space)

If the spacing is incorrect, the vegetation and/or percentage values will be misread by the program, resulting in an incorrect ASCII file.

The mask file should be in ArcView ASCII format, with NODATA values set to 9999. If the exported ASCII grid contains negative values, these must be changed before use in the LCMF. The mask file size is limited to 10 MB, approximately 1400 x 1400 cells. This size restriction is based only on the number of cells and not the resolution – the actual map area that can be modified decreases as resolution increases.

To run the executable, open a DOS command line window and navigate to the directory containing the model and the input files. Enter “cmd /c lcmf” and hit Return. The model will generate a new ASCII file, with the new name, in the directory. This file can be imported into the GIS using the appropriate method.

References

- Arnold, C.L. and C.J. Gibbons, 1996. Impervious surface coverage: the emergence of a key environmental indicator. *J. American Planning Assoc.* 62:243-258.
- Arnold, J.G., J.R. Williams, R. Srinivasan, K.W. King, and R.H. Griggs, 1994. SWAT-Soil Water Assessment Tool. USDA, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, Texas.
- Aronoff, S., 1985. The minimum accuracy value as an index of classification accuracy. *Photogrammetric Engineering & Remote Sensing*, 51(1): 99-111.
- Band, L.E. and I.D. Moore, 1995. Scale: landscape attributes and geographical information systems, in: scale issues in hydrological modeling (Eds.) Kalma, J. D. and M. Sivapalan, John Wiley & Sons
- Band, L.E., 1986. Topographic partition of watersheds with digital elevation models. *Water Resources Research*, 22(1):15-24.
- Band, L.E., D.L. Peterson, R. Nemani, and S.W. Running, 1993. Forest ecosystem processes at the watershed scale: incorporating hillslope hydrology, *Ecol. Modell.*, 63: 93-126.
- Band, L.E., D.L. Peterson, S.W. Running, J.C. Coughlan, R.B. Lammers, J. Dungan, and R. Nemani, 1991. Forest ecosystem processes at the watershed scale: basis for distributed simulation, *Ecol. Modell.*, 56: 151-176.
- Calore, C., P. La Barbera, and G. Roth, 1997. On the use of informational entropy in GIS. in: *Remote Sensing and Geographic Information Systems for Design and Operation of Water Resources Systems*, Proceedings of Rabat Symposium, IAHS, Publ. No. 242.
- Canfield, H.E., D.C. Goodrich, and I.S. Burns, 2004. Selection of Parameters Values to Model Post-fire Runoff and Sediment Transport at the Watershed Scale in Southwestern Forests. *ASCE Conference Proceedings* 178 (48).
- Charbonneau, R., and G.M. Kondolf, 1993. Land use change in California, USA: nonpoint source water quality impacts. *Environ. Man.* 17:453- 460.
- Chow, V.T., D.R. Maidment, and L.W. Mays, 1988. *Applied Hydrology*, McGraw Hill, New York , N.Y., p. 147-154.
- Clarke, R.T., 1998. *Stochastic Processes for Water Scientists: Developments and Applications*. John Wiley & Sons, Inc., New York, 183pp.
- Congalton, R.G., M. Balogh, C. Bell, K. Green, J.A. Milliken, and R. Ottman, 1998. Mapping and monitoring agricultural crops and other land cover in the Lower Colorado River Basin. *Photogrammetric Engineering & Remote Sensing*, 64(11): 1107-1113.
- Congalton, R.M. and K. Green, 1999. *Assessing the accuracy of remotely sensed data: principles and practices*. Lewis Publishers, CRC Press, NY.
- Congalton, R.M., R.G. Oderwald, and R. Mead, 1983. Assessing Landsat classification accuracy using discrete multivariate statistical techniques. *Photogrammetric Engineering & Remote Sensing*, 49(12): 1671-1678.
- Crawford, N.H., and R.K. Linsley, 1966. Digital simulation on hydrology: Stanford Watershed Model IV. Stanford University Tech. Rep. No. 39. Palo Alto, Cal.: Stanford University.

- Driessen, P., J. Deckers, O. Spaargaren, F. Nachtergaele, editors, 2001. Lecture Notes on the Major Soils of the World. FAO, Publishing and Multimedia Service, Information Division, Viale delle Terme di Caracalla, 00100 Rome, Italy. <http://www.fao.org/DOCREP/003/Y1899E/Y1899E00.HTM>
- Ebert, D.W., and T.G. Wade, 2004. Analytical Tools Interface for Landscape Assessments (ATiLA), User Manual Version 2004, U.S. EPA Office of Research and Development, National Exposure Research Laboratory, Environmental Division, Landscape Ecology Branch, EPA/600/R-04/083.
- Engman, E.T. and R.J. Gurney, 1991. Remote sensing in hydrology. Chapman and Hall, Van Nostrand Reinhold, NY.
- Entekhabi, D., H. Nakamura, and E.G. Njoku, 1994. Solving the inverse problem for soil moisture and temperature profiles by sequential assimilation of multifrequency remotely sensed observations. IEEE Trans. Geosci. Remote Sensing, 32: 438-448.
- Engel, B., J. Harbor, M. Bland, A. Krause, D. George, 2004. Impacts of Land Use Change on Water Resources, Purdue Research Foundation, West Lafayette, Indiana 47907. <http://www.ecn.purdue.edu/runoff/index.html>
- Famiglietti, J.S. and E.F. Wood, 1991. Evapotranspiration and runoff for large land areas: land surface hydrology for atmospheric general circulation models. Surv. Geophys., 12: 179-204.
- Famiglietti, J.S. and E.F. Wood, 1994. Multi-scale modeling of spatially variable water and energy balance processes. Water Resources Research, 30: 3061-3078.
- Famiglietti, J.S. and E.F. Wood, 1995. Effects of spatial variability and scale on areal-average evapotranspiration. Water Resources Research, 31: 699-712.
- FAO/UNESCO, 2003. Digital Soil Map of the World and Derived Soil Properties, Version 3.6. CD-ROM, Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy. <http://www.fao.org/ag/agl/agll/dsmw.stm>
- Franklin, J.F., 1992. Scientific basis for new perspectives in forests and streams. pp. 25-72. IN: R. J. Naiman (ed.) Watershed Management. Springer-Verlag, NY.
- Garbrecht, J. and L.W. Martz, 1993. Network and subwatershed parameters extracted from digital elevation models: The Bills Creek Experience, Water Resources Bulletin, American Water Resources Association, 29(6): 909-916.
- Garbrecht, J. and L.W. Martz, 1995. TOPAZ: An automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation and subcatchment parameterization; overview. ARS Pub. No. NAWQL 95-1, USDA-ARS, Durant, OK, 16 pp.
- Garbrecht, J., and L.W. Martz, 1996. Digital landscape parameterization for hydrological applications, in HydroGIS 96: Applications of Geographic Information Systems in Hydrology and Water Resources Management, IAHS Publ., 235.
- Goodrich, D.C., 1991. Basin scale and runoff model complexity, University of Arizona, Dep. of Hydrology and Water Resources Technical Report No. HWR 91-010, 361 p.
- Graf, W. L., 1988. Fluvial Processes in dryland rivers, Springer-Verlag Berlin Heidelberg, Germany.
- Hernandez, M., W.G. Kepner, D.J. Semmens, D.C. Goodrich, and S.N. Miller, 2003. Integrating a Landscape/Hydrologic Analysis for Watershed Assessment, First Interagency Conference on

- Research in the Watersheds, Oct 27-30, Benson, AZ, U.S. Department of Agriculture, Agricultural Research Service.
- Hord, R.M. and W. Brooner, 1976. Land-use map accuracy criteria. *Photogrammetric Engineering & Remote Sensing*, 42(5): 671-677.
- Hunsaker, C.T., and D.A. Levine, 1995. Hierarchical approaches to the study of water quality in rivers. *BioScience* 45:193-203.
- Hunsaker, C.T., D.A. Levine, S.P. Timmins, B.L. Jackson, and R.V. O'Neill, 1992. Landscape characterization for assessing regional water quality. Pp. 997-1006, in D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (eds.), *Ecological indicators*. Elsevier Appl. Sci., New York.
- Jackson, T.J., R.M. Ragan, and R.P. Shubinski, 1976. Flood frequency studies on ungauged urban watersheds using remotely sensed data. *Proc. Natl. Symp. on Urban Hydrology, Hydraulics and Sediment Control*, University of Kentucky, Lexington, KY.
- Jackson, T.J., R.M. Ragan, and W.N. Fitch, 1977. Test of landsat-based urban hydrologic modeling. *ASCE J. Water Resources Planning Management Division*, 103, No. WR1 Proc. Paper 12950, pp 141-158.
- Jarrell, W. (Discovery Farms Program), and L. Bundy (Department of Soil Science, University of Wisconsin), 2002. <http://wpindex.soils.wisc.edu/hydrologicsoilgroup.html>
- Jenson, S.K. and J.O. Domingue, 1988. Extracting topographic structure from digital elevation data for geographical information system analysis. *Photogrammetric Engineering and Remote Sensing* 54(11):1593-1600.
- Junk, W. J., P.B. Bailey, and R.E. Sparks, 1989. The flood pulse concept in river-floodplain systems. *Can. Spec. Publ. Fish. Aquat. Sci.* 106:110- 127.
- Karr, J.R. and I.J. Schlosser, 1978. Water resources and the land-water interface. *Science* 201:229-233.
- La Barbera, P. and G. Roth, 1994. Scale properties and scale problems: network morphology and network identification from digital elevation maps. In: *Advances in Distributed Hydrology* (Ed.) Rosso et al., 131-148, Water Resources Publication, Colorado.
- Langbein, W.B. and S.A. Schumm, 1958. Yield of sediment in relation to mean annual precipitation. *Trans. Am. Geophys. Union*, 39:1076- 1084.
- Law, A.M., and Kelton, W.D., 1982, *Simulation Modeling and Analysis*. McGraw-Hill Inc., 400pp.
- Lowrance, R.R., R.L. Todd, J. Fail, O. Hendrickson, R. Leonard, and L.E. Asmussen, 1984. Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34:374-377.
- Maidment, D.R., 1993. *Handbook of Hydrology*. David R. Maidment, ed., McGraw Hill, Inc.
- Mark, D., J. Dozier, and J. Frew, 1984. Automated basin delineation from digital elevation data. *GeoProcessing*, 2:299-311.
- Martz, L.W., and J. Garbrecht, 1993. Automated extraction of drainage network and watershed data from digital elevation models. *Water Resources Bulletin*, American Water Resources Association, 29(6):901-908.
- Meentemeyer, V. and E.O. Box, 1987. Scale effects in landscape studies. In: *Landscape heterogeneity and disturbance*, pp. 15-34. (Ed.) M. G. Turner, Springer-Verlag, NY.

- Miller, S.N., 1995. An Analysis of Channel Morphology at Walnut Gulch Linking Field Research with GIS Applications. Masters Thesis, School of Renewable Natural Resources, University of Arizona. Available from UMI Dissertation Services. 169 pp.
- Moore, I.D. and R.B. Grayson, 1991. Terrain based prediction of runoff with vector elevation data. *Water Resources Research*, 27: 1177-1191.
- Moore, I.D., A.K. Turner, J.P. Wilson, S.K. Jenson, and L.E. Band, 1993. GIS and land surface-subsurface modeling. In: *Geographic Information Systems and Environmental Modeling* (Eds.) Goodchild, M. F., P. O. Parks, and L. Y. Stayaert, Oxford University Press, Oxford, pp. 196-230.
- Moore, I.D., E.M. O'Loughlin, and G.J. Burch, 1988. A contour-based topographic model for hydrological and ecological applications. *Earth Surface Processes Landforms*, 13: 305-320.
- Nemani, R., L.L. Pierce, S.W. Running, and L.E. Band, 1993. Ecological processes at the watershed scale: sensitivity to remotely sensed leaf area index estimates. *Int. J. Remote Sensing*, 14: 2519-2534.
- Nielsen, D.R. and J. Bouma, 1985. Soil spatial variability. In: *Proceedings of a Workshop of the International Soil Science Society and the Soil Science Society of America*, Pudoc, Wageningen, 243 pp.
- O'Callaghan, J.F. and D.M. Mark, 1984. The extraction of drainage networks from digital elevation data. *Computer Vision, Graphics and Image Processing*, 28:323-344.
- Omernik, J.M. 1987. Ecoregions of the United States: Map at a scale of 1:7,500,000. *Suppl. Annals American Assoc. Geogr.* 77(1).
- Osborn, H.B., L.J. Lane, and V.A. Myers, 1980. Rainfall/watershed relationships for Southwestern thunderstorms; *Transactions of the ASAE*, v. 23, n. 1, p. 82-91.
- Peterjohn, W.T. and D.L. Correll, 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. *Ecology* 65:1466-1475.
- Press, W.H., 1996. *Numerical Recipes in Fortran 90: the art of parallel scientific computing*. 2nd Edition. Cambridge University Press, New York.
- Ragan, R.M. and T.J. Jackson, 1980. Runoff Synthesis Using Landsat and SCS Model, *J. of Hydrology, Divn., ASCE, Vol. 106 (HYS5):* 667-678.
- Rango, A., A. Feldman, T.S. George, III, and R.M. Ragan, 1983. Effective use of Landsat data in hydrologic models. *Water Resources Bulletin*, 19, 165-74.
- Rawls, W.J., D.L. Brakensiek, and K.E. Saxton, 1982. Estimation of soil water properties. *Transactions of the American Society of Agricultural Engineers* 25(5):1316-1320.
- Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder (Coordinators), 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agricultural Handbook No. 703., U. S. Department of Agriculture, Washington, D.C. 404 p.
- Reynolds, C.A., T.J. Jackson, and W.J. Rawls, 1999. Estimated Available Water Content from the FAO Soil Map of the World, Global Soil Profile Databases, and Pedo-transfer Functions. <http://www.ngdc.noaa.gov/seg/cdroms/reynolds/reynolds/reynolds.htm>

- Rosenfield, G.H., K. Fitzpatrick-Lins, and H. Ling, 1982. Sampling for thematic map accuracy testing. *Photogrammetric Engineering & Remote Sensing*, 48(1):131-137.
- Roth, N.E., J.D. Allan, and D.L. Erickson, 1996. Landscape influences on stream biotic integrity assessed at multiple scales. *Landscape Ecology* 11:141-156.
- Saupe, D. and H. Peitgen, eds., 1988. *The Science of Fractal Images*. Springer, New York.
- Scott, S.N., 2005. Implementing best management practices in hydrologic modeling using KINEROS and the Automated Geospatial Watershed Assessment (AGWA) Tool. Masters Thesis, School of Natural Resources, University of Arizona. 204p.
- Shannon, C.E., 1948. A mathematical theory of communications. *Bell System Technology Journal*, 27: 379-423, 623-659.
- Singh, V.P., 1995. Watershed modeling, In *Computer Models of Watershed Hydrology* (V. P. Singh, Ed.). Water Resources Publications, Highlands Ranch, Colorado. p. 1-22.
- Soil Conservation Service, 1973. A Method for Estimating Volume and Rate of Runoff in Small Watersheds; SCS-TP-149, U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.
- Soil Conservation Service, 1986. Urban hydrology for small watersheds, Technical release No. 55; Soil Conservation Service, U.S. Department of Agriculture, Washington, DC.
- Spanner, M.A., L.L. Pierce, D.L. Peterson, and S.W. Running, 1990. Remote sensing of temperate forest leaf area index: influence of canopy closure, understory vegetation and background reflectance. *Int. J. Remote Sensing*, 11: 96-111.
- Spanner, M.A., L. Johnson, J. Miller, R. McCreight, J. Freemantle, J. Runyon, and P. Gong, 1994. Remote sensing of seasonal leaf area index across the Oregon transect. *Ecol. Appl.*, 4: 258-271.
- Sparks, R.E., 1995. Need for ecosystem management of large rivers and their floodplains. *BioScience* 45:168-182.
- Star, J.L., J.E. Estes, and K.C. McGwire, 1997. *Integration of Geographic Information Systems and Remote Sensing*, Cambridge University Press, Cambridge, UK.
- Sweet, W.V. and J.W. Geratz, 2003. Bankfull Hydraulic Geometry Relationships and Recurrence Intervals for North Carolina's Coastal Plain. *Journal of the American Water Resources Association* 39(4): 861-871.
- Syed, K.H., 1999. The impacts of digital elevation model data type and resolution on hydrologic modeling. Doctoral Dissertation, Department of Hydrology and Water Resources, University of Arizona, 269pp.
- U.S. Department of Agriculture, Soil Conservation Service, 1972. *National Engineering Handbook*, Section 4, Hydrology US Government Printing Office, Washington, D.C.
- U.S. Department of Agriculture, Natural Resources Conservation Service, 1994. *State Soil Geographic (STATSGO) Data Base: Data Use Information*, National Cartography and GIS Center, Fort Worth, Texas.
- U.S. Department of Agriculture, Natural Resources Conservation Service, 1995. *Soil Survey Geographic (SSURGO) Data Base: Data Use Information*, National Cartography and GIS Center, Fort Worth, Texas.

- U.S. Army Corps of Engineers, 1976. Urban storm water runoff, STORM. Computer program 723-L2520, Hydrologic Engineering Center, Davis, CA.
- van Genderen, J.L. and B.F. Lock, 1977. Testing land use map accuracy. *Photogrammetric Engineering & Remote Sensing*, 43(9): 1135-1137.
- Weller, M.C., M.C. Watzin, and D. Wang, 1996. Role of wetlands in reducing phosphorus loading to surface water in eight watersheds in the Lake Champlain Basin. *Environ. Man.* 20:731-739.
- Wigmosta, M.S., L.W. Vail, and D.P. Lettenmier, 1994. A distributed hydrology-vegetation model for complex terrain. *Water Resources Research*, 30:1665-1680.
- Williams, J.R., 1969. Flood routing with variable travel time or variable storage coefficients. *Trans. ASAE* 12(1):100-103.
- Wischmeier, W.H., and D.D. Smith, 1978. Predicting rainfall erosion loss: A guide to conservation planning. *Agricultural handbook 537*. U. S. Department of Agriculture, Washington, D.C.
- Wood, E.F., 1994. Scaling, soil moisture and evapotranspiration in runoff models. *Advances Water Resources*, 17: 25-34.
- Wood, E.F., M. Sivapalan, K. Beven, and L. Band, 1988. Effects of spatial variability and scale with implications to hydrologic modeling. *Journal of Hydrology*, 102: 29-47.
- Woolhiser, D.A., R.E. Smith, D.C. Goodrich, 1990. KINEROS, a kinematic runoff and erosion model: Documentation and user manual. U.S. Department of Agriculture, Agricultural Research Service, ARS-77, 130p. SWRC Reference No.: 703.