The KINEROS2-AGWA Suite of Modeling Tools

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Abstract

KINEROS2 (K2) is a spatially distributed rainfall-runoff erosion model dating back to the 1960's. Development and improvement of K2 has continued for a variety of projects and purposes resulting in an informal suite of K2-based modeling tools. Like any detailed, distributed watershed modeling tool, the K2 suite of tools can require considerable time to delineate watersheds, discretize them into modeling elements and then parameterize these elements. These requirements motivated the development of the Automated Geospatial Watershed Assessment (AGWA) tool (see: www.tucson.ars.ag.gov/agwa or https://www.epa.gov/water-research/automated-geospatial-watershed-assessment-agwa-tool-hydrologic-modeling-and-watershed). AGWA is a GIS interface jointly developed by the USDA-Agricultural Research Service, the U.S. Environmental Protection Agency, the University of Arizona, and the University of Wyoming to automate the parameterization, execution, and visualization of simulation results of a suite of hydrologic and erosion models (RHEM, KINEROS2, and SWAT) using nationally available data or user provided input. The objectives of this paper are to: 1) Provide background on K2 and AGWA; 2) Provide an overview of the main features of K2 and AGWA tools; 3) Describe new features and tools; and, 4) Discuss plans for future model improvements.

Introduction

The KINEROS2 (K2) and AGWA suite of modeling tools have been discussed in prior Joint Federal Interagency and SEDHYD conference papers (Goodrich et al. 2010; 2015). Therefore, abbreviated information on the background and development of K2 and AGWA will be presented herein. Greater emphasis will be given to describing features (historic and new) of K2 and AGWA.

KINEROS2 - KINematic Runoff and EROSion Model

Development of KINEROS and subsequently KINEROS2, by the USDA-Agricultural Research Service dates back to the 1960s. KINEROS was formally released in 1990 (Woolhiser et al. 1990; Smith et al. 1995). The model simulates runoff, erosion, and sediment transport. The kinematic equations used for flow routing are coupled interactively with the Smith-Parlange infiltration equation. KINEROS and K2 represent a watershed as a collection of overland flow elements (planar or curvilinear) contributing to channels as depicted in Figure 1. Representation of the watershed in this form enables solution of the flow-routing partial differential equations in one dimension that substantially reduces simulation time. KINEROS2, released in 2002 (Goodrich et al. 2002) includes an updated overall computational structure and additional model element types compared to KINEROS.

In addition to the overland flow and trapezoidal channel model element depicted in Figure 1, KINEROS2 includes the following additional model elements:

- Compound trapezoidal channel: Includes an overbank channel section with the capability of having different infiltration and roughness characteristics
- Irregular channel cross-section: As might be derived from a ground survey or extracted from LIDAR-derived topography (more details provided below)
- Ponds/Detention Structures: Arbitrary shape, controlled outlet – discharge as a *f*(stage)
- Urban: Mixed infiltrating/impervious surfaces with various runoff-runon combinations
- Culverts/Pipes: Circular with free surface flow
- Injection: Hydrographs and sedigraphs injected from outside the modeled system, or from a point discharge (e.g. pipe, drain)
- Diversion: Divert water and sediment from a single upstream element to as many as 10 downstream elements
- Adder: Summing the outflow from more than two upstream elements

A relatively thorough overview of the theoretical background of K2, including several applications, is presented by Semmens et al. (2008). Goodrich et al. (2012) provided further details on K2 and included a discussion of model limitations, expectations, and strategies and approaches for K2 calibration and validation. Both of these publications are available at https://www.tucson.ars.ag.gov/unit/Publications/Search.html. K2 is public domain software that is distributed freely, along with associated model documentation and example input files (www.tucson.ars.ag.gov/kineros). Additional versions of KINEROS2 have been developed for specialized applications. They include the KINEROS2-Opus2 (K2-O2) continuous model that can simulate biogeochemical nutrient cycling and plant growth under various types of management (Massart et al. 2010). The documentation and user manual for K2-O2 are available at http://www.tucson.ars.ag.gov/k2o2/doku.php. A flash flood forecasting version of K2 for a rapidly responding basin that ingests National Weather Service (NWS) Digital Hybrid Reflectivity (DHR) or Digital Precipitation Rate (DPR) radar products has also been developed (Unkrich et al. 2010). It has undergone testing on 40+ watersheds in over a dozen NWS Weather Forecasting Offices (Schaffner et al. 2014; 2016; 2017) and is operational in 10+ watersheds in the southwest. Guber et al. (2010) used K2 as the runoff and routing tool to simulate the transport of indicators for organisms and manure-borne pathogens by coupling K2 to the Simulator of Transport With Infiltration and Runoff (STWIR).

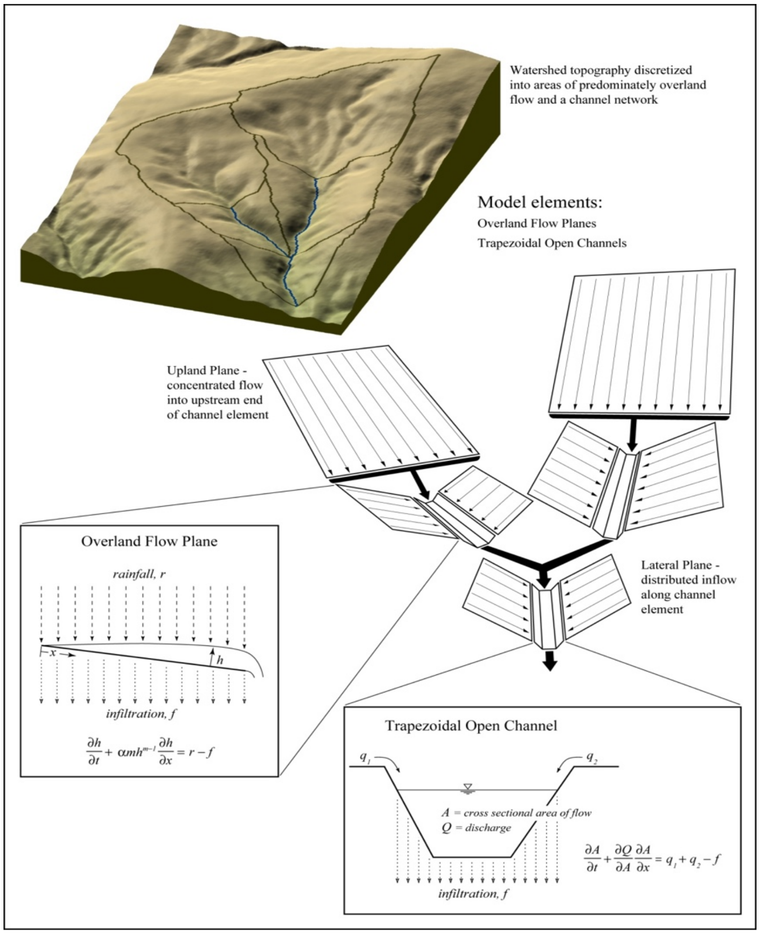

Figure 1. Abstraction of watershed discretized into KINEROS2 model elements (Goodrich et al. 2012)

The Automated Geospatial Watershed Assessment (AGWA) Tool

AGWA (Miller et al. 2002; 2007) was developed to support the parameterization, execution, and visualization of simulation results of K2 and the Soil Water Assessment Tool (SWAT; Arnold and Fohrer 2005) using GIS tools and geospatial data. AGWA was developed jointly by the USDA-ARS Southwest Watershed Research Center, US EPA Landscape Ecology Branch, University of Arizona, and University of Wyoming. The development of AGWA was undertaken with the following objectives: 1) that it provides simple, direct, transparent, and repeatable parameterization routines through an automated, intuitive interface; 2) that it is applicable to ungauged watersheds at multiple scales; 3) that it evaluates the impacts of management and be useful for scenario development; and 4) that it uses free and commonly available GIS data layers. Like K2, AGWA is public domain software available from the AGWA website (Miller et al. 2007; www.tucson.ars.ag.gov/agwa). The current version of AGWA is for ArcGIS/ArcMap 10.x. The AGWA web site also contains documentation, supporting references, tutorials, and a user forum. Support for K2 and AGWA is typically accomplished via the user forum, e-mail, or phone communication.

To derive watershed model parameters with AGWA, descriptive geospatial data layers over the watershed of interest are required. These include raster based digital elevation model (DEM) data, polygon soils data, and a raster based land cover/land use data. In addition to relatively common DEM data from the USGS, LIDAR data can also be used if interpolated into a raster format. Soils data that are supported include NRCS SSURGO and STATSGO as well as FAO data. Land cover and land use data that are supported by AGWA include NLCD, NALC, and GAP. Precipitation data are required to drive the model and can be input in several different formats.

The primary steps for conducting watershed modeling and analysis with AGWA are depicted in Figure 2 and include:

- Selection of a watershed outlet and delineation of the contributing watershed area
- Model selection and watershed discretization into model elements
- Watershed model element parameterization
- Precipitation input
- Model execution
- Change Analysis
- Results visualization.

AGWA intuitively guides the user through these steps. In addition to analyzing a single watershed, AGWA has an area of interest tool for multi-watershed analysis. During the delineation step AGWA will automatically fill the DEM if necessary and compute associated flow direction and flow accumulation rasters.

There are several options for *discretizing* the watershed into spatially distributed model elements. At this stage the user selects whether K2 or SWAT will be used, as the two models conceptualize stream contributing areas differently. Commonly used is the contributing source area (CSA). At this area, the head of a first order channel is initiated. The CSA can be input as an area or a percentage of the total drainage of the watershed being analyzed. The second option is selecting a maximum hillslope flow length before stream initiation, and third, importation of a pre-existing stream network. A fourth case uses a point theme to define channel initiation points. In the third and fourth case the most upstream points of the existing stream network and the initiation points, respectively, are snapped to the stream network defined by DEM flow accumulation.

In the *parameterization* step the model element polygons are intersected with soil polygons and the land use/land cover raster. AGWA contains lookup tables (editable) that relate the land cover, soils, and topographic properties to necessary hydrologic parameters for each model element. These tables were developed based on prior studies (Woolhiser et al. 1990; Rawls et al. 1982, etc.), experimental data, and expert opinion. AGWA uses regional empirical hydraulic geometry relationships (Bieger et al. 2015) to estimate trapezoidal channel geometry if that option is selected. It should be stressed that model parameters derived from the look-up tables and channel geometry regressions should only be viewed as initial estimates. An interface is provided to input multipliers to a subset of the more sensitive parameters that are applied uniformly across all model elements to facilitate simple manual calibration. As AGWA generates input files for K2 and SWAT it is relatively straightforward to link to external parameter estimation software (Hernandez et al. 2000) if model calibration is desired.

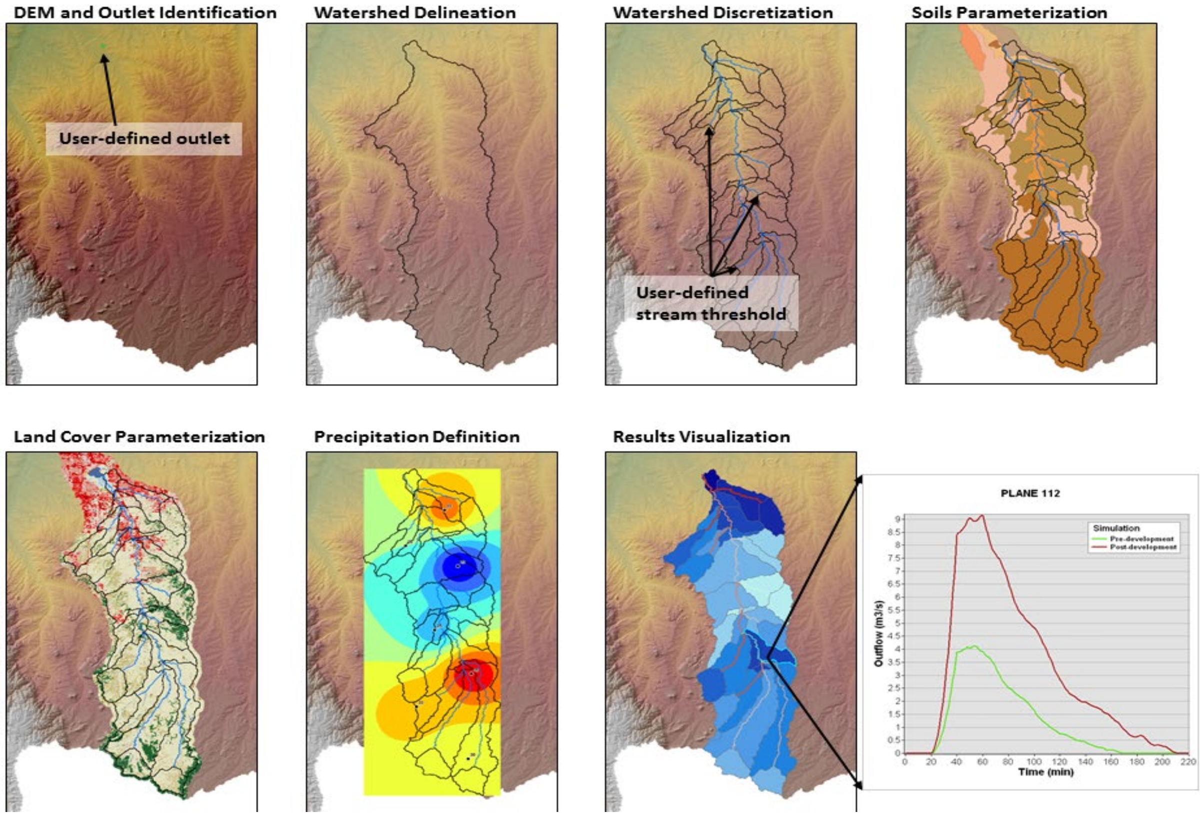

Figure 2. Primary steps in a watershed assessment using AGWA. Watershed delineation and subdivision into model elements is done using a DEM. Model elements are parameterized with soils, topography and land cover layers. Precipitation drives the model and spatially distributed results for each model element are imported and visualized in the GIS. Hydrographs and sedigraphs for any model element selected can also be displayed (lower right) (Goodrich et al. 2015).

To drive either K2 or SWAT, *precipitation inputs* must be defined. As SWAT is a continuous model, daily rainfall from one or more rain gauges is required. Daily precipitation and temperature files can also be generated from a nearby, user-selected weather station (weather stations are included in AGWA for the US). In the case of more than one gauge, AGWA will create Thiessen polygons that are intersected with watershed elements to create area-weighted precipitation inputs. The current release version of K2 is event-based but a continuous version is undergoing testing (see below). For the event-based version the user can input observed or user-defined hyetographs, design storms, or raster based precipitation surfaces representing return period-durations depths. For NOAA design storms, intensity distributions defined by SCS regional types can be selected.

Model execution also encompasses model simulation file creation. Simulation creation entails selection of the files created in the prior steps. Between creation and execution the user may select parameter multipliers for K2. In SWAT, the user can define other aspects of the simulation not defined by AGWA in the steps above, such as subbasin adjustment factors, crop types, simulation start and stop dates, groundwater parameters and the output time step. By separating creation and execution, the user can edit input files and apply the adjustments noted above and rerun the simulation without having to repeat the prior processing steps in AGWA.

Change analysis is facilitated in AGWA by storing simulation results for all the model elements in flat files associated with the simulation. AGWA has the capability to difference results from multiple simulations and save the result in terms of absolute change or percent change for a variety of model outputs for each model element. This capability is especially useful for scenario analysis where the user can explore the hydrologic impacts of land cover change resulting from things like development or wildfires, changes in storm inputs, or the addition of ponds or constructed channel features.

Model *results visualization* maps the simulation results back into the GIS environment for selected output variables and for differences of output variables (absolute or percent change) between two simulations. A variety of outputs can be displayed for any upland or channel model element including major water balance components and fluxes (e.g. peak runoff rate, runoff volume, sediment yield, etc. – for a full list see the AGWA documentation). This function enables the user to visualize the spatial variability of model results and readily identify problem areas where conservation or mitigation efforts might be focused (e.g. application of post-fire mulch to reduce erosion). For K2 simulations, hydrographs and sedigraphs can also be displayed.

Specialized Tools Within AGWA: A number of tools within AGWA have been developed for various users to enable scenario analysis. These tools have been available for some time and include:

- Land Cover Modification Tool
- Multi-Point and Multi-Watershed Tool
- Riparian Buffer Tool
- Post Fire Assessment Tool
- Urban Tool (add-in to ArcMap)
- Channel Diversion – Artificial Wetlands Tool

New tools and features are described in the following section.

The ***Land Cover Modification Tool*** (LCMT) has proven to be one of the more widely used tools and its implementation within AGWA is the basis for several of the other tools. The LCMT allows users to modify a land cover map and run AGWA to simulate the hydrologic effects of the land cover change. Land cover modifications can account for fire, urbanization, or other natural or anthropogenic changes. The tool can be used with the supported AGWA datasets (MRLC, NALC, etc.) or with custom defined land covers. The classification choices for the modified surface are limited to those classifications found in the selected land cover look-up table.

The Land Cover Modification Tool offers four modification options. They allow the user to modify the land cover within an interactively drawn polygon, or within an existing polygon map.

- Single Change: Change all of the land cover in an area to a new land cover type
- Single Change: Change one land cover type in an area to a new land cover type
- Random Distribution: Change all of the land cover in an area to up to 3 new land cover types in a spatially distributed random pattern
- Random Distribution: Change all of the land cover in an area to up to 3 new land cover types in a patchy fractal distribution pattern

The multifractal surface generator was implemented to create more realistic land cover surfaces for multiple land cover classifications than those created with the spatially random surface generator. It is based on a two-dimensional midpoint displacement algorithm (Saupe and Peitgen 1988) and allows users to specify multiple land cover classifications, the proportion of each class to be found in the new surface, the degree of clustering, and the boundary of the modification area. The modified surface contains land cover patches whose size is determined by the degree of clustering within the boundary area. A variant of the patchy fractal distribution pattern allows the user to specify the success level of a best management practice (e.g. brush management). For example, if herbicide application and reseeding in an area is 70% percent successful, then the final surface is created with a combination of 70% of the new land cover class (grass) and 30% of the current class (brush). This feature enables the simulation of various vegetation changes associated with management actions for U.S. Natural Resources Conservation Service's ecological sites and their state and transition models (Scott 2005).

The *Multi-Point and Multi-Watershed Tool* has two functions. The multipoint tool forces the watershed discretization to create the downstream location of channel element at specified locations or points of interest from a user input point shape file (e.g. campground, road crossing) so model simulation output is available at that point of interest. If point locations of downstream channel elements are not specified, their location is controlled by the discretization and flow accumulation process where channels converge. The multi-watershed tool was implemented so users could more efficiently perform AGWA analyses over an area of interest that includes multiple watersheds. A polygon defining the area of interest (e.g. property boundary, allotment boundary, parks) is input as well as an analysis extent region to limit the search area for the potential watershed outlets. AGWA will automatically delineate all watersheds within the boundary of interest and carry out the additional steps noted above (discretization, parameterization, etc.).

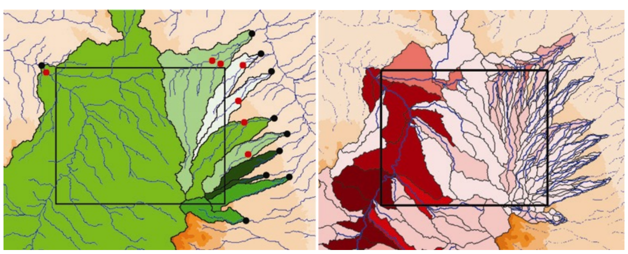

Figure 3. (left) Area of Interest outlet identification and delineation for the boundary. Red points indicate a potential outlet; black points are final watershed outlets that ensure watershed coverage of the area of interest. (right) Area of Interest watershed discretization

The *Riparian Buffer Tool* allows users to identify a section of a channel reach to insert a riparian buffer strip, one of the most commonly used best management practices, and simulate its effects using K2 (Scott 2005). Scenarios of buffer location, buffer geometry, and buffer land cover composition can be explored with the tool. If the selected reach does not fall along the entire length of a channel derived from AGWA discretization, the tool will further discretize the channel segment and the upland areas contributing to the buffer (Figure 4). A separate overland flow model element representing the buffer (No. 35 in Figure 4) is inserted between the upland area (No. 33) and the stream segment as K2 can simulate runoff-runon from one overland flow element to another with different characteristics. Geometry and cover characteristics for the element are entered by users via an AGWA input interface.

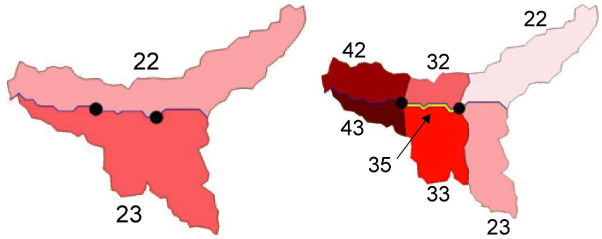

Figure 4. KINEROS2 Buffer discretization. (left) The unbuffered overland flow elements with buffer location and length defined by points. (right) The buffered overland elements (Goodrich et al. 2006)

AGWA/K2 and the *Post Fire Assessment Tool* has gained relatively widespread use with the increasing size and frequency of wildfires. It has been adopted by the U.S. Department of Interior (DOI) National Burned Area Emergency Response (BAER) Team for post-fire watershed assessments following large wildfires. Its use by the DOI BAER team has greatly streamlined the hydrologic analysis component of the comprehensive, interdisciplinary BAER process (limited to 14 days) to develop a post-fire treatment plan. As part of the BAER process, a soil burn severity map is produced from a field verified remotely sensed Burned Area Reflectance Classification (BARC) map of the wildfire area. Burn severity is classified as high, medium, or low. With analysis from a limited number of watersheds where good rainfall-runoff data were available (Canfield et al. 2005; Sheppard 2016) look up tables were developed to adjust the saturated hydraulic conductivity and hydraulic roughness as a function of burn severity and pre-burn land cover. AGWA imports the soil burn severity map and automatically makes the parameter adjustments, with appropriate spatial weighting, to burn affected modeling elements. Pre- and Post-fire simulations driven by the same design storm can be done and using the AGWA simulation differencing the BAER teams can easily identify at-risk areas for high runoff and erosion potential to focus post-fire mitigation efforts. AGWA also has the ability to assess common post-fire treatments, such as the application of straw mulch. AGWA/K2 has been used on over 52 wildfires on over 3.8 million acres since 2011, and the AGWA team and a number of users were the recipients of the 2018 Federal Laboratory Consortium's Interagency Partnership Award. Further details on the Post-Fire Assessment and its application can be found in Guertin et al. (2019a; 2019b), Sidman et al. (2016a; 2016b), Natural Resources Conservation Service (2016), and Chen et al. (2013).

The AGWA *Urban Tool* was developed with the intent of using K2 within AGWA to conduct relatively rapid green infrastructure (GI) planning and assessments from the lot-to-subdivision-to-watershed level (Korgaonkar et al. 2015). K2 provides the capability to model the built environment using its urban component by representing various flow-on and flow-off areas at the scale of a single housing lot or parcel. The AGWA Urban tool can model urban hydrology by representing different roof, driveway, yard, and street characteristics using the KINEROS2 urban element. The AGWA Urban tool is also capable of representing green infrastructure (GI) practices such as retention/detention basins, permeable driveways and streets, and rainwater harvesting off the roofs (Figure 5). The AGWA Urban tool can be utilized to model urban watersheds at various scales (parcel, subdivision, neighborhood, or city). Additionally, it can be used to assess the effect of GI practices on peak flows, volumes, and on water availability for domestic use. Korgaonkar et al. (2018) demonstrates these capabilities by modeling a small subdivision in Sierra Vista, Arizona.

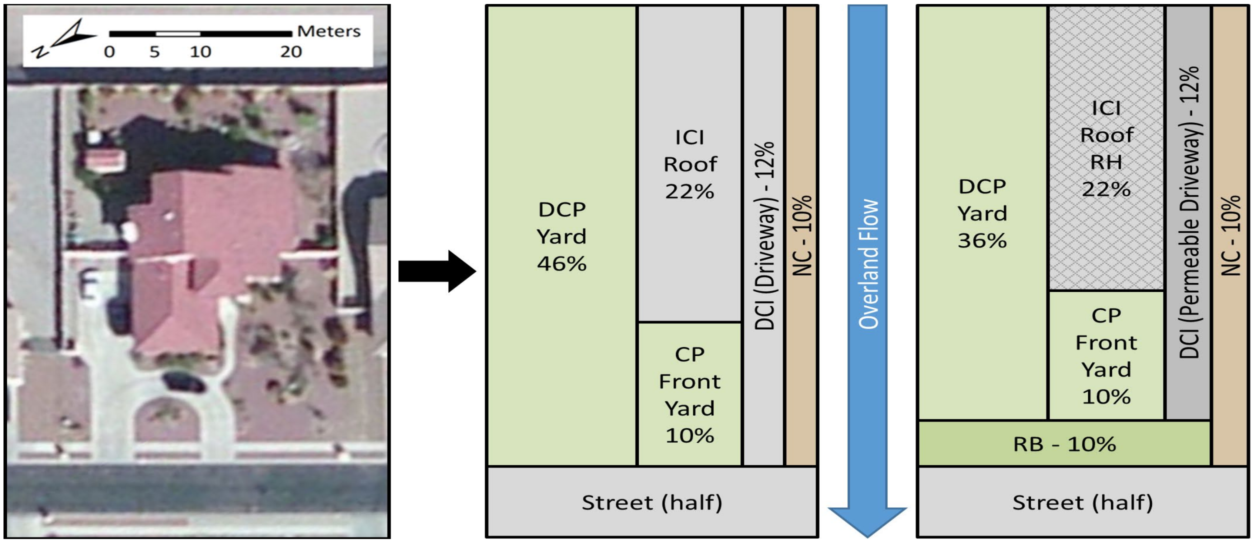

Figure 5: Representing a typical housing lot (Left) using the KINEROS2 Urban Element without GI practices (Center), and with retention basin (RB), permeable driveway (PD), and rainwater harvesting (RH) GI practices (Right). Percent values of each of the overland flow areas are indicative of the percent of the total parcel area. DCP: directly connected pervious; ICI: indirectly connected impervious; CP: connecting pervious; DCI: directly connected impervious; NC: noncontributing area. (Source: Korgaonkar et al. 2018)

Most natural watersheds are morphologically analogous to a tree structure where upstream elements can only contribute to a single downstream element. The basic structure of K2 mimics this concept. The AGWA *Channel Diversion – Artificial Wetlands Tool* was developed to address partial diversion of flow such as for irrigation, into constructed wetlands, etc. It consists of a K2 diversion element and input interface describing diversion functions. This element can divert water and sediment from a single upstream element to as many as 10 downstream elements. Diversion rates are determined from a user-supplied tabular relationship between the inflow rate from the upstream element and the rates diverted into each downstream element.

New Tools and Features

AGWA

The following tools have recently been developed for AGWA:

- Military Disturbance Tool
- Storage/Pond Characterization Toolbox
- Inundation Tool
- Facilitator Export Tool.

The AGWA *Military Disturbance Tool* (MDT) is used to simulate on-site and downstream effects on runoff and erosion resulting from military training activities. It is an optional tool in AGWA's parameterization step, and includes three general disturbance levels: light, moderate, and heavy. It modifies key input parameters for AGWA's embedded hydrologic models based on the disturbance level. Reductions to soil porosity, surface roughness (Manning's n), and canopy cover for each level are applied in K2, with hydraulic conductivity adjusted according to porosity. Reductions are also applied to canopy cover, litter cover, and basal cover for RHEM. Curve numbers in SWAT are modified for each disturbance level based on land cover type condition and hydrologic soil group according to published data (i.e., USDA-NRCS 2004). The MDT is currently implemented only for K2 within AGWA, but will be available in the near term for RHEM. The MDT is discussed in more detail in another paper being presented at this conference (Levick et al. 2019).

The *Storage Characterization Toolkit* (SCT) has recently been developed and is currently available for AGWA. The SCT uses high-resolution topographic data (typically LIDAR) to characterize existing stocks ponds and link those with K2 discretizations created in AGWA. Using a user-defined threshold and an unfilled DEM, it can automatically identify features with a minimum area in the landscape/topography that detain or retain water. Once storage features are identified, the SCT determines their stage-volume-surface area relationship. Following this characterization and using additional user-defined outflow properties, the SCT can calculate and add discharge to the stage-volume-surface area relationship. The final step in the SCT associates the previously derived stage-volume-surface area-discharge relationship with a KINEROS2 discretization for use in AGWA. This tool has been developed as a separate toolkit and is in the process of being implemented in AGWA. The SCT is discussed in more detail in another paper being presented at this conference (Guertin et al. 2019b).

The *Inundation Tool* was developed to aid BAER teams to quickly estimate and map inundated areas at values at risk (VAR - e.g. visitor center) in post-fire situations**.** The AGWA Post-Fire Assessment tool discussed above can estimate post-fire peak discharge (Qp) rates from design storm input at any location in the watershed being modeled**.** The inundation tool was developed by Barlow (2017) as Python scripts accessed through an ArcGIS Toolbox that can use the AGWA/KINEROS2 Qp estimate with algorithms from the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-2 model (CEIWR-HEC 1990)**.** It requires inputs related to channel properties that can be collected at specified channel cross sections in the field or estimated using high-resolution elevation data (e.g. LIDAR) in addition to hydraulic roughness values**.** It computes surface water elevations that are then compared to the channel cross section ground elevations to come up with **the** wetted area and mapped to estimate the inundated area**.** The tool is limited to relatively simple channel geometry and downstream conditions (without major constriction and backwater)**.** This tool has been developed and is in the process of being implemented in AGWA.

The *Facilitator Export Tool* was developed to ingest K2 outputs for peak flow and sediment yield into the Facilitator Decision Support System. The Facilitator software helps individuals and groups of people in making decisions by encouraging participation by all stakeholders. It uses decision rules, a hierarchical system for ranking criteria, score functions and linear programming to identify preferred management options consistent with the ranking of criteria. It can accommodate measured data, simulation results from models like K2 and expert opinions in the decision making process (Yakowitz and Weltz 1998; Lawrence et al. 1997; (https://sourceforge.net/projects/facilitator/files/). It is also useful for documenting the decision making process.

Several new features have also been included to take advantages of new land cover data, more generalized channel geometry, more regionally specific storm distribution type curves, as well as tutorials. In the first case, AGWA has incorporated *Regional Hydraulic Geometry Relationships* from the United States compiled by Bieger et al. (2015) to improve initial channel geometry estimates nationally. The user can elect to have AGWA automatically select a relationship associated with the Physiographic Division, Province, or Section that intersects or is closest to the watershed, but also has the option of overriding that selection. These additional relationships may provide better initial channel widths, which is important to channel infiltration dynamics and flow timing, because the relationships are based on physiographic regions, which are more representative of the climate and weather, geomorphology, soils, and land use patterns that influence channel geometries.

The ability to ingest and use the *LANDFIRE Existing Vegetation Cover* (EVC; www.landfire.gov) dataset natively in AGWA has been added and offers the opportunity for improved land cover parameterizations. The EVC dataset has canopy cover information at the pixel level for tree, shrub, and herbaceous lifeforms, which is an improvement over the standard practice in AGWA where canopy cover is static and set to the average condition of each land cover type used. For K2, this addition invokes spatially varying saturated hydraulic conductivity (Ks) within a soil type given that soil-based Ks is adjusted by cover using the following equation:

$$Ks_{adjusted} = Ks_{soils} * (2.71828^{(canopy\ cover\ *\ 0.0105)}) * (1 - \text{percent impervious}) \qquad (1)$$

Note that this improvement will only be observed for the tree, shrub, and herbaceous lifeforms with canopy cover information in the dataset; the other land cover types will default to their average condition value from the AGWA land cover look-up table.

Regional Rainfall Distribution Curves: The use of 23 NRCS and Northeast Regional Climate Center (NRCC) rainfall distribution curves for K2 precipitation input has been added to AGWA to improve regional rainfall distribution of design storms. These additional curves cover 29 states, and offer an alternative to the SCS Type II rainfall distribution curve previously used in AGWA. In addition to the regional/state-based NRCS and NRCC distribution curves, the Type I, IA, and III curves were also added to AGWA to establish complete coverage of the United States. The AGWA website has an assortment of step-by-step *tutorials* highlighting different functionality available in the tool. Currently there are 11 tutorials, and the requisite data to run them, available on the AGWA website, with plans to add more as new features and tools are released. Additionally, a series of YouTube video tutorials have been requested by users and are currently being developed and will be released as they are completed.

K2

For the overland flow elements, K2 now allows unequal widths at the upstream and downstream ends of the element. This essentially generalizes the plan form shape of the element from a rectangle to a trapezoid, and effectively creates a convergent/divergent flow condition depending on the relative widths at the upstream and downstream ends of the element. For channels, a new efficient method has been developed to carry out channel routing in a natural cross-section without having to approximate the channel with a trapezoidal shape. The hydraulic properties and their derivatives are obtained during routing by interpolation using piecewise cubic Hermite interpolating polynomials (Fritsch and Butland 1984), which have desirable shape and monotonicity properties for this application. Using components adapted from the model Opus (Smith 1992), K2 can also track the evolution of soil moisture between events, allowing continuous simulation. The soil water model is a finite difference solution to Richards' equation, and potential evapotranspiration is estimated using a method developed by Ritchie (1972).

Future Plans and Model Development

The flash flood forecasting (FFF) version of K2 is currently a standalone tool. This version utilizes input from NOAA National Weather Service radar products. Weighting coefficients relating the radar grid to the K2 model elements are currently computed via an external GIS operation. Incorporating the FFF version of K2 into AGWA will require a few additions: 1) distributing the FFF version of K2 with AGWA; 2) distributing the polar-centric radar grids for all available radars in the US; and, 3) adding and automating the GIS functionality that intersects the radar grid and watershed discretization to derive the weighting coefficients that associate radar grids cells to K2 model elements.

With the greater availability of LIDAR derived topographic data and the new functionality in K2 to do routing in an irregular channel cross-section, initial development of an AWGA channel cross-section extraction tool has been carried out. It will segment existing stream reaches identified by AGWA in the discretization into user defined intervals and extract channel cross sections perpendicular to the stream at the defined interval. Once the cross sections are extracted the tool will perform calculations to develop a table of stage, wetted area, and wetted perimeter that can be input into K2. Further refinement is required to treat cases where more than one channel section is identified near channel junctions. In addition, the K2 web site and documentation will be updated and efforts will be initiated to incorporate the continuous version of K2 into AGWA.

Future Releases of AGWA

Anticipating preliminary releases in the second half of 2019, the next major releases of AGWA will include dotAGWA, featuring a transition to the internet with a fully-featured, rich web-application, and AGWA for ArcGIS Pro, featuring a transition to ESRI's latest professional desktop GIS application. Although major ESRI ArcMap releases beyond 10.6 are not anticipated, support for AGWA 3.x for ArcMap 10.x versions will continue indefinitely. Additionally, support for AGWA 2.x for ArcMap 9.x and AGWA 1.x for ArcView 3.x can be provided for users who are unable to transition to current ESRI desktop GIS applications.

The transition to dotAGWA and AGWA for ArcGIS Pro will feature a shared Python codebase of core functionality. This will allow both versions to maintain parity such that output between the two is indistinguishable given the same input. This may also offer the opportunity to import/export input and output between the applications. The transition will also more completely leverage the geoprocessing tools in ArcToolbox, improving robustness and reliability, and allowing for improved troubleshooting of unexpected behavior.

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