AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT TOOL (AGWA): UNCERTAINTY ANALYSIS OF COMMON INPUT DATA

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Abstract

The Automated Geospatial Watershed Assessment Tool (AGWA) is a GIS-based hydrologic modeling tool that is available as an extension for ArcView 3.x from the USDA-ARS Southwest Watershed Research Center (www.tucson.ars.ag.gov/AGWA/) and US-EPA BASINS website (www.epa.gov/OST/BASINS/). AGWA was designed to facilitate the assessment of land-use and climate-change impacts on water yield and quality at multiple scales. It parameterizes two watershed runoff and erosion models, the Kinematic Runoff and Erosion Model (KINEROS2) and the Soil and Water Assessment Tool (SWAT), using readily available topographic, soils, and land-cover data. After parameterization, the selected model is run through the AGWA interface, and results are imported back into the GIS for display and analysis. AGWA was designed to be a user-friendly tool and allows users to enter available input from their watersheds. This feature increases AGWA's accessibility, and permits data of different scales and qualities to be used together to parameterize AGWA's models. The goal of this study was to evaluate the effects of using different combinations of commonly available soil and topographic data on runoff volume and peak flow using KINEROS2. KINEROS2 was selected because it was designed to model relatively small watersheds, up to roughly 100 square kilometers. AGWA can obtain hydrologic parameters from three soils databases: the State Soil Geographic (STATSGO), Soil Survey Geographic (SSURGO), and Food and Agriculture Organization of the United Nations (FAO) digital soil map of the world. The three soil data types will be evaluated in combination with two USGS digital elevation model (DEM) resolutions: 10 and 30 meters. This paper will report the comparison of observed and simulated results from the six combinations of the three soil datasets and the two topographic datasets (DEMs).

INTRODUCTION

This paper compares simulation results from the Automated Geospatial Watershed Assessment tool (AGWA) (Goodrich et al. 2006) and the KINEROS2 hydrologic model (Woolhiser et al. 1990) for the FAO, STATSGO and SSURGO soils datasets for 10m and 30m DEM resolutions on three different sized watersheds. AGWA was originally designed for use with the STATSGO soils data in the United States. When SSURGO and FAO soils datasets became available they were incorporated into AGWA, but simulation results from the three datasets have not been compared using observed data. The three soil data types were evaluated in combination with two USGS digital elevation model (DEM) resolutions: 10 and 30 meters.

This study was conducted at the USDA-Agricultural Research Service's Walnut Gulch Experimental Watershed (WGEW), located in southeastern Arizona. To assess the effects of watershed scale, the following watersheds were selected for the evaluation: WS11 (8 km^2), WS15 (24 km^2) and WS2 (114 km^2). Twenty-seven observed precipitation events from WGEW were used for this study. All 27 events occurred during the summer monsoon season, from June through October, since these high-intensity convective thunderstorms produce most of the runoff in this semi-arid desert/grassland environment.

BRIEF DESCRIPTION OF THE SOILS DATASETS

The Soil Survey Geographic database (SSURGO) is currently available for selected counties and areas of the United States and its territories. These maps were digitized from the original survey maps, and are generally the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. They are most useful for landowners, townships, and county natural resource planning and management (Soil Survey Staff, 2005). The State Soil Geographic database (STATSGO) is available for the entire United States, including Alaska, Hawaii, and Puerto Rico, and is organized by state. These maps are generalizations of the detailed county soil series data and are most effective for broad planning and management uses covering state, regional, and multi-state areas (Soil Survey Staff, 2005).

The Food and Agriculture Organization of the United Nations (FAO) soils dataset was originally published in 1974 as the Soil Map of the World (SMW). The latest version, released in 2003, is a digital dataset that includes a total of nearly 5000 mapping units and more than 200 soil-units world-wide. The SMW was compiled from individual country soils data, which used a variety of local soils data, and is a generalization of those data. The FAO maps are arranged into 10 major continental regions: Africa, Australasia, Central America, South America, Europe and West of the Ural, North America, Central and North East Asia, Near East, Far East, and South East Asia (FAO/UNESCO, 2003).

The FAO maps are the coarsest, most generalized of the three soils datasets at a scale of 1:5,000,000. The SSURGO maps are at scales ranging from 1:12,000 to 1:63,360, while STATSGO maps are at a scale of 1:250,000.

METHODS

Runoff and peak flow were simulated using AGWA and KINEROS2 for watersheds WS2, WS11 and WS15 at the USDA-ARS Walnut Gulch Experimental Watershed in southern Arizona (Figure 1), and then compared to observed data. Walnut Gulch is one of the most instrumented watersheds in the United States with over 100 locations consisting of rain gages and/or stream gages (flumes), and over 50 years of data. The simulations used observed precipitation data for 27 rainfall events. These events ranged in size from 0.9 mm to 41.9 mm, with a mean of 16.3 mm and a standard deviation of 9.4. For comparison purposes, a 10-year 1-hour design storm for this region would produce a rainfall depth of 20.56 mm. The three study watersheds were modeled for all 27 rainfall events, using each of the three soil maps (Figure 2), and on both the 10m and 30m DEMs. The 1997 North American Land Cover (NALC) map was used for land cover. In configuring the watersheds into contributing planes and channels a 1.5% contributing source area factor was applied (see AGWA website for documentation).

The look-up table used by AGWA to derive soil-related parameters for KINEROS2 was developed based on the original KINEROS documentation (Woolhiser et al., 1990). Its parameter values were then optimized using STATSGO soils for Walnut Gulch Sub-Watershed 11. Subsequent development of the parameterization routine for SSURGO soils required only minor modification of the STATSGO procedure because the two datasets share a common set of soil-property tables. The FAO soil-property tables, however, are unique and required an entirely new approach (Levick et al., 2004).

The objective of this study was to evaluate the relative performance of KINEROS2 when parameterized through AGWA using a variety of different datasets. Calibrating KINEROS2 would have homogenized the results and removed the signatures of the data and parameterization routines being evaluated. In this analysis the models were therefore not calibrated, and instead used the default, automated parameterization procedures from AGWA.

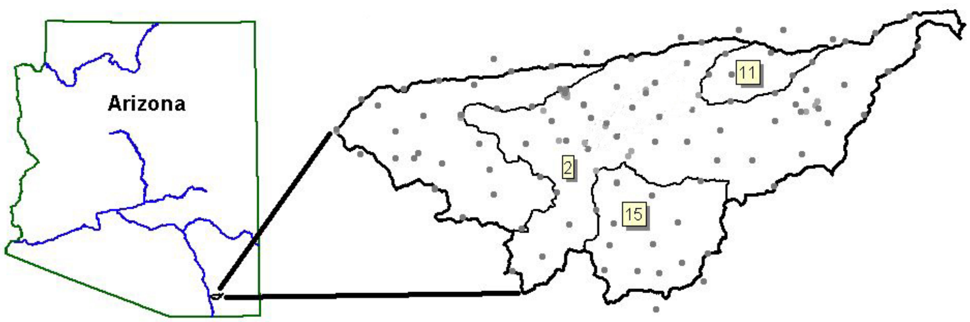

Figure 1 Walnut Gulch Experimental Watershed, Arizona, with Sub-Watersheds 2, 11, and 15, and Rain Gages.

Figure 2 Watershed 2 outline with (a) FAO, (b) STATSGO and (c) SSURGO soils

The simulation results were compared using several metrics. Regressions between the observed and simulated runoff (mm) were created and compared against a 1:1 (observed runoff) line (Figures 3 – 8). Two measures of model performance were also computed: root mean square error (RMSE) and matched pairs t statistic test (t-paired) (Lapin 1975). Statistics of the observed and simulated runoff are also presented (Tables 1-3). The matched pairs t statistic was computed as the difference between the simulated and observed. The null hypothesis is that the mean difference is zero, or that the simulated runoff is equal to the observed runoff. For comparison the t statistic for a probability level of 0.95 with 26 degrees of freedom is 2.056. A computed negative t statistic indicates the simulated values are less than the observed.

RESULTS

Figures 3 through 8 show a comparison of observed vs. simulated runoff at each watershed for each of the three soil types for both the 30m and 10m DEMs. Tables 1, 2 and 3 show the statistical and performance results for all three watersheds with the soils-DEM combinations.

For WS11 (Figures 3 & 4, Table 1) the FAO simulations performed poorly based on the t statistics, although they did have low RMSEs. FAO consistently underestimated runoff and peak flows. SSURGO and STATSGO performed equally well, with SSURGO having lower RMSE and STATSGO have better t statistics. The 10m DEM performed better with both SSURGO and STATSGO based on the t statistics, although the 30m DEM had slightly lower RMSEs.

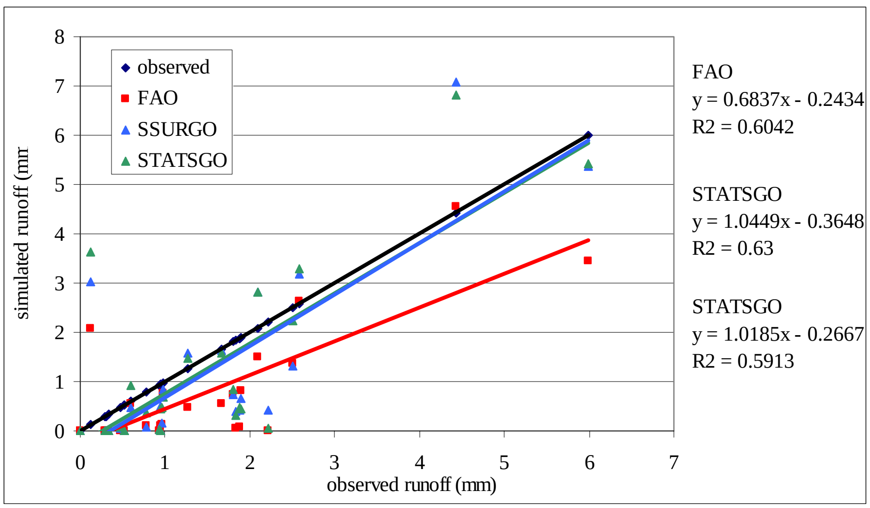

Figure 3 Watershed 11 Runoff (mm), 30m DEM

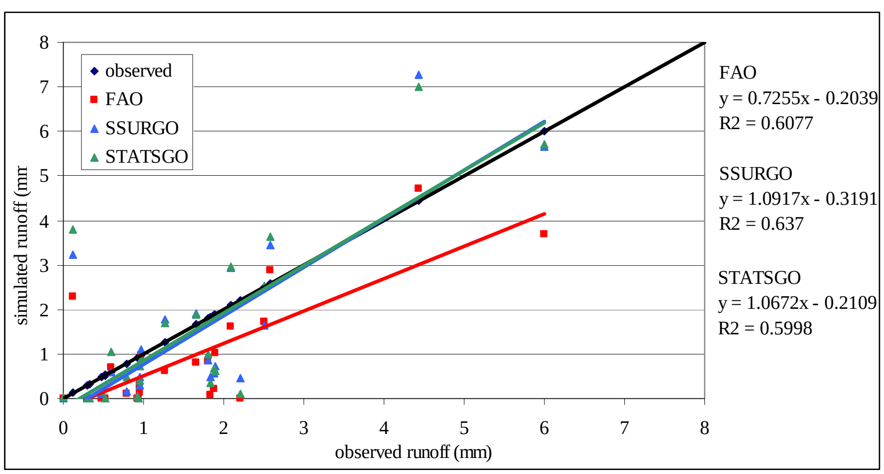

Figure 4 Watershed 11 Runoff (mm), 10m DEM

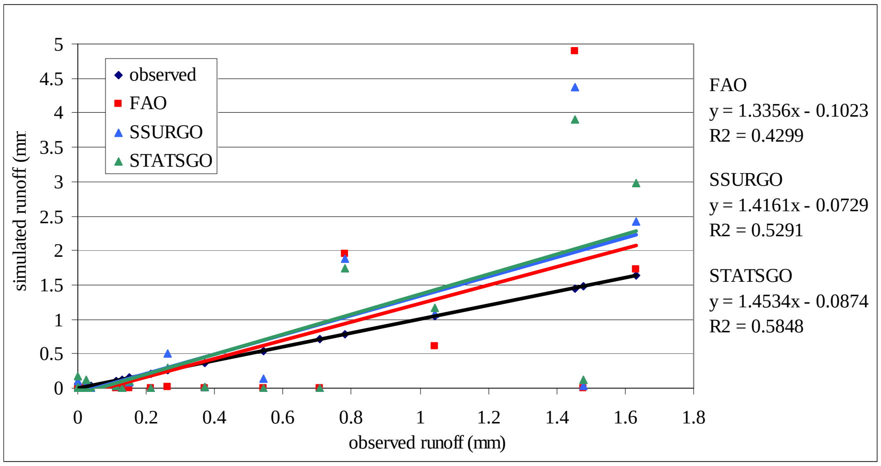

Figure 5 Watershed 15 Runoff (mm), 30m DEM

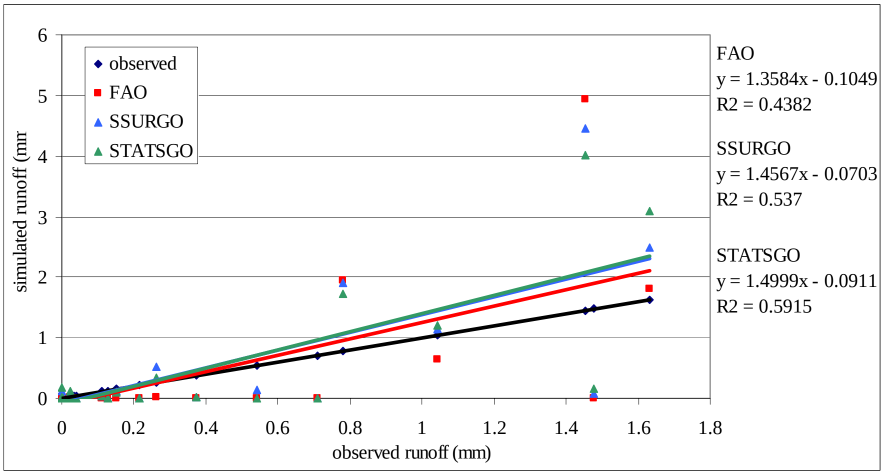

Figure 6 Watershed 15 Runoff (mm), 10m DEM

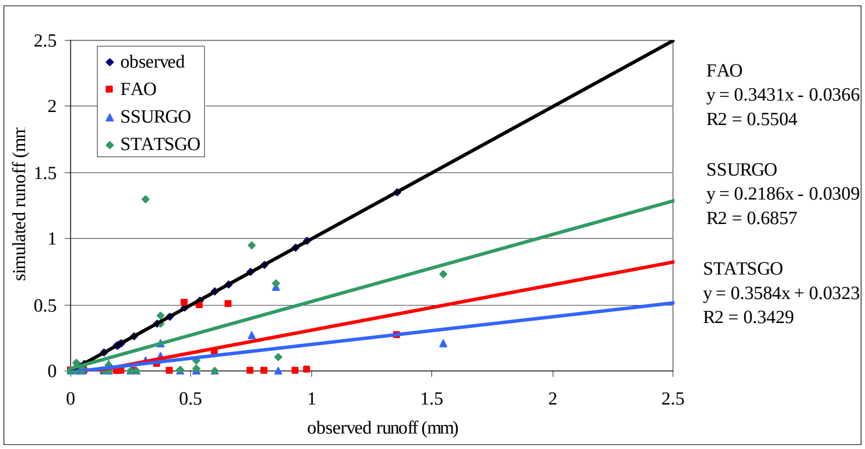

Figure 7 Watershed 2 Runoff (mm), 30m DEM

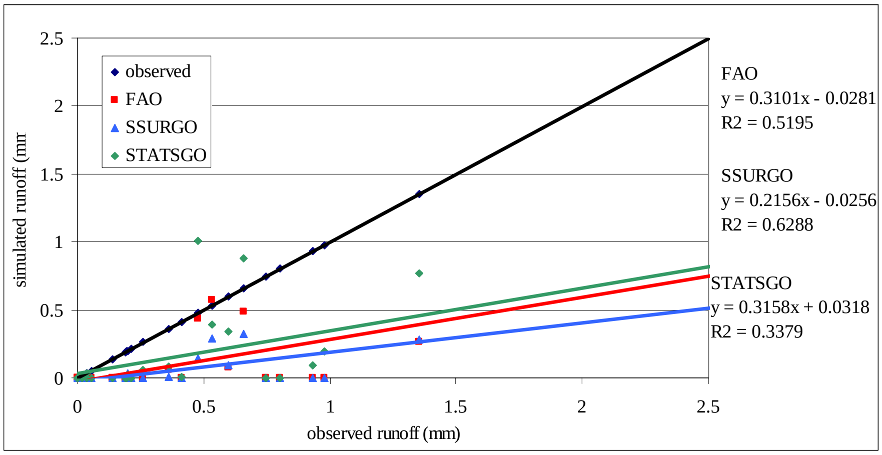

Figure 8 Watershed 2 Runoff (mm), 10m DEM

Table 1 Watershed 11 results for runoff and peak flow. The reported values include mean, standard deviation (SD), coefficient of variation (CV), minimum value (min), maximum value (max), root mean square error (RMSE) and matched pair t statistic (t-paired).

WS11 Results			10m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	1.439	2.492	0.840	1.776	1.252	2.811	1.325	2.932
SD	1.338	2.316	1.245	2.752	1.830	4.329	1.843	4.360
CV	0.929	0.930	1.481	1.549	1.461	1.540	1.391	1.487
Min	0	0	0	0	0	0	0	0
Max	5.998	11.067	4.713	10.142	7.274	16.280	7.002	15.929
RMSE			1.036	2.090	1.104	3.671	1.153	3.844
t-paired			-3.612	-1.897	-0.876	0.553	-0.507	0.722
			30m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak flow (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	1.439	2.492	0.741	1.481	1.139	2.483	1.199	2.559
SD	1.338	2.316	1.177	2.416	1.761	3.965	1.772	3.979
CV	0.929	0.930	1.588	1.632	1.545	1.597	1.477	1.555
Min	0	0	0	0	0	0	0	0
Max	5.998	11.067	4.550	8.158	7.068	13.988	6.809	13.874
RMSE			1.090	1.679	1.095	3.227	1.137	3.320
t-paired			-4.258	-2.945	-1.453	-0.017	-1.102	0.123

For WS15 (Figures 5 & 6, Table 2) all the combinations performed reasonably well. All the computed t statistics (absolute values) fell within the 0.95 probability level indicating that the matched paired differences are equal to zero. Based on the t statistics, the FAO outperformed both SSURGO and STATSGO on WS15, with the 30m DEM having slightly better results than the 10m DEM. However, the RMSE was highest for FAO indicating a larger range of differences between the simulated and observed values. Based on Figures 5 and 6, and statistics in Table 3 it can be argued that the model is operating equally well for both SSURGO and STATSGO on both DEMs.

Table 2 Watershed 15 results for runoff and peak flow. The reported values include mean, standard deviation (SD), coefficient of variation (CV), minimum value (min), maximum value (max), root mean square error (RMSE) and matched pair t statistic (t-paired).

WS15 Results			10m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	0.333	0.350	0.348	0.479	0.415	0.623	0.408	0.648
SD	0.510	0.730	1.047	1.322	1.014	1.560	0.995	1.789
CV	1.532	2.086	3.012	2.761	2.444	2.503	2.436	2.760
Min	0	0	0	0	0	0	0	0
Max	1.632	2.745	4.928	4.924	4.457	6.926	4.010	8.609
RMSE			0.791	0.986	0.719	1.234	0.676	1.466
t-paired			0.094	0.595	0.584	1.145	0.572	1.108
			30m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak flow (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	0.333	0.350	0.343	0.479	0.399	0.619	0.397	0.632
SD	0.510	0.730	1.039	1.300	0.993	1.528	0.970	1.697
CV	1.532	2.086	3.034	2.714	2.490	2.471	2.444	2.687
Min	0	0	0	0	0	0	0	0
Max	1.632	2.745	4.904	4.656	4.373	6.402	3.906	7.948
RMSE			0.788	0.971	0.704	1.205	0.657	1.374
t-paired			0.061	0.587	0.479	1.120	0.497	1.097

Table 3 Watershed 2 results for runoff and peak flow. The reported values include mean, standard deviation (SD), coefficient of variation (CV), minimum value (min), maximum value (max), root mean square error (RMSE) and matched pair t statistic (t-paired).

WS2 RESULTS			10m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	0.435	0.308	0.107	0.103	0.068	0.068	0.169	0.163
SD	0.557	0.370	0.239	0.236	0.151	0.153	0.302	0.310
CV	1.281	1.204	2.245	2.293	2.223	2.246	1.789	1.900
Min	0	0	0	0	0	0	0	0
Max	2.536	1.545	0.980	0.957	0.650	0.643	1.006	1.080
RMSE			0.526	0.536	0.571	0.576	0.518	0.549
t-paired			-4.073	-3.095	-4.268	-3.932	-3.043	-2.273
			30m DEM					
	observed		FAO		SSURGO		STATSGO	
value	runoff (mm)	peak flow (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)	runoff (mm)	peak (mm/hr)
Mean	0.435	0.308	0.114	0.100	0.064	0.058	0.188	0.176
SD	0.557	0.370	0.255	0.225	0.147	0.137	0.341	0.343
CV	1.281	1.204	2.242	2.250	2.292	2.350	1.812	1.948
Min	0	0	0	0	0	0	0	0
Max	2.536	1.545	1.091	0.944	0.676	0.634	1.162	1.298
RMSE			0.510	0.534	0.571	0.582	0.507	0.541
t-paired			-4.120	-3.224	-4.349	-4.110	-2.838	-2.003

The simulation results for WS2 (Figures 7 & 8, Table 3) were poor for all combinations. As indicated in Figures 7 and 8, all three soil types significantly underestimated runoff. Peak flows were also significantly underestimated. The t-statistics were all relatively high and negative, with STATSGO performing the best of the three soil types.

DISCUSSION

There are many factors that may explain the results from these simulations including the AGWA parameterization and source of the original look-up tables, the variations in watershed size, and the difference in resolution of the soil data, relative to the resolution (geometric complexity) of the watershed discretization. The results illustrate that the default parameterization procedures performed well, with both DEMs, for both the SSURGO and STATSGO soil types at the smaller watershed scales. FAO did not perform similarly, performing poorly on WS11 and having the higher RMSEs on WS15, which should be expected since its lookup tables were developed based on different soil property tables compared to STATSGO and SSURGO (Levick et al. 2004).

AGWA/KINERSO2 did not perform well on WS2. WS2 is the largest watershed where channel processes, including transmission losses, will have a greater influence compared to hillslope processes. The results may indicate a problem with modeling or parameterizing channel elements. Furthermore, studies have found this result should be expected in an influent (e.g. losing) stream environment where the uncertainty in rainfall model inputs become a larger percentage of the modeled runoff signal as basin size increases (Goodrich et al. 1997; Syed 1999).

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