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Evaluation of Soil Erosion and Sediment Yield From Ridge Watersheds Leading to Guánica Bay, Puerto Rico, Using the Soil and Water Assessment Tool Model

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Abstract: Increased sediment loading to reservoirs and, ultimately, to Guánica Bay and reef areas is a significant concern in Puerto Rico. Sediment deposition has significantly reduced storage capacity of reservoirs, and sediment-attached contaminants can stress corals and negatively impact reef health. In this study, we examined sediment yield from an upper mountainous watershed, Yahuecas, contributing sediment to Lago Yahuecas reservoir and eventually Guánica Bay, Puerto Rico, to gain a better understanding on sediment loss. This watershed was chosen because it was the only watershed where runoff was monitored in Guánica Bay basin. The Soil and Water Assessment Tool was calibrated and validated using 4½ years of flow data (07/1980 to 01/1985) from the Yahuecas watershed. Five and a half years of suspended sediment concentration data (04/2000 to 09/2005) from the adjacent Adjuntas watershed were used to calibrate sediment simulation of the model because no sediment data were available for Yahuecas. After calibration and validation, Soil and Water Assessment Tool was used to evaluate temporal-spatial soil erosion and sediment yield and assess factors that impact sediment yield. From 1975 to 2011, approximately 80% of annual sediment yield occurred during the two rainy seasons (February to May and August to November). Heavy rainfall, erodible soils, and steep mountain slopes were the primary causes of sediment yield in the Yahuecas watershed. Land use that reduces the protective forest canopy (like sun-grown coffee farming) can exacerbate soil loss. More sediment per hectare was lost from areas producing coffee than forested or grass-covered areas. Conversion of coffee farming practices from sun-grown to shade-grown will reduce soil erosion and sediment yield.

Key Words: Coffee farming, land use, Puerto Rico, ridge watersheds, sediment yield, soil erosion, SWAT

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Sediment and associated contaminants have increased fivefold to 10-fold since precolonial levels and an additional twofold to threefold in the last 40 to 50 years (Wilkinson and Brodie, 2011; Sturm et al., 2012). Primary concerns with increased sediment loading to reservoirs and ultimately to the Guánica Bay and reef areas are (1) sediment deposition has significantly reduced the storage capacity of reservoirs in the Guánica Bay Basin and (2) sediment and its associated contaminants can stress corals and negatively impact reef health (Wilkinson and Brodie, 2011). Sedimentation can also reduce photosynthetic activity of aquatic plants and algae and increase water-treatment costs for domestic and industrial uses (Verhoeven et al., 2006). Therefore, preventing soil erosion and reducing sediment yield are of paramount importance in the Guánica Bay basin.

Although sedimentation occurs naturally, sediment transport to reservoirs and, ultimately, to Guánica Bay and reef areas from surrounding watersheds is exacerbated by steep slopes, high mean annual rainfall, and episodic intense rainfall events of tropical storms and hurricanes (Scatena and Larsen, 1991). The high, often intense rainfall can cause large amounts of soil loss from landslides and debris flows, especially in disturbed areas (Warne et al., 2005; Arekhi et al., 2012). Furthermore, suspended sediment (SS) loading may also increase because of agricultural production. Since the 1950s, the agricultural production of coffee, especially sun-grown coffee plantations in ridge watersheds, has increased soil loss (Ortiz-Zayas et al., 2001). Traditionally, coffee has been grown in shaded environments, with the shade being provided by canopies of many different trees, which benefit the soil by adding nutrients and preventing soil erosion. In 1990s, farmers were encouraged to replace traditional shade-grown coffee with sun cultivation in order to increase coffee yield. The sun-grown coffee system has little or no canopy cover.

There is a growing need to understand soil erosion and sediment transport processes in ridge watersheds to better control soil loss and reduce sediment transport into reservoirs and bays. To estimate soil erosion and develop optimal erosion management plans, many models such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), the Annualized Agricultural Nonpoint Source Pollutant Loading model (Bingner et al., 2015), the Water Erosion Prediction Project (Laflen et al., 1997), the Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2011b), and the European Soil Erosion Model (Morgan et al., 1998) have been developed and used. Of these, SWAT has been used extensively for hydrologic and water quality simulations at different spatial scales to assess the impact of management strategies on water quality (Arnold et al., 1999; Borah et al., 2006; Shirmohammadi et al., 2006; Gassman et al., 2007 and 2014). The model has received extensive evaluation and validation throughout the United States and internationally (Gassman et al., 2007 and 2014) and has previously been applied, evaluated, and validated for estimating sediment yields from other watersheds (Muleta and Nicklow, 2005; White and Chaubey, 2005; Easton et al., 2010; Ayana et al., 2012; Zabaleta et al., 2014). The SWAT model was therefore chosen for this study.

The objectives of this study were to apply the SWAT model to (1) investigate spatial and temporal patterns of sediment yield from a ridge watershed feeding Guánica Bay and (2) to evaluate the impact of land cover and land management on sediment yield so that improved management options to control soil erosion and sediment yield can be developed.

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METHODS AND PROCEDURES

SWAT Model Description

SWAT is a continuous simulation, long-term, physically based model that assesses the impacts of land use and management changes on hydrological processes, sediment yield, and pollution transport in watersheds (Arnold et al., 1998; Neitsch et al., 2011a, b). The model was developed by the U.S. Department of Agriculture (USDA) Agricultural Research Services. In the model, a watershed is divided into subwatersheds or sub-basins, which are further partitioned into a series of hydrological response units (HRUs) by setting a threshold percentage of dominant land use, soil type, and slope group; an HRU is assumed to be homogeneous in hydrologic response and consists of homogeneous land use, soil, slope, and management practices (Gassman et al., 2007; Williams et al., 2008; Neitsch et al., 2011b). Hydrological components, soil erosion and sediment yield, and nutrient cycles are simulated for each HRU, and yields from HRUs are aggregated for the subwatersheds. Runoff, sediment, and chemicals are routed from each subwatershed through a channel network to the outlet of the watershed.

The surface runoff is estimated using a modification of the SCS (Soil Conservation Service, now the Natural Resources Conservation Resource) curve number method (USDA-NRCS, 2004) with daily rainfall amounts. The SWAT estimates water routed through the channels using the storage routing variable; water storage in the reach can be lost by transmission and evaporation. The Universal Soil Loss Equation (USLE) calculates soil erosion, and the Modified Universal Soil Loss Equation (MUSLE) estimates sediment yield (Williams, 1995). The simplified version of Bagnold equation (Bagnold 1977) is used to determine the sediment transport capacity of the sediment receiving stream.

The MUSLE (Williams, 1995) is:

$$Y = 11.8(Q^*q^*A)^{0.56} {}^*K^*C^*P^*\mathrm{LS}^*\mathrm{CFRG}$$

where Y is the sediment yield (metric tons); Q is the surface runoff volume (mm) calculated using the SCS curve number (CN) method (USDA-NRCS, 2004); q is the peak runoff rate (m^3/s); A is the area of the HRU (ha); K is the USLE soil erodibility factor; C is the USLE land cover and management factor; P is the USLE support practice factor; LS is the USLE topographic factor; and CFRG is the coarse fragment factor. When simulating sediment routing, amounts of sediment deposition and/or degradation in channel are calculated by comparing the channel sediment transport capacity, a function of peak channel velocity, to initial sediment concentration in the reach (Bagnold, 1977). Details on sediment routing can be found in Chapter 7:2 of SWAT theoretical document (Neitsch et al., 2011b). Briefly, the amount of deposition is calculated as follows:

$$\mathrm{sed}_{\mathrm{dep}} = \left(\mathrm{con}_{\mathrm{sed,ch,j}}\text{-}\mathrm{con}_{\mathrm{sed,ch,mx}}\right)^* V_{\mathrm{ch}}$$

The amount of degradation is calculated as follows:

$$\mathrm{sed}_{\mathrm{deg}} = \left(\mathrm{con}_{\mathrm{sed,ch},j}\text{-}\mathrm{con}_{\mathrm{sed,ch},j}\right)^* V_{\mathrm{ch}} K_{\mathrm{ch}} C_{\mathrm{ch}}$$

where $\mathrm{sed}_{\mathrm{dep}}$ and $\mathrm{sed}_{\mathrm{deg}}$ are the amount of sediment deposited and re-entrained in the reach segment (metric tons), respectively; $\mathrm{con}_{\mathrm{sed,ch},j}$ is the initial sediment concentration in the reach (kg/L or ton/m^3); $\mathrm{con}_{\mathrm{sed,ch,mx}}$ is the maximum concentration of sediment that can be transported by water (kg/L or ton/m^3); and V_{ch} is the volume of water in the reach segment (m^3); K_{ch} is the channel erodibility factor; and C_{ch} is the channel cover factor. The maximum concentration of sediment that can be transported by water ($\mathrm{con}_{\mathrm{sed,ch,mx}}$) is calculated as follows:

$$\mathrm{con}_{\mathrm{sed,ch,mx}} = C_{\mathrm{sp}}{}^* v_{\mathrm{ch,pk}}{}^{\mathrm{spexp}}$$

where c_{sp} is the re-entrainment coefficient, and spexp is exponent of re-entrainment for channel sediment routing; and $v_{\mathrm{ch,pk}}$ is the peak channel velocity.

Degradation is calculated only when $\mathrm{con}_{\mathrm{sed,ch,j}}$ is less than $\mathrm{con}_{\mathrm{sed,ch,mx}}$. Otherwise, deposition is calculated. Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach and the amount of sediment transported out of the reach are determined.

Study Area and Available Measurements on Runoff and Sediment

The Guánica Bay basin (~38,850 ha), located in the southwestern part of Puerto Rico, includes the urbanized area of Yauco and five small subwatersheds and their associated reservoirs: Lago Yahuecas, Lago Guayo, Lago Prieto, Lago Lucchetti, and Lago Loco (Fig. 1). Those reservoirs, connected by underground tunnels, were originally built for hydroelectric power generation and irrigation of croplands during the 1950s. The storage capacity of the reservoirs of those watersheds was significantly reduced, according to U.S. Geological Survey (USGS) sedimentation reports (Soler-López, 1997; Soler-López et al., 1997): for example, Lago Yahuecas reservoir lost 81% of its storage capacity over a period of 41 years (1956–1997). This loss was directly caused by soil erosion due to agricultural farming, particularly coffee farming on steep, highly erodible lands in the upper mountainous watershed (Ortiz-Zayas et al., 2001). The flow originates in Lago Yahuecas and flows southwest into Guánica Bay. F1

Runoff was only measured at the outlet of Yahuecas watershed (USGS gauge #50014000), and no sediment was collected in the entire Guánica Bay basin; the Yahuecas watershed, with an area of 4,520 ha, was thus selected for a pilot study. Elevations in the watershed range from 370 to 1,200 m, with steep slopes of 25% to 60% occupying approximately 60% of the watershed. Annual precipitation is approximately 2,000 mm; more than 65% of the rainfall occurs in the two rainy seasons (February to April and August to November). From 1970 to 2011, the highest and lowest temperatures were 34.4°C and −0.6°C, respectively. Major land uses are forest, coffee plants, and range grasses, which account for approximately 60%, 20%, and 10% of the watershed, respectively. Major soil series include Humatas (very fine, parasesquic, isohyperthermic Typic Haplohumults), Maricao (very fine, mixed, subactive, isothermic Typic Haplohumults), Consumo (Fine, mixed, semiactive, isohyperthermic Typic Haplohumults), and Mucara (Coarse-loamy, vermiculitic, isohyperthermic Dystric Eutrudepts). These soil series are characterized as well drained soils with moderately permeable to moderately slowly permeable. PR688HmF2-1 (Humatas clay), PR688MkF2-1 (Maricao clay), and PR688MuF2-1 (Mucara silty clay) are the three major ones. Although no SS samples were collected in the Guánica Bay basin, SS was measured at Adjuntas watershed next to the Yahuecas watershed (Fig. 1). The Adjuntas has an area of 4,840 ha, and its topography, slope, soil type, and land use are similar to those of the Yahuecas (Hu and Yuan, 2013).

Daily flow and SS concentration data were downloaded from the USGS monitoring gages (Fig. 1: Station 50014000 in Yahuecas for runoff and Station 50020500 in Adjuntas for sediment). Collected data and sources for Yahuecas and Adjuntas watersheds are summarized in Table 1. T1

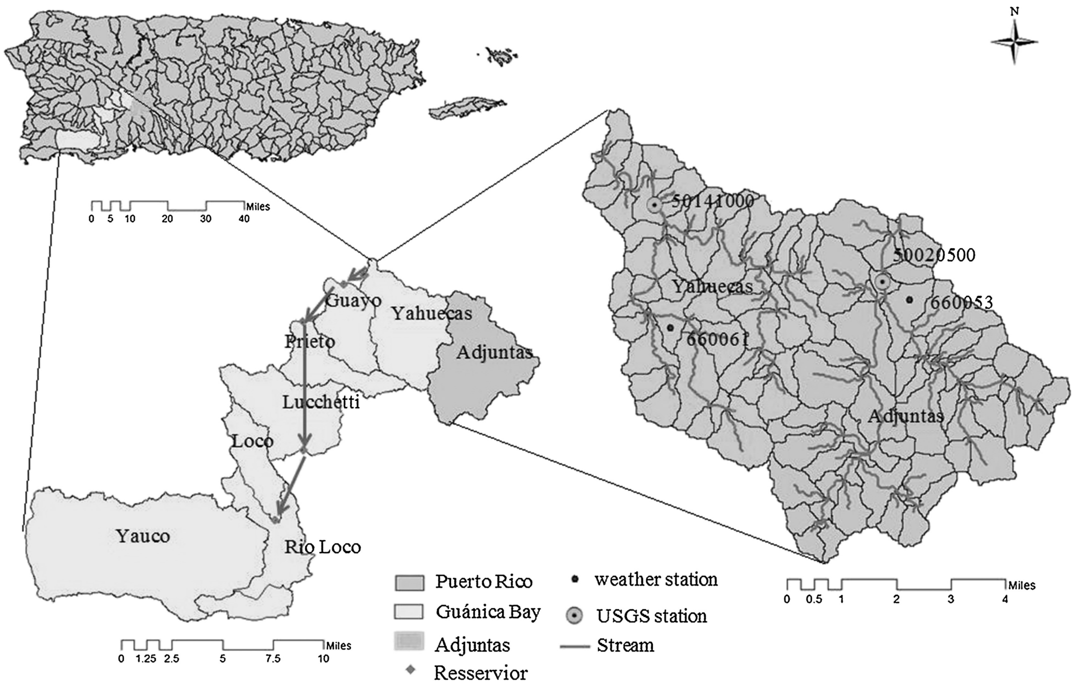


FIG. 1. Location of the study area, weather stations, and USGS monitoring stations. A color version of this figure is available in the online version of this article. full color online

Modeling Approach and Input Preparation

Because of the complexity of the Guánica Bay basin and the limitations on monitored runoff and sediment data, a comprehensive modeling approach was used. The SWAT model was set up for both Yahuecas and Adjuntas watersheds. Runoff parameter sensitivity, calibration, and validation were first performed on Yahuecas; the calibrated parameters from Yahuecas runoff simulation were then transferred to the Adjuntas watershed. Sediment parameter sensitivity and calibration were performed on Adjuntas watershed using monitored sediment data from the Adjuntas watershed. Finally, the impact of alternative management practices on sediment yield was simulated on the Yahuecas watershed after taking calibrated sediment-related parameters from the Adjuntas simulation.

Basic SWAT model input includes DEM, land use and land management, soil data, and meteorological data. The DEM, land use, and soil data were downloaded from USGS (http://seamless.usgs.gov/), National Land Cover Database (http://www.mrlc.gov/nlcd01_data.php), and USDA (http://soildatamart.nrcs.usda.gov), respectively. Daily precipitation and minimum and maximum temperature were collected at weather stations 660061 and 660053 (Fig. 1) from the National Oceanic and Atmospheric Administration Web site (http://www.noaa.gov/) (Table 1).

The Pearson Type III statistics and hydrological frequency curve analysis showed that rainfall characteristics of the Yahuecas

TABLE 1. Collected Data and Sources

Data	Source	Date	Description
DEM	National Elevation Data	2001	30 × 30-m resolution, USGS
Soil	Soil Survey Geographic Database	2012	Digital representation of County Soil Survey maps published by the USDA-NRCS
Land use	National Land Cover Database	2001	30 × 30-m resolution raster published by Multi-resolution Land Characterization consortium
Weather	Daily precipitation values from Yahuecas substation (Station ID 660061) and Adjuntas 1 NW (Station ID 660053). Daily temperature values from Adjuntas substation (Station ID RQC00660061).	1970–2011	National Oceanic and Atmospheric Administration, NCDC Precipitation unit: tenths of mm Temperature unit: tenths of degrees Celsius
Streamflow	Annual and monthly flow from USGS gages (50014100 and 50020500)	50014100: 1946–1966 and 06/1980–01/1985 50020500: 1946–1950 and 03/2000–01/2007	USGS gage Unit: cubic feet per second
Sediment	Annual and monthly data for SS obtained from USGS gage (Station ID50020500)	04/2000–09/2005	USGS gage, Unit: milligrams per liter

TABLE 2. Results of Pearson Type III Statistics of Hydrologic Frequency Analysis of Annual Rainfall (1970–2011) in Yahuecas and Adjuntas Watersheds

Statistics	Yahuecas (Station 660061)	Adjuntas (Station 660053)
Average annual rainfall	1949.7 mm	2015.7 mm
Cv	0.2	0.2
Cs/Cv	3.8	3.5
Frequency 75% (dry year)	1667.0 mm	1663.6 mm
Frequency 50% (normal year)	1900.7 mm	1948.7 mm
Frequency 25% (wet year)	2179.2 mm	2295.1 mm
Frequency 90%	1492.3 mm	1455.3 mm

Cs: coefficient of deviation; Cv: coefficient of variation.

(weather station 660061) and Adjuntas (weather station 660053) watersheds were similar (Table 2 and Fig. 2). The average annual precipitation in Yahuecas is 1,950 mm, and it is 2,016 mm in Adjuntas (Table 2). Second, both watersheds had dry, normal, and wet periods with similar amount of precipitation for those periods (Table 2). Third, more than 65% of the rainfall occurs in the rainy season (February to April, August to November) in both watersheds. Finally, hydrologic frequency curves of annual rainfall for both watershed are similar (Fig. 2). These comparisons between the two watersheds provide support for the similarity of runoff and erosion processes, thus coupling runoff and sediment modeling of two watersheds. F2 T2

Using the 30 × 30-m DEM, the Yahuecas watershed was subdivided into 58 sub-basins, which were divided further into 1,288 HRUs, based on threshold values for land use (10%), soil (10%), and slope (0%). The Adjuntas watershed was subdivided into a total of 68 sub-basins, which were divided further into 1,382 HRUs using the same threshold values as above for land use, soil, and slope type. Watershed parameterization includes calculating sub-basin geometry parameters from DEM and assigning various values to HRUs through SWAT's internal database.

Because coffee farming in this region is the major agricultural practice and is also considered to be one of the main reasons for soil erosion and sediment yield, it was very important to set management practices for coffee production properly in the model simulation. Based on personal communication and a literature review on coffee cultivation (Miguel et al., 2002), the land is usually cleared first, a process that involves cutting trees and grass before the young coffee trees are planted (usually in May), then they are fertilized about 1 month after transplanting and every 3 months thereafter during the first year. Fertilizer is spread on the ground around each tree, starting approximately 4 inches from the trunk and extending as far as tips of the lateral branches. The crop is harvested by hand from August to January of the next year; three or four partial harvests are recommended. A summary of coffee farming practices is shown in Table 3. T3

Model Sensitivity, Calibration, and Validation

The purpose of a sensitivity analysis is to investigate influence of model inputs, especially those that are difficult to measure on model outputs (Lane and Ferreira, 1980; Yuan et al., 2015a, b), which helps a modeler to evaluate if calibration is possible with user modification of input parameters. Twenty-seven flow-related input parameters and six sediment-related parameters were included in the sensitivity analysis (Table 4). Sensitivity analysis was performed using SWAT's built-in Latin hypercube one-factor-at-a-time random sampling procedure (Holvoet et al., 2005). MUSLE factors of slope (slope steepness factor), SlpLgth (slope length factor), and USLE-LS (slope length and steepness factor) were not included in sensitivity analysis because those factors were calculated based on DEM, which is generally considered certain and accurate. In addition, the USLE_K factor derived from USDA Soil Survey Geographic Database database was not considered in the sensitivity analysis. After sensitivity analysis T4

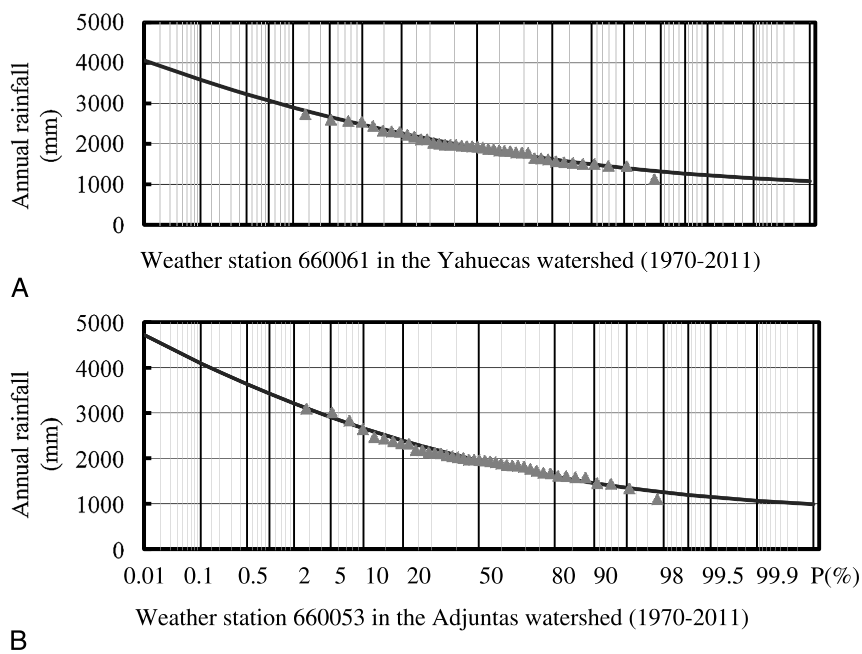


FIG. 2. Hydrologic frequency curve of annual rainfall for (A) weather station 660061 in Yahuacas watershed and (B) weather station 660053 in Adjuntas watershed. A color version of this figure is available in the online version of this article.

TABLE 3. Summary of Management Practices of Coffee Farming

Management	Schedule
Planting	Coffee trees were assumed to have been already planted
Fertilizer	Four times (500 kg/ha per time) per year: February 1, May 1, August 1, November 1
Harvest	Three to four times per year: August 15, September 15, November 15, December 15

was performed, the model was calibrated by manually adjusting the most sensitive parameters and matching the monitored annual and monthly runoff from Yahuecas and sediment from Adjuntas. Flow data from July 1980 to December 1982 were used for calibration, and data from January 1983 to January 1985 were for validation in Yahuecas watershed, and sediment data from April 2000 to September 2005 were used for calibration in Adjuntas watershed because complete records were available for those periods (Table 1). Although flow data were available from March 29, 2000, to January 29, 2007, in Adjuntas, preliminary data analysis found that the amount of runoff for some months was almost the same as the rainfall amount, and the flow for a few months was even higher than the rainfall, which led further investigation; further investigation on the runoff from Adjuntas watershed was inconclusive. The best explanation from the USGS was (1) the across section for measurements may be flooded during large events, which led to inaccurate stage readings, and/or (2) inaccurate drainage area may be assessed in flow calculation. However, the USGS could not correct the measurements. Five years of data from 1970 to 1974 were used for model warm-up.

Four criteria were used to evaluate goodness of fit: relative error (RE) was used for annual flow and sediment yield evaluation; relative mean error (RME) or prediction error, Nash and Sutcliffe (1970) model efficiency (NSE), and coefficient of determination R^2 were used for monthly simulation evaluation.

TABLE 4. Parameters Used in the Sensitivity Analysis of the SWAT Model

Name		Definition	Process
Hydrology-related parameters	CN2	SCS runoff curve number for moisture condition II	Runoff
	surlag	Surface runoff lag coefficient	Runoff
	canmx	Maximum canopy index	Runoff
	GW_DELAY	Groundwater delay (d)	Groundwater
	GW_REVAP	Groundwater “revap” coefficient	Groundwater
	rchrg_dp	Groundwater recharge to deep aquifer(fract)	Groundwater
	REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm)	Groundwater
	ALPHA_BF	Baseflow alpha factor (d)	Groundwater
	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/h)	Channel
	Ch_n	Manning coefficient for channel	Channel
	epco	Plant uptake compensation factor	Evaporation
	ESCO	Plant evaporation compensation factor	Evaporation
	BlAI	Maximum potential leaf area index for crop	Crop
	BIOMIX	Biological mixing efficiency	Soil
	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Soil
	sol_alb	Moist soil albedo	Soil
	SOL_AWC	Available water capacity (mm/mm soil)	Soil
	Sol_K	Soil conductivity (mm/h)	Soil
	Sol_Z	Soil depth (mm)	Soil
	SFTMP	Snowfall temperature (°C)	Snow
	SMFMN	Minimum melt rate for snow (mm $°C^{-1}$ d^{-1})	Snow
	SMFMX	Maximum melt rate for snow (mm $°C^{-1}$ d^{-1})	Snow
	SMTMP	Snow melt base temperature (°C)	Snow
	TIMP	Snow pack temperature lag factor	Snow
	SLOPE	Average slope steepness (m/m)	Geomorphology
	SLSUBBSN	Average slope length (m/m)	Geomorphology
	TLAPS	Temperature laps rate (°C/km)	Geomorphology
Sediment-related parameters	*USLE_P*	USLE support practice factor	Sediment erosion
	USLE_C	USLE land cover and management factor	
	SPCON	Linear re-entrainment c for channel sediment routing	Channel routing
	SPEXP	Exponent of re-entrainment parameter for channel sediment routing	
	Ch_COV	Channel cover factor	
	Ch_K	Channel erodibility factor	

TABLE 5. Calibrated SWAT Parameters

Parameters	Description	Value
CN2	SCS curve number	Forest: 45[B] 55[C] 65[D] Range grasses: 60[B] 70[C] 75[D] Coffee: 52[B] 68[C] 75[D]
ESCO	Soil evaporation compensation factor	0.3
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	100
USLE_P	USLE support practice factor	1
USLE_C	USLE land cover and management factor	Forest: 0.004 Range grasses: 0.003 Coffee: 0.01
USLE_K	Soil erodibility factor	PR688HmF2-1 Humatas clay: 0.24 PR688MkF2-1 Maricao clay: 0.4 PR688MuF2-1 Mucara silty clay: 0.4
SPEXP	Exponent of re-entrainment parameter for channel sediment routing	1.5
Ch_COV	Channel cover factor	0.2
Ch_K	Channel erodibility factor	0.2

B, C, and D refer to hydrologic soil groups, which indicate runoff potential of the soil when thoroughly wetted. There are four hydrologic soil groups (A, B, C, and D), and A has the lowest runoff potential, and D has the highest runoff potential.

Evaluation of Impact of Land Use and Land Management on Sediment Yields of Yahuecas

Based on the management practices for coffee farming listed in Table 3, coffee production may not cause much disturbance of the soil; however, the preparation of land for coffee planting in the initial period disturbs the soil's surface, which may cause serious erosion.

Because the primary land uses are forest, coffee plants, and range grasses, three scenarios were simulated to evaluate the impact of individual land use on soil erosion and sediment yield: (1) the entire watershed is forest, (2) the entire watershed is coffee plants, and (3) the entire watershed is range grasses. Those scenarios may be unrealistic but contribute to a better understanding of the impact of each land use on soil erosion and sediment yield.

To evaluate the impact of sun-grown/shade-grown coffee on sediment yield, two additional scenarios were designed: one assumes all coffee cultivation in the watershed is sun-grown, and the other assumes all coffee cultivation is shade-grown because the two are not distinguishable on a land use map. To differentiate sun-grown coffee from shade-grown in SWAT simulations, different curve numbers and the maximum leaf area (BLAI) were used. Generally, shade-grown coffee plants have lower curve numbers (higher vegetation cover) and higher BLAI values (Bote and Struik, 2011). The BLAI is the key parameter for determining leaf area development of a plant species during the growing season. BLAIs of 1.35 and 3.8 were used for sun-grown coffee and shade-grown coffee, respectively, based on Bote and Struik (2011) study.

Long-term annual average information is needed for evaluating the alternative land use and management scenarios because it better reflects multiyear climatic variability and helps ensure that a range of events and conditions are covered. Thus, long-term simulation from 1970 to 2011 was performed to evaluate the impact of land use and land management on sediment yields in Yahuecas because weather information was available during that period. Five years of data from 1970 to 1974 were used for model warm-up, and data analysis was performed for years from 1975 to 2011.

Evaluation of MUSLE Factors on Sediment Yield

After exploring the impact of land use and land management on sediment yields, multiple linear regression analyses were performed using SPSS Statistics version 2 (Eelko H., 2007) to determine the relative importance of MUSLE factors of slope (slope steepness factor), SlpLgth (slope length factor), USLE_K (soil erodibility factor), and USLE-LS (slope length and steepness factor) on sediment yields for each land use and land management scenario. Those factors are relatively stable and do not change with time. For this analysis, the SWAT simulated average annual water (WYLD_Q) and average annual sediment yield (SYLD) of each HRU were dependent variables, whereas slope, SlpLgth, USLE_K, and USLE-LS were independent variables.

TABLE 6. Comparison of Measured and SWAT Simulated Mean Annual and Monthly Stream Flows in Yahuecas Watershed

	Annually				Monthly			
	Year	Measured (m^3/s)	Simulated (m^3/s)	RE (%)	Period (mm/y)	R^2	NSE	RME
Calibration period	1981	1.12	1.05	−6.4	07/1980–12/1982	0.91	0.90	−0.05
	1982	0.91	0.90	−1.1				
Validation period	1983	0.71	0.89	25.6	01/1983–02/1985	0.90	0.86	0.16
	1984	1.25	1.39	11.1				

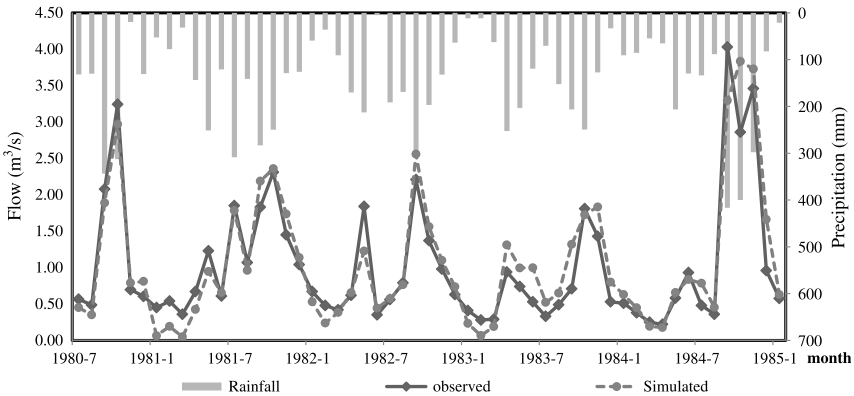


FIG. 3. Comparison of measured and SWAT simulated mean monthly stream flows of Yahuecas watershed (07/1980–01/1985). Note: R^2, NSE and RME are 0.91, 0.90, and −0.05 for the calibration period (07/1980–12/1982); and R^2, NSE and RME are 0.90, 0.86, and 0.16 for the validation period (01/1983–01/1985). A color version of this figure is available in the online version of this article. full color online

Multiple linear regression analyses were performed for each land use and land management scenario (the entire watershed is forest, the entire watershed is coffee plants, and the entire watershed is range grasses). In other words, the same USLE_P and USLE_C factors were used for regression analysis.

RESULTS AND DISCUSSION

Sensitivity Analysis, Calibration, and Validation

The curve number (CN2), soil evaporation compensation factor (ESCO), and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) were found to be the three most sensitive parameters pertaining to hydrology in the Yahuecas watershed. CN2 estimates runoff depth from total rainfall depth; ESCO adjusts depth distribution for evaporation from the soil to account for effects of capillary action, crusting, and cracks; and the GWQMN represents how surface and groundwater interact in the watershed. Those parameters were calibrated, and their values are listed in Table 5. T5

USLE_P (USLE support practice factor) and USLE_C (USLE land cover and management factor) were found to be the most sensitive parameters for sediment simulation. Parameters related to channel erosion and channel sediment routing such as Ch_COV (channel cover factor), Ch_K (channel erodibility factor), SPCON (linear re-entrainment parameter for channel sediment routing), and SPEXP (exponent of re-entrainment parameter for channel sediment routing) also affect sediment simulation, as demonstrated by other studies (White and Chaubey, 2005; Muleta and Nicklow, 2005). Those six parameters were therefore adjusted during calibration, and their final values are also listed in Table 5.

Evaluation of Runoff Simulation

The measured annual mean stream flows at the USGS gauging station were 1.12 and 0.91 m^3/s for 1981 and 1982, respectively, and the SWAT-simulated flows were 1.05 and 0.90 m^3/s for 1981 and 1982, respectively, during calibration (Table 6). Relative errors were less than 10% for both years, indicating satisfactory performance. During validation, REs were 25.6% and 11.1% for 1983 and 1984, respectively (Table 6). T6

The SWAT-simulated monthly stream flows matched the measured values very well at the gauging station in the Yahuecas watershed (Fig. 3). During the calibration period, the R^2, NSE, and RME of monthly measured and simulated stream flows were 0.91, 0.90, and −0.05, respectively, showing very good model performance. During the validation period, simulated monthly flows also showed good agreement with measured data, with an R^2 of 0.90, NSE of 0.86, and RME of 0.16 (Table 6). Although the overall performance of the model is satisfactory, differences were observed for some months. For example, the SWAT-simulated flow was lower than observed in September 1984 and higher than observed in October 1984; possible reasons are the limitation of curve number method. For example, the SCS curve number method used in the SWAT model does not consider the duration and intensity of precipitation. F3

Evaluation of Sediment Simulation

Using the three calibrated hydrologic parameters from the Yahuecas watershed shown in Table 5, SWAT simulation of the Adjuntas watershed was performed. The SWAT simulated mean annual stream flows were all less than measured at the USGS gauging station due to reasons stated previously. The R^2, NSE, and RME of mean monthly measured and simulated stream flows

TABLE 7. Comparison of Measured and SWAT Simulated Mean Annual and Monthly Sediment Concentrations of Adjuntas Watershed

Annually				Monthly			
Year	Measured (mg/L)	Simulated (mg/L)	RE (%)	Period (mm/y)	R^2	NSE	RME
2001	43.94	46.71	6.3	04/2000–09/2005	0.77	0.70	−0.08
2002	77.96	64.02	−17. 8				
2003	71.44	61.04	−14.6				
2004	59.68	59.91	0.4				

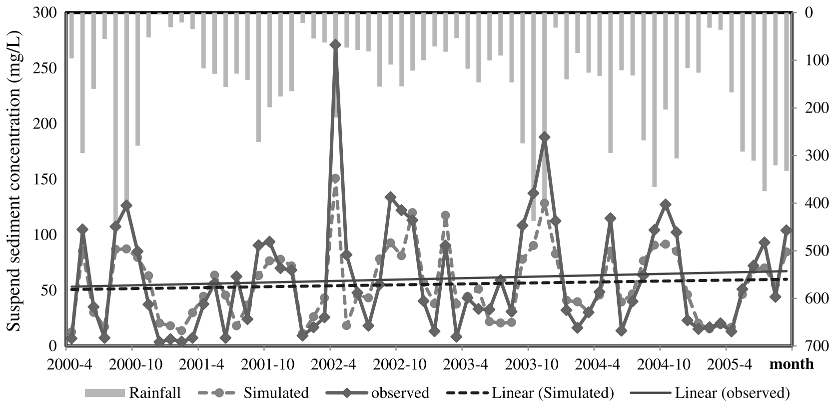


FIG. 4. Comparison of measured and SWAT simulated mean monthly sediment concentrations of Adjuntas watershed (04/2000–09/2005). Note: R^2, NSE, and RME are 0.77, 0.71, and –0.07. A color version of this figure is available in the online version of this article. full color online

were 0.64, 0.59, and −0.23, respectively, which indicates that the SWAT model of the Yahuecas represented hydrologic trend of the Adjuntas.

The comparison between simulated and measured mean annual sediment concentrations in the Adjuntas watershed from 2001 to 2004 is shown in Table 7. Although the model overestimated the mean annual sediment concentration in 2001 and underestimated it in 2002 and 2003, REs are all less than 20% (Table 7), showing a satisfactory model performance (Moriasi et al., 2007). The simulated mean monthly SS concentrations followed the trend of the measured ones with the R^2, NSE, and RME of 0.77, 0.70, and −0.08, respectively (Fig. 4), which indicate good model performance (Moriasi et al., 2007). Although the overall performance of the model is good as shown in Table 7, the simulated SS concentrations generally underestimated measured ones, especially in months with high sediment concentrations (Fig. 4). Other studies also demonstrated underestimation of sediment yields by SWAT (Chiang et al., 2014; Bieger et al., 2014).

During sediment calibration, values of USLE_K (soil erodibility factor) were increased to match the observed sediment, and their values for major soils in the watershed are listed in Table 5. In addition to calibrating MUSLE factors to match observed sediment, values of SPCON and SPEXP were also increased so that the maximum amount of sediment that can be transported from the reach could be augmented to match observed sediment. However, changing those two parameters did not have much impact on sediment yield. The channel cover factor and erodibility factor were set to 0.2 and 0.2 (Table 5), respectively, because channels are mostly gravel and relatively stable based on observations.

During rainy season, frequent intense storms and hurricanes often trigger landslides (Larsen and Torres-Sánchez, 1998). Field investigation found that landslides occurred on steep slopes. Larsen and Torres-Sánchez (1998) noted the Adjuntas watershed is located in an area moderately susceptible to landslide. Gullies also form during large rainfall events. Underestimation of sediment concentration may be due to the fact that the SWAT model could not simulate landslides or gully erosion.

Modeling sediment yield in the Adjuntas watershed helps to evaluate the sediment module of the SWAT model in this region, and provides insights into soil erosion and sediment transport mechanisms. It also provides scientific background for sediment analysis of the Yahuecas watershed. Using sediment parameters calibrated in the Adjuntas watershed, sediment simulation was performed for the Yahuecas, and results are presented in the following section.

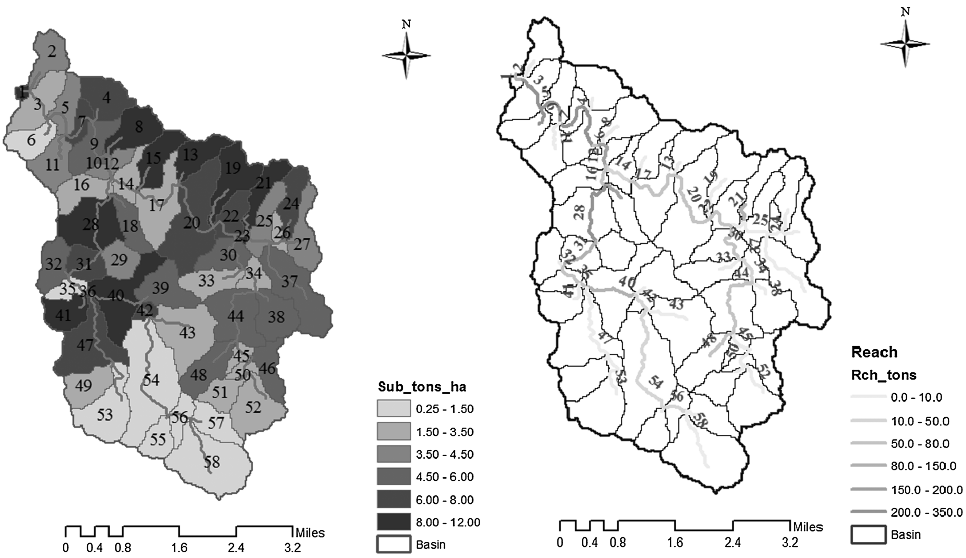
Sediment Yield in the Yahuecas Watershed

Simulated annual sediment yields at the outlet of the Yahuecas watershed were 4.80, 2.52, 2.90, and 8.13 t ha^{-1} y^{-1} for years 1981, 1982, 1983, and 1984, respectively. Sediment yields in 1981 and 1984 were much higher than those in 1982 and 1983, possibly due to higher amounts of rainfall (Table 8). In addition, rainfall intensity and timing also impact sediment yield. For example, there were more sediments produced during the rainy season of 1981 than those of 1982 and 1983, although the rainfall was less during rainy season of 1981 (Table 8).

The long-term annual average (1975–2011) is 6.31 t ha^{-1} y^{-1}. Based on USGS topographical and bathymetric surveys (Soler-López, 1997; Soler-López et al., 1997), the storage capacity of

TABLE 8. Measured Precipitation and SWAT Simulated Sediment Loss During Rainy Season in Yahuecas Watershed

	Precipitation			Simulated Sediment Loss			
Year	Rainy Season Feb to Apr, Aug to Nov (mm)	Annual Total (mm)	Percentage of Rainy Season to Annual Total (%)	Rainy Season Feb to Apr, Aug to Nov (t)	Annual Total (t)	Annual Total (t ha^{-1})	Percentage of Rainy Season to Annual Total (%)
1981	1,056.0	1,914.6	55.2	15,023.2	21,678.5	4.80	69.3
1982	1,089.4	1,622.6	67.1	9,141.84	11,398.7	2.52	80.2
1983	1,079.6	1,498.0	72.1	10,195.8	13,105.2	2.90	77.8
1984	1,408.0	2,050.5	68.7	29,224.5	36,760.4	8.13	79.5
Mean	1,158.3	1,771.4	65.8	15,896.3	20,735.7	4.59	76.7



Sediment export rate (tons $ha^{-1}year^{-1}$) in the subwatersheds
A

Channel degradation (ton $year^{-1}$) in the channels
B

FIG. 5. Soil and Water Assessment Tool–simulated mean annual sediment export rate (t ha^{-1}) in the subwatersheds of Yahuecas (left) and the SWAT-simulated stream channel degradation of subwatershed stream channels in Yahuecas (right) for 1975–2011. A color version of this figure is available in the online version of this article. full color online

the Lago Yahuecas reservoir was reduced by 81% over 41 years (1956–1997), which resulted in an average annual sediment loss of 7.57 t ha^{-1} y^{-1} from the Yahuecas watershed. Although the value of 7.57 t ha^{-1} y^{-1} cannot be used for model validation, it provides a general idea of model simulation. Sediment yield may be underestimated because landslides and gully erosion were not simulated.

Annual sediment yield in the Yahuecas watershed exhibited temporal and spatial variations, according to SWAT simulation results. Analysis of the monthly distribution of sediment yield indicates that more than 77% of the sediment yield was produced during the two rainy seasons (February to April and August to November) (Table 8) for the years from 1981 to 1984. The same occurred for the period 1975–2011 with approximately 80% of the sediment yield produced during the two rainy seasons.

The highest sediment yield of 11.57 t ha^{-1} y^{-1} (918.3 metric tons total) was produced by Subwatershed 15, whereas the lowest
F5 is 0.29 ha^{-1} y^{-1} from Subwatershed 58 (Fig. 5). Subwatershed 20 generated the highest total sediment load (1275.1 t), with a sediment yield of 6.31 t ha^{-1} y^{-1} (Fig. 5). In comparing land use of Subwatersheds 15 and 58, forest, coffee plants, and range grasses account for 61.6%, 23.1% and 15.3%, respectively, of Subwatershed 15, whereas the entire area is forest for Subwatershed 58. Furthermore, different slope causes different degrees of erosion—steep terrain usually exports more sediment than flat. The percentage of slope above 60% in Subwatershed 15 is 8.0%, but only 3.5% for Subwatershed 58. In Subwatershed 20, the percentage of forest, coffee plants, and range grasses is 42.6%, 31.7%, and 25.7%, respectively, and slope greater than 60% occurs on 4.0% of the land surface. This suggests that coffee farming in conjunction with steep slopes may exacerbate soil erosion in this region.

The highest bed degradation of 304.7 tons is in Reach 9. Sediment in the stream increases as the water travels downstream. Comparing Fig. 5B to Fig. 5A shows that reaches with high bed degradation were typically downstream from subwatersheds with high sediment load, which is consistent with other studies (Muleta and Nicklow, 2005; White and Chaubey, 2005). Overall, 13% of the sediment yield comes from channel degradation.

Impact of Land Use and Land Management on Sediment Yields

Soil and Water Assessment Tool–simulated annual sediment yields for the three land cover scenarios are 1.96 “”t ha^{-1} y^{-1} if the entire watershed is forested, 3.12 t ha^{-1} y^{-1} if the entire watershed is range grasses, and 7.45 t ha^{-1} y^{-1} if the entire watershed is coffee. Coffee land cover produces the largest amount of sediment, followed by range grass, and forest produces the least, which is consistent with the review by Gyssels et al. (2005).

If sun-grown coffee trees are all replaced by shade-grown coffee trees, the annual sediment yield will be reduced by 9%—from 6.31 t ha^{-1} y^{-1} (28,511.2 t) to 5.75 t ha^{-1} y^{-1} (25,990 t)
(Table 9). The reduction is significant given the fact that coffee T9
land use is less than one third of the watershed. Therefore, instead of replacing traditional shade-grown coffee with sun cultivation, farmers should be encouraged to stick to the traditional shade-grown coffee to reduce sediment transport to reservoirs and bay

TABLE 9. Parameter Setting and SWAT-Simulated Sediment Yield of Sun-/Shade-Grown Coffee in Yahuecas Watershed (1975–2011)

		Sun-Grown	Shade-Grown
CN2	B	52	48
	C	68	65
	D	75	73
BLAI		1.35	3.8
Average annual water yield (mm y^{-1})		1050.8	1008.6
Average annual sediment yield (t ha^{-1} y^{-1})		6.31	5.75

areas. Government agencies such as USDA-NRCS could develop financial incentive programs for farmers to adopt traditional shade-grown coffee.

Results of Regression Analysis

From the multiple linear regression analysis, "slope" is the strongest factor influencing water yield, and "USLE_K" and "slope" are the two factors influencing sediment yield the most for a given land use and land management scenario. Other studies also show that steep terrain and soils with higher erodibility highly
AQ2 influence sediment yields (Yuan et al., 2015). Thus, coffee farming should be avoided in steep terrain and highly erodible soils.

CONCLUSIONS

The SWAT model simulated stream flow very well in Yahuecas watershed, but calibration and validation of sediment simulation were limited because of a lack of monitored sediment data in the watershed. However, the SWAT model performed well in simulating sediment of Adjuntas, an adjacent watershed of Yahuecas, with similar weather, topography, slope, soil type, and land use after calibration. Based on the sensitivity analysis, the curve number (CN2), soil evaporation compensation factor (ESCO), and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) were found to be the three most sensitive parameters pertaining to hydrology, and USLE_P (USLE support practice factor) and USLE_C (USLE land cover and management factor) were found to be the most sensitive parameters for sediment simulation. Long-term evaluation of sediment yields shows that rainy seasons (February-May and August-November) contributed the majority of annual sediment yield. Second, coffee land use yielded more sediment per hectare than forest and grass. In addition, conversion from sun-grown to shade-grown coffee can reduce soil erosion by 9%. Finally, for the same land use and management practices, "USLE_K" and "slope" are the two factors influencing sediment yield the most. In summary, sediment loss in Yahuecas is mainly caused by the interaction of heavy rainfall, steep terrain, and erodible soils. Coffee farming exacerbated risks of soil erosion and sediment loss due to a reduction in protective canopy.

REFERENCES

Arekhi S., B. Ali Darvishi, S. Afshin, F. Hassan, and A. Salman 2012. Mapping soil erosion and sediment yield susceptibility using RUSLE, remote sensing and GIS (case study: Cham Gardalan Watershed, Iran). Adv. Environ. Biol. 6:109–124.

Arnold J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams 1998. Large area hydrologic modeling and assessment. Part I: Model development. J. Am. Water Resour. Assoc. 34:73–89.

Arnold J. G., R. Srinivasan, R. S. Muttiah, and P. M. Allen 1999. Continental scale simulation of the hydrologic balance. J. Am. Water Resour. Assoc. 35:1037–1051.

Ayana A. B., D. C. Edossa, and E. Kositsakulchai 2012. Simulation of sediment yield using SWAT model in Fincha Watershed, Ethiopia. Kasetsart J. Nat. Sci. 46:283–297.

Bagnold R. A. 1977. Bed load transport by natural rivers. Water Resour. Res. 13:303–312.

Bieger K., G. Hörmann, and N. Fohrer 2014. Simulation of streamflow and sediment with the Soil and Water Assessment Tool model in a data scarce catchment in the Three Gorges Region. China J. Environ. Qual. 43:37–45.

Bingner R. L., F. D. Theurer, and Y. Yuan. 2015. AnnAGNPS Technical Processes. Available at: http://www.ars.usda.gov/Research/docs.htm?docid=5199. (accessed February 2, 2016).

Borah D. K., G. Yagow, A. Saleh, P. L. Barnes, W. Rosenthal, E. C. Krug, and L. M. Hauck 2006. Sediment and nutrient modeling for TMDL development and implementation. Trans. ASAE . 49:967–986.

Bote A. D., and P. C. Struik 2011. Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. J. Horticult. Forestry. 3:336–341.

Chiang L., Y. Yuan, M. Mehaffey, M. Jackson, and I. Chaubey 2014. Assessing SWAT's performance in the Kaskaskia River watershed as influenced by the number of calibration stations used. Hydrol. Process. 28:676–687.

Easton Z. M., D. R. Fuka, E. D. White, A. S. Collick, B. Biruk Ashagre, M. McCartney, S. B. Awulachew, A. A. Ahmed, and T. S. Steenhuis 2010. A multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia. Hydrol. Earth Syst. Sci. 14:1827–1841.

Eelko H. 2007. Applied Statistics With SPSS . Sage Publications, London.

Gassman P. W., M. R. Reyes, C. H. Green, and J. G. Arnold 2007. The soil and water assessment tool: Historical development, applications, and future research directions. Trans. ASABE . 50:1211–1250.

Gassman P. W., A. M. Sadeghi, and R. Srinivasan 2014. Applications of the SWAT model special section: Overview and insights. J. Environ. Qual. 43:1–8.

Gyssels G., J. Poesen, E. Bochet, and Y. Li 2005. Impact of plant roots on the resistance of soils to erosion by water: A review. Prog. Phys. Geogr. 29:189–217.

Holvoet K., A. van Griensven, P. Seuntjens, and P. A. Vanrolleghem 2005. Sensitivity analysis for hydrology and pesticide supply towards the river in SWAT. Phys. Chem. Earth. 30:518–526.

Hu W., and Y. Yuan 2013. Evaluation of Soil Erosion and Sediment Yield for Ridge Watersheds in the Guánica Bay, Puerto Rico Using SWAT model. EPA/600/X-13/146, US Environmental Protection Agency, Washington, DC.

Laflen J. M., W. J. Elliot, D. C. Flanagan, C. R. Mayer, and M. A. Nearing 1997. WEPP-predicting water erosion using a process based model. J. Soil Water Conserv. 52:96–102.

Lane L. J., and V. A. Ferreira 1980. Chapter 6: Sensitivity analysis. *In*: CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. Conservation Report No. 26. Knisel W. G. (ed.). USDA-SEA. Washington, DC.

Larsen M., and A. J. Torres-Sánchez. 1998. The frequency and distribution of recent landslides in three montane tropical regions of Puerto Rico. Geomorphology . 24:309–331.

Miguel M. I., A. Wanda, O'Farrill Hipólito, and A. N. Alvarado-Ortiz. 2002. Crop Profile for Coffee in Puerto Rico [online]. University of Puerto Rico at Mayagüez. Available at http://www.ipmcenters.org/cropprofiles/docs/prcoffee.pdf (accessed November 2, 2015).

Morgan R. P. C., J. N. Quinton, R. E. Smith, G. Govers, J. W. A. Poesen, K. Auerswald, G. Chisci, D. Torri, and M. E. Styczen 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Proc. Landforms. 23:527–544.

Moriasi D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASAE 50:885–900.

Muleta M. K., and J. W. Nicklow 2005. Sensitivity and uncertainty analysis coupled with automatic calibration for a distributed watershed model. J. Hydrol. 306:127–145.

Nash J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models. Part 1. A discussion of principles. J. Hydrol. 10: 282–290.

Neitsch S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, J. R. Williams, and E.B. Haney 2011a. Soil and Water Assessment Tool Input/Output File Documentation, Version 2009. Texas A & M University. Texas Water Resources Institute, Report No. 365.

Neitsch S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams 2011b. Soil and Water Assessment Tool theoretical documentation, Version 2009 Texas Water Resources institute, Report No. 406.

Ortiz-Zayas J. R., J. J. Terrasa-Soler, and J. V. Cruz 2001. Allocating water resources for public supply within a complex hydroelectric system: The case study of Yauco, Puerto Rico. Proceedings of the Water Environment Federation, WEFTEC Latin America249–278.

Renard K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yodercoordinators. 1997. Predicting Soil Erosion by Water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703. Washington, DC: USDA.

Scatena F. N., and M. C. Larsen 1991. Physical aspects of Hurricane Hugo in Puerto Rico. Biotropica. 23:317–323.

Shirmohammadi A., I. Chaubey, R. D. Harmel, D. D. Bosch, R. Muñoz-Carpena, C. Dharmasri, A. Sexton, M. Arabi, M. L. Wolfe, J. Frankenberger, C. Graff, and T. M. Sohrabi 2006. Uncertainty in TMDL models. Trans. ASABE. 49:1033–1049.

Soler-López L. R., 1997. Sedimentation survey results of the principal water-supply reservoirs of Puerto Rico. U.S. Geological Survey. Available at http://pr.water.usgs.gov/public/reports/soler.html. (accessed November 12, 2015).

Soler-López L. R., F. Pérez-Blair, and R. M. T. Webb 1997. Sedimentation survey of Lago Yahuecas, Puerto Rico. U.S. Geological Survey Report No. 98–4259.

Sturm P., R. Viqueira, R. Ferguson, and T. Moore 2012. Addressing land based sources of pollution in Guánica, Puerto Rico. Proceedings of the 12th International Coral Reef Symposium. Cairns, Australia, pp. 9–13.

USDA-NRCS. 2004. National Engineering Handbook Part 630: Hydrology. Chapter 10: Estimation of Direct Runoff from Storm Rainfall.

Verhoeven J. T., B. Arheimer, C. Yin, and M. M. Hefting 2006. Regional and global concerns over wetlands and water quality. Trends Ecol. Evol. 21:96–103.

Warne A. G., R. M. T. Webb, and M. C. Larsen 2005. Water, sediment, and nutrient discharge characteristics of rivers in Puerto Rico, and their potential influence on coral Reefs. U.S. Geological Survey Report No. 2005–5206.

White K. L., and I. Chaubey 2005. Sensitivity analysis, calibration, and validations for a multisite and multivariable SWAT model. J. Am. Water Resour. Assoc. 41:1077–1089.

Wilkinson C., and J. Brodie 2011. Catchment Management and Coral Reef Conservation. Available at: http://cmsdata.iucn.org/downloads/2011_012_2.pdf. (accessed February 3 2016).

Williams J. R., J. G. Arnold, J. R. Kiniry, P. W. Gassman, and C. H. Green 2008. History of model development at Temple, Texas. Hydrol. Sci. J. 53:948–960.

Williams J. R., 1995. Chapter 25: The EPIC model. *In*: Computer Models of Watershed Hydrology. Singh V. P. (ed.). Water Resources Publications. Highlands Ranch, CO, pp. 909–1000.

Yuan Y., Y. Jiang, E. V. Taguas, E. G. Mbonimpa, and W. Hu 2015a. Sediment loss and its cause in Puerto Rico watersheds. Soil . 1:595–602.

Yuan Y., Y. Khare, X. Wang, P. B. Parajuli, I. Kisekka, and S. Finsterle 2015b. Hydrologic and water quality models: Sensitivity. Trans. ASABE. 58:1721–1744.

Zabaleta A., M. Meaurio, E. Ruiz, and I. Antigüedad 2014. Simulation climate change impact on runoff and sediment yield in a small watershed in the Basque Country, northern Spain. J. Environ. Qual. 43:235–245.

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