



Automated Geospatial Watershed Assessment (AGWA) to Aid in Sustaining Military Mission and Training

FINAL REPORT

**ESTCP Resource Conservation and Resiliency Project
RC201308**

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USDA-ARS/Southwest Watershed Research Center**

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14. ABSTRACT This project demonstrates the Automated Geospatial Watershed Assessment (AGWA) tool coupled with the Facilitator Decision Support System (DSS) for scientifically based watershed assessments to address installation managers concerns of land disturbance from military training and testing, flooding, and erosion. Demonstration sites are Piñon Canyon Maneuver Site and Fort Carson, Colorado, and Fort Bliss, Texas/New Mexico. AGWA is a publicly available Geographic Information Systems (GIS) interface that uses national data to parameterize, execute, and visualize outputs of two watershed models at multiple temporal and spatial scales over a range of environmental conditions. The Facilitator DSS provides a flexible, easy to use, framework to structure and document installation manager experience, expert knowledge, and AGWA simulation model results to select a preferred management action. Tools within AGWA are the military training disturbance tool to evaluate changes in soil and vegetation cover resulting from training events; the erosion control structure tool to design and place these structures for flood and erosion control; the burn severity tool to evaluate prescribed and wildfire effects on site and downstream; the urban tool to evaluate stormwater flooding and green infrastructure practices; and the climate assessment tool. Two 1.5 to 2-day training sessions were conducted at each installation using hands-on tutorials, presentations, discussion sessions, and surveys. AGWA's embedded hydrologic models (KINEROS2, RHEN, and SWAT) were evaluated via data quality, and calibration/validation.				
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LIST OF ACRONYMS

AGWA	Automated Geospatial Watershed Assessment Tool
ARPA	Archaeological Resource Protection Act
ARS	Agricultural Research Service
ATTACC	Army Training and Testing Area Carrying Capacity
BAER	Burned Area Emergency Response
BASINS	Better Assessment Science Integrating point & Non-point Sources
BFAST	Breaks For Additive Season and Trend
BGEPA	Bald and Golden Eagle Protection Act
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BRAC	Base Realignment and Closure
ft ³ /s	cubic foot per second
CH_K	channel hydraulic conductivity
cm	centimeter
CN	Curve Number
CON	Certificate of Networthiness
CPW	Colorado Department of Parks and Wildlife
CSA	Contributing Source Area
C/V	Calibration/Validation
CWA	Clean Water Act
DDS	Dynamically Dimensioned Search
DEM	Digital Elevation Model
DoD	Department of Defense
DOI	Department of Interior
DPTMS	Directorate of Plans, Training, Mobilization and Security
DPW	Directorate of Public Works
DSS	Decision Support System; also file extension for Facilitator input file
EC	Erosion Control (dams)
EDYS-L	Ecological Dynamics Simulation Model – Light
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency (USEPA)
ESA	Endangered Species Act
ESD	Ecological Site Descriptions
ESRI	Environmental Systems Research Institute

ESTCP	Environmental Security Technology Certification Program
FAO	United Nations Food and Agriculture Organization
GeoHMS	Geospatial Hydrologic Modeling Extension
GHCN	Global Historical Climatology Network
GI	Green Infrastructure
GIS	Geographic Information System
GPS	Global Positioning System
GWLF	Generalized Watershed Loading Function
ha	hectare
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
HRU	Hydrologic Response Unit
HSPF	Hydrological Simulation Program—Fortran
IMCOM	Installation Management Command
INRMP	Integrated Natural Resources Management Plan
IT	Information Technology
ITAM	Integrated Training Area Management
JAR	Java Archive file
JER	Jornada Experimental Research Station
JRE	Java Runtime Environment
K2	KINEROS2
KINEROS2	Kinematic Runoff and Erosion Model, which includes RHEM
LHS	Latin Hypercube Sampling
LID	Low Impact Development
LiDAR	Light Detection and Ranging
LRAM	Land Rehabilitation and Maintenance
M	million
MBTA	Migratory Bird Treaty Act
MDT	Military Disturbance Tool
MIM	Military Impact Miles
mm	millimeter
mm/hr	millimeter per hour

MUSLE	Modified Universal Soil Loss Equation
NDVI	Normalized Difference Vegetation Index
NEPA	National Environmental Policy Act
NLCD	National Land Cover Dataset
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
NWS	National Weather Service
OPAL	Optimal Allocation of Land for Training and Non-training uses
PBIAS	Percent bias
PCMS	Piñon Canyon Maneuver Site
PO	Performance Objective
RHEM	Rangeland Hydrology and Erosion Model
RMSE	Root Mean Square Error
RSR	RMSE-observations standard deviation ratio
RTLA	Range and Training Land Assessment
SATVI	Soil adjusted total vegetation index
SCT	Storage Characterization Toolbox
SERDP	Strategic Environmental Research and Development Program
SRP	Sustainable Range Program
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
STM	State and Transition Models
SUS	System Usability Scale
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
SWReGAP	Southwest Re-Gap Analysis Program
TER-S	Threatened, endangered, and at-risk species
TUDM	Training Use Distribution Model
UA	University of Arizona

USDA	United States Department of Agriculture
USDA-FS	United States Department of Agriculture – Forest Service
US-F&WS	United States Fish & Wildlife Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
VDMTS	Vehicle Dynamics Monitoring and Tracking System
XML	Extensible Markup Language
X-S	Cross Section

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Abstract

Introduction and Objectives

The objective of this project was to demonstrate and refine the Automated Geospatial Watershed Assessment (AGWA) tool coupled with the Facilitator Decision Support System (DSS) for scientifically-based watershed assessments on three DoD installations (Fort Carson and Pinon Canyon Maneuver Site, Colorado, and Fort Bliss, Texas/New Mexico) to aid installation managers in sustaining their mission and meeting stewardship requirements in support of testing and training. The tools address installation watershed management concerns of rehabilitation of disturbed areas (due to military training activities, fire, etc.), flooding, erosion, water supply, water quality, and planning for future installation growth and mission expansion. AGWA was evaluated via calibration, validation, uncertainty, and data quality analyses.

Technology Description

AGWA-Facilitator was demonstrated through two 1.2 – 2-day hands-on trainings at each installation. AGWA is a publicly available Geographic Information Systems (GIS) interface that uses freely available national data to parameterize, execute, and visualize outputs of the Soil and Water Assessment Tool (SWAT), the KINematic Runoff and EROSION (KINEROS2), and the Rangeland Hydrology Erosion Model (RHEM) watershed models. Utilization of these models within the AGWA framework enables users to conduct watershed modeling and assessments at multiple temporal and spatial scales over a range of environmental conditions. The Facilitator DSS provides the framework to structure and document installation manager knowledge, expert opinion, and AGWA simulation model results to select a preferred management action.

Performance and Cost Assessment

Thirteen Performance Objectives were identified to evaluate the performance and acceptance of the AGWA-Facilitator tools, and the costs of implementing the system. Most of the data used in AGWA-Facilitator are generally available at all military installations, and personnel typically have computers capable of running the tools, therefore there would be little cost associated with data or hardware. Both AGWA and Facilitator are public domain and can be downloaded without cost via the internet. AGWA is currently designed to use commercial software (ESRI ArcGIS; <https://www.esri.com/en-us/arcgis/about-arcgis/overview/>), which requires the user to purchase the software, and have a computer with sufficient RAM and storage capacity to effectively use it (minimum of four gigabytes of RAM). Costs to apply the models depends on personnel skills and knowledge, site complexity, data availability, and stakeholder involvement; however, estimated costs for tool application for one management issue may be:

- AGWA-Facilitator operation, new data acquired and prepared, \$1,038
- AGWA-Facilitator operation, all data prepared, no EC dams, or outside stakeholders, \$902
- AGWA-Facilitator operation, all data prepared, with EC dams, no outside stakeholders, \$1,502
- AGWA-Facilitator operation, all data prepared, with EC dams and outside stakeholders, \$1,942
- Training cost (personnel time and materials preparation), \$23,456

Implementation Issues

Implementation issues are lack of awareness of the tools by upper management who would authorize use of the tools, and lack of continuity in staff due to high turnover (contractors).

Publications

Military Disturbance Tool in the Automated Geospatial Watershed Assessment (AGWA) Tool for Management of Military Lands. 2019. L.R. Levick, H. Wei, I.S. Burns, D.P. Guertin, and D.C. Goodrich. Oral Presentation and paper for the 2019 Federal Interagency Sedimentation and Hydrologic Modeling Conference (SEDHYD), June 24-28, 2019, Reno, NV.

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EXECUTIVE SUMMARY

INTRODUCTION

Nationally the Department of Defense (DoD) manages about 25 million acres (~10 M hectares (ha)) of land on about 500 active installations (DoD, 2015) to meet its mission and maintain its stewardship commitment. Proper management of these lands, including protection of natural and water resources and associated biodiversity, is necessary for sustainable military testing and training. Vegetation and soil disturbances associated with military training activities such as from military vehicles, heavy foot traffic, and deployment encampments risk disruption of the ecological integrity of an installation, potentially jeopardizing the military mission. Degraded landscapes fail to provide realistic training opportunities, and limit the areas available for training.

To address this issue, the DoD implemented a Natural Resources Program to ensure that both the land and its resources are preserved for continued support of mission-related activities, and that installations comply with all federal and state environmental laws and regulations (DoD 4715.03). This program recommends a watershed-based approach for natural resources management of installations, as they are often the source of essential water resources for installation operations and for sustaining habitat for numerous threatened, endangered, and at-risk species (TER-S; Stein et al., 2008). Essential elements of watershed protection include identification of areas prone to erosion, degraded areas most amenable to mitigation, and areas providing water for military personnel and TER-S. In addition, watershed modeling and decision tools are essential to assess the potential impacts of future installation growth and training.

This report presents the demonstration of the AGWA-Facilitator tool that couples a watershed modeling tool with a decision support system to allow the user to explore the effects of different management scenarios. The demonstrations were conducted at Pinon Canyon Maneuver Site (PCMS) and Fort Carson, Colorado, and Fort Bliss, Texas/New Mexico. AGWA (Automated Geospatial Watershed Assessment Tool; Miller et al., 2007; www.tucson.ars.ag.gov/agwa) incorporates the hydrologic and erosion models KINEROS2 (KINematic Runoff and EROSion, K2; Smith et al., 1995; Semmens et al., 2008; Goodrich et al., 2012; www.tucson.ars.ag.gov/kineros), RHEM (Rangeland Hydrology and Erosion model; Nearing et al., 2011; <https://apps.tucson.ars.ag.gov/rhem/docs/>), and SWAT (Soil and Water Assessment Tool versions 2000 and 2005; Arnold et al., 1998; Arnold and Fohrer, 2005; <http://swat.tamu.edu/>). The Facilitator Decision Support System (DSS) (<https://sourceforge.net/projects/facilitator/>) uses AGWA outputs either through a tool that writes directly to a Facilitator input file, or by manually entering the information in the DSS.

The PCMS Demonstration was initiated in January 2015 and completed in July 2016. The Fort Carson Demonstration was initiated in January 2017 and completed in February 2018. The Fort Bliss Demonstration was initiated in December 2016 and completed in March 2018. Although Fort Carson and PCMS are managed by the same staff located at Fort Carson, their management issues and land uses are different, resulting in different potential applications of our tools, and separate demonstrations. The calibration, validation, and data quality analysis of the watershed models, KINEROS2, RHEM, and SWAT, was also presented.

OBJECTIVES

This project's main objective was to demonstrate the Automated Geospatial Watershed Assessment tool (AGWA) coupled with the Facilitator Decision Support System (DSS) for scientifically based watershed assessments on three DoD installations to aid installation managers in sustaining their mission and meeting stewardship requirements in support of testing and training. The thirteen Performance Objectives were grouped into three general areas: POs 1, 2, 6, and 7 apply to AGWA-Facilitator and its general application at military installations, POs 3, 4 and 5 apply to the model calibration/validation work, and POs 8 through 13 apply to the AGWA-Facilitator trainings and survey responses. The demonstrations consisted of two 1.5-2-day trainings at each installation. The purpose was to show how AGWA-Facilitator could address installation watershed management concerns of water supply, water quality, rehabilitation of disturbed areas, and planning for future installation growth and mission expansion. A secondary objective of this demonstration was to determine via calibration, validation, and data quality analysis of the models, AGWA's applicability to DoD installation management issues, and suggest an appropriate configuration of rainfall and streamflow gauges to support watershed modeling.

TECHNOLOGY DESCRIPTION

The demonstrated technologies are the AGWA tool coupled with the Facilitator multi-objective DSS. AGWA is a publicly available Geographic Information Systems (GIS) interface that automates the parameterization and execution of a suite of hydrologic and erosion models (KINEROS2, RHEM, and SWAT) within the AGWA framework that enables users to conduct watershed modeling and assessments at multiple temporal and spatial scales over a range of environmental conditions using freely available national data. The recommended use of AGWA is to investigate via a relative change assessment, the effects of land cover change and management to identify sensitive and "at-risk" areas on-site and downstream of locations of interest within the watershed.

The Facilitator DSS provides a flexible, easy to use, framework to structure and document installation manager knowledge and experience, expert opinion, and AGWA simulation model results to select a preferred management action. The Facilitator can be used to graphically compare alternatives, ultimately leading to the selection and implementation of an alternative management action that improves on the status quo as defined by the stakeholders ranking of base criteria. Two types of HTML reports are available to document and support the decision process: an indexed report and a flat report.

The AGWA-Facilitator Export Tool in AGWA provides for the transfer of AGWA model results (i.e., peak flow and sediment yield) directly into a Facilitator decision analysis document, to link the two tools. The Tool is included in AGWA.

Technology transfer and determination of usability of these tools was accomplished mainly through our AGWA-Facilitator 1.5 to 2-day trainings. These trainings were comprised of presentations, discussions, and hands-on tutorial exercises that reflect specific management concerns identified by installation personnel, thus making the application of the tools more transparent and meaningful. Two trainings were conducted at each installation, and all training

participants filled out surveys at the end of each training to assess the usability of the tools and the effectiveness of the training.

The surveys are based on the System Usability Scale (SUS), which is a Likert scale developed by Brooke (1986). It employs ten forced-choice questions, where the respondent indicates the degree of agreement or disagreement on a 5-point scale with 1 being “strongly disagree” to 5 “strongly agree”. The questions are carefully worded to represent extreme expressions of the attitudes being captured, and alternate as positive and negative responses to force the respondent to think about whether they agree or disagree with each question. Both the Usability and Training Effectiveness surveys employed at our trainings have slight modifications to the wording of the questions, but maintaining the overall format and intent of the SUS. The Usability survey focuses on whether the participant felt the tools were useful and intends to use them. The Training Effectiveness survey focuses on how well the training taught the participant to use and understand the tools. Both surveys include 3 additional optional questions not included in the final scoring that assess their comfort with using GIS, their background in hydrologic principals or modeling, and their name and primary job responsibility (optional). Copies of the final surveys are attached as Appendix B.

In addition to the surveys, discussion sessions were held during the trainings to obtain additional feedback on the AGWA-Facilitator tools, tutorials, and training format. We also monitored each participant during the trainings to determine whether they had any difficulty performing the tutorial tasks, which tasks gave them trouble, if there were any issues with the tutorials themselves, and how long it took each participant to complete each tutorial. This information, along with their GIS skill level and background in hydrologic principals or modeling (provided in the surveys), was used to better understand the appropriate knowledge and skill level required to best utilize our tools.

After the second (final) training at each installation, we provided the installation managers with a DVD containing all of the tutorials and supporting data, the AGWA package and add-in, and the Facilitator application. While we provide some ongoing technical support for users of AGWA-Facilitator, support of these tools is not our primary function. AGWA-Facilitator was specifically developed and designed for non-watershed modeling specialists. Many other watershed modeling systems assume a higher level of watershed modeling knowledge and expertise, presenting a barrier to the adoption and use by natural resources professional lacking watershed modeling or hydrologic expertise.

The hydrologic models were calibrated and validated to assess the improvement in performance using local stream flow and precipitation data, and varying levels of data quality. Although uncalibrated, unvalidated, well tested, distributed, physically-based watershed models can provide useful information regarding relative change and relative spatial differences in watershed response (Goodrich et al., 2012), if adequate input data, basin characterization data, runoff observations, and spatially distributed precipitation data are available, greater confidence in model predictions and associated uncertainty can be provided. This analysis will aid in establishing the level of confidence and type of applications for which the models can be used by installation resources managers. An additional outcome will be an assessment of the value of the current precipitation and streamflow gauges to help derive recommendations for a minimum

number of gauges and other ancillary monitoring needed for installation watershed management and regulatory needs.

PERFORMANCE ASSESSMENT - DEMONSTRATION RESULTS

The thirteen Performance Objectives were grouped into three general areas: POs 1, 2, 6, and 7 apply to AGWA-Facilitator and its general application at military installations, POs 3, 4 and 5 apply to the model calibration/validation work, and POs 8 through 13 apply to the AGWA-Facilitator trainings and survey responses.

Results for the POs are as follows:

- PO1 Assess the ability to use nationally available input datasets for an uncalibrated, out of the box AGWA set up at demonstration installations: Met, for all three study watersheds at PCMS.
- PO2 Package AGWA-Facilitator for distribution and installation on military computers: Met, all data and installation files were delivered on DVDs and installed on staff computers at all three installations.
- PO3 Determine the ceiling for model execution time: Met, for both KINEROS2 and SWAT without Monte Carlo simulations, runtimes were under 10 minutes; Not Met for simulations with Monte Carlo, runtimes were greater than 6 hours.
- PO4 Assess the improvement in performance of the models when calibrated with varying levels of data to determine the degree to which the models need to be calibrated and validated in order to be used for regulatory purposes: Met for RHEM, successfully calibrated and validated with the best available dataset at PCMS. Met for KINEROS2, successfully calibrated with the out-of-the-box dataset. Met for evaluation of input data quality on model predictions. Partially Met for calibration of SWAT, parameterized with national soil and vegetation assuming consistent conditions, although validation partially failed. Met for the Fort Carson analysis to demonstrate utility of KINEROS2 for EISA Section 438 stormwater analysis. Met for demonstration of application as a relative change tool at Fort Bliss.
- PO5 Assess the ability of AGWA to identify the relative ranking of model outputs: Met, relative rankings of predicted runoff, peak flow, and sediment yield were achieved with varying levels of input data and compared with the rankings created from the calibrated model.
- PO6 Relate training disturbance to change in vegetation cover and soil properties: Met, using published literature and expert knowledge from installation staff, and based on three levels of training disturbance (light, moderate, and heavy).
- PO7 Assess the ability to parameterize the Facilitator Decision Support System with AGWA model outputs and additional criteria defined by decision makers: Met, via the AGWA-Facilitator Export Tool.

The following POs address the two AGWA-Facilitator trainings held at each installation. The trainings were evaluated based on results from two surveys given to participants, and addressed Training Effectiveness, and Tool Usability. The trainings utilized hands-on tutorials in addition to presentations, discussion sessions, and surveys. The goal of the surveys was to have a total score of at least 68 for each survey, with no one response being less than 50. Each survey included a request for additional comments and suggestions. Responses were summarized and

converted to a scale from 0 to 100, where higher scores indicate a more effective training or greater tool usability. The surveys from each training were scored and then averaged to get an overall final score for Training Effectiveness and for Usability of the tools.

- PO8 Assess the effectiveness of first AGWA-Facilitator training and needs assessment: Not met based on overall survey scores, low scores due to trainings too short, and missing managers who would authorize use of the tools
- PO9 Define the resources and expertise required to set up the model by a GIS specialist level individual: Met based on Training Effectiveness survey question #9, trainees are able to set up the models on their own within one week
- PO10 Determine the expertise required to interpret the results of the models by an individual trained on the AGWA-Facilitator tools: Not met based on Training Effectiveness survey question #4, trainees felt they needed more time and training to interpret the results
- PO11 Evaluate the effectiveness of second AGWA-Facilitator training: Not met based on overall survey scores, participants felt the trainings were too short to fully understand the tools and functionality, they had no management support to use the tools in their daily tasks and the tools were therefore not applicable to their job
- PO12 Determine the ability of trained individuals to develop and run new scenarios: Met based on Training Effectiveness survey question #10, trainees felt they could develop and run a new scenario within 1-2 days
- PO13 Evaluate overall user acceptance of the modeling system and intent to use it in decision-making: Not met based on overall results for Usability Survey, but *was met* based on question #1 “I think that I would like to incorporate AGWA or AGWA-Facilitator into my workflow when possible”

Final overall scores were low for both surveys: Training Effectiveness: 64, Usability: 61. We did not meet Performance Objectives 8, 10, 11, or 13. Based on the participants GIS and hydrologic skill levels, job duties, and verbal feedback, we attribute these low scores to several factors:

1. These tools are not currently required for their typical job duties, and participants did not feel they could use them or incorporate them into their workflow (i.e., low usability).
2. The products and analyses from these tools are not required for their jobs. A participant who gave particularly low scores noted that his “customers are soldiers who only want maps”, and his supervisor does not request the types of analyses available with our tools (i.e., low usability).
3. While AGWA is designed for resource managers and not necessarily hydrologic modelers, some background in hydrology is still needed to be able to interpret the results. For example, a participant commented that while they can run the tools, their lack of background and ability to interpret the results decreases the credibility of their analyses.
4. The trainings were not long enough for participants to learn the tools (i.e., low training effectiveness).

COST ASSESSMENT

The types of management issues of concern at an installation and the geospatial data available will influence how and if AGWA-Facilitator should be implemented. This includes collection of field data on specific additional attributes such as additional climate or stream flow data, or data regarding the locations of erosion control dams or other features that would affect model

parameterization and results, and the degree of stakeholder engagement. Inclusion of non-installation stakeholders in the stakeholder engagement process and/or the need for quantification of stakeholder preferences will significantly increase costs. Most of the data used in the AGWA-Facilitator are currently available at all military installations, and personnel typically have computers capable of running the tools, including a DoD site license for the ArcGIS software (required to run AGWA), therefore there would be little cost associated with data or hardware. There are no costs associated with acquiring AGWA-Facilitator; both tools are public domain and can be downloaded without cost via the internet.

The following personnel types and costs (includes fringe benefits and overhead at ~34.7%) were assumed for calculating the cost estimates in the table below. Average salary data were obtained from USA Jobs website (<https://www.usajobs.gov/>; accessed August 17, 2016 and April 20, 2018), searching for job postings for the U.S. Army for these job titles in Natural Resources or Administration, and using the average salary listings divided by 2080 hours to get hourly rates. Time required for each cost element is assumed based on experience at AGWA trainings for this project and others such as for BAER teams, universities, and federal agencies, and from estimates from AGWA Team members in Tucson, Arizona.

- GIS Specialist: Average \$70,000 annual cost, \$34/hr.
- AGWA/GIS Programmer: Average \$101,000 annual cost, \$49/hr.
- Natural Resources Officer: Average \$94,500 annual cost, \$45/hr.
- Project Manager/Supervisor: Average \$135,000 annual cost, \$65/hr.

Cost Elements for Project Cost Assessment (based on 2016 and 2018 data)

Cost Element	Data Tracked During the Demonstration	Estimated Costs
1. AGWA Setup	• Time required to gather data and use AGWA to characterize the military installation and parameterize the models, with existing data and for preparing new data.	• GIS Specialist: 3 hours, \$102 • Non-GIS user or Natural Resources staff: 8 hours, \$360 • Additional GIS Specialist time to gather and prepare all new data: 4 hours, \$136
2. Model refinement	• Time to complete performance objectives. • Time required to calibrate and validate the model if possible.	• Approximately 2 years, one supervisor, two GIS specialists, two GIS programmers, \$954,000 • Approximately 6 months, one GIS specialist, \$35,000
3. Modify AGWA	• Time and cost to modify AGWA to assess different scenarios, if required. • Military Disturbance Tool • Erosion Control Dams Pond Tool • Facilitator DSS	• AGWA Programming Costs: \$20,850 • Military Disturbance Tool: GIS specialist, 80 hours \$2,720, plus GIS programmer, 60 hours \$2,940, Total \$5,660 • Pond Tool: GIS programmer, 190 hours, \$9,310 • Facilitator: GIS programmer, 120 hours, \$5,880
4. Equipment	• Procurement costs associated with computers, and data storage.	• Computer: \$3,500 • Data storage 2 TB: \$60

5. Training	• Time and costs associated with training military land managers how to use AGWA and the Facilitator DSS, 1.5 – 2-day training.	• Training Personnel: two Supervisors, two GIS Programmers, 4 days, \$11,696 • Training Materials Preparation: three Programmers, 80 hrs. each, \$11,760
6. Field work	• Time and costs associated with field trips to gather and interpret military vegetation monitoring, soils, and remotely-sensed data as appropriate.	• Site visits: Two project supervisors, three AGWA GIS programmers, 4 days, \$13,264
7. Data Preparation	• Time and costs associated with preparing local data for entry into AGWA. • Time and costs associated with preparing input data for the Facilitator	• Prepare new data including downloading from internet, clipping, and projecting to study area: GIS Specialist, 4 hours, \$136 • Prepare input data for erosion control dams (locations, and stage-discharge data) using AGWA Pond Toolbox and Add Storage Tool: GIS Specialist \$12 per pond/EC dam. Add \$25 per pond/EC dam if added manually. Assume 50 EC dams added using the tool, \$600. • Identify and prepare input data for alternatives and criteria for the Facilitator, no non-installation stakeholders: Two project supervisors, 4 hours, \$260, two natural resource officers, 4 hours, \$180 = \$440 • Identify and prepare input data for alternatives and criteria for the Facilitator, with outside stakeholders: Two project supervisors, 8 hours, \$520, two natural resource officers, 8 hours, \$360 = \$880
8. Alternative approaches	• Time required to run the USGS StreamStats stream gauged based runoff regression relationships at each of the PCMS gauging stations.	• GIS specialist: 1 hour, \$34
9. Personnel	• Identify the personnel requirements for the operational deployment of AGWA on a military installation.	• IT or GIS staff to install AGWA-Facilitator on personnel computers, GIS staff to prepare and distribute data, and Natural Resources and ITAM staff familiar with ArcGIS to operate AGWA-Facilitator and provide expert knowledge of the site; GIS Programmer, \$49/hr, GIS Specialist \$34/hr, Natural Resources/ITAM staff \$45/hr, project manager/supervisor \$65/hr

Total costs		• AGWA-Facilitator operation, all data prepared, no EC dams, or outside stakeholders, \$902 • AGWA-Facilitator operation, new data acquired and prepared, \$1,038 • AGWA-Facilitator operation, all data prepared, with EC dams, no outside stakeholders, \$1,502 • AGWA-Facilitator operation, all data prepared, with EC dams, with outside stakeholders, \$1,942 • Training cost (personnel and materials preparation), \$23,456 • AGWA-Facilitator modifications (EC Dams and Add Storage Tools, Military Training Disturbance Tool, AGWA-Facilitator coupling), \$20,850
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IMPLEMENTATION ISSUES

Participants at the trainings had generally favorable reactions to the tools and their potential usefulness in their job duties; however, they did not have the authority to approve use of the tools in their workflow. We identified several issues that impede implementation of the tools at these locations, and possible courses of action to facilitate implementation.

Issue #1:

GIS staff (DoD employees and contractors) need a request from management to apply AGWA and perform an analysis; they cannot do it on their own. However, most managers do not know about the program or its capabilities.

Course of Action: Identify managers likely to require these analyses (Integrated Training Area Management (ITAM), Storm Water, Conservation/Fire, Sustainable Range, Master Planning, etc.) and provide a project brief with a short demo of the tools (1-2 hours, including discussion). Follow up with additional material and/or trainings.

Issue #2:

Although several managers were at the trainings, a directive from higher up may be needed for them to be able to incorporate the tools into their typical workflow. For example, an operations order would come from the Army Environmental Command (AEC) at the Installation Management Command (IMCOM) to the Directorates and Garrison, and then be implemented by each Directorate and Branch in the Directorate of Public Works (DPW). For ITAM, this would be through the Deputy Chief of Staff G-3 and the Sustainable Range Program (SRP). Wording would have to be included by the Directorates in the contracts for contractors.

Course of action: Presentations of our tools to higher management in the military system, such as AEC/IMCOM and G-3-SRP/ITAM, may be a way to facilitate their use. Presentations at relevant conferences and meetings is also recommended.

Issue #3:

Frequent staff turnover makes incorporating these tools into their regular workflow difficult. Although we provide a DVD with all materials needed to use the tools, once trained staff are gone, no one is aware of the tools or the DVD.

Course of Action: Knowledge of these tools by upper management in the Directorates, AEC, G-3, and so on, would increase their visibility and the likelihood that their use would be requested. Overall acceptance by DoD as an approved tool would increase implementation. Online courses or YouTube Video would make the materials more accessible by new staff.

Issue #4:

A successful model calibration/validation in a watershed that is exposed to frequent training activities requires high quality observed streamflow and rainfall data, a network of rain gauges, and local soils and vegetation data that can capture the changes in vegetation and soil caused by training and land rehabilitation disturbances. These data were not available for the calibration/validation at PCMS. Only seven rain gauges were available for the Red Rock Canyon watershed, no local soils data were available, and only three sets of vegetation data were available for our 10-year study period. However, the current data are adequate for relative change analyses in AGWA.

Course of Action: Place more rain gauges and stream flow gauges in the watersheds, and collect vegetation data more frequently, especially before and after major training events. This would improve the data available for model applications and management decision-making.

1.0 INTRODUCTION

This report presents the results of the Demonstrations of the AGWA-Facilitator tools conducted at Pinon Canyon Maneuver Site (PCMS) and Fort Carson, Colorado, and Fort Bliss, Texas/New Mexico. AGWA (Automated Geospatial Watershed Assessment Tool; Miller et al., 2007; www.tucson.ars.ag.gov/agwa) incorporates the hydrologic and erosion models KINEROS2 (KINematic Runoff and EROSION, K2; www.tucson.ars.ag.gov/kineros), RHEM (Rangeland Hydrology and Erosion model; Nearing et al., 2011; <https://apps.tucson.ars.ag.gov/rhem/docs/>), and SWAT (Soil and Water Assessment Tool versions 2000 and 2005; <http://swat.tamu.edu>). The Facilitator Decision Support System (DSS; <https://sourceforge.net/projects/facilitator/>) uses AGWA outputs either through the AGWA-Facilitator Export Tool that writes directly to a Facilitator input file, or by manually entering the information in the DSS.

The PCMS Demonstration was initiated in January 2015 and completed in July 2016. The Fort Carson Demonstration was initiated in January 2017 and completed in February 2018. The Fort Bliss Demonstration was initiated in December 2016 and completed in March 2018. The calibration and validation of the watershed models, KINEROS2, RHEM, and SWAT, and data quality analysis, are also presented.

1.1 BACKGROUND

Nationally, the Department of Defense (DoD) manages about 25 million acres (~10 M hectares (ha)) of land on about 500 active installations (DoD, 2015) to meet its mission and maintain its stewardship commitment. Proper management of these lands, including protection of natural and water resources and associated biodiversity, is necessary for sustainable military testing and training. Vegetation and soil disturbances associated with military training activities such as from military vehicles, heavy foot traffic, and deployment encampments risk disruption of the ecological integrity of an installation, potentially jeopardizing the military mission. Degraded landscapes fail to provide realistic training opportunities, and limit the areas available for training.

To address this issue DoD implemented a Natural Resources Program to ensure that both the land and its resources are preserved for continued support of mission-related activities, and that the installation complies with all federal and state environmental laws and regulations (DoD 4715.03). This program recommends a watershed-based approach for natural resources management of installations as they are often the source of essential water resources for installation operations and for sustaining habitat for numerous threatened, endangered, and at-risk species (TER-S; Stein et al., 2008). At the same time, watersheds and the streams draining them can deliver undesirable constituents to downstream receiving waters. Due to increased regulations associated with the Clean Water Act (CWA), the Safe Drinking Water Act, and the Energy Independence and Security Act (EISA; USEPA, 2009), DoD is expanding storm water management and application of a watershed protection approach to military land management. Essential elements of watershed management include identification of areas prone to erosion, areas that are degraded but most amenable to mitigation, and areas providing water for military personnel and TER-S habitat. Watershed-based modeling and decision tools are essential to assess the potential effects from training activities and future installation growth. Proper analysis

of watershed functions on DoD lands is limited by the lack of scientifically based watershed modeling and decision tools that are broadly applicable, easy to use, and easily interpreted. This project demonstrates such a technology that couples a watershed modeling tool with a decision support system that allows exploration of the effects of different management scenarios. The AGWA-Facilitator tool includes numerous tools and functionality to assist land managers in protecting and preserving military lands in support of mission-related activities.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this project was to demonstrate a scientifically based watershed modeling and decision support system to DoD installation managers that is broadly applicable, easy to use, and with results that are easily interpreted. The project addressed installation watershed management concerns of erosion, flooding, fire, water supply, water quality, assessment and rehabilitation of disturbed areas, and planning for future installation growth and mission expansion. The technologies demonstrated were AGWA and the Facilitator DSS. The AGWA tool supports watershed modeling through its embedded hydrologic models, KINEROS2, RHEM, and SWAT, and is used to evaluate the relative changes to runoff and erosion due to installation activities such as training, urbanization, fire, and range development. The Facilitator allows managers to evaluate alternative management scenarios in a multi-objective decision framework to support and document decision-making. The demonstrations were performed on three DoD installations: Fort Carson and Pinon Canyon Maneuver Site (PCMS) in Colorado, and Fort Bliss in Texas/New Mexico. Although Fort Carson and PCMS are both managed by the same personnel, separate demonstrations were performed because land uses and conditions are different between the two locations. In addition, the hydrologic models in AGWA were calibrated and evaluated for various levels of data to demonstrate model performance, and to identify the number of precipitation and streamflow gauges for improved watershed management and analysis.

Thirteen Performance Objectives (PO) were developed for this project in three general categories: 1) the applicability and usability of AGWA-Facilitator at DoD installations, 2) the effectiveness of the trainings used to demonstrate the tools, and 3) calibration/validation of the models embedded in the AGWA tool. Sections 3.0 and 6.0 discuss each PO and the demonstration results in detail.

1.3 REGULATORY DRIVERS

Military reservations are subject to a variety of natural resource-related laws and regulations. The main regulatory drivers that this technology can help address are:

1. The Sikes Act requires all military reservations to develop and implement an Integrated Natural Resources Management Plan (INRMP) in cooperation with the United States Fish and Wildlife Service (US-F&WS), and in Colorado with the Colorado Department of Parks and Wildlife (CPW). The purpose is to promote effectual planning, development, maintenance, and coordination of wildlife, fish, and game conservation and rehabilitation in military reservations.
2. The National Environmental Policy Act (NEPA) requires all federal agencies to assess the environmental effects of their proposed actions prior to making decisions.
3. The Endangered Species Act (ESA) protects and recovers imperiled species and the ecosystems upon which they depend, and lists species as either threatened or endangered.

4. The Archaeological Resource Protection Act (ARPA) aims to protect archaeological resources and sites on public, federal, and Indian lands.
5. The Migratory Bird Treaty Act (MBTA) makes it illegal for anyone to take, possess, import, export, transport, sell, purchase, barter, or offer for sale, purchase, or barter, any migratory bird, or the parts, nests, or eggs of such a bird except under the terms of a valid permit issued pursuant to Federal regulations. Migratory bird species under protection are listed.
6. The Bald and Golden Eagle Protection Act (BGEPA) prohibits anyone, without a permit issued by the Secretary of the Interior, from "taking" bald eagles, including their parts, nests, or eggs. The Act defines "take" as "pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb."
7. The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters.
8. The National Pollutant Discharge Elimination System (NPDES) is a permit program, created in 1972 by the Clean Water Act (CWA), to help address water pollution by regulating point sources that discharge pollutants to waters of the United States.
9. The Energy Independence and Security Act (EISA) of 2007 reinforces the energy reduction goals for federal agencies. The three key provisions enacted are the Corporate Average Fuel Economy Standards, the Renewable Fuel Standard, and the appliance/lighting efficiency standards.

Most of these regulations are covered under the DoD Natural Resources Conservation Program number 4715.03, issued on March 18, 2011. Responsibility for ensuring that environmental policies are followed is shared primarily between the Directorate of Public Works (DPW) and the Directorate of Plans, Training, Mobilization and Security (DPTMS), both of which stand to benefit from the AGWA-Facilitator technology in addressing these regulations. The DPW Environmental Division directs NEPA processes for installation construction or maintenance projects, ensures projects that affect wetlands are in compliance with CWA Section 404, and monitors water quality as part of a stormwater program. The DPTMS is responsible for ensuring all range activities are compliant with the INRMP provisions and monitors and repairs damage resulting from training activities under the Integrated Training Area Management (ITAM) program.

EISA Section 438 stormwater management requirements include the use of Low Impact Development (LID) techniques, to demonstrate "no net increase" in stormwater runoff due to new development (USEPA, 2009; U.S. Army Corps of Engineers, 2013). Although AGWA and its embedded model KINEROS2 are not listed as an approved methodology to meet EISA Section 438 requirements, AGWA/KINEROS2 includes LID, green infrastructure, and urban element features that can be used when modeling stormwater runoff. We demonstrated the model's value for EISA Section 438 stormwater runoff analysis at the Fort Carson cantonment, using a hypothetical new development. Pre- and post-development conditions can be simulated, using AGWA/KINEROS2 LID features for stormwater runoff.

The "Department of Defense Installation Watershed Impact Assessment Protocol" (Cisar and Rohr, 2005) provides guidance for complying with Total Maximum Daily Load (TMDL) and

drinking water requirements; however, EISA Section 438 has a broader approach that includes requirements that the hydrologic impacts of new developments not exceed stormwater runoff amounts prior to the development. In addition, updated LID techniques are recommended.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

This section provides a description of the technologies demonstrated: the AGWA Tool, the KINEROS2, SWAT, and RHEM models embedded in AGWA, and the Facilitator Decision Support System.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The technologies demonstrated in this project are the AGWA tool, its embedded hydrologic models KINEROS2, RHEM, and SWAT, and the Facilitator multi-objective DSS (Figure 1). AGWA is used to evaluate the relative changes to runoff, erosion, and sediment yield due to installation activities such as training, urbanization, fire, and range development. The Facilitator allows managers to evaluate alternative management scenarios and AGWA output in a multi-objective decision framework. The AGWA-Facilitator Export Tool in AGWA provides for the transfer of AGWA model results (i.e., peak flow and sediment yield) directly into a Facilitator decision analysis document, to link the two tools. AGWA with KINEROS2 and SWAT, and the Facilitator were used in the tutorials and presentations at each installation for this demonstration project. RHEM was used in the calibration/validation for Performance Objective 4. It was not used in the tutorials because it requires more detailed input data than are generally available.

2.1.1 Automated Geospatial Watershed Assessment Tool (AGWA)

The Automated Geospatial Watershed Assessment Tool (AGWA) is a publicly available Geographic Information Systems (GIS) interface jointly developed by the U.S. Environmental Protection Agency Office of Research and Development (EPA– ORD), United States Department of Agriculture (USDA) Agricultural Research Service (ARS), and University of Arizona (UA). The AGWA tool supports watershed modeling along a continuum of spatial and temporal scales, ranging from hillslopes (~hectares) to large watersheds (>1000 km²) and from individual storm events (minute time steps) to continuous simulation (daily time steps over multiple years) (Guertin et al., 2015). It employs nationally available data layers to parameterize, execute, and visualize outputs of its embedded watershed models. During the development of AGWA, numerous watershed modeling systems were reviewed to identify a versatile, well validated, operational watershed model that could be used from small catchment to basin scale events, to multi-year simulations, with accurate process and spatial representation of management practices, land-use, and land cover changes (i.e., riparian buffer strips, vegetation changes, urbanization, etc.; Goodrich et al., 2000). The review concluded that a single watershed model could not adequately meet these requirements. Therefore, both SWAT and KINEROS2 were incorporated into AGWA to enable seamless multi-scale watershed analysis. Users can assess watershed condition and temporal trends at the broad basin scale using the SWAT model to identify areas of potential concern over large basins. These areas of concern, typically smaller watersheds, can then be modeled at a finer resolution using KINEROS2 to identify concerns with greater specificity and then evaluate potential conservation or mitigation strategies (Miller et al., 2002; Semmens et al., 2008). RHEM was added subsequently to improve the analysis of rangeland conditions where detailed land cover data are available, and is discussed later in this document.

AGWA can evaluate the runoff and erosion impacts from several best management practices (BMPs) including brush removal, revegetation, watering locations, retention/detention ponds, prescribed fire at the hillslope or watershed scale (Guertin et al., 2015), and green infrastructure. Management tools available in AGWA include a land cover modification tool for land cover change; a burn severity tool using burn severity maps for post-fire assessment; a military disturbance tool to evaluate vegetation and soil changes from military maneuvers; a pond tool to design, place, and evaluate flood and erosion control structures; and an urban tool to evaluate the effect of new developments on runoff and erosion with and without green infrastructure practices (permeable pavements, infiltration basins, or rainwater harvesting). AGWA's current outputs include runoff (volumes and peaks), erosion, and sediment yield, plus nitrogen and phosphorus with the SWAT model (Figure 2). These outputs can be derived for any stream reach within the discretized watershed, enabling the analysis of management actions in a pre- or post-disturbance scenario. AGWA is best suited for evaluation of the relative change in runoff and erosion from land disturbance such as ground maneuvers, fire, urbanization, or road construction. High-quality rainfall-runoff observations are required for calibration and confidence in quantitative model predictions (Goodrich et al., 2012). AGWA is aimed towards natural resources professionals who do not necessarily have a background in hydrology or watershed modeling. However, some proficiency in GIS and hydrologic understanding is helpful.

AGWA is an add-in to ESRI ArcGIS 10.x (<http://www.esri.com/arcgis/about-arcgis>). It is a free download from the website www.tucson.ars.ag.gov/agwa as a “package” containing all tables and models to run AGWA. It is added to ArcGIS by double clicking on the add-in file, and then enabling the AGWA Toolbar in ArcMap. Using only basic, easily available GIS data, AGWA reduces model setup time from watershed delineation through model execution and results analysis. AGWA provides a simple, direct, and repeatable methodology for hydrologic model setup. A robust and intuitive GUI, the AGWA Toolbar, guides the user through the required steps to perform a watershed assessment. The steps to run the models in AGWA are: 1) watershed delineation; 2) model selection and watershed discretization; 3) watershed parameterization; 4) precipitation input; 5) model input file creation; 6) model execution; and 7) model results visualization and analysis (Figure 2).

Watershed Delineation: This step is performed using a DEM and a watershed outlet to create the watershed outline. AGWA can fill the DEM (to ensure hydrologic correctness), and create the flow direction and flow accumulation rasters, if those rasters have not already been created.

Watershed Discretization: Watershed discretization is performed by defining the stream network and using it to subdivide the watershed into smaller elements. Element size is determined as a minimum accumulated area required for stream initiation (contributing source area), as a minimum accumulated flow length required for stream definition, from a pre-existing stream network, or from input channel initiation points. Model selection occurs at this step because the models have non-compatible watershed representations (Guertin et al., 2015).

Watershed Parameterization: During this step, the model elements are intersected with the DEM, soils data, and land cover data to create model parameterizations based on the topographic, soils and land cover properties for each modeling element that are required for model input.

Precipitation Input: KINEROS2 and RHEM are event-based models and the precipitation data are created from user-defined hyetographs, user-defined depths and durations, pre-defined storms, or precipitation surfaces representing return period-duration depths. Precipitation can also be represented with a uniform intensity, or with an intensity derived from the SCS Type II distribution. SWAT uses continuous data created by selecting one or more rain gages and providing a continuous, daily rainfall record for each gage. For more than one gage, AGWA will create Thiessen polygons to intersect with the watershed elements to area-weight the depth for each subwatershed (Guertin et al., 2015).

Model Input Files: AGWA will create a simulation with the model-specific input files using the watershed discretization, parameterization, and precipitation data. Other options available during this step include applying a parameter multiplier for KINEROS2, or using the optional weather generator for daily precipitation and temperature for SWAT. Input files may be edited by the user if necessary.

Model Execution: After all previous steps are performed, AGWA will execute the selected simulation using the model input files.

Model Results Visualization: After the model is successfully executed, the simulation results are imported back into AGWA so the model outputs can be mapped onto the watershed discretization. Hydrographs can be displayed for KINEROS2 simulations. AGWA can calculate differences in the results from all models as either a percentage or absolute difference for relative change analysis.

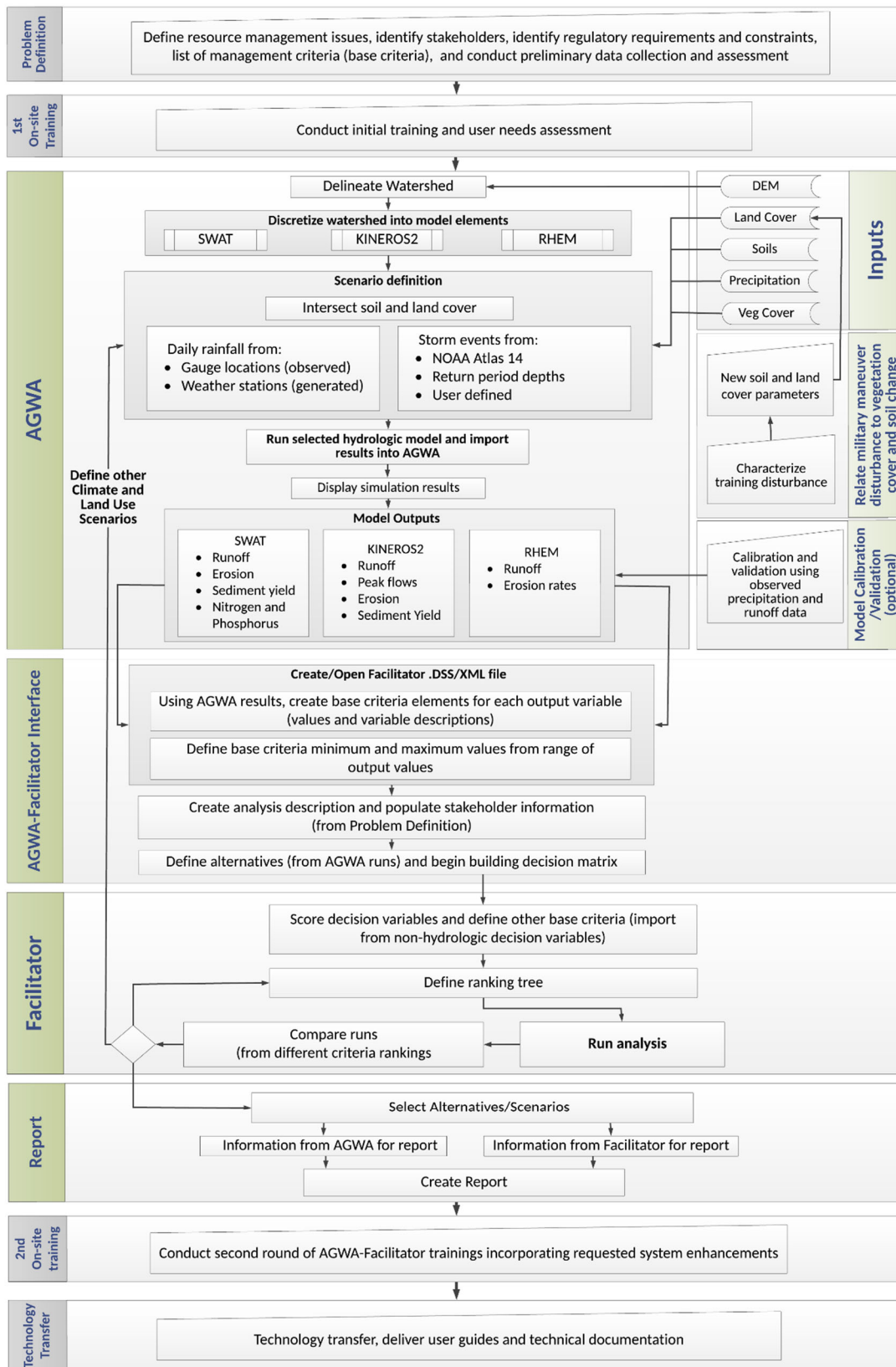


Figure 1. AGWA-Facilitator application flowchart

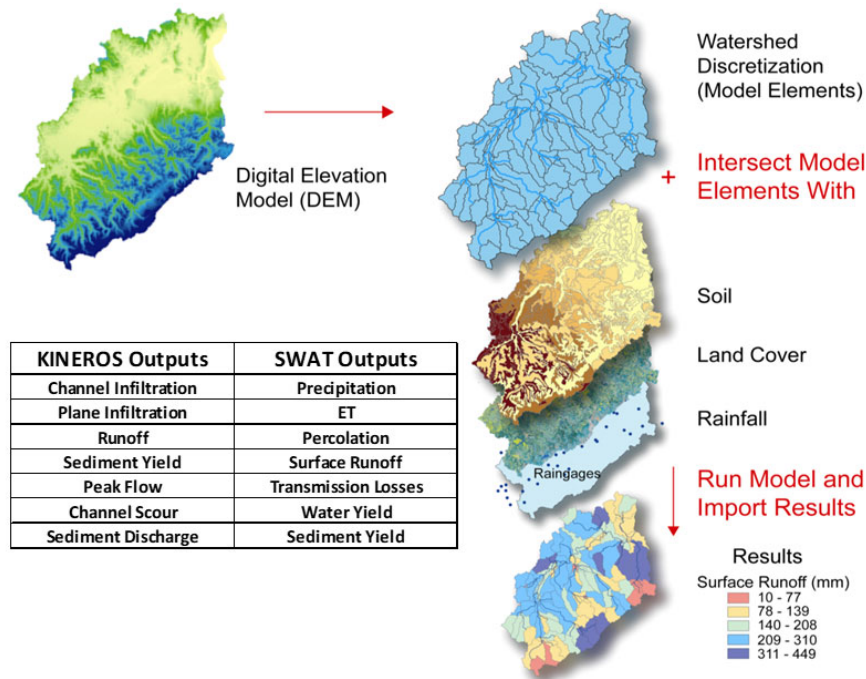


Figure 2. AGWA work flow and model outputs

2.1.2 KINEROS2 (K2)

KINEROS2 (K2) is a spatially distributed, event-based, watershed runoff and erosion model embedded in AGWA. It originated at the USDA-ARS in the late 1960s as a model that routed runoff from hillslopes, represented by a cascade of overland-flow elements using the stream path analogy proposed by Onstad and Brakensiek (1968), and then laterally into channels (Woolhiser et al., 1970). Conceptualization of the watershed in this form enabled solution of the flow-routing partial differential equations in one dimension. Rovey (1974) coupled interactive infiltration to this model, while several other investigators added erosion and sediment transport as well as a number of additional enhancements. After substantial validation using experimental data, K2 was formally released in 1990 (Woolhiser et al., 1990; Smith et al., 1995). The model was developed for spatial scales ranging from plots ($<10 \text{ m}^2$) to large watersheds up to a thousand square kilometers. However, it has only been thoroughly validated for watersheds of approximately one hundred square kilometers where sufficient observations exist in experimental watersheds (Goodrich et al., 2002; 2004; 2012). Computational run time on a typical desktop PC is typically several minutes or less for watersheds with a drainage area of about 100 km^2 . Computational time intervals are automatically adjusted to minimize numerical errors and the user can select the time interval at which simulation output is reported. Goodrich et al. (2012) reviewed the use, calibration, and validation of K2 across numerous geographies and applications. K2 is public domain software that is distributed freely via the internet, along with associated model documentation and example input files (www.tucson.ars.ag.gov/kineros). A summary of K2 attributes and function is provided in Appendix C.

2.1.3 Rangeland Hydrology and Erosion Model (RHEM)

The Rangeland Hydrology and Erosion Model (RHEM) is used to model runoff and erosion from hillslope modeling elements in AGWA when detailed vegetation and soils information are available. RHEM is sensitive to vegetation basal and canopy cover in predicting runoff, erosion, and sediment transport. Changes in vegetation cover can occur due to military training exercises, and RHEM input parameters (i.e., canopy cover, basal cover, and litter cover) can represent those changes. The development of the RHEM model was initiated in 2003, in response to the need for a process-based rangeland erosion model with the ability to assess the potential impacts of management actions on soil erosion and sediment yield at both the hillslope and watershed scales. The development and parameterization of RHEM was based on rainfall simulator experimental measurements from 204 plots in 49 rangeland sites across 15 western states to represent undisturbed and disturbed semi-arid rangeland processes, and parameterize infiltration and erosion parameters as a function of rangeland plant community characteristics (Al-Hamdan et al., 2014; Wei et al., 2007, 2008, 2009). AGWA executes RHEM for all hillslopes within a watershed. Runoff and sediment are then routed through channels draining the hillslopes, enabling rapid watershed scale assessments. RHEM has been applied to evaluate ecological site conditions across the southwestern U.S. using Natural Resources Inventory data (Hernandez, 2013; Weltz et al., 2011b). AGWA and RHEM have been used in the USDA Grazing Lands Conservation Evaluation Assessment Project (CEAP; Goodrich et al., 2011; Weltz et al., 2009, 2011a).

2.1.4 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. SWAT has undergone continued review and expansion of capabilities since it was created in the early 1990s. Key enhancements for previous versions of the model (SWAT 94.2, 96.2, 98.1, 99.2, and 2000) are described by Arnold and Fohrer (2005) and Neitsch et al. (2005a), including the incorporation of in-stream kinetic routines from the QUAL2E model (Brown and Barnwell, 1987). Documentation for all versions of the model is available at the SWAT web site, <https://swat.tamu.edu/documentation/>. The 2000 and 2005 versions of SWAT are available in AGWA. Detailed theoretical documentation and a user's manual for the 2005 version of the model (SWAT2005) are given by Neitsch et al. (2005a, 2005b). The 2005 version of the model is briefly described here from Gassman et al. (2007), to provide an overview of the model structure and execution approach. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management. Climatic inputs used in SWAT include daily

precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated. In their comprehensive review of SWAT, Gassman et al. (2007) summarize SWAT's historical development, its capabilities, strengths and weaknesses, as well as calibration, validation, and numerous applications (over 250 peer reviewed publications). They note that SWAT has gained national and international acceptance as a robust interdisciplinary watershed modeling tool that has also been adopted as part of the U.S. EPA BASINS software package and is being used by many U.S. Federal and state agencies.

2.1.5 Facilitator

The Facilitator is a flexible multi-objective DSS that been developed over several decades (Heilman et al., 2002; Yakowitz et al., 1993) by the USDA-ARS and Queensland Department of Natural Resources in Australia. The decision-making flow of the Facilitator is similar to many of the recommendations made in the decision theory literature (Hammond et al., 1999). The Facilitator provides a structured approach in which the decision makers document the problem, define objectives (and the variables, or criteria, that reflect those objectives), define management alternatives, calculate the effect of the alternatives on the criteria to understand consequences, and visualize tradeoffs through score functions that map the desirability of each criterion (Figure 3). Instead of specifying a weight for the criteria, the user ranks the criteria and then the Facilitator calculates an overall score for each alternative as the sum of scores for each criterion times the weight for that criterion.

Figure 3 illustrates an example Facilitator application of a military range experiencing accelerated erosion following heavy training maneuvers. Decision makers define the criteria, such as cost, sediment yield or peak, effect on training, and effect on water resources that reflect the installation's objectives. The AGWA-Facilitator Export Tool in AGWA provides for the transfer of AGWA model results (i.e., peak flow and sediment yield) directly into a Facilitator decision analysis document, to link the two tools. The Tool is included in AGWA.

Next, alternatives are defined, such as: maintain the status quo, prescribe a long period of rest to allow the range to recover, or install a potentially costly conservation treatment. The Facilitator is used to graphically compare alternatives, ultimately leading to the selection and implementation of an alternative that improves on the status quo (Figure 3, bottom panel). Users can assess the impact of alternative importance rankings that may reflect different values or interests from different managers (i.e., environmental, ITAM, mission training, etc.). The end result is a ranking of the alternatives, ideally with one alternative ranked higher than the status quo. The decision is documented with the problem, alternatives, and criteria, and a populated matrix with a score function for each criterion, a matrix of scores relating each alternative to each criterion, the importance rating of criteria specified by the users, and the graphics that display the ranking. The Facilitator results window in Figure 3 (bottom panel) shows a ranking of alternatives for an example. The ranking in importance is shown, and the location of the bars in the graphic indicates the overall desirability, from 0 to 1, with better options being closer to 1. In this example, the Status Quo alternative was scored 0.5 for each criterion, so it is shown by a red line rather than a green bar. Results for different runs can be viewed to show the effect of other rankings of the criteria.

Facilitator Decision Support Tool Flow

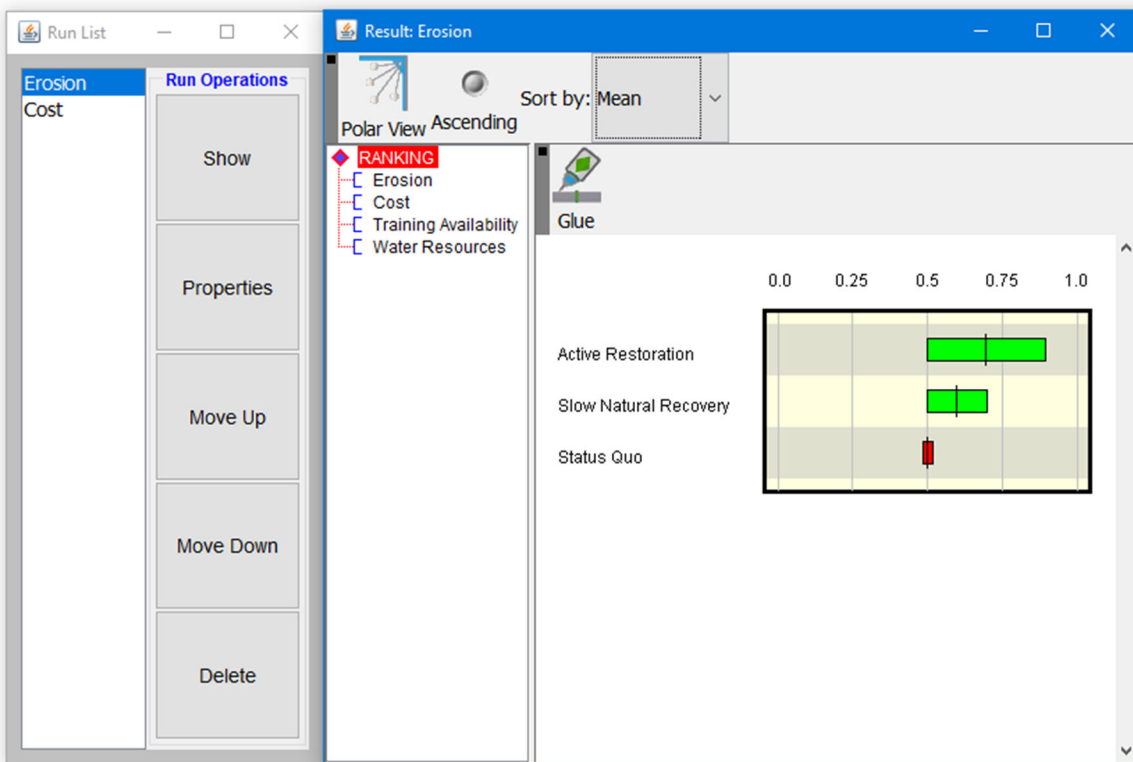
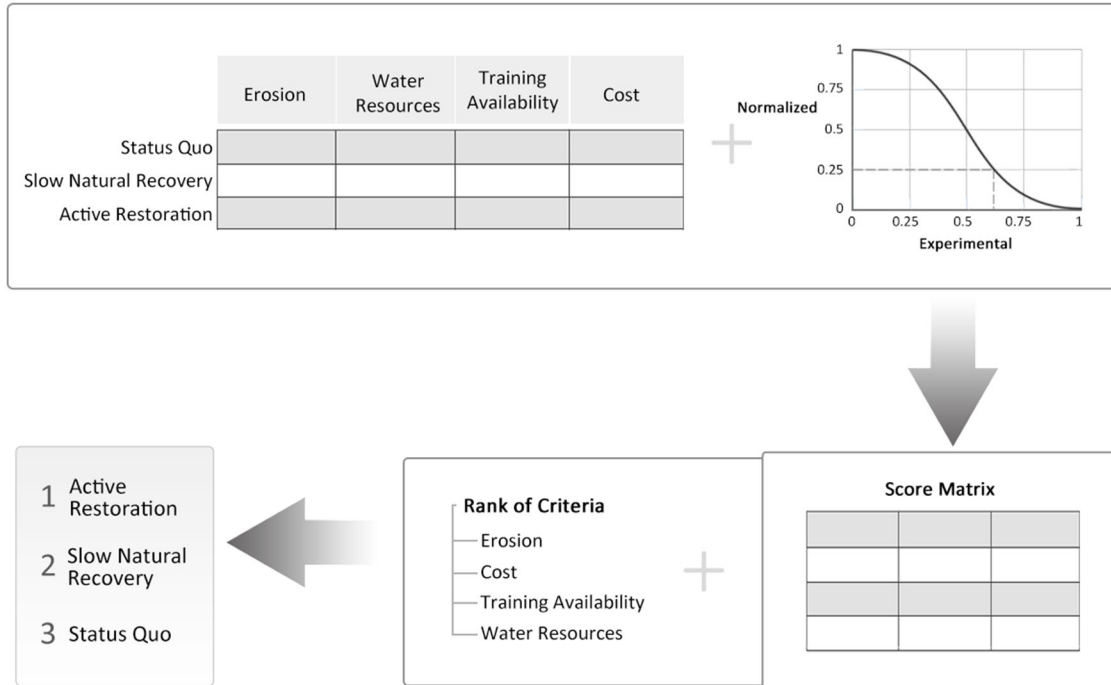


Figure 3. Facilitator decision-making flow diagram and output example

2.1.6 Technology Transfer

Technology transfer and determination of the usability of these tools were accomplished mainly through our AGWA-Facilitator 1.5 to 2-day trainings. These trainings were comprised of presentations, discussions, and hands-on tutorial exercises that reflect specific management concerns identified by installation personnel, thus making the application of the tools more transparent and meaningful. Two trainings were conducted at each installation, and all training participants fill out surveys at the end of each training to assess the usability of the tools and the effectiveness of the training.

The surveys are based on the System Usability Scale (SUS), which is a Likert scale developed by Brooke (1986). It employs ten forced-choice questions, where the respondent indicates the degree of agreement or disagreement on a 5-point scale with 1 being “strongly disagree” to 5 “strongly agree”. The questions are carefully worded to represent extreme expressions of the attitudes being captured, and alternate as positive and negative responses to force the respondent to think about whether they agree or disagree with each question. Both the Usability and Training Effectiveness surveys employed at our trainings have slight modifications to the wording of the questions, but maintain the overall format and intent of the SUS. The Usability survey focuses on whether the participant felt the tools were useful and intends to use them. The Training Effectiveness survey focuses on how well the training taught the participant to use and understand the tools. Both surveys include 3 additional optional questions not included in the final scoring that assess their comfort with using GIS, their background in hydrologic principals or modeling, and their name and primary job responsibility (optional). Copies of the final (blank) surveys are attached as Appendix B.

In addition to the surveys, discussion sessions were held at various times during the trainings to obtain feedback on the AGWA-Facilitator tool, the tutorials, and the training format. We also monitored each participant during the trainings to determine whether they had any difficulty performing the tutorial tasks, which tasks gave them trouble, if there were any issues with the tutorials themselves, and how long it took each participant to complete each tutorial. This information, along with their GIS skill level and background in hydrologic principals or modeling (provided in the surveys), was used to better understand the appropriate knowledge and skill level required to best utilize our tools.

After the second (final) training at each installation, we provided the installation managers with a DVD containing all of the tutorials and supporting data, the AGWA package and add-in, and the Facilitator files. While we provide some ongoing technical support for users of AGWA-Facilitator, support of these tools is not our primary function. AGWA-Facilitator was specifically developed and designed for non-watershed modeling specialists. Many other watershed modeling systems assume a higher level of watershed modeling knowledge and expertise, presenting a barrier to the adoption and use by natural resources professional lacking watershed modeling or hydrologic expertise.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

A key innovation of the AGWA-Facilitator tool as compared to other watershed modeling systems is that it was specifically developed and designed for non-watershed modeling specialists. AGWA's development was prompted by the desire of the Landscape Ecology Branch of the U.S. EPA to obtain a tool that could be used by landscape ecologists to provide hydrologic and water quality metrics of watershed condition and trends in watershed condition over time (Goodrich et al., 2000). Working closely with EPA landscape ecologists, AGWA was developed with intuitive interfaces as well as documentation, help screens, and tutorials that are understandable by knowledgeable natural resources professionals without hydrologic modeling terminology and the assumption of a high-level watershed modeling background. Other watershed modeling systems assume a higher level of watershed modeling knowledge and expertise, which can present a barrier to the adoption and use by a natural resources professional without watershed modeling expertise. We have conducted AGWA training sessions for natural resources professionals from many agencies (BLM, BIA, NPS, USDA-FS, NRCS, DoD, EPA, several state agencies, consultants, and graduate students) and obtained post training questionnaire responses indicating trainees were very pleased with their ability to use AGWA and understand the results. Detailed, in-depth background and theory of AGWA and its models are available on the AGWA, KINEROS2, SWAT, and RHEM web sites if a user desires more peer-reviewed, research level modeling system specifics. Subsequent adoption of AGWA, most recently by Department of Interior (DOI) National Burned Area Emergency Response (BAER) teams for rapid post-fire watershed assessments, is evidence for the ease of use of AGWA by non-watershed modeling specialists.

AGWA is currently designed to use commercial software (ESRI ArcGIS; <https://www.esri.com/en-us/arcgis/about-arcgis/overview/>), which requires the user to purchase the software, and have a computer with sufficient RAM and storage capacity to effectively use it (minimum of four gigabytes of RAM). ESRI ArcGIS currently does not run on Apple computers. We have determined during training workshops and while providing assistance to users that a working knowledge of ESRI ArcGIS, especially ArcMap, is important for the successful execution of AGWA. However, some background in hydrology is also helpful for interpreting AGWA results. AGWA 3.x has an Enterprise Certificate of Networthiness (CON #201418208, Oct. 28, 2014) that has currently been extended pending implementation of the new Assess Only protocol.

Prominent alternative watershed modeling technologies that have a number of common features with AGWA, but some key differences are the EPA BASINS (Better Assessment Science Integrating Point & Non-point Sources) and HEC (U.S. Army Corps of Engineers - Hydrologic Engineering Center) HMS (Hydrologic Modeling System)/GeoHMS (Geospatial Hydrologic Modeling Extension) modeling tools (<http://www.hec.usace.army.mil/software/hec-hms/>). BASINS, HEC, and AGWA software products are all in the public domain and freely available. However, AGWA and HEC-GeoHMS require proprietary ESRI ArcGIS software with the Spatial Analyst extension while BASINS employs non-proprietary, open-source MapWindow GIS software. Most Federal agencies have agency-wide site licenses for ArcGIS, including DoD, so there are no additional costs involved in using AGWA (or GeoHMS). If agency licensing of

ArcGIS were to be discontinued, licensing expenses would be incurred to use AGWA or GeoHMS.

Erosion and sediment modeling capabilities are essential for this demonstration project, as erosion and sediment management are important components of installation management with any significant outdoor training requirements. One of the main advantages of AGWA is its capability to model runoff, erosion, and sediment yield across all watershed hillslopes. For DoD installations dominated by grass, shrub, rangeland, or woodland vegetation communities, it is essential to employ erosion technology designed for the appropriate environment. Most erosion models, including the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978), were originally developed for agricultural environments. Development of RHEM (Nearing et al., 2011) was motivated by the need to better represent hillslope runoff and erosion processes in rangelands and semi-arid ecosystems. RHEM has been incorporated into KINEROS2 to represent hillslope runoff and erosion processes, and represents the state-of-the-art in runoff and erosion modeling for semi-arid ecosystems where detailed soil and vegetation data are available. RHEM was used in this project for the model calibration and validation at PCMS.

The EPA BASINS tool (<http://water.epa.gov/scitech/datait/models/basins/>) contains numerous models including the SWAT model included in AGWA. The other primary watershed models within BASINS include HSPF (Hydrological Simulation Program - Fortran; Bicknell et al., 1997), GWLF (Generalized Watershed Loading Function; Haith and Shoemaker, 1987), and the Storm Water Management Model (SWMM; <http://www.epa.gov/athens/wwqtsc/html/swmm.html>) for urban areas. The erosion models in SWAT, HSPF, and GWLF are all based on variants of the USLE, which was developed for crop lands. Therefore, the watershed models within EPA BASINS would be expected to be less applicable than KINEROS2 or RHEM for the rangeland dominated installations covered by this demonstration project.

Another notable advantage of AGWA is the inclusion of a new AGWA tool, the Military Disturbance Tool. Runoff and erosion processes are influenced by vegetation and soil condition independent of the source of disturbance (military use, fire, drought, livestock grazing, etc.), so a tool was created that utilizes parameterization procedures developed for this demonstration to estimate changes in runoff and erosion due to the effects of military exercises on soil compaction and vegetation cover in rangeland environments. The Military Disturbance Tool was limited to modification of the input parameters for KINEROS2 for this demonstration, but the capability to modify input parameters for RHEM will be available in future versions of AGWA.

3.0 PERFORMANCE OBJECTIVES

Thirteen quantitative and qualitative Performance Objectives were identified for evaluating the performance and acceptance of the AGWA-Facilitator tool, and the costs of implementing the system.

provides a list of the Performance Objectives along with related metric information, data requirements, the success criteria used to determine if the objectives are met, and the results. The Performance Objectives apply to all installations except as otherwise noted in the table. As noted previously, the primary objective of this project is to provide watershed modeling and decision tools to DoD installation managers that are broadly applicable, easy to use, and with results that are easily interpreted. For each of the performance objectives we indicate in the text following the table if it relates to the project team, the installation managers, or both, and state our working assumptions.

POs 1, 2, 6, and 7 apply to AGWA-Facilitator and its general use at military installations, POs 3, 4 and 5 apply to the model calibration/validation work, and POs 8 through 13 apply to the AGWA-Facilitator trainings and survey responses.

The survey questions were directly related to the POs as follows (see Appendix B for the surveys and

):

Training Effectiveness Survey

PO 8: Overall survey scores

PO 9: Question 9

PO 10: Question 4

PO 11: Overall survey scores

PO 12: Question 10

PO 13: Questions 3, 6, and 8

Usability Survey

PO 13: Overall survey scores, Question

Table 1. Performance Objectives and Results

Performance Objective		Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives					
1	Assess the ability to use nationally available input datasets for an uncalibrated, out of the box AGWA set up at demonstration installations	AGWA produces appropriate watershed representation and produces meaningful hydrologic results	• USGS 10 m DEM data • SWReGAP or NLCD land cover data • NRCS SSURGO or STATSGO soils data • NOAA design storm estimates (KINEROS2); GHCN-Daily climate data (total daily precipitation /maximum and minimum temperatures) and Stochastic Weather Generator inputs for SWAT • USGS StreamStats regional discharge regression relationship	• Define drainage area within 3% of independently derived area at a USGS gauging station • Watershed response is proportional to precipitation inputs (e.g., when precipitation is doubled runoff increases by less than a factor of two, annual output/input ratios) • Global water balance is less than 3% of total precipitation inputs	Success Criteria met: • Drainage areas: 0.09%, 0.21%, 0.46% for Red Rock, Taylor and Lockwood Watersheds • AGWA was successfully parameterized with national data in PCMS watersheds and produced meaningful results in runoff and sediment. • Runoff reasonably responded to rainfall input in both KINEROS2 and SWAT. When doubling rainfall input, the watershed response/precip proportions were close to 2 • Global water balance errors were <1% for KINEROS2, and <3% for SWAT
2	Package AGWA-Facilitator for distribution and installation on military computers	Ability of an installation GIS technician or specialist to obtain the AGWA-Facilitator package and install it on installation computers.	IT support from each installation	An installation GIS technician or specialist can obtain the AGWA-Facilitator package and install it on installation computers.	Success Criteria met: AGWA add-in, Facilitator application, and all supporting data and files delivered on DVDs to each installation. AGWA was successfully installed on staff computers.
3	Determine the ceiling for model execution time (item 2e*)	Run time of SWAT with and without Monte Carlo or Dynamically Dimensioned Search (DDS) analysis for uncertainty estimates	For SWAT: 10 years of input climate data and successful model watershed set-up (e.g., PO1)	SWAT and KINEROS2: Run time not to exceed 10 min for any PCMS watershed without Monte Carlo; Not to exceed 6 hours with Monte Carlo uncertainty for a variety of scenarios	Success Criteria met for runtime without Monte Carlo: runtime was under 10 minutes to complete a single KINEROS2 or SWAT simulation Success Criteria not met for runtime with Monte Carlo: Monte Carlo simulations took longer than 6 hrs.
		Run time of KINEROS2 with and without Monte Carlo or Dynamically Dimensioned Search (DDS) analysis for uncertainty estimates	For KINEROS2; NOAA design storms and successful model watershed set-up (e.g., PO1)		

4	PCMS: Assess the improvement in performance of AGWA when calibrated with varying levels of data to determine the degree to which the models need to be calibrated and validated in order to be used for regulatory and planning purposes Fort Carson: 1) Assess improvement in performance of the models when calibrated with “best” datasets (rainfall, basin characteristics) as identified from PCMS results 2) Test at cantonment area for regulatory requirements (EISA Section 438 for stormwater analysis) Fort Bliss: Assess model performance with a relative change analysis for a heavily disturbed scenario	PCMS Comparison of simulated vs observed hydrograph characteristics (runoff volume, peak runoff rate) using the following evaluation metrics: • Nash-Sutcliffe Efficiency (NSE) • Coefficient of Determination (R2) • Bias • RMSE • Standard deviation ratio (RSR) As a function of different levels of input data starting with an out of the box assessment (PO1), to a “best-case” calibration /validation, and then substituting lower resolution, or lower quality datasets or observed precipitation inputs from closest or adjacent gauges or multiple gauges Fort Carson, using: • KINEROS2 Urban Tool • “Best-case” data from PCMS calibration / validation • observed precipitation inputs from closest or adjacent gauges or multiple gauges, or design storms Fort Bliss, using: • Out-of-the-box data set • Military Disturbance Tool in KINEROS2	Rainfall Data: • NOAA design storms (KINEROS2) • Stochastic generated climate data (SWAT) • Observed precipitation data (gauges: single nearest, single most distant, all) • NWS radar data (KINEROS2: Level 2 with and w/o bias correction; SWAT 4 km daily MPE) • Observed runoff data (StreamStats, gauges: watershed modeled, adjacent, combinations of all adjacent) • SSURGO and STATSGO soils • USGS DEM (10 m) and DoD Lidar • Time varying Landsat derived landcover and static landcover (PCMS only) • Local data (with, w/o plot data, local training knowledge) • Channel cross-sections (regional, extracted from LIDAR)	PCMS Calibration / Validation Metrics: NSE > 0.5 RSR ≤ 0.7 r² > 0.5 PBIAS ± 25% for runoff with consideration for uncertainty in observed runoff, based on USGS quality ratings Fort Carson: The Urban Tool in KINEROS2 is able to demonstrate changes in runoff due to implementation of LID practices that can be used to show compliance with EISA Section 438 Requirements Fort Bliss: The Military Disturbance Tool in KINEROS2 is able to show relative change in runoff and sediment yield due to different levels of disturbance from military training activities	PCMS Calibration: RHEM: Success Criteria met for Calibration at Red Rock Canyon Watershed: NSE = 0.41 r² = 0.66 PBIAS = 21.18% RSR = 0.77 Observation uncertainty: NSE = 0.67 r² = 0.67 PBIAS = 16.24% RSR = 0.57 Success Criteria met for validation at Red Rock Canyon Watershed: NSE = 0.78 r² = 0.93 PBIAS = -13.91% RSR = 0.47 Observation uncertainty: NSE = 0.92 PBIAS = -5.90% RSR = 0.29 SWAT: Success Criteria met for Calibration at Red Rock Canyon Watershed: NSE = 0.74 r² = 0.75 PBIAS = 13.85% RSR = 0.51 Observation uncertainty: NSE = 0.84 PBIAS = 2.73% RSR = 0.40 Success Criteria partially met for validation at Red Rock Canyon Watershed: NSE = -0.94 r² = 0.05
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					PBIAS = -23.44% RSR = 1.39 Observation uncertainty: NSE = -0.55 PBIAS = -32.40% RSR = 1.24 <u>Fort Carson:</u> Success Criteria Met <u>Fort Bliss:</u> Success Criteria Met
5	Assess the ability of AGWA to identify the relative ranking of model outputs.	Identify and rank (high to low) areas of high runoff, high peak flows, and/or high erosion.	USGS 10 m DEM and DoD Lidar Land cover data Rainfall data Observed runoff data Relationships between military land use and changes in land cover and soils SSURGO and STATSGO soils data	Ranking of areas at risk is consistent between different input data sets. (Spearman's Rank correlation coefficient will be tested for the null hypothesis that the coefficient is equal to zero at a 5% significance level to determine if the correlation coefficient is significant)	Success Criteria met: Demonstrated how to use ranking of relative differences to locate areas of risk Assessed the influences on input data quality on rankings of runoff, peak flow, and sediment yield through Spearman's Rank correlation coefficient. Results showed that the out-of-the-box data can be used for identifying areas of risk.

6	Relate training disturbance to change in vegetation cover and soil properties	PCMS • Reductions in percent vegetation cover between pre- and post-disturbance. • Years required for post-disturbance vegetation cover to return to pre-disturbance levels • Extent of reduced vegetation cover caused by a military training event • Change in soil compaction / bulk soil density as a function of military foot or vehicle traffic. Fort Bliss and Fort Carson • Change in percent vegetation cover (canopy, basal, and litter) between pre- and post-disturbance. • Change in soil hydraulic properties (Ks, porosity, Manning's n, and Curve Number) as a function of level of disturbance from military foot or vehicle traffic.	PCMS: • Landsat imagery, pre- and post-disturbance imagery • Maps or high-resolution imagery of developed roadways Recommended but optional for quantifying vegetation cover and soil compaction / bulk density response to training: • RTLA data • SSURGO • NRCS ESD and STM • Military facilities utilization reports • Military facilities vehicle reports • Visual identification of highly compacted roads or areas • Cone penetrometer soil measurements of highly disturbed areas Fort Bliss and Fort Carson, Required: • RTLA data • SSURGO soils data • NRCS ESD and STM • GIS polygon layers of disturbed areas Recommended but optional to confirm vegetation cover and soil compaction response to training: High-resolution imagery and photos before and after a recent major training event	PCMS • Successful identification of areas with at least 5% reduction in NDVI due to military training disturbance from areas with little to no military disturbance. • Successful identification of at least 5% change in NDVI greenness index between pre- and post-training yrs. • Quantification of number of years required for post-disturbance NDVI to return to within 10% of pre-disturbance levels. • Successful incorporation of cone penetrometer measurements and pedotransfer functions to alter soil hydraulic properties as a function of these measurements in addition to translating military activities into altered AGWA parameters. Fort Bliss and Fort Carson • Successful incorporation of adjustments to soil hydraulic and vegetation properties based on levels of training disturbance into AGWA input parameters, as approved by installation personnel	Original Success Criteria not met: • Unable to identify areas with >5% reduction in NDVI using Landsat data • For paired-plots, disturbed vs. non-disturbed • NDVI reduction <5% not statistically significant (t = -0.92, P one-tail = 0.19) • Cover reduction <5%, is significant for heavy impacts (t = -2.5, P one-tail = 0.01) • Estimates of 4 – 8 years required for disturbed areas to return to pre-disturbance conditions (climatically dependent) • Cone penetrometer not feasible due to access and dig permit requirements Alternative Method, Success Criteria met: • Used three disturbance levels to relate training disturbance to changes in vegetation cover and soil properties: light, moderate, heavy • Altered model Soil Hydraulic Properties determined for Ks, Porosity, CN, and Manning's n, and Vegetation properties of canopy, litter, and basal cover, based on level of disturbance
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7	Assess the ability to parameterize the Facilitator DSS with AGWA model outputs and additional criteria defined by decision makers.	- AGWA output added to Facilitator dss file - Base managers input	Revised Facilitator dss file (XML output)	100% of AGWA outputs for each overland and channel model element is consumed into Facilitator DSS	Success Criteria met: The Facilitator is successfully parameterized using AGWA outputs for peak flow and sediment yield via the Facilitator input file (dss)
8	Assess the effectiveness of first AGWA-Facilitator training and needs assessment	1-5 (best) rating scale on a variety of survey questions measuring effectiveness of training**	Survey results on effectiveness of training in introducing the models and presenting their applicability	Average of survey responses equal to or greater than a rating of 68 with no individual response less than 50 (maximum possible score = 100).	Success Criteria not met: - Training Effectiveness - Average score: 62 - Lowest score: 43 - Low scores due to not enough time for the trainings, and missing managers participation
Qualitative Performance Objectives					Results
9	Define the resources and expertise required to set up the model by a GIS specialist level individual (item 2d*)	Time, resources, and expertise required of a GIS specialist-level individual to set up the model for installation watersheds after initial AGWA-Facilitator training	Feedback from a trained individual on effectiveness of the training and their confidence level in setting up the model Feedback from a trained individual on their understanding of the model inputs	A GIS-specialist trained on the AGWA-Facilitator tools is able to gather and organize the data to set up the model with minimal technical support within one week (40 hours) with remote assistance.	Success Criteria met: Training Effectiveness Survey results after second training: Survey Response to Question #9: Agree (able to set up the model within one week)
10	Determine the expertise required to interpret the results of the models by an individual trained on the AGWA-Facilitator tool (item 2f*)	Ability of an AGWA-Facilitator trained individual to understand and interpret model results	User survey of background in GIS, hydrology, and watershed modeling	An AGWA-Facilitator trained individual is able to interpret model results for management recommendations with minimal technical support.	

			User feedback on understanding of model results		Success Criteria not met: Training Effectiveness Survey results after second training: • Survey Response to Question #4: Agree (need more training to be able to interpret results) • Comments indicated training did not give them background to interpret model results, more time and lecture material are needed to better understand the tools, how to use them, and interpret results
11	Evaluate the effectiveness of second AGWA-Facilitator training	1-5 (best) rating scale on a variety of survey questions measuring effectiveness of the training and usability of the modeling system	User survey on usability of the modeling system and its ability to improve management decision-making User survey on whether training was: 1) too short, 2) too long, 3) missing critical components, 4) assumed too high a level of GIS expertise, 5) inadequate for them to learn the model	Users can successfully analyze and interpret model results after participating in a training course with tutorials, test data sets, and supporting documentation that demonstrates how to set-up, parameterize, and run the model	Success Criteria not met: Training Effectiveness Survey results: • Overall score = 65 • Lowest score = 30 Note: Success Criteria was met for overall score when two (out of five) trainees who felt the tools were not relevant to their jobs were removed as outliers: • Overall score = 71 • Lowest score = 40
12	Determine the ability of trained individuals to develop and run new scenarios.	Ability of a trained individual to develop and run a new scenario after the second training	Feedback from the trained individual on the value and usability of the technology Time and resources, beyond training, for an individual to develop and run a new scenario	A trained individual is able to develop and run a new scenario with minimal technical support in 1-2 days, and interpret the results, following the second AGWA-Facilitator training	Success Criteria met: Training Effectiveness Survey results after second training: • Survey Response to Question #10: Agree (they could develop and run a new scenario within 1-2 days)

13	Evaluate overall user acceptance of the modeling system and intent to use it in decision-making.	Anonymous survey of installation resource managers including technology transfer and near-term support, using a 1-5 (best) rating scale	Survey results on acceptance of the modeling system and whether they intend to use it in their management decision-making	Average of Usability Survey responses equal to or greater than a rating of 68 with no individual response less than 50 (maximum possible score = 100).	Success Criteria not met for overall survey: Usability Survey results: • Overall score = 64 • Lowest score = 40 Success Criteria met for Question #1: Agree (desire to incorporate the tools into their workflow)
* Items from June 5, 2012 ESTCP review letter (file: 13 EB-RC4-021 Letter Federal Non-DoD.pdf)					
** See Appendix B for surveys					

3.1 Performance Objective 1

Assess the ability to use nationally available input datasets for an uncalibrated, out of the box AGWA set up at demonstration installations. (Quantitative; relates to project team and installation managers)

AGWA is designed to use readily available data to parameterize its suite of models. The four required data inputs include a Digital Elevation Model (DEM), soils data (SSURGO, STATSGO or FAO), land use/land cover data (NLCD, SWReGAP), and climatic data (NOAA design storms, Global Historical Climatology Network (GHCN)-Daily climate data). The best available data were obtained either from the installation's GIS database or via the internet.

AGWA was used to delineate three watersheds on PCMS that have USGS gauging stations: Taylor Arroyo, Lockwood Canyon, and Red Rock Canyon. The watershed areas derived by AGWA were compared to the published USGS values and were considered acceptable if within three percent of those values. The watersheds were discretized into modeling elements at an appropriate resolution to capture all areas of concern (e.g., training areas). The watersheds were parameterized and simulations were conducted, driven by artificial, well-defined, precipitation (e.g., spatially and temporally uniform precipitation of sufficient duration for the watershed response to reach a steady state). Simulation results from the artificial input scenarios were evaluated to ensure they were physically reasonable (output/input response ratios, water balance computation closure with a reasonable tolerance, < 3%) and useful for decision-making on the installation (areas of concern adequately described). To examine output/input response, annual and event metrics were used. The annual metric of runoff/rainfall ratios were computed using observed data from PCMS. For events, we compared precipitation to runoff response to ensure the model is responding reasonably and predictably. The assessment determined if the models and AGWA's parameterization process provides reasonable results at PCMS. However, AGWA is best used as a relative change tool unless careful calibration is performed with high quality rainfall/runoff data.

This Performance Objective was met for the three watersheds at PCMS that were evaluated.

3.2 Performance Objective 2

Package AGWA-Facilitator for distribution and installation on military computers. (Quantitative; relates to project team and installation manager)

This objective will be deemed successful if an installation GIS technician or specialist is able to download and install the AGWA-Facilitator tool on installation computers. The AGWA package and the Facilitator DSS are available for download from the AGWA website at <http://www.tucson.ars.ag.gov/agwa>. The AGWA package includes the models KINEROS2, RHEM, and SWAT, which are public domain simulation models.

AGWA runs within ArcGIS, which requires the Microsoft .NET framework and the Spatial Analyst extension for ArcMap. The AGWA tool is an ArcGIS for Desktop add-in. The add-in is

copied to an ArcGIS user directory and registered with ArcGIS for Desktop by double-clicking the file. The Facilitator Decision Support System is an accessible, open-source tool that was written to run on any environment that supports the Java Runtime Environment (JRE), and requires JRE 1.7 and above. There is no installation required by the Facilitator software since it runs as a Java ARchive (JAR) executable. The user will only need to run the JAR file (i.e., double-click on the file) to begin a decision support workflow with the Facilitator system.

The minimum experience level for the user is someone with experience with ArcGIS Desktop and minimal Java setup experience. If internet access is restricted, the material from the AGWA web site and the Facilitator Decision Support System are supplied to the installation staff and GIS specialists on a DVD.

This Performance Objective was fully met for all installations.

3.3 Performance Objective 3

Determine the ceiling for model execution time. (Quantitative; relates to project team)

Although this performance objective refers to “the amount of time to run AGWA”, it actually addresses the amount of time to run the models, and the ability to run these models and obtain output variables of interest within a fixed amount of time. This performance objective does not include the setup of the models using AGWA (see PO1), but instead seeks to assess if the SWAT, RHEM, and KINEROS2 models can be run within a reasonable amount of time such that model runtime is not a prohibitive barrier to the application of this methodology. Model execution time varies with:

- watershed size;
- discretization of contributing source area (CSA);
- presence and number of EC Dams;
- resolution of the DEM (i.e., LiDAR 1 m or 2 m vs USGS 10 m);
- simulation time period; and
- event(s) duration.

The data required to accomplish this objective is related to and dependent upon the successful completion of PO1. The models cannot be run without the data required for parameterization, the successful delineation and discretization of watersheds of interest, or the successful parameterization of the delineated and discretized watersheds of interest. The project team created the initial simulations for each installation, but in the future, the installation managers will create various simulation scenarios.

This objective has multiple success criteria. It will be deemed successfully met if:

- Individual simulations using SWAT with simulation time periods of up to 10 years on ~100 km² watersheds can be completed within ten minutes;
- Monte Carlo simulations using SWAT with simulation time periods of up to 10 years on ~100 km² watersheds can be completed within six hours;
- Individual simulations using KINEROS2 with event durations up to six hours on ~100 km² watersheds can be completed within 10 minutes; and,

- Monte Carlo simulations using KINEROS2 with event durations up to six hours on ~100 km² watersheds can be completed within six hours.

Individual simulations may be used when the model has been successfully calibrated based on high quality precipitation and runoff observations. Monte Carlo simulations will be used to define uncertainty when model calibration is not practical. Not practical means that there are no (or too few) observations of watershed response to confidently validate model predictions. For SWAT, less than two full water years of input and output observations would not be sufficient for calibration and validation. For KINEROS2 at least ten events (five for calibration and five for validation) with input and output observations are required.

This Performance Objective was met for runtime without Monte Carlo, but was not met for runtime with Monte Carlo.

3.4 Performance Objective 4

Assess the improvement in performance of AGWA's models when calibrated with varying levels of data to determine the degree to which the models need to be calibrated and validated in order to be used for regulatory and planning purposes. (Quantitative; relates to project team)

The goal of PO4 is to assess the improvement in performance with AGWA and its associated models by calibrating the models using local stream flow and precipitation data. Additional goals are to assess the performance of the Urban Tool in KINEROS2 at the Fort Carson cantonment area for regulatory requirements (EISA Section 438 for stormwater analysis), and assess model performance with a relative change analysis for a heavily disturbed scenario at Fort Bliss. The premise is that uncalibrated, unvalidated, well-tested, distributed, physically-based watershed models can provide useful information regarding relative change and relative spatial differences in watershed response (Goodrich et al., 2012); however, if adequate input data, basin characterization data, runoff observations, and especially spatially distributed precipitation data are available, greater confidence in model predictions and associated uncertainty can be provided. This performance objective will aid in establishing the level of confidence and type of applications for which the model can be used by installation resources managers. An additional outcome of the analysis conducted under PO4 (and PO5) will be an assessment of the value of the current precipitation, streamflow, and possibly sediment gauges at PCMS. The analysis at PCMS will help to derive recommendations for the number of gauges and other ancillary monitoring needed for installation watershed management and regulatory needs.

PCMS Calibration/Validation

While few DoD installations in the southwestern U.S. have adequate input and watershed response observations to conduct thorough model calibration and validation, PCMS has sufficient precipitation and runoff observations for calibration and validation of the SWAT, RHEM, and KINEROS2 models. The metrics that will be used to assess whether this objective is met include Nash-Sutcliffe Efficiency (NSE; Nash and Sutcliffe, 1970), Coefficient of Determination (R^2), Bias, Root Mean Squared Error, and standard deviation ratio (RSR) of simulated versus observed hydrographs or attributes of the hydrographs (Moriassi et al., 2007; see Section 6.4 for descriptions of these metrics). The criteria for determination of a satisfactory

calibration and validation (split sample testing) was $NSE > 0.5$, $RSR \leq 0.7$, $r^2 > 0.5$, and $PBIAS \pm 25\%$ for runoff. These thresholds represent “satisfactory” results for most situations (Moriasi et al., 2007).

High-quality observations of precipitation, both in time and space, and runoff observations, preferably at nested watershed locations are required for model calibration and validation. Ideally, for SWAT calibration and validation, precipitation gauge density of one gauge or more per 25 km², with a temporal recording resolution of daily or shorter, and a period of continuous record of 10 years or greater would be available. USGS runoff observations over the same 10 or more years as the precipitation observations with a daily resolution would also be required. Higher resolution data are required to calibrate and validate KINEROS2, ideally with a precipitation gauge density of one gauge or more per two km² and approximately 30 observed rainfall-runoff events spanning a range of dry to wet initial conditions and small to large runoff events (10-year return event or greater at the large end of the range).

The stream gauge data at PCMS were sufficient to support the calibration and validation for runoff. However, the sediment data are not continuous, consist of individual samples for select events, and only measure suspended sediment but not bed load samples. Therefore, total sediment yield cannot be computed, and the calibration and validation of hillslope erosion was not possible; however, we were able to assess the relative rankings for erosion and sediment yield (PO5).

To address the value of precipitation and stream gauges, an initial set of simulations were conducted by applying RHEM and SWAT without any calibration to all of the PCMS gauged watersheds (PO1). Parameter values were generated from nationally and locally available spatial input datasets (soils, land cover/land use, and topography) using the look-up tables programmed into AGWA. In the original development of these look-up tables, a combination of high-quality observations, field experiments, and literature were used to derive initial watershed model parameters from nationally available spatial datasets (i.e., infiltration, hydraulic roughness, erodibility, interception, etc.). For broad scale, nationally available vegetation data layers, a medium percent cover condition was assumed. Climate data to drive SWAT were generated from a stochastic weather generator whose parameters are derived from nearby long-term weather stations. For KINEROS2, precipitation input was from NOAA Atlas 14 design storms for a variety of return periods. This type of AGWA application represents a scenario where no local observations are used as inputs to the model, or for initial parameter estimates. This approach is analogous to the “Blind Validation” approach presented in the white paper by Donigian (2014) but starting at a point with no local data.

The model evaluation metrics described above were used to evaluate model performance using observed runoff for each of the gauged watersheds for SWAT. Using the same metrics, KINEROS2 simulated design storm runoff results were compared to results derived from regional regression equations derived by the USGS (Capesius and Stephens, 2009) from stream gauge data. These equations can be interactively accessed within a geographic interface as part of the StreamStats program (<https://streamstats.usgs.gov/ss/>).

Given the relatively good set of input/output (rainfall and runoff) observations available at PCMS, we developed a “best case” calibration/validation (C/V) for each of the USGS gauged watershed listed in Table 1 (with the exception of the Big Arroyo near Thatcher, CO gauge due to its limited length of record). To test whether additional stream gauges would improve model predictions the following sets of simulations were conducted:

- Apply the parameters from the best case C/V for one gauged watershed to all the other gauged watersheds without change and evaluate model performance using observed runoff data;
- Repeat this for each of the gauged watersheds;
- Compute the best case C/V for two of the gauged watersheds and use the average of the calibrated parameters for simulations on each of the other gauged watersheds and evaluate model performance using observed runoff data;
- Repeat the procedure for three gauged watersheds and so on until the average parameters for all gauged watersheds are applied to each of the individually gauged watersheds;
- Systematically assess the change in model performance as a function of the number of stream gauges; and,
- Systematically examine the changes and overall range of model parameters across all of the simulations.

This analysis will not only shed some light on the value of stream gauges but the stability, or lack thereof, of the model parameters will indicate how transferrable the calibrated model from one gauged watershed may be to the others nearby. As in Donigian (2014), the quality of the gauged data as defined by the USGS rating will be considered in assessing the uncertainties associated with the best case C/V. The stream gauge configuration at PCMS differs somewhat from those examined for information worth by Donigian (2014), which are more nested and cover a greater range of basin scales than at PCMS. In the data richness versus model performance procedure outlined in task 5 of ESTCP project RC-201307 (Donigian, 2014) the assessment using incremental recalibration proceeds upstream using gauging station data from watersheds with successively smaller watershed areas.

To assess the value of additional model input information (i.e., precipitation gauges, radar-derived precipitation, and more detailed watershed characteristics) a series of simulations will be conducted with decreasing levels of observations for each PCMS watershed. The starting point for these simulations will be the best-case calibration/validation, using the most detailed observations for each PCMS gauged watershed. Given the known sensitivity and importance of high-resolution precipitation data required for acceptable watershed model simulations, a substantial series of simulations, calibrations, and validations will be conducted with various combinations of precipitation inputs from the stations listed in Table 1 and Table 2, and with and without National Weather Service Radar data. The second set of simulations will explore the value of various levels of land cover and land use information that reflect the level of knowledge or observations of military training activities on watershed response.

The best case C/V for each watershed will utilize all available high-quality observational data available for all the watersheds. Based on data availability at PCMS this will consist of the following information:

- LiDAR derived DEM data;

- Channel cross-section (X-S) geometry derived from LiDAR data, and ground surveyed X-S where available;
- NRCS SSURGO soils;
- Land Cover / Land Use that is time varying derived from classified Landsat imagery with local plot data and local knowledge of training and restoration; and
- National Weather Service (NWS) radar-derived precipitation data with bias corrections from the PCMS precipitation gauges.

The model predictability metrics (NSE; RSR; $r^2 > 0.5$; and, PBIAS) will be used to determine the best-case C/V for each PCMS watershed. These results will also be compared to the USGS StreamStats regional regression results. A series of simulations will then be conducted by successively replacing the highest quality data listed above with data that is assumed to be of lower quality. The model predictability measures will be computed for each case of using data of lower quality. The change in model predictability metrics as a function of data type and quality can then be computed. This will provide a measure of data worth and will help address the question of what data would be most important to collect on installations that may not be currently collecting it. The alternate, lower-quality, datasets that will be used in this series of simulations are listed below for each data or observation type.

- Topographic (DEM) data
 - Alternate #1: 10 x 10 m USGS DEM data
 - Alternate #2: 30 x 30 m USGS DEM data (Note: This alternate was not used, as 10 m DEM data are now nationally available.)
- Channel Geometry data
 - Alternate #1: X-S geometry derived from regional regression relationships
- Soils Data
 - Alternate #1: NRCS STATSGO data
- Land Cover / Land Use Data
 - Alternate #1: Time varying cover from remotely sensed data only – no local data or knowledge
 - Alternate #2: Classified land cover from NLCD or SWReGAP with temporally variable local plot data
 - Alternate #3: Time invariant land cover (NLCD, or SWReGAP) with an assumed medium cover condition
- Precipitation Data
 - Alternate #1: NWS radar derived precipitation without rain gauge bias correction
 - Alternate #2: All PCMS rain gauges
 - Alternate #3: Closest single rain gauge (spatially uniform rainfall)
 - Alternate #4: Furthest PCMS rain gauge (spatially uniform rainfall)

Fort Carson EISA Section 438 analysis

This part of PO4 will test the Urban Tool and LID practices available in KINEROS2 at the Fort Carson cantonment area for regulatory requirements (EISA Section 438 for stormwater analysis), to demonstrate that the tool can be used to show changes in runoff due to implementation of LID practices.

Fort Bliss relative change analysis

This part of PO4 will assess model performance with a relative change analysis for a hypothetical heavily disturbed scenario at Fort Bliss, using the Military Disturbance Tool in KINEROS2, to demonstrate that the tool can be used to evaluate different levels of military training disturbance and the subsequent changes in runoff and sediment yield.

This Performance Objective was met for RHEM for calibration and validation at the Red Rock Canyon Watershed, and for the SWAT calibration at the Red Rock Canyon Watershed, but was not completely met for validation at Red Rock Canyon Watershed. This Performance Objective was met for both the Fort Carson and Fort Bliss analyses.

3.5 Performance Objective 5

Assess the ability of AGWA to identify the relative ranking of model outputs. For KINEROS2, peak runoff rate in overland and channel model elements, and sediment yield for overland flow elements will be ranked. For SWAT, surface runoff and sediment yield contributions from subbasins to reaches will be ranked.

For each of the best case C/V simulations for each of the PCMS gauged watersheds the internal, distributed model element outputs were ranked from high to low. For each of the subsequent simulations the ranking was also performed and stored. If the relative ranking remains the same between simulations it implies the AGWA tool can predict areas with a higher likelihood of flooding and erosion as a function of different levels of data availability. This analysis also included the “worst-case” simulations discussed above where calibration and validation was not conducted.

To assess the ability of the model to reproduce relative ranking of watershed modeling elements we employed the approach discussed in Sidman et al. (2015) where the ranking order is compared for each level of data/information using the Spearman’s Rank correlation coefficient as outlined in McBean and Rovers (1998). If the rankings are identical for two simulations, the Spearman coefficient equals 1, while a coefficient of -1 corresponds to an inverse ranking agreement. The Spearman’s Rank correlation coefficient will be tested for the null hypothesis that the coefficient is equal to zero at a 5% significance level to determine if the correlation coefficient is significant (Snedecor and Cochran, 1967).

To further test the tool’s ability to identify watershed areas with a high potential for flooding and erosion, a set of training scenarios were developed in consultation with PCMS managers. The training scenarios were applied on different areas of PCMS for each of the best case C/V simulations above. The Spearman’s Rank correlation coefficient test was applied again to assess if areas affected by training are consistently identified. For peak flows for a series of return periods these results were also compared to peak flow estimated by the USGS StreamStats regional regression equations.

This Performance Objective was met.

3.6 Performance Objective 6

Relate training disturbance to change in vegetation cover and soil properties. (Quantitative; relates to project team)

The purpose of this objective is to relate military maneuver disturbance to changes in vegetation cover and soils properties. Our original proposal was to quantify changes in vegetation cover due to military maneuver disturbance primarily using remotely sensed Landsat imagery because site specific plot and disturbance data (timing, type, and number of troops or vehicle passes) are quite limited. For soil disturbance and compaction, we proposed to use a combination of remote and field measurements (visual and from instruments such as a cone penetrometer if it can be safely used in training areas). We propose to demonstrate that local data can also be used by AGWA when available as described in Sections 5.2 and 5.3.2.

Several model input parameters will be altered by military training activities, including hydraulic roughness, porosity, effective hydraulic conductivity, and the splash and sheet erosion parameters. These parameters are in turn a function of soil texture, soil properties such as bulk density, soil moisture, soil chemistry, and vegetation and surface cover characteristics. RHEM was designed to estimate hydraulic roughness, effective hydraulic conductivity, and erosion parameters based on soil texture, plant form, and ground and canopy cover characteristics (see RHEM discussion in Section 2.1.3). As noted above, ITAM vegetation transect data (Range and Training Land Assessment data, RTLA; Schulte et al., 2012; Walton et al., 2008, 2009) were examined to assess whether a significant relationship could be established between training activities and vegetation change. In addition, resource managers were interviewed to capture their knowledge of vegetation responses to maneuvers (see Section 5.3). A secondary alternative entailed using many of the studies cited by Donigian (2013) to develop general look-up table with relationships between training and vegetation change that can be incorporated into AGWA. As a third alternative, we employed remotely sensed methods to quantify reduction in vegetation cover resulting from military training. This approach was prompted by the uncertainties in RTLA records noted by Donigian (2013) and concerns expressed by the ESTCP project office.

Donigian (2013) provides methodologies to quantify vehicular impacts from military training on sediment transport, vegetation, and soil properties. Specific methodology is presented for adjustment of RUSLE factors as a function of vehicle type, soil type, soil moisture, and military impact miles. This procedure is applicable to adjust erosion parameters in the SWAT model within AGWA that employs a variant of USLE, namely the Modified USLE, or MUSLE. SWAT, like HSPF used by Donigian (2013), is not capable of explicitly representing roads. The Donigian (2013) study therefore used output from the WEPP:ROAD model (Elliot et al., 1999) to develop loading inputs into HSPF. This project will not attempt to couple WEPP:ROAD to SWAT. The impact of military trainings will be addressed in more detail with KINEROS2.

Landsat imagery (1984-2013) was acquired to relate training to vegetation cover at PCMS and was analyzed by a contractor without cost to ESTCP. The contractor produced the normalized difference vegetation index (NDVI) depicting vegetation cover before and after military maneuver disturbance and change over time (see Section 5.3.2). Using the NDVI data, we attempted to evaluate reductions in vegetation cover due to maneuver training, the number of

years required for vegetation cover to return to pre-maneuver levels, and the extent of maneuver disturbance within a training area after large military maneuvers. The following success criteria identified whether we achieved this PO.

1) We will have successfully identified a relationship between military training maneuvers and vegetation cover when we find at least a five percent reduction in NDVI following maneuver training. Weather induced changes in vegetation cover will be accounted for by subtracting the year-to-year changes in undisturbed NDVI from maneuver disturbed NDVI training areas.

2) We will have successfully identified the extent of military maneuver training when we find at least a five percent change in NDVI between areas not disturbed by maneuvers and areas disturbed by maneuvers that had similar NDVI prior to military maneuvers.

3) We will have successfully identified a relationship between military training maneuvers and the time required for vegetation cover to return to pre-maneuver disturbance levels when we find that at least one year is required before vegetation cover returns to within 10% of pre-maneuver training levels.

4) We will have successfully incorporated cone penetrometer measurements and the pedotransfer function to alter soil hydraulic properties.

The disturbance from military vehicles and substantial foot traffic requires estimates of compaction in addition to changes in vegetation. Jones and Kunze (2004) noted that military vehicle and foot traffic in training areas will typically result in soil compaction, and Donigian (2013) noted a decrease in soil infiltration of 20% per tank pass at Eglin AFB. However, the degree of compaction is a function of not only the vehicle type and number of passes, but soil properties, soil moisture, and climate. Soil compaction in turn results in changes in porosity for some soil textures. Both of these factors affect the soil hydraulic conductivity resulting in greater runoff and erosion potential (Braunack, 1986; Thurow et al., 1995). A less intrusive and more rapid measure of compaction can be made with a cone penetrometer. These measurements can be related to changes in bulk density (Perumpral, 1987). We proposed using cone penetrometer measurements at PCMS, and training natural resource personnel to use them to acquire measurements on existing roads and training areas prior to, and after, maneuver; however, we were not able to obtain the required permissions to perform these measurements. Since direct measurements could not be made, changes in soil compaction and soil properties as a function of military traffic were compiled from the literature (Affleck, 2005; Althoff et al., 2007; Halvorson et al., 2001; Lindsey et al., 2012; Sullivan and Anderson, 2000; Trumbull et al., 1994; von Guerard et al., 1993; Webb, 2002), and were reviewed by installation personnel during our trainings and meetings.

Based on the Success Criteria listed above for this Performance Objective, we met the first three criteria in that we performed the analyses using the Landsat NDVI data. However, using those data we were not able to relate training disturbance to changes in soil and vegetation properties. Using the Landsat data, at 30 m resolution, we were not able to determine land cover changes at the scale required (i.e., tank tracks). We did not meet the fourth criteria since we were unable to apply cone penetrometers at PCMS due to access issues. We did, however, meet the Performance Objective to develop relationships between levels of training disturbance and changes to soil and vegetation properties. Our method is based on the literature and expert knowledge from

installation staff, and is incorporated into a look-up table for KINEROS2 that is used in the Military Disturbance Tool in AGWA. More details are provided in Section 6.6.

This performance objective was met via the Military Disturbance Tool.

3.7 Performance Objective 7

Assess the ability to parameterize the Facilitator Decision Support System with AGWA model outputs and additional criteria defined by decision makers. (Quantitative; relates to project team)

The AGWA-Facilitator Export Tool allows the transfer of decision maker experience, expert opinion, and AGWA model results to construct a Facilitator decision analysis document. This includes the management issue description and regulatory requirements defined for the area of interest, the stakeholder or decision maker information, the list of initial management (base) criteria defined by the stakeholders, and the alternative scenario results (i.e., peak flow and sediment yield) created when running the AGWA tool.

Once the management issue has been documented, and the Facilitator analysis parameterized, the user (resource managers) will be able to designate an importance order to the base criteria and run the Facilitator to understand the consequences of different scenarios, visualize results, and ultimately select an alternative that will be an improvement on the status quo. Expert opinion from the decision makers (such as installation and other land managers) will be important during this step since they will define the importance of each of the ranked base criteria before additional decision runs are created to determine the best and worst management alternatives. This objective will be successfully accomplished when a Facilitator analysis document is created using AGWA results from simulation runs, the management issue description collected during the problem definition step, and expert opinion used to define management criteria importance order.

This Performance Objective was met via the AGWA-Facilitator Export Tool within AGWA.

3.8 Performance Objective 8

Assess the effectiveness of the first AGWA-Facilitator training and needs assessment. (Qualitative; from feedback from installation managers being trained)

An important component for the success of this demonstration is assessment of the effectiveness of the trainings provided to installation resources managers and staff. If the training is not effective, the utility of the AGWA-Facilitator tool will be low, or it will not be used by the installations. The assessment of effectiveness is qualitative in nature and will utilize survey questions to: 1) Determine trainee experience, knowledge, and background of GIS, watershed processes, and watershed modeling; and 2) Determine the change in knowledge of these attributes after the training in addition to questions assessing the usability of the tool, and how it and the training may be improved.

This PO was evaluated using two surveys given to all trainees. The primary survey questions use a Likert scale with similar questioning as the System Usability Scale (SUS; Brooke, 1986). Section 2.1.6 includes more information on the SUS. Responses were summarized and converted to a scale from 0 to 100, where higher scores indicate a more effective training. If the group average of the converted scores of the survey questions is above 68 (considered average based on research from hundreds of surveys) and all individual converted scores are above 50 (indicating that the user feels comfortable analyzing and interpreting the model results after participating in a training course), the training will be judged successful. In addition, comments were summarized in an attempt to further gauge the overall satisfaction with the demonstration and to acquire suggestions on improving follow-on demonstrations. Survey results were collected and reported on a per installation basis initially, but during final reporting survey results were averaged across installations. Additionally, minimum outlier scores may be disregarded when small sample sizes may cause large bias.

This Performance Objective was met only for the Fort Carson training (see Sections 5.4 and 6.8).

3.9 Performance Objective 9

Define the resources and expertise required to set-up the model by a GIS specialist level individual. (Qualitative; relates to installation managers)

The GIS experience of the individual, an understanding of the decision-making process and terminology (required by Facilitator), the ability to dedicate time to the task, and the freshness of their training on the AGWA-Facilitator methodology will influence the successful completion of this objective. So that this objective can be more easily met, remote assistance can be provided by the AGWA-Facilitator team via phone, email, or the public AGWA support group/forum to help resolve problems, or to refresh the steps of the methodology when significant time has passed since the initial training.

The successful completion of this objective will be defined by the ability of a GIS specialist-level individual to gather and organize the data required to run AGWA-Facilitator and then set up the tools, with the aforementioned support if necessary, to run through the methodology within one week or 40 hours dedicated to the task. To complete this objective within that timeframe, the project team assumes the training will be recent and that the individual will have the ability to dedicate large blocks of time within close proximity of each other to minimize time spent to re-familiarize oneself with the task. For the scope of this project, if PCMS personnel with the described experience cannot dedicate time for this PO, an AGWA-Facilitator team member, which may include but is not limited to a graduate student, will ensure the success criteria for this PO is met. To use the AGWA-Facilitator tool on installations not included in the scope of this project, outside contractors at the described GIS experience level will be required if installation personnel cannot dedicate the time to gather and organize the data and setup the model. The same timeframe applies to outside contractors. For installations not included in the scope of this project, limited technical support via email, phone, or the public AGWA support group/forum by the AGWA team will also be made available to installation personnel or the outside contractors. Limited technical support, in this instance, means the same support, which is based on our availability and time constraints, that is offered to all other AGWA users.

This Performance Objective was met based on survey responses, and follow-up email communication.

3.10 Performance Objective 10

Determine the expertise required to interpret the results of the models by an individual trained on the AGWA-Facilitator tools. (Qualitative; relates to installation managers)

This performance objective relies on the project team receiving feedback from trained individuals on their understanding of model results (from SWAT and KINEROS2) and Facilitator output. It also relies on the basic knowledge and experience of the individual performing the modeling in areas such as GIS, hydrology, watershed modeling, the Facilitator decision-making process and terminology, and on their familiarity with the different management scenarios used at the military installation. The objective will be deemed successful if the individual using AGWA-Facilitator is able to interpret the simulation model and Facilitator results such that these results can be used to inform management decisions. The minimum experience level for the tester should be someone with experience in soil and water conservation, and environmental issues.

This Performance Objective was not met based on survey responses and discussions during the trainings. A background in GIS and some knowledge of hydrologic principals and modeling are required for individuals to successfully interpret the results of the models. While GIS experience was common, a background in hydrologic principals and modeling was not.

3.11 Performance Objective 11

Evaluate the effectiveness of the second AGWA-Facilitator training. (Qualitative; from feedback from installation managers being trained)

The second AGWA-Facilitator training incorporated tutorials and scenarios derived from discussions with installation staff, and based on the needs assessment carried out during the first training. To fully demonstrate the coupled AGWA-Facilitator tools in this training session, a concerted effort was made to include management staff for DPW Environmental, Forestry, and Wildlife, ITAM, environmental, and natural resource programs who make decisions.

As in the first training, the assessment of effectiveness was qualitative in nature but utilized a different set of survey questions to attempt to: 1) assess the usability of the AGWA-Facilitator tools, and 2) assess the ability of the system to improve management decisions. Additional survey questions were posed to acquire insights as to how the training might be altered and improved for subsequent demonstrations. Questions included whether the training was: 1) too short, 2) too long, 3) missing critical components, 4) assumed too high a level of GIS expertise or watershed modeling expertise, and 5) inadequate for them to learn the system.

This Performance Objective was not met based on survey responses from all training participants. However, if the responses from participants who felt these tools were not relevant to

their job duties were removed (two of the five trainees), we did meet the Performance Objective for the SUS score. Section 6.11 provides additional information.

3.12 Performance Objective 12

Determine the ability of trained individuals to develop and run new scenarios. (Qualitative; relates to installation managers)

The second training workshop included discussions on developing and executing a new scenario (e.g., assessing the disturbances from a training exercise, implementation of a best management practice) using tools in AGWA, and question # 10 of the Training Effectiveness Survey asked if they felt they could do this on their own in 1-2 days. In our experience, trainees that can independently develop and execute a modeling case study, and also correctly interpreted the results, have gained sufficient skills and knowledge to be self-supporting with no or limited remote support.

This Performance Objective was met as defined. Based on survey responses and discussion sessions, trainees felt they could set up and run a new scenario on their own.

3.13 Performance Objective 13

Evaluate overall user acceptance of the modeling system and intent to use it in decision-making. (Qualitative; from feedback from installation managers being trained)

The final surveys of installation resource managers and staff addressed the overall quality of the demonstration including technology transfer, acceptability of AGWA-Facilitator, and whether they intend to use it in their management decision-making. In addition, written comments and discussions were summarized in an attempt to further gauge the overall satisfaction of the demonstration and to acquire suggestions on improving our trainings. Survey results were collected and reported on a per installation basis initially, but during final reporting survey results were averaged across installations.

This Performance Objective was not met based on the overall score for the Usability Survey, but was met based on Question #1. See Section 6.13 for more information.

4.0 SITE DESCRIPTION

Three military installations were selected for this demonstration project: Fort Carson Military Reservation, and Piñon Canyon Maneuver Site in Colorado, and Fort Bliss Army Base in Texas/New Mexico.

Fort Carson Military Reservation and Piñon Canyon Maneuver Site (PCMS) are both managed by the staff at Fort Carson, although they have different training schedules. These installations were selected as demonstration sites because of the high quality hydrologic data available. Both locations are used extensively for training of mechanized units such as tanks and armored personnel carriers, resulting in widespread disturbance to their fragile grasslands. In addition, Fort Carson is located adjacent to urbanized areas, and has flooding, erosion, and water quality concerns, allowing those issues to be addressed with our tools.

Fort Bliss Army Base was chosen as a demonstration site because it offers the opportunity to demonstrate how the AGWA-Facilitator Tool can perform as a relative change tool in a location with limited hydrologic data. Because of the Base Realignment and Closure (BRAC) process, and because the installation offers excellent training opportunities, it is experiencing an expansion of training activities. Increased ground based training could lead to increased land degradation primarily from the disturbance of soils and vegetation communities. Fort Bliss was also selected because of previous work for a SERDP funded project (RC-1727) that already collected and formatted most of the necessary data (landcover, soils, digital elevation datasets, and climate data) needed to run the hydrologic models. The results from the AGWA simulations from that project were of particular interest to natural resources staff at Fort Bliss. Previous site visits by team members also provided a familiarity with the landscape and watershed conditions that was useful for this project.

4.1 SITE LOCATION AND HISTORY

Fort Carson Military Reservation

Fort Carson is located directly south of Colorado Springs in southeastern Colorado (Figure 4). Fort Carson was established partly in response to the attack on Pearl Harbor in 1941, and trained over 100,000 soldiers including tank battalions during World War II (Fort Carson, 1972). Between 1965 and 1966 Fort Carson acquired over 404 km² (100,000 acres) in a series of land swaps and purchases bringing it to its current size of approximately 558 km² (138,000 acres) to become a mechanized division training area. The installation is used extensively for training of mechanized units such as tanks and armored personnel carriers, resulting in widespread disturbance to the fragile grasslands, and occasional wildfires.

Piñon Canyon Maneuver Site (PCMS)

Piñon Canyon is located 240 km southeast of Fort Carson and Colorado Springs, in Southeastern Colorado and is part of the Arkansas River Basin (Figure 4). The PCMS was acquired by the military via land purchases and eminent domain in 1983 to provide an additional 950 km² (245,000 acres) of land for training operations for soldiers from Fort Carson and other military installations (Fort Carson, 1972). Prior to the purchase, Piñon Canyon was home to several ranches that utilized the land for large livestock grazing operations since the 1970's, but following its acquisition by the military all grazing was stopped (INRMP, 2017). It is bordered

by private lands that consist of ranches, farms and a few residences, as well as the USFS managed Comanche National Grasslands to its northeast (INRMP, 2017). The main objective of PCMS is to ensure the preparedness of troops and equipment for rapid deployment in combat operations primarily through mechanized maneuver training.

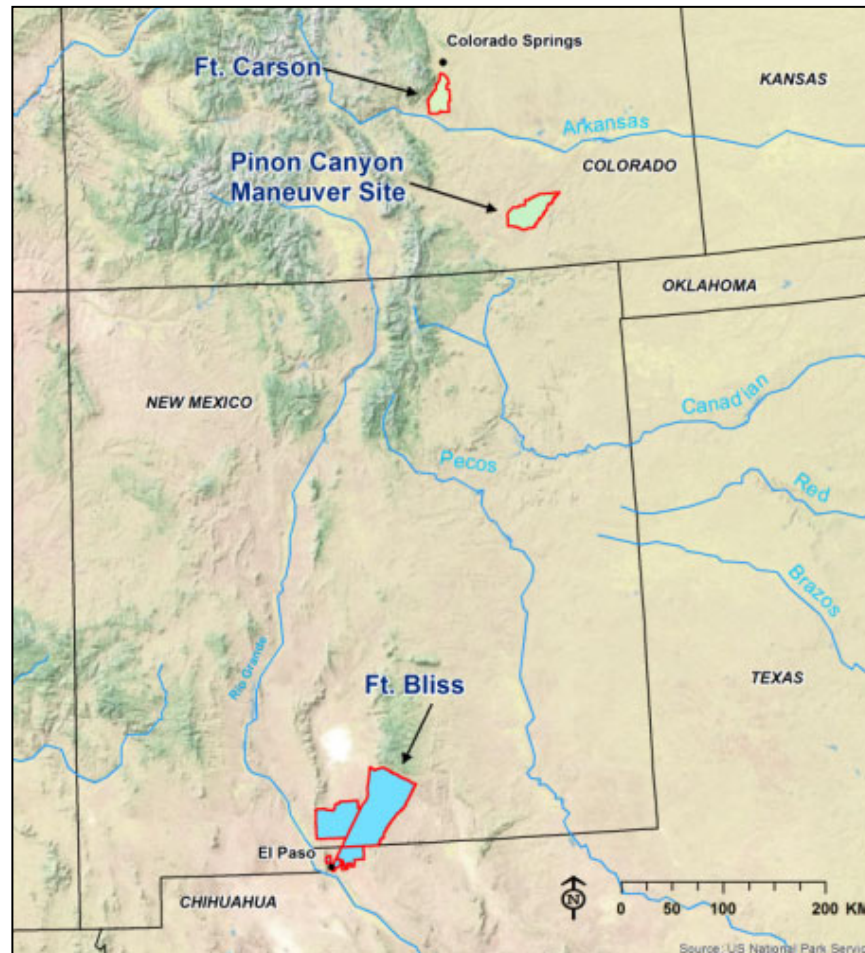


Figure 4. Location map of demonstration sites

Fort Bliss Army Base

Fort Bliss is located north of El Paso, Texas, covers over 4,350 km² (1,075,000 acres) of the Chihuahuan Desert, and extends from southern-central New Mexico into the Trans-Pecos (Far West) portion of Texas (Figure 4). The installation is subdivided into ranges and training areas including the McGregor Range, which extends south from the Sacramento Mountains to the Texas state line and includes parts of Otero Mesa in the east and the Tularosa Basin in the west; the Doña Ana Range, which lies west of McGregor to the Organ Mountains; and the South Training area, which extends south from McGregor to the Main Cantonment Area located adjacent to the city of El Paso. Fort Bliss was first established in 1848 as an army post to defend the newly established U.S. border with Mexico and to protect travelers from attacks by local Native American tribes (Metz, 2013). During the 1940's the installation expanded from a few thousand acres to over one million acres to become an anti-aircraft training center and by the late 1990's was home to over 28,000 military and civilian personnel (Metz, 2013). The installation's

main objective is to ensure the preparedness of troops and equipment for rapid deployment in combat operations.

Fort Bliss hosts a large number of military and civilian activities such as troop and equipment training, air defense and air-to-ground maneuver training, and ground maneuver training. These activities have the potential to damage soils and vegetation communities and impact wildlife habitat. Active grazing is also taking place in and around Otero Mesa and the Sacramento Mountains, and could potentially lead to additional land degradation.

4.2 SITE CHARACTERISTICS

Fort Carson and Pinon Canyon Maneuver Site

Fort Carson covers approximately 560 km² of Western Great Plains Shortgrass Prairie and Piñon-Juniper woodland ecosystems. Elevations range from 1,620 m at the southern boundary to over 2,000 m in the western mountainous part of the fort and is classified as semi-arid with mean annual precipitation ranging from 300 mm/yr in lower elevations to over 400 mm/yr in higher elevations. The Piñon Canyon Maneuver Site covers approximately 950 km² that are classified primarily as Western Great Plains Shortgrass Prairie. Elevations at Piñon Canyon range from 1,300 to 1,700 m with a mean annual precipitation around 340 mm/yr.

The sensitive nature of the Shortgrass Prairie grasslands (which cover approximately half of each installation) makes them especially vulnerable to erosion and gulying caused by vehicle exercises and ground-based training. The USGS is currently managing sediment yields from PCMS with more than 70 erosion-control reservoirs, a streamflow gauging station on the Purgatoire River, and five seasonal streamflow-sediment gauging stations on tributaries draining more than 60 percent of the PCMS (INRMP, 2017). Frequent occurrence of wildfires at both installations, ignited by both natural causes and training activities, also has the potential to increase land degradation through vegetation removal and requires a high level of management and monitoring activities.

Both Fort Carson and PCMS are home to high concentrations of big and small game species as well as non-game wildlife species due to the urban encroachment on surrounding lands forcing them into protected areas of military lands. This has led to increased environmental restrictions that require additional land management efforts in order to sustain training activities while minimizing environmental disturbances.

The Mexican Spotted Owl (*Strix occidentalis lucida*) is the only wildlife species protected by the ESA at Fort Carson (INRMP, 2017), and is listed as “threatened”. The Arkansas darter (*Etheostoma cragini*) is the only candidate species known to occur on Fort Carson (INRMP, 2017). Both Bald Eagles (*Haliaeetus leucocephalus*) and Golden Eagles (*Aquila chrysaetos*) occur on Fort Carson and PCMS, and are managed by the Bald and Golden Eagle Protection Act. In addition, there are numerous Colorado species of special concern at both installations. There are no federally listed wildlife species at PCMS, although there are many that are rare, imperiled, or vulnerable globally or within the state of Colorado (INRMP, 2017). There are currently no known federally listed plant species that occur at either installation.

High quality precipitation and temperature data are required to drive KINEROS2 and SWAT, and both installations have a local network of USGS meteorological (met) stations. At Fort Carson, there are three met stations located within the fort boundaries with more than 10 years of precipitation data, while at PCMS there are 5 met stations with records going back to at least 1999 (Table 1).

Table 1. List of USGS meteorological stations located within Fort Carson and Piñon Canyon Maneuver Site and dates with available daily precipitation data

Installation	USGS Met Station	Name	Precipitation (in)	
			From Date	To Date
Fort Carson	383159104540701	SULLIVAN PARK MET STATION AT FORT CARSON, CO	5/5/1999	Current
	384053104492001	ROD AND GUN METEOROLOGIC STATION AT FT CARSON, CO	5/21/1999	Current
	383109104431301	YOUNG HOLLOW METEOROLOGIC STATION AT FT CARSON, CO	5/5/1999	Current
PCMS	372319104073301	BROWN SHEEP CAMP MET STATION NEAR TYRONE, CO,	6/9/1999	Current
	372721103595601	CIG PIPELINE SOUTH MET. STATION NEAR SIMPSON, CO	7/8/1983	Current
	373232103555201	BEAR SPRINGS HILLS MET STATION NEAR HOUGHTON, CO	8/1/1983	Current
	373315103493101	UPPER RED ROCK CANYON MET STATION NR HOUGHTON, CO	8/11/1983	Current
	373823103465601	UPPER BENT CANYON MET STATION NR DELHI, CO	7/8/1983	Current

Calibration requires the comparison of actual streamflow observations at a specified outlet, usually a stream gauge, to simulated results at the same location. Different parameter settings are adjusted until modeled discharge is within a certain level of agreement with actual discharge values. At Fort Carson, there are eight USGS stream-gauging stations located within the installation with at least 10 years of continuous daily discharge. An additional four gauges are located on streams near the installation that are hydrologically connected to lands within the installation. At PCMS, there are four USGS stream gauges located within the installation boundary that have at least a decade of continuous discharge data and an additional two gauges with at least a decade of continuous data on streams hydrologically connected to the site (Table 2).

Table 2. List of USGS stream gauges located within or near (shaded) Fort Carson and Piñon Canyon Maneuver Site and dates with available daily discharge and suspended sediment data

Installation	USGS Stream Gages	Name	Daily Discharge		Suspended Sediment	
			From Date	To Date	From Date	To Date
Fort Carson	07105800	FOUNTAIN CREEK AT SECURITY, CO	10/1/64	Current		
	07099080	RED CREEK BELOW SULLIVAN PARK AT FORT CARSON, CO	7/26/2000	10/31/2003	7/13/2001	8/9/2003
	07099215	TURKEY CREEK NEAR FOUNTAIN, CO	5/25/1978	10/14/2012		
	07105820	CLOVER DITCH DRAIN NEAR WIDEFIELD, CO	4/1/1981	9/30/1988		
	07105900	JIMMY CAMP CREEK AT FOUNTAIN, CO	1/16/1976	Current		
	07105924	WOMACK DITCH NEAR FORT CARSON, CO	6/5/1978	2/4/1991		
	07105940	LITTLE FOUNTAIN CREEK NEAR FOUNTAIN, CO	5/23/1978	Current		
	07105945	ROCK CREEK ABOVE FORT CARSON RESERVATION, CO	5/19/1978	Current		
	07106000	FOUNTAIN CREEK NEAR FOUNTAIN, CO	10/1/1938	Current		
	07106300	FOUNTAIN CREEK NEAR PINON, CO	4/1/1973	Current		
	383637104531301	STROBEL DITCH FROM TURKEY CR AT FT. CARSON, CO	10/1/1998	4/3/2013		
	383619104520401	LYTLE DITCH AT FT. CARSON, CO	10/1/2003	4/3/2013		
	383944104474201	MERRIAMS L. FOUNTAIN DITCH AT FT. CARSON, CO	10/1/2002	2/18/2013		
	384037104472001	MERRIAMS ROCK CREEK DITCH AT FT. CARSON, CO	10/1/1998	Current		
	384047104510301	RIPLEY DITCH FROM L. FOUNTAIN CR AT FT. CARSON, CO	10/1/2002	4/3/2013		
PCMS	384048104504901	WOMACK DITCH FROM L. FOUNTAIN CR NR FT. CARSON, CO	10/1/1998	Current		
	384220104503701	GALE DITCH FROM ROCK CR NR FORT CARSON, CO	10/1/1998	4/3/2013		
	07126415	RED ROCK CANYON CREEK AT MOUTH NEAR THATCHER, CO	5/26/1983	Current	6/13/2002	9/14/2011
	07120620	BIG ARROYO NEAR THATCHER, CO	3/15/1983	9/30/90	8/1/1983	9/29/1990
	07126140	VAN BREMER ARROYO NEAR TYRONE, CO	5/21/1985	11/16/04		
	07126200	VAN BREMER ARROYO NEAR MODEL, CO	7/1/1966	Current	6/12/1999	8/5/2011
	07126325	TAYLOR ARROYO BELOW ROCK CROSSING NEAR THATCHER, CO	3/18/1983	Current	4/21/1983	8/5/2011
	07126390	LOCKWOOD CANYON CREEK NEAR THATCHER, CO	4/21/1983	Current	5/14/1999	8/31/2011
	07126480	BENT CANYON CREEK AT MOUTH NEAR TIMPAS, CO	10/1/1983	Current	7/15/1984	5/14/2012
	07126485	PURGATOIRE RIVER AT ROCK CROSSING NR TIMPAS, CO	6/1/1983	Current	8/1/1983	8/27/2004

Fort Bliss

The climate at Fort Bliss is considered semi-arid, with approximately 250 mm of annual precipitation, half of which falls during the summer monsoon season. Elevations range from approximately 1,170 to 2,700 m. Vegetation within the installation is dominated by a shrub-grassland community and Chihuahuan Desert scrub, with some woodland communities present in upland areas. The major land cover types are Mesquite coppice dunes, creosote piedmont shrubland, mesa grasslands, and foothill desert grasslands (INRMP, 2016). Large sections of the McGregor and Doña Ana Ranges are covered by coppice sand dunes where few defined stream channels exist. Currently, there are more than 30 wildlife species found on the installation that are listed as threatened, endangered, or a species of concern including Burrowing owls (*Athene cunicularia*), Ferruginous hawks (*Buteo regalis*), Black-tailed prairie dogs (*Cynomys ludovicianus*), and Gray vireos (*Vireo vicinior*).

All streams within Fort Bliss are ephemeral with localized flow occurring primarily in direct response to high-intensity convective storms during the summer monsoon season. The inability to accurately represent the high spatial variability of these storms due to a lack of precipitation observations poses a challenge to hydrologic modeling efforts. In addition, an absence of observed flow data from any stream at Fort Bliss prevents model calibration and validation needed to accurately assess model results. However, application of the models is still possible when used to show relative change between present and future scenario conditions (see Section 6.4.5).

5.0 TEST DESIGN

This section contains detailed descriptions of the 1.5 – 2 day AGWA-Facilitator trainings, surveys, and tools and modeling components of AGWA/KINEROS2 and the Facilitator DSS, and AGWA/SWAT. The RHEM model was not demonstrated in the trainings because the input data are too complex for a 1.5- to 2-day training. The workflow and criteria that address the performance objectives described in Section 3.0 are discussed as they relate to the models, trainings, and surveys used to evaluate the trainings and tools.

5.1 CONCEPTUAL TEST DESIGN

The overall test of the AGWA-Facilitator tool is that land managers find it useful in managing installation natural resources for sustainability while maintaining training and mission requirements. The tool will help military land managers maintain their land in conditions suitable for continued military training, comply with environmental laws, and minimize runoff, erosion, and on- and off-site impacts. Broadly, the demonstration test design involved four primary phases after initial contact with installation resource managers, inventory of data available, and assessment of the regulatory environment (see workflow diagram, Figure 1).

- Phase One: Problem definition and preliminary data collection and assessment
- Phase Two: Technology introduction via on-site training and user needs assessment
- Phase Three: AGWA application
- Phase Four: Second on-site training, technology transfer, and overall demonstration assessment.

Aspects of Phase One were addressed as part of the site selection process and initial discussions with installation resources managers. However, for future application of the AGWA-Facilitator tool at another installation it will be essential to conduct thorough discussions with installation resources managers to:

- Provide AGWA-Facilitator publications, fact sheets, and background information on the tool's capabilities,
- Define resource management issues,
- Identify stakeholder groups within the military, regulatory agencies, and the surrounding community,
- Identify regulatory requirements and constraints,
- Understand the decision-making process, installation management criteria, and the personnel making recommendations and decisions, and,
- Conduct a comprehensive inventory of installation specific data (GIS, field data, and other relevant databases)

The findings of this effort will affect the nature of how the AGWA-Facilitator tool can be used by installation managers, expectations of modeling results, as well as identify further information that should be acquired during Phase Two.

In Phase Two, installation resource managers and staff were provided on-site training of the AGWA-Facilitator tool. The training sessions took place over one and a half to two days. After

introductions and training goals were presented, a short ArcGIS refresher was offered as we have found this makes subsequent training proceed much more smoothly for those who are not GIS specialists. Presentation of model background and concepts followed, allowing plenty of time for discussion and questions. The trainees then worked on tutorials, and if needed, an on-screen demo was given showing the first part of a tutorial. The trainers were available at all times to answer questions and guide trainees. Interspersed between the tutorials were additional presentations discussing management tools within AGWA, data sources and data needs to apply the decision tools, and more detailed concepts on GIS and watershed hydrology that are useful to improve understanding of the tool, as well as a discussion of limitations and cautions. During both days, feedback was obtained from the trainees on the quality of the training so far, and more importantly, acquiring further understanding of the resource managers' decision-making process. A "needs assessment" was conducted in discussion sessions to determine how the decision tool workflow and menus might be improved to better meet their needs. Assessment of the training was conducted with surveys, as well as from our detailed notes and recordings taken during training sessions. Surveys developed for assessing whether the training meets performance criteria are included in Appendix B. PO8 is the primary PO for this phase of the project.

Phase Three focused on the application of AGWA to watersheds on the installation to assess data needs from national geospatial data sets, assess the value and need for local data, perform calibration and validation, quantify uncertainty and assess the time and knowledge level required to run the AGWA-Facilitator tool. This part of the demonstration was assessed using PO1, PO3, PO4, PO5, PO6, and portions of PO8. PO7 was also addressed during this phase but this was an internal programming task to couple AGWA to the Facilitator so AGWA output can be used directly by the Facilitator.

Phase Four consisted of a second 1.5 to 2-day on-site training session. It provided a refresher of the general material presented in the first training session but focused on technology transfer via site-specific tutorial exercises to train installation resource managers on the AGWA-Facilitator tool to achieve desired products, and included an overall demonstration assessment using surveys. Several in-depth discussions were conducted to obtain direct feedback on the value of the tools, and effectiveness of the training.

The trainings included tutorials based on watersheds and decision scenarios from the installation itself, and were designed to measure the expertise required to set up and run the model (PO9) and interpret model results (PO10). Trainees were provided a tutorial utilizing the SWAT Climate Assessment Tool applied at an existing training location (PO12) that demonstrates how to modify current climate based on climate change projections. During each training, we monitored and surveyed trainees to assess their ability to perform all tasks with the AGWA-Facilitator tool. Finally, the combination of surveys and discussion sessions assessed the effectiveness of the second training session (Training Effectiveness Survey) and overall acceptance of the decision system tool and their intent to use it in future management and decision-making (Usability Survey; PO11 and 13).

Relative to PO6, we presented the Military Disturbance Tool that represents training disturbances via changes to model parameters, to ensure they were in agreement with our method. We also provided instruction on how to apply their RTLA data for use in the RHEM

model to estimate the changes in land cover from military training activities. Fort Carson collects RTLA data, but Fort Bliss no longer does. The Land Cover Modification Tool was presented as another method of representing land cover change resulting from military training disturbance in the absence of RTLA data, and in addition to the Military Disturbance Tool.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

Phase One of the demonstration is a critical aspect of baseline characterization and preparation. As noted above, many of the tasks listed under phase one were accomplished during the site selection process via introductory conference calls between the demonstration team and installation managers. In addition, we conducted a site visit to meet resource managers, physically tour accessible areas of the installation if possible, acquire local data (i.e., already in the installation's GIS database) and locally measured data on soil, land cover, rainfall, runoff and documentation on points of interests. We conducted additional phone and e-mail inquiries to better understand their decision-making process, installation management criteria, and those personnel making recommendations and decisions. In addition, we investigated whether National Weather Service (NWS) Next-Generation Radar (NEXRAD) data are of sufficient quality for calibration and validation of the models, and if using the radar data improves performance. We also ascertained which modeling and decision tools are currently being used to manage range resources. For example, PCMS has an active RTLA program that routinely monitors the vegetation and surface soil condition at 375 transect locations, with recent data available for 2009, 2012, and 2015.

Multiple parameters were used to represent the effect of training and restoration activities in AGWA, including changes in vegetation, litter, and basal cover, surface roughness, and soil porosity. New parameterization procedures were incorporated into AGWA for soil compaction based on the literature (Affleck, 2005; Althoff et al., 2007; Halvorson et al., 2001; Lindsey et al., 2012; Rawls and Brakensiek, 1983; Sullivan and Anderson, 2000; Trumbull et al., 1994; Webb, 2002), and through discussions with personnel at Fort Bliss and Fort Carson. For example, military vehicles can increase soil bulk density from 0% to 40% depending on soil type, soil moisture, season, and type of vehicles.

Features added to AGWA/KINEROS2 have successfully been used on urban environments (Kennedy et al., 2013) to address stormwater runoff in urban and developed areas and assess the impacts of Low Impact Development (LID) or Green Infrastructure practices (Korgaonkar et al., 2014). These features are available through the AGWA Urban Tool, which was demonstrated at Fort Carson and Fort Bliss where large cantonment areas exist.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

The key components of this demonstration are the AGWA-Facilitator Trainings, the calibration and validation of AGWA, and the determination of the relationship between military maneuver disturbance and changes in vegetation and soil for input to the models.

5.3.1 AGWA-Facilitator Tool Trainings

The AGWA-Facilitator tool was demonstrated through two 1.5 – 2 day trainings conducted at each installation. These trainings were comprised of several hands-on tutorial exercises, some of which were developed to reflect specific management concerns identified by installation personnel, thus making the application of the tools more transparent and meaningful. All training participants filled out surveys at the end of each training to assess the usability of the tools and the effectiveness of the training.

Tutorials

The tutorials were designed to demonstrate the key tools within AGWA and application of the Facilitator to either analyze or document an issue and the model results. In addition to presenting the tutorials developed for specific installation issues, we also provided tutorials created for other projects that demonstrate additional tools and applications within AGWA. Each training focused on two main tutorials for AGWA and the Facilitator, with optional tutorials available. Tutorials created specifically for one of the installations in this project were also used at the other installations. The tutorials presented at each training are listed below.

1. PCMS Training 1, May 19-21, 2015
 - a. AGWA-KINEROS2, Vehicle Maneuver Impacts and Land Rehabilitation using the Land Cover Modification Tool (PCMS, Upper Taylor watershed). Analyze a training area after a hypothetical heavy training event, create a new land cover map representing the area after reseeding, and compare the difference in runoff and sediment yield using KINEROS2.
 - b. Facilitator DSS to evaluate three different alternatives for land recovery following a training event.
2. PCMS Training 2, June 29-30, 2016
 - a. AGWA-KINEROS2 Erosion Control Dam at Red Rock Canyon Watershed, PCMS. Use the Pond Characterization Tool to design and place an erosion control dam, and evaluate the difference in runoff and sediment yield before and after placement.
 - b. AGWA-KINEROS2 Military Disturbance Tool, Taylor Arroyo Watershed, PCMS. Analyze three hypothetical training areas in different terrain disturbed by heavy military training exercises for changes to downstream hydrology and sediment yield.
 - c. AGWA-Facilitator Export Tool in AGWA to export peak flow and sediment yield results from the Military Disturbance Tool tutorial directly into a Facilitator input file.
 - d. Facilitator DSS to analyze the results from the Military Disturbance Tool Tutorial, to determine which location to treat first, assuming funds are limited and only one site can be recovered at this time.
 - e. AGWA Burn Severity Tool. Assess the impacts of a prescribed burn at three sites with different terrain at Red Rock Canyon Watershed, PCMS, on runoff and sediment yield at the site and downstream.
3. Fort Carson Training 1, May 23-24, 2017

- a. AGWA Burn Severity Tool. Assess the impacts of the Sullivan Fire (2016) at Fort Carson on an erosion control dam and training area downstream. Use the Group Watershed tool, Land Cover Modification tool, Add Storage tool, and the Burn Severity tool to compare pre- and post-fire watershed response, and with and without erosion control dam storage.
 - b. AGWA-Facilitator Export Tool to export peak flow and sediment yield from the Sullivan Fire Tutorial directly into a Facilitator input file.
 - c. Facilitator DSS to evaluate the simulation results from the Sullivan Fire tutorial to select the type of post-fire treatment to perform.
 - d. AGWA-KINEROS2 Military Disturbance Tool, Taylor Arroyo Watershed, PCMS. Analyze three hypothetical training areas in different terrain disturbed by heavy military training exercises for changes to downstream hydrology and sediment yield.
 - e. AGWA-KINEROS2 Burn Severity Tool. Assess the impact of the Mountain Fire (2013, California) on runoff and erosion, using the Burn Severity Map.
 - f. Erosion Control Dams & Pond Tool. Characterize a stock pond and evaluate its impacts on runoff in a small watershed on the Walnut Gulch Experimental Watershed, Arizona.
 - g. AGWA Urban Tool. Use the Urban Tool to assess the potential impacts of green infrastructure practices in a new development adjacent to Fort Huachuca, Arizona.
4. Fort Carson Training 2, Jan. 30-31, 2018
 - a. AGWA Urban Tool. Use the Urban Tool at the Iron Horse Neighborhood at Fort Carson located upstream from a park that experiences flooding, and apply green infrastructure practices to evaluate their effect in mitigating downstream flooding.
 - b. Facilitator DSS to analyze the results from the AGWA Urban Tool at the Iron Horse Neighborhood. Learn to manually input the required information to run the Facilitator.
 - c. AGWA Precipitation Inputs and the Land Cover Modification Tool at Fort Bliss Range 88. Investigate the manner in which land cover change and various precipitation events can affect runoff processes at Range 88 at Fort Bliss. The facilities at this location had recently flooded.
 - d. AGWA-Facilitator Export Tool to export the results from the Fort Bliss Range 88 tutorial into a Facilitator file.
 - e. Facilitator DSS to document the various precipitation events and land cover change simulations from the Fort Bliss Range 88 tutorial.
 - f. SWAT Climate Change. Use the SWAT Climate Assessment Tool to change local climate based on climate change predictions, and view the difference in AGWA.
5. Fort Bliss Training 1, April 6-7, 2017
 - a. AGWA-KINEROS2 Military Disturbance Tool, Taylor Arroyo Watershed, PCMS. Analyze three hypothetical areas in different terrain disturbed by heavy military training exercises for changes to downstream hydrology and sediment yield.
 - b. AGWA-Facilitator Export Tool. Use the Export Tool in AGWA to export peak flow and sediment yield results from the Military Disturbance Tool tutorial directly into a Facilitator input file.

- c. Facilitator DSS to analyze the results from the Military Disturbance Tool Tutorial, to determine which location to treat first, assuming funds are limited and only one site can be recovered at this time.
 - d. AGWA-KINEROS2 Burn Severity Tool. Assess the impact of the Mountain Fire (2013, California) on runoff and erosion, using the Burn Severity Map.
 - e. Erosion Control Dams & Pond Tool. Characterize a stock pond and evaluate its impacts on runoff in a small watershed on the Walnut Gulch Experimental Watershed, Arizona.
 - f. AGWA Urban Tool. Use the Urban Tool to assess the potential impacts of green infrastructure practices in a new development adjacent to Fort Huachuca, Arizona.
6. Fort Bliss Training 2, March 7-8, 2018
- a. AGWA Precipitation Inputs and the Land Cover Modification Tool at Fort Bliss Range 88. Investigate the manner in which land cover change and various precipitation events can affect runoff processes at Range 88 at Fort Bliss. The facilities at this location had recently flooded.
 - b. AGWA-Facilitator Export Tool to export the results from the Fort Bliss Range 88 tutorial into a Facilitator file.
 - c. Facilitator DSS to document the various precipitation events and land cover change simulations from the Fort Bliss Range 88 tutorial.
 - d. AGWA Urban Tool. Use the Urban Tool at the Iron Horse Neighborhood at Fort Carson located upstream from a park that experiences flooding, and apply green infrastructure practices to evaluate their effect in mitigating downstream flooding.
 - e. Facilitator DSS to analyze the results from the AGWA Urban Tool at the Iron Horse Neighborhood. Learn to manually input the required information to run the Facilitator.
 - f. SWAT Climate Change. Use the SWAT Climate Assessment Tool to change local climate based on climate change predictions, and view the difference in AGWA.

Surveys

Two surveys were given at each training: the Training Effectiveness Survey and the Tool Usability Survey. The surveys are based on the System Usability Scale (SUS; Brooke, 1986), which is a Likert scale developed by Brooke (1986), with slight modifications to the wording of the questions, but maintaining the overall format and intent. It employs ten forced-choice questions, where the respondent indicates the degree of agreement or disagreement on a 5-point scale with 1 being “strongly disagree” to 5 “strongly agree”. A response of “3” is “neutral”. The questions are carefully worded to represent extreme expressions of the attitudes being captured, and alternate as positive and negative responses to force the respondent to think about whether they agree or disagree with each question. The Usability survey focuses on whether the participant feels the tools are useful and intends to use them. The Training Effectiveness survey focuses on how well the training taught the participant to use and understand the tools. Both surveys include 3 additional questions not included in the final scoring that assess their comfort with using GIS, their background in hydrologic principals or modeling, and their name and primary job responsibility (optional). These three questions were used to help evaluate both the effectiveness of the training and their perceived usability of the tools. Blank copies of the final surveys are included in Appendix B.

In addition to the surveys, discussion sessions were held during the trainings to obtain additional feedback on the AGWA-Facilitator tools, the tutorials, and the training format. We also kept track of each participant during the trainings and whether they had any difficulty performing the tutorial tasks, which tasks gave them trouble, if there were any issues with the tutorials themselves, and how long it took each participant to complete each tutorial. This information, along with their GIS skill level and background in hydrologic principals or modeling (provided in the surveys), is used to better understand the appropriate knowledge and skill level required to best utilize our tools.

Results from the scoring of the surveys from the first training at PCMS were used to guide how we conducted the second training and the types of tutorials we developed. The results from the second training were used to improve the methods used in future trainings, including modifications to the tutorials such as better detail and explanation of each step and interpretation of the results. In addition, these modifications will be applied to the online AGWA documentation. Improving our documentation, both online and in handouts, will strengthen the usability and acceptance of AGWA-Facilitator. AGWA is used around the globe and is constantly being updated and improved, often as a result of user-feedback.

After the second (final) training at each installation, we provided the installation managers with a DVD containing all of the tutorials and supporting data, the AGWA package and add-in, and the Facilitator files.

5.3.2. Military Maneuver Disturbance and changes to soil properties and vegetation cover

Changes to soil properties and vegetation cover, such as those caused by military training disturbance, influence erosion and runoff estimates in AGWA. AGWA can estimate erosion and runoff using broad-scale nation-wide data; however, localized data improves the accuracy of these estimates relative to military training disturbance. The ability to estimate future soil and vegetation cover response to military training is necessary to allow military planners to try what-if scenarios before actually conducting military training. Examples of a what-if scenario could be, “If training was conducted on that military range, what would be the subsequent erosion and runoff?”, or “Which range would experience the least amount of erosion?”

In an attempt to define the relationship between military maneuver disturbance and vegetation cover we evaluated several types of data, using PCMS as the example. Landsat imagery from 1984-2013 for PCMS was acquired to attempt to track vegetation cover changes over time. We used Landsat classified by vegetation cover and NDVI to find localized changes in cover to relate to military maneuvers, and to determine the number of years required for vegetation to return to pre-training conditions (see Section 3.6). We determined that Landsat imagery was not suitable for our analyses due to its coarse resolution (30 m), and the temporal limitations in datasets, as described in Section 6.6.

In addition, we obtained RTLA data from ITAM personnel at PCMS that included line-point intercept measurements of plant species composition to determine if the data could approximate the condition/state of areas where training has greatly reduced vegetation cover. These data could be useful if the transects occurred within the areas of training disturbance, but that was not the

case. However, we used the RTLA data for input to the RHEM model, as described in Section 6.4.4.5. Because we were unable to use the Landsat or RTLA data to define the relationship between military training and vegetation cover, we did not add this information to ecological state-and-transition models (STM).

The Rosetta Model (Schaap et al., 2001) can be used to estimate unsaturated hydraulic properties from surrogate soil data such as soil texture data and bulk density. Models of this type are called pedotransfer functions (PTFs) since they translate basic soil data into hydraulic properties. We evaluated this model to determine if it could be used to adjust porosity and saturated hydraulic conductivity based on changes in soil bulk density resulting from military activities, but this model did not provide the site-specific georeferenced results required for AGWA.

Because the above methods did not produce satisfactory results, we developed an alternative method based on previous studies found in the literature (Affleck, 2005; Althoff et al., Halvorson et al., 2001; Lindsey et al., 2012; Rawls and Brakensiek, 1983; Sullivan and Anderson, 2000; Trumbull et al., 1994; Webb, 2002; 2007; and others), and on local knowledge from ITAM and DPW staff at Fort Carson/PCMS and Fort Bliss. New parameterization procedures were incorporated into AGWA for vegetation, litter, and canopy cover, soil roughness, and soil porosity to represent changes due to military training activities. Section 6.6 describes the methodology and results in detail.

5.4 FIELD TESTING AND RESULTS

Field testing consisted of 1.5 – 2 day on-site hands-on trainings using tutorials demonstrating the functionality and capabilities of the AGWA-Facilitator tool. Two trainings were conducted at each installation (Table 3, in chronological order). Tutorials were developed for each installation based on actual resource management issues and locations. All participants filled out two surveys after the trainings: Training Effectiveness, and Tool Usability. The surveys are based on the System Usability Scale (SUS; Brooke, 1986), described in Section 5.3.1. Blank surveys are included in Appendix B. This section summarizes each training and the survey results. The number of attendees indicates the total number of people who attended the first morning presentations. The number of survey responses reflects the number of people who worked on the tutorial exercises.

Table 3. Locations and dates of AGWA-Facilitator Trainings

Location	Dates	No. of Attendees	No. of Survey responses
PCMS #1	May 19-21, 2015	12	5
PCMS #2	June 29-30, 2016	9	6
Fort Bliss #1	April 6-7, 2017	13	10
Fort Carson #1	May 23-24, 2017	6	6
Fort Carson #2	January 30-31, 2018	8	5
Fort Bliss #2	March 7-8, 2018	11	8

5.4.1 PCMS First Training, May 19-21, 2015

The first AGWA-Facilitator Training was held at Fort Carson/PCMS on May 19-21, 2015, and focused on issues at PCMS. A one-day training was held on May 19 at Fort Carson where most of the management personnel are located. Twelve personnel attended including staff and contractors from ITAM, Range Operations, DPW Conservation, Environment, Forestry, and GIS. This training included a 1.5-hour user needs assessment and discussion. This was an abbreviated training due to their schedule and preparations for a Stryker Brigade that would start the following week. Many of the personnel were not able to attend more than a few hours or one day's worth of training. In addition, we learned very late in our planning that the personnel from PCMS were not able to travel to Fort Carson for the training, and that most of the management personnel were located at Fort Carson. Thus, we conducted short trainings at both locations.

A second brief training was conducted at PCMS for the staff located there. Three people attended the overview and needs assessment discussion the first afternoon, including the Site Supervisor, and the two wildlife biologists. Only one of the wildlife biologists was able to attend the training the following morning, which we conducted as a demonstration since he does not use GIS. Information gathered from that trip was used to develop a data request to them for additional information, and the needs assessment for model enhancements.

Two tutorials were presented:

1. AGWA application of the Land Cover Modification Tool to represent military maneuver impacts from a hypothetical training event and subsequent rehabilitation at PCMS.
2. Facilitator DSS application using the results of the AGWA tutorial.

Comments and discussion during the training indicated that most people felt the tools could be useful with some enhancements, such as:

1. Drop-down menus reflecting training exercises (number, types of vehicles, MIMs) and changes (increase/decrease) to vegetation cover and soil properties (infiltration, erosion, and compaction)
2. Be able to model EC Dams with a drop-down menu for data input
3. Be able to estimate sediment leaving the installation to the Purgatoire River, to help justify funding requests for projects
4. Use Facilitator to evaluate EC Dam locations, relative benefits of reseeding or not, etc.

All participants filled out two surveys: one for usability of AGWA-Facilitator, and one for effectiveness of the training. The Training Effectiveness Survey was used to determine if PO8 was met ("Assess the effectiveness of First AGWA-Facilitator training and needs assessment"). We did not use these survey results to evaluate whether we met the PO's that refer to the second training. The surveys are based on the SUS (Brooke, 1986). See Section 5.3.1 for a description of this method.

Scores were generally low, with a SUS score of 49 (55 for GIS users) for usability, and a score of 55 (65 for GIS users) for the training effectiveness. Lowest scores were 40 for usability, and 43 for training effectiveness, indicating that we did not meet PO8. We attribute these low scores

to several factors. Most of the individuals at the training did not have GIS skills, use GIS, or were the staff who would ultimately use these tools. Furthermore, these trainings were abbreviated, and did not allow enough time to adequately present and discuss the tools, or for the participants to fully understand the models. This was due to time constraints (we realized very late in our planning that we would have to conduct trainings at both PCMS and Carson), and the attendees not having more time for the training. This suggested that we should: 1) ensure the appropriate people attend, such as the storm water management and Range Operations staff; 2) require a full training of at least 1-2 days; and 3) confirm with higher management to require attendance at the full training by the appropriate staff.

Training Effectiveness Survey

Overall SUS score: 55 (65 for GIS users)

Range of scores: 43 - 70

Usability Survey

Overall SUS score: 49 (55 for GIS users)

Range of scores: 40 - 63

5.4.2 PCMS Second/Final Training, June 29-30, 2016

The second and final AGWA-Facilitator training for PCMS was held at Fort Carson on June 29-30, 2016. Nine people attended the training, but only six performed the AGWA tutorials and filled out surveys. This training was 1.5 days and included presentations on the AGWA-Facilitator tools, how to use RTLA data to create a vegetation cover layer, and calibration of KINEROS2.

Five tutorials were provided, and reflected the comments and areas of interest from the first training:

1. AGWA application of the Pond Tool for erosion control dams at the Red Rock Canyon Watershed, PCMS
2. AGWA application of the Military Disturbance Tool to evaluate the effects of military activities at the Taylor Arroyo Watershed, PCMS (note that this tool was created in response to comments from the first training; see Section 6.6 for more information on the tool)
3. AGWA-Facilitator Export Tool to export model results from the AGWA Military Disturbance Tool tutorial for use in the Facilitator
4. Facilitator DSS to evaluate the results of the Military Disturbance Tool tutorial
5. AGWA application of the Burn Severity Tool to evaluate prescribed fire effects at the Red Rock Canyon Watershed, PCMS

During this training, we observed each participant to determine how long it took them to work through the tutorials, and the types of problems encountered. Then, based on their GIS and hydrologic background information (obtained via the surveys), we determined the degree of expertise required to adequately use AGWA and Facilitator (PO9 and PO10). Results indicated that a GIS background was important for use of AGWA, and a hydrologic background was useful for results interpretation and understanding but not necessary to operate AGWA.

Comments and discussions indicated that they felt more comfortable with the tools after several tutorials (repetition was good), but they felt they needed more time to be able to read all the text in the tutorials. They saw potential uses for the tools. We provided them with a follow-up "homework" exercise and form to fill out; however, although they were interested in doing the exercise, they commented that finding the time to fit it into their current duties would be a problem. As a result, they were not able to complete the exercise although several of them worked with AGWA after the training.

All participants filled out two surveys: Training Effectiveness and Tool Usability. The surveys address Performance Objectives 9 – 13. The overall survey results show that we met this PO for training effectiveness, but not for tool usability. We met the PO for the individual lowest score being greater than 50 for both surveys.

Training Effectiveness Survey

Overall SUS score: 71

Range of scores: 53 - 85

Usability Survey

Overall SUS score: 66

Range of scores: 55 - 75

5.4.3 Fort Bliss First Training, April 6-7, 2017

The first AGWA-Facilitator training at Fort Bliss was held on April 6-7, 2017. Thirteen people attended the training, including four from ITAM (ITAM Coordinator and three GIS staff), and nine from DPW (stormwater manager, geologist, ecologist, NEPA planner, archeologist, environmental site design, master planning engineering tech, and two GIS specialists).

The 1.5-day training included presentations on the project background, AGWA background, hydrologic modeling, Facilitator DSS background, and management options. Several discussion and question/answer sessions were included. Six tutorials were provided that illustrate the range of tools available within AGWA and Facilitator:

1. AGWA application of the Military Disturbance Tool to evaluate the effects of military activities at the Taylor Arroyo Watershed, PCMS
2. AGWA-Facilitator Export Tool to export model results from the AGWA Military Disturbance Tool tutorial for use in the Facilitator
3. Facilitator DSS to evaluate the results of the Military Disturbance tutorial
4. AGWA Urban Toolkit using green infrastructure practices (rainwater harvesting, basins, and permeable pavements) at Sierra Vista, Arizona
5. AGWA Erosion Control Dams using the Storage Tool at the Walnut Gulch Experimental Watershed, Arizona
6. AGWA Burn Severity Tool at the Mountain Fire, California, BAER scenario

Since this was the first training at Fort Bliss, we held a discussion on the parameter changes that were developed at PCMS for the Military Disturbance tool. The purpose was to determine if these parameter revisions were appropriate for conditions at Fort Bliss. No conclusions were reached due to the overall difficulty in representing the variability in military training activities, types and numbers of vehicles, use of the vehicles, length of training, soil types, topography, climate, soil moisture conditions, vegetation types, etc. Therefore, we will continue using the parameters developed for PCMS.

Feedback and comments during the training indicated that participants wanted more instruction on how to use the tools, as opposed to the background information on the models presented. To address this concern, we modified the second day's schedule to include a live on-screen demonstration of how to use AGWA by stepping through one of the tutorials. This allowed for more detailed questions and discussion on the features and functions of the AGWA tool, and greatly improved understanding and willingness to use the tool. Discussions also included their specific concerns and management issues to guide the development of a tutorial for the final training. Several range and training areas were discussed that had flooding issues due to improperly sized culverts, or badly designed drainage at buildings and other facilities. One of the sites was selected for a site-specific tutorial that was created for the second training.

All participants filled out two surveys: one for usability of AGWA-Facilitator, and one for effectiveness of the training. The Training Effectiveness Survey was used to determine if PO8 was met ("Assess the effectiveness of First AGWA-Facilitator training and needs assessment"). We did not use these survey results to evaluate whether we met the PO's that refer to the second training.

We did not meet PO8 based on the Training Effectiveness survey. Several of the participants were not experienced GIS users, or did not have a background in hydrology or hydrologic modeling. As noted above, more instruction on how to set-up, use and apply the tool was requested, and was included in the second training. Results for the two surveys are as follows:

Training Effectiveness Survey

Overall SUS score: 58
Range of scores: 43 - 73

Usability Survey

Overall SUS score: 58
Range of scores 43 - 68

5.4.4 Fort Carson First Training, May 23-24, 2017

The first training for Fort Carson was held on May 23-24, 2017. Attendance was light due to conflicts with other meetings and maneuvers at PCMS, with six people attending for the presentations and hands-on tutorials. Attendees included two GIS specialists from DPW, the DPW Environmental Wildland Fire manager, the DPW Environmental Invasive Species and Pest Management Program Manager, the ITAM GIS Coordinator, and the DPW Environmental

Stormwater Manager. In addition, the Range Officer who manages the ITAM program sat in for the first morning's introductory presentations.

The training included overview presentations of the project, AGWA, the Facilitator, and the various tools and functionality within AGWA. In addition, a live on-screen demonstration of the first parts of an AGWA tutorial was given to aid in the understanding of how the tool is used. Multiple discussion sessions were included and were recorded. The format of these presentations and the AGWA Demo were based on feedback from the first training at Fort Bliss the previous month (Section 5.4.3).

Seven tutorials were available that illustrated the functionality of AGWA, and were geared towards management issues at Fort Carson. Some of the attendees were only able to attend part of the training, but everyone ran at least one tutorial. Tutorials presented were:

1. AGWA application at Fort Carson Sullivan Fire and Erosion Control Dams, with mulch treatment for the burn areas
2. AGWA-Facilitator Export Tool to export AGWA results from the Sullivan Fire tutorial for use in the Facilitator Decision Support System
3. Facilitator DSS using results from the Sullivan Fire tutorial
4. Optional:
 - a. AGWA application of the Military Disturbance Tool to evaluate the effects of military activities at the Taylor Arroyo Watershed, PCMS
 - b. AGWA Urban Toolkit using green infrastructure practices (rainwater harvesting, basins, and permeable pavements) at Sierra Vista, Arizona
 - c. AGWA Erosion Control Dams using the Storage Tool at the Walnut Gulch Experimental Watershed, Arizona
 - d. AGWA Burn Severity Tool at the Mountain Fire, California, BAER scenario

All participants filled out two surveys: one for usability of AGWA-Facilitator, and one for effectiveness of the training. The Training Effectiveness Survey was used to determine if PO8 was met ("Assess the effectiveness of First AGWA-Facilitator training and needs assessment"). We did not use these survey results to evaluate whether we met the PO's that refer to the second training. Based on the survey results we met PO8 for training effectiveness, and usability of the tools; however, we did not meet the PO for lowest individual score for tool usability. We believe that the low score was due to one of the participants not attending the first day of the training when the introductory presentations and discussions were given. When the scores were tallied for the participants who attended the entire two-day training, PO8 was met for both training effectiveness and tool usability, both overall SUS score and range of scores.

Results for all participants, including those who did not attend the entire training, including the first morning introductory overview presentations and the AGWA demonstration are shown below. The difference in results clearly shows the value in the presentations and live AGWA tutorial demonstration.

Results for all participants including those who did not attend the entire training
Training Effectiveness Survey

Overall SUS score: 75
Range of scores: 53 - 98

Usability Survey

Overall SUS score: 68
Range of scores 43 - 100 (lowest score was from the ITAM GIS Coordinator who missed the first day of the training and overview presentations)

Results only for participants who attended the entire two-day training were:

Training Effectiveness Survey

Overall SUS score: 83
Range of scores: 70 - 98

Usability Survey

Overall SUS score: 79
Range of scores: 58 - 100

5.4.5 Fort Carson Second/Final Training, January 30 – 31, 2018

The second and final training for Fort Carson was held January 30 - 31, 2018, at Fort Carson. Eight people attended the training, including two from ITAM (Assistant Coordinator, and GIS Coordinator), and six from DPW (Chief of Conservation, Invasive Species and Pest Management Program Manager, Forestry and Natural Resources Team Lead, Bio-Science Technician/Forestry and Fire, and two GIS Specialists).

This training was organized differently, based on feedback from the previous trainings. The first morning was presented as a Manager's Briefing, with overview presentations of the project and tools, and discussion sessions. A live demonstration of an AGWA tutorial was presented immediately after lunch. The intention was to bring the managers up to speed so they could request the types of analyses available with our tools. Although the GIS analysts would operate the tools, the managers would request the analyses. Following the Manager's Briefing, an introduction to the tutorials was presented, and the hands-on tutorial sessions followed.

Six new tutorials were developed for this training:

1. AGWA Urban Tool application at Fort Carson in the Iron Horse Neighborhood located upstream from Iron Horse Park that has flooding issues. Demonstrate how to create the input files for the Urban Tool, and apply green infrastructure practices to evaluate changes in runoff and infiltration.
2. Facilitator DSS analysis of the results from the Fort Carson Urban Tool tutorial for Iron Horse Park, to evaluate the green infrastructure applications. Demonstrate how to manipulate the Facilitator input and create a report.
3. AGWA Precipitation Inputs and the Land Cover Modification Tool at Fort Bliss Range 88. The facilities at this location had flooded during a past storm event, and the tutorial demonstrates how to create the various types of precipitation inputs available in AGWA. In addition, the tutorial demonstrates how to use the Land Cover Modification Tool to update a

2011 land cover dataset to more closely represent the development of Range 88 and improve the AGWA model simulations.

4. AGWA-Facilitator Export Tool to export the AGWA model simulation results from the Fort Bliss Range 88 tutorial directly into a Facilitator input file.
5. Facilitator DSS tutorial to document the AGWA simulation results from the different precipitation inputs and land cover change.
6. AGWA-SWAT Climate Assessment Tool to modify climate data from the Fort Bliss area based on climate change projections, and evaluate how a changing climate affects runoff, peak flow, and infiltration at Range 88.

Two surveys were given to all participants: Training Effectiveness and Tool Usability. The surveys address Performance Objectives 9 – 13, which address the second training. The overall survey results show that we did not meet this PO for the overall SUS score for training effectiveness, but we did meet it for usability. We did not meet the lowest individual score PO for either survey. We attribute this to very low scores given by the two ITAM staff who felt that these tools were not applicable to their current job duties because their supervisor would not request analyses using the tools. There were only five participants in this training, and those two responses greatly influenced the overall results. When those two scores were removed, we met all POs except for the lowest score for usability. These results underscore the importance of having managers aware of and supportive of the use of these tools.

Results for all participants including ITAM staff

Training Effectiveness Survey

Overall SUS score: 63

Range of scores: 30 – 85

Usability Survey

Overall SUS score: 57

Range of scores: 30 - 73

Results without ITAM staff

Training Effectiveness Survey

Overall SUS score without ITAM staff responses: 79

Range of scores without ITAM staff responses: 70 - 85

Usability Survey

Overall SUS score without ITAM staff responses: 70

Range of scores without ITAM staff responses: 68 – 73

5.4.6 Fort Bliss Second/Final Training, March 7-8, 2018

The second and final AGWA-Facilitator training at Fort Bliss was held on March 7-8, 2018. Eleven personnel attended the first morning's Manager's Briefing, and ten of those remained to do the tutorials. Attendees included four ITAM staff (the ITAM Coordinator, GIS/LRAM Coordinator, GIS Coordinator, and GIS Specialist), and seven DPW Environmental staff

(including representatives from Compliance, NEPA, Archeology, Conservation, and GIS support). Overall response was positive.

This 2-day training was organized the same as the final Fort Carson training (see Section 5.4.5) with the exception of the order of the tutorials, and the subject of the AGWA Demo. For this training, the participants worked on the Fort Bliss tutorials first, and the demo used the AGWA Range 88 tutorial.

The six tutorials presented for this training were:

1. AGWA Precipitation Inputs and the Land Cover Modification Tool at Fort Bliss Range 88. The facilities at this location had flooded during a past storm event, and the tutorial demonstrates how to create the various types of precipitation inputs available in AGWA. In addition, the tutorial demonstrates how to use the Land Cover Modification Tool to update a 2011 land cover dataset to more closely represent the development of Range 88 and improve the AGWA model simulations.
2. AGWA-Facilitator Export Tool to export the AGWA model simulation results from the Fort Bliss Range 88 tutorial directly into a Facilitator input file.
3. Facilitator DSS tutorial to document the AGWA simulation results from the different precipitation inputs and land cover change.
4. AGWA Urban Tool application at Fort Carson in the Iron Horse Neighborhood located upstream from Iron Horse Park that has flooding issues. Demonstrate how to create the input files for the Urban Tool, and apply green infrastructure practices to evaluate changes in runoff and infiltration.
5. Facilitator DSS analysis of the results from the Fort Carson Urban Tool tutorial for Iron Horse Park, to evaluate the green infrastructure applications. Demonstrate how to manipulate the Facilitator input and create a report.
6. AGWA-SWAT Climate Assessment Tool to modify climate data from the Fort Bliss area based on climate change projections, and evaluate how a changing climate affects runoff, peak flow, and infiltration at Range 88.

The ITAM staff at Fort Bliss were very interested in incorporating AGWA-Facilitator into their workflow and the discussion sessions reflected their interest and current use. Their questions were more in-depth, showing their understanding of how the models operated, and they requested more information on model application and background. They suggested a follow-up longer training of five days, three of which would be in-depth AGWA-Facilitator background and training, and two days of one-on-one meetings to work through their actual applications. We are considering this request, which is dependent on time and funding available.

The Training Effectiveness and Tool Usability surveys were given to all participants. The surveys address Performance Objectives 9 – 13. The overall survey results show that we did not meet this PO for either survey. We attributed this to the participants wanting more in-depth presentations and a longer training, due to their familiarity with the tools from the first training. It is difficult to predict the knowledge and skill level of trainees and to format a training accordingly. Some of the attendees had prior predictive modeling experience, and others had advanced GIS skills. Others had attended the first training and were already using the tools.

Comments during the discussions were positive regarding the value of the tools, but their survey responses reflected their desire for more in-depth information and a longer training (i.e., they felt that this training was not long or detailed enough).

Training Effectiveness Survey

Overall SUS score: 62

Range of scores: 40 - 93

Usability Survey

Overall SUS score: 60

Range of scores: 45 - 75

On the second morning of the training, the ITAM Coordinator arranged for a side meeting with other managers (DPW and ITAM) to introduce them to these tools. Present were the Range Development Officer, Range Maintenance Manager, and Range Safety Officer. In addition, the Master Planner, who had attended the first Fort Bliss training, was present. This one-hour meeting included a targeted presentation and open discussion of the tools. General responses were positive, and most felt that the tools should be applied in the design phase before new project construction to improve the decision process.

6.0 PERFORMANCE ASSESSMENT

This section describes the methodology and results for the thirteen Performance Objectives described in Section 3.0.

6.1 - PO1: Assess the ability to use nationally available data sets to set up AGWA at demonstration installations.

6.1.1 Introduction

The focus of this PO is to test if AGWA can successfully delineate watersheds in PCMS and run with nationally available datasets (i.e., the out-of-the-box input dataset), and if KINEROS2 and SWAT behave reasonably to changes in precipitation input. Note that the intention of this PO was not to compare model predictions with USGS streamflow gauge data and demonstrate how well the models predict runoff in installation watersheds, which is a focus of PO4. The success criteria for this PO are measured as PASS/FAIL, without complex data analysis that would require statistical procedures/tests to judge performance.

6.1.2 Drainage area and watershed delineation

The criterion for drainage delineation is that AGWA-derived drainage areas should be no more than 3% different from the independently derived areas at the USGS gauging stations. This test was done at PCMS where three watersheds with USGS gauging stations, Taylor Arroyo, Lockwood Canyon, and Red Rock Canyon, were delineated in AGWA with a nationally available 10 m DEM. When compared to the USGS published drainage areas, the largest difference was 0.46% (<3%) at the Lockwood Canyon watershed (Table 4).

Table 4. AGWA derived watershed areas compared to USGS drainage areas

Watershed	USGS drainage area (mile²)	AGWA derived area (mile²)	Difference (%)	Pass/Fail
Taylor Arroyo	48.4	48.5	0.21	Pass
Lockwood Canyon	48.8	49.0	0.41	Pass
Red Rock Canyon	48.7	48.7	0.00	pass

6.1.3 AGWA simulations using nationally available data responds reasonably to precipitation inputs

Parameterization of AGWA models with national data

This test was performed at the Taylor Arroyo watershed. After the watershed delineation was performed using a 10 m DEM, Taylor was discretized into hillslope and channel elements, and parameterized with 2011 NLCD land cover and SSURGO soils data for both KINEROS2 and SWAT. This created the uncalibrated, out-of-the-box scenario based on nationally available data. Using a design storm for KINEROS2 and precipitation data from a GHCN gauge for SWAT, both models ran successfully with runoff and sediment predicted in every watershed element and at the outlet (Table 5 and Table 6).

Runoff response to rainfall input in KINEROS2

Runoff response in KINEROS2 was tested on a fabricated watershed surface where no infiltration would occur, and runoff should increase proportionately to precipitation input. The Taylor Arroyo watershed land cover was changed to impermeable by assigning the infiltration parameter (effective hydraulic conductivity) on all hillslope and channel elements to “0”. Two storms with the same duration but different rainfall intensities were simulated long enough to reach a steady runoff rate. In this configuration, the infiltration rate is expected to be “0”, the steady state runoff rate is expected to be equal to the rainfall intensity, and when doubling the rainfall intensity, runoff should increase by a factor close to two. Simulation results are shown in Table 5. The infiltration rate for both storms was “0” and the steady state runoff rates were similar to the rainfall intensities. When doubling the rainfall input from Storm 1 to Storm 2, runoff volume increased by a factor of $156.60/76.80 = 2.04$, which is close to 2.

Table 5. Runoff response to precipitation input in KINEROS2 (uncalibrated)

	Storm 1	Storm 2	Criteria	Pass/fail
Rainfall (mm)	80	160		
Duration (min)	720	720		
Rainfall Intensity (mm/hr)	6.67	13.33		
Results				
Interception (mm)	0.52	0.52		
Storage (mm)	2.66	2.83		
Infiltration (mm)	0	0	Expected to be “0”	pass
Runoff (mm)	76.80	156.60	Storm 2 expected to generate twice the runoff as Storm 1	pass with a ratio of 2.04
Steady state runoff rate (mm/hr)	6.67	13.33	Expected to be equal to rainfall intensity	pass

Runoff response to rainfall input in SWAT

To test the runoff response in SWAT, three scenarios were designed for the Taylor Arroyo watershed (Table 6). Scenario 1 was the out-of-the-box condition. In Scenario 2, the channel hydraulic conductivity (CH_K) was set to “0” to test if transmission losses become “0”. In Scenario 3, hillslope infiltration was turned off by setting all Curve Numbers (CN) to the maximum extreme of 99. Results showed that compared to Scenario 1, Scenario 2 yielded “0” transmission losses, and all transmission losses in Scenario 1 (8.04 mm) became part of the total water yield in Scenario 2 ($8.04 + 3.95 = 11.99$). When hillslope infiltration in Scenario 3 was turned off, the increase in surface runoff and the decrease in lateral runoff became total water yield and a water balance was achieved, i.e., $(148.92 - 11.88) = (0.11 - 0.03) + (148.95 - 11.99)$.

Table 6. Infiltration and runoff response in SWAT (uncalibrated) for three scenarios

	Scenario 1 Out-of-the- box	Scenario 2 CH_K=0	Scenario 3 CH_K=0, CN=99	Criteria	Pass/fail
Precipitation (mm)	273.4	273.4	273.4		
Surface Runoff Q (mm)	11.88	11.88	148.92		
Lateral Q (mm)	0.11	0.11	0.03		
Transmission Losses (mm)	8.04	0	0	expected to be 0	pass
Total Water Yield (mm)	3.95	11.99	148.95	water balanced	pass

In summary, both KINEROS2 and SWAT passed the criteria with infiltration and runoff behaving reasonably to precipitation input.

6.1.4 Global water balance error

The global water balance error is defined as:

$$(\text{Volume In} - \text{Volume Out} - \text{Change in Storage}) / \text{Volume In} * 100\%$$

In PO1, the global water balance error is expected to be less than 3% for both KINEROS2 and SWAT. This test was performed at the Red Rock Canyon watershed. KINEROS2 was tested with three artificial storms: a spatially uniform storm recorded at a rain gauge, a 50 year-1 hour design storm, and a storm with rainfall from multiple gauges (Table 7). A 10-year simulation of SWAT, from Jan. 1, 2001 to Dec. 31, 2010, was tested using daily precipitation data at the GHCN gauge, USC00054726, located north of PCMS, and Stochastic Weather Generator temperature data (Table 8). Results are shown in Table 7 and Table 8. For KINEROS2, the event water balance errors were less than 3% for all three storms (the last row in Table 7). For SWAT, the annual water balance errors during the simulation period (2001-2010) were less than 3% (the last column in Table 8). This indicates that both models behaved correctly and that there were no unexpected water gains or losses during the simulations.

Table 7. KINEROS2 water balance (uncalibrated)

	Storm 1 Uniform, single gauge	Storm 2 NOAA SCS 50 year- 1 hour, single gauge	Storm 3 multiple gauges varying intensity and length
Rainfall (mm)	20.00	61.47	26.18
Plane infiltration (mm)	15.82	21.24	19.55
Channel infiltration (mm)	0.20	0.73	0.21
Interception (mm)	0.52	0.52	0.52
Storage (mm)	0.17	0.30	0.48
Outflow (mm)	3.21	38.49	5.38
Global Water Balance Error (%)	0.44	0.32	0.17

Table 8. SWAT annual water balance (uncalibrated)

Year	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	Q (mm)	SW (mm)	ET (mm)	Water YIELD (mm)	Water Balance Error (%)
2001	361.20	17.92	0.56	0	0	0	4.02	349.06	3.35	
2002	223.90	1.67	0.31	0	0	0	15.52	214.73	0.32	-1.79
2003	288.60	3.96	0.50	0	0	0	3.35	296.31	0.55	0.17
2004	428.70	24.77	0.73	0	0	0	32.58	373.92	5.40	0.18
2005	368.60	41.51	0.74	0	0.32	0	18.43	340.21	17.73	0.19
2006	402.99	42.21	0.51	0	0.09	0	103.11	265.46	10.15	2.62
2007	354.80	57.57	0.95	0	3.84	0	36.79	368.79	30.56	-2.56
2008	336.76	20.11	0.65	0	0	0	47.10	305.69	4.54	0.19
2009	359.61	16.09	0.63	0	0	0	39.20	350.80	2.05	0.17
2010	309.90	10.68	0.54	0	0	0	16.06	321.86	1.62	0.16

In summary, PO1 was successfully met. AGWA-delineated watershed areas were less than 3% different from the USGS values. Both KINEROS2 and SWAT ran with nationally available datasets, runoff behaved reasonably to changes in precipitation input, and global water balance errors were less than 3%.

6.2 - PO2: Package AGWA-Facilitator for distribution and installation on military computers.

PO2 is successfully achieved if an installation GIS technician or specialist can obtain the AGWA-Facilitator package and install it on installation computers. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

We met the success criteria for this PO. The AGWA Add-in for ArcGIS and the Facilitator installation file were delivered on DVDs to DPW Environmental, GIS, and ITAM staff at Fort Carson/PCMS and Fort Bliss. We observed AGWA being successfully installed on the DPW GIS and Forestry staff computers at PCMS, and staff at Fort Bliss have successfully installed and run the tools.

6.3 - PO3: Determine the ceiling for model execution time.

PO3 will be successfully achieved if SWAT and KINEROS2 simulations can be executed in less than 6 hours when run with Monte Carlo simulations to predict uncertainty, or in less than 10 minutes for SWAT over 5 years, and 10 minutes for KINEROS2 for a single event. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

6.3.1 Single event simulation

KINEROS2 was tested with 10 storms ranging from 21.97 mm to 59.22 mm with durations up to six hours and all were completed in from under one second to three seconds. For SWAT, a simulation with monthly output reporting with 32 years of rainfall input took ~25 seconds to complete. This evaluation was done with a discretization of the Taylor Arroyo watershed derived with nationally available input data, using a desktop computer with an Intel Xeon 64-bit processor, 8 cores, and 32GB RAM.

6.3.2 Monte Carlo simulations

Monte Carlo simulations are commonly used for model calibration and allow iterations of model simulations done with input parameters randomly sampled within the assigned range. The runtime of KINEROS2 or RHEM with a Monte Carlo simulation is determined by the complexity of the model discretization, number of runoff events, duration of input rainfall storms, number of iterations, number of model parameters to be sampled, and computer capacity. In general, more events and more iterations result in better calibration results, but longer runtime. The calibration of the Red Rock Canyon watershed in PO4 was done with seven model parameters, 21 events, 10,000 iterations and a discretization of 630 modeling elements. This size of calibration, with a total of 210,000 single model runs, requires a powerful computer if runtime performance is a concern. To speed up the calibration, the procedure was set up in Python 2.7 with the multiprocessing module and conducted on a high-performance computing server with 1TB RAM and 144 cores. It was completed in 10.69 hours.

The calibration of SWAT in PO4 at the Red Rock Canyon watershed was done with 3,000 iterations, 10 years of daily precipitation input, and a discretization of 270 sub-watersheds. It was completed in 9.83 hours in Python 2.7 with the multiprocessing module, on a desktop computer with an Intel Xeon 64-bit processor, 8 cores, and 32GB RAM.

In summary, this PO was successfully met for KINEROS2 and SWAT simulations without Monte Carlo as it took under 10 minutes to complete a single simulation. This PO was not met for simulations with Monte Carlo, as it took longer than 6 hours to complete the Monte Carlo simulations for both models. A computing server with performance power higher than what was used in this study should be used for Monte Carlo simulations if a 6-hr or shorter completion time is desired.

6.4 - PO4: Assess the degree to which the AGWA models need to be calibrated and validated.

The goal of PO4 is to assess the improvement in performance with AGWA and its models by calibrating the models using local stream flow and precipitation data. Additional goals are to demonstrate the suitability of the Urban Tool in KINEROS2 at the Fort Carson cantonment area for regulatory requirements (EISA Section 438 for stormwater analysis), and assess model performance with a relative change analysis for a heavily disturbed scenario at Fort Bliss.

PO4 will be successfully met when the success criteria shown in

are met. The AGWA models were calibrated and validated for the study watersheds at PCMS and the results were compared to non-calibrated results.

6.4.1. PO4 Objectives and workflow

Analyses in PO4 were designed to test AGWA's model prediction in PCMS watersheds and provide insights on model applications with different levels of data availability and quality. PO4 focuses on:

- The calibration, validation, and uncertainty analysis of models in AGWA
- The degree to which AGWA models need to be calibrated
- The influence of input data quality on model prediction
- Comparing predicted runoff peak with USGS StreamStats estimates
- Testing if the model calibrated at one PCMS watershed can be transferred to another

A successful calibration/validation indicates the model's ability to provide accurate predictions in the study area. The degree to which AGWA models need to be calibrated helps determine the data needed for model calibration. The influence of input data quality provides insights into data worth and cost-effectiveness of data collection. Comparison of model predictions with the StreamStats estimates shows the differences in two ways of obtaining runoff peak. The transferability analysis looks at the degree of similarity in three PCMS watersheds and if a model calibrated at one watershed can be applied to another.

All three models in AGWA (RHEM, KINEROS2, and SWAT) were used in PO4. Features of these models are discussed in Section 2.0 Technology/Methodology Description. Differences in these models will be further discussed in the methods and results sections of PO4. Calibration/validation was done for RHEM and KINEROS2 at the event scale and for SWAT at the monthly scale. The influence of input data quality was evaluated only for RHEM because RHEM input data, especially vegetation, of varying qualities were available. The transferability analysis was done with RHEM. The comparison with StreamStats was done with both RHEM and KINEROS2. PO4 will be successfully met if the following analyses are successfully conducted with the required statistical procedures or tests (RHEM and KINEROS2 related analyses are presented in Figure 5):

- RHEM: Calibration/validation and uncertainty at the event scale
- RHEM and KINEROS2: The degree to which the models need to be calibrated
- RHEM: Influence of input data quality on model predictability
- RHEM and KINEROS2: Comparing peak flow predictions with StreamStats estimates
- RHEM: Model transferability analysis
- SWAT: Calibration/validation and uncertainty at the monthly scale

Because an important component of PO4 was to use input data for RHEM of various types and qualities, a review of all data options is included in Methods Section 6.4.3 (including observed runoff data needed for calibration). In addition, we also review the changes made to PO4 and training disturbances in PCMS.

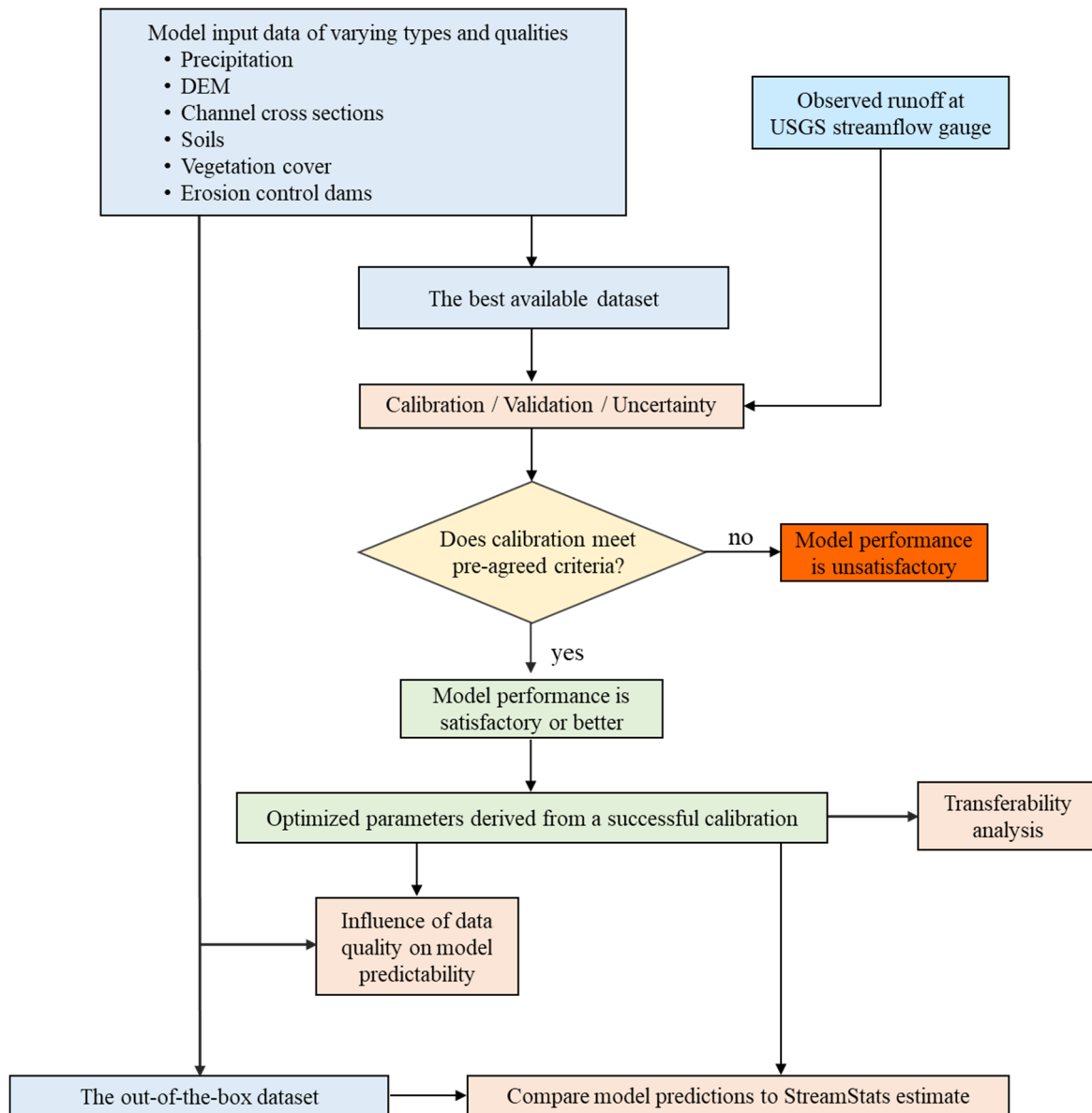


Figure 5. Flowchart of the RHEM and KINEROS2 analyses in PO4

6.4.2. Changes made to PO4

In this section, three changes made to PO4 are described.

1. Three modeling features were removed: sediment yield analysis, 30 m DEM, and time-varying vegetation.
2. Erosion control dams were added to the model simulations because they are abundant in PCMS.
3. Uncertainty in observed data was taken into consideration because this information is available from USGS.

6.4.2.1 Removal of sediment yield analysis, 30 m DEM, and time varying-vegetation cover

There were insufficient sediment data to support calibration and validation for sediment yield, so this was not attempted. Other projects (i.e., Johnson et al., 2018; ESTCP project RC-201302) demonstrated that filling in the sediment record did not result in a good observational data set. The 30 m USGS DEM data was also dropped from PO4 because 10 m data are now nationally available. Time-varying vegetation cover derived from remote sensing products was also excluded because reliable relationships between remote sensing data and RHEM cover variables, such as litter and basal, are not available and difficult to develop with the currently available data.

6.4.2.2 Erosion control dams



Figure 6. Erosion control dam at PCMS

Erosion control dams were added to the modeling because there are over 600 dams at PCMS (Figure 6 and Figure 7). Model predictions will be more accurate by accounting for the water and sediment trapped by the large number of dams at PCMS. However, adding dams adds complexity. Dams and ponds are also assumed to lower the runoff/rainfall ratio, making it more difficult to calibrate due to reduced runoff and a lower number of runoff events. This is especially true for the Taylor Arroyo and Lockwood Canyon watersheds (see Section 6.4.3.4).

About 190 erosion control dams located in three PCMS watersheds were simulated in PO4 (Figure 7). Details on characterization of these dams are included in Section 6.4.3.2.

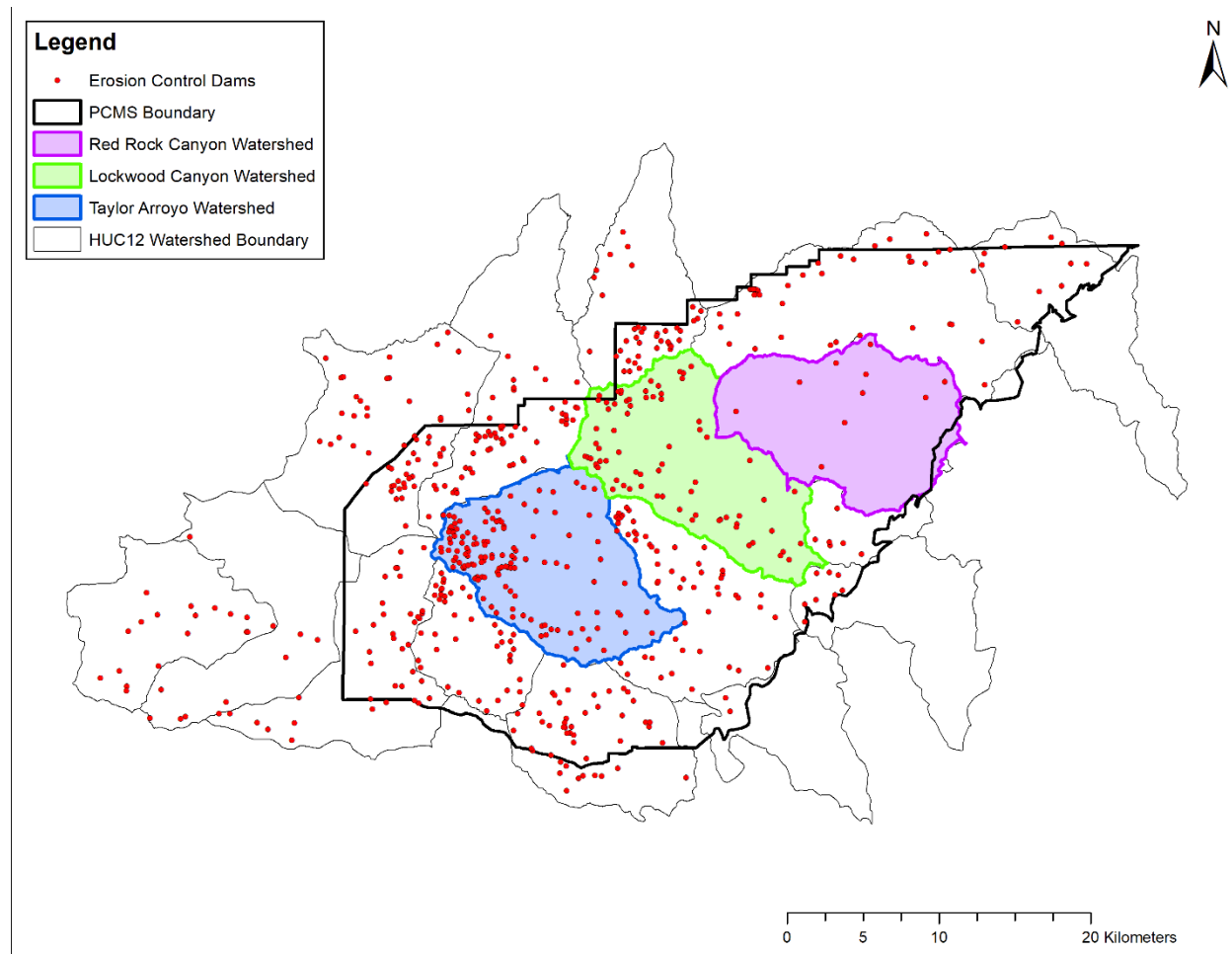


Figure 7. Map of the erosion control dams and study watersheds at PCMS

6.4.2.3 Uncertainty in observed data

All measurements are subject to uncertainty (error). Presenting uncertainty in the observations allows for a better understanding of model prediction and facilitates informed model evaluation and decision-making (Harmel et al., 2006). In PO4, the runoff data collected by USGS serves as observed measurements for evaluating model prediction. In addition to the runoff data in the USGS Water-Data Report, they also publish quality ratings on the runoff measured at each stream gauge. These ratings were incorporated in PO4 and four model performance indicators were added to adjust for the uncertainty in observed data, in addition to the five described in Section 3.4. These four indicators are RMSE*, NSE*, RSR* and PBIAS* (equations are in Harmel et al., 2010). Details for runoff data ratings are included in Section 6.4.3.1.

Table 9 summarizes the nine model performance indicators, their definitions, and their corresponding criteria for “very good”, “good”, and “satisfactory” performance for runoff

simulation, as recommended by Moriasi et al. (2007). These indicators and criteria were used in PO4 for calibration/validation evaluation. It should be noted that:

- 1) The criteria in the last column in Table 9 are assigned to runoff simulations at the monthly time step, based on Moriasi et al. (2007). For event simulations from RHEM and KINEROS2, such standards are not available but the criteria may be less strict. For example, $NSE > 0$ can be considered as satisfactory for event simulations (Moriasi et al., 2007, and personal communication with Moriasi in Feb. 2019).
- 2) According to Moriasi et al. (2016), NSE is an indicator used to determine how well the model simulates temporal variability of the output response of interest during the simulation period. PBIAS is an indicator of how well the model simulates the average magnitudes for the output response of interest during the simulation period. Positive PBIAS indicates model underestimation of bias and negative PBIAS indicates model overestimation of bias. Being able to track the temporal variability and keep the average error minimal are important when predicting runoff, thus higher importance was given to NSE and PBIAS when determining model performance.

Table 9. Model performance indicators, definitions, and performance criteria

Performance Indicator	Definition	Performance Criteria for monthly runoff simulation (Moriasi et al., 2007)
RMSE Root Mean Square Error	a measure of the error between observed values and model predictions	the lower the better
NSE Nash-Sutcliffe efficiency	normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance	very good: $NSE > 0.75$ good: $0.65 < NSE \leq 0.75$ satisfactory: $0.5 < NSE \leq 0.65$
PBIAS Percent bias	the average tendency of the simulated data to be larger or smaller than their observed counterparts	very good: $PBIAS < \pm 10$ good: $\pm 10 < PBIAS \leq \pm 15$ satisfactory: $\pm 15 < PBIAS \leq \pm 25$
RSR RMSE-observations standard deviation ratio	standardizes the RMSE by using the observations standard deviation	very good: $RSR \leq 0.50$ good: $0.50 < RSR \leq 0.60$ satisfactory: $0.60 < RSR \leq 0.70$
r² coefficient of determination	describes the degree of collinearity between simulated and measured data	No criteria were provided. NSE criteria were used.
RMSE*, NSE*, PBIAS*, and RSR*	indicators added to adjust for the uncertainty in the observed data	Same as RSME, NSE, PBIAS, and RSR, respectively.

* adjusted for the uncertainty in the observed data

6.4.2.4 Changes in calibration/validation due to limited data

Two changes were made to the calibration/validation analysis due to limited data. They are briefly mentioned as follows and will be discussed in detail in later sections.

- 1) Model calibration/validation was done in the Red Rock Canyon watershed only. It was not performed in Taylor Arroyo and Lockwood Canyon because runoff data in these two watersheds were not sufficient to support calibration/validation (see Section 6.4.3.4).
- 2) The original plan uses the corrected Radar rainfall as the best quality rainfall input data, based on which RHEM will be calibrated and validated. However, because Radar rainfall data in the Red Rock Canyon watershed was found to be insufficient to support calibration/validation, gauge rainfall was used instead (see Section 6.4.3.2).

6.4.3 Methods

This section presents the methods that were used to calibrate RHEM and KINEROS2, including descriptions of the data, and discussions of the uncertainty in the data and model results.

6.4.3.1 Observed runoff data for calibrating RHEM and KINEROS2

Observed runoff events

For the event-based models RHEM and KINEROS2, runoff volume and runoff peak are the model outputs to be calibrated. Instantaneous runoff rates at USGS stream gauges from 2007 to 2017 were available at three PCMS watershed outlets and served as observed data for model evaluation. The USGS data were downloaded (<https://waterdata.usgs.gov/nwis>) and organized into runoff events; runoff volume and runoff peak were then determined for each event. A runoff event is defined as a series of continuous non-zero runoff rates recorded at the USGS streamflow gauge. A runoff event is different from a rainfall event in that not all rainfall events generate runoff at the watershed outlet, and a runoff event often occurs later than a rainfall event, as it takes time for water to accumulate and travel to the watershed outlet. Runoff volume is the total amount of runoff collected at the watershed outlet, and runoff peak is the maximum instantaneous runoff rate during a runoff event. In PO4 and PO5, if not otherwise specified, runoff volume and peak are presented in depth (mm) and depth per hour (mm/hr), to relate to rainfall depth (mm) and rainfall rate (mm/hr), respectively.

Not all runoff events downloaded were used in the calibration. Small events below certain thresholds are often excluded because large events that potentially cause flooding and sedimentation issues are of greater concern and small events often have higher uncertainty. In PO4, small events are defined as events with runoff volume < 0.1 mm, rainfall < 5 mm, and runoff/rainfall ratio < 0.01. Ideally, > 30 runoff events spanning a range of dry to wet initial conditions and small to large events (10-year return event or greater) are needed for calibrating event based models such as RHEM and KINEROS2. Details on the number of runoff events in the PCMS watersheds are included in Section 6.4.3.4.

Uncertainty (error) in observed runoff

Runoff measurements typically involve continuous water stage (depth) recorded with a device such as a bubbler, pressure transducer, or float sensor. Water stage is then converted to runoff rate with a stage-discharge relationship based on the surveyed cross-sectional channel geometry.

Accurate flow depth measurements can be difficult to obtain, especially with rapid changes in the flow depth or for channel beds covered by cobbles or soft sediment (Harmel et al., 2006). In addition, the stage-discharge relationship should be calibrated with channel structures correctly installed and confirmed at least annually with direct streamflow measurement (Harmel et al., 2006). The USGS Water Resources Division (WRD) Water Data Reports Preparation Guide states that “Accuracy (in streamflow data) depends primarily on the stability of the stage-discharge relation, and the frequency and reliability of stage and discharge measurements” (Novak, 1985).

In PO4, the uncertainty in the observed streamflow was incorporated in the model evaluations in the following two ways:

- 1) The USGS Water-Data Report published annually (water year: October through September) reports the stream flow quality ratings on a scale of “poor” to “excellent” (USGS, 2012). The WRD Water Data Reports Preparation Guide associates this rating to a certain accuracy in daily discharge in percentage: a rating of “excellent” means that about 95% of the daily discharges are within 5% of the true discharge; “good” within 10%; “fair” within 15%; and “poor” means that daily discharges had less than “fair” accuracy (Novak, 1985). Based on this system, we used 5%, 10%, 15%, and 20% uncertainty for accuracy ratings of “excellent”, “good”, “fair” and “poor”, for observed runoff volume and runoff peak, respectively. Table 10 shows the accuracy rating record and the corresponding uncertainty at the Red Rock Canyon streamflow gauge during the study period. Note that these ratings were not available at this gauge after 2013, so the 2013 rating was used for 2014 through 2017.

Table 10. Accuracy ratings and uncertainty of streamflow measurements at the Red Rock Canyon gauge (ID: 07126415) between 2007 and 2017, from the USGS Water-Data Report

	2007	2008	2009	2010	2011	2012	2013	2014-2017
Accuracy Rating	good	poor	poor	poor	poor	fair	fair	not available
Uncertainty (%)	10	20	20	20	20	15	15	15 (assumed)

These ratings were incorporated into the model evaluation by reporting four additional performance indicators: RMSE*, NSE*, RSR* and PBIAS* following the equations in Harmel et al. (2010). See Section 6.4.2.3 for more information regarding these ratings.

- 2) The USGS “data-value qualification codes” and instantaneous runoff rates were used for data screening. These codes are “P” for “Provisional” and “A:e” for “Approved with Estimation”. Provisional data were included in the analysis to incorporate more runoff events. The data with code “A:e” were included because some of the high runoff rates came with this code. For quality control, the daily runoff records were also used to compare with the daily runoff calculated from the instantaneous rates. When these values did not agree for the “A:e” data, the daily runoff was used to compute the event runoff volume, unless the daily record had a code indicating error. In that case, the observed peak runoff was denoted as missing.

6.4.3.2 RHEM and KINEROS2 input data

RHEM and KINEROS2 require input data such as rainfall, DEM, soil, vegetation or land cover, and initial soil moisture. In addition, channel cross-sections in the watershed should be characterized and common conservation practices such as erosion control dams that alter the watershed hydrology should also be captured for a better representation of the study watershed. In the PCMS watersheds, these data are available in varying levels of quality and resolution. In this section, the collection and derivation of model inputs or watershed characteristics and their options are described.

- Rainfall
- DEM
- Channel cross-section
- Erosion control dam
- Soil
- Vegetation or land cover
- Initial soil moisture

For each category, we will also briefly discuss how it is used in AGWA and the errors associated with each option when simulating watershed hydrology. Table 13 is a summary of all data used in the analyses. In addition, three combinations of data will be described in detail: **the best available dataset** that combines the best-quality input data available for PCMS watersheds, **the out-of-the-box dataset** that represents the “worst” scenario where no local data exists and only national data can be used to describe a watershed, and the **10 m high-quality dataset** that best describes a watershed with a 10 m DEM.

Rainfall

Rainfall parameters, including volume, intensity, and duration, are known to be the most important and sensitive input in watershed hydrology models such as RHEM. In PO4, the following five rainfall input options are used:

- Radar rainfall, uncorrected
- Bias corrected Radar rainfall
- Gauge rainfall from multiple rain gauges
- Gauge rainfall from the closest rain gauge
- Gauge rainfall from the furthest rain gauge

KINEROS2 and RHEM in AGWA use rainfall input from a single gauge or multiple gauges in the time-depth breakpoint format, based on which hydrology and erosion algorithms are simulated at a user-defined time interval. AGWA also allows for radar rainfall input as multiple gauges. When a single gauge is used, spatially uniform rainfall is applied to the entire watershed. When multiple gauges or Radar rainfall is used, AGWA creates areal rainfall through spatial interpolation (Semmens et al., 2008). At each time-step, AGWA computes the spatially aggregated rainfall across the watershed. At the end of the storm, the rainfall amount aggregated

at the watershed outlet is called the **Space-Time-Averaged** rainfall amount, and is different from the arithmetic mean of rainfall collected at all gauges used for simulation.

Radar rainfall was used in our modeling efforts because of its broad coverage and ability to provide instantaneous measurements. Digital Hybrid Scan Reflectivity, **DHR**, is a widely used radar reflectivity product measured through the WSR-88D Precipitation Processing Subsystem and scanned on a $1^\circ \times 1$ km polar grid (Fulton et al., 1998). Digital Precipitation Rate, **DPR**, available at $1^\circ \times 0.25$ km resolution is an improved radar product measured with the Dual-frequency Precipitation Radar, which provides three-dimensional measurements of the shapes and sizes of raindrops and allows a better understanding of the physical properties of storms (Shinta et al., 2013). In PO4, DHR and DPR data measured at roughly five-minute intervals at KPIX-Pueblo, CO, a radar site approximately 120 km from PCMS, were used. DHR data were converted to rainfall rates through the relationship $Z=300R^{1.4}$ (Fulton et al., 1998). Both DHR and DPR were screened to remove questionable values (e.g., negative values) before being converted into the format required for AGWA.

Radar rainfall error has been extensively studied. Sources of error include uncertainties associated with calibration, attenuation, bright band, anomalous propagation, beam blockage, ground clutter, spurious returns, random errors, etc. (Krajewski et al., 2010). It is generally recommended to correct radar rainfall based on sufficient rain gauge measurements if applied to hydrology models, especially when absolute predictions are desired. In PO4, bias correction of DHR/DPR was done using hourly gauge/radar ratios calculated at each gauge, which were then interpolated across the watershed through a Kriging technique and applied to the DHR/DPR. Rain gauge network density plays an important role and a dense network improves the quality of radar rainfall corrections.

Rain gauges are often considered the standard instrument for measuring rainfall and the “ground truth” when evaluating other types of rainfall data such as radar rainfall. However, a major error in gauge rainfall data as point measurements is losses from tipping bucket and wind (Alena et al., 1990). The undercatch from wind and turbulence are usually around 5% but can be as large as 40% in high winds (Wilson and Brandes, 1979). Error in gauge rainfall as areal measurements arises from sampling a rainfall field with substantial variation through point measurements (Alena et al., 1990), which is highly dependent on the gauge density and storm pattern, especially in large watersheds. The suggested rain gauge density for calibrating RHEM and KINEROS2 is ≤ 2 km² per gauge. However, such high gauge density is rarely available and a watershed may be equipped with only one gauge. Thus, for this analysis, multiple gauges and a single gauge (both the closest and the furthest gauge) are compared for their ability to predict runoff.

Originally, the bias corrected Radar rainfall was selected as the best available rainfall data. However, due to limited runoff events for radar rainfall, gauge rainfall was used instead (see Section 6.4.3.4).

DEM

A DEM is used in AGWA to delineate and discretize the watershed. Discretization is the process of dividing a watershed into multiple hillslope and channel elements, and it can be done to a fine

resolution to capture areas of concern. A different discretization is generated when a different DEM is used. DEMs can also be used to derive channel cross sections and erosion control dam profiles if the resolution is fine enough. In PO4, two DEM options were used:

- 2 m DEM, LiDAR-derived
- 10 m DEM

The 2 m DEM, created from the LiDAR data provided by PCMS staff, is used as the best quality DEM, and 10 m as the low-quality alternative. The 2 m LiDAR-derived DEM was also used to create channel cross-section profiles and erosion control dam profiles. When the 10 m DEM was used, the channel cross-section was derived using regional regression equations, and generic erosion control dams were used. Details are as follows.

Channel cross-sections

Channel geometry describes the shape and area of a channel segment subject to infiltration and runoff. In AGWA, two channel cross sections, one at the upper end of the stream reach, and one at the lower end, are used to describe a channel geometry. In PO4, two methods were used to derive the cross-sections:

- Regional channel cross-sections based on regional regression equations
- LiDAR-derived channel cross-sections

The regional method assumes trapezoidal sections with 1:1 side slopes and calculates the bankfull width, depth, and cross-sectional area as a function of drainage area, based on Bieger et al.'s (2015) regional regression method. The reliability of this method depends largely on the number of observations used for creating the regression equation, and how well the equation describes the channels in the study watershed. The regional method is available in AGWA. For PCMS watersheds, equations for the Great Plains Region were used.

Using the PCMS LiDAR, a protocol was developed to obtain the channel geometry. The upper and lower cross sections were drawn perpendicularly to the top and bottom 5% of the channel segments, with each section described by a set of elevation increments and the corresponding channel width, wetted perimeter, and cross sectional area. The LiDAR-derived channel cross section was used as the high quality data in PO4, and the regional method as the low-quality alternative.

Erosion Control Dams

PO4 had three levels of data availability concerning ponds that resulted in three different erosion control dam scenarios:

- Best available data - erosion control dam profiles derived with LiDAR
- 10 m high-quality dataset - generalized erosion control dam profiles
- Out-of-the-box dataset - erosion control dams not included in simulations

The Storage Characterization Toolbox (SCT) and the Add Storage Tool in AGWA were used directly and indirectly for the first and second scenario, and no tools or additional inputs were required for the third. The SCT contains three tools: 1) the "Identify and Characterize Existing

Storage” tool; 2) the “Calculate Storage Discharge” tool; and 3) the “Export summary files to KINEROS2 input files” tool. The first tool uses an unfilled DEM, a dam locations point feature class, and a minimum threshold pond area to derive a polygon shapefile of the pond surface areas and the stage-surface area-volume relationships for the ponds. The second tool uses a secondary output from the first tool of a point shapefile of pond locations with user-added attributes of outflow characteristics to calculate discharge values for the ponds and associate them with the stage-surface area-volume relationship for the ponds. The third tool creates pond element blocks for KINEROS2 based on the stage-surface area-volume-discharge relationships from the first and second tool. The Add Storage Tool uses the outputs of the SCT to associate the dam locations and their stage-surface area-volume-discharge relationships with a discretization, allowing the relationships to be selected for simulations.

All three tools in the SCT and the Add Storage Tool were used for the derivation of the erosion control dam elements in the best available dataset scenario. The unfilled DEM from the PCMS LiDAR was used to identify and characterize the ponds with a minimum pond surface area threshold of 500 m². Three different thresholds for contributing area to the ponds were used to classify the derived ponds into small (contributing area less than 40 acres), medium (contributing area between 40 acres and 150 acres), and large (contributing area greater than 150 acres) categories of contributing area. The three size categories of contributing area for the ponds were characterized with different discharge characteristics used by the second tool in the SCT to calculate discharge at different stages of each pond. The small category dams had no culvert, the medium category dams had an 18” culvert 2 feet from the bottom of the pond, and the large category dams had a 24” culvert 2 feet from the bottom of the pond. All category dams had spillways that started 4 feet from the top of the dam with spillway widths assigned based on contributing area (Table 11).

Table 11. Spillway widths based on contributing area for the erosion control dams

Contributing Area (acres)	Spillway Width (feet)
0	8
20	9
40	11
60	14
80	16
100	21
140	25
180	28
220	33
260	35
300	38
350	42
400	44
450	46
500	51
600	55
700	58

800	62
900	66

For the 10 m high-quality dataset scenario that used generalized erosion control dam profiles, three dam profiles were created to associate with the three size categories of contributing area. Using information from the Colorado Revised Statutes C.R.S. 37-87-122, the generalized pond shapes were created with 2 acre-feet maximum dead storage, 10 acre-feet maximum detention storage at the emergency spillway, and with a maximum height of 15 feet from the bottom of the inflowing channel to the bottom of the emergency spillway. Using Agriculture Handbook 590 example A-1 (USDA-NRCS, 1997), the side slope of the generalized profile was set at 2:1. Storage was calculated using the prismoidal formula in Appendix A of Agriculture Handbook 590. The generalized large pond associated with the large contributing area category had a parabola shape with a 200 foot chord length and 250 foot height when full, and a 180 foot chord length and 220 foot height when empty, which satisfied the 10 acre-feet maximum storage at the bottom of the emergency spillway set 15 feet above the bottom of the pond. The 2 acre-feet maximum dead storage was satisfied by putting the bottom of an outlet culvert 3 feet above the bottom of the pond. The total dam height for calculating discharges out of the spillway was set at 19 feet, based on conversations with PCMS personnel who indicated that the emergency spillways (at 15 feet above the bottom of the dam) were installed 4 feet below the top of the dam. The generalized medium pond associated with the medium contributing area category used the same parabolic shape as the large pond but with a dam height of 14 feet with the emergency spillway beginning at 10 feet. The generalized small pond associated with the small contributing area category used the same shape as the large pond but with a dam height of 9 feet with the emergency spillway beginning at 5 feet. Culverts were sized at 18" for the medium contributing area category and 24" for the large contributing area category, and no culvert was used for the small contributing area category.

Using the SCT and Add Storage Tool in the best available data scenario resulted in 10 simulated ponds in Red Rock Canyon Watershed, 64 simulated ponds for Lockwood Canyon Watershed, and 117 simulated ponds in Taylor Arroyo Watershed. The generalized pond profiles and Add Storage Tool in the 10 m high quality dataset scenario resulted in eight simulated ponds in Red Rock Canyon Watershed. The generalized pond profiles were not used in Lockwood Canyon Watershed or Taylor Arroyo Watershed because those watersheds were not simulated under the 10 m high quality dataset scenario.

Soil

Soil texture and soil porosity are important inputs to the infiltration and sediment algorithms in RHEM and KINEROS2. Local soil data is not available for the PCMS watersheds; therefore, two national soil databases developed by the Natural Resources Conservation Service were used in PO4:

- Soil Survey Geographic Database (SSURGO)
- State Soil Geographic dataset (STATSGO)

SSURGO was used as the high-quality data because it was collected at fine scales ranging from 1: 12,000 to 1: 63,360, compared with STATSGO at the scale of 1: 250,000 (Levick et al., 2004).

Vegetation and land cover

Resilience of soil to erosion has largely been attributed to adequate plant cover (Spaeth et al., 2016). RHEM and KINEROS2 require different vegetation inputs. In RHEM, surface cover such as basal, litter, rock, and canopy cover are required inputs. These cover data are incorporated into the infiltration, friction factor, and erosion parameters and algorithms to reflect the complex role that vegetation serves in reducing the erosive power of rainfall, protecting soil from rainfall splash and detachment, facilitating infiltration, and increasing surface roughness. RHEM also distinguishes the influence of plant growth form on hydrology and erosion dynamics. Plant growth form refers to the genetic tendency of a plant to grow in a certain shape and height (e.g., plants may be classified as trees, shrubs, vines, herbs, etc.) (Spaeth et al., 2016). Field studies have shown that infiltration is usually greatest under trees and shrubs, followed by bunchgrass, annual grasses, and sod grass (Spaeth et al., 2016). The vegetation cover and plant growth form data are usually obtained through the on-site Line Point Intercept method, by placing a “pin” or other point intercept device along a line transect at regular intervals to determine the proportion of points that “hit” canopy, basal, litter, rock or bare soil. For KINEROS2, only total canopy cover is required, which allows NLCD land cover data to be used for model parameterization.

The following three types of cover data were used in PO4:

- The Range and Training Land Assessment (RTLA) data
- National Resource Inventory (NRI) vegetation data
- 2011 NLCD land cover data

The RTLA data was used as the best available data, the NRI data was used as the low-quality alternative in RHEM, and NLCD was used in the out-of-the-box scenario in KINEROS2.

At PCMS, the ITAM Program has been collecting RTLA data on over 300 transects across the installation (Figure 8 as an example for 2015). RTLA transect measurements follow the common Line Point Intercept procedures with 50 m long transects sampled at 1 m intervals. Three years of RTLA data, 2009, 2012, and 2015, were available for our study period, 2007-2017 (Table 12). The incorporation of RTLA data into RHEM starts with computing RHEM cover parameters (litter, basal, rock, and canopy cover) of four plant growth forms (bunch grass, sod grass, shrub, and annual and forb) at each transect location. A species-plant growth form lookup table was developed to facilitate the growth form classification. Then, all cover values were interpolated from transect locations to the entire watershed, using the Inverse Distance Weighted (IDW) technique (Figure 9 as an example), and assigned to each hillslope element with the zonal mean tool in ArcMap 10.4. RTLA data were applied to runoff events that occurred close to the year that the data were collected (Table 12).

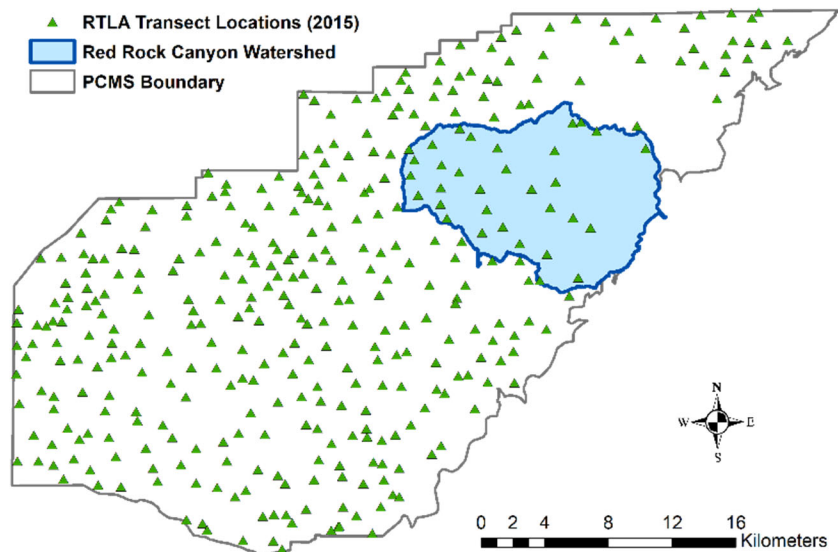


Figure 8. Map of 2015 RTLA transect locations at PCMS and the Red Rock Canyon watershed

Table 12. RTLA data at PCMS and the Red Rock Canyon watershed

Year transect data were collected	Number of transects at PCMS	Number of transects at Red Rock Canyon	Years applied to runoff events
2009	330	34	2008-2010
2012	371	35	2011-2013
2015	368	32	2014-2017

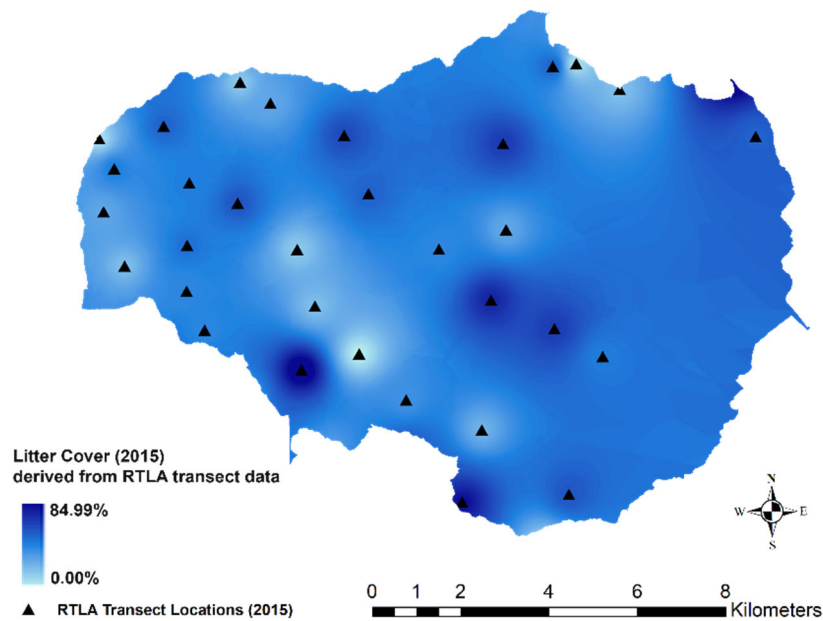


Figure 9. Map showing RTLA litter cover data interpolated from transect locations to the entire Red Rock Canyon watershed using IDW

The uncertainty (error) of applying RTLA data to a watershed model is associated with how well spatially and temporally the data represent the PCMS watershed vegetation. Frequency of the survey, number of transects, transect length, sampling frequency along a transect, and measurement accuracy can all contribute to the uncertainty.

- 1) For calibrating a series of runoff events in a watershed that is subject to frequent disturbances, cover data measured prior to each runoff event is preferred, but unavailable in PCMS. Instead, three sets of data were applied to the 10 year study period (Table 12). This can create uncertainty in the model predictions because actual vegetation conditions for some runoff events may not be well described, and larger events have greater influence on the calibration. For example, for a runoff event that occurred right after a military training, if vegetation measurements from before the disturbance are applied because measurements immediately after the training are not available, it would most likely lead to under-prediction of runoff and erosion, because of failure in capturing the vegetation loss due to training. This is problematic when RTLA data are not collected immediately following a training or rehabilitation treatment.
- 2) Spatially, the RTLA transects are not evenly distributed across PCMS. Compared to Taylor Arroyo and Lockwood Canyon, Red Rock Canyon has fewer transects (only ~10% of the total PCMS transects) especially in the eastern part of the watershed where there are many channels (Figure 8).
- 3) IDW is not the preferred method for interpolating vegetation cover. In our previous study at the Cienega Creek watershed, AZ, ecological sites were used as the spatial unit for interpolation, under the assumption that vegetation tends to be homogenous within the same ecological site. However, an ecological site map is not available for PCMS, so IDW of the RTLA data was used instead.

NRI is a series of land condition assessment protocols used by NRCS on rangelands that involve Line-Point-Intercept transect measurements. NRI transects are surveyed on private lands, therefore the locations are classified and unavailable. With access to the NRI database at the USDA-ARS Tucson office, a set of transect data from the location closest to PCMS was obtained, although the exact survey date and location are unknown. It was then converted into RHEM parameters and applied to the entire watershed, assuming spatially uniform coverage and consistency through 10 years of the study period. NRI provides an alternative to local transect data; however, using NRI transect data for calibrating runoff creates great uncertainty, as no temporal and or spatial variation in watershed vegetation can be assumed. Without the exact location, it is unknown how well the data represent the watershed vegetation. NRI data may not be accessible to all installations and NRI transects may not be available near an installation watershed.

In PO4, NLCD 2011 data are only used in the out-of-the-box dataset for running KINEROS2. These data cannot be used for RHEM because detailed litter, basal, and canopy cover data are not included. The advantage of NLCD is that it does not require local data collection efforts.

Initial Soil Moisture

Dry soil absorbs more water at a higher speed than saturated soil. Initial soil moisture, the soil water content prior to a specific storm event, is a required RHEM and KINEROS2 input. Field measurements of initial soil moisture are often unavailable; therefore, it is usually estimated for calibration. In this study, an indirect estimate based on the daily rainfall prior to the runoff event was used for initial values. Daily rainfall for all rain gauges was obtained from the USGS website (<https://waterdata.usgs.gov/nwis/>) and initial soil moisture prior to a runoff event at each rain gauge was computed using the following algorithm:

- If no rain falls on the previous day, the initial soil moisture was set at 0.2, indicating a very dry condition where only 20% of soil pores contain moisture.
- If 25.4 mm or more fell on the previous day, initial soil moisture was set at 0.98 assuming a fully saturated condition.
- For events with previous daily rainfall between 0 and 25.4 mm, a linear interpolation was applied.

Data summary

Table 13 summarizes the data options mentioned above. Six categories and sixteen options were used (see the left two columns).

Table 13. Data used for the best available dataset, the out-of-the-box dataset, and the 10 m high-quality dataset

Data Category	Data Options	The best available dataset planned	The best available dataset used	The out-of-the-box dataset	The 10 m high-quality dataset
Rainfall	multiple gauges		x	x	x
	closest gauge				
	furthest gauge				
	corrected DHR	x			
	uncorrected DHR				
	design storm				
DEM	2 m LiDAR-derived	x	x		
	10 m			x	x
Vegetation/ Land Cover	RTLA	x	x		x
	NRI				
	NLCD 2011			x	
Soil	SSURGO	x	x		x
	STATSGO			x	
Channel Cross-section	LiDAR-derived	x	x		
	regional			x	x
Erosion Control Dam	LiDAR-derived	x	x		
	generic				x
	excluded			x	

Given the data categories and options, there are numerous ways to combine them for input into the models. However, it is unrealistic to simulate or calibrate all possible combinations. Three combinations were selected: the best available dataset that combines all high-quality options in each data category; the out-of-the-box dataset that combines all the lowest quality options; and the 10 m dataset that combines the high-quality data available with a 10 m DEM. The data options for each dataset and their use in PO4 and PO5 are shown in Table 13 and Table 14. The data were applied in three analyses:

- 1) In the calibration/validation analysis, RHEM was calibrated with the best available dataset. This calibrated model then was used as the baseline in PO4 and PO5 to test the influence of input data quality on model prediction and relative change analysis.
- 2) In the analysis to determine “the degree to which AGWA models need to be calibrated”, the best available dataset was used for calibrating RHEM, and the out-of-the-box dataset was used for calibrating KINEROS2. The “best” case uses all available high-quality input data, the 2 m DEM, locally measured vegetation, and erosion control dams. The out-of-the-box case uses a 10 m DEM, coarse national land cover, and soils data. It does not include local data, and therefore does not address local conservation practices such as erosion control dams.
- 3) A 10 m high-quality dataset was also created to represent the “best” data that can be applied when only a 10 m DEM is available. This option was included because not all watersheds have high-resolution LiDAR DEM data available. The 10 m high-quality dataset was only used in PO5, but listed here for comparison.

Table 14. Datasets and their related analyses

Datasets	Used for analyses
The best available dataset	• calibration/validation of RHEM (Sections 6.4.3.5 and 6.4.4.2) • calibration of RHEM in analysis of “the degree to which AGWA models need to be calibrated” (Sections 6.4.3.6 and 6.4.4.3) • StreamStats analysis (Sections 6.4.3.9 and 6.4.4.6) • relative change analysis in PO5
The out-of-the-box dataset	• calibration of KINEROS2 in analysis of “the degree to which AGWA models need to be calibrated” (Sections 6.4.3.6 and 6.4.4.3) • StreamStats analysis (Sections 6.4.3.9 and 6.4.4.6) • relative change analysis in PO5
The 10 m high-quality dataset	• relative change analysis in PO5

The data used for the best available dataset are included in Table 13. Because radar rainfall was found to be insufficient for model calibration, gauge rainfall (multiple gauges) was used instead (see Section 6.4.3.4).

- 1) As mentioned above, the best available dataset represents the “best” case with all available high-quality input data. The quality of the best available data is specific to the study watershed, and errors associated with this dataset can be significant. At PCMS, data quality can be improved by collecting local soil data, implementing more rain gauges, and measuring RTLA vegetation more frequently, etc.
- 2) The best available dataset may not produce the best calibration results because calibration performance is not only dependent on input data and model structure, but also on the quality of the observed data. Calibration includes input parameter optimization, and accounts for the complicated relationships between the input parameters in a complex process-based model. For example, if observed runoff volumes were consistently underestimated due to instrument error, under-estimated rainfall or over-estimated vegetation cover in the less than best available datasets may produce a better calibration than the best available datasets with better rainfall or vegetation cover estimates. In addition, large runoff events tend to drive the calibration, especially with a limited number of events or when the observed data are skewed.

6.4.3.3 Training related disturbances

Training activities can dramatically change the watershed surface and thus alter the hydrology and erosion. For example, a training that occurs during wet weather or an intense storm falling on disturbed and saturated soil, may cause serious damage that requires expensive repair and long-term rehabilitation. The frequent training disturbances at PCMS pose a challenge to model calibration and increases the uncertainty of model predictions.

Military training at PCMS began on July 29, 1985 (von Guerard et al., 1993). A thorough review of past training activities is unavailable; however, the following is a partial list of land use activities identified through the literature and written or verbal communications with PCMS personnel.

- Prior to 1997, the Army practiced rest-and-rotation land management at PCMS, when for 2 years approximately one-half of the training lands were rested while other areas were used for training exercises (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written communication, March 2008). In addition, prior to 1997, training was not allowed between April and June.
- In 1997, PCMS was opened to year-round training use, although training activities were not continuous throughout a year. The Army indicated training generally occurred in the Taylor Arroyo and Lockwood Canyon watersheds (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written communication, March 2008).
- From 2001 to recently, armored tracked-vehicle training has been limited because many troops were deployed overseas.

- July 18 – 31, 2010: 4-4 Brigade
- Feb. 18 – March 22, 2013: 2-4 Brigade and Battalion level training in Training Areas 7, 10, and 12, with severe damage at the north end of 10 and 12.
- May - June 2015: The Armored Brigade Combat Teams conducted maneuver training at PCMS for collectively 19 days.
- Areas of intensive use are rotated out of mechanized training for rehabilitation until they meet a required vegetation cover percentage.

When calibrating a model in a watershed that is exposed to frequent training, model input parameters should be modified in a timely fashion to reflect the temporal change in soil and land cover. In addition, management and rehabilitation practices such as reseeding, rut removal, and erosion control dams should be incorporated into input data. However, such detailed data at PCMS are unavailable. General descriptions of several large-scale training events exist, but the actual disturbed areas and disturbance levels are not available. In addition, local soils data are not available, and only three sets of RTLA data are available during the 10 years of our study period. Thus, timely adjustments to soil and land cover/vegetation data to reflect the training disturbance and rehabilitation is not possible, and this limitation constrains our ability to represent a constantly changing watershed and creates uncertainty in modeling results.

6.4.3.4 Runoff events and gauge rainfall in PCMS watersheds

Runoff events

The Red Rock Canyon watershed has the highest quality rainfall data (i.e., the greatest number of high-quality precipitation events of sufficient size (runoff/rainfall ratio); see Goodrich et al., 2012) and the fewest erosion control dams of the three watersheds completely contained within the PCMS boundary. As mentioned previously, >30 runoff events spanning a range of small to large are desired for calibration. At the Red Rock Canyon watershed outlet, only 21 runoff events were available for calibration, following the procedures described in Section 6.4.3.1 for data collection, screening, and elimination of small events. The 21 events included two marked as ‘provisional’, five marked with “approved with estimation”, and three with runoff volumes estimated from daily records due to missing instantaneous rates.

Furthermore, only 16 of the 21 events had DHR data available, and three had DPR data available. Due to the small number of events and lack of medium and large size events, these data were dropped from the analysis and were replaced with gauge rainfall in the best available dataset (see Section 6.4.3.2). If the 16 DHR runoff events were split into two sets for calibration and validation, the principle of having the observed events span a range of small to large event size would not be satisfied for calibration.

Figure 10 compares the daily discharge in the three watersheds for our study period. The flow rates were especially low and runoff events were few in Taylor Arroyo and Lockwood Canyon. Following the same procedures described in Section 6.4.3.1, we compiled the runoff data and determined that only 10 runoff events were available in Taylor Arroyo and seven in Lockwood Canyon. Furthermore, most of these events were small, with insufficient numbers of medium to large events required for calibration. Therefore, the calibrations at these two watersheds were not attempted.

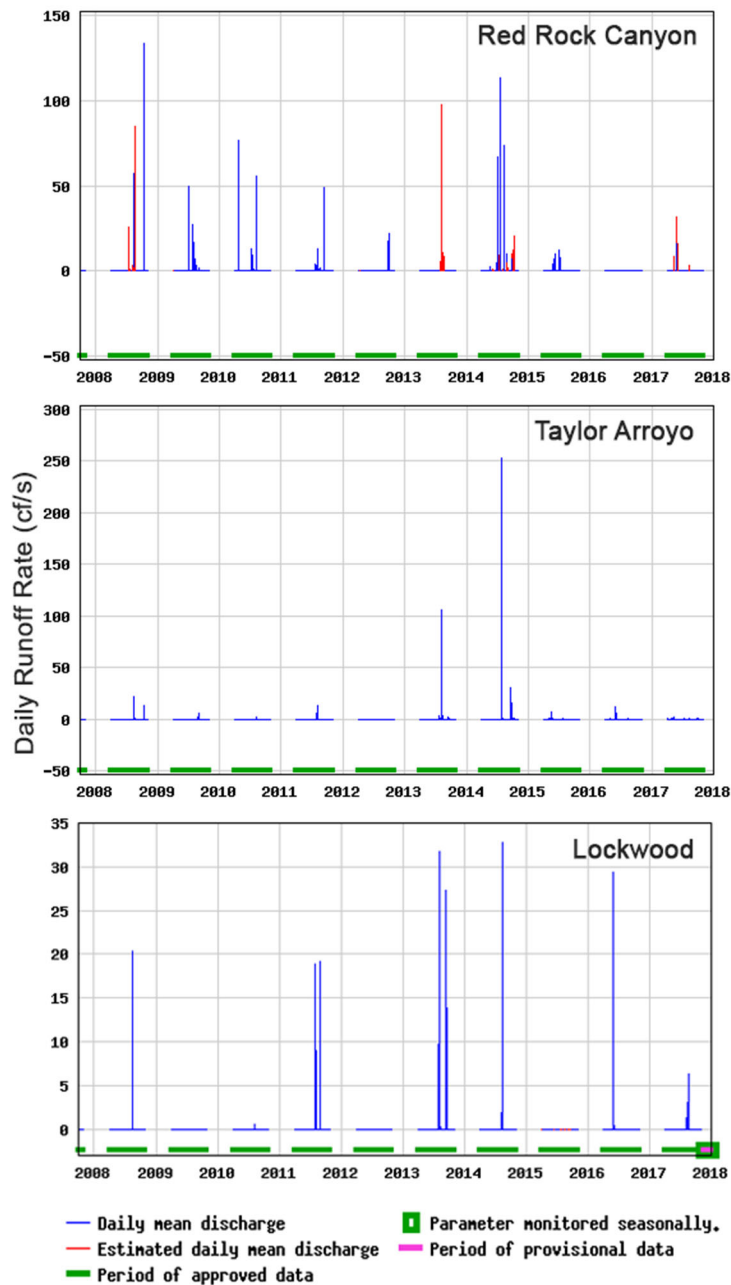


Figure 10. Graphs of USGS daily runoff rates (<https://waterdata.usgs.gov/nwis/>) for three PCMS study watersheds. Note different y axes on each graph

Gauge rainfall and density

Rainfall data from seven USGS rain gauges located in or close to the Red Rock Canyon watershed were used (Figure 11). Four of the seven gauges were operated seasonally (Apr. through Oct.), and the remaining three are operated year round. These gauges cover an area of

~492 km² and form a network with a density of ~70 km² per gauge. The Red Rock Canyon watershed spans 126 km².

Downloaded rainfall were organized into the format required for running the models. After an initial simulation, the Space-Time-Average rainfall was obtained for screening small events. Storms with missing rainfall at three or more gauges were not used. Small rainfall events < 5 mm and events with runoff/rainfall ratio < 0.01 were excluded. Finally, twenty-one runoff events with Space-Time-Average rainfall ranging from 6.21 mm to 61.63 mm were selected for calibration and validation.

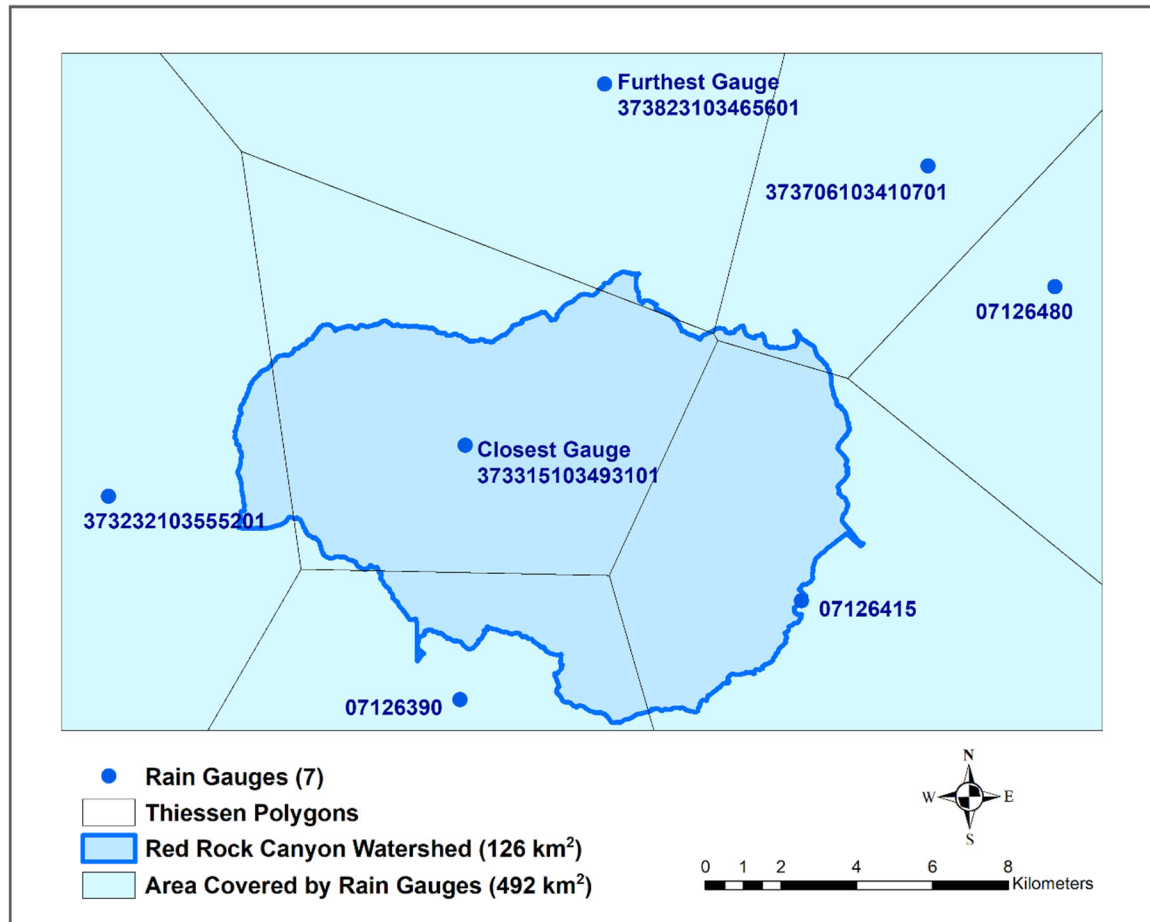


Figure 11. Map showing the seven rain gauges that span ~492 mile², with a network density of ~70 km² per gauge, used for calibrating RHEM at the Red Rock Canyon watershed

6.4.3.5 Calibration/Validation for the Red Rock Canyon Watershed

Model calibration is the process of achieving a model representation in the study area through parameter tuning. Validation is the process of model evaluation by applying the calibrated model to a new set of data, usually a new study period. Calibration and validation performance can be quantitatively measured by comparing model predictions with observations using criteria such as

$NSE > 0$. If the criteria for both calibration and validation are met, a model's predictive ability is satisfactory, and a calibrated model representation, or a set of optimized model parameters, is achieved for the study area.

The calibration performance indicators and criteria used in PO4 are shown in Table 9. Model parameters to be calibrated and their ranges were selected based on modeling knowledge and expertise. Parameter multipliers are sampled within assigned ranges and applied to the entire watershed in the process of calibration. Both runoff and runoff peak were calibrated. The calibration of runoff was first conducted with 10,000 iterations. Based on the set of model parameters optimized for runoff, we then narrowed down the hillslope parameter ranges and fine-tuned the channel parameters to calibrate runoff peak. Latin Hypercube Sampling (LHS; McKay et al., 1979), a statistical sampling method for generating a near-random sample of parameter values from a multidimensional distribution (https://en.wikipedia.org/wiki/Latin_hypercube_sampling) was used in the calibration. LHS ensures that the ensemble of random samples is representative of the real variability whereas traditional random sampling is just an ensemble of random numbers without any guarantees (https://en.wikipedia.org/wiki/Latin_hypercube_sampling).

Twenty-one runoff events (with gauge rainfall) collected at the Red Rock Canyon watershed were split into two sets: 16 events from 2007 to 2013 (including 2013) for calibration, and five events from 2014 to 2017 for validation. The splitting was done to ensure that the runoff events used for calibration span a wide range and are not clustered around small or medium size events (Nelson et al., 2017). Seven RHEM parameters were calibrated; their descriptions, lower and upper multiplier bounds are given in Table 15. After a successful calibration was achieved, validation was done by applying the optimized parameter multipliers to the five validation events.

Table 15. Calibrated RHEM parameters, and their lower and upper bounds

Parameter	Description	Multiplier Lower Bound	Multiplier Upper Bound
SAT	initial soil moisture	0.25	1.25
KE_P	hydraulic conductivity in hillslopes	0.5	4
CV_P	coefficient of variation of KE_P	0.5	2
CANOPY_P	canopy cover	0.5	1.25
CHEZY_P	Chezy coefficient	0.5	75
MAN_C	Manning's N in channels	0.5	4
KE_C	hydraulic conductivity in channels	0.5	3

6.4.3.6 The degree to which the models need to be calibrated

To determine the degree to which the models need to be calibrated, we calibrated two extreme datasets: the best available dataset with RHEM, and the out-of-the-box dataset with KINEROS2. The best available dataset was applied to RHEM because it contains detailed vegetation measurements required by RHEM. The out-of-the-box dataset was applied to KINEROS2 where detailed input is not required. For both calibrations, gauge rainfall with all 21 runoff events was applied to include a wide range of observed events. Model parameters selected for calibration

and their multiplier ranges are shown in Table 15 for RHEM and in Table 16 for KINEROS2. Ten thousand iterations were applied, and the same LHS sampling method described in Section 6.4.3.5 was used.

Table 16. Calibrated KINEROS2 parameters, and their lower and upper bounds

Parameter	Description	Multiplier Lower Bound	Multiplier Upper Bound
SAT	initial soil moisture	0.25	1.25
MAN_P	Manning's N in hillslopes	0.25	1.25
KS_P	hydraulic conductivity in hillslopes	0.25	1.25
CV_P	coefficient of variation of KS_P	0.25	1.75
CANOPY_P	canopy cover	0.75	1.25
MAN_C	Manning's N in channels	0.5	1.5
KS_C	hydraulic conductivity in channels	0.25	1

6.4.3.7 Uncertainty Analysis

The Generalized Likelihood Uncertainty Estimation (GLUE) technique was used in PO4 for uncertainty analysis. GLUE was introduced by Beven and Binley in 1992 and has been widely used in hydrology since then. GLUE is built on the concept that given our inability to use a mathematical model to exactly represent how nature works, the quality of the model simulation results is not determined by a single parameter but a set of model parameters that behave similarly and provide acceptable results (Beven and Binley, 1992). The group of model responses that are considered to behave similarly are called behavioral model responses and are usually determined with Monte Carlo simulations and a likelihood threshold (for example, $NSE > 0$). Model prediction uncertainty is then estimated based on the behavioral model responses. The proportion of observations bracketed by the uncertainty and the thickness of the uncertainty bounds are usually used to quantify the uncertainty performance.

In PO4, the same set of 10,000 Monte Carlo simulations for calibrating RHEM (Section 6.4.3.6) were used for estimating prediction uncertainty, with $NSE^* > 0$ chosen as the likelihood threshold to determine behavioral model response. Then the prediction uncertainty was quantified by the 95% prediction uncertainty band (95PPU) calculated at the 2.5% and 97.5% levels of the cumulative distribution function of the behavioral model response. The goodness of prediction uncertainty was then quantified by the P-factor, the percentage of observations bracketed by 95PPU, and the R-factor, the average thickness of the 95PPU band divided by the standard deviation of the measured data (Yang et al., 2008). A P-factor of one and an R-factor of zero indicates a simulation that exactly corresponds to the measured data (Khalid et al., 2016). The SWAT Calibration and Uncertainty Program (SWAT-CUP) documentation (Abbaspour, 2015) suggested a P-factor $> 70\%$ and an R-factor of around 1 for daily discharge predictions in SWAT. For the event-based model RHEM, because the evaluation time step decreases from daily to single-event, the performance rating may be less strict (Moriasi et al., 2007), and a lower P-factor and higher R-factor may be acceptable.

6.4.3.8 Influence of input data quality on model predictions

Data collection requires time and money. Evaluating the influence of input data quality on model predictions provides insights into data worth and model application in installations where high quality input and specific watershed characteristics are unavailable, or conservation practice like erosion control dams cannot be mathematically described. The objective of this section is to look at the change in model prediction when replacing the input data in the best available dataset with its low-quality alternative, one at a time, using the calibrated RHEM derived in Section 6.4.3.5 as a base line for comparison. As an example: to evaluate the influence of the closest rain gauge on model prediction, rainfall input with the closest rain gauge instead of the multiple gauges was applied to the calibrated RHEM model, with optimized parameter multipliers applied. Model performance indicators and scatter plots will be presented so change in model output can be easily detected. Nine case studies were evaluated and are shown in Table 17.

Table 17. Nine case studies used in evaluating the influence of data quality on model prediction

Data Category	Data Options	the best available dataset	Case studies with low-quality data options							
			Closest Gauge Case	Furthest Gauge Case	Corrected DHR case	Uncorrected DHR case	NRI case	STATSGO soil case	Regional channel Case	Erosion Control Dam case
Rainfall	Multiple Gauges	x								
	Closest Gauge		x							
	Furthest Gauge			x						
	Corrected DHR				x					
	Uncorrected DHR					x				
DEM	2 m LiDAR	x	x	x	x	x	x	x	x	x
	10 m									
Vegetation	RTLA	x	x	x	x	x		x	x	x
	NRI						x			
Soil	SSURGO	x	x	x	x	x	x		x	x
	STATSGO							x		
Channel Cross-section	LiDAR-derived	x	x	x	x	x	x	x		x
	Regional								x	
Erosion Control Dam	Lidar-derived profile	x	x	x	x	x	x	x	x	
	excluded									x
	Generic profile									x

6.4.3.9 Comparison of model predictions and USGS StreamStats

To aid water resource planning and engineering design, the USGS has developed a web-based computer program, StreamStats (Version 4, available at <https://water.usgs.gov/osw/streamstats>), which can be used to delineate drainage areas and estimate peak flow based on regional-regression equations (Ries et al., 2004). The objective of this analysis is to compare RHEM and KINEROS2 predicted peak flow with the StreamStats estimates, using the Red Rock Canyon watershed as an example.

According to Kohn et al. (2016), the StreamStats peak flow regional regression equations in the eastern Colorado region were developed based on a total of 188 stream gauges, a mean of approximately 35 years' record per stream gauge, with estimated Paleoflood and non-exceedance bound ages adding a higher degree of certainty. For the Red Rock Canyon watershed, the regression equations for the Plains Hydrologic Region in eastern Colorado were used (Figure 12). These equations are used in PO4 to estimate the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year peak flows (ft³/s). The drainage area (48.70 mile²), mean basin slope (11.1%) and clay content (18.1%) were obtained from Table 2 in Kohn et al. (2016).

Peak-Streamflow Equations for the Plains Hydrologic Region				
Generalized-least squares regression, 99 streamgages				
<i>A</i> , drainage area in square miles; <i>S</i> , mean basin slope in percent; <i>C</i> , amount of clay in basin in percent; $Q_{0.5}$, $Q_{0.2}$, $Q_{0.1}$, $Q_{0.04}$, $Q_{0.02}$, $Q_{0.01}$, $Q_{0.005}$, $Q_{0.002}$, discharge with an annual exceedance probability of 0.5, 0.2, 0.1, 0.04, 0.02, 0.01, 0.005, 0.002, respectively				
Approximate range of predictor variables				
<i>A</i> : 0.26–3,560 square miles, <i>S</i> : 0.41–21.9 percent, <i>C</i> : 5.20–38.5 percent				
$Q_{0.5} = 10^{-1.033} A^{0.378} S^{0.683} C^{1.742}$	$SEP = 131$,	$pseudoR^2 = 49$,	$SME = 126$,	
$Q_{0.2} = 10^{-0.934} A^{0.385} S^{0.652} C^{2.046}$	$SEP = 102$,	$pseudoR^2 = 57$,	$SME = 98$,	
$Q_{0.1} = 10^{-0.877} A^{0.390} S^{0.640} C^{2.190}$	$SEP = 103$,	$pseudoR^2 = 58$,	$SME = 98$,	
$Q_{0.04} = 10^{-0.797} A^{0.396} S^{0.621} C^{2.329}$	$SEP = 113$,	$pseudoR^2 = 55$,	$SME = 107$,	
$Q_{0.02} = 10^{-0.728} A^{0.399} S^{0.606} C^{2.408}$	$SEP = 123$,	$pseudoR^2 = 53$,	$SME = 117$,	
$Q_{0.01} = 10^{-0.654} A^{0.403} S^{0.593} C^{2.470}$	$SEP = 136$,	$pseudoR^2 = 50$,	$SME = 129$,	
$Q_{0.005} = 10^{-0.577} A^{0.407} S^{0.581} C^{2.518}$	$SEP = 150$,	$pseudoR^2 = 48$,	$SME = 142$,	and
$Q_{0.002} = 10^{-0.473} A^{0.412} S^{0.567} C^{2.567}$	$SEP = 170$,	$pseudoR^2 = 44$,	$SME = 160$.	

Figure 12. Regional regression equations for peak flow for the Plains Hydrologic Region, from Kohn et al. (2016). SEP is standard error of prediction and SME is standard model error.

To get the same set of peak flow estimates from RHEM and KINEROS2, we used the 6-hr, 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year design storms from NOAA Atlas 14, volume 8, version 2.0 (Perica et al., 2013), disaggregated into hyetographs using the NRCS SCS Type II methodology. Calibrated RHEM described in Section 6.4.3.5 and uncalibrated KINEROS2 with the out-of-the-box data were used.

6.4.3.10 Transfer of the calibrated model to an adjacent watershed

An original objective of this analysis was to test how transferrable the calibrated model from one gauged watershed may be to the others nearby. The success of transferring a calibrated model to a different watershed depends on how similar the watersheds are and if similar sizes of runoff events are used. RHEM calibrated with the best available dataset at the Red Rock Canyon watershed was applied at the Taylor Arroyo and Lockwood Canyon watersheds. Model predicted runoff volumes were compared to observed values in these two watersheds.

6.4.3.11 Calibration/validation and uncertainty analysis of SWAT

SWAT was developed based on the curve number method for runoff prediction and MUSLE for erosion prediction. It runs on a daily basis, and monthly runoff rate was calibrated in PO4. Currently, the methods described in Section 6.4.3.2 for parameterizing RHEM with local RTLA data, and incorporating LiDAR-derived channel cross-sections are not available for SWAT. The only local data that can be included is for the erosion control dams. The SWAT model calibrated in PO4 was discretized with the 10 m DEM, parameterized with 2011 NLCD land cover and SSURGO soils, and with erosion control dams. Daily rainfall at seven rain gauges was used as rainfall input.

More than 10 years of daily rainfall and runoff data and a rain gauge density of one gauge or more per 25 km² are suggested for calibration of SWAT. At the Red Rock Canyon stream gauge, 28 years of daily runoff from 1983 through 1990, and from 2000 through 2017 were available. Data between 2000 and 2017 were used for calibration/validation to account for the shift in the military training activities in 2001, when armored tracked-vehicle training was limited because many troops were deployed overseas (Section 6.4.3.3). Prior to 1997, the Army practiced rest-and-rotation land management at PCMS, when for 2 years approximately one-half of the training lands were rested while other areas were used for training exercises (Jeff Linn, U.S. Department of the Army, Directorate of Environmental Compliance and Management, written communication, March 2008). Because no data exist prior to 2001 to track the training related activities for SWAT, data between 1983 and 1990 were not used.

The runoff data between 2000 and 2017 were split into two sets: one from 2000 to 2009 for calibration, and one from 2010 to 2017 for validation. Monthly observed runoff values greater than zero were selected for calibration. Five thousand iterations were applied, and 13 SWAT parameters were calibrated. The LHS method described in Section 6.4.3.5 was used for parameter sampling. The same GLUE method described in Section 6.4.3.7 was used for SWAT.

6.4.4 Results and Discussion

6.4.4.1 Watershed discretization of the Red Rock Canyon Watershed

The Red Rock Canyon watershed was discretized using the 2 m LiDAR-derived DEM and the USGS 10 m DEM. Based on the 2 m DEM, the watershed was discretized into 442 hillslope elements and 178 channel elements (Table 18 and Figure 13). The hillslope element sizes ranged from 209 m² to 4.26 km², with an average of 0.282 km². When using the 10 m DEM, 451 hillslope elements, and 182 channel elements were created. Both discretizations created hillslope elements small enough to capture areas of concern, such as training disturbance zones.

Table 18. Discretization results based on the 2 m and 10 m DEM at the Red Rock Canyon watershed

DEM Options	Number of hillslope elements	Number of channel elements	Average hillslope size (km ²)	Maximum hillslope size (km ²)	Used in dataset
LiDAR-derived 2 m DEM	442	178	0.28	4.26	Best available dataset
10 m DEM	451	182	0.28	4.60	10 m high-quality dataset Out-of-the-box dataset

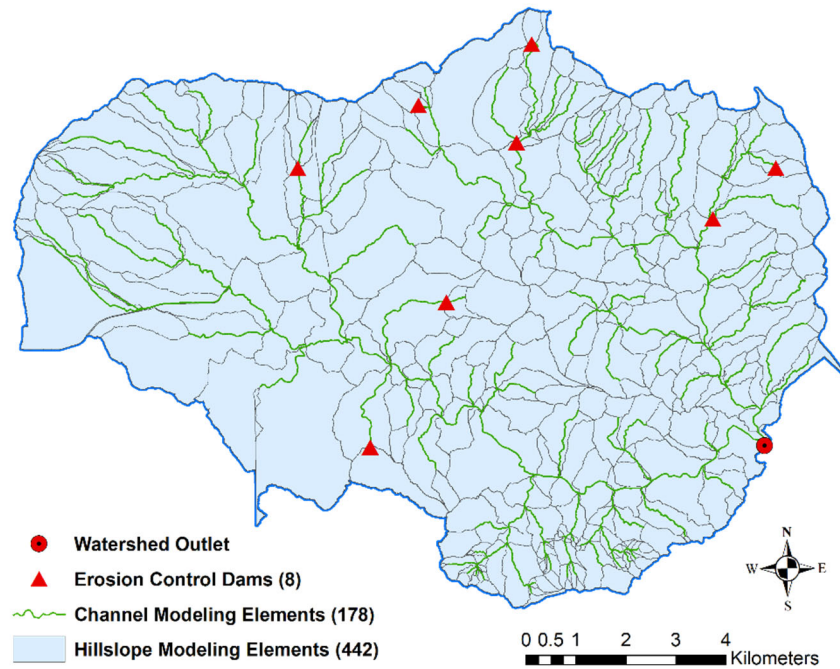


Figure 13. Map showing the discretization of the Red Rock Canyon watershed into 442 hillslope elements and 178 channel elements, using the LiDAR-derived 2 m DEM

6.4.4.2 Calibration/validation of RHEM

Results of the calibration and validation of RHEM predicted runoff volume with the best available dataset are shown in Table 19, with background colors indicating the performance levels, and Figure 14, with error bars indicating the uncertainty in the observed runoff volume. When taking into account the uncertainty in observed runoff volumes, all indicators met the success criteria. Without taking into account the uncertainty, NSE was 0.41 and RSR was 0.77, and the success criteria were not met for the calibration. Validation was successful. Overall, this is a successful calibration/validation that indicates RHEM's ability to predict runoff volume in the Red Rock Canyon watershed. As mentioned in Section 6.4.2.3, $NSE > 0.5$ is set up for monthly simulations and $NSE > 0$ can be considered as satisfactory for event scale calibration. The values

of PBIAS indicate that the average error in runoff volume magnitude was around 21%, and 16% if adjusted for the uncertainty in observations.

Table 19. Calibration/validation results for RHEM predicted runoff volume with the best available dataset

Analysis Type (number of events)	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
Calibration (16)	0.66	1.07	0.41	0.77	21.18%	0.80	0.67	0.57	16.24%
Validation (5)	0.93	0.36	0.78	0.47	-13.91%	0.22	0.92	0.29	-5.90%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

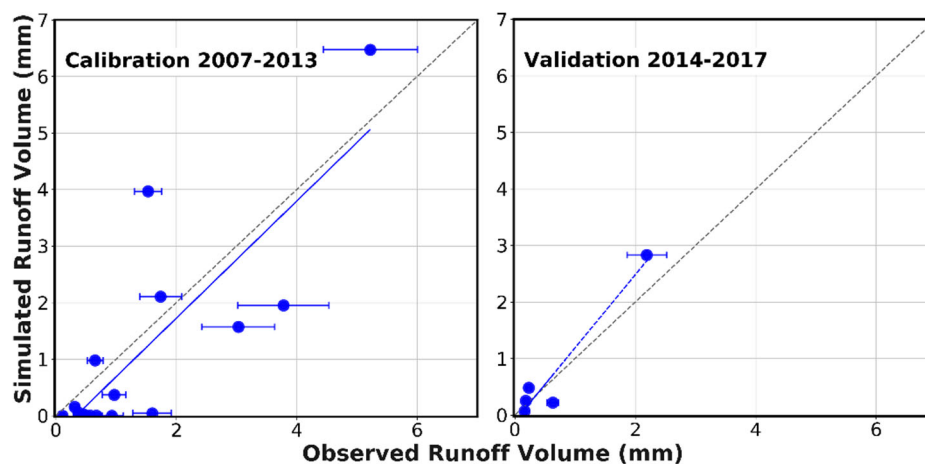


Figure 14. Plots showing the calibration and validation of RHEM with the best available dataset; error bars indicate uncertainty in the observed runoff volume

The calibration/validation can be improved if:

- 1) More runoff events were available: 16 events for calibration and 5 events for validation is not adequate, and the observed runoff events were somewhat skewed with only one large event. More runoff events during a longer study period, especially more large events, are needed to improve the calibration and validation.
- 2) More frequently sampled local input data were available. Among the events for calibration, the largest event occurred in Aug. 2013, and two medium size events occurred in Aug. 2008 and Oct. 2008. The vegetation condition during these three events were represented by RTLA cover data measured in 2012, 2009, and 2009, respectively. It is unclear how representative the cover data were for these events, especially with a training that occurred in Feb. – March 2013 (see Section 6.4.3.3) and no information available to incorporate any changes in vegetation and soil caused by the training. Timely measurements on vegetation and soil disturbance are needed for better results.

The calibration/validation of runoff peak did not pass the success criteria. Results are shown in Figure 15 and Table 20.

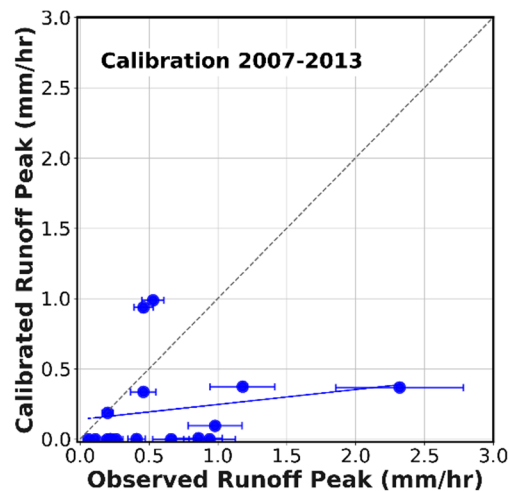


Figure 15. Scatter plot of RHEM calibrated runoff peak and observed runoff peak

Table 20. Calibration performance of RHEM for runoff peak

Analysis Type (number of events)	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
Calibration (16)	0.03	0.71	-0.68	1.30	66.56%	0.55	-0.01	1.01	50.62%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

The calibration of runoff peak is inherently more difficult than calibrating runoff volume. Runoff peak calibration should be done following a successful calibration of runoff, with good quality measurements of observed runoff and rainfall. Calibration of runoff peak is also more difficult in large watersheds as uncertainty in measured runoff rates is expected to be higher. In the Red Rock Canyon watershed, water travels a long distance to the outlet, and often multiple peaks were recorded with estimated runoff rates (i.e., the data had the code “A:e”). In addition, more than seven rain gauges and 16 runoff events representing a range of sizes are suggested for calibration; only one large event was available for our study period.

6.4.4.3 Calibration results

Table 21. Calibration performance with uncalibrated and calibrated KINEROS2 and RHEM

Analysis Type (number of events)	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
Uncalibrated KINEROS2 (21)	0.03	1.66	-0.61	1.27	82.99%	1.36	-0.08	1.04	67.75%
Calibrated KINEROS2 (21)	0.73	0.73	0.69	0.56	13.63%	0.58	0.80	0.44	5.46%
Uncalibrated RHEM (21)	0.45	2.2	-1.83	1.68	-45.34%	2.00	-1.35	1.53	-44.19%
Calibrated RHEM (21)	0.67	0.92	0.50	0.70	24.37%	0.68	0.73	0.52	20.14%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

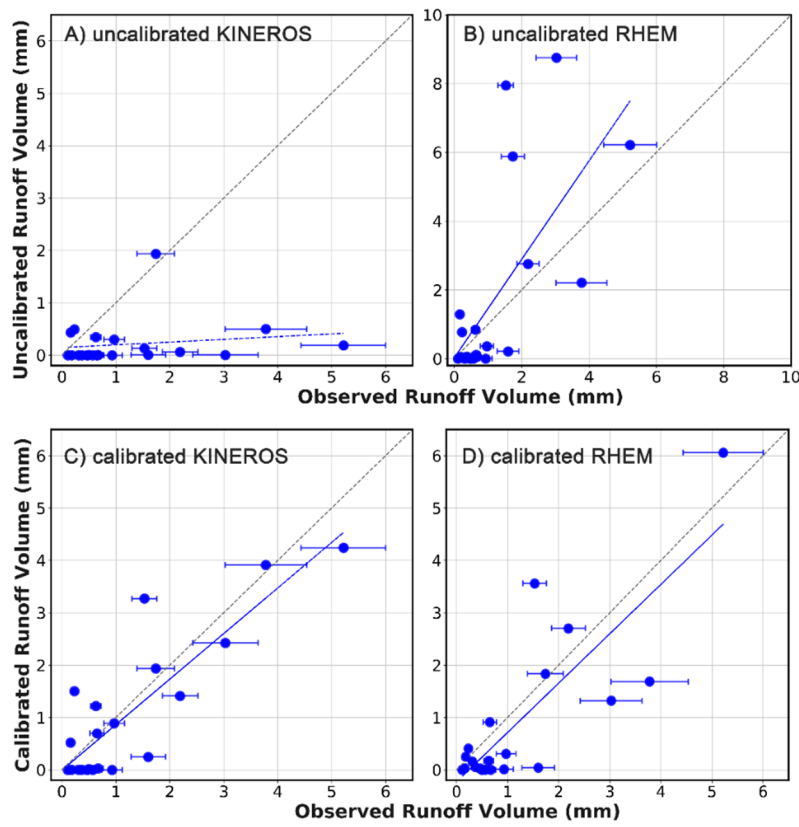


Figure 16. Scatter plots of simulated and observed runoff volume: A) uncalibrated KINEROS2; B) uncalibrated RHEM; C) KINEROS2 calibrated with the out-of-the-box dataset; and D) RHEM calibrated with the best available dataset

The calibration of RHEM with the best available dataset and KINEROS2 with the out-of-the-box dataset were both successful (Figure 16 and Table 21). The model performance and scatter plot of the uncalibrated models are also presented. A comparison of the performances follows:

- 1) Uncalibrated KINEROS2 under-predicted runoff with an average error of 83%. Uncalibrated RHEM over-predicted runoff with a lower average error of -45% (negative indicates overestimation). The scatter plots also show that uncalibrated RHEM predictions were closer to observed values compared to KINEROS2. This demonstrates that with the parameter equations developed specifically for rangeland applications, and incorporating locally measured RTLA vegetation data, RHEM provided better runoff predictions than KINEROS2.
- 2) When calibrated, both models produced satisfactory results with all indicators passing the success criteria. KINEROS2 behaved slightly better than RHEM with higher NSE (NSE*) and lower PBIAS (PBIAS*).

6.4.4.4 Uncertainty

Uncertainty results for RHEM are shown in Figure 17. For each of the 21 events, all behavioral predictions were plotted as scatter dots, with black boxes showing the 95PPU (95% prediction uncertainty band). Observed runoff volumes are shown as red dots with bars indicating the error in observations. Runoff events in Figure 17 are shown according to magnitude. Table 22 summarizes the P-factor and R-factor. When taking into account the error in the observations, the P-factor for all 21 events was 38%, meaning that 38% of the events had observations bracketed by the prediction uncertainty. However, note that most of the events that failed were small events. The P-factor for events greater than 1 mm was 57%, and 75% for events greater than 2 mm. One event greater than 2 mm failed (Aug. 2013 with an estimated runoff rate) and may have been affected by a training that occurred earlier in the year (Feb. – March 2013). R-factors ranged from 0.87 to 2.27.

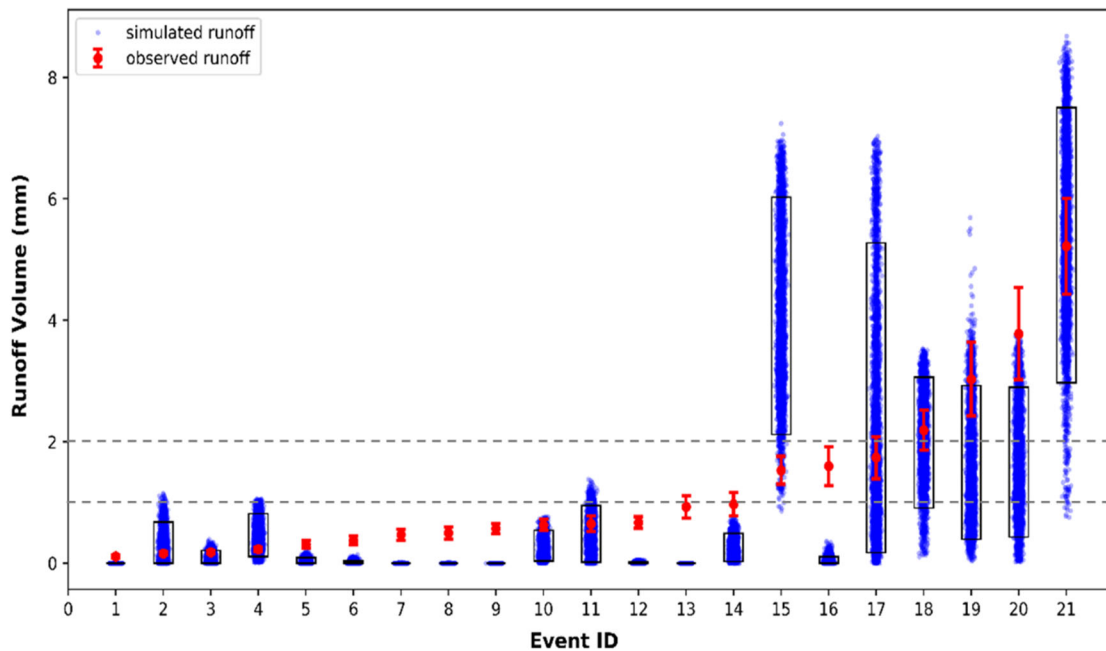


Figure 17. Uncertainty in RHEM predicted runoff volumes for 21 events in the Red Rock Canyon watershed, estimated based on the Generalized Likelihood Uncertainty Estimation (GLUE) method. Blue dots indicate behavioral predictions; black outlines indicate 95% prediction uncertainty band (95PPU); red dots indicate observed runoff with red bars showing error in the observations.

Table 22. Uncertainty in RHEM predicted runoff volume in the Red Rock Canyon watershed

	P-factor	P-factor considering the error in observation	R-factor
all 21 events	33%	38%	0.87
7 events > 1 mm	43%	57%	2.16
4 events > 2 mm	50%	75%	2.27

Summary

- 1) A successful calibration/validation of RHEM predicted runoff was achieved with the best available dataset. This indicates RHEM's ability to provide accurate runoff estimates with confidence when calibrated with high quality data.
- 2) To assess the degree to which the models need to be calibrated, RHEM was calibrated with the best available dataset, and KINEROS2 was calibrated with the out-of-the-box dataset. Both models were successfully calibrated. This indicates that KINEROS2 does not need to be parametrized with the best available dataset to achieve a good calibration, and the out-of-the-box dataset is adequate in a watershed like Red Rock Canyon.
- 3) As shown in Figure 17, the predictions for runoff had high uncertainty for the Red Rock Canyon watershed. This was because the number and spatial distribution of rain gauges were insufficient to capture the rainfall patterns, there were not enough observed runoff events for an ideal calibration, and the input data had high uncertainty and estimated values. In addition, the watershed is consistently exposed to training related disturbances and the best available local data does not represent the changes in soil and vegetation caused by those disturbances. If these conditions are addressed, a better calibration/validation can be achieved.

6.4.4.5 Influence of Input Data Quality on Model Predictability

Influence of Rainfall input

Four case studies were used to evaluate the influence of rainfall input. Table 23 and Figure 18 show the change in predicted runoff when multiple gauges in the calibrated RHEM model were replaced by the closest gauge, furthest gauge, uncorrected DHR, and corrected DHR. Input data for all case studies are presented in Table 17. Results showed that:

- 1) RHEM performed poorly when multiple gauges were replaced with one single gauge. The closest gauge consistently over-predicted runoff volumes because it consistently caught more rainfall than the rainfall interpolated from multiple gauges. The furthest gauge performed better than the closest gauge but worse than the multiple gauges. The average error for the closest gauge case was more than double the error for the other cases.
- 2) Uncorrected DHR consistently over-estimated rainfall and thus over-predicted runoff. Bias correction improved the performance with predictions closer to the multiple gauge case and observed values. Corrected DHR produced the lowest PBIAS and PBIAS*, i.e., the lowest average error was achieved when using corrected DHR. In addition, there were only 12 events available with DHR rainfall. With more large events, corrected DHR may provide better results.

Table 23. Impact of rainfall input quality and rain gauge configuration on RHEM model performance

Case studies	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
best available dataset (multiple gauges)	0.66	1.07	0.41	0.77	21.18%	0.80	0.67	0.57	16.24%
Closest gauge case	0.51	6.06	-18.04	4.36	-165.11%	5.81	-16.5	4.18	-163.95%
Furthest gauge case	0.47	1.26	0.18	0.91	51.91%	0.95	0.53	0.69	40.43%
uncorrected DHR case	0.27	4.82	-25.08	5.11	-316.04%	4.65	-23.28	4.93	-297.56%
corrected DHR case	0.36	1.24	-0.73	1.32	10.94%	1.11	-0.38	1.17	0.54%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

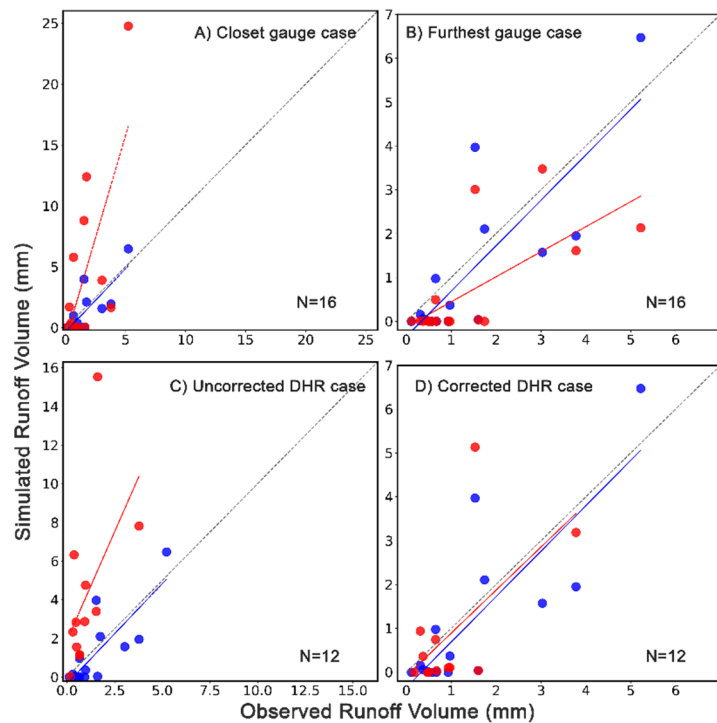


Figure 18. Plots showing the influence of rainfall input on predicted runoff. Blue dots indicate runoff predicted with RHEM calibrated with the best available dataset. Red dots are runoff predicted when replacing multiple gauges with: A) the closest gauge, B) the furthest gauge, C) the uncorrected DHR, and D) the corrected DHR. Note differences in y axes and number of events.

In summary, these case studies indicate that rainfall input has a great influence on model prediction capabilities. In a watershed as large as Red Rock Canyon, using one single gauge or uncorrected DHR for model calibration or absolute model predictions is not recommended. In addition, adding more rain gauges in the watershed will help capture the rainfall spatial heterogeneity and will improve Radar bias correction. Currently there are seven gauges in operation for the Red Rock Canyon watershed.

When a watershed is larger than the thunderstorm extent, rainfall spatial variation is expected to be high, and one gauge does not capture the spatial heterogeneity. As an example, for the event

on Aug. 7, 2013, the closest gauge recorded 74.17 mm rainfall, the furthest gauge recorded 28.20 mm, and the AGWA-generated Space-Time-Average was 42.27 mm (Figure 19). On the temporal scale, rainfall rates can also vary significantly when a single gauge or multiple gauges are used. Figure 20 shows the hyetograph (plot of rainfall rate against time) of a storm on Sep. 14, 2011, generated with multiple gauges and with three different single gauge configurations. At the outlet gauge, rain started more than an hour before the other gauges at a relatively high intensity. When using multiple gauges, the Space-Time-Average rainfall rate captured the entire duration with lower peak rates.

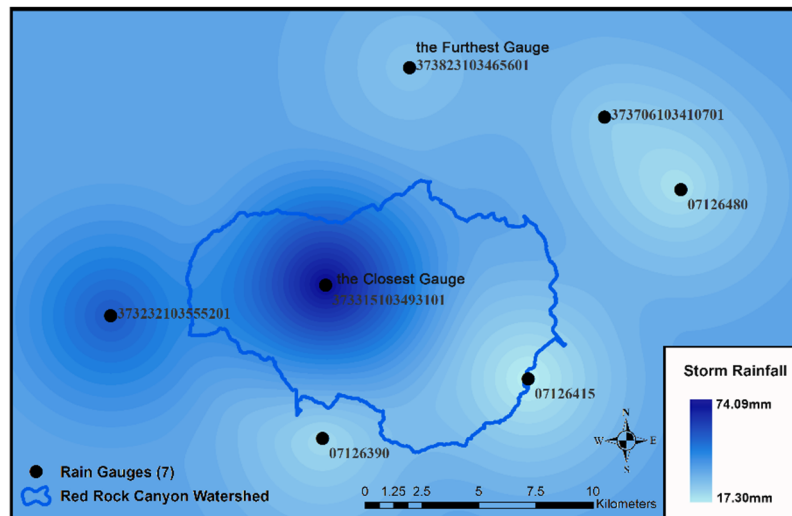


Figure 19. Map showing interpolated total rainfall for the Aug. 7, 2013 storm

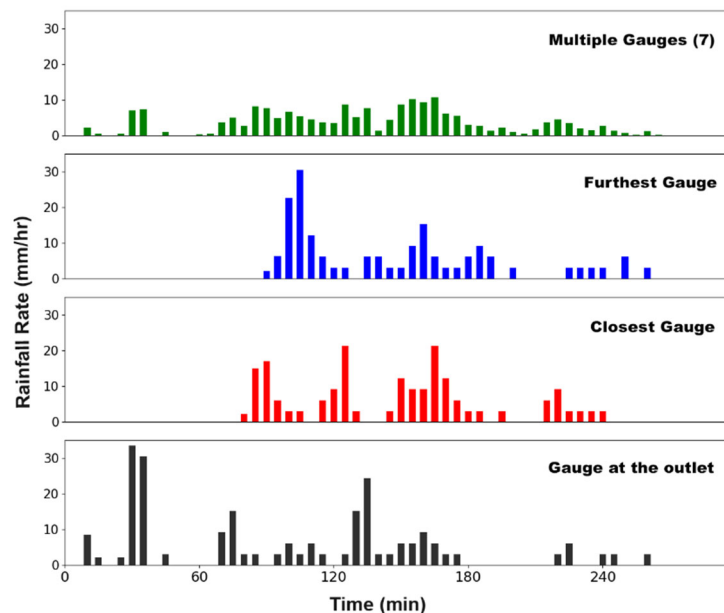


Figure 20. Hyetographs of the Sep. 14, 2011 storm. The top chart shows the AGWA aggregated Space-Time-Average rainfall rates with seven gauges. The bottom three charts show rainfall rates captured with different single gauge locations.

Influence of vegetation, erosion control dams, channel cross-sections, and soils data

Four case studies were developed to evaluate the influence of vegetation, erosion control dams, channel cross-sections, and soil on RHEM model performance. Results are shown in Figure 21 and Table 24.

Table 24. Influence of soils data, erosion control dams, and channel profiles on RHEM model performance

Case studies	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
the best available dataset	0.66	1.07	0.41	0.77	21.18%	0.80	0.67	0.57	16.24%
NRI case	0.75	0.92	0.56	0.66	-0.81%	0.74	0.71	0.54	-0.31%
Erosion Control dam case	0.66	1.07	0.40	0.77	20.43%	0.80	0.67	0.58	15.49%
regional channel case	0.67	1.09	0.39	0.78	17.80%	0.82	0.66	0.59	12.86%
STATSGO soil case	0.63	1.16	0.31	0.83	55.87%	0.86	0.62	0.62	39.85%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

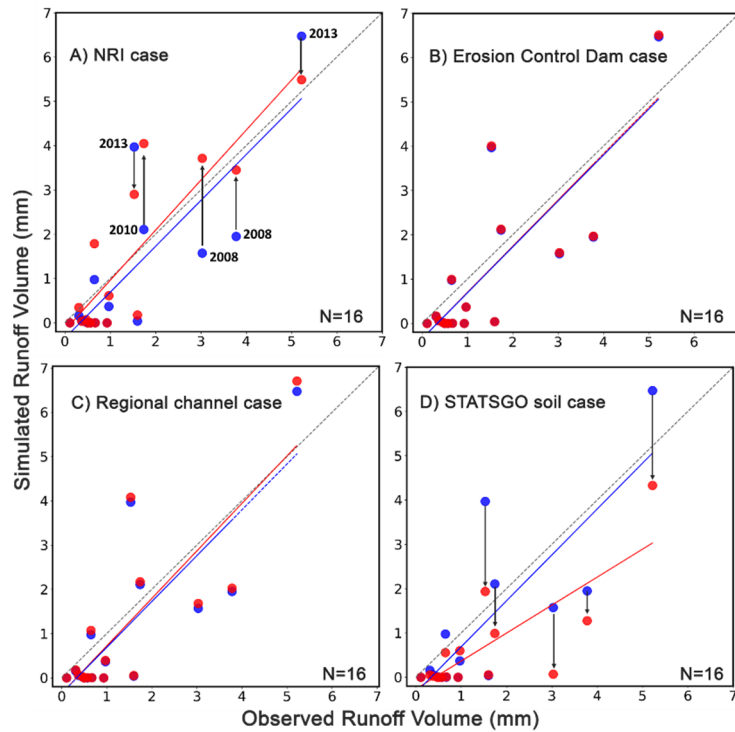


Figure 21. Influence of input data quality on predicted runoff. Blue dots indicate runoff predicted with RHEM calibrated with the best available dataset. Red dots are runoff predicted when: A) RTLA vegetation is replaced with NRI data, B) Erosion Control Dams are excluded from the simulation, C) LiDAR-derived channel cross-sections are replaced with regional regression equations, and D) SSURGO soil is replaced with STATSGO soil.

Replacing RTLA data with NRI data produced higher runoff values for 3 events in 2008 and 2010, and lower values for 2 events in 2013 (as indicated by the arrows in Figure 21A). The overall average error was reduced and predictions were closer to the observed values. This suggests that that NRI data may represent the vegetation in 2013 better than the 2012 RTLA data (see Table 12). However, using one set of NRI data for calibration across the entire watershed and for a 10-year study period creates great uncertainty in the model predictions. Furthermore, three years of RTLA data over a 10-year period in a frequently disturbed watershed cannot capture the changes in vegetation or soil. More frequent RTLA data collection may be able to capture the changes to vegetation from training and rehabilitation activities, which would improve the model predictions when using RTLA data.

Predicted runoff slightly increased when erosion control dams were not included. However, the influence was not significant because only eight dams were included in the Red Rock Canyon simulation, although it may be significant in a watershed such as Taylor Arroyo with 117 ponds. Besides runoff, adding erosion control dams would also change the sediment yield and runoff peak, and these results suggest that including them in the simulation improves model results.

Replacing the LiDAR derived channel cross sections in all 178 channel elements with the regional cross sections led to a slight increase in runoff volume. Larger events resulted in a greater difference. LiDAR in general generated wider channels and greater wetted perimeter than the regional method, resulting in more channel infiltration and thus lower runoff.

For most of the events, especially the medium and large events, STATSGO soils produced less runoff than SSURGO did. The influence was greater than that of erosion control dams and regional channel cross-sections.

Summary

Results in this section showed the change in predicted runoff when high-quality data was replaced with its low-quality alternative. In summary:

- 1) Replacing multiple gauges with a single gauge or uncorrected DHR produced the largest change in runoff prediction. One gauge cannot capture the spatial rainfall pattern and can greatly over- or under-predict runoff.
- 2) Assuming that NRI data is consistent throughout the study period and represents uniform coverage for the entire study area increases the uncertainty in model predictions. Our results suggest that vegetation should be sampled more frequently and especially after a major disturbance or rehabilitation occurs. As shown in Section 6.4.4.3, uncalibrated RHEM performed better than KINEROS2. This is largely because of the incorporation of RTLA data, allowing RHEM infiltration and runoff algorithms to be parameterized with local data.
- 3) LiDAR derived (or on-site measured) channel cross sections and SSURGO soils produced better model results. STATSGO soil predicted lower runoff than SSURGO soil.

- 4) Erosion control dams can reduce runoff, sediment yield, and peak flows, especially in watersheds with many dams.

6.4.4.6 Comparison of model predictions and USGS StreamStats

Results showed that the peak flow predictions from KINEROS2 with the out-of-the-box dataset were much lower than the peak flows estimated with StreamStats regional regression equations (Table 25 and Figure 22). The calibrated RHEM model (see Section 6.4.4.2) predicted peak flows that were 2-3 times the StreamStats estimates. Because the RHEM calibration of runoff peak failed, the model calibrated for runoff was used, which increased the uncertainty in predicted peak flow, and resulted in an overestimated peak in comparison with the StreamStats estimates. However, there is uncertainty in the StreamStats estimates that are based on drainage area, clay content, and average watershed slope in the regional regression equations. It should also be noted that:

- 1) StreamStats estimates based on regional regression equations assume transferability to a nearby watershed, which is not always a valid assumption.
- 2) StreamStats does not reflect spatial variation across the watershed, or disturbances such as land cover change and military training activities.
- 3) Besides peak flow, RHEM and KINEROS2 also provide runoff amounts and sediment yield predictions that are useful for management, planning, and decision-making. An example of using RHEM and KINEROS2 to evaluate training impacts is described in PO5.

Table 25. Peak flow predicted with calibrated RHEM and uncalibrated KINEROS2, compared to the USGS StreamStats estimates, for a 6-hr rainfall event and various return periods

Return Period (year)	6-hr Rainfall (mm)	Peak Flow (ft ³ /s)		
		StreamStats estimate	uncalibrated KINEROS2	calibrated RHEM
2	30	322	7	641
5	37	931	36	1843
10	50	1590	121	4968
25	61	2800	218	8692
50	76	4040	385	16426
100	87	5620	511	22144
200	99	7620	670	28742
500	111	11000	837	34644

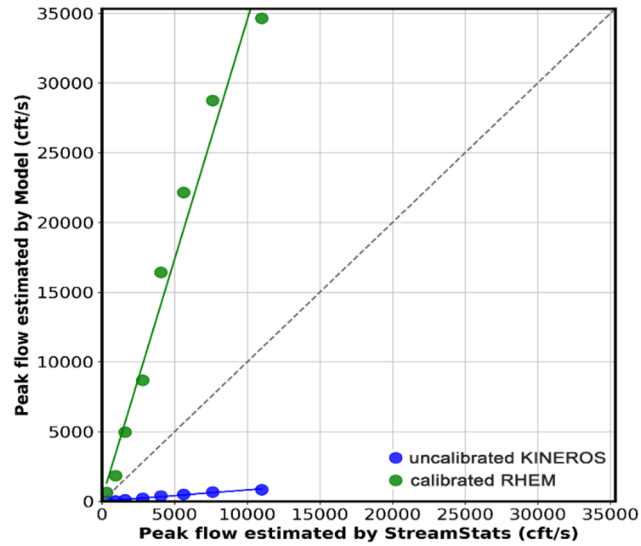


Figure 22. Model predicted and StreamStats estimated peak flow for 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year events

6.4.4.7 Transfer of the calibrated model to an adjacent watershed

The testing of transferability showed that RHEM calibrated in the Red Rock Canyon watershed could not be applied at Taylor Arroyo and Lockwood Canyon (Figure 23). This is due to multiple factors described below.

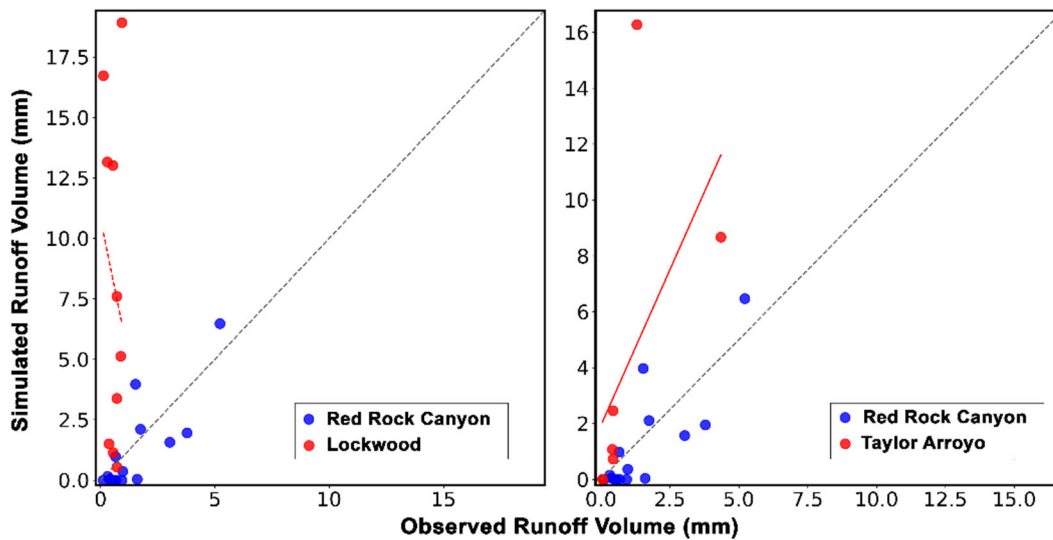


Figure 23. Scatter plots of simulated vs. observed runoff showing the application of RHEM calibrated at the Red Rock Canyon watershed to Lockwood Canyon and Taylor Arroyo

Taylor Arroyo and Lockwood Canyon watersheds differ from the Red Rock Canyon watershed in a number of ways. One significant difference lies in the streamflow rates. Compared to Red Rock Canyon, Taylor Arroyo and Lockwood Canyon had significantly fewer and smaller flow

events (see Figure 10). This may be because Lockwood Canyon and Taylor Arroyo are located on flatter terrain with few channels and significantly more erosion control dams (Figure 24).

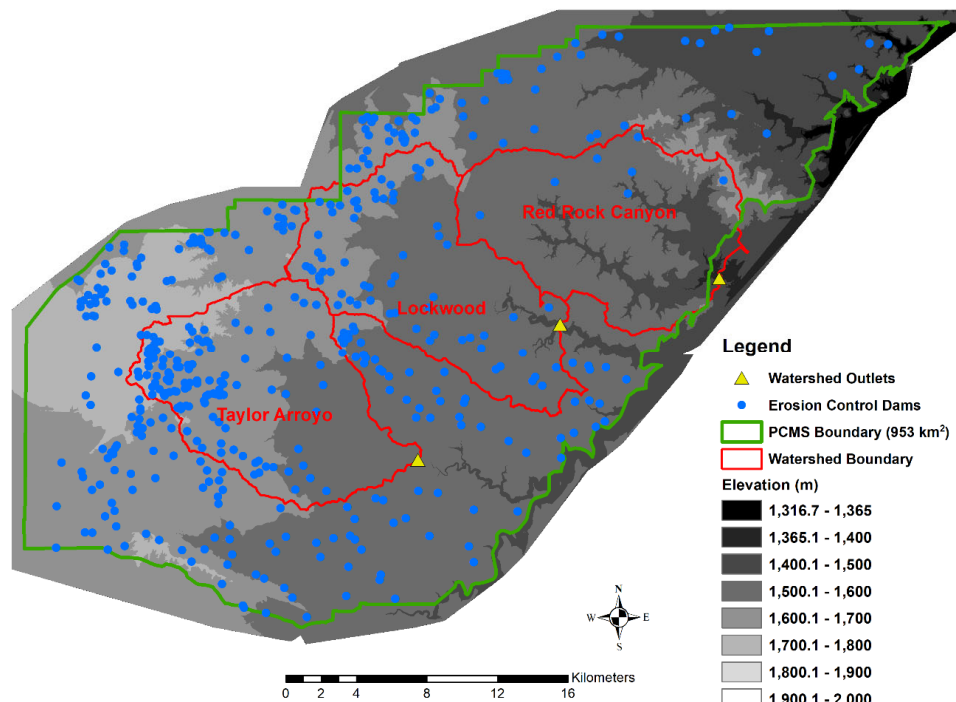


Figure 24. Map showing elevation and erosion control dams at PCMS and the Red Rock Canyon, Lockwood Canyon, and Taylor Arroyo watersheds

In addition, there are differences in soil textures in the three watersheds. Figure 25 shows histograms of soil textures in hillslope modeling elements from the three watersheds. The dominant soil texture at Red Rock Canyon is loamy sand and sandy loam. At Lockwood Canyon, loamy sand, sandy loam, and sandy clay loam are common. At Taylor Arroyo, sandy clay loam and clay loam are more common than in the other two watersheds.

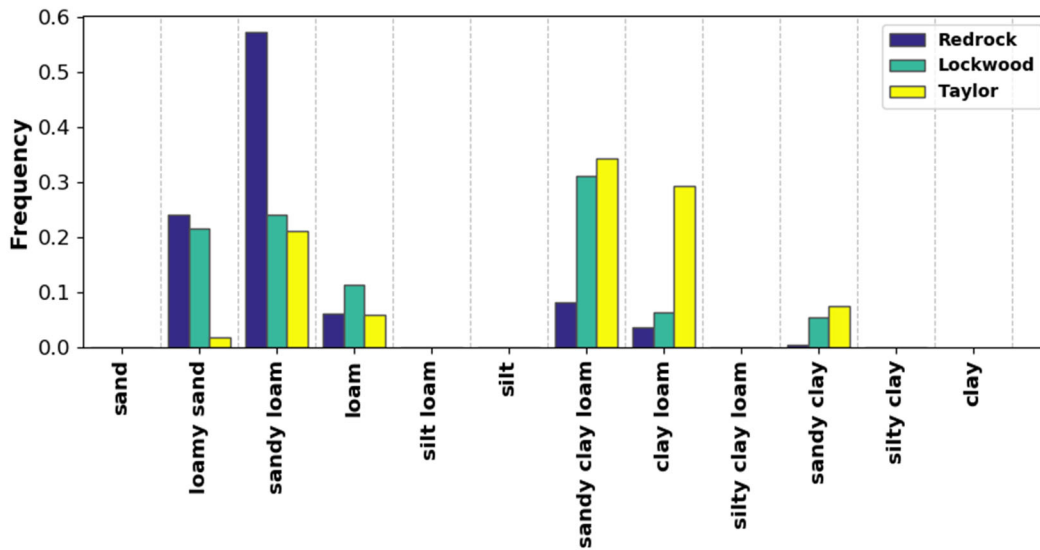


Figure 25. Histograms of soil textures for Redrock Canyon, Lockwood Canyon, and Taylor Arroyo watersheds

In summary, the RHEM model calibrated in the Red Rock Canyon watershed cannot be transferred to Taylor Arroyo and Lockwood Canyon for absolute runoff predictions, because of the differences in terrain, erosion control dams, soil, and vegetation in the three watersheds.

6.4.4.8 Calibration/validation and uncertainty analysis for SWAT

A successful calibration was achieved with all performance indicators passing the success criteria. The validation, however, failed (Figure 26 and Table 26). Using fixed input parameters, i.e., assuming a consistent watershed condition during the entire calibration and validation period, is problematic. Using time-varying input data reflecting changes in the watershed due to climate and training disturbances would produce a more applicable calibration, and possibly a successful validation. In addition, more rain gauges would also improve the calibration and validation performance.

Table 26. Calibration and validation results for SWAT

Analysis Type (number of year)	Performance Indicator **								
	R ²	RMSE	NSE	RSR	PBIAS	RMSE*	NSE*	RSR*	PBIAS*
Calibration (10)	0.75	0.04	0.74	0.51	13.85%	0.03	0.84	0.40	2.73%
Validation (8)	0.05	0.12	-0.94	1.39	-23.44%	0.11	-0.55	1.24	-32.40%

** performance levels are indicated by indicator background color:

unsatisfactory Lower values are better Satisfactory Good Very good

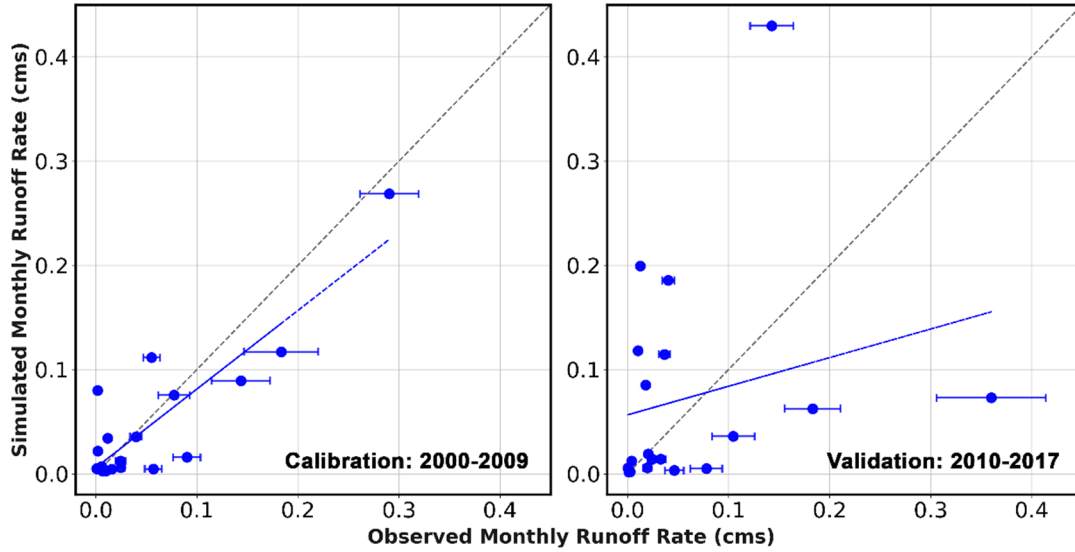


Figure 26. Plots of observed and simulated monthly runoff rates for calibration and validation of SWAT

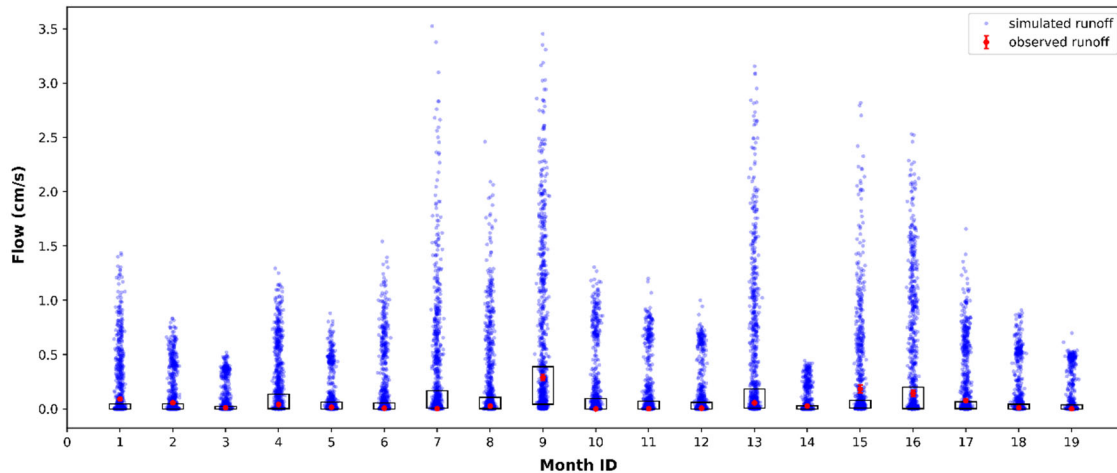


Figure 27. Uncertainty results for SWAT. Blue dots indicate behavioral predictions; black outlines indicate 95% prediction uncertainty band (95PPU), red dots indicate observed runoff with red bars showing error in the observations.

Uncertainty results for SWAT with the GLUE method are shown in Figure 27. The P-factor was 67% and was 71% when considering the error in observations. As stated previously, the uncertainty analysis was poor due to a lack of local and time-varying input data.

6.4.4.9 Summary

In PO4, a successful calibration/validation was achieved for RHEM in the Red Rock Canyon watershed with the best available dataset that included multiple rain gauges, a 2 m DEM, and locally measured RTLA vegetation data. Using this calibrated RHEM model as the baseline prediction, the influence of input data quality on model predictions was evaluated. Replacing

multiple rain gauges with a single gauge created the greatest uncertainty in model predictions; therefore, a single gauge is not recommended for calibration or absolute model predictions. An uncertainty analysis of RHEM was performed and sources of model uncertainty were discussed. In addition, the calibration of KINEROS2 with the out-of-the-box dataset also passed the success criteria, which indicates that high-quality data are not required for a successful calibration in the study watershed. Finally, a successful calibration of SWAT was achieved, but the validation failed due to the lack of local and time-varying SWAT input parameters needed to reflect the changes in the watershed due to climate and training disturbances.

6.4.5 Fort Bliss relative change analysis

Fort Bliss Army Base is located north of El Paso, Texas, and hosts a large number of military and civilian activities. A detailed description of Fort Bliss is provided in Section 4.0. Fort Bliss was chosen as a demonstration site because it offers the opportunity to demonstrate how AGWA can perform as a relative change tool in a location with limited hydrologic data, and significant training activities. The Military Disturbance Tool (MDT) within KINEROS2 in AGWA was developed for this project to evaluate the changes to runoff and sediment yield resulting from military activities that affect soil and vegetation properties by applying reductions to model parameters (Table 27). See Section 6.6 for more information on the MDT.

Table 27. Modifications to model input parameters for KINEROS2 and RHEM applied in the Military Disturbance Tool

Disturbance Level	Reductions to Model Parameters from Undisturbed Condition				
	KINEROS2 and RHEM		RHEM		
	Soil Porosity*	Roughness**	Canopy Cover	Litter Cover	Basal Cover
Undisturbed	0%	0%	0%	0%	0%
Light	-5%	-25%	-15%	-15%	-10%
Moderate	-10%	-40%	-30%	-30%	-20%
Heavy	-20%	-70%	-65%	-65%	-25%

6.4.5.1 Range 83 watershed and a training scenario

The watershed at Range 83 (221 km²) is located in the central area of Fort Bliss, and is heavily used for various types of training. A hypothetical training scenario in the watershed was developed with three areas of different disturbance levels (Figure 28). The three areas represent light, moderate, and heavy disturbances, using the changes to soil and cover parameters as shown in Table 27. The pre-training scenario was parameterized with the unmodified out-of-the-box dataset that included a 10 m DEM, 2011 NLCD land cover, STATSGO soils, and regional channel cross-sections. Model input parameters were modified for the three levels of training disturbance in the three training areas for the post-training scenario. A 10 year-1 hour design storm (39 mm) was used for both pre- and post-training simulations. The Range 83 watershed was discretized into 606 hillslope elements and 245 channel elements. The relative differences for runoff and sediment yield were plotted across the watershed.

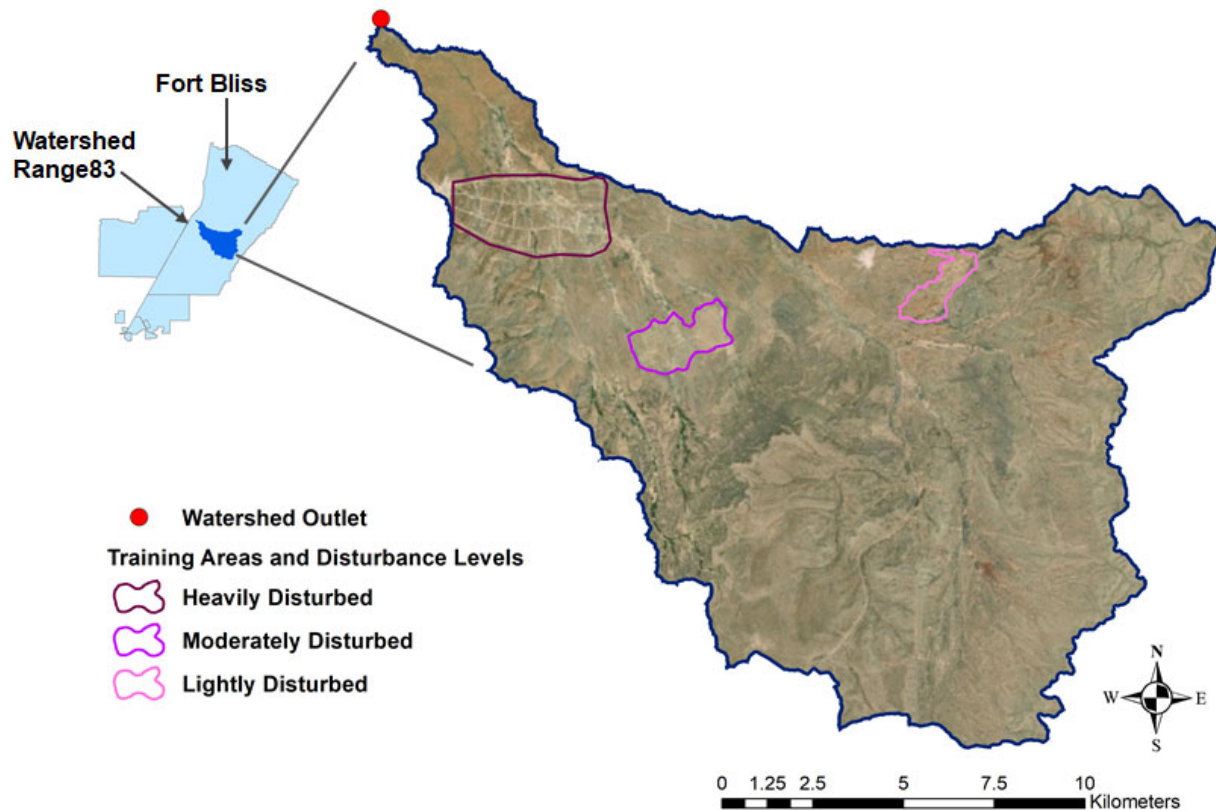


Figure 28. Map showing the watershed at Range 83 (221 km²) at Fort Bliss and three disturbance areas for a hypothetical training scenario. See Figure 4 for Fort Bliss location.

6.4.5.2 Results

The relative differences in runoff volume and sediment yield between the pre- and post-training simulations were determined in AGWA and are shown in Figure 29. Darker colors and thicker lines indicate greater change, and designate the hillslope elements and channel elements that are subject to risk of increased runoff and sediment yield caused by this hypothetical training. Subwatersheds that intersect the disturbed areas show over 300% increase in runoff from the hillslopes and in the channels, and over 600% increase in sediment yield from the hillslopes and nearly 500% increase in the channels. These simulation results demonstrate that AGWA can be used to identify areas at risk of increased runoff and sediment yield as a result of military training exercises in a rangeland environment.

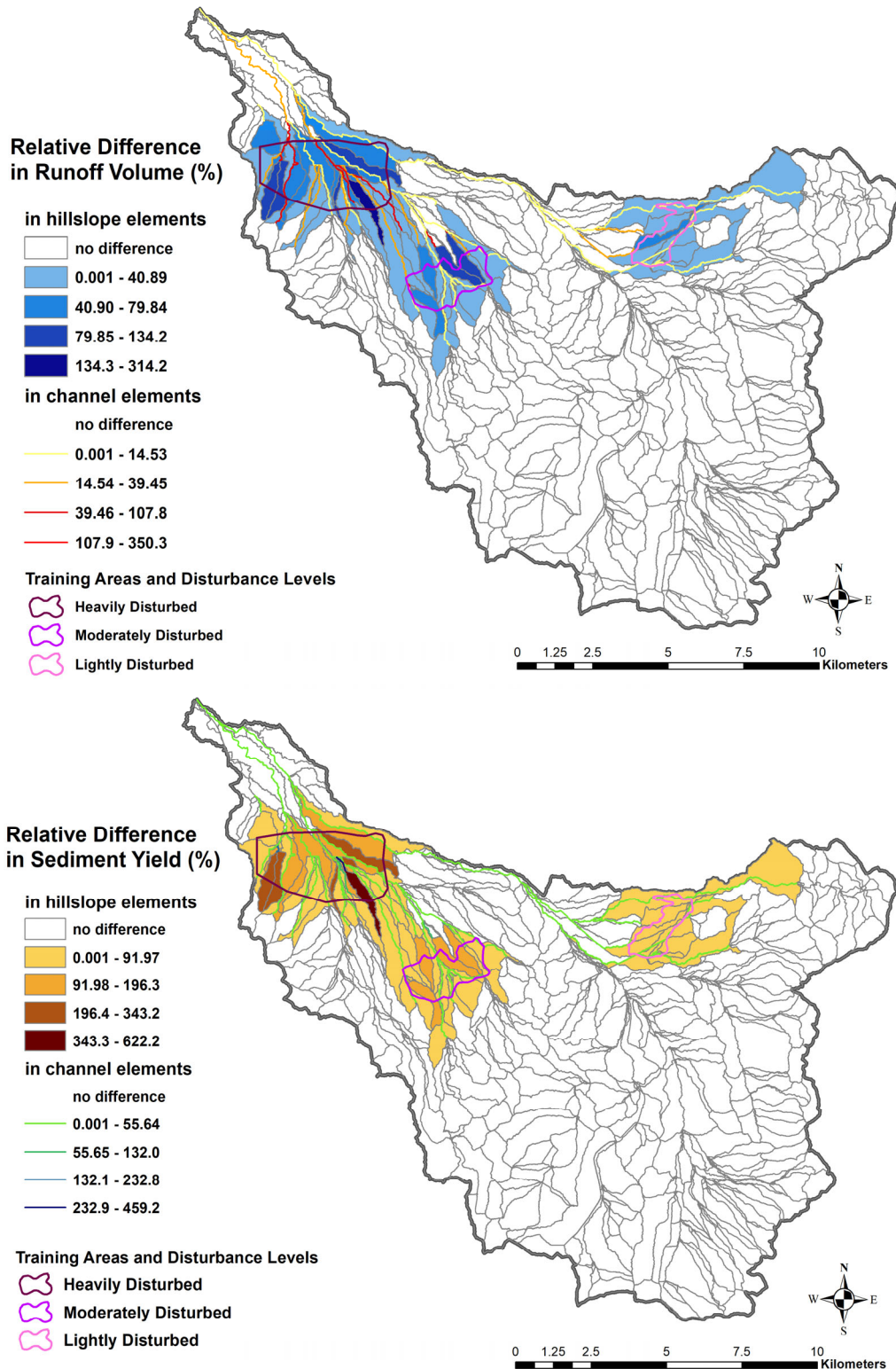


Figure 29. Maps showing the relative difference (%) in runoff volume (top) and sediment yield (bottom) between pre- and post- training simulations, at the three disturbance areas, in the Range 83 watershed at Fort Bliss. Darker colors for hillslope elements indicate greater change. Color gradation for channel elements indicates percent change.

6.4.6 Fort Carson EISA Section 438 demonstration using the AGWA Urban Tool

Water pollution from stormwater runoff in urban and developing areas is a leading cause of impaired waters. Section 438 of the Energy Independence and Security Act of 2007 (EISA) requires federal agencies to reduce stormwater runoff from federal development projects to address this concern. The primary aim is to “maintain pre-development site hydrology by retaining rainfall on-site through infiltration, evaporation/transportation, and re-use to the same extent as occurred prior to development (USEPA, 2009).” A variety of stormwater management practices falling under the umbrella of green infrastructure (GI) or low impact development (LID) can be used for compliance. The AGWA Urban Tool incorporates many green infrastructure practices and was tested here to demonstrate its suitability for EISA Section 438 compliance.

The AGWA Urban Tool allows for the design and placement of GI practices such as retention basins, permeable pavements, and rainwater harvesting using the KINEROS2 “Urban” element (Figure 1). The Urban element represents up to six overland flow areas that contribute runoff to a paved, crowned street. Streets are used as conveyances out of the watershed, which here is a neighborhood or subdivision. The following configurations are supported: (1) directly connected pervious area, DCP, (2) directly connected impervious area, DCI, (3) indirectly connected pervious area, ICP, (4) indirectly connected impervious area, ICI, (5) connecting pervious area, CP, and (6) connecting impervious area, CI.

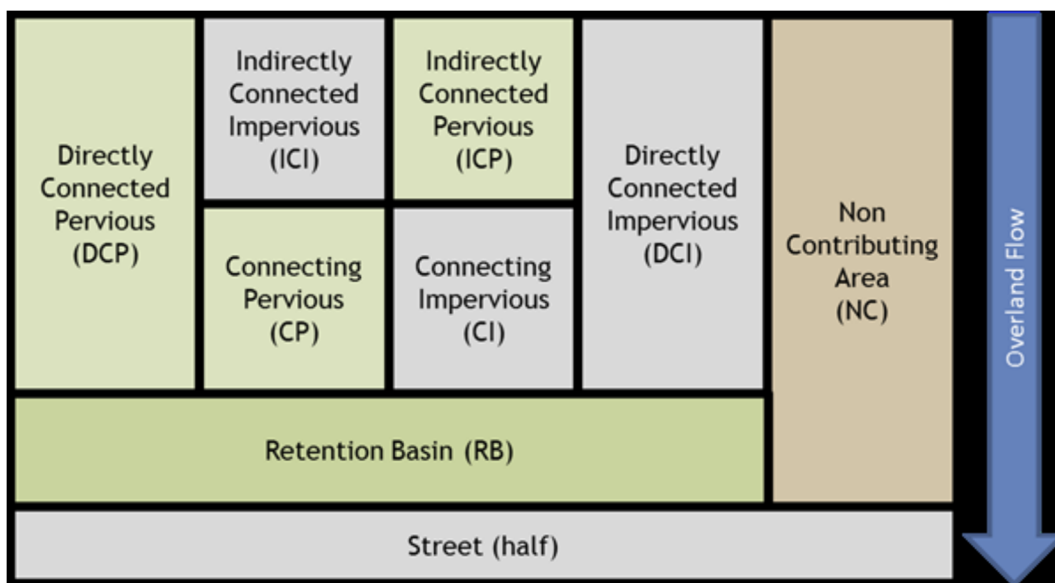


Figure 30. Schematic of the KINEROS2 Urban Element

6.4.6.1 Approach

A subdivision of the Iron Horse Park Neighborhood located in Fort Carson, Colorado (Figure 31) was used for this demonstration. The 46 parcels of the subdivision (Figure 32) were represented by a parcels shapefile created by on-screen digitizing of Google Earth Imagery. The streets of the subdivision were created by using a subtract/erase GIS function to remove the parcels polygons

from a bounding polygon. Official parcel and streets maps with surveyed dimensions would allow for more accurate water balance accounting and should be used whenever possible, although for this exercise the digitized parcels and streets are sufficient to demonstrate the applicability of the AGWA Urban Tool for stormwater management.

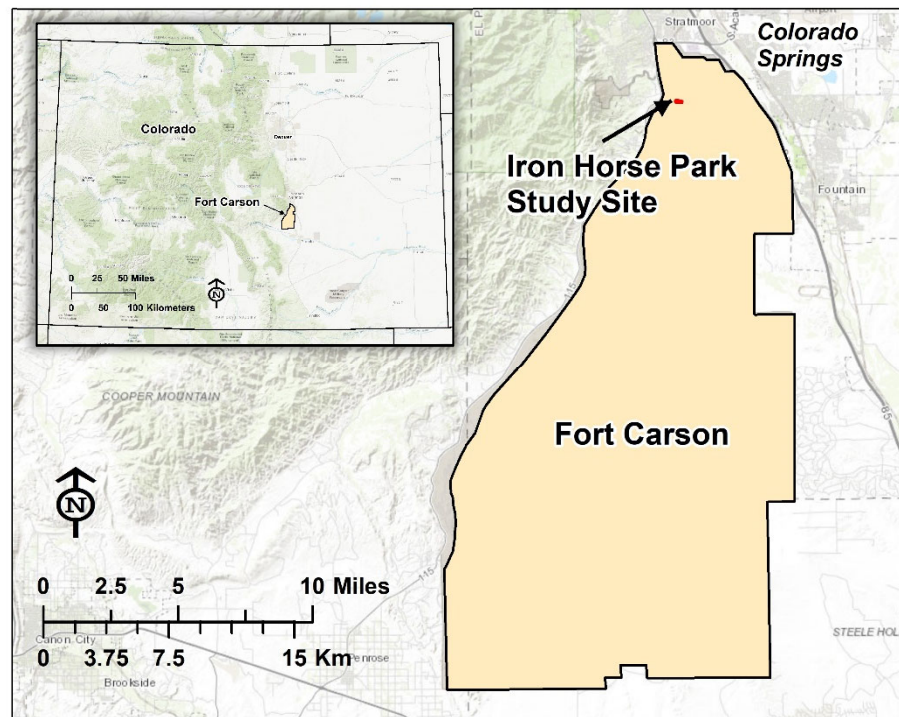


Figure 31. Location map of Fort Carson, Colorado, and the Iron Horse Park study site

To evaluate the suitability of the AGWA Urban Tool to model impacts of development and the green infrastructure necessary to reduce the associated increase in stormwater runoff, three simulations were performed: 1) a pre-development scenario that establishes the runoff target for post-development; 2) a post-development scenario that illustrates the increase in runoff caused by the development; and 3) a post-development with green infrastructure scenario that illustrates the AGWA Urban Tool, and the green infrastructure practices built into it, that can be used to demonstrate, via simulation, compliance with Section 438.

Section 438 specifies that onsite management practices should capture the 95th percentile storm. This is defined as “the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily event occurrences during this period.” (USEPA, 2009). In lieu of the entire daily record for this location, which was not readily available, the NOAA Atlas 14 Precipitation Frequency Atlas (Perica et al., 2013) was used via the NOAA Precipitation Frequency Data Server (<https://hdsc.nws.noaa.gov/hdsc/pfds/>). The atlas contains precipitation frequency estimates for a range of durations and return periods, of which the 25-year, 24-hour event is most similar to the storm requirements for Section 438 (Figure 4). The depth for this event was 92.96 mm, which

was disaggregated into a hyetograph for KINEROS2 using the NRCS Type II (USDA NRCS, 2015) methodology.



Figure 32. Image of the analysis area, showing the parcels at the Iron Horse Park neighborhood (yellow outlines), at Fort Carson, Colorado

The three scenarios (pre-development, post-development, and post-development with green infrastructure) all used the same parcels and streets map. The pre-development scenario depicts the delineation of the lots, with the lots represented with natural land cover and soil properties (derived from SSURGO soils), and the roads representing an existing street network. The post-development scenario adds houses and driveways to the pre-development scenario. The post-development with green infrastructure scenario adds retention basins to the post-development scenario, though permeable pavements and rooftop rainwater harvesting features could also be added but were unnecessary to maintain the pre-development site hydrology.



NOAA Atlas 14, Volume 8, Version 2
 Location name: Colorado Springs, Colorado, USA*
 Latitude: 38.734°, Longitude: -104.7956°
 Elevation: 5868.69 ft**
 * source: ESRI Maps
 ** source: USGS



POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Deborah Martin, Sandra Pavlovic, Ishani Roy, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Michael Yekta, Geoffrey Bonnin

NOAA, National Weather Service, Silver Spring, Maryland

[PF tabular](#) | [PF graphical](#) | [Maps & aeries](#)

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches) ¹										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.246 (0.200-0.305)	0.294 (0.239-0.365)	0.378 (0.306-0.472)	0.455 (0.366-0.570)	0.569 (0.444-0.752)	0.664 (0.503-0.890)	0.765 (0.557-1.06)	0.873 (0.606-1.25)	1.03 (0.682-1.51)	1.15 (0.739-1.72)
10-min	0.360 (0.293-0.446)	0.430 (0.349-0.534)	0.554 (0.449-0.690)	0.666 (0.536-0.834)	0.833 (0.650-1.10)	0.972 (0.736-1.30)	1.12 (0.815-1.55)	1.28 (0.888-1.83)	1.50 (0.998-2.22)	1.68 (1.08-2.51)
15-min	0.439 (0.357-0.544)	0.524 (0.426-0.651)	0.676 (0.547-0.842)	0.812 (0.653-1.02)	1.02 (0.792-1.34)	1.19 (0.898-1.59)	1.37 (0.994-1.89)	1.56 (1.08-2.23)	1.83 (1.22-2.70)	2.05 (1.32-3.06)
30-min	0.640 (0.521-0.794)	0.768 (0.624-0.953)	0.993 (0.804-1.24)	1.20 (0.961-1.50)	1.50 (1.17-1.98)	1.75 (1.33-2.35)	2.02 (1.47-2.79)	2.30 (1.60-3.29)	2.71 (1.80-4.00)	3.04 (1.95-4.53)
60-min	0.825 (0.671-1.02)	0.970 (0.788-1.20)	1.24 (1.00-1.55)	1.50 (1.20-1.87)	1.89 (1.49-2.53)	2.24 (1.70-3.02)	2.61 (1.91-3.63)	3.02 (2.11-4.34)	3.62 (2.41-5.36)	4.11 (2.64-6.13)
2-hr	1.01 (0.826-1.24)	1.17 (0.958-1.45)	1.49 (1.21-1.84)	1.80 (1.45-2.24)	2.29 (1.82-3.05)	2.72 (2.09-3.67)	3.21 (2.37-4.44)	3.74 (2.63-5.36)	4.53 (3.05-6.68)	5.18 (3.36-7.69)
3-hr	1.10 (0.906-1.35)	1.26 (1.03-1.55)	1.58 (1.29-1.95)	1.91 (1.55-2.37)	2.46 (1.97-3.29)	2.95 (2.28-3.98)	3.51 (2.60-4.86)	4.13 (2.93-5.91)	5.06 (3.43-7.46)	5.84 (3.81-8.63)
6-hr	1.26 (1.04-1.54)	1.43 (1.18-1.74)	1.78 (1.46-2.18)	2.15 (1.76-2.65)	2.78 (2.25-3.71)	3.36 (2.62-4.52)	4.02 (3.01-5.55)	4.77 (3.41-6.79)	5.89 (4.03-8.63)	6.83 (4.50-10.0)
12-hr	1.43 (1.19-1.73)	1.64 (1.36-1.98)	2.05 (1.70-2.50)	2.48 (2.04-3.04)	3.19 (2.59-4.21)	3.83 (3.01-5.10)	4.55 (3.44-6.23)	5.37 (3.87-7.58)	6.58 (4.54-9.57)	7.60 (5.05-11.1)
24-hr	1.62 (1.36-1.95)	1.88 (1.57-2.27)	2.38 (1.98-2.88)	2.87 (2.38-3.49)	3.66 (2.97-4.76)	4.35 (3.42-5.72)	5.12 (3.88-6.92)	5.97 (4.33-8.33)	7.22 (5.01-10.4)	8.25 (5.53-11.9)
2-day	1.86 (1.56-2.22)	2.17 (1.82-2.60)	2.76 (2.31-3.31)	3.31 (2.76-4.00)	4.18 (3.41-5.38)	4.93 (3.90-6.42)	5.76 (4.39-7.71)	6.66 (4.86-9.21)	7.98 (5.59-11.4)	9.05 (6.13-13.0)
3-day	2.03 (1.71-2.42)	2.38 (2.00-2.83)	3.02 (2.54-3.61)	3.62 (3.03-4.36)	4.56 (3.73-5.83)	5.37 (4.26-6.95)	6.25 (4.78-8.33)	7.21 (5.29-9.93)	8.61 (6.06-12.2)	9.74 (6.64-14.0)
4-day	2.18 (1.84-2.59)	2.55 (2.15-3.03)	3.22 (2.71-3.84)	3.86 (3.23-4.62)	4.84 (3.97-6.17)	5.68 (4.53-7.33)	6.60 (5.07-8.77)	7.61 (5.60-10.4)	9.06 (6.40-12.8)	10.2 (7.01-14.6)
7-day	2.58 (2.19-3.04)	2.96 (2.51-3.50)	3.67 (3.11-4.36)	4.34 (3.65-5.18)	5.38 (4.43-6.81)	6.27 (5.02-8.04)	7.24 (5.60-9.55)	8.30 (6.15-11.3)	9.84 (7.00-13.8)	11.1 (7.65-15.8)
10-day	2.92 (2.49-3.43)	3.33 (2.84-3.92)	4.08 (3.46-4.83)	4.78 (4.03-5.68)	5.86 (4.84-7.36)	6.77 (5.44-8.63)	7.77 (6.02-10.2)	8.85 (6.58-12.0)	10.4 (7.44-14.6)	11.7 (8.09-16.5)
20-day	3.84 (3.29-4.49)	4.40 (3.77-5.14)	5.35 (4.57-6.28)	6.19 (5.26-7.31)	7.42 (6.12-9.16)	8.41 (6.78-10.6)	9.46 (7.37-12.2)	10.6 (7.90-14.1)	12.1 (8.72-16.8)	13.3 (9.33-18.7)
30-day	4.60 (3.96-5.35)	5.29 (4.55-6.16)	6.43 (5.51-7.52)	7.40 (6.30-8.70)	8.76 (7.23-10.7)	9.82 (7.93-12.2)	10.9 (8.52-14.0)	12.0 (9.02-16.0)	13.5 (9.78-18.6)	14.7 (10.4-20.6)
45-day	5.57 (4.81-6.46)	6.42 (5.54-7.45)	7.79 (6.70-9.07)	8.91 (7.62-10.4)	10.4 (8.62-12.6)	11.6 (9.37-14.3)	12.7 (9.96-16.2)	13.9 (10.4-18.2)	15.3 (11.1-20.9)	16.4 (11.6-22.9)
60-day	6.41 (5.55-7.41)	7.39 (6.39-8.55)	8.94 (7.71-10.4)	10.2 (8.73-11.9)	11.8 (9.78-14.2)	13.1 (10.6-16.0)	14.2 (11.2-18.0)	15.4 (11.6-20.2)	16.9 (12.2-22.9)	17.9 (12.7-24.9)

¹ Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).
 Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
 Please refer to NOAA Atlas 14 document for more information.

Figure 33. Precipitation Frequency Table from the NOAA Precipitation Frequency Data Server (<https://hdsc.nws.noaa.gov/hdsc/pfds/>)

6.4.6.2 Results

The 92.96 mm of rainfall resulted in 58.26 mm of runoff in the pre-development scenario, and 71.72 mm of runoff in the post-development scenario (Table 1), or a 23.1% increase in runoff. According to Section 438, the additional 13.46mm of runoff resulting from the development should be managed on-site. Retention basins, permeable pavements, and rainwater harvesting cisterns installed on the lots are all typical on-site design options available in the AGWA Urban Tool that could be used to meet this objective. In this analysis, retention basins sized 12 feet long by 4 feet wide by 1.5 feet deep and installed on all lots with houses were able to successfully reduce the post-development stormwater runoff to within 1.5% of the pre-development runoff (Table 28). Increasing the retention basins size, adding permeable pavements, and adding rainwater harvesting cisterns could actually reduce the post-development runoff beyond the pre-development scenario. This exercise successfully demonstrated the ability of the AGWA Urban Tool to simulate the management of stormwater runoff to meet Section 438 guidance.

Table 28. Results of the AGWA Urban Tool exercise demonstrating utility for Section 438 analysis

Simulation	Infiltration (mm)	Runoff (mm)	Difference from Pre-development	
			Infiltration	Runoff
Pre-development	33.05	58.26	-	-
Post-development	20.53	71.72	-37.9%	23.1%
Post-development with Retention Basins	33.13	59.12	0.2%	1.5%

6.5 - PO5: Assess the ability of AGWA to identify the relative ranking of model outputs.

To assess ability of the model to reproduce the relative ranking of watershed modeling elements we employed the approach discussed in Sidman et al. (2015) where the ranking order is compared for each level of data using the Spearman's Rank correlation coefficient as outlined in McBean and Rovers (1998).

6.5.1 Introduction

AGWA provides useful decision-making tools for users to visualize and compare modeling results. For example, ranking the AGWA watershed elements by runoff or erosion predictions can be used to locate areas with high risk of flooding or sediment yield. Ranking the elements by the differences between two simulations (e.g., pre- and post-disturbance simulations), is an effective way to identify areas affected by this disturbance. The differences between two scenarios can be viewed as absolute or relative change. For absolute difference, the model should be carefully calibrated and validated with high quality input data. A relative difference analysis using out-of-the-box data, however, has proven to be effective in identifying areas of risks with an uncalibrated model.

The goals of this PO are to:

- 1) Demonstrate how to use the ranking of relative difference to locate areas of risk.
- 2) Evaluate the influence of an uncalibrated model and low data quality on the ranking of difference through the Spearman's Rank correlation coefficient analyses, by replacing the high-quality input with its low-quality alternative, one at a time. If a particular set of input data produces similar rankings to the calibrated model, then it can be used for identification of areas of risk to aid in decision-making.

The above analyses were conducted in the Red Rock Canyon watershed using RHEM input data of different qualities. Results of this PO can help installation managers understand how to use AGWA to aid in decision-making and assess the influence of data quality.

6.5.2 Methods

Procedures

The following steps were taken to meet PO5 (see flowchart in Figure 34).

- Step 1: Develop a military training scenario with different disturbance levels. This was based on a training that occurred in the Red Rock Canyon watershed in 2015.
- Step 2: Establish the pre- and post-training simulations using the RHEM model calibrated with the best available dataset described in Section 6.4.3.2. Demonstrate the visualization of the ranked differences in runoff volume, runoff peak, and sediment between the two simulations. This set of rankings will serve as the base line ranking for investigating the influence of data quality.
- Step 3: Replace the input data in the calibrated model with an uncalibrated model and low-quality alternatives one at a time, compute new rankings, and compare to the baseline rankings generated in Step2. Spearman's Rank correlation coefficient analysis will be used to provide statistical significance. Ten scenarios with different input alternatives were developed and compared.

10 m model configuration

A Spearman's Rank correlation coefficient analysis was conducted in the Red Rock Canyon watershed using the 10 m high-quality dataset as the baseline compared to the out-of-the-box dataset with a design storm. This was done because: 1) a model calibrated with the best available dataset as demonstrated in PCMS watersheds may not be available at other installations; 2) the 10 m discretization generated a different configuration of model elements that cannot be directly compared to the 2 m simulations; and 3) this allows for an evaluation of the value of the uncalibrated, out-of-the-box input dataset in decision-making. The uncalibrated model with the out-of-the-box dataset is represented by nationally available data, when used with a design storm, and does not require any local data. Please refer to Section 6.4.3.2 and Table 13 for data options for the different datasets.

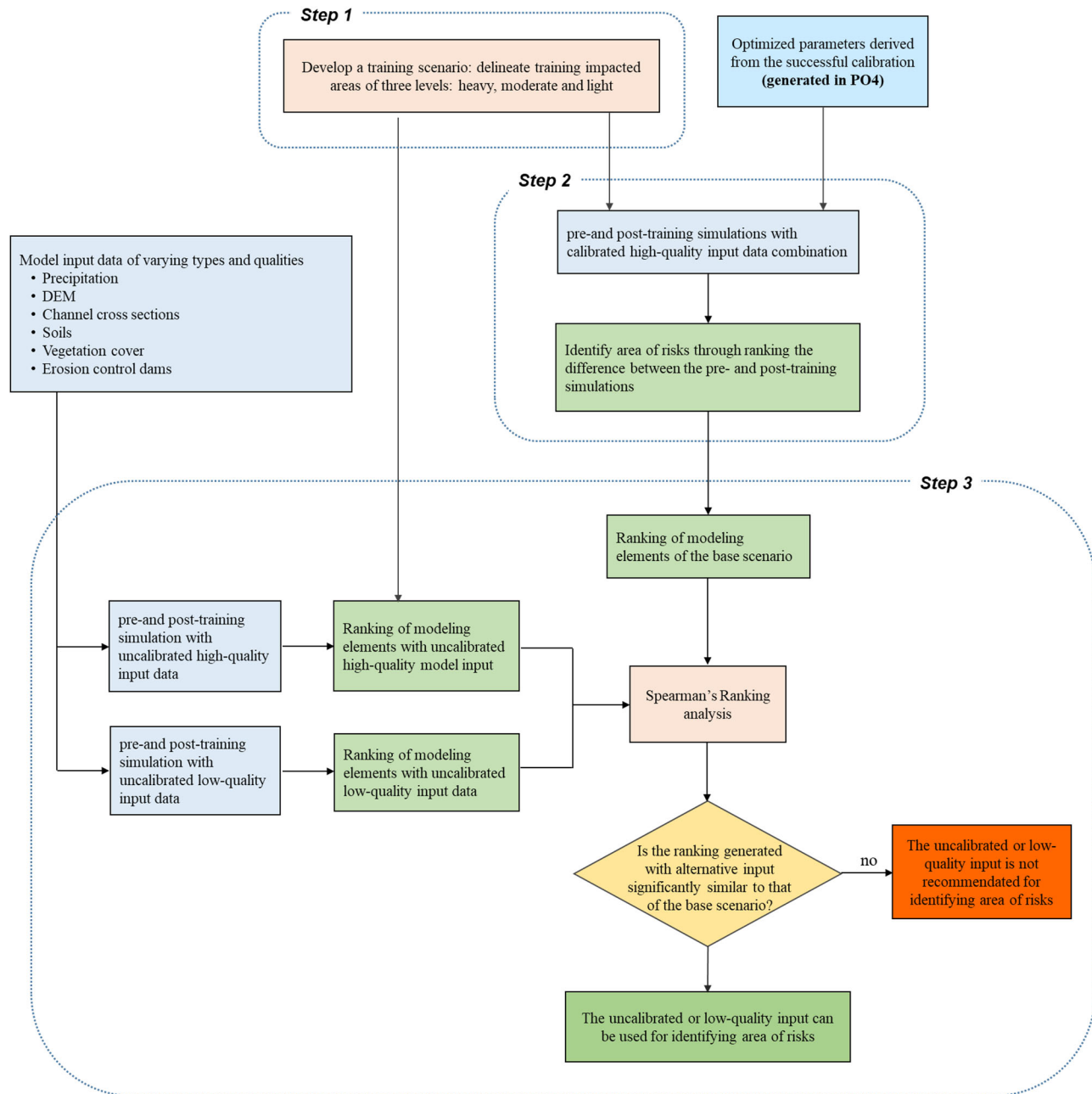


Figure 34. Flowchart of the relative change analysis conducted in the Red Rock Canyon watershed for PO5

Spearman's Rank correlation coefficient analysis

To assess the ability of the model to reproduce the relative ranking of watershed modeling elements we employed the approach discussed in Sidman et al. (2015) where the ranking order is compared for each level of data/information using the Spearman's Rank correlation coefficient as outlined in McBean and Rovers (1998). The Spearman's Rank correlation coefficient was tested for the null hypothesis that the coefficient is equal to zero and used a 5% significance level to determine if the correlation coefficient is significant (Snedecor and Cochran, 1967).

Spearman's Rank correlation coefficient measures the strength and direction of the association between two ranked variables (<https://statistics.laerd.com/statistical-guides/spearmans-rank-order-correlation-statistical-guide.php>). The coefficient will be high when two variables have a similar rank, and low when they have a dissimilar rank. A perfect Spearman's Rank correlation coefficient of +1 or -1 occurs when there is a perfect identical or opposed monotone association between the ranks of two variables, and 0 indicates no association (https://en.wikipedia.org/wiki/Spearman%27s_rank_correlation_coefficient). In this demonstration, we call the association strong, or the ranking is similar when the Spearman's Rank correlation coefficient is greater than 0.7, and weak or the ranking is dissimilar when the Spearman's Rank correlation coefficient is less than 0.3 (McBean and Rovers, 1998). The association is significant when $p < 0.05$.

Relative difference

Relative difference is defined as the percentage of the absolute difference between the pre- and post-training simulations relative to the pre-training results. Using runoff as an example:

$$\text{Relative Difference (\%)} = (\text{Runoff}_{\text{post}} - \text{Runoff}_{\text{pre}}) / \text{Runoff}_{\text{pre}} * 100$$

6.5.3 Results

6.5.3.1 Military training disturbance scenario

In 2015, a large military training event occurred at PCMS, although the exact disturbance levels and locations were unavailable to us. The PCMS ITAM staff, through field observations immediately following this training, mapped severely damaged areas that required mechanical repair. Surrounding these critical areas, we applied three buffers, 100 m, 500 m, and 1500 m, to create an estimate of disturbed areas for three levels: heavy, moderate, and light (Figure 35). Based on these buffers, about 28.16% of the watershed area and 36% of hillslope elements were disturbed, entirely or partially. The Red Rock Canyon watershed was used for this analysis.

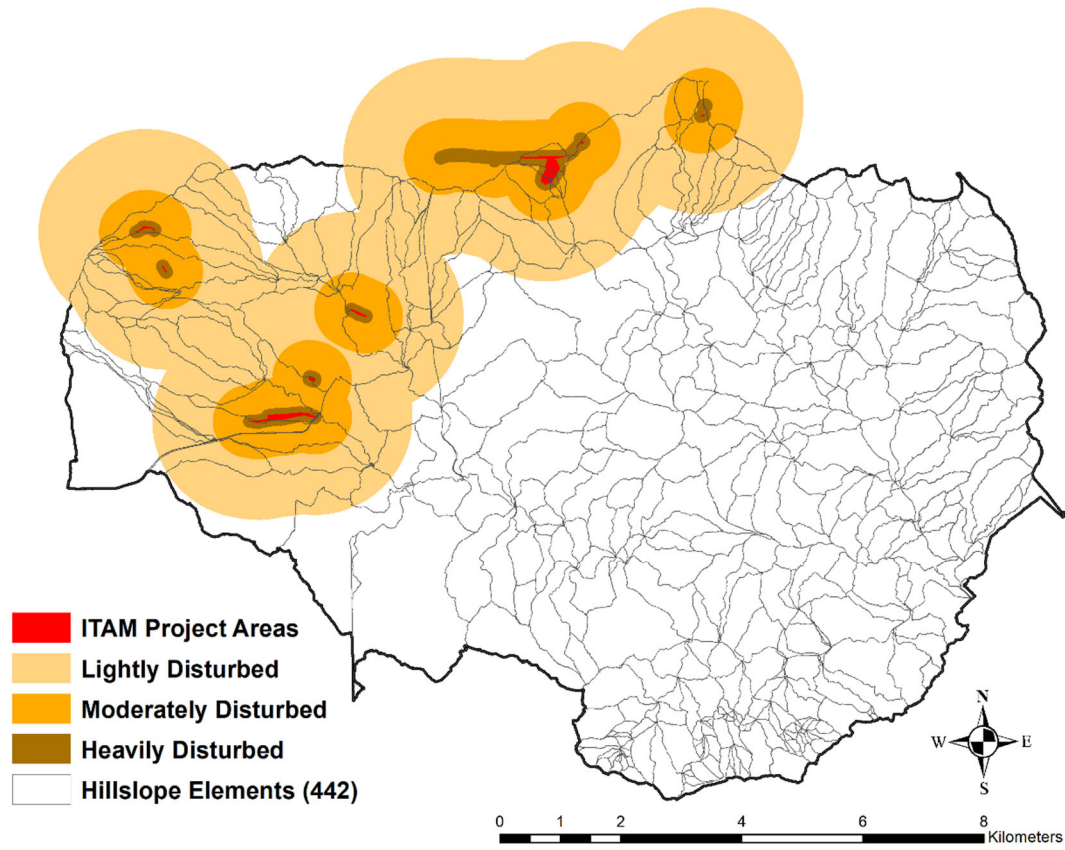


Figure 35. Map of hypothetical training disturbance areas at the Red Rock Canyon watershed based on areas mapped by PCMS ITAM staff, after the 2015 PCMS training

6.5.3.2 Pre- and post-training simulations

Using the calibrated high-quality input data derived in PO4 for RHEM (i.e., 2015 RTLA cover data, 2 m LiDAR DEM, LiDAR derived channel cross sections, erosion control dams, and SSURGO soils; see Section 6.4.3.2), the pre-training simulation was performed. Using the AGWA Military Disturbance Tool, which estimates the changes in canopy, basal, soil porosity, infiltration, and surface roughness due to the three levels of disturbance from vehicle compaction and removal of plants, the post-training parameter set was determined (see Section 6.6). Gauge rainfall from a storm on July 16, 2014 (ranging from 1.27 mm to 39.12 mm from seven gauges) was applied to the pre- and post-training parameter sets, and the relative difference between the two simulations in each modeling element was calculated.

6.5.3.3 Relative change following training activities

The relative differences in runoff and sediment yield across the watershed are displayed in Figure 36, with the color gradient showing the ranking of differences. Darker colors and thicker lines indicate greater change. In Figure 36, all relative differences are positive, indicating an increase in runoff and sediment yield in the disturbed elements. In the hillslope elements with the

highest risk, runoff increased by a factor of 7.41 and sediment increased by a factor of 17.06 (with relative differences being 741% and 1706%, respectively). This training also affected the runoff and sediment at the watershed outlet. Ranking of the elements provides a guide for decision makers to prioritize areas for cost assessment and remediation planning.

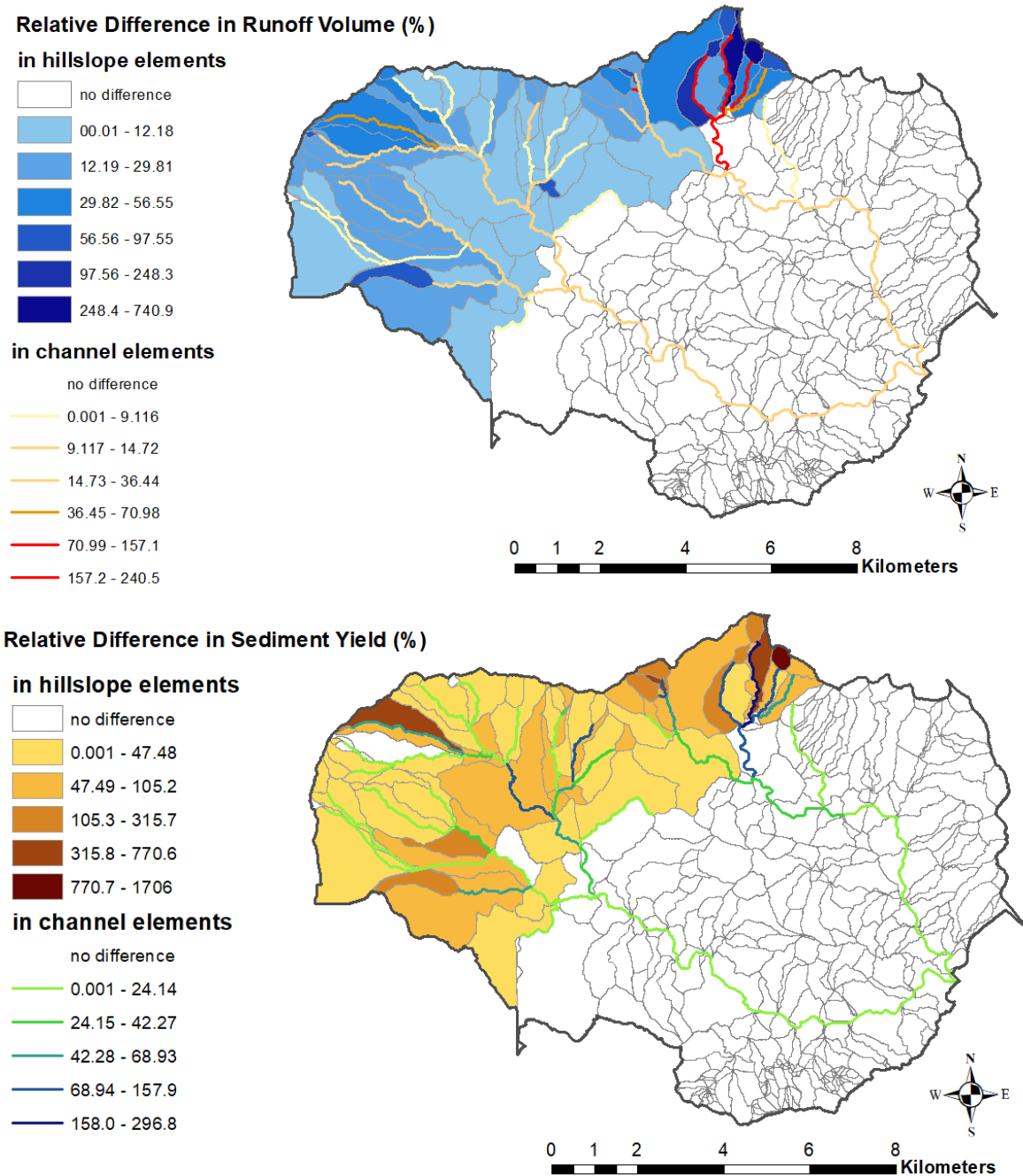


Figure 36. Maps showing the relative difference (%) in runoff volume and sediment yield between pre- and post- training simulations at the Red Rock Canyon watershed

6.5.3.4 Influence of data quality on ranking of differences caused by training

Results showed that replacing the calibrated model with the uncalibrated model did not significantly change the ranking of runoff or sediment yield in the model elements. Comparisons were done in both hillslope elements and channel elements. Table 29 shows the results for the hillslopes. Replacing gauge rainfall, RTLA cover, SSURGO soils, complex slopes, erosion control dams, and LiDAR derived channel cross sections with their lower quality alternatives all produced a ranking of modeling elements significantly similar to the baseline ranking created with the calibrated model. The influences on peak and sediment yield were greater than on runoff, with slightly lower coefficients.

Table 29. Spearman's Rank correlation coefficient analysis results for hillslope elements, with RHEM calibrated with the best available dataset as the baseline for comparison

Alternative Scenario	Spearman's Rank correlation coefficient (p)*		
	Runoff Volume	Runoff Peak	Sediment Yield
uncalibrated	0.99 (p<0.01)	0.97 (p<0.01)	0.88 (p<0.01)
closest gauge	0.97 (p<0.01)	0.97 (p<0.01)	0.90 (p<0.01)
furthest gauge	0.99 (p<0.01)	0.99 (p<0.01)	0.90 (p<0.01)
corrected DHR	0.97 (p<0.01)	0.97 (p<0.01)	0.87 (p<0.01)
uncorrected DHR	0.98 (p<0.01)	0.94 (p<0.01)	0.82 (p<0.01)
50 year-1 hour design storm	0.99 (p<0.01)	0.99 (p<0.01)	0.90 (p<0.01)
NRI cover	0.99 (p<0.01)	0.99 (p<0.01)	0.89 (p<0.01)
STATSGO soils	0.98 (p<0.01)	0.97 (p<0.01)	0.87 (p<0.01)
regional channel cross section	0.99 (p<0.01)	0.97 (p<0.01)	0.88 (p<0.01)
erosion control dams excluded	0.99 (p<0.01)	0.97 (p<0.01)	0.88 (p<0.01)

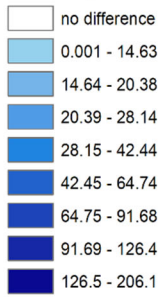
* strong when Spearman's Rank correlation coefficient >0.7; weak when Spearman's Rank correlation coefficient <0.3; significant when p<0.05

6.5.3.5 The 10 m high-quality dataset and the out-of-the-box dataset

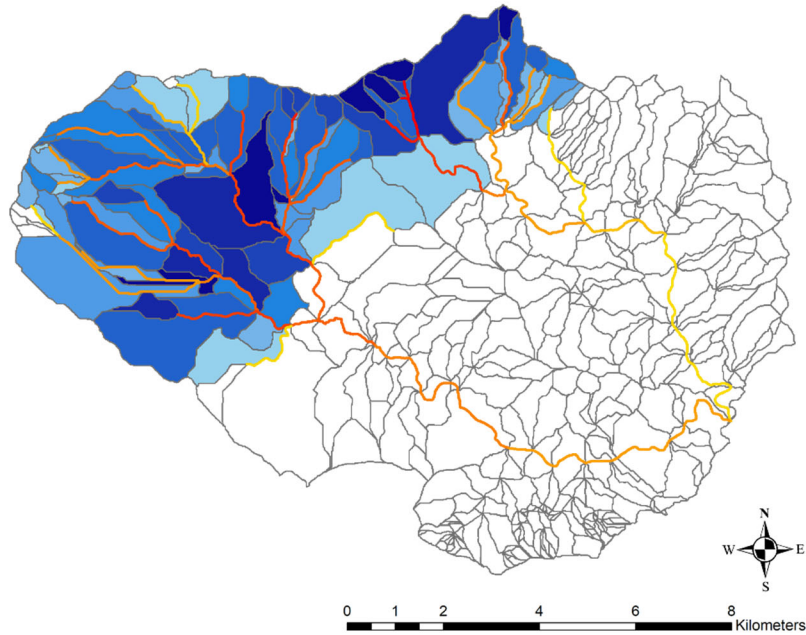
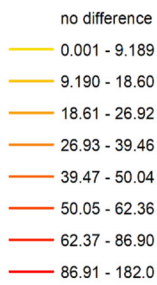
The results for the relative difference in runoff and sediment yield for pre- and post-disturbance based on the 10 m high-quality dataset with gauge rainfall from July 14, 2014 are shown in Figure 37. Spearman's Rank correlation coefficient analysis showed that the out-of-the-box dataset with a 50 year-1 hour design storm (56 mm) generated similar rankings to baseline rankings created with the 10 m high-quality dataset (Table 30). All changes were positive, indicating an increase in runoff and sediment yield due to the training.

Relative Difference in Runoff Volume (%)

in hillslope elements

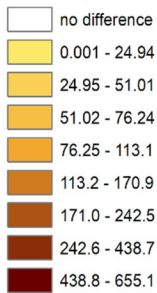


in channel elements



Relative Difference in Sediment Yield (%)

in hillslope elements



in channel elements

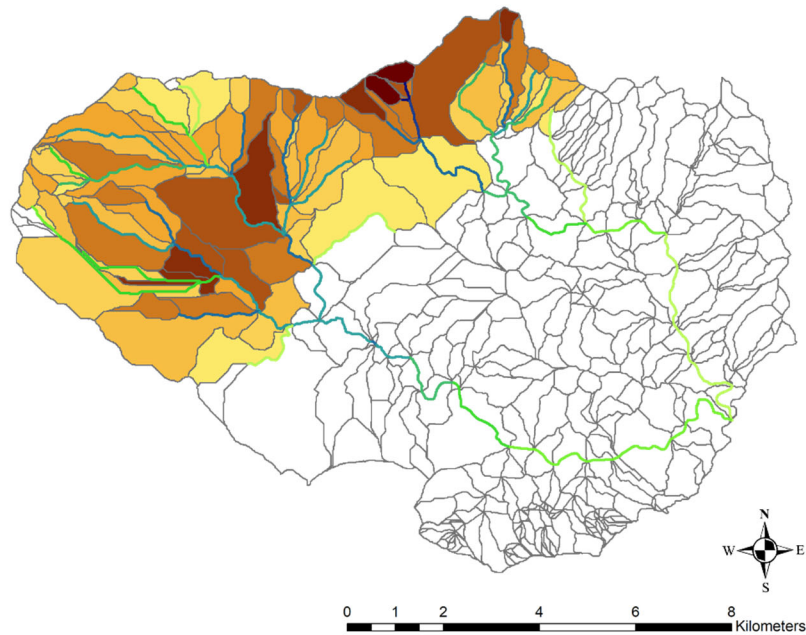
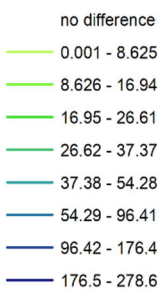


Figure 37. Maps showing the relative difference (%) in runoff volume and sediment yield between pre- and post- training simulations using the 10 m out-of-the-box scenario at the Red Rock Canyon watershed, PCMS

Table 30. Spearman’s Rank correlation coefficient analysis results for hillslope elements, with uncalibrated RHEM and the 10 m high-quality dataset as the baseline for comparison

Alternative Scenario	Spearman’s Rank correlation coefficient (p)*		
	Runoff Volume	Runoff Peak	Sediment Yield
10 m DEM, out-of-the-box, 50 year-1 hour design storm	0.97 (p<0.01)	0.98 (p<0.01)	0.98 (p<0.01)

* strong when Spearman’s Rank correlation coefficient >0.7; weak when Spearman’s Rank correlation coefficient <0.3; significant when p<0.05

6.5.4 Summary and Discussion

The success criteria for PO5 were met. This analysis successfully demonstrated the ranking of relative differences in modeling elements to locate areas of risk using different data sets. The Spearman’s Rank correlation coefficient analysis indicated that when using the 2 m discretization, no significant differences in ranking of model elements were identified if high-quality input data in the calibrated model was replaced with the uncalibrated model or with the low-quality data alternative. In addition, the out-of-the-box dataset with a design storm produced significantly similar rankings to the 10 m high-quality dataset. These results suggest that data quality is not an issue in identifying areas of risk through ranking the differences between a set of pre- and post-training simulations. However, it is important that the discretization produce elements of appropriate size to capture the training disturbances, and the design storm be large enough to produce runoff at the watershed outlet.

6.6 - PO6: Relate training disturbance to change in vegetation cover and soil properties.

The objectives of PO6 are to complete the following tasks and identify the following relationships:

- Complete the acquisition and analysis of Landsat imagery identifying changes in NDVI related to military training;
- Identify a relationship between military training maneuvers and vegetation cover when we find at least a five percent reduction in NDVI following maneuver training;
- Identify a relationship between military training maneuvers and the time required for vegetation cover to return to pre-maneuver disturbance levels when we find that at least one year is required before vegetation cover returns to within 10% of pre-maneuver training levels;
- Determine the extent of military maneuver training when we find at least a five percent change in NDVI between areas not disturbed by maneuvers and areas disturbed by maneuvers that had similar NDVI prior to military maneuvers;
- Identify changes in soil compaction/bulk density as a function of military activities determined with cone penetrometer measurements and pedotransfer functions.

This PO was successfully achieved in that we were able to relate training disturbance to changes in vegetation cover and soil properties. However, this was not achieved through the methods

defined in our original proposal that required actual military disturbance data and time-series Landsat NDVI data to develop the relationships. Actual disturbance data such as site-specific military land use data (dates, location, type and number of troops and vehicles, number of passes, etc.) were not readily available to us for this task. In addition, the Landsat NDVI data could not be used to identify areas of military training disturbance because NDVI did not show enough of a contrast between disturbed vs. undisturbed locations in this semi-arid grassland site. This was because the training disturbances on average did not result in site disturbances that significantly affected vegetation greenness or the changes to vegetation were masked by other factors (e.g., senescent vegetation).

In addition to NDVI, we also attempted to use a Landsat soil-adjusted total vegetation index (SATVI) product for vegetation cover to define the temporal relationship between training activities and vegetation change, but were only able to define this relationship when higher resolution imagery was first used to identify the locations of heavily disturbed areas (i.e., Google Earth). By selecting several visibly disturbed areas, we were able to determine a 4.9% reduction in Landsat-derived vegetation cover at these locations. For paired-plots using a Google Earth-identified heavily trained area and a nearby apparently undisturbed area, NDVI reduction was not statistically significant ($t = -0.92$, P one-tail = 0.19), but reduction in vegetation cover was significant for heavy disturbances ($t = -2.5$, P one-tail = 0.01). This indicated that the Landsat SATVI product was more effective in identifying heavily disturbed areas than Landsat NDVI in this semi-arid grassland. Using the Landsat time-series SATVI data we estimate that 4-8 years are required for heavily disturbed areas to return to pre-disturbed conditions, although this is climatically dependent, and it is also not known if any treatments were applied (i.e., seeding, mulching, etc.). We were unable to ground-truth these results because the images were from 1983 through 2013.

Our conclusion regarding use of Landsat data is that it is not suitable for this task because: 1) the data are too coarse (i.e., resolution = 30 m) to capture disturbances (often less than 30 m in extent); and 2) we did not have enough images to relate to actual training dates (only one spring and one fall image per year); and 3) actual training locations for all but the most recent events are difficult to identify. Improving the method of tracking actual training use areas could potentially make the use of Landsat data more feasible.

Another method we investigated is a time-series decomposition algorithm, BFAST (Breaks For Additive Season and Trend; Verbesselt et al., 2012; <http://bfaster-forge.r-project.org/>), to detect training activities and determine their effect on vegetation cover over time. The BFAST approach breaks down a dense time series of observations (i.e., Landsat NDVI time series) into long-term trend and seasonal components, and has shown promise in various ecosystem types for detecting abrupt changes in vegetation cover or land cover type (Verbesselt et al., 2010). The performance of BFAST improves with the length of the time series and the density of observations within that time series (i.e., number of NDVI images per year); for this reason, BFAST is a more robust method of analyzing vegetation change than the NDVI (Verbesselt et al., 2010) and SATVI analyses described above. However, BFAST implementations with Landsat data can be challenging due to irregularities of data availability throughout the year (e.g., due to clouds or smoke). Analyses with BFAST at PCMS were inconclusive and did not

achieve satisfactory results. We determined that this methodology would not meet our requirements.

Various studies and models have used data from training events or from experiments using military vehicles to evaluate changes in land condition (soil and vegetation cover properties) from military maneuvers for the purpose of determining land condition, carrying capacity, or land rehabilitation costs (e.g., see Donigian, 2013; Guertin and Meyer, 2002; Sullivan and Anderson, 2000). However, due to the wide variability in training activities (i.e., types and numbers of vehicles, duration of the exercise, types of maneuvers, etc.), and in landscapes (i.e., soil types, vegetation communities, topography, and climate) it is difficult to extrapolate results from those studies to other locations or to characterize a training event in terms of direct changes to soils and vegetation.

We investigated several Army models including TUDM (Training Use Distribution Model; Guertin and Meyer, 2002), and ATTACC (Army Training and Testing Area Carrying Capacity; Sullivan and Anderson, 2000), but sources indicate they have not been successfully applied due to the large amount of variability in training land conditions and training types. Other Army models were also unsuitable for our task, including EDYS-L (Ecological Dynamics Simulation Model – Light; Coldren et al., 2011), OPAL (OPAL Land Condition Model; Koch et al., 2014), and VDMTS (Vehicle Dynamics Monitoring and Tracking System; Koch et al., 2012). We also conducted an evaluation to better understand what occurs during military trainings: types of vehicles (wheeled or tracked), maneuver impact miles (MIMs), types of unit (Stryker Brigade, Armored Brigade, Infantry Brigade, Battalion, etc.), and types of training exercises (Heavy Division/Armored, Armored Division, Heavy Division/Mechanized, Mechanized Infantry Division, etc.).

Donigian (2013) provides an extensive literature review on methods to quantify vehicular impacts from military training on sediment transport, vegetation, and soil properties. He presents specific methodology for adjustment of various model input factors as a function of vehicle type, soil type, soil moisture, and military impact miles; however, he notes the difficulty in extrapolating results to other installations and ecological sites without extensive ground truthing, which is not within the scope of our project. P.J. Guertin (pers. comm., 2015) expressed concern regarding this variability, noting the lack of a reliable way to model training exercises, and recommended developing a more generic approach, including working with Range Operations and other installation staff.

Our solution to relate training disturbance to changes in vegetation cover and soil properties is to modify model input parameters for the level of disturbance, and perform a relative risk analysis (i.e., relative change) as opposed to an absolute value analysis. In cooperation with installation land managers at Fort Carson and Fort Bliss, we developed the Military Disturbance Tool (MDT) within AGWA to simulate changes in runoff and erosion resulting from military maneuvers. The tool relates disturbance of soil and vegetation cover from military maneuvers to changes in soil and vegetation cover properties for three general disturbance levels: light, moderate, and heavy.

The MDT is an optional tool in AGWA's parameterization step. The levels of disturbance and corresponding modifications to model input parameters (Table 31) are based on reviews of published literature and tables, RTLA data, NRCS soils data, and expert knowledge by installation managers, including natural resources, ITAM, and Range Operations personnel, at Fort Carson/PCMS.

The three levels of disturbance identified as representative of the most typical types of training effects are light, moderate, and heavy, with the following general descriptions of vehicle use and effects on vegetation and soil:

1. Light: few vehicle passes, mostly foot traffic, short duration, over a small area, little reduction in vegetation cover and ample seed sources for natural revegetation, soil stability is good, dry conditions that result in no visible ruts.
2. Moderate: moderate number of wheeled vehicles with some tracked vehicles, multiple vehicle passes, over a moderate area (i.e., approx. less than 50% of a training area), moderate loss of vegetation cover with some seed sources remaining for natural revegetation, soils are disturbed, with some ruts.
3. Heavy: large numbers of heavy wheeled vehicles and tracked vehicles, many vehicle passes, over more than 50% of the training area, for long duration (i.e., weeks), extreme loss of vegetation cover leaving mostly bare soil and no seed sources remaining for natural revegetation, increased soil disturbance with deep and numerous ruts, requires mechanical repair (to smooth ruts and reshape contours), reseeding, and mulch treatment necessary for recovery.

Model parameters that are most affected by training activities and that could be represented in KINEROS2, RHEM, and SWAT were identified based on published information and previous studies (Table 31, Table 32, and Table 33). For KINEROS2, we apply a percentage reduction in soil porosity and surface roughness (Manning's n), with saturated hydraulic conductivity and infiltration suction adjusted accordingly. The parameter revisions are currently implemented in a look-up table that can be revised for a new location if relevant information is available. For RHEM, additional parameter modifications include canopy cover, litter cover, and basal cover, with hydraulic conductivity, infiltration suction, and splash and sheet erosion adjusted accordingly. Curve numbers in SWAT are modified for each disturbance level based on land cover type condition and hydrologic soil group. The MDT is currently only implemented in AGWA for KINEROS2, but will be implemented for RHEM in the near future.

Table 31. Modifications to model input parameters for KINEROS2 and RHEM

Disturbance Level	Reductions to Model Parameters from Undisturbed Condition				
	KINEROS2 and RHEM		RHEM		
	Soil Porosity*	Roughness**	Canopy Cover	Litter Cover	Basal Cover
Undisturbed	0%	0%	0%	0%	0%
Light	-5%	-25%	-15%	-15%	-10%
Moderate	-10%	-40%	-30%	-30%	-20%
Heavy	-20%	-70%	-65%	-65%	-25%

* Soil Porosity is modified according to the degree of compaction (from von Guerard et al., 1993)

** Roughness or Manning's n is proportional to the amount of bare ground created by training activities. Defined for a given surface (i.e., grass, bare ground, pavement, shrub, etc.) as an "effective roughness coefficient that includes: the effect of raindrop impact; the effect of channelization of flow; the effects of obstacles such as litter, crop ridges, rocks, and roughness from tillage; the friction drag over the surface; and the erosion and transport of sediment" (Engman, 1986).

This method was presented to installation personnel during our AGWA-Facilitator trainings to get their feedback on the modifications to the model parameters. To further confirm our parameter modifications, Fort Carson staff provided SPOT satellite imagery taken immediately before a large training event in 2015 at PCMS, and imagery and photos taken immediately after that same event. We reviewed these images and photos with PCMS staff to confirm the three levels of disturbance and changes to parameters. The managers at Fort Carson and Fort Bliss approved the application of these values for AGWA. Overall responses were positive; they were in agreement with our categories of maneuver disturbance and parameter modifications, and suggested some minor revisions, which were incorporated. Figure 38 illustrates the effects of vehicle disturbance on soil and vegetation properties.



Figure 38. Illustrations of vehicle disturbances to soil porosity, surface roughness, and canopy, basal, and litter cover

To evaluate changes in runoff and sediment yield resulting from military training activities in the MDT, installation managers provide a polygon(s) of a disturbed area, and select the level of disturbance. To perform a relative risk analysis, soils and land cover data specific to the area of interest are used to create the pre-training parameterizations for the models. The MDT is then used to apply the appropriate changes to the parameters based on level of disturbance, and the model is run again to identify specific hillslopes or channel reaches most at risk of increased runoff or sediment yield as a result of the training disturbance. This method avoids the problems related to using Range Facility Management Support System (RFMSS) or Army Range Requirements Model (ARRM) data to determine training use, which are reported at the training area level, assume uniform use, and do not always reflect the number and types of vehicles that actually trained (i.e., use of these datasets requires numerous assumptions).

Table 32. Modifications to KINEROS2 and RHEM model input parameters for the Military Disturbance Tool

Model input parameters	KINEROS2	RHEM
Ks (effective hydraulic conductivity)	Calculated from Rawls et al. (1982)*; Modified values due to training calculated based on porosity change from von Guerard, et al. (1993); expert knowledge	Basal and litter cover (i.e., from RTLA data), and expert knowledge
G (infiltration suction)	Calculated from relationship between Ks and G from AGWA lookup table	Calculated from relationship between Ks and G from AGWA lookup table
Soil Porosity	Based on level of disturbance and resulting soil compaction; von Guerard, et al. (1993); Rawls and Brakensiek (1983); expert knowledge	Based on level of disturbance and resulting soil compaction; von Guerard, et al. (1993); Rawls and Brakensiek (1983); expert knowledge
Surface Roughness	Manning's n, from expert knowledge, based on percent of bare ground	Friction Factor, based on basal and litter cover (Hernandez et al., 2017), expert knowledge
Kss (splash and sheet erosion coefficient)	not a KINEROS2 parameter	Canopy and ground cover, from RTLA data and expert knowledge
Input Parameters	SWAT	
Curve Number	Curve Numbers based on National Engineering Handbook, Chapter 9, Table 9-2 (NEH; USDA-NRCS, 2004) for land cover type, and modified based on vegetation cover condition for level of disturbance	

* Equation to calculate Ks as a function of porosity (Rawls et al., 1982)

$$K_s = a \frac{\theta e^2}{\psi b^2} \frac{\lambda^2}{(\lambda+1)(\lambda+2)}$$

where θe = effective porosity (cm^3/cm^3), λ = pore size distribution, ψb = bubbling pressure (cm), a = a constant

Table 33. Modifications to Curve Numbers for SWAT based on land cover type and Hydrologic Soil Group

Disturbance Level	Hydrologic Soil Group	MRLC Cover Type: 71 Grasslands/Herbaceous	Curve Number	MRLC Cover Type: 52 Scrub/Shrub	Curve Number	MRLC Cover Type: 42 Evergreen Forest	Curve Number
Undisturbed	A	Herbaceous, Good to Fair conditions*	52	Desert Shrub, Fair to Good conditions	52	Pinyon-Juniper, grass story, Fair to Good conditions*	52
	B		67		70		50
	C		78		80		67
	D		87		85		76
Light	A	Herbaceous, Fair conditions	55	Desert Shrub, Fair conditions	55	Pinyon-Juniper, grass story, Fair conditions*	55
	B		71		72		58
	C		81		81		73
	D		89		86		80
Moderate	A	Herbaceous, Fair to Poor conditions*	59	Desert Shrub, Fair to Poor conditions	59	Pinyon-Juniper, grass story, Fair to Poor conditions*	59
	B		76		75		75
	C		84		83		83
	D		91		87		87
Heavy	A	Fallow, crop residue cover, Poor conditions	76	Fallow, crop residue cover, Poor conditions	76	Fallow, crop residue cover, Poor conditions	76
	B		85		85		85
	C		90		90		90
	D		93		93		93

Curve Numbers are based on Chapter 9, Table 9-2, National Engineering Handbook (NEH; USDA-NRCS, 2004)

*Desert Shrub values for HSG A were used where those values were missing from the table.

Poor condition: <30% ground cover (litter, grass, and brush overstory)

Fair condition: 30 to 70% ground cover

Good condition: >70% ground cover

6.7 - PO7: Assess the ability to parameterize the Facilitator Decision Support System with AGWA model outputs and additional criteria defined by decision makers.

PO7 assesses the successful creation of a Facilitator DSS analysis document which is built as an XML file (*.dss) using AGWA simulation results. An interface between AGWA and the Facilitator DSS will allow this functionality to be implemented. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

The success criteria for this PO were met. The AGWA model outputs were successfully exported directly into the Facilitator input file (.dss) for use in the Facilitator analyses. This was accomplished as a separate function within the AGWA tool, as the AGWA-Facilitator Export Tool. The tool can create the dss input file or it can modify an existing input file. After AGWA writes the simulation output data to the Facilitator file, the file can be opened in Facilitator to perform the decision analysis.

6.8 - PO8: Assess the effectiveness of the first AGWA-Facilitator training and needs assessment.

PO8 will be successfully achieved if results from the post-training surveys are positive and the needs assessment provides the necessary information to advance the project. Survey results will be collected and reported on a per installation basis initially, but during final reporting survey results will be averaged across installations. Section 5.3.1 describes the surveys, and blank forms are included in Appendix B. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

Based on the results of the Training Effectiveness surveys from the first trainings at each installation we met this PO only for the Fort Carson training. We did not meet this PO for the PCMS or Fort Bliss trainings. Average overall survey score was 63 and the lowest score was 43 (Table 34). We attributed these low scores to several factors:

1. The trainings were not long enough to adequately convey the functionality and applicability of the tools to their daily duties.
2. We had poor representation of the managers who would request the analyses provided by the tools.
3. Trainees did not feel they could use the tools in their workflow unless it was requested by their managers.

Table 34. Results of the Training Effectiveness Survey for the first trainings at Fort Carson, PCMS, and Fort Bliss

Training Effectiveness Survey		
	SUS score	lowest score
PCMS #1	55	43
Carson #1	75	53
Bliss #1	58	43
Average	63	

Following the first trainings, we modified our tutorials, presentations, and training agenda to improve effectiveness of the trainings, to reflect feedback from the trainees. Section 6.11 discusses these changes.

6.9 - PO9: Define the resources and expertise required to set-up the model by a GIS specialist level individual.

PO9 will be successfully achieved if following training the installation personnel can set-up AGWA in a reasonable period of time (< 40 hours) without additional support. Knowledge requirements for a user to set-up a session with the AGWA-Facilitator tools include GIS experience and an understanding of the decision-making process and terminology required by Facilitator. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

This PO was successfully met as determined by observing and interviewing participants at the second training. In addition, this PO was specifically addressed by Question #9 of the Training Effectiveness Survey (Table 37 and Appendix B):

“I think that this training gave me the skills to gather and organize the data to set up the model within a regular 40-hour week, with some remote assistance (if necessary).”

The average response to Question #9 from all trainings was 3.6 (Table 37), where the goal was 5 (strongly agree), indicating that we met this PO. Based on discussions following the training and survey results, most participants felt they would be able to set-up AGWA within the expected time frame (less than 40 hours). Some trainees performed the follow-up task of keeping track of the time it took them to set up and run AGWA-Facilitator on their own, and they were able to perform all tasks in less than 40 hours. Our experience indicates that users with some GIS experience are able to meet this time frame. More advanced GIS users would take significantly less time (8 to 16 hours), while inexperienced GIS users would require assistance and may require up to or more than 40 hours.

Most of our tutorials are designed to take 90 – 120 minutes, and are provided with all data ready to be used in the models. Observations during the second AGWA-Facilitator trainings showed this to be the case: the GIS personnel finished all tutorials quickly (within 90 minutes or less), while the other less experienced GIS users took longer (i.e., 130 minutes). In addition to GIS experience, total time is dependent on whether new datasets must be downloaded and prepared, the number of EC dams being modeled, the type of precipitation data being used, whether a fire scenario is included, and whether a full stakeholder meeting is held to develop the Facilitator input data. Data collection is the most time consuming task and includes downloading from a website, clipping to the area of interest, and re-projecting to the common data projection. The size of the dataset and study area, and the internet connection speed will also affect the total time required.

6.10 - PO10: Determine the expertise required to interpret the results of the models by an individual trained on the AGWA-Facilitator tools.

PO10 assesses the ability of installation managers and staff to understand the results produced by AGWA and the Facilitator DSS. Some of the knowledge required for this understanding include GIS concepts, hydrology, watershed modeling, the Facilitator decision-making process and terminology, and familiarity with the different management scenarios used at the military installation. At the end of the second training, surveys and discussion sessions enabled us to assess managers and trainees understanding of the AGWA modeling process, the Facilitator decision support process, and their ability to interpret results from both. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

This PO was not met based on Question #4 from the Training Effectiveness Survey (Table 37 and Appendix B):

“I think that I would need more training to be able to interpret the results from the AGWA-Facilitator decision-support system.”

The final overall score for this question was 3.4, “slightly agree” (Table 37), while the goal was “disagree” or 1. Most participants had good GIS skills (i.e., felt “comfortable using GIS”), but background in hydrologic principals and modeling varied as determined by the survey questions

regarding GIS skill and hydrologic principals/modeling background. Participants whose job duties were limited to GIS analysis with little interpretation did not feel they needed more training. However, participants that also performed interpretation, but had little hydrologic background, felt they needed more training. In general, participants commented that they would like more time to work with the data and models. These results suggest that a background in GIS and some knowledge of hydrologic principals are required for individuals to successfully interpret the results of the models. In addition, more lecture material addressing results interpretation, and/or stronger hydrologic backgrounds are required. While GIS experience was common, a background in hydrologic principals and modeling was not.

6.11 - PO11: Evaluate the effectiveness of the second AGWA-Facilitator training.

PO11 will be successfully achieved if results from the post-training survey are positive, indicating that the goals of the demonstration have been achieved. Further validation of the second training is based on the results from PO9, PO10, PO12, and PO13. Survey results were collected and reported on a per installation basis initially, but during final reporting survey results are averaged across installations. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

This success of this PO was determined based on the overall survey results from the second trainings for the Training Effectiveness Survey. The second trainings were organized with the first morning as a briefing to the managers where the overview presentations focused on the tools and applications within AGWA and the Facilitator. We invited the managers from most of the divisions, but few attended. We attribute this to our invitational materials not providing enough detail to convey the applicability of our tools to their job duties. Most attendees that ran the tutorials were GIS and other support staff. During the discussions, most trainees expressed interest in using the tools, although the most common comment was the need for more time for the trainings, more lecture and background material, and more buy-in from their supervisors.

The effectiveness of the trainings and the overall acceptance of the tools and intent to use them were determined using the survey responses and feedback during the discussion sessions at the trainings. In addition to the 10 Likert Scale questions (see Section 5.3.1), we included three additional questions on the surveys to help us understand the responses and determine the GIS and hydrologic backgrounds needed to use the tools. Table 35 shows the summary of SUS scores for each installation and training, and the overall average, for each survey. For the overall training results, we averaged the SUS scores across all trainings for each survey and for the individual questions that addressed the specific POs (Table 35 and Table 36). Appendix B includes blank copies of the two surveys.

Average overall score from all trainings based on the Training Effectiveness Survey was 64 (ranging from 30 to 93), indicating that we did not meet this PO (Table 35). We attribute this to very low scores given by the two Fort Carson ITAM staff at their second training who felt that these tools were not applicable to their current job duties because their supervisors would not request analyses using the tools. Their responses to the surveys reflected their perception that these tools were not useful to them. There were only five participants in this training and those

two scores strongly influenced the results. When their scores were removed from the total, the average score for all installations for the second training was 71, and the lowest individual score was 40.

Table 35. Summary of SUS survey scores for each installation and training

Training Effectiveness Survey			Usability Survey		
	SUS score	lowest score		SUS score	lowest score
PCMS #1	55	43	PCMS #1	49	40
PCMS #2	71	53	PCMS #2	66	55
Carson #1	75	53	Carson #1	68	43
Carson #2	63	30	Carson #2	68	43
Bliss #1	58	43	Bliss #1	58	43
Bliss #2	62	40	Bliss #2	60	45
Average	64		Average	61	

Table 36. Survey Questions used to address Performance Objectives

Performance Objective	Description	Survey	
		Training Effectiveness	Tool Usability
PO8	Assess the effectiveness of the first AGWA-Facilitator training and needs assessment	Survey total	n/a
PO9	Define the resources and expertise required to set up the model by a GIS specialist level individual	Question 9	n/a
PO10	Determine the expertise required to interpret the results of the models by an individual trained on the AGWA-Facilitator DST	Question 4	n/a
PO11	Evaluate the effectiveness of the second AGWA-Facilitator training	Survey total	n/a
PO12	Determine the ability of trained individuals to develop and run new scenarios after the second training.	Question 10	n/a
PO13	Evaluate overall user acceptance of the modeling system and intent to use it in decision-making, after the second training.	Questions 3, 6, and 8	Survey total and Question 1

PO8 and PO11 addressed the effectiveness of the first and second trainings, respectively (Table 37 and Appendix B). The overall survey results for all training showed that we did not meet the POs for either training effectiveness or tool usability. In general, the scores improved for the second training for each installation (see Section 5.4.5 for the Fort Carson second training results) after we revised the tutorials and presentations based on feedback from the first trainings to better meet the individual skill levels of the personnel. The surveys and questions were also used to determine if we met PO 8 through 13. Table 37 shows these results.

Table 37. Results for Performance Objectives as determined by survey questions

Training Effectiveness Survey			
Performance Objective	Questions	Result	Goal
PO 8: First Training Effectiveness	1st training average survey scores	62: not met	68
PO 9: Expertise needed to set up model in 40 hr week	Question 9 average response	3.6: met	5
PO 10: Expertise needed to interpret results	Question 4	3.4: not met	1
PO 11: Second Training Effectiveness	2nd training average survey scores	65: not met	68
PO 12: Develop and run new scenario	Question 10	2.4: met	1
PO 13: User acceptance and intent to use the tools	Question 3	3.9: met	5
2nd training results	Question 6	2.5: met	1
	Question 8	1.9: met	1
Usability Survey			
Performance Objective	Questions	Result	Goal
PO 13: User acceptance and intent to use the tools	Overall average survey scores	64: not met	68
Second training results	Question 1	4.4: met	5

Although the scores and results from the surveys indicate that we did not meet the performance objectives for training effectiveness (PO8 and PO11), feedback during the discussion sessions showed that most participants felt that the tools were valuable and could help them in their typical workflow. In fact, the ITAM staff at Fort Bliss has been applying AGWA since their first training in April 2017.

The key comments from trainees, and the reasons we believe the survey results were poor, were that the trainings were not long enough for the trainees to feel confident using the tools, and the presentations did not provide enough background on the tools. The second trainings were slightly longer, and the presentations and tutorials were more targeted; however, trainees wanted multi-day sessions with opportunity to bring in their own projects. The staff at Fort Bliss indicated that a 5-day training would be best for them, with 3 days of lectures, discussions, and hands-on tutorials, followed by 2 days of one-on-one sessions where a trainer helped apply AGWA-Facilitator to an actual problem.

Scores were low for Tool Usability from the first trainings and improved slightly from the second trainings after trainees became more familiar with the tools, and our presentations were revised. It is difficult to predict the knowledge and skill level of trainees and to format a training accordingly, and as a result, we presented different types of information and revised the agenda for each round of trainings. Future trainings should be preceded by a meeting with the relevant managers to better understand their workflow, and provide a better presentation of our tools and their applications. Presentations should include background information on hydrological modeling in general, on the models embedded in AGWA, and example applications more directly related to management of military lands.

6.12 - PO12: Determine the ability of trained individuals to develop and run new scenarios.

PO12 will be successfully achieved if after the second training installation personnel can use AGWA and Facilitator to develop, execute, and compare new scenarios and interpret results with limited support in one to two days. The success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

We met the success criteria for this PO, which was assessed using Question #10 of the Training Effectiveness survey (Table 37 and Appendix B).

“I do not think I could set up, run, and interpret a new scenario with minimal technical support in AGWA-Facilitator in 1-2 days.”

The final overall average score for this survey question was 2.4, “disagree” (goal = 1, strongly disagree), indicating that they did think they could set up a scenario within 1-2 days. Note that this survey question was negative (i.e., they thought they could not set up, run, and interpret a new scenario in 1-2 days); therefore, if they thought they could set up, run, and interpret a new scenario in 1-2 days, they would mark “disagree”. The highest scores (i.e., agree or strongly agree) were from staff with strong GIS or hydrologic backgrounds.

A follow-up task was provided that requested installation personnel to report the time they took to develop and run a new scenario on their own. A follow-up form listed each task, and requested the participants to show the time spent on that task, who performed the task, and provide any other comments. Although most trainees expressed a desire to do this, we received only one response, from the ITAM GIS/LRAM Coordinator at Fort Bliss. His follow-up form showed that he was able to perform all AGWA tasks within one day. He did not use the Facilitator for this exercise.

6.13 - PO13: Evaluate overall user acceptance of the modeling system and intent to use it in decision-making.

PO13 will be successfully achieved if the survey results from the second training are positive. However, the ultimate measure of success will be if the installation begins using AGWA on an operational basis. Survey results will be collected and reported on a per installation basis initially, but during final reporting survey results will be averaged across installations. The

success criteria for this PO are measured as PASS/FAIL without complex data analysis that would require statistical procedures/tests to judge performance.

This PO was addressed with the overall results from the Usability Survey (Table 37 and Appendix B), and specifically in Question #1 from that survey:

“I think that I would like to incorporate AGWA or AGWA-Facilitator into my workflow when possible.”

This PO was not met based on overall score of 65 for the Usability Survey from the second training. However, based on the results for Question #1 (4.4, “agree”), we did meet the PO. Trainees were interested in using AGWA-Facilitator in their workflow, and the staff at Fort Bliss already are using it.

7.0 COST ASSESSMENT

This section provides cost information for implementation of AGWA-Facilitator at a military installation. The AGWA-Facilitator tools will provide added support to military resource managers in their decision making to ensure sustainability of natural resources and the military mission.

7.1 COST MODEL

Table 38 presents a cost model for the implementation of AGWA-Facilitator. Additional details for the Cost Elements in Table 38 are included after the table. This model assumes that the required geospatial data are already available at the installation and in a common projection. Our prior experience with military installations confirms this is a valid assumption. The table includes cost information for developing additional data for analysis of features such as erosion control dams or training disturbance areas. Required geospatial data are:

- DEM (LiDAR or 10 m)
- Land cover/land use (NLCD or SWReGAP)
- Soils database (SSURGO, STATSGO, or FAO)
- Precipitation data (design storms or observed events)

Suggested supplemental data to assist in scenario development are:

- Erosion Control Dams location layer, and dam configuration
- Polygon layer of training disturbance areas with level of disturbance (undisturbed, light, moderate, or heavy)
- Installation boundary layer
- Roads layer
- Training Areas layer

The following personnel types and costs (includes fringe benefits and overhead at ~34.7%, based on University of Arizona rates) were assumed for calculating the cost estimates in Table 38. Average salary data were obtained from the USA Jobs website (<https://www.usajobs.gov/>; accessed August 17, 2016 and April 20, 2018), searching for job postings for the U.S. Army for these job titles in Natural Resources or Administration, and using the average salary listings divided by 2080 hours to get hourly rates. Time required for each cost element is assumed based on experience at AGWA trainings for this project and others such as BAER teams, universities, and federal agencies, and from estimates from AGWA Team members in Tucson, Arizona.

- GIS Specialist: Average \$70,000 annual cost, \$34/hr.
- AGWA/GIS Programmer: Average \$101,000 annual cost, \$49/hr.
- Natural Resources Officer: Average \$94,500 annual cost, \$45/hr.
- Project Manager/Supervisor: Average \$135,000 annual cost, \$65/hr.

Table 38. Cost Elements for Project Cost Assessment (based on 2016 and 2018 data)

Cost Element	Data Tracked During the Demonstration	Estimated Costs
1. AGWA Setup	• Time required to gather data and use AGWA to characterize the military installation and parameterize the models, with existing data and for preparing new data.	• GIS Specialist: 3 hours, \$102 • Non-GIS user or Natural Resources staff: 8 hours, \$360 • Additional GIS Specialist time to gather and prepare all new data: 4 hours, \$136
2. Model refinement	• Time to complete performance objectives. • Time required to calibrate and validate the model if possible.	• Approximately 2 years, one supervisor, two GIS specialists, two GIS programmers, \$954,000 • Approximately 6 months, one GIS specialist, \$35,000
3. Modify AGWA	• Time and cost to modify AGWA to assess different scenarios, if required. • Military Disturbance Tool • Erosion Control Dams Pond Tool • Facilitator DSS	• AGWA Programming Costs: \$20,850 • Military Disturbance Tool: GIS specialist, 80 hours \$2,720, plus GIS programmer, 60 hours \$2,940, Total \$5,660 • Pond Tool: GIS programmer, 190 hours, \$9,310 • Facilitator: GIS programmer, 120 hours, \$5,880
4. Equipment	• Procurement costs associated with computers, and data storage.	• Computer: \$3,500 • Data storage 2 TB: \$60
5. Training	• Time and costs associated with training military land managers how to use AGWA and the Facilitator DSS, 1.5 – 2-day training.	• Training Personnel: two Supervisors, two GIS Programmers, 4 days, \$11,696 • Training Materials Preparation: three Programmers, 80 hrs. each, \$11,760
6. Field work	• Time and costs associated with field trips to gather and interpret military vegetation monitoring, soils, and remotely-sensed data as appropriate.	• Site visits: Two project supervisors, three AGWA GIS programmers, 4 days, \$13,264

7. Data Preparation	• Time and costs associated with preparing local data for entry into AGWA. • Time and costs associated with preparing input data for the Facilitator	• Prepare new data including downloading from internet, clipping, and projecting to study area: GIS Specialist, 4 hours, \$136 • Prepare input data for erosion control dams (locations, and stage-discharge data) using AGWA Pond Toolbox and Add Storage Tool: GIS Specialist \$12 per pond/EC dam. Add \$25 per pond/EC dam if added manually. Assume 50 EC dams added using the tool, \$600. • Identify and prepare input data for alternatives and criteria for the Facilitator, no non-installation stakeholders: Two project supervisors, 4 hours, \$260, two natural resource officers, 4 hours, \$180 = \$440 • Identify and prepare input data for alternatives and criteria for the Facilitator, with outside stakeholders: Two project supervisors, 8 hours, \$520, two natural resource officers, 8 hours, \$360 = \$880
8. Alternative approaches	• Time required to run the USGS StreamStats stream gauged based runoff regression relationships at each of the PCMS gauging stations.	• GIS specialist: 1 hour, \$34
9. Personnel	• Identify the personnel requirements for the operational deployment of AGWA on a military installation.	• IT or GIS staff to install AGWA-Facilitator on personnel computers, GIS staff to prepare and distribute data, and Natural Resources and ITAM staff familiar with ArcGIS to operate AGWA-Facilitator and provide expert knowledge of the site; GIS Programmer, \$49/hr, GIS Specialist \$34/hr, Natural Resources/ITAM staff \$45/hr, project manager/supervisor \$65/hr

Total costs		• AGWA-Facilitator operation, all data prepared, no EC dams, or outside stakeholders, \$902 • AGWA-Facilitator operation, new data acquired and prepared, \$1,038 • AGWA-Facilitator operation, all data prepared, with EC dams, no outside stakeholders, \$1,502 • AGWA-Facilitator operation, all data prepared, with EC dams, with outside stakeholders, \$1,942 • Training cost (personnel and materials preparation), \$23,456 • AGWA-Facilitator modifications (EC Dams and Add Storage Tools, Military Training Disturbance Tool, AGWA-Facilitator coupling), \$20,850
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Detailed Description of Cost Elements in Table 38.

7.1.1 AGWA Setup

Costs are based on experience at Fort Carson and Fort Bliss, and at numerous AGWA trainings (i.e., National DOI BAER teams, US EPA, NWS, BLM, BIA, and USGS). GIS skill level varied greatly at those trainings, and times used in this estimate represent average times assuming the geospatial data are already prepared. Cost to setup AGWA is dependent on GIS experience, and type and quality of available data (see Section 6.9). For example, if all data are already prepared and available (DEM, land cover, soils, and precipitation), and no Erosion Control Dams or other special features will be modeled, time and costs will be lower than if all new data are procured via the internet (download, clip, and project to the study area), or if field work is required to obtain coordinates of erosion control dams or training disturbance locations.

7.1.2 Model refinement

This cost refers to the total time required to complete all performance objectives, for one demonstration site. Our first demonstration site, PCMS, required approximately two years to complete; however, several new tools for AGWA were created as part of that demonstration, as noted elsewhere in this report. This was a one-time cost, and therefore subsequent demonstrations were completed in less time, i.e., one year, assuming no additional modifications to AGWA-Facilitator are requested by the installation. This cost assumes one supervisor, two GIS specialists, and two GIS programmers.

Calibration and validation of the hydrologic models embedded in AGWA is also part of the model refinement. This will enable an assessment of data worth across installations with varying levels of watershed observations. The calibration and validation costs are one-time costs for the PCMS demonstration, and not projected to be a cost for the deployment of this technology and

methodology for installations after this demonstration. This cost assumes one GIS specialist to perform the calibration/validation analysis.

7.1.3 Modify AGWA

New tools created for AGWA-Facilitator included the ability to design and model erosion control dams, and the ability to represent three levels of military training disturbance (light, moderate, and heavy). In addition, a new tool was created that adds the AGWA simulation results (peak flow and sediment yield) to the Facilitator input file (.dss). Note that these modifications were a one-time cost and were added due to the land uses at Pinon Canyon Maneuver Site and requests from the ITAM and Natural Resources staff. Application of these tools at other installations may require modification or development of additional tools that could require additional programming and related costs.

7.1.4 Equipment

AGWA operates on computers that have ArcGIS installed; however, a more powerful processor and increased RAM are recommended for the most efficient operation. The estimates in the table are based on computers currently being used at our facility to run AGWA. Data storage is dependent on the type of datasets being used, with larger storage required for LiDAR data and imagery.

7.1.5 Training

Estimates are based on AGWA-Facilitator trainings conducted at PCMS/Fort Carson and Fort Bliss for this project. In addition, costs for AGWA trainings at Fort Irwin, YPG, Fort Bliss, Fort Huachuca (SERDP Project RC-1727), and other agencies (BAER, EPA, NWS, etc.) were considered. Note that only the Fort Carson and ESTCP Fort Bliss trainings included the Facilitator, and although no stakeholders or community members were present, estimates are based on those trainings and previous experience with the Facilitator.

Costs include time required to develop the training materials specific to the concerns and issues at the installation, and all personnel costs associated with travel to/from the training location, for a total of 4 days. Personnel include two supervisors, and two GIS programmers to conduct the training, and three GIS programmers to develop training materials. This is an anticipated cost for each installation where the technology and trainings are deployed.

7.1.6 Field work

No field work was conducted for this project; however, two site visits were conducted for the first demonstration at PCMS, and one site visit was conducted at Fort Bliss. The first site visit to Fort Carson/PCMS was to view disturbed areas, rehabilitated sites, EC dams, and overall land condition, and to meet with personnel to discuss their practices, data, and concerns. The second site visit was to meet with personnel and present our proposed modifications to AGWA-Facilitator for their input and approval before the initial training materials were developed. The

site visit to Fort Bliss was to meet with installation personnel and introduce the project. This is an anticipated cost for each new installation where the technology and trainings are deployed.

7.1.7 Data Preparation

Costs for data preparation are dependent on whether the required datasets are already available (i.e., DEM, soils, landcover, and precipitation), the condition of those data (e.g., common projection, and clipped to the study watersheds), or need to be downloaded from the internet and prepared (the most time consuming condition).

The time required to prepare the model input data for erosion control dams (locations and stage-discharge data) using the AGWA Pond Toolbox and Add Storage Tool also depends on the available data. The least costly condition is if all erosion control dam locations and configurations are known and represented in the LiDAR DEM. Field work to locate the dams and manually enter their location into the DEM could add significant time, depending on the number of dams.

Time required to prepare the model input data for analysis of disturbed sites would be minimal since staff presently evaluate those sites for land recovery and rehabilitation. The GIS data layers, photos, site condition information, and rehabilitation costs can be readily used in AGWA-Facilitator.

7.1.8 Alternative approaches

KINEROS2 simulated design storm runoff were compared to results derived from regional regression equations derived by the USGS Stream Stats website (Capesius and Stephens, 2009) from stream gauging data. These equations can be interactively accessed within a geographic interface as part of the StreamStats (<http://water.usgs.gov/osw/streamstats/colorado.html>) program.

7.1.9 Personnel

Based on our experience, IT or GIS staff are required to install and operate AGWA-Facilitator on installation computers, GIS staff are needed to prepare and distribute geospatial data, and Natural Resources and ITAM staff familiar with ArcGIS are needed to develop scenarios, and provide expert knowledge of the site. This is an anticipated cost for each installation where the technology is deployed.

7.1.10 Total Costs

Costs are described in Table 38 for implementation by the installation using different levels of data, for our costs for modifying the tools as requested by the installation, and for training them on the tools. Costs for implementation by the installations are dependent on the expertise and knowledge of the potential users, and data availability including locations and descriptions of EC dams, and locations and conditions of disturbed sites or burned areas.

7.2 COST DRIVERS

The primary cost drivers in assessing whether to implement AGWA-Facilitator at a facility are described below. In general, initial meetings with installation managers regarding their procedures, practices, data, concerns, and typical work flow will be the first step in determining whether to implement these tools.

AGWA:

The key management issues of concern at an installation and the geospatial data available will influence how and if AGWA should be implemented. This includes collection of field data on specific additional attributes such as additional climate or stream flow data, or data regarding the locations of erosion control dams or other features that would affect model parameterization and results. Another consideration is the acceptability of applying AGWA as a relative change tool to determine change in runoff or sediment yield resulting from a land use such as a military training exercise, or newly developed areas. In these cases, accurate information regarding the footprint and nature of the change (soil, land cover, or topography) would be required. Beyond using AGWA as a relative change tool, additional labor costs will be added if a need is defined that requires the models to be calibrated and validated.

Facilitator:

The costs of applying the Facilitator depend on the degree of stakeholder engagement needed, and on the difficulty in estimating the effects of alternatives on the criteria of interest (other than runoff and sediment yield estimated by AGWA). Inclusion of non-installation stakeholders in the stakeholder engagement process and/or the need for quantification of stakeholder preferences will significantly increase costs beyond what is projected in this section. Increased costs will be associated with possibly hiring a public outreach expert and expert facilitator (may be the same person) and may significantly increase the level of effort for installation personnel to attend meetings, workshops, focus groups, etc. Installations that experience severe encroachment issues, or installations where mission changes may affect the surrounding community, may require more intensive stakeholder engagement than installations not facing such issues. If no stakeholders outside of the installation were involved, costs would be limited to what is required to estimate the effects of the alternatives on the criteria of interest. This may require significant time to research the actual costs of management actions such as the design and placement of erosion control dams, or green infrastructure practices.

7.3 COST ANALYSIS AND COMPARISON

A key focus of this project was to apply AGWA-Facilitator for relative change assessments of runoff and sediment yield due to land disturbance from military training activities and to prioritize site recovery efforts. There are no comparable hydrologic models available for this purpose that can be used for cost comparison. This type of modeling analysis is typically not performed, and selection of disturbed sites for recovery is historically done via visual observation, site reconnaissance, and satellite/aerial imagery. However, AGWA-Facilitator can provide a more efficient method of selecting the most cost effective and highest risk sites for recovery, thereby decreasing the overall cost of training land recovery.

Most of the data used in the AGWA-Facilitator are currently available at all military installations, and personnel typically have computers capable of running the tools, including a DoD site license for the ArcGIS software (required to run AGWA), therefore there would be little cost associated with data or hardware. There are no costs associated with AGWA-Facilitator; both tools are public domain and can be downloaded without cost via the internet.

StreamStats is a web-based product from U.S.G.S. that provides users with previously published information for USGS data-collection stations (<http://water.usgs.gov/osw/streamstats/>).

StreamStats may be quicker to apply, and therefore less costly, but it does not have the ability to determine relative change, provide input to Facilitator, or use local data, which are all available in AGWA.

8.0 IMPLEMENTATION ISSUES

This demonstration included two trainings on the tools, and additional meetings as necessary at each of the three installations. The trainings involved presentations, discussion sessions, and hands-on tutorial exercises using AGWA-Facilitator, and were focused on land management concerns identified by the installation managers and staff. The tutorials provide step-by-step detailed instructions on running the models, and all geospatial data were provided in a ready-to-use format. While the trainings were well received and participants expressed interest in using the tools, finding the time required to become proficient enough to apply the tools in their routine workflow is a concern. Implementation of the tools will be more likely if administrative and/or upper management personnel are familiar with the tools, understand their value in improving land management efforts, and request the types of analyses from their personnel that AGWA-Facilitator provides.

It is expected that the tools will be a time-saver in the long-term as staff with years of field experience retire and are replaced by staff with GIS expertise but little field knowledge. The tools will aid in the prioritization of disturbed or burned areas to be recovered, and locations for new erosion control dams, without time-consuming and costly field work, and will focus limited funding on the most at-risk locations. Other implementation issues are training of staff on use of the tools, turnover of trained staff (lack of continuity), and incorporating the tools into their routine workflow. The changes applied to the variables for each disturbance level in the Military Disturbance Tool may need to be revised for different installations, requiring modifications to the look-up tables in AGWA.

No computer installation issues are associated with AGWA-Facilitator, and there are no regulations or restrictions on the use of the tools. AGWA is in the public domain and operates within the ArcGIS environment as an add-in (plug-in). DoD personnel have access to ArcGIS, therefore no new software or installation is required. From an installation perspective, software installed on military computers requires a Certificate of Networkiness prior to installation. AGWA obtained a Certificate of Networkiness (CON; Cert# 201418208, dated 10/28/14, currently extended through 2020 pending the new Access Only protocol, and applicable to AGWA version 3.x). Facilitator is open-source, and runs in the Java Runtime Environment (JRE) as a Java Archive (JAR) executable, therefore no installation is required. Facilitator is approved under this CON for Java. Online documentation, tutorials, and updates for AGWA are freely available at www.tucson.ars.ag.gov/AGWA. Facilitator documentation and updates are freely available at <http://facilitator.sourceforge.net/>.

This demonstration included calibration and validation of the models embedded in AGWA (KINEROS2, RHEM, and SWAT) with various levels of data. The purpose was to recommend the types of data best suited for installation applications, and to determine the optimal number of precipitation and streamflow gages needed for AGWA's predictive capabilities. Calibration of the models is only necessary if absolute model output values are required. If a relative change assessment is acceptable, calibration is not necessary.

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APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Dave Goodrich	USDA-ARS Southwest Watershed Research Center 2000 E. Allen Rd., Tucson, AZ 85719	Tel: 520-603-2194 Fax: 520-670-5550 Dave.Goodrich@usda.gov	Lead PI
Phil Heilman	USDA-ARS Southwest Watershed Research Center 2000 E. Allen Rd., Tucson, AZ 85719	Tel: 520-647-9202 Fax: 520-670-5550 Phil.Heilman@usda.gov	Co-PI
Phil Guertin	University of Arizona School of Natural Resources & the Environment-Research Tucson, AZ 85721	Tel: 520-621-1723 Fax: 520-621-8801 dpg@email.arizona.edu	Co-PI
Lainie Levick	University of Arizona School of Natural Resources & the Environment-Research Tucson, AZ 85721	Tel: 520-647-9153 Fax: 520-670-5550 llevick@email.arizona.edu	Co-PI
Leonard Cook	Fort Carson Directorate of Public Works Environmental Division 1626 Evans Street Bldg. 1219 Fort Carson, CO 80913	Tel: 719-526-1696 leonard.cook32.civ@mail.mil	Fort Carson/PCMS Contact, DPW Environmental, Conservation/Fire
Everett L. Duis Jr.	Fort Bliss Army Base, DPTMS, Trng Div, ITAM Bldg 2412, Rm 4 2412 Hinman Rd USAG Ft Bliss, TX 79916	Tel: 915-568-7444 everett.l.duis3.civ@mail.mil	Fort Bliss Contact, ITAM Coordinator

Appendix B: Training Effectiveness and System Usability Surveys

AGWA-Facilitator Survey: Evaluate the effectiveness of this Final Training

1. I think that the training was worthwhile.

Strongly Disagree	2	3	4	Strongly Agree
1				5
2. I found the training was too short to cover the material adequately.

Strongly Disagree	2	3	4	Strongly Agree
1				5
3. I think I will want to use the results from an AGWA or AGWA-Facilitator analysis.

Strongly Disagree	2	3	4	Strongly Agree
1				5
4. I think that I would need more training to be able to interpret the results from the AGWA-Facilitator decision-support system.

Strongly Disagree	2	3	4	Strongly Agree
1				5
5. I found the training contained a sufficient mix of background material and hands-on use of the tools.

Strongly Disagree	2	3	4	Strongly Agree
1				5
6. I found the training was missing critical components or information needed for me to successfully integrate AGWA-Facilitator into my workflow.

Strongly Disagree	2	3	4	Strongly Agree
1				5
7. I found the training was equally accessible to individuals with backgrounds in GIS, and individuals with backgrounds in range management, hydrology, watershed modeling, biology, or forestry.

Strongly Disagree	2	3	4	Strongly Agree
1				5
8. I found the training did **not** improve my ability to make more informed and/or better management decisions.

Strongly Disagree	2	3	4	Strongly Agree
1				5
9. I think that this training gave me the skills to gather and organize the data to set up the model within a regular 40 hour week, with some remote assistance (if necessary).

Strongly Disagree	2	3	4	Strongly Agree
1				5
10. I do **not** think I could set up, run, and interpret a new scenario with minimal technical support in AGWA-Facilitator in 1-2 days.

Strongly Disagree	2	3	4	Strongly Agree
1				5
11. I feel comfortable using GIS.

Strongly Disagree	2	3	4	Strongly Agree
1				5
12. I do not have a strong background in hydrologic principals or modeling.

Strongly Disagree	2	3	4	Strongly Agree
1				5
13. Optional
 - a. Name _____
 - b. Primary Job Responsibility _____

Please use the reverse side of this paper for additional comments. Thank You for your participation!
 Email or mail this completed survey to Lainie Levick, llevick@email.arizona.edu
 USDA-ARS/SWRC, 2000 E. Allen Road, Tucson, AZ 85719

AGWA-Facilitator Final Survey on System Usability
Evaluate your overall acceptance and intent to use this system in decision-making

1. I think that I would like to incorporate AGWA or AGWA-Facilitator into my workflow when possible.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

2. I found both AGWA and the AGWA-Facilitator tool unnecessarily complex.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

3. I thought both AGWA and the AGWA-Facilitator tool were easy to use.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

4. I think that I would need the support of a technical person to be able to use AGWA or AGWA-Facilitator.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

5. I don't have the expertise/time to use this tool, but I see value in it if someone could perform an analysis for me.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

6. I think the tutorials, supporting online documentation, and data need revision or additional content to provide sufficient background for me to be able to use this system.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

7. I think that most people could learn to use the AGWA or the AGWA-Facilitator tool quickly.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

8. I do **not** think that AGWA-Facilitator can help document the decision-making process.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

9. I felt very confident using AGWA and/or the AGWA-Facilitator tool in the tutorials.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

10. I need to learn a lot of things before I could get going with AGWA and AGWA-Facilitator.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

11. I feel comfortable using GIS.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

12. I do not have a strong background in hydrologic principals or modeling.

Strongly Disagree 1	2	3	4	Strongly Agree 5
------------------------	---	---	---	---------------------

13. Optional

a. Name _____

b. Primary Job Responsibility _____

Please use the reverse side of this paper for additional comments. Thank You for your participation!

Email or mail this completed survey to Lainie Levick, llevick@email.arizona.edu
 USDA-ARS/SWRC, 2000 E. Allen Road, Tucson, AZ 85719

Appendix C: Supporting Technical Data

Table 39. Brief descriptions of characteristics, capabilities, and intended applications of the AGWA watershed models: SWAT and KINEROS2

AGWA Watershed Runoff and Erosion Models	KINEROS2	SWAT
a. Temporal resolution (i.e., event, average annual, or fully dynamic).	event; user-defined time step in minutes	continuous time, long-term yield; daily time step with reporting options for daily, monthly, or yearly
b. Spatial resolution (i.e., spatially averaged, fully discrete, or hybrid).	spatially averaged	non-spatial hydrologic response units define spatially averaged subwatersheds
c. Computational requirements (i.e., computing platforms and run times).	Windows based; seconds to several minutes depending on event duration and watershed size and complexity	Windows based, seconds to several minutes depending on time simulated and watershed size and complexity
d. Data input needs (e.g., rainfall, stream flow, vegetation maps, etc. and their spatial and temporal resolution).	Digital elevation model (DEM), soils data (NRCS SSURGO or STATSGO datasets, FAO soils), land cover (MRLC, NALC, SWReGAP, user supplied), event-based precipitation data (time-depth/intensity pairs, or depth/duration pairs, available as user input or generated from within AGWA)	Digital elevation model (DEM), soils data (NRCS SSURGO or STATSGO datasets, FAO soils), land cover (MRLC, NALC, SWReGAP, user supplied), climate data (uniform or distributed multi-gage data; daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, input from measured records and/or generated observations)
e. Biophysical setting (i.e., regionally specific, climatically specific, or broadly applicable).	developed for arid and semi-arid rangeland or urban applications dominated by Hortonian overland flow (not deep snow, or coastal/wetland applications)	broadly applicable
f. Output variables (e.g., loading to water bodies, routing and processes in water bodies for water flow, sediment, nutrients, etc.) (if applicable, separate by loading vs. water body processes). <i>Note: These are the current AGWA outputs from SWAT and KINEROS2; additional output variables are available from each model and can be added in response to installation feedback and needs.</i>	runoff (mm or m3), peak discharge (m3/s or mm/hr), channel infiltration (m3/km), plane infiltration (mm), sediment yield (kg) channel scour (mm), sediment discharge (kg/s)	overall hydrologic water balance for each hydrologic response unit (HRU) and/or subwatershed: precipitation (mm), sediment yield (t/ha), evapotranspiration (mm), channel discharge (m3/day), surface runoff (mm), percolation (mm), transmission loss (mm), nitrogen, phosphorous
g. Application history (i.e., types of management decisions to which the model or modeling system has been applied in the past).	land cover change, post-fire effects, stream network connectivity, peak flow analyses, detention basin recharge potential, evaluation of the effectiveness of conservation practices	land cover change, post-fire effects, climate change impact studies, pollutant loading into streams for Clean Water Act compliance and TMDL analyses (non-point source issues), flow permanence analyses, recharge estimation, evaluation of the effectiveness of conservation practices (BMP's such as filter strips, terracing, etc.), reservoir dynamics, snowmelt runoff, irrigation and brush removal scenarios, applicable for ungauged watersheds
h. Military land use context (i.e., degree to which parameters and processes in the proposed model are relevant to military land management needs).	AGWA model outputs and scale of analysis are relevant to military land management decision-making, and can be used to evaluate impacts of new or existing training activities or expansion of cantonments. The linked decision support tool (Facilitator) will enhance and streamline this analysis and decision-making process.	same as for the KINEROS2 model
i. Source code availability (i.e., open, proprietary, partially-proprietary, free to government users).	open-source	open-source
j. Model accessibility (i.e., website access, downloadable file).	freely available on the internet, http://www.tucson.ars.ag.gov/kineros/	freely available on the internet, http://www.brc.tamus.edu/swat/

Appendix D: ARS Manuscript Procedures Checklist – Submission Form

USDA-ARS Southwest Watershed Research Center, Tucson, AZ

CRIS # 871-2022-10-00-00-00

Peer Reviewers: **Peer Review was conducted by the Department of Defense, Environmental Security Technology Certification Program, see attached.**

Person Submitting Request: **Dave Goodrich**

Person to Contact for More Information: **Dave Goodrich**

Contact Phone Number: **520-647-9241**

E-mail address: **dave.goodrich@usda.gov**

Mark all that apply:

- ☐ Peer Reviewer comments addressed (on ARS-533 form or separate sheet of paper)
☐ Cleared by Cooperative Agencies/Institutions
☐ Abstract Only
☒ First Formal Report of Research Other Than Abstracts
☐ Date paper submitted to RL

Prominent issues

- ☐ Potential to Attract Media Interest/Attention
☒ Represents a Significant Scientific Advancement
☐ Significantly affect Existing or Future USDA Policy
☐ Potential Trade Implications
☐ Other (Specify)

Manuscript Title:

Automated Geospatial Watershed Assessment (AGWA) to Aid in Sustaining Military Mission and Training, Final Report, v2

Journal/Equivalent to which Manuscript is Being Submitted and date submitted:

Department of Defense, Environmental Security Technology Certification Program, Sept. 27, 2019

Publication Type (Proceedings, Refereed Journal, Book Chapter, etc): **Final Report**

Previous Submittal if Any: **none**

Due to Patent Potential, is Retention of Intellectual Property Rights Desired: **No**

Author: Last Name, Initials	Mode Code: All ARS authors have a Mode Code Ours is: 2022-10-00-00-00	Employer: If not ARS
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Armendariz, G.	5342-45-00-00-00	
Wei, H.		University of Arizona

Abstract:

This is the Final Report for the Department of Defense, Environmental Security Technology Certification Program project that demonstrates the Automated Geospatial Watershed Assessment (AGWA) tool coupled with the Facilitator Decision Support System (DSS) for scientifically based watershed assessments to address installation managers concerns of land disturbance from military training and testing, flooding, and erosion. Demonstration sites are Piñon Canyon Maneuver Site and Fort Carson, Colorado, and Fort Bliss, Texas/New Mexico. AGWA is a publicly available Geographic Information Systems (GIS) interface that uses national data to parameterize, execute, and visualize outputs of several watershed models at multiple temporal and spatial scales over a range of environmental conditions. The Facilitator DSS provides a flexible, easy to use, framework to structure and document installation manager experience, expert knowledge, and AGWA simulation model results to select a preferred management action. Tools within AGWA are the military training disturbance tool to evaluate changes in soil and vegetation cover resulting from training events; the erosion control structure tool to design and place these structures for flood and erosion control; the burn severity tool to evaluate prescribed and wildfire effects on site and downstream; the urban tool to evaluate stormwater flooding and green infrastructure practices; and the climate assessment tool. Two 1.5 to 2-day training sessions were conducted at each installation using hands-on tutorials, presentations, discussion sessions, and surveys. AGWA's embedded hydrologic models (KINEROS2, RHEM, and SWAT) were evaluated via data quality, and calibration/validation.

Interpretive Summary

This is the Final Report for the Department of Defense, Environmental Security Technology Certification Program project that demonstrates the Automated Geospatial Watershed Assessment (AGWA) tool coupled with the Facilitator Decision Support System (DSS). The purpose of the project is to support installation managers concerns of land disturbance from military training and testing, flooding, and erosion. Demonstration sites are Piñon Canyon Maneuver Site and Fort Carson, Colorado, and Fort Bliss, Texas/New Mexico. AGWA is a publicly available Geographic Information Systems (GIS) interface that uses national data to parameterize, execute, and visualize outputs of several watershed models at multiple temporal and spatial scales over a range of environmental conditions. The Facilitator DSS provides a flexible, easy to use, framework to structure and document installation manager experience, expert knowledge, and AGWA simulation model results to select a preferred management action. Management tools within AGWA are the military training disturbance tool to evaluate changes in soil and vegetation cover resulting from training events; the erosion control structure tool to design and place these structures for flood and erosion control; the burn severity tool to evaluate prescribed and wildfire effects on site and downstream; the urban tool to evaluate stormwater flooding and green infrastructure practices; and the climate assessment tool. Two 1.5 to 2-day training sessions were conducted at each installation using hands-on tutorials, presentations, discussion sessions, and surveys. AGWA's embedded hydrologic models (KINEROS2, RHEM, and SWAT) were evaluated via data quality, and calibration/validation.