AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT TOOL FOR RANGELANDS

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Abstract

Soil and water conservation is the keystone to sustainable livestock grazing and maintenance of native species on our western rangelands. Good rangeland management requires the ability to assess the potential impacts of climate and management actions on runoff and erosion at both hillslope and watershed scales. The premise of our research project is that the practice of rangeland management can be improved if rangeland managers have Decision Support Tools (DSTs) that are easy-to-use, built on range management concepts, use readily available data, and are designed for rangeland hydrologic and erosion processes. The project uses the Automated Geospatial Watershed Assessment tool (AGWA) as the foundation of a DST for rangeland watershed management. AGWA is GIS interface for data organization, parameterization, integration, and visualization of models to support watershed assessments; it was developed jointly by the USDA-ARS, U.S. EPA, University of Arizona, and University of Wyoming. The project integrates several ongoing projects to transform the current operational AGWA tool into a comprehensive DST for rangeland watershed management. Specifically, the project comprises: incorporating the Rangeland Hydrology and Erosion Model (RHEM) into the AGWA interface for hillslope assessments; developing parameterization methods that represent the complexity of rangeland sites for different models; developing tools that will allow users to represent and analyze the impacts common rangeland management practices have on runoff and erosion; and developing tools that will allow users to assess the costs of soil and water conservation practices. For more information visit the website: www.tucson.ars.ag.gov/agwa/.

INTRODUCTION

Soil and water conservation is the keystone to sustainable livestock grazing and maintenance of native species on our western rangelands. The negative effects of erosion on soil vegetation productivity can have significant economic impacts on a rancher and sedimentation is the leading water quality problem in the western United States degrading our reservoirs and aquatic environments. Good rangeland management requires the ability to assess the potential impacts of management actions on soil erosion and sediment yield at both the hillslope and watershed scales. Our current technology (Weltz et al. 1996) for assessing and evaluating the effects of rangeland management practices on soil and water resources were originally developed for traditional cropland agricultural practices, assuming a uniform distribution of vegetation and surface cover across a landscape, which poorly represent typical rangeland conditions. The current technology also does not directly utilize Ecological Site Descriptions and associated State and Transition Models which are being adopted by agencies responsible for rangeland monitoring, assessment and management (i.e. Natural Resource Conservation Service, Bureau of Land Management, and the Bureau of Indian Affairs). Importantly, watershed assessment tools must be able to directly utilize rangeland ecological site characteristics which account for both management and climate affects on vegetation characteristics (Spaeth et al. 1996).

The premise of our project is that the practice of rangeland management can be significantly improved if rangeland managers have Decision Support Tools (DSTs) that are easy-to-use, built on range management concepts, use readily available data, and are designed to represent rangeland hydrologic and erosion processes. The study will use the Automated Geospatial Watershed Assessment tool (AGWA; Miller et al. 2007) as the foundation of the DST. AGWA is a GIS interface to automate the parameterization and execution hydrologic models that was developed and is jointly supported by the USDA Agricultural Research Service (ARS), U.S. Environmental Protection Agency, University of Arizona, and University of Wyoming. AGWA currently includes two hydrologic models; the Soil Water Assessment Tool (SWAT; Arnold et al. 1994) and KINEmatic Runoff and EROSion model (KINEROS2; Smith et al. 1995; Goodrich et al. 2006). The application of these two models allows AGWA to conduct hydrologic modeling and watershed assessments at multiple temporal and spatial scales. Unlike many models, KINEROS2 also enables users to explicitly place best management practices (BMPs) in a geographically correct position (e.g. grazing allotment which may cover multiple hillslopes and small watersheds) and dynamically model runoff and runon effects of these BMPs on a hillslope. AGWA's current outputs are runoff (volumes and peaks) and sediment yield, and for SWAT also nitrogen and phosphorus. AGWA uses commonly available GIS data layers to fully parameterize, execute, and visualize results from both SWAT and KINEROS2.

Through an intuitive interface the user selects an outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM) based on the individual model requirements (Figure 1). The watershed model elements are then intersected with soils and land cover data layers to derive the requisite model input parameters. AGWA can currently use STATSGO, SSURGO and FAO soils and nationally available National Land Cover Data (NLCD), North American Landscape Characterization (NALC) and GAP land cover/use data. Users are also provided the capability to use their own soil and land cover/use data. The chosen model is then executed, and the results are imported back into AGWA for visualization. This allows managers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused (Miller et al. 2002). AGWA can difference results from multiple simulations to examine relative change from alternative input scenarios (e.g. climate/storm change, land cover change, present conditions and alternative futures). AGWA also has other features including pre- and post-fire watershed assessment, options for user-defined land cover change, implementation of streamside buffer zones, and installation of retention/detention structures (Goodrich et al 2005; Goodrich et al. 2006). The AGWA tool, originally developed for ESRI ArcView 3.x, has been migrated to ESRI ArcGIS 9.x and an Internet-based service (Cate et al. 2007) to provide ready access to environmental decision-makers, resource managers, researchers, and user groups. For more information visit the website: www.tucson.ars.ag.gov/agwa/.

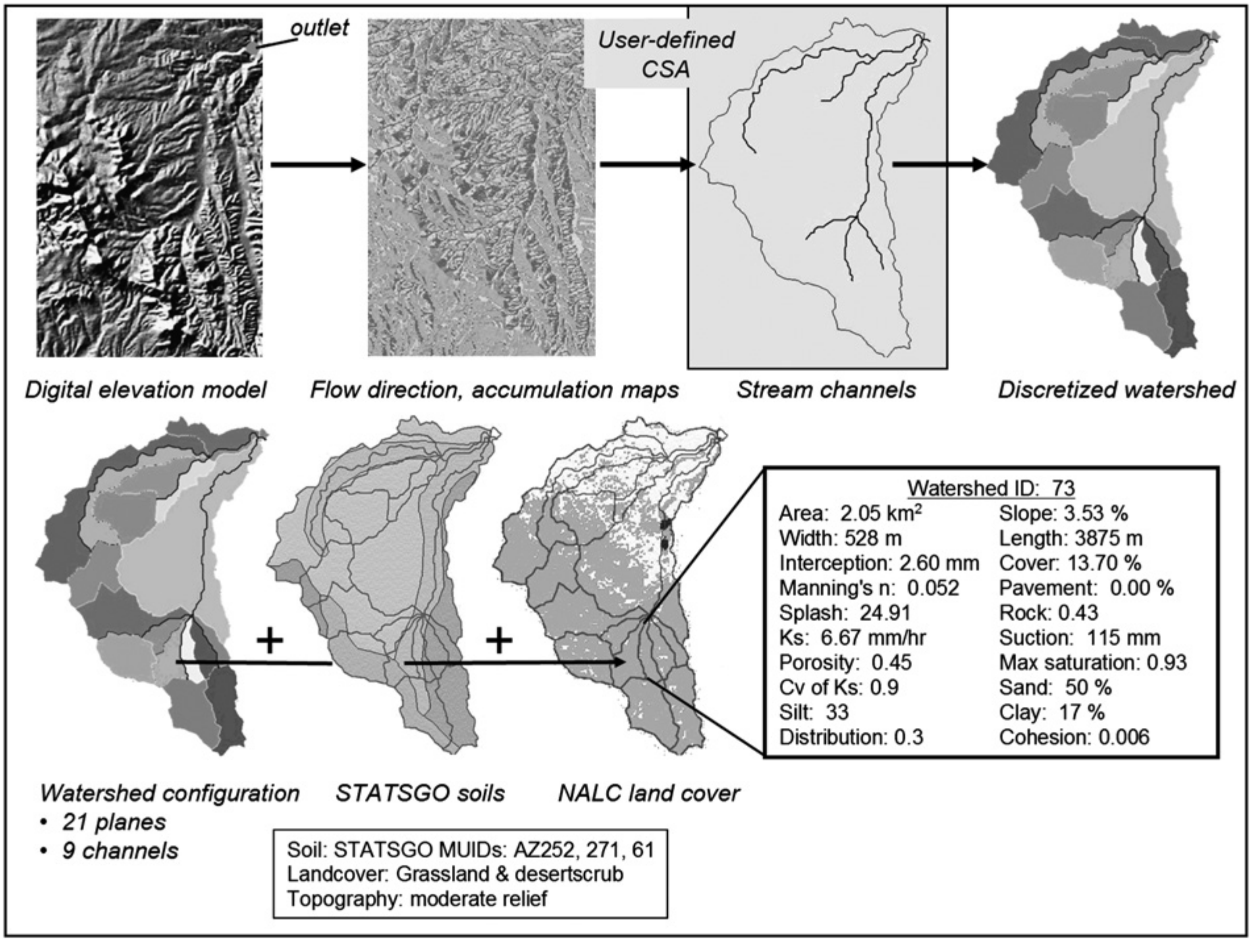

Figure 1: An illustration of the AGWA process to parameterize the KINEROS2 hydrologic model based on topography, soils, and land-cover GIS data. A DEM is used to subdivide the watershed into hillslope and channel model elements, each of which are parameterized according to their soil, topographic, and land-cover characteristics.

The current project is integrating several previous and ongoing projects to transform the operational AGWA tool into a comprehensive Automated Geospatial Watershed Assessment Tool for Rangelands (AGWA-R) that will operate at multiple scales. More specifically, we will expand the functionality of AGWA to address rangeland watershed issues. AGWA-R will be a GIS interface to support data organization, parameterization, integration, and visualization for models to support rangeland watershed assessments (Goodrich et al. 2006; Miller et al. 2007). AGWA-R will have a user-friendly interface that will allow resource managers, ranchers and other stakeholders to enhance their knowledge of watershedprocesses, and to evaluate individually or as a group, how various rangeland management, climate and fire induced changes may affect soil quality, water quantity and water quality at different scales. To support rangeland watershed assessments and planning, AGWA-R will perform model parameterization and results visualization for several models; the newly developed Rangeland Hydrology and Erosion Model (RHEM) (Wei 2007; Wei et al. 2009) and the Kinematic Runoff and Erosion Model (KINEROS2). The resulting tool will support assessments at the hillslope and small watershed (< 150 km^2, or a 10 digit Hydrologic Unit Code watershed or smaller) scales.

AGWA-R will also continue to support the Soil and Water Assessment Tool (SWAT), but SWAT will not be modified in this study. SWAT is used to support assessments for relatively large watersheds (150 – 1500 km^2 or a 6-8 digit Hydrologic Unit Code watershed).

NEW FEATURES IN AGWA-R

Current watershed assessment tools do not integrate the complexities of our rangelands into the models. An issue with many hydrologic and erosion models is that they only utilize a simple representation of vegetation, with most models using only the percent cover for parameterization. Recent research has indicated that vegetation type and patterns can have a significant impact of runoff and erosion rates from a hillslope (Spaeth et al. 1996). The hypothesis of this study is that model performance for rangelands will improve if the complexity of vegetation characteristics of a hillslope or watershed is accounted for in the parameterization process. Ecological Site Descriptions provide information on vegetation characteristics and can be used to characterize a hillslope. Developing parameterization procedures for hydrologic and erosion models that are based on Ecological Site Descriptions and/or rangeland monitoring data will improve their utility for performing rangeland watershed assessments

An important outcome of this study will be the linkage between rangeland ecological site characteristics and site descriptions, rangeland monitoring data, rangeland health assessments, and state and transition models, and the physically-based RHEM and KINEROS2 models. These linkages are necessary in order to use rangeland vegetation descriptions to parameterize physically based models. The resulting tools will allow for a quantified assessment of a watershed's health through the modeling of runoff, erosion and sediment yield. The tools will support the analysis of alternative management systems and do an evaluation of the economic consequences. It will link rangeland field measurements directly to decision-making for public land management and improving conservation programs.

Incorporating the Rangeland Hydrology and Erosion Model (RHEM)

RHEM will be incorporated into the AGWA-R tool to represent hillslope runoff and erosion processes. Users will be requested to identify their area of interest by drawing a polygon within the interface using background information such as aerial photographs or digital maps. AGWA-R will then delineate the hillslopes within the area of interest based on a DEM. Hillslopes will be defined using the same algorithms currently used in AGWA to define upland and channel side overland flow planes for KINEROS2. The user will be able to specify the level of detail (i.e. average size) over which hillslopes will be defined. This is accomplished in AGWA using an adjustable parameter called Contributing Source Area (CSA). CSA is the size an upland watershed needs to be to cause channel initiation. After the hillslopes have been defined they will be intersected with the DEM, soils data and vegetation data to derive the parameter representation for the hillslope. AGWA-R will be able to use STATSGO, SSURGO and FAO soils data. Parameterization based on vegetation will be discussed in the next section. AGWA-R will execute RHEM and the results will be visualized through the GIS interface.

RHEM (Wei 2007; Wei et al. 2009) is a newly conceptualized model which was adapted and significantly changed from relevant portions of the WEPP (Water Erosion Prediction Project) model (Flanagan and Nearing, 1995; Laflen et al. 1991). RHEM is being developed jointly by the USDA-ARS watershed research units in Tucson, Arizona and Boise, Idaho, and the Natural Resource Conservation Service (NRCS). RHEM models splash and sheet erosion, which usually is the dominant process on rangeland sites in good condition with adequate cover. A new splash and sheet erosion equation was developed for RHEM and it is the first equation developed strictly for rangeland systems and is the first process-based model that accounts for the joint effect of rainfall impact on interrill erosion. The model is also represents the process of concentrated flow erosion that may be important as a site is disturbed or if the cover consists of shrubs with large interplant distances of bare ground. RHEM incorporates the interaction between hydrology and erosion processes and plant forms by parameterizing the hydraulic conductivity based on the classification of plant growth forms and other vegetation measurements such as basal cover, canopy cover and percent bare soil. Importantly, the new RHEM formulation (Dynamic RHEM) has been incorporated into the KINEROS2 model to represent rangeland hillslope elements (Bulygina et al. 2007; Mark Nearing, USDA-ARS, Tucson, AZ, Personal Correspondence) and the two models have similar parameters and hillslope representation. This will allow parameterization algorithms to be developed that can support both models.

Parameterization for Vegetation Condition

RHEM and KINEROS2 share the same basic formulation and parameters for simulating runoff and erosion from a hillslope. Hillslopes are idealized as a rectangular overland flow plane (OFP) model element that delivers runoff and sediment from hillslopes. AWGA currently computes area weighted average parameters for each OFP and channel element based on the different land cover/soil combinations. This scheme can lead to the under representation of landscape features that are important to the runoff and erosion processes. For example, a patch of impervious area (e.g. road) can product significantly more runoff than the surrounding pervious area (i.e. grassland in good condition). However, if the size of the impervious patch is relatively small in an OFP element, compared to the pervious area, its affect will be “averaged out.” RHEM and KINEROS2 use a kinematic wave formulation to model overland flow from a hillslope. The current numerical techniques will support the explicit representation of an OFP element by allowing further subdivision of an OFP into smaller OFP as either a cascade (runoff-runon) or in parallel strips across a hillslope (Figure 2). In this manner, hydrologically distinct patches, which may produce an inordinate amount of runoff or sediment in relation to their area are explicitly represented and modeled in a more hydrologically realistic fashion. The parameterization algorithm will delineate flow paths across the OFP element based on terrain and then partition each flow path based on land cover/soil criteria. The project is investigating different levels of discrimination of the OPF elements and assessing the effect of discriminating between different vegetation forms (e.g. shrubs, perennial grasses).

The project is developing the parameterization algorithms based on (Paige et al. 2000; Paige et al. 2002; Stone and Paige 2003; Simanton et al. 1991; Franks et al. 1998) rainfall simulator plot data. The rainfall simulator plot data will be divided into two groups to support both algorithm development and validation. It is envisioned that the parameterization process will have several steps. Soil data will provide the initial soil parameters (e.g. texture, rock content) from which bare soil hydrologic properties will be computed (e.g. saturated hydraulic conductivity, porosity). Vegetation cover and type on the OFP will then modify the bare soil hydrologic properties. Finally, vegetation patches will be distributed across the OFP to emulate the surface cover pattern. Using the rainfall simulator data algorithms to modify soil properties based on vegetation characteristics and surface cover patterns will be calibrated. The project will also develop “cross-walks” between “traditional” rangeland monitoring data (e.g. cover, fetch distance) and vegetation patterns.

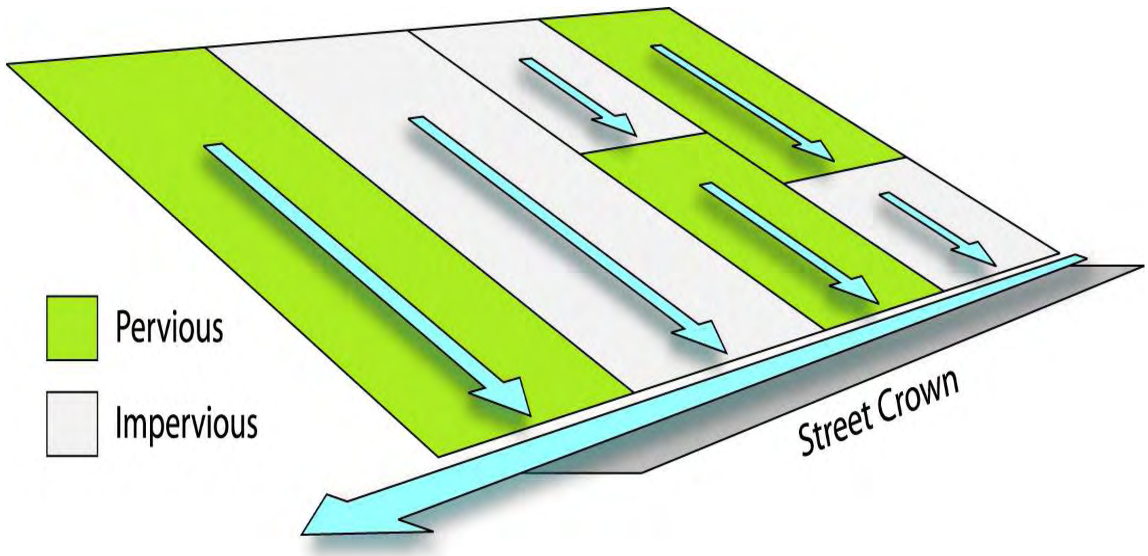

Figure 2: Hypothetical example of explicitly discretizing an overland flow plane element for an urban area in KINEROS2. Flow paths are partitioned into pervious and impervious sections based on watershed characteristics. Currently overland flow planes are assigned weighted average parameter values for the entire plane. For a rangeland hillslope strips or patches of bare soil and different vegetation forms would represent an overland flow plan element (Paige et al. 2000, 2002)

The new parameterization procedures will be tested using the remaining rainfall simulator plot data and, in the case of KINEROS, the small watershed data from both the Walnut Gulch Experiment Watershed (WGEW) and Santa Rita Experiment Range (SRER), located in southeastern Arizona. The SRER datasets will allow for the evaluation of a range of different range management practices and climate variability. The measured runoff and erosion from each experimental watershed will be used to test the models with the parameterization procedures.

Tools will be designed and developed for the AGWA interface to automate the parameterization of RHEM and KINEROS2. The tools will include data entry forms that allow users and stakeholders to enter their own rangeland monitoring data and a land cover modification tool that allows stakeholders to spatially assign and/or change the Ecological Site Description and/or State Transition Model for a pasture to emulate management practices or climate variability. The tools will be linked to “look-up” tables and algorithms that will parameterize the models based on the entered vegetation type and condition. The parameterization schemes will be robust and use general vegetation characteristics (plant growth form, cover, fetch distance). Vegetation will be used to modify basic soil conditions defined by soil data (i.e. SSURGO or STATSGO) and the hydraulic overland flow properties.

Rangeland Management Toolkit

Tools will be added to AWGA-R so common rangeland management practices can be assessed. AGWA can currently change between different land covers and insert streamside buffers. AGWA can simulate the effect of retention and detention ponds, but a more user- friendly tool will be created as part of this project. Tools will be created that will allow users to locate current ponds and incorporate new ponds. Research has already started to incorporate fire effects into AGWA (Goodrich et al. 2005; Paige et al. 2003, 2005) and will be included in AWGA-R as well. AWGA-R will retain the ability to evaluate changes in runoff, erosion, and sediment yield resulting from different management alternatives.

AWGA-R will be able to add fencing and water sources to modify animal distribution. Several studies have identified that biotic factors such as forage species and quantity, and abiotic factors such as distance to water, slope, and fencing, are important influences affecting the pattern of forage removal (Senft et al. 1983; Holechek et al. 1989; Coughenour 1991; Pinchak et al. 1991; Martin and Morton 1993; Irving et al. 1995; Brock and Owensby 2000; Vallentine 2001). Using these relationships Guertin et al. (1998) developed RangeMap, a GIS-based tool that predicted the impact of fencing, slope and water location on forage utilization and changes in cover. RangeMap will be updated based on new studies (Miller et al. 2004; Duan et al. 2006) and added to AWGA-R. This information then is passed to both the vegetation parameterization module and economic assessment module. Tools will be included so users can enter and modify their water locations, fences, and buffers within the GIS interface to develop a ranch management plan.

Economic Analysis Toolkit

The current version of the economic assessment approach (http://tucson.ars.ag.gov/sdss/) calculates a ranch (watershed) budget as a function of the structure of the cow-calf herd, fixed and variable costs, the costs of conservation measures, and the price of calves/stockers. A constrained optimization model calculates an abatement cost curve for sediment at the watershed outlet by solving the model a number of times while reducing the amount of sediment allowed. The logic behind the optimization model is that in the short- to medium-term a rancher can either harvest vegetation, converting it to pounds of beef, or leave it to protect the soil from erosion.

State and transition models provide a powerful new conceptual foundation for rangeland management as they address the long-term issue of managing for the desired vegetation community. Rangeland managers can identify both the feasible states attainable from the current state and the magnitude of the effort needed to cause the required transition. Interpretations about the effects associated with a given state can be made, such as on runoff, erosion, and forage production. To really take advantage of state and transition models additional tools are needed, that quantify the cost and expected effects of shifting from the current states to other, more desirable, states, which is the objective of the economic assessment module.

The current optimization model contains a series of constraints that act as a simple simulation model to link grazing to vegetation biomass, cover, erosion and sediment yield. A more sophisticated, physically-based approach is possible using the combined RHEM and KINEROS2 simulation models to describe the effect of management on erosion and sediment yield that can then be processed and incorporated into the constrained optimization model. The optimization model will also have to be modified to support multiple ranches within a watershed. The product of the economic assessment module will be an assessment of the economic costs for the rancher and NRCS or land-owning agency of a set of management practices to conserve soil and reduce sediment yield. The analysis will provide a cost-effectiveness, rather than a cost-benefit estimate. This approach is chosen because, rather than offsite estimates of benefits from sediment yield reductions, the limits on erosion and sediment yield will come from public land agency and/or rancher sustainability goals, rangeland erosion tolerance concepts, proper functioning condition concepts, thresholds from quantified rangeland health procedures, or sediment abatement goals from TMDL planning.

APPLICATION EXAMPLE

A common rangeland management practice is the installation of stock ponds to provide water to livestock. Stock ponds can also be viewed as storm water retention structures and sediment basins, common best management practices for flood and water quality mitigation. In this example a stock tank is placed in a 7.8 km^2 watershed where 1.5 km^2 of the watershed (19%) is drained into the stock tank (Figure 3). It is assumed that 100% of the runoff from the subwatershed is retained in the stock tank with no release. This is a common design for stock tanks in the western United States. AGWA-R was used to evaluate the impact of the stock tank on runoff and sediment yield.

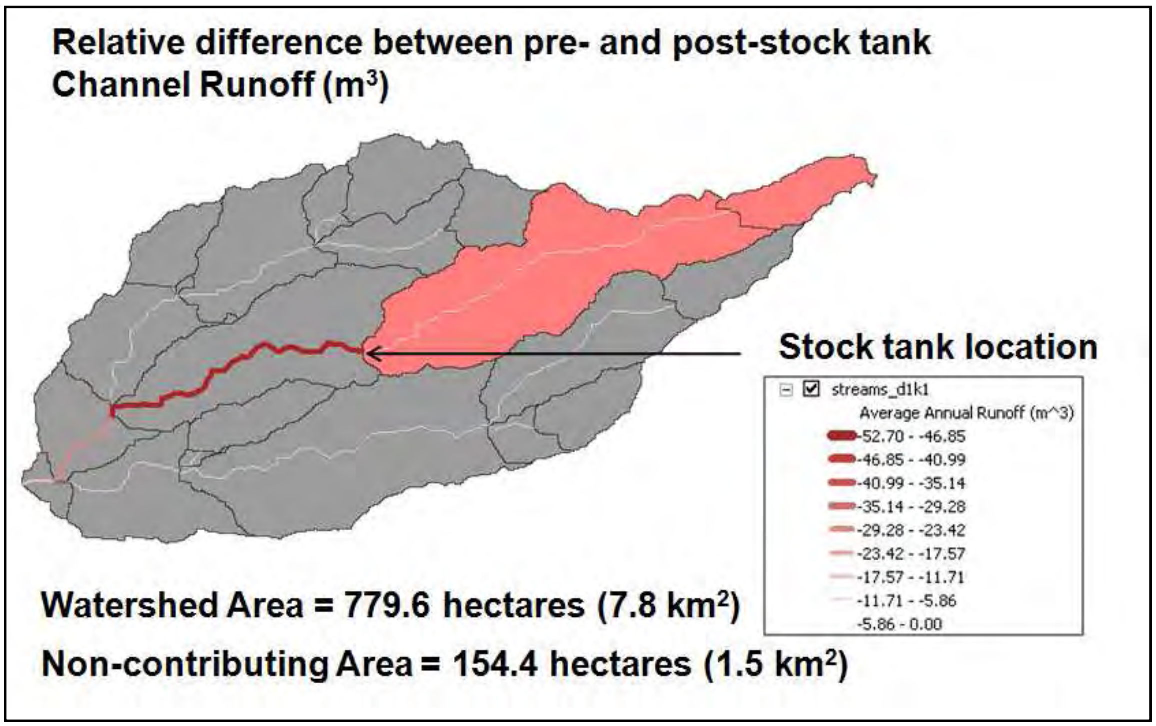

Figure 3: Example of the effect from a stock tank on average annual runoff (cubic meters). The drainage area for the stock tank is in red.

Table 1 provides a summary of the results. The stock tank decreased runoff by 15.9% and peak flow by 9.7%, while sediment yield was reduced by 1.1%. The example illustrates the affect of a stock tank on a small watershed where the largest net change is directly downstream of the stock tank location. AGWA-R can be used to examine the accumulative effect of multiple stock tanks across a larger watershed, or the accumulative effect of a suite of different best management practices.

Table 1: Results from a before and after stock tank scenario for a small 7.8 km^2 watershed.

	Pre-stock tank	Post-stock tank	Percent Difference
Runoff (m^3)	82885	69685	-15.9%
Sediment Yield (kg/ha)	5039	4982	-1.1%
Peak Flow (m^3/s)	50.5	45.6	-9.7%
Peak Sediment Flow (kg/s)	2566	2111	-17.7%

SUMMARY

The study will address one of the most pressing problems facing rangeland science today, the linkage of vegetation and ecological site characteristic data from rangeland health assessments, rangeland monitoring and/or Ecological Sites Descriptions, to physical-based models that can quantify runoff and erosion at both the hillslope and watershed scales. The study will incorporate these results into the AGWA-R tool, a GIS-based decision support tool, to directly support environment and economic sustainable rangeland management.

Specially, the study is:

1. Developing relationships among monitoring data, state and transition models, rangeland health assessments to create model input parameters for AGWA-R.
2. Developing parameterization methods for the physically-based models RHEM and KINEROS2 that represent the complexity of rangeland vegetation and site characteristics.
3. Developing a DST that will allow users to represent and analyze the impacts of common rangeland management practices on runoff and erosion.
4. Developing a DST that will allow users to economically assess the costs of soil and water conservation practices.
5. Developing a comprehensive DST to support rangeland watershed assessment and planning.

The final result will serve as a framework to support future rangeland hydrology research and support rangeland management decision making.

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