Final Report

Project Title: Quantification of Runoff and Erosion on Semi-arid Grasslands following a Wildfire

JFSP Project No: 03-2-3-11

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Project Location: Southeastern Arizona

Summary

Background

- The objectives of the study were to 1. quantify the effects of a wildfire on runoff and erosion and 2. parameterize the USFS ERMiT model for two ungrazed desert grassland sites in southeastern Arizona.
- Rainfall simulator experiments were conducted on the two sites immediately after a wildfire and for subsequent years to document the recovery process.

Objective 1

- Rates and amounts of runoff increased, but not significantly, immediately after the fire or for the subsequent years.
- Rates and amounts of erosion significantly increased after the fire but decreased to unburned levels within three to four years after the fire.
- A comparison with another ungrazed grassland fire site in southeastern Arizona suggest that litter dams formed by burnt vegetative material can significantly trap sediment being transported by flowing water.

Objective 2

- A comparison of ERMiT default parameter values and those obtained from optimization using the data set from this study showed that the optimized interrill and rill erodibility parameters fell within the range of the default values, the effective hydraulic conductivity value was significantly higher, and the critical shear stress was significantly lower.
- Analysis of data from these and other grassland fire sites in southeastern Arizona suggest that for unburned conditions, erosion by raindrop impact dominates the erosion process and that rill erosion is only active immediately after a fire.

Conclusions

- For good condition grasslands, increases in runoff are minimal while increases in erosion are significant immediately after a wildfire. The biomass which is burnt can form litter dams which trap the eroded soil and reduce the amount of sediment leaving the area at low and moderate rainfall intensities.
- The recovery period for erosion after the fire is three to four years, although for these sites, significant reductions were observed two years after the fire.

- The default ERMiT parameter values for hydraulic conductivity should be modified to reflect the minimal increase in runoff on desert grasslands. The default ERMiT parameters for erosion are within the range of values computed for this study and should not be changed.

Background
Rainfall simulator experiments were conducted to measure infiltration, runoff and erosion rates following a wildfire on a semi-arid grassland. This study was funded by the Joint Fire Science Program (JFSP) and addresses JFSP RFP-2003-2-Task 3. The objectives were to: 1) quantify the changes in runoff and erosion responses immediately after and for the subsequent two year period following a wildfire in a semi-arid grassland, and 2) use the data from burned and unburned rainfall simulator plots to develop semi-arid grassland parameters for USFS Disturbed WEPP post fire hydrologic and erosion assessment tool. To accomplish these objectives, rainfall simulation experiments were used to measure the post-wildfire runoff and erosion rates on two Natural Resource Conservation Service Ecological Sites on the Audubon Research Ranch near Sonoita, Arizona. The data gained from this project were used to: 1) quantify runoff and erosion processes on semiarid grasslands following a wildfire, and 2) develop an input parameter dataset for semi-arid grassland ecosystems for the Disturbed WEPP post fire erosion risk management tool (ERMiT).

The Ryan Fire burned over 17,000 hectares of southwestern semi-arid grassland and oak woodland areas in Southeastern Arizona in April and May 2002. The burn severity was evaluated as low by the BAER team analysis because of the lack of woody fuel. The Research Ranch (TRR), operated by Audubon Society, is an 3,600 hectare refuge located in the center of the burned area. TRR encompasses a mix of vegetation types including semi-arid grasslands, oak savannah, and oak woodland ribboned with riparian ecosystems. In June 2002, immediately following the Ryan Fire, rainfall simulator plots (2x6 m) were installed on two grassland Ecological Sites, Loamy Uplands (LoU) and Limy Slopes (LS), on TRR. Both Ecological Sites have a gravely sandy loam soil texture. Rainfall simulator experiments were conducted on three plots at the LS site and two plots at LoU site for two different soil moisture conditions (initial and wet) for a range of rainfall intensities between 50 and 180 mm/h. Runoff and erosion rates were measured for each rainfall intensity. In addition total ground and canopy cover, gap, and fetch were measured on each plot. In 2003, additional 2x6 meter plots were installed at both sites so that each site had four plots. Rainfall simulations were also conducted on four 0.76 m^2 plots at each site using the same experimental procedures. The larger plots were used to quantify runoff and the integrated erosion response (interrill and rill detachment and deposition) while the small plots were used to quantify interrill erosion. In 2004, simulation runs were completed at the two sites on all of the large and small plots. In 2006, the final simulation runs were completed at the LoU site only.

Results

Objective 1

Cover – Changes in canopy and ground cover for the Limy Slopes and Loamy Upland Ecological Sites are plotted in Figure 1 and shown in Figure 2. There has been relatively little change in the total ground cover while the canopy cover increased for two years the fire but decreased in year four possibly due to the persistent drought conditions in southeastern Arizona. The ground cover is still less than pre-fire conditions, primarily due to differences in litter cover.

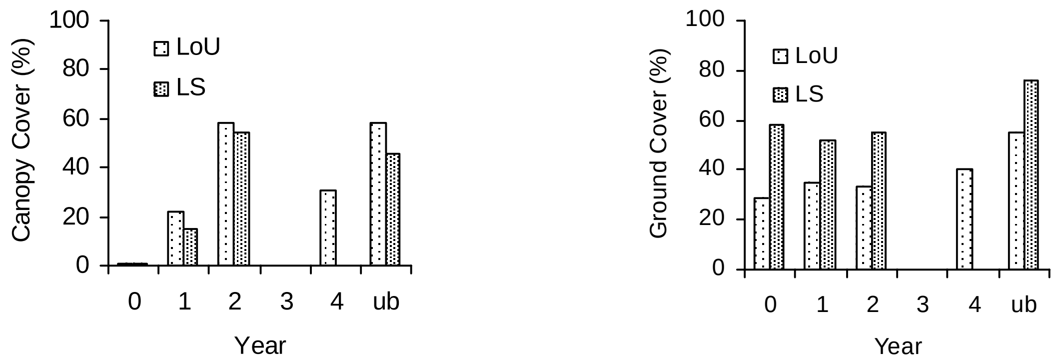

Figure 1. Change in site average canopy and ground cover for the Loamy Upland (LoU) and Limy Slopes (LS) Ecological Sites immediately after the fire (year 0), for successive years, and for unburned sites (ub).

Runoff Ratio – The runoff ratios, computed as the volume of runoff, Q (mm), divided by the volume of applied rain, P (mm), for the Limy Slopes site are shown in Figure 3. Immediately after the fire, the burned plot runoff ratios were about 25% less than the unburned ratios for the Loamy Upland plots and about 6% more for the Limy Slope plots. For both sites, the ratio has remained at a relatively constant value for the subsequent years. It is unclear why the Loamy Upland site ratio increased in the years after the fire. One factor may be that the persistent drought in the region has limited the recovery of the vegetation. However, the same response was not evident for the Limy Slope site. Hydrophobicity was not observed on any of the plots probably due to the lack of wood fuel and the low burn severity.

Sediment Yield Ratio – The sediment yield ratios, computed as the mass of sediment, SY (g), divided by the volume of runoff times the plot slope gradient, S_0, are shown in Figure 3. The ratios immediately after the fire for the Loamy Upland burned plots were about 100% greater than the unburned plots and about 465% greater for the Limy Slopes site. The ratios have been decreasing steadily

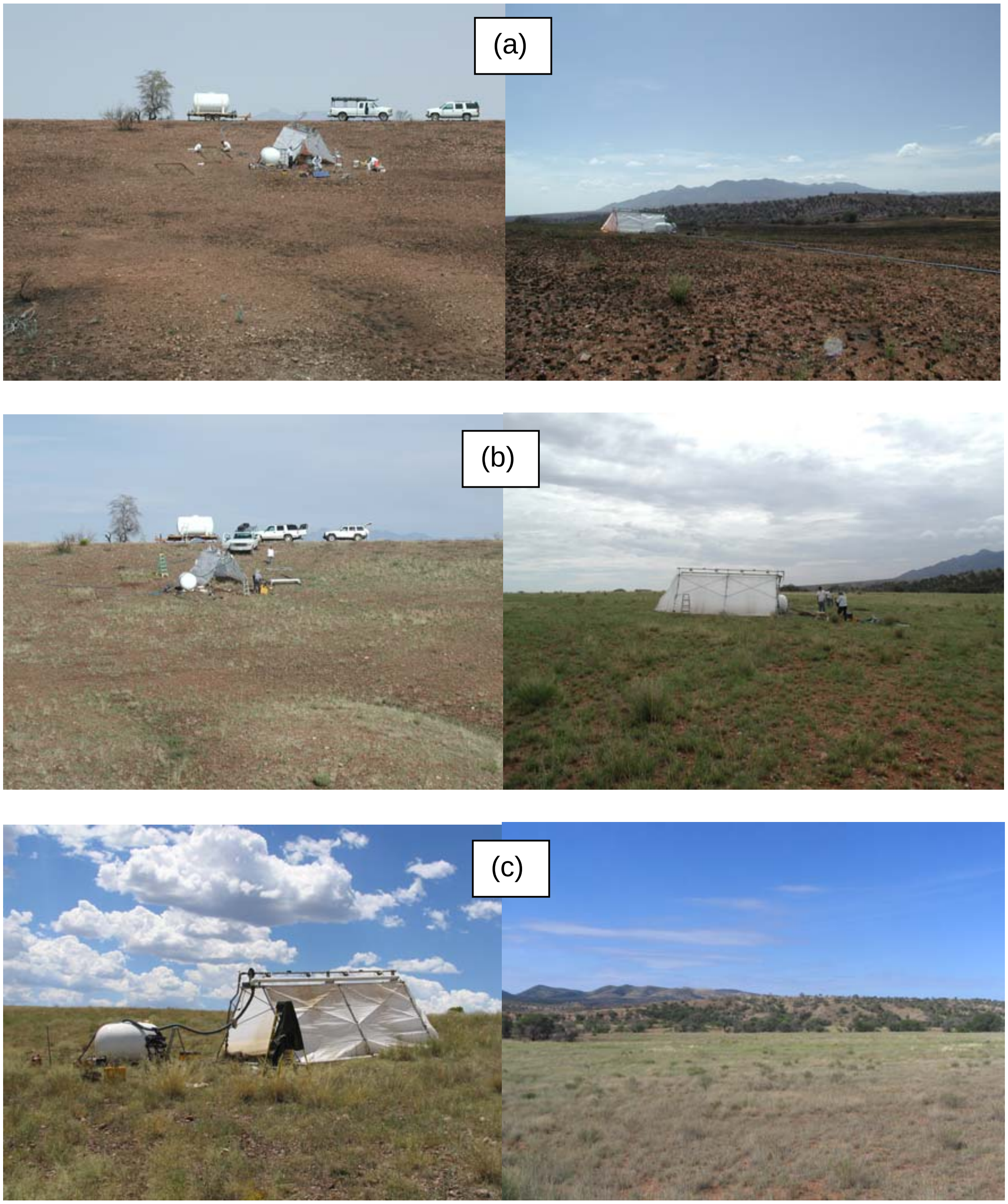

Figure 2. The Limy Slope (left) and Loamy Upland (right) sites in (a) 2002, the year of the fire, (b) 2003, and (c) 2004.

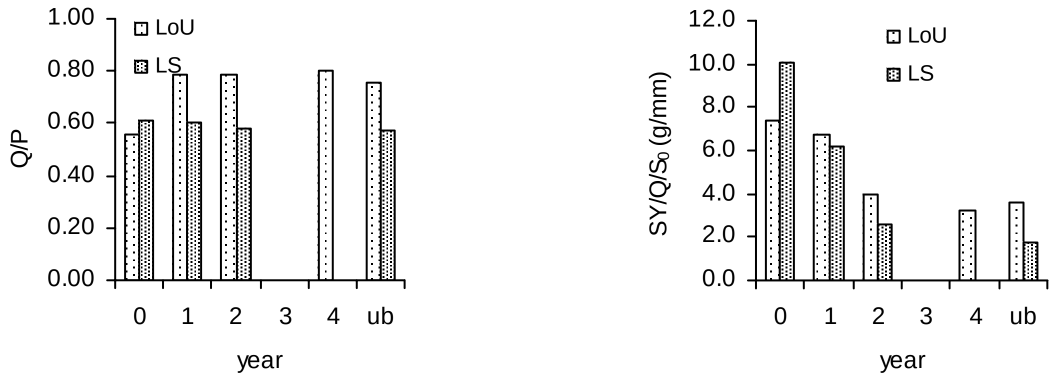

Figure 3. Change in site average runoff ratio (Q/P) and sediment yield ratio ($SY/Q/S_0$) for the Loamy Uplands (LoU) and Limy Slopes (LS) Ecological Sites immediately after the fire (year 0), for successive years, and for unburned sites (ub).

for the subsequent years and are approaching the values from the unburned sites.

Litter Dams and Microterraces – During simulations immediately following the fire, it was observed that some litter was transported off the plot by overland flow. However, much of the litter formed dams behind flow obstructions caused by rocks or vegetative bases. Generally the dams began forming about 1-2 meters from the upslope edge of the plot. This process was dynamic, with the dams forming during the lower runoff rates of the dry and wet runs and being breached at the higher rates (Figure 4). After the wet run, the length of each litter dam was measured and the height of the dam face was estimated from photos taken during the simulations at both sites. Using the length and height, the plot slope, and assuming a rectangular horizontal surface area of the microterrace and a bulk density of 1.3 g/cm^3, an estimate of the total mass of deposited sediment was computed. Assuming that the measured sediment yield plus the sediment mass in the microterraces equaled the total soil detached during the wet run, about 40% of the detached soil was deposited on the Limy Slope plots and about 80% on the Loamy Upland plots. The distribution of litter dams and microterraces is shown in Figure 5 for another grassland site with similar characteristics of the Loamy Upland site in this study after a burn. The image was taken over the plot during a simulation. Green dye was distributed in a line perpendicular to the runoff flow direction. It can be seen that the extensive network of litter dams ponds water behind them; this decreases the flow velocity and promotes sediment deposition.

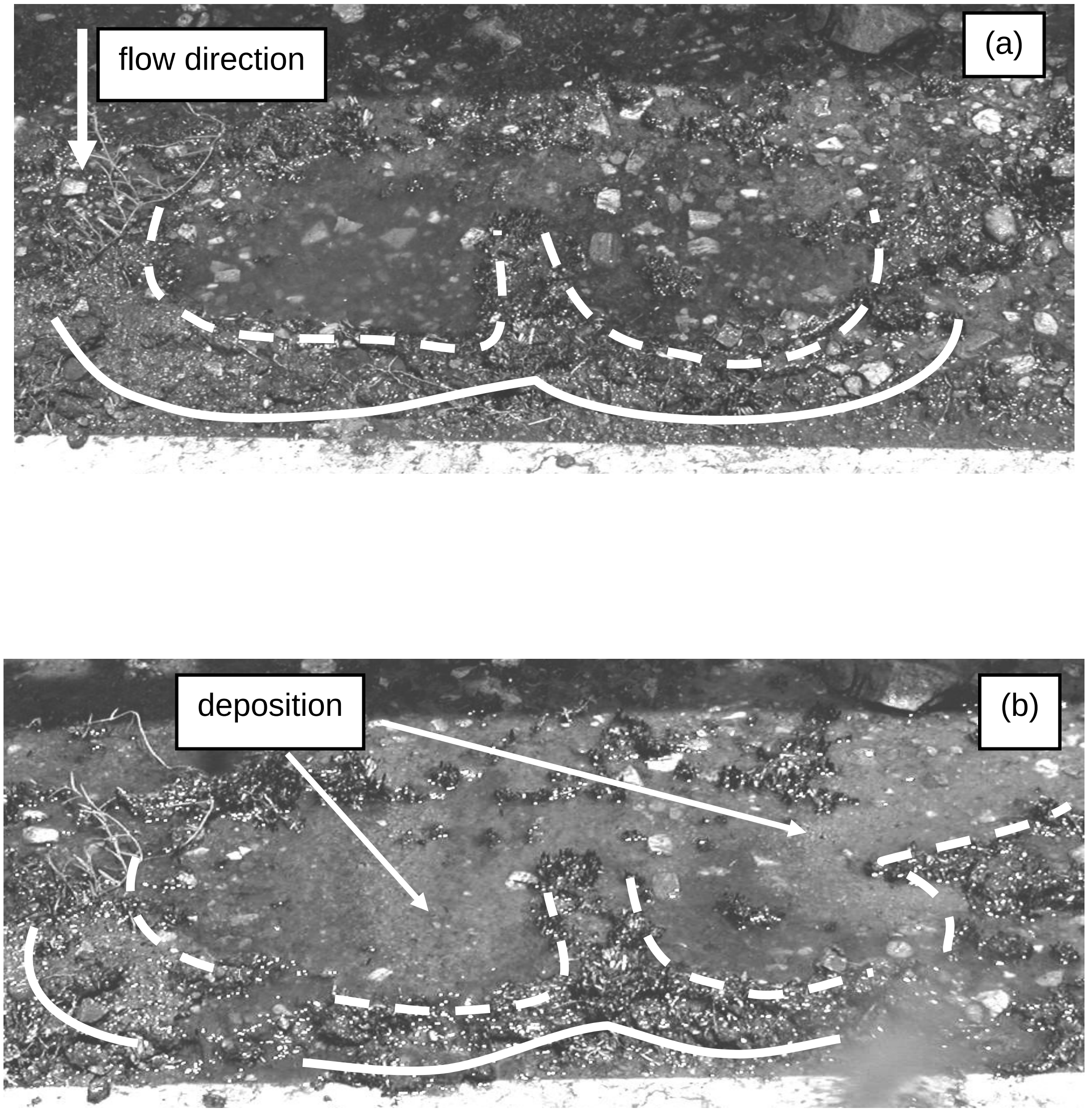

Figure 4. Microterrace formation between rainfall simulator application rates of (a) 52 mm/hr and (b) 177 mm/hr. Dashed white lines are the top of the litter dam and solid lines are the bottom of the dam. (a) at 52 mm/hr notice ponded water and gravel visible behind litter dam. (b) at 177 mm/hr, sediment (light colored material) has been deposited above the litter dams and has covered some of the gravel. Both litter dams have been breached.

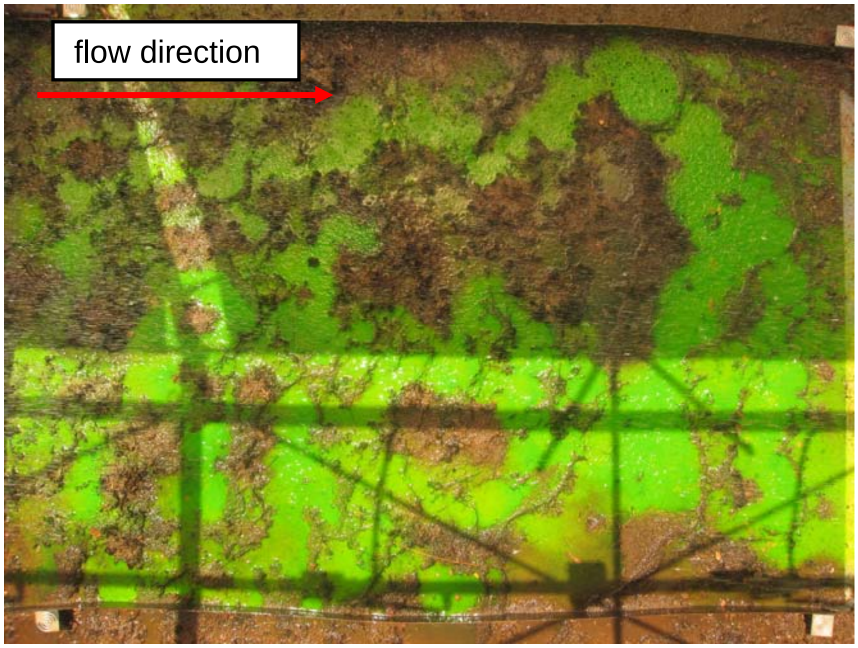

Figure 5. Overhead view of the distribution of microterraces shown by green dye application. The length of the plot shown in the images is 3 meters and the width is 2 meters. The dye shows the extensive ponded areas immediately upstream from the litter dams.

Objective 2

ERMiT Parameter Values - The ERMiT model (http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl) was developed by the US Forest Service to predict post fire runoff and erosion on forest and rangelands. The model is a modification of the Water Erosion Prediction Model (WEPP). The most important model parameters which are affected by fire are the infiltration parameter, effective hydraulic conductivity, K_e (mm/hr), and three erosion parameters, interrill erodibility, K_i (kg-s/m^4), rill erodibility, K_r (s/m), and critical shear stress, τ_c (N/m^2). Default values for these four parameters were developed for forest, range, and chaparral vegetation types. Because prior to this study, no post-fire data were available for southwestern semi-arid grassland to validate the default values, the data from this study were used to compute the four parameters. In order to compute the model parameters, a model was used that contains the same hydrology and erosion routines as ERMiT but in a format that facilitates model optimization. Table 1 compares the ERMiT default parameter values with those obtained using the data from this study.

Effective hydraulic conductivity, K_e - K_e is the most sensitive parameter in the runoff calculation. The rainfall and runoff data from the wet runs were used to optimize the value of K_e by adjusting its value until the model computed runoff volume matched the observed volume. The immediate post fire K_e values were higher than the default ERMiT values (Table 1) and similar to those for unburned conditions.

Interrill erodibility coefficient, K_i - The K_i parameter represents the resistance of the soil surface to detachment by raindrop impact. Because small plot data were not taken immediately after the fire, data from similar burned ecological sites and from the first year after the fire at TRR were used to compute the parameter. The values obtained for post fire conditions were within the range of the default ERMiT parameters (Table 1).

Rill erodibility coefficient, K_r, and critical shear stress, τ_c - The K_r parameter represents the resistance of the soil surface to detachment by flowing water and the τ_c parameter represents the threshold flow shear required to initiate detachment by flowing water. For rangeland conditions, these two parameters cannot be measured directly but need to be optimized. Because there is a relationship between the two parameters, both are optimized simultaneously. The optimized K_r parameter was within the range of the default ERMiT values while the τ_c parameter was significantly lower than the default values (Table 1). Data from other burned and unburned sites suggest that the rill process is only active immediately after a fire on grassland sites, particularly those in “good” condition.

Table 1. Comparison of default parameter values for ERMiT and observed parameter values from this study. The values are for a sandy loam soil texture and a low burn severity.

Parameter	ERMiT		Observed		
	Cover	Parameter range	Cover		Parameter range
			Ground (%)	Canopy (%)	
K_e (x 10^3) (mm h^{-1})	high	8 - 17	55-76	46-58	16 - 39
	low	7 - 14			
K_i (x 10^{-4}) (kg-s m^{-4})	high	50 - 650			57 - 500
	low	175 - 3610			
K_r (s m^{-1})	high	.020 - .093			.04 - .15
	low	6.2 - 54			
τ_c (N m^{-2})	high	15.4			.18 - .28
	low	7.5			

Recovery period parameter values - Both K_e and K_i were computed for the subsequent years after the fire (Figure 6). Comparisons of the small and large plot data from this study and other fire sites suggest that the rill process is not active during the recovery period so the two rill erosion parameters, K_r and τ_c were not computed for the recovery period. For the Loamy Upland site, K_e steadily decreased with time and appears to have reached a constant value. In contrast, for the Limy Slopes site, K_e has increased in the years after the fire. For the Loamy Upland site, K_i increased in second year after the fire but decreased in the fourth year while for the Limy Slopes site, K_i has decreased for year 1 and 2 after the fire.

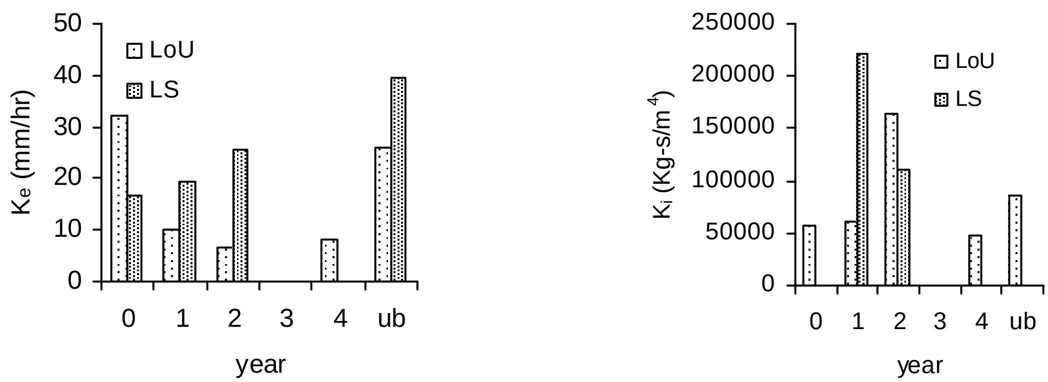

Figure 6. Change is site average K_e and K_i for the Loamy Uplands (LoU) and Limy Slopes (LS) Ecological Sites immediately after the fire (year 0), for successive years, and for unburned sites (ub).

Appendix Contents

Appendix 1 - Crosswalk table

Appendix 2 - Workshop agenda and participants

Appendix 3 - Paige, G.B., J.J. Stone, D. P. Guertin, R. McGee, and H. Blumenfeld. 2003. Runoff and erosion on a semi-arid grassland after a wildfire. Second International Wildfire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology, American Meteorological Society. Orlando, FL. November 16-20.

Appendix 4 - Paige, G.B., J. J. Stone, and D. P. Guertin. 2004 Evaluation of post-wildfire runoff and erosion on semiarid ecological sites. Biodiversity and Management of the Madrean Archipelago II: Connecting Mountain Islands and Desert Seas, Tucson, AZ. May 11-14.

Appendix 5 - Stone, J.J., J. Wickre, G.B. Paige, P. Guertin, G. Gottfried. 2006. Post wildfire runoff and erosion response on grassland and oak woodlands in southeastern Arizona. Borders, Boundaries and Time Scales. Sixth Conference on Research and Resource Management in the Southwestern Deserts. May 2-5, Tucson, AZ.

Appendix 1. Crosswalk between proposed and delivered activities

Proposed	Delivered	Status
Documentation of increases in runoff and erosion from burned sites	Paige, G.B., J.J. Stone, D. P. Guertin, R. McGee, and H. Blumenfeld. 2003. Runoff and erosion on a semi-arid grassland after a wildfire. Second International Wildfire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology, American Meteorological Society. Orlando, FL. November 16-20. (Presentation and Appendix 3)	Done
Annual progress reports	Progress report 2004 Progress report 2005 Final report 2006	Done
Documentation of post fire recovery (over 3 year period) on burn sites	Paige, G.B., J. J. Stone, and D. P. Guertin. 2004 Evaluation of post-wildfire runoff and erosion on semiarid ecological sites. Biodiversity and Management of the Madrean Archipelago II: Connecting Mountain Islands and Desert Seas, Tucson, AZ. May 11-14. (Presentation and Appendix 4). Paige, G.B. 2004. Measurement of Runoff and Erosion on Semiarid Rangelands. RAD Seminar Series, University of Wyoming, Laramie WY., October 28. (Presentation) Paige, G.B., J.J. Stone, D.P. Guertin, G. Gottfried, and J. Wickre. 2005. Quantification of Runoff and Erosion on Semi-arid Grasslands following a Wildfire. Joint Fire Science PI Workshop, San Diego, CA November 1-4. (Presentation) Stone, J.J., J. Wickre, G.B. Paige, P. Guertin, G. Gottfried. 2006. Post wildfire runoff and erosion response on grassland and oak woodlands in southeastern Arizona. Borders, Boundaries and Time Scales. Sixth Conference on Research and Resource Management in the Southwestern Deserts. May 2-5, Tucson, AZ. (Presentation and Appendix 5). Wickre, J., J. Stone, G. Paige, R. Hawkins, D. Breshears. 2005. Parameterizing the WEPP model for post-fire conditions in semi-arid grasslands using a rainfall simulator. 4th USGS Wildland Fire Science Workshop, Tucson, AZ, December 6-9. (Poster)	Done
Disturbed WEPP input parameters for semi-arid grasslands	Wickre, J. 2006. Parameterizing the WEPP model for post-fire conditions in semi-arid grasslands using a rainfall simulator. Masters Thesis. University of Arizona.	Done
Workshop for landuse managers	Workshop on Predicting post wildfire hydrology and erosion on semi-arid grassland and oak woodlands. August 8-9 2006. Audubon Research Ranch, Elgin, AZ. See Appendix 2 for agenda and participants. Presentations are online at http://www.ars.usda.gov/Business/docs.htm?docid=13766	Done

Appendix 2. Workshop Agenda and Participants

NOTE: Workshop presentations are online at
http://www.ars.usda.gov/Business/docs.htm?docid=13766

Workshop on
PREDICTING POST WILDFIRE HYDROLOGY AND EROSION ON SEMI-ARID GRASSLAND AND OAK WOODLANDS

August 8-9 2006
Audubon Research Ranch, Elgin, AZ

AGENDA

Workshop Objectives: To help decision makers, land use managers, and BAER team members understand what information and technology is available to predict wildfire effects on semi-arid grasslands and oak woodlands

Workshop Leaders
Jerry Gottfried, Hydrologist, USFS
Phil Guertin, Hydrologist, University of Arizona
Ginger Paige, Hydrologist, University of Wyoming
Jeff Stone, Hydrologist, USDA-ARS

Day 1

8:00 – 8:15	Introduction **- Stone**
8:15 – 8:30	Overview of Joint Fire Science Program Project **- Paige**
8:30 - 9:15	Hydrology and erosion processes **- Stone**
9:15 – 10:00	Data from rainfall simulator experiment **- Paige**
10:00 - 10:15	**BREAK**
10:15 – 10:45	BAER team technology – **Lefevre**
10:45 - 11:15	Hydrology and Erosion on Oak Woodlands - **Gottfried**
11:15 – 12:00	Hydrology and erosion model overview
	AGWA **– Guertin**
	ERMiT **– Paige**
12:00 – 1:00	**LUNCH**
1:00 – 5:00	Field trip to fire sites, Empire (grass) and Willow (grass)

Day 2

8:00 – 9:00	Observe data collection with the rainfall simulator
9:00 – 10:00	Run ERMiT- **Paige**
10:00 – 10:15	**BREAK**
10:15 – 11:30	Run ERMiT- **Paige**
11:30 – 12:00	Conclusions and end of workshop

Table A2. Workshop participants and presenters.

Name	Affiliation	email
	Participants	
Sharon Biedenbender	FS-Sierra Vista	sbiedenbender@fs.fed.us
Emilio Carrillo	NRCS-Tucson	Emilio.Carrillo@az.usda.gov
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Darde Deroulhac	Gila Co. Flood Control	dderoulh@co.gila.az.us
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Phil Guertin	SNR-University of Arizona	phil@nexus.srnr.arizona.edu
Bob Lefevre	FS-Coronado S.O.	rlefevre@fs.fed.us
Ginger Paige	University of Wyoming	gpaige@uwyo.edu
Jeff Stone	ARS-Southwest Watershed Res.	jstone@tucson.ars.ag.gov

Appendix 3.

1B.9 RUNOFF AND EROSION ON A SEMI-ARID GRASSLAND AFTER A WILDFIRE

Ginger B. Paige*, Jeffry J. Stone, D. Phillip Guertin[2], Rachel McGee[2], Hana Blumenfeld[2]
USDA-ARS Southwest Watershed Research Center, Tucson, Arizona
[2]University of Arizona, Tucson, Arizona

1. INTRODUCTION

Fire is a natural and important part of the regime of many ecosystems, including semi-arid southwestern grasslands. Historical evidence indicates that fires were prevalent on grasslands in the southwestern US and that periodic fires helped to maintain grasslands in a relatively shrub-free state (McPherson, 1995). Natural fire regimes have changed since the 1890s and the frequency of natural wildfires to maintain the grasslands is not expected to return (Bahre, 1991; McPherson, 1995). However, wildfires still occur on southwestern grasslands and as the wildland urban interface expands and more rangelands are being settled the need to evaluate the short and long term risks and impacts associated with wildfires is becoming more important.

Land managers and BAER teams need to be able to assess the effects of wildfires on semi-arid grasslands to be able to calculate the on and offsite risks due to potential increases in runoff and erosion. Currently in southeastern Arizona, peak runoff and erosion rates following a grassland fire are estimated using TR55 (USDA-NRCS, 1972) and Universal Soil Loss Equation (ULSE) (Wischmeier, 1959). Although these methods are robust, they may not be applicable in the southwest where high intensity thunderstorm rainfall dominates the runoff and erosion processes. Both of the methods have uncertainties in parameter estimation and questions regarding their applicability to semi-arid rangelands.

Post wildfire runoff and erosion rates, as well as recovery rates of semi-arid grassland ecosystems are not well known. In the 1970s and 1980s, prescribed fire became an important management tool. Several studies have looked at the effects of prescribed burns on infiltration and erosion rates on semi-arid rangelands using rainfall simulation experiments (Emmerich and Cox, 1992; Emmerich and Cox, 1994, O'Dea and Guertin, 2003). Although there has been considerable research conducted on the ecological effects of fires on rangelands, there has been relatively little research on the effects of fire on runoff and erosion rates on semi-arid grassland ecosystems. Wild fires in semi-arid regions of the southwestern US generally occur in the few months before the onset of summer rainfall, the loss of cover caused by a fire along with the high intensity thunderstorms typical of summer rainfall could significantly increase runoff and erosion. However, little or no research has been done to evaluate the hydrologic and erosion effects from grassland wildfires.

The Ryan Fire burned over 17,000 ha of southwestern semi-arid grassland and oak woodland areas in Southeastern Arizona in April and May 2002. The Research Ranch (TRR), operated by Audubon Society, is a 4,000 ha refuge located in the center of the burned area. TRR encompasses a mix of vegetation types including semi-arid grasslands, oak savannah, and oak woodland ribboned with riparian ecosystems. In 1968 the Appleton family established TRR for ecological research. At that time all cattle were removed and grazing has not occurred here since. Other disturbances have also been reduced or eliminated.

In 1997, the USDA-ARS Southwest Watershed Research Center (SWRC) established two hillslope erosion research sites, East Mesa (EM) and Post Canyon (PC), on two different Ecological Sites (Loamy Uplands and Limey Slopes, respectively) on TRR. Overland flow paths at the hillslope scale were identified and measurements of slope, vegetative canopy and surface ground cover were made. Ecological Sites (ES) are the primary resource management unit used by the USDA Natural Resources Conservation Service (NRCS) on semi-arid ecosystems in the western United States. These sites were selected as part of a larger on going project to characterize the hydrologic and erosion processes on NRCS Ecological Sites on semi-arid rangelands.

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The Ryan Fire started on April 29th and was contained May 2, 2002 (USDA Forest Service, 2002). Of the 17,000 ha burned, over 7,000 ha are managed by the National Forest Service, 770 are State lands, 5,000 are private and approximately 4,000 ha are managed by other Federal Agencies. Approximately 70% of the area burned at low intensity and the remainder at moderate intensity. One of the research sites, EM, was burned at moderate intensity while the PC site was in the low intensity area. There was no remaining canopy cover at either site after the fire. The estimated vegetation recovery period for the entire area is 3 to 10 years (USDA Forest Service, 2002).

Rainfall simulator plots were installed at the two ESs and rainfall simulator experiments were conducted to measure runoff and erosion. The rainfall simulator experiments were conducted immediately following the fire before the onset of the summer monsoon and again one year later. The results from the two years of simulations on the burned sites will be compared with each other and with results from similar unburned ESs. The objective of this paper is to present the preliminary evaluation of the runoff and erosion results from the two years of post wildfire rainfall simulations.

2. METHODS AND MATERIALS

In June 2002, immediately following the Ryan Fire, rainfall simulator plots were installed at the two burned ESs, Limey Slopes (LSb) and Loamy Uplands (LoUb), on TRR and a rainfall simulator was used to apply water at variable application rates. Due to constraints of time and logistics, it was not possible to install plots on unburned areas adjacent to TRR. However, rainfall simulator data were available for unburned conditions at a Limey Slopes (LSn) and Loamy Upland (LoUn) ES within the same Major Land Resource Area (MLRA) at the Walnut Gulch Experimental Watershed (WGEW).

2.1 *Study Sites*

TRR is located in southeastern Arizona at an elevation of 1600 m and with an average annual precipitation of 450 mm. The ranch is within MLRA 41-1, Mexican Oak-Pine Woodland and Oak Savanna (annual precipitation between 400 and 500 mm) and has had grazing excluded since 1968. The topography is rolling hills with predominately sandy gravely loam soils forming the hillslopes and clay loams in the bottom lands. Two plots (PC 1 and PC 2) were installed at the LoU ES and two (EM 2 and EM 3) at the LS ES for the first year of simulation. Additional plots, PC4 at the LoU ES and EM1 at the LS ES were added for the second year.

The WGEW ESs are located within a unit source area sub-watershed. WGEW is within MLRA 41-3, Southwestern Desert Grassland (annual precipitation 350 mm) and has a history of moderate grazing. The LS and LoU ESs occur on the watershed as an association for which the LoU ES is present on the upper parts of the hillslopes and the LS ES occupies the middle to lower parts. Three plots (K3, K7, and K8) were installed on the LS ES and two plots (K4 and K5) were installed on the LoU ES. Selected characteristics of the ESs are listed in Table 1. The soils at all the sites have a gravely sandy loam texture for the top soil. The LoU ES has a clay layer at a depth of 10-20 cm and the LS ES has a calcic layer at a depth of 10-15 cm. Because of the differences in annual precipitation, vegetation productivity, and grazing history, the plots at the WGEW are not strictly controls for the burned plots at TRR. However, for comparison purposes, they can be considered an estimate of pre-burn conditions.

Table 1. Selected characteristics of the ESs used in the study.

ES	Soil Series	Vegetation % by weight - dominant species	Slope %
LoUn	Elgin	80% grass - sideoats grama *Bouteloua curtipendula* , cane beardgrass *Bothriochloa barbinodis*, plains lovegrass *Eragrostis intermedia*	11
LoUb	Terrarosa	85% grass - sideoats grama, cane beardgrass, plains lovegrass	8-9
LSn	Stronghold	70% grass - sideoats grama, black grama *Bouteloua eriopoda*	11
LSb	Blacktail	67% grass - sideoats grama, rough tridens *Tridens muticus*	12-15

2.2 *Measurement Methods*

Rainfall simulator experiments were conducted on 2 m by 6 m rainfall simulator plots using the Walnut Gulch Rainfall Simulator (WGRS). The WGRS (Paige et al., 2003) is an oscillating boom simulator which can apply water at variable intensities ranging from 12 to 177 mm/hr. It uses VeeJet 80100 nozzles that apply approximately the same energy of natural rainfall and have a median drop size of about 3 mm. The simulation run sequences were as follows. All plots had a dry run at initial soil moisture conditions followed by a wet run one hour after the cessation of runoff from the dry run. The dry and wet runs on EM2, K4, and K5 consisted of a sequence of application rates starting at 177 mm/hr and decreasing in 25 mm/hr increments until a rate of 25 mm/hr. For the remainder of the plots, the dry run was of a constant intensity of 60 mm/hr for 45 minutes. For the wet run, a sequence of application rates from 25 to 177 mm/hr in increasing increments was used. For all the runs with multiple application rates, the rates were changed after runoff had reached steady state for at least five minutes.

Plot characteristics, canopy and ground cover, were measured using a point frame on a 15 by 20 cm grid for a total of 400 points. Canopy cover was recorded as grass, shrub, and forb. Ground cover was recorded as rock (> 2 mm), litter, vegetative base, and bare soil, both inside and outside the canopy. Runoff was measured at the downslope outlet of the plot using a pressure depth gage attached to a flume. The runoff depth was converted to discharge using a pre-calibrated flume stage-discharge relationship. Sediment samples were taken during the wet run using grab samples, dried, and weighed to compute sediment concentrations. Soil moisture was measured by gravimetric samples taken before the dry and wet runs.

2.3 *Analysis*

Results from the rainfall simulator experiments were analyzed using data collected from the wet runs. Differences in total runoff and sediment yield amounts from the two years of simulation at the burned sites and the unburned sites were compared. Ratios were used to account for the different amounts of water applied on the plots. The runoff ratio, the total runoff (Q) divided by the total amount of water applied (I), was used to quantify the differences in runoff as a result of the fire. The sediment yield ratio was computed as the total sediment yield (Sy) divided by the total runoff (Q) amount times the plot slope (So) to account for the range of slopes (8-15%) of the sites.

3. RESULTS AND DISCUSSION

The total amount of rainfall applied and the runoff and erosion measurements from all of the wet runs are presented in Table 2 along with the runoff and sediment yield ratios.

Table 2. Total rainfall (I), runoff (Q), and sediment (SY) amounts and runoff (Q/I) and sediment yield (SY/Q S_0)
ratios for the wet runs.

ES	Plot	I	Q	Sy	Q/I	SY/QSo
		mm	mm	T/ha		T/ha/mm
LSb	EM2_02	85	58	6.50	0.69	0.74
LSb	EM3_02	106	52	5.58	0.50	0.89
ave:					**0.59**	**0.81**
LSb	EM1_03	81	52	3.69	0.64	0.59
LSb	EM2_03	99	43	2.27	0.43	0.35
LSb	EM3_03	91	68	4.53	0.74	0.56
ave:					**0.60**	**0.50**
LSn	K3	151	83	0.65	0.55	0.07
LSn	K7	141	98	2.99	0.70	0.28
LSn	K8	91	39	0.63	0.43	0.15
ave:					**0.56**	**0.17**
LoUb	PC1_02	94	48	2.53	0.50	0.66
LoUb	PC2_02	94	58	3.21	0.62	0.61
ave:					**0.56**	**0.64**
LoUb	PC1_03	85	67	3.14	0.78	0.59
LoUb	PC2_03	85	68	2.74	0.79	0.45
LoUb	PC4_03	90	71	4.33	0.79	0.68
ave:					**0.79**	**0.57**
LoUn	K4	125	45	0.11	0.36	0.02
LoUn	K5	96	28	0.09	0.29	0.03
ave:					**0.33**	**0.03**

The two years of simulation on the burned plots, LoUb and LSb are indicated by “02” for immediately following the fire in 2002 and “03” for the simulations this summer in 2003, after one year of recovery. Evident in Table 2 is the large differences in runoff and erosion measurements when comparing the three different conditions. It is important to note that there is some variability within condition, especially for the unburned sites, LoUn and LSn.

3.1 *Comparison of burned vs. unburned*

Comparing the 2002 results from the two ESs, both the unburned and burned plot runoff ratios were less for the LoU ES than the LS ES (Table 3). The burned plot runoff ratios were 74% more than the unburned ratios for the LoU plots and about 5% more for the LS plots (Table 4). The sediment yield ratios for the LoU burned plots were about 2200% times greater than the unburned plots but were less than the burned plots of the LS ES. The difference between the LS burned and unburned plots was less (399% times greater) than the difference for the LoU ES. Although the relative difference was much greater for the LoU ES, the sediment yield ratios were less. An in depth analysis and discussion of the results form the 2002 burned and unburned sites is presented in Stone et al. (2004, *in review*).

Table 3. Site average runoff (Q/I) and sediment (SY/Q S_0) ratios and percent change (C) for the unburned (U) and burned (B) plots.

ES	Q/I			SY/Q S_0 T/ha/mm		
	U	B	C	U	B	C
LoU	0.33	0.56	74	0.03	0.64	2230
LS	0.56	0.58	5	0.17	0.82	399

3.2 *Comparison of 2002 and 2003 burned plots*

The changes in runoff and sediment yield ratios from 2002 to 2003 (Table 4) were much less than the changes seen when comparing the unburned and burned (Table 3). Though there was a decrease in sediment yield, 11% for the LoUb ES and 38% for the LSb ES, there was an increase in the runoff ratio for both ESs. Though the decrease in sediment yield was expected the increases in runoff was not. The interesting point to note is that there was a larger increase in the runoff ratio for LoUb, 41% compared with 2% for the LSb, and that the ratios for LoUb 03 are greater than LSb 03.

Table 4. Site average runoff (Q/I) and sediment (SY/Q S_0) ratios and percent change (C) for the burned plots of the two years of simulation.

ES	Q/I			SY/Q S_0 T/ha/mm		
	'02	'03	C	'02	'03	C
LoUb	0.56	0.79	41	0.64	0.57	-11
LSb	0.59	0.60	2	0.81	0.50	-38

3.3 *Cover characteristics*

The summary cover data from the point measurements are presented in Table 5. The canopy cover on the burned sites increased as expected. The total canopy cover changed from 0 to 18 % and 22% on LSb and LoUb, respectively. The canopy cover on the burned sites is still much lower than the 64 and 88% measured on the unburned sites, LSn and LoUn. There was a decrease in total ground cover between 2002 and 2003 on LSb. The change is primarily attributed to movement of liter from both the simulations and natural rainfall. The total ground cover on the burned sites is still lower than the unburned, especially for LoU.

Table 5. Summary of total canopy and ground cover percentages from the point measurements.

ES	Plot	Canopy Cover (%)	Ground Cover (%)
LSb	EM2_02	0	57
LSb	EM3_02	0	58
LSb	EM1_03	15	44
LSb	EM2_03	13	66
LSb	EM3_03	25	62
LSn	K3	67	64
LSn	K7	63	61
LSn	K8	61	56
LoUb	PC1_02	0	38
LoUb	PC2_02	0	20
LoUb	PC1_03	22	37
LoUb	PC2_03	22	36
LoUb	PC4_03	22	32
LoUn	K4	86	87
LoUn	K5	90	77

Hydrologic and erosion processes have been highly correlated with both canopy and ground cover characteristics on rangelands. Comparing pre and post fire results from prescribed burns, increases in runoff and erosion amounts or rates have been correlated with decreases in total ground cover (Roundy et al., 1978; Johansen et al. 2001), litter (Roundy et al., 1978), and organic matter (Hester et al., 1997). The explanation generally put forward is that the decrease in cover can cause both soil crusting (Hester et al. 1997) thus decreasing infiltration rates and the breakdown of soil aggregates (Johansen et al. 2001) which, along with the additional exposure of the soil surface to raindrop impact, increases erosion rates. Deceases in ground cover have also been correlated with increases in runoff and erosion rates on the LoU as well as other Ecological Sites at WGEW (Simanton and Renard, 1985). Similar results were found when looking at the results from TRR.

The runoff and sediment yield ratios from all of the plots were compared with the measured plot characteristics. Comparing the runoff ratios with the cover characteristics, the strongest relationship was found with percent ground cover (Fig. 1). The general decrease in runoff ratio with an increase in ground cover follows the trend found following prescribed burns (Johansen et al. 2001).

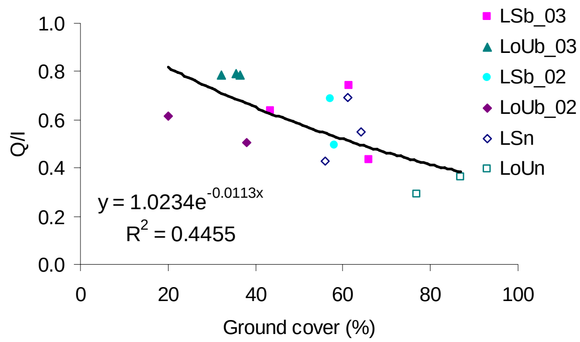

Fig. 1. Relationship between runoff ratio and percent ground cover.

Strong relationships were found with the sediment ratio and cover characteristics. The relationship between the total ground and canopy cover with the sediment yield ratios are presented in Figures 3 and 4, respectively. In both cases, there is a decrease in erosion with an increase in percent cover. The strongest relationship is with canopy cover, R^2 value of 0.86, compared with an R^2 of 0.54, for ground cover. The primary effect of the loss of cover on the burn sites (Table 5) appears to be an increase in the area exposed to raindrop impact and overland flow. The increase in area exposed to raindrop impact and overland flow results in higher runoff and erosion rates.

It is evident from the results presented in Figures 1 -3 that the processes are much more complex than the relationships presented herein. The LSb site appears to be more sensitive to changes in ground cover than LoUb (Fig. 2). The increases in the runoff ratios on the burned sites between 2002 and 2003, with increases in canopy cover indicate that there are changes that have occurred with the soil surface and the infiltration capacity on the sites (Hester et al. 1997; Johansen et al., 2001). At this point it is not known if these observed changes in the soil surface and infiltration rates will have a long term impact on the recovery of the site.

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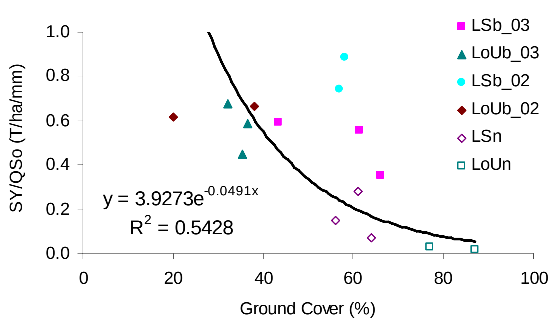

Fig. 2. Relationship between sediment yield ratio and percent ground cover.

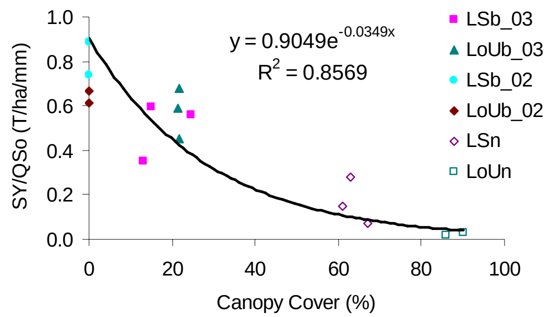

Fig. 3. Relationship between percent canopy cover and the sediment yield ratios.

4. SUMMARY

Rainfall simulator experiments were conducted to measure and quantify runoff and erosion processes on a semi-arid grassland following a wildfire. The experiments were conducted immediately following the fire and again one year later. The results from the two years of rainfall simulation were compared with results from similar unburned ESs. The results from the rainfall simulator experiments immediately following the Ryan fire showed an increase in the runoff ratio (runoff/rainfall) from 5 to 74% and in the sediment yield ratio (sediment yield/runoff/slope) from 399 to 2230% for the Limey Slopes and Loamy Upland ESs, respectively. These results are significantly higher than results from a prescribed burn study in southeastern Arizona (Emmerich and Cox, 1994), but follow the same trends in increasing runoff and erosion as a prescribed burn study on the Edwards Plateau in Texas (Hester et al., 1997). The increases in erosion could result in a decrease in the productivity of the site and/or a change in the recovery rate of the ecosystem.

This first look at the recovery of the burned sites, comparing results from 2002 and 2003, showed a decrease in sediment yield, however, there was an increase in the runoff. These results indicate that there may be a decrease in the productivity of the site or a longer recovery rate than predicted. The long term effects of the wildfire on the productivity of the site will not be known for several more years.

The preliminary post wildfire runoff and erosion results presented herein are from two of the most dominant ESs in southeastern Arizona. Along with Sandy Loam Uplands, these ESs are the most wide-spread, productive, and economically important upland sites on semi-arid grasslands in the southwest. Based on these results, there is an identified need to 1) quantify the potential increases in runoff and erosion on semi-arid grasslands, and 2) evaluate the post fire recovery process. In addition, land managers and BAER teams need an easy to use post-fire erosion risk management tool.

The results from this and other studies will be used to develop semi-arid grassland parameters that can be used in Disturbed WEPP to evaluate runoff and erosion risks following wildfires (Elliot and Hall, 1997, Elliot et al., 2000; http://forest.moscowfsl.wsu.edu/fswepp/docs/distweppdoc.html). The model is being implemented as a component of an erosion risk management tool (ERMT) in the Great Basin region (Pierson et al., 2001; Robichaud et al., 2000; Robichaud et al., 1999). The model is easy to use and parameterize and has an extensive database for the soil-vegetation complexes considered in the Great Basin. WEPP has the potential to be more applicable than TR55 and USLE to conditions in the southwest because the hydrology and erosion components account for rainfall intensity and spatial characteristics of overland flow.

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We would like to thank Bill Brennan and Linda Kennedy of The Research Ranch for facilitating the rainfall simulator experiments at the ranch and Dan Robinette and Don Breckenfeld, Arizona

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Appendix 4.

EVALUATION OF POST-WILDFIRE RUNOFF AND EROSION ON SEMIARID ECOLOGICAL SITES

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ABSTRACT

Field studies are being conducted to quantify runoff and erosion rates following wildfires in semiarid rangelands. Rainfall simulator experiments were conducted on two grassland sites and one oak woodland site in Southern Arizona immediately following wildfires in 2002 and 2003. The experiments applied a range of rainfall intensities between 50 and 180 mm/h. Infiltration, runoff and erosion rates were measured for each application rate. The post wildfire runoff and erosion responses are much higher on the oak woodland site and show much more variability than the responses from the two grassland sites. The results from this and other field studies will be used to determine model input parameters for a post wildfire erosion risk tool.

INTRODUCTION

Land managers and Burned Area Emergency Rehabilitation (BAER) teams need to be able to quickly assess the effects of wildfires on runoff and erosion processes on semiarid rangelands to determine the potential on and offsite risks. However, post wildfire runoff and erosion rates on semiarid rangeland ecological sites are not well known. Currently in southeastern Arizona, peak runoff and erosion rates following a rangeland fire are typically estimated by the USFS using TR55 (USDA-NRCS, 1986) and Universal Soil Loss Equation (ULSE) (Wischmeier, 1959). Although these methods are robust, they may not be applicable in the southwest where high intensity thunderstorm rainfall dominates the runoff and erosion processes. Both these methods have uncertainties in parameter estimation and questions regarding their applicability to semiarid rangelands. Field experiments using a variable intensity rainfall simulator are being conducted immediately following wildfires to quantify post wildfire runoff and erosion rates and over a two year period to monitor the recovery. This paper presents post-wildfire results from three Natural Resource Conservation Service (NRCS) Ecological Sites. In April 2002, the Ryan Fire burned two grassland sites, a Loamy Upland Ecological Site (Post Canyon) and a Limey Slopes Ecological Site (East Mesa) on the Audubon Research Ranch near Elgin, Arizona. An oak woodland site (A-Bar), dominated by manzanita, burned in May 2003 as a result of the A-Bar fire near the San Rafael Valley. This site is also mapped as a Loamy Upland Ecological Site.

METHODS

The rainfall simulator experiments were conducted immediately following the fires and before the onset of the summer monsoons. The Walnut Gulch Rainfall Simulator, an oscillating boom, variable intensity rainfall simulator (Paige et al., 2003a) was used to apply a range of rainfall intensities (50 to 180 mm/h) over 2m by 6m plots installed at the three sites. Two plots were installed at the grassland sites on “uniform” hillslopes. Four plots were installed at the A-Bar site; two on shrub interspace areas and two on interspace (no shrub mounds) areas. All plots had a dry run, 60 mm/h for 45 minutes, at initial soil moisture conditions followed by a wet run one hour after the cessation of runoff from the dry run. For the wet run, a sequence of application rates from 25 to 177 mm/hr in increasing increments was used. The application rates were changed after runoff had reached steady state for at least five minutes. Runoff was measured at the down slope outlet of the plot using a pressure depth gage attached to a pre-calibrated flume. Sediment samples were taken during the runs using grab samples, dried, and weighed to compute sediment concentrations. Plot cover characteristics, canopy and ground, were measured at 400 point per plot using the point intercept method.

RESULTS & DISCUSSION

Results from the rainfall simulator experiments were analyzed using data collected from the wet runs. Ratios were used to account for the different amounts of water applied on the plots. The runoff ratio, the total runoff (Q) divided by the total amount of water applied (I), was used to quantify the differences in runoff. The sediment yield ratio was computed as the total sediment yield (SY) divided by the total runoff (Q) amount times the plot slope (So) to account for the range of slopes (8-15%) at the sites. The total amount of applied rainfall and the runoff and erosion measurements from the wet runs are presented in Table 1 along with the runoff and sediment yield ratios. A comparison between runoff and sediment yield ratios from the burned grassland ecological sites with similar unburned ecological sites showed increases in runoff from 5% to 74% and significant increases in erosion (399% to 2200%) on the burned sites (Paige et al., 2003b). The results from the oak woodland site are much greater than those from the burned grassland sites, especially for the sediment yield (Table 1). The runoff ratio from the A-Bar site is 18 to 22% greater than the two grassland sites and the sediment yield is 58 to 68% higher. There is more variability in the runoff results from East Mesa and Post Canyon (22 and 15%) than for the A-Bar site (10%). However, there is much greater variability in the erosion (88%) from the A-Bar site than the East Mesa and Post Canyons Sites (13 and 5%).

Comparing the results from the A-Bar site, the sediment discharge rate as a function of runoff rate is much higher on plots 1 and 2 (Figure 1). Concentrated flow was observed on plots 1 and 2, the shrub interspace plots, at the higher intensities. Multiple flow paths developed on plot 1 while plot 2 developed a single flow path down the center of the plot. Plots 3 and 4, displayed uniform sheet flow similar to the flow observed on the burned grassland sites.

Differences in the runoff and erosion responses for the full range of rainfall intensities from the three burned sites are illustrated in Figure 2. The responses for the East Mesa and Post Canyon grassland sites show strong relationships between measured runoff and sediment discharge rates with R^2 values of 0.99 and 0.95, respectively. The runoff and erosion responses from the A-Bar oak woodland site show much more variability and a much greater range in sediment discharge rates for similar runoff rates. However, the response from plots 3 and 4 from the A-Bar site, which did not have shrub mounds, are very similar to Post Canyon grassland sites. Both sites are mapped as a Loamy Upland Ecological Site. This preliminary evaluation of the data from three wildfire burn sites indicates 1) that there is a range of runoff and erosion responses that can occur due to variable intensity rainfall and 2) that there appear to be significant differences between oak woodland and grassland responses immediately following wildfires.

NEXT STEP

The post wildfire runoff and erosion measurements from this and future field studies will be used to develop parameters for semiarid rangelands that can be used in Disturbed WEPP (Elliot et al., 2000) to evaluate runoff and erosion risks following wildfires. The model is being implemented within an erosion risk management tool (ERMiT http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl) in the Great Basin region (Elliot et al., 2001). The model is easy to use and parameterize and has an extensive database for the soil-vegetation complexes considered in the Great Basin. WEPP has the potential to be more applicable than TR55 and USLE to conditions in the southwest because the hydrology and erosion components account for rainfall intensity and spatial characteristics of overland flow.

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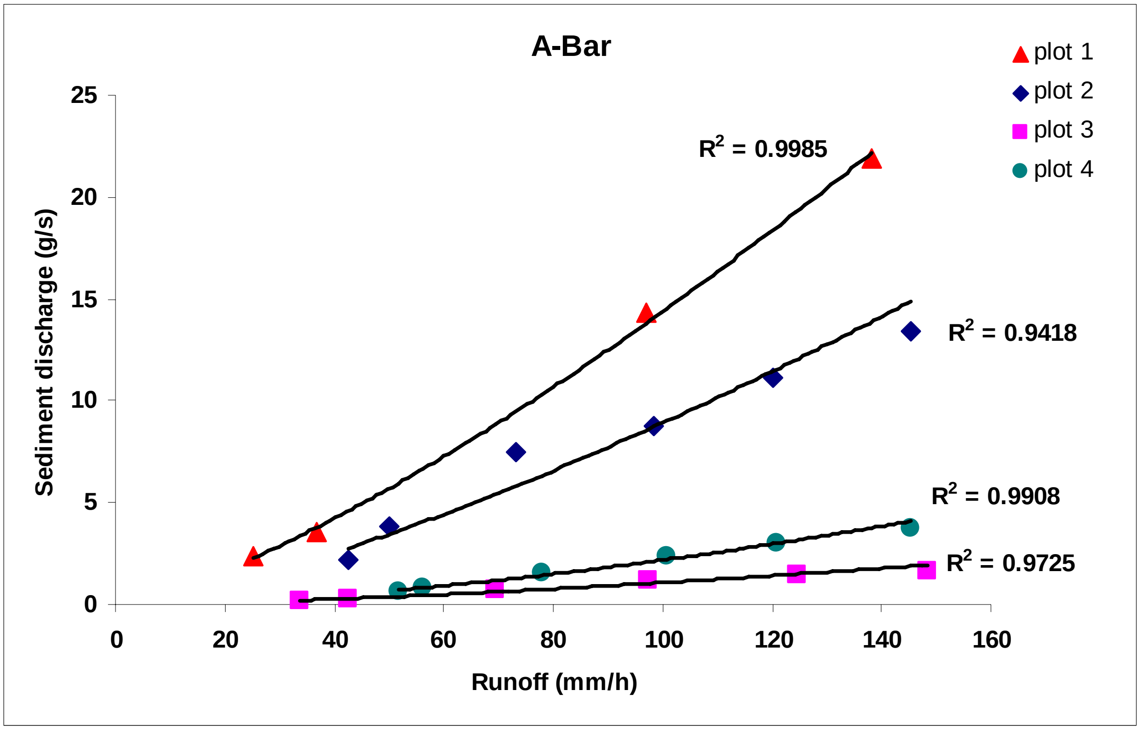
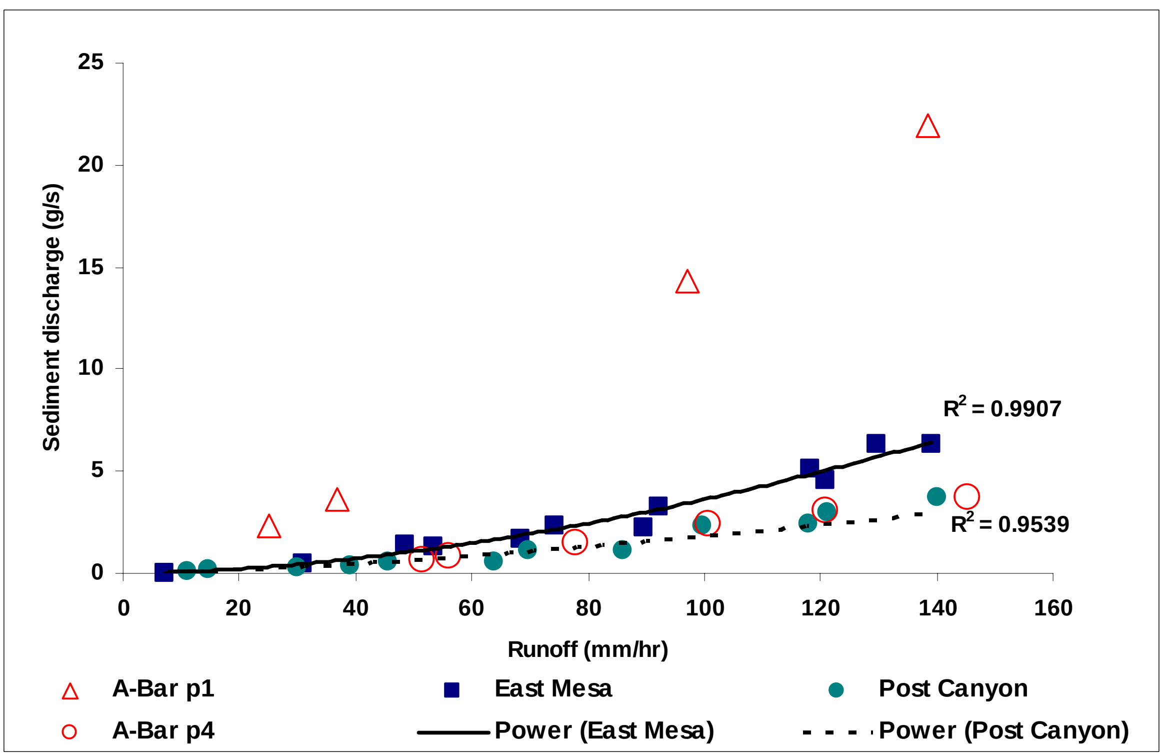
Site	Plot	I mm	Q mm	SY T/ha	Q/I	SY/QSo T/ha/mm
East Mesa	EM2	85	58	6.50	0.69	0.74
	EM3	106	52	5.58	0.50	0.89
Average:					**0.59**	**0.81**
Post Canyon	PC1	94	48	2.53	0.50	0.66
	PC2	94	58	3.21	0.62	0.61
Average:					**0.56**	**0.64**
A-Bar	AB1	64	40	16.43	0.63	3.98
	AB2	84	62	16.11	0.74	2.84
	AB3	90	65	2.11	0.72	0.40
	AB4	84	68	4.42	0.81	0.66
Average:					**0.72**	**1.97**



A-Bar
plot 1
plot 2
plot 3
plot 4
R2 = 0.9985
R2 = 0.9418
R2 = 0.9908
R2 = 0.9725
Sediment discharge (g/s)
Runoff (mm/h)



R2 = 0.9907
R2 = 0.9539
Sediment discharge (g/s)
Runoff (mm/hr)
A-Bar p1
East Mesa
Post Canyon
A-Bar p4
Power (East Mesa)
Power (Post Canyon)

Table 1. Total rainfall (I), runoff (Q), and sediment (SY) amounts and runoff (Q/I) and sediment yield ($SY/Q\ S_0$) ratios for the wet runs.

Figure 1. Comparison of sediment discharge rate as a function of runoff rate from the four plots at the A-Bar site.

Figure 2. Sediment discharge rate as a function of runoff rate from the East Mesa and Post Canyon grassland sites and plots 1 and 4 from the A-Bar site. The erosion response from plot 4 (A-Bar) is very similar to the response from the Post Canyon Site.

Appendix 5.

POST WILDFIRE RUNOFF AND EROSION RESPONSE ON GRASSLAND AND OAK WOODLANDS IN SOUTHEASTERN ARIZONA.

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ABSTRACT

Very little research has been conducted on the effect of wildfires on changes in runoff and erosion on grassland and oak woodland ecosystems in southeastern Arizona. As a result, land use managers and Burned Area Emergency Response teams face a high degree of uncertainty in evaluating post fire effects. Experiments using a rainfall simulator are being conducted after wildfires to measure runoff and erosion with the objective to develop methods for post fire evaluations. Data from four grassland and two oak woodland sites are presented and compared. The results for each vegetation community show that the increase in runoff ranges from no difference for grasslands to 20% for the oak woodlands while the increase in erosion is 350 to 500% for grassland and oak woodland respectively. Although the change in runoff is similar for both vegetation types, the increase in erosion is much greater for the oak woodland sites. This difference in erosion between the vegetation types is attributed to a change in the dominant erosion process from one that is primarily due to raindrop detachment for pre-fire conditions to one which is dominated by rill erosion immediately after a fire. For those sites with multiple years of data after the fire, both runoff and erosion appear to approach pre-fire conditions within two to three years.

INTRODUCTION

Land managers and Burned Area Emergency Rehabilitation (BAER) teams need to be able to quickly assess the effects of wildfires on runoff and erosion processes on semiarid rangelands to determine the potential on and offsite risks. However, post wildfire runoff and erosion rates on semiarid rangeland ecological sites are not well known. Currently in southeastern Arizona, peak runoff and erosion rates following a rangeland fire are typically estimated by the USFS using TR55 (USDA-NRCS, 1986) and Universal Soil Loss Equation (ULSE) (Wischmeier, 1959). Although these methods are robust, they may not be applicable in the southwest where high intensity thunderstorm rainfall dominates the runoff and erosion processes. Both these methods have uncertainties in parameter estimation and questions regarding their applicability to semiarid rangelands.

Field experiments using a variable intensity rainfall simulator are being conducted immediately following wildfires to quantify post wildfire runoff and erosion rates and over a four year period to monitor the recovery. This paper presents post-wildfire runoff and erosion results from two oak woodland fires, ABar and Antonio, and three grassland fires, Ryan, Tank, and Empire. All of the fires were located in southeastern Arizona and were low to moderate severity burns. Characteristics of the sites are listed in table 1.

METHOD

The rainfall simulator experiments were conducted immediately following the fires and before the onset of the summer monsoons. Simulations were also conducted on the same site for an unburned condition and are being conducted during the recovery period for a period of four years. The Walnut Gulch Rainfall Simulator, an oscillating boom, variable intensity rainfall simulator (Paige et al., 2003) was used to apply a range of rainfall intensities (50 to 180 mm/h) on four small (0.75 m^2) and four large (2x6 m) plots installed at the sites. The small plot data were used to quantify erosion by rain drop detachment and the large plot data were used to quantify runoff and the integrated erosion response of rain drop detachment, flow detachment, sediment transport, and deposition. All plots had a dry run with a rainfall intensity of 60 mm/h for 45 minutes at initial soil moisture conditions followed by a wet run one hour after the cessation of runoff from the dry run. For the wet run, a sequence of rainfall intensities were applied from 25 to 177 mm/hr in increasing increments. The application rates were changed after runoff had reached steady state for at least five minutes. Runoff was measured at the down slope outlet of the plot using a pressure depth gage attached to a pre-calibrated flume. Sediment samples were taken during the runs using grab samples, dried, and weighed to compute sediment concentrations. Plot cover characteristics, canopy and ground, were measured at 400 point per plot using the point intercept method.

RESULTS AND DISCUSSION

Results from the rainfall simulator experiments were analyzed using data collected from the wet runs and are presented as the average for grassland sites and oak woodland sites. The runoff ratio, the total runoff (Q) divided by the total amount of water applied (I), was used to quantify the differences in runoff. The sediment yield ratio was computed as the total sediment yield (SY) divided by the total runoff (Q) amount times the plot slope (So) to account for the range of slopes (8-30%) at the sites. The runoff ratios immediately after the fire were not significantly different for the grassland sites but significantly increased for the oak woodland sites (figure 1a) by about 20% immediately after the fire. In contrast with the runoff ratios, the sediment ratios were significantly larger after the fire for both vegetation communities, ranging from about 350% for the grassland sites to 500% for the oak woodland sites (figure 1b). However, the oak woodland sites had post fire ratios about 2.5 times larger than the post fire ratios for the grassland sites. For those sites with two years of recovery data, the sediment ratios are not significantly different than the pre-fire ratios for both vegetation communities.

The difference in sediment ratios between the oak woodland and grassland sites can be attributed in part to the dominant erosion process active at the sites. In the following discussion, we assume that rain drop detachment of soil is the same on the small and large plots and that the difference, if any, in sediment discharge between the two size plots is due to the dominant erosion process on the large plots. Theoretically if the small plot sediment discharge is larger than the large plot discharge, then there is deposition of rain drop detached sediment on the large plot. If the small plot sediment discharge is smaller than the large plot discharge, then flow detachment should be occurring on the large plot. If the sediment discharge on both plots is the same, then all that is being detached by rain drop impact is being transported off the large plot. Comparisons of small and large plot steady state sediment discharge versus steady state runoff discharge times slope for pre-fire and immediately after the fire for both communities are shown in figures 2 and 3. The curves in the figures are best fit log-log regression lines. For the grassland sites, the pre-fire small plot relationship is larger than the large plot relationship (figure 2a) indicating deposition on the large plot. After the fire (figure 2b) both the small and large plot relationships are the same, meaning that all that is being detached by rain drop impact is being transported off the plot. In contrast, for the oak woodland sites, the pre-fire relationship for the small and large plots is the same (figure 2a) while for the post fire, the large plot relationship is larger than the small plot (figure 2b). These figures suggest that for pre-fire conditions, the dominant erosion process is rain drop detachment on both vegetation communities but that the oak woodlands is on the threshold of flow detachment. After a wild fire, the dominant erosion process approaches flow detachment on the grasslands but transitions to flow dominated detachment on the oak woodlands. The difference between pre-fire and post fire response was primarily due to a loss of canopy and ground cover slightly increasing rain drop detachment but significantly increasing transport capacity. The difference in sediment yield between the vegetation communities is hypothesized to be due to a higher transport capacity caused by differences in microtopography. Flow on the grassland sites generally is obstructed by grass plants, litter, and rocks so that the surface roughness is high and the flow path is sinuous, particularly at the lower flow rates. Thus, there is greater opportunity for deposition of detached sediment. In contrast, the microtopography on the oak woodland sites consists of topographic high areas (mounds) under the oaks and manzanita shrubs and topographic low areas (interspace) populated by grasses. At both the oak woodland sites, these interspace areas were continuous in the downslope direction and concentrated runoff during the simulations. These continuous concentrated flow areas appear to be more efficient at transporting sediment off the site.

SUMMARY

Rainfall simulator experiments are being conducted after five wildfires on oak woodlands and grassland sites in southeastern Arizona. Results from the experiments show that runoff does not significantly increase for the grassland sites and slightly increases for the oak woodland sites. Erosion increases dramatically for both vegetation communities immediately after a fire, with the oak woodland having the largest increase. The increase in erosion is attributed to a change in the dominant erosion process from rain drop detachment to a threshold flow detachment for the grassland sites and a threshold flow detachment to flow detachment for the oak woodland sites. Both vegetation communities appear to be approaching pre-fire erosion rates two years after the fire.

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Table 1. Site characteristics

Site	Fire (year of fire)	Ecological Site	Vegetation Community	Average Slope (%)
ABar	ABar (2003)	Loamy Upland	Oak	8
Antonio	Antonio (2005)	Loamy Upland	Oak	16
Empire	Empire (2005)	Loamy Upland	grass	16
East Mesa	Ryan (2002)	Limey Slopes	grass	12
Post Canyon	Ryan (2002)	Loamy Upland	grass	8
Tank	Tank (2004)	Clay Loam Upland	grass	30

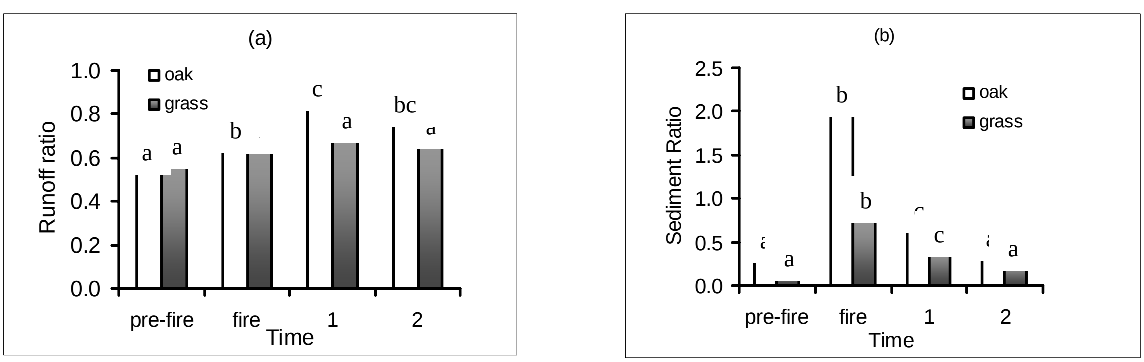

Figure 1. Vegetation community average (a) runoff ratios and (b) sediment ratios for pre-fire, immediately after the fire, and during the 1st and 2nd year after the fire. Bars for the same vegetation community followed by the same letter are not significantly different at $p \leq 0.05$.

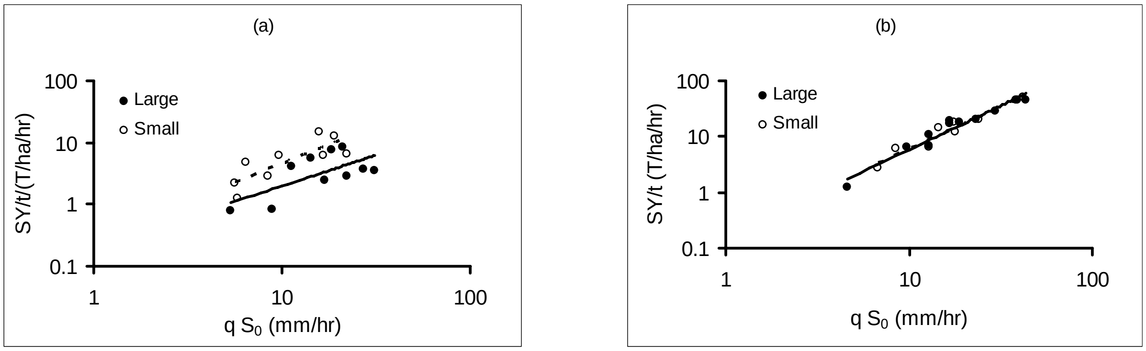

Figure 2. Comparison of small and large plot steady state sediment discharge (SY/t) versus steady state runoff discharge times slope (q S_0) for the grassland sites for (a) unburned and (b) burned conditions.

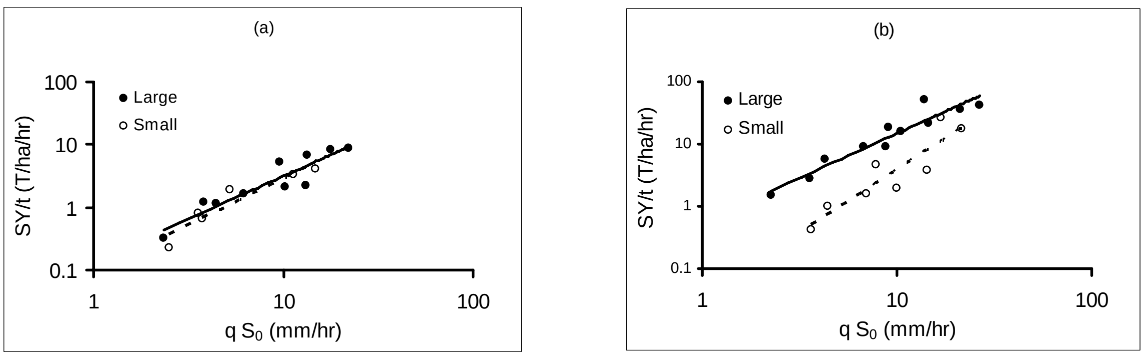

Figure 3. Comparison of small and large plot steady state sediment discharge (SY/t) versus steady state runoff discharge times slope (q S_0) for the oak woodland sites for (a) unburned and (b) burned conditions.