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.

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

* Ginger B. Paige, USDA-ARS Southwest Watershed Research Center, 2000 E. Allen Rd. Tucson, AZ 85719; e-mail:gpaige@tucson.ars.ag.gov.

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 mm	Q mm	Sy T/ha	Q/I	SY/QSo 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).

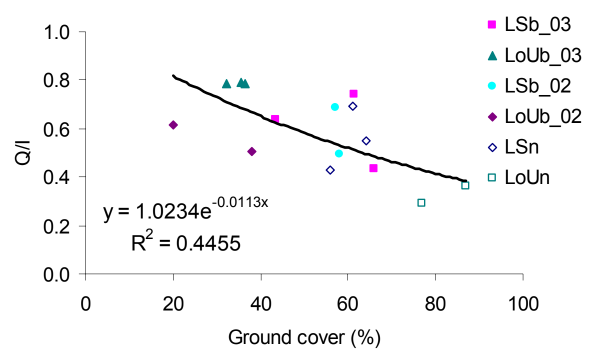

Fig. 1. Relationship between runoff ratio and percent ground cover.

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.

.

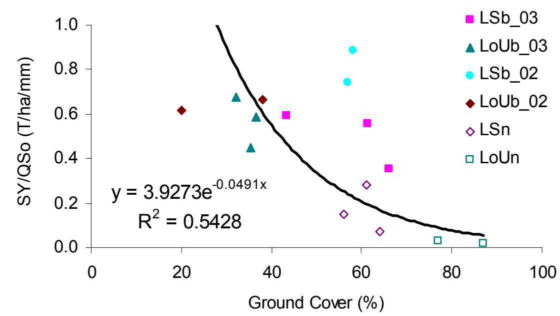

Fig. 2. Relationship between sediment yield ratio and percent ground cover.

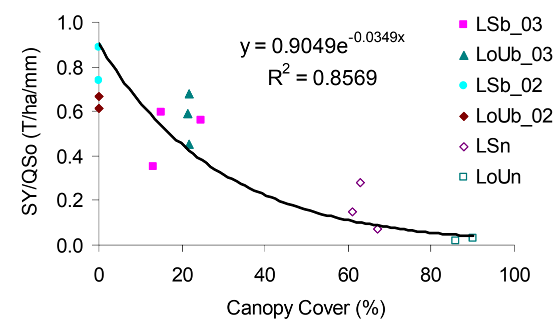

Fig. 3. Relationship between percent canopy cover and the sediment yield ratios.

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.

Acknowledgements

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 NRCS Range Conservationist and Soil Scientist respectively, for the assistance in Ecological Site selection.

5. REFERENCES

Bahre, C.J. 1991. A Legacy of Change: Historic Impact on Vegetation in Arizona Borderlands. University of Arizona Press, Tucson.

Elliot, W.J. and D.E. Hall. 1997. Water Erosion Prediction Project (WEPP) forest applications. General Technical Report INT-GTR-365. Moscow, ID: Intermountain Research Station. 11 p.

Elliot, W.J., D.L. Scheele, and D.E. Hall. 2000. The Forest Service WEPP Interfaces. ASAE Paper No. 005021. Presented at the 2000 ASAE Annual International Meeting, July 9-12, 2000, Milwaukee, WI. 8 p. St. Joseph, MI: American Society of Agricultural Engineers.

Emmerich, W.E. and J. R. Cox. 1992. Hydrologic characteristics immediately after seasonal burning on introduced and native grasslands. J. Range Management 45:476-479.

Emmerich, W.E. and J.R. Cox. 1994. Changes in surface runoff and sediment production after repeated rangeland burns. Soil Science Society of America Journal 58: 199–203.

Hester, J.W., T L. Thurow, and C.A. Taylor, Jr. 1997. Hydrologic characteristics of vegetation types as affected by prescribed burning. J. Range Management. 50:199-204.

Johansen, M.P., T.E. Hakonson, F.W. Wihicker, J.R. Simanton, and J.J. Stone. 2001. Hydrologic response and radionuclide transport following fire at semiarid sites. J. Environ. Qual. 30:2010-2017.

McPherson, G.R. 1995. The role of fire in desert grassland. *In* M.P. McClaran and T.R. Van Devender (eds.). The Desert Grassland. University of Arizona Press, Tucson, AZ. Pp 130-151.

O'Dea, M. and D.P. Guertin. 2003. Prescribed fire effects on erosion parameters in a perennial grassland. J. Range Management 56:27-32.

Paige G.B., J.J. Stone, J.R. Smith, and J.R. Kennedy. Accepted. The Walnut Gulch Rainfall Simulator: A computer controlled variable intensity rainfall simulator. ASAE Applied Engineering and Agriculture.

Pierson, F.B., P.R. Robichaud, and K.E. Spaeth. 2001. Spatial and temporal effects of wildfire on the hydrology of a steep rangeland watershed. Hydrologic Processes. 15:2905–2916.

Robichaud, P.R., W.J. Elliot, F.B. Pierson, and P.M. Wohlgemuth. 1999. Risk Assessment of Fuel Management Practices on Hillslope Erosion Processes. Proceedings of the Joint Fire Science Conference and Workshop, Volume II, June 15-17, 1999, Boise, ID. Moscow, ID: University of Idaho, International Association of Wildland Fire. 58-64.

Robichaud, P.R., J.L. Beyers, and D.G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Roundy, B.A., W.H. Blackburn, and R.E. Eckert. 1978. Influence of prescribed burning on infiltration and sediment production in the pinyon-juniper woodland, Nevada. J. Range Management 31(4):250-253.

Simanton, J.R. and K.G. Renard. 1985. Time related changes in rangeland erosion. *In* Proceeding of the Rainfall Simulator Workshop, January 14-15, 1985, Tucson AZ.

Stone, J.J., G.B. Paige, D. P. Guertin, H. Blumenfeld. (in review) Post wildfire runoff and erosion on two grassland ecological sites in southeastern Arizona. Journal of Range Management.

USDA-NRCS. 1972. Hydrology. Section 4. National Engineering Handbook. Soil Conservation Service. USDA. Washington, D.C.

USDA Forest Service. 2002. BAER report FSH 2509.13. Coronado National Forest, Tucson AZ.

Wischmeier, W.H. 1959. A rainfall erosion index for a Universal Soil-Loss Equation. Soil Sci. Soc. Am. Proc. 23:246-249.