Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation
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STOP SEDIMENT ON THE WATERSHED, NOT IN THE STREAM

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ABSTRACT Thirty years ago, the chaparral cover of a 2.5 km^2 research watershed was destroyed by an intense wildfire, leading to 2.5 x 10^6 m^3 of channel sediment deposits. Nearly all of the deposit remained in place. About 90% of the original chaparral density regrew with a mosaic-like distribution that also formed vegetation buffer strips on the hillside contours. While an average of 1165.8 kg ha^{-1} $year^{-1}$ of sediment was delivered from bare areas to the strips, only 0.2 kg ha^{-1} $year^{-1}$ left them. These deposits attained depths up to 0.5 m and are still growing. Since fine soils are missing, the deposits are still not compacted and can therefore be easily mobilized, should the vegetation be destroyed again. For management, it appears to be more prudent to prevent this mobilization than to build expensive structures in the channels to hold the sediment in place, but ways must be found to protect buffer strips.

INTRODUCTION

Interrelationships between the watershed and its stream network are still poorly understood and much of the literature on the subject is based on inference. This paper rests on field research in both the watershed and stream system.

The primary objective of watershed management is to maintain their components intact to prevent sediment delivery into stream channels. But the problem becomes more complicated if the sediment is readily available on the watershed: how do you prevent it from entering the stream? On our research watershed, burned 30 years ago by an intense wildfire, chaparral canopy cover has recovered to 90% of the original. Yet sediment is still being produced on the watershed. Relatively large bare areas, interspersed among shrubs, have neither organic cover nor topsoil and generate overland flow and sediment.

In the stream network, immense volumes of sediment have been deposited by storms following the fire. Later storms were not sufficient to remove it, leaving the network in a very unstable condition.

Our research objective was to determine the routing of the sediment produced on the watershed, from the site of production to and through the channel network. This knowledge should serve as a guide for future management actions.

PAST WORK

By far, most research in chaparral ecosystems has been done in California. Sediment surface movement seems to be dominated by dry processes in the southern California steeplands (Wohlgemuth, 1985). This contrasts with Arizona chaparral, where rainfall is the main agent (Heede, 1989). Reports on the effects of wildfire in chaparral are numerous, but most are short-term studies (Heede *et al.*, 1988).

Rowe (1948) demonstrated that repeated fires in southern California chaparral led to the formation of erosion pavements (matrices of different rock and pebble sizes on the ground surface) with high soil erosion rates as compared with the undisturbed floor under shrub cover. Rice (1974) suggested that, in fully vegetated chaparral, overland flow is a rare event. Wohlgemuth (1985) found in the San Gabriel Mountains of southern California that aspect and slope had no significant influence on sediment production. The annual sediment transport had a mean magnitude of 65±57 cm^3 cm^{-1} $year^{-1}$.

A detailed study of erosion processes by Brock & DeBano (1982) showed that overland flow increased manyfold when vegetation and litter were removed. They also demonstrated that litter cover is more important in controlling erosion (surface wash) than slope angle, because it increases infiltration and reduces overland flow. Indeed, relatively small increases in litter volume caused substantial increases in infiltration.

STUDY AREA

El Oso Creek watershed (drainage area, 2.5 km^2) is located in central Arizona on the east flank of the Mazatzal Mountains. Average elevation is 1100 m; bedrock geology consists predominantly of deeply weathered coarse-textured Precambrian granite. During the two study years, average annual precipitation was 414 mm, only 33% of which fell in summer. Extremely high summer temperatures (up to 43°C) reduced the effective precipitation substantially.

El Oso Creek is a fifth-order stream, about 5000 m long. Its overall gradient is 12.4%. Channel fills up to 25-m depth were determined seismographically, and the deposits were estimated at 2.5×10^6 m^3 (Laird, 1986).

METHODS

At different elevations and aspects, 10 hillslope segments or microwatersheds, representing topographic swales, were selected and surveyed. Five microwatersheds had only bare ground cover, while the other five had bare ground cover with a relatively dense strip of chaparral on their downhill border. Strip width ranged between 2.5 and 4.5 m. To prevent breaching of the swale boundaries by intense overland flows, sheet-metal strips were sunk into the ground. At the downhill side of the microwatersheds, 4-m-long runoff collector troughs caught and conveyed the water-sediment mixture into tanks for volumetric measurements. A precipitation network was installed.

RESULTS

Table 1 presents average annual overland flow and sediment delivery from the two types of microwatersheds. In evaluating this table, one must consider that 1989 was a drought year in Arizona. For example, in 1988 the average total annual sediment delivery from the microwatersheds with bare area amounted to 2324 kg ha^{-1} $year^{-1}$, while in 1989 it was only 21 kg ha^{-1} $year^{-1}$.

TABLE 1 Annual overland flow and sediment delivery from the two vegetation cover types in a chaparral woodland, 1988 and 1989.

Subdrainage no.	Area ha	Average slope %	Overland flow mm year^{-1} 1988	1989	Sediment delivery kg ha^{-1} year^{-1} 1988	1989
			Bare areas			
1	0.01	39	3.3	0.2	863.34	2.02
3	0.02	16	5.2	0.3	2973.89	9.96
4	0.01	22	27.3	0	5194.82	0
5	0.06	35	37.0	2.2	2470.23	94.32
10	0.01	33	0.7	0	38.39	0
Ave.			14.7	0.5	2324.37	21.26
			Areas with buffer strips			
7	0.01	40	0	0	0	0
8	0.01	35	0	0	0	0
9	0.01	33	0.3	0	2.18	0
17	0.01	19	0	0	0	0
18	0.21	64	0	0	0	0
Ave.			0.1	0	0.44	0

Comparison of the two-year averages of overland flow and sediment delivery for the two types of microwatersheds shows that buffer strips retained all flows and practically all sediment. As repeatedly described in the literature, the organic ground cover available in the strips increased water infiltration and eliminated the vehicle for sediment transport. Infiltration was also enhanced by the sediment deposited at the buffer strips. Permeameter observations indicated that these deposits have high hydraulic conductivities, i.e., 12.20 mm h^{-1} compared with 6.72 mm h^{-1} for the bare areas (Heede *et al.*, 1988). Insufficient numbers of replications did not allow statistical testing. The depositional process resulted in substantial accumulations of sediment at the uphill side of the strips, which reached depths up to 0.5 m.

Slope gradient influenced neither flow nor sediment. In 1988, a 39% slope produced 3 mm year^{-1} of flow and 863 kg ha^{-1} year^{-1} sediment, while a 16% slope generated 5 mm year^{-1} and 2974 kg ha^{-1} year^{-1} of flow and sediment, respectively. Obviously, other variables play a role also.

Production of flow and sediment (Table 2) is much higher in summer than winter due to the high intensity summer storms that produce higher flow and sediment volume.

The great variability of the data for sediment delivery between the individual subdrainages also suggests that factors other than those considered enter into the processes. This variability also existed between years which, due to the drought, was extreme during the two years of investigation. Absolute data, unless based on long-time records and expressed in error or probability terms, are therefore not useful. The importance of the study results lies in the fact that immense differences existed between sediment delivery from vegetation buffer strips and bare ground.

TABLE 2 Seasonal overland flow and sediment delivery from the two vegetation cover types in a chaparral woodland, 1988 and 1989.

Subdrainage no.	Overland flow ($mm\ season^{-1}$)				Sediment delivery ($kg\ ha^{-1}\ season^{-1}$)			
	Winter		Summer		Winter		Summer	
	1988	1989	1988	1989	1988	1989	1988	1989
				Bare area				
1	0	0	3.3	0.2	0	0	863.34	2.02
3	2.2	0.1	3.0	0.2	203.42	2.00	2770.47	7.96
4	16.0	0	11.3	0	401.75	0	4793.07	0
5	8.9	0.8	28.1	1.4	173.91	6.04	2296.32	88.28
10	0.2	0	.5	0	1.76	0	36.63	0
Ave.	5.5	0.2	9.2	1.8	156.17	1.61	2151.97	19.65
				Areas with buffer strips				
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0.3	0	0	0	2.18	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
Ave.	0.1	0	0	0	0.44	0	0	0

DISCUSSION AND CONCLUSION

Inspection of the chaparral buffer strips on the watershed provided not one instance where a buffer strip was overrun by flow and sediment. It is probable of course that large storms would produce enough overland flow to overrun the buffer strips. In our arid conditions, storms are very scattered in time and space, and it is possible that sufficient time has elapsed since the occurrence of such a storm to allow eradication of all signs. Litter fall and duff development may have been the agents to hide the event.

Bare areas are distributed in a mosaic pattern on the watershed. Thus sediment transport, occurring by surface movement, takes place intermittently; continuous transport is rare. Even if sediment could move downslope toward the channel, most would finally be stopped by the continuous chaparral buffer strip lining the channels. Due to the greater soil moisture there, these strips are generally very dense. A large volume of sediment is being stored by the many buffer strips in the watershed. Derived from coarse-grained granite that has weathered into small particles (diameter about 0.5 cm), the material is cohesionless and therefore would be easily transported again if the buffer strips were destroyed by a future intense wildfire. A subsequent storm could set vast masses of material into motion. Thus, a negative feedback mechanism exists and must be realized by management.

Large quantities of post-fire sediment are also being stored in the stream channel network itself because of a lack of major storm events. These deposits are still increasing in size, as evidenced by large and small in-channel fans. These are fed by steep-gradient tributary streams, most of them twice as steep as the main channel. Due to the sediment deposits, the new main channel is wide and shallow, creating flows of small depth with decreased competence for sediment transport. The loose, cohesionless deposits absorb great amounts of water, decreasing the chances for the occurrence of a channel-cleaning flow. Yet, if such a major flow should occur, a large portion of the 2.5×10^6 m^3 of material could be set into motion toward an important reservoir about 3 km downstream from the watershed. To prevent this, expensive channel control structures would be required. It would probably be much less costly to develop and apply measures to protect the buffer strips and retain the sediment on the watershed if a wildfire strikes. For example, controlled burning, with the objective of preventing future "hot" fires, could be designed to leave existing buffer strips intact or create new ones. In short, we should learn to prevent damage in the first place, and eliminate the need for future "band-aid" corrective actions.

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