# HYDROLOGIC BEHAVIOR OF GULLIES IN THE SOUTH CAROLINA PIEDMONT

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**Abstract.** The Piedmont region in the United States has been eroded and gullied due to deforestation and cultivation during the 1700 and 1800. Currently, a majority of these gullies are under forest vegetation and appear stable; however, neither the hydrology of these gullies, nor their sediment contribution to surface waters, has been quantified. This study instrumented eight gullies ranging in size from 36-90 m long, 2.4 to 9.5 m wide, and 0.9 to 3.0 m deep with weirs, stage recorders, and stormwater samplers to assess gully response to prescribed burning. Results from pre-burn data show that only four out of the eight gullies exhibit flow during storm events ranging up to 25.7 mm. Higher rainfall amounts, such as those achieved during hurricanes, may be needed to initiate flow in all gullies. This observation has implications for understanding gully re-activation and associated erosion.

## INTRODUCTION

The Piedmont region suffered severe erosion in the past due to deforestation and cultivation (Trimble, 1974; Richter and Markewitz, 2001). Evidence of this history is recognizable in the turbid condition of rivers and streams today that is unlike those of pre-European colonization described by William Bartram (Harper, 1998), and the large gullies that are present under secondary forest vegetation. The role these gullies play in the overall hydrologic function of a site is not known (Hansen and Law, in press). Likewise, the contribution of these gullies, through continued erosion, to the overall sediment production of a watershed are typically unaccounted for in erosion models (e.g. WEPP and USLE; Poesen et al. 2003) and yet could play a significant role in producing non-point source sediment pollution.

Non-point source pollution associated with sediment is one of the key issues in the southern United States (Neary et al. 1988; Baker 1992). In forested watersheds, best management practices are often followed, in part, to minimize sediment input to streams. These practices often focus on activities proximal to streams (Lynch et al., 1985) with little regard to gully networks. If gullies, however, behave like an ephemeral stream, policies pertaining to prevention of sediment movement might logically be extended to include these land features. This is especially true for gullies which connect directly to perennial streams and, thus, readily facilitate direct transport of sediments and nutrients from upslope areas. Rivenbank and Jackson (2004) found 50% of the breakthrough of sediment from recently clearcut and site prepared sites to stream channels, passed the Streamside Management Zones (SMZ), due to convergence (swales) and gullies.

The overall objective of this study is to understand the hydrologic behavior of gullies within the Piedmont of South Carolina. In particular, we are assessing if prescribed burning alters this behavior and, in so doing, increase sediment inputs to streams. This paper reports on the pre-burn calibration results for eight instrumented gullies.

## MATERIALS AND METHODS

This study is being conducted at the north end of the Long Cane Ranger District, Sumter National Forest, South Carolina. This area is part of the Piedmont region which extends from Virginia to Mississippi. This region was subjected to deforestation and intensive cotton cultivation from the late 1800's to early 1900's, which resulted in massive gully formation (Trimble, 1974). The study area is characterized by Cecil series soils (fine, kaolinitic, thermic, typic Kanhapludults), an elevation range of 120 to 180 masl, and an average annual rainfall of about 1,210 mm, distributed evenly throughout the year (USDA, 1980).

Eight gullies ranging in size from 36 to 90 m long, 2.4 to 9.5 m wide, and 0.9 to 3.0 m deep were instrumented with $90^o$ V-notch weirs between November to December, 2005. Morphological properties of the individual gullies were measured following the procedure outlined in Galang et al. (in press), with the exception of conducting the measurements between the headcut and weir instrumentation point instead of to the gully mouth. Six of the eight gullies are near one another (Table 1, gullies 1-6) within two management compartments (with three gullies each), while the other two gullies are in a separate location

Table 1. Summary of the morphological properties of the instrumented gullies within the Sumter National Forest in the Piedmont of South Carolina. Data were collected on April 2006.

| **Gully** No. | **Slope** (%) | **Headcut** (m) Depth | Height | **CS** (%) | **Length** (m) | **Width** (m) | **Depth** (m) | **Cover** (%) FF | Can |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 0.8 | 3.9 | 14 | 68 | 5.9 | 1.5 | 100 | 92 |
| 2 | 6 | 2.9 | 12.3 | 5 | 40 | 9.5 | 2.7 | 96 | 94 |
| 3 | 15 | 2.1 | 5.2 | 11 | 54 | 9.2 | 3.0 | 100 | 95 |
| 4* | 7 | 2.7 | 11.5 | 9 | 68 | 6.2 | 2.1 | 96 | 93 |
| 5* | 8 | 0.8 | 2.1 | 11 | 50 | 2.4 | 0.9 | 96 | 92 |
| 6* | 4 | 1.6 | 2.0 | 6 | 52 | 4.3 | 1.2 | 100 | 89 |
| 7* | 7 | 1.3 | 4.8 | 17 | 90 | 7.9 | 2.0 | 96 | 92 |
| 8 | 16 | 1.3 | 4.4 | 6 | 36 | 4.3 | 1.4 | 96 | 92 |

CS = Contributing slope, measured above the headcut, FF = Forest Floor, Can = Canopy cover
* exhibited flow during the observation period

<1 km from the other six. All the gullies are under mature pine stands of about 30 years old with occasional hardwood trees established in the gully bed and side slope. Forest floor depth ranges from 3 to 5 cm. Data-logging pressure transducers and stormwater samplers were installed in each gully to estimate the amount of flow and collect runoff samples for analysis. One raingauge was installed near the first six gullies and another one near the two other gullies. Four soil moisture sensors were also installed atop the side slope of four selected gullies, recording soil moisture content in the 0-15 cm depth.

Data were collected during a 3-month observation period (January 22 - April 27, 2006) and are on-going.

## RESULTS AND DISCUSSION

Of the eight gullies instrumented, only four exhibited flow during the observation period (Table 1, Figure 1A). Due to the small discharge observed in each gully, the data are presented in terms of depth (cm); measured on the upstream side of the weir, instead of as discharge (L $sec^{-1}$). Gully 7 was the most active of all the four gullies producing ponding as high as 31 cm during winter that decreased as the season progressed to spring. Gully 4 exhibited almost the same pattern as gully 7 but with a lesser degree of ponding and greater periods of inactivity during some rain events. Gullies 5 and 6 were also much alike showing the same periods of activity and inactivity from January to April, 2006.

None of the gullies instrumented flowed following the rain events of March 10 or 14, 2006, which, respectively, produced 6 and 13 mm of rainfall. A decreasing trend in soil moisture content had already started in this period and the drier antecedent moisture contents (<0.24 $m^3/m^3$) likely affected this response (Figure 1B). These rain events did not increase soil moisture content enough to create saturation overland flow nor did intensities exceed infiltration to produce Hortonian overland flow. However, a rain event of 19 and 16 mm in consecutive days with a 30-min intensity of 19 mm/hr triggered flow in two of the gullies on March 20, 2006 (Figure 1C and 1D). These rain events increased soil moisture content to ~0.30 $m^3/m^3$, which did not decrease to values <0.25 $m^3/m^3$ for several days.

Gully flow is not only a function of soil saturation or infiltration excess mechanisms but also appears related to topographic position of each gully. Mapping of the relative positions of each gully and its relation to the overall drainage network is currently on-going but preliminary results from Geographic Information Systems (GIS) Analysis show that the four gullies which exhibited flow have larger drainage areas and are positioned lower in relation to the overall drainage network. Gullies, which did not exhibit flow, i.e. gullies 1 to 3, were found to have a higher average width, which might require a greater volume of runoff to initiate flow. It is believed in this case, that runoff channeled through the gullies infiltrates the bed and side slopes of the gulley prior to emerging at the bed further downslope and inducing flow. Hansen and Law (in press) observed erosion in a small ephemeral gully (0.25 acre or 0.1 ha) only during severe storms, which is probably induced by large flow created during those rain events.

The flow or no flow conditions observed in this study may have significant implications for non-point source pollution. In forested watersheds containing hydrologically active gullies, transport of sediments or chemical inputs such as fertilizers and pesticides, can be directly channeled to the floodplain and stream. This might require significant re-consideration in terms of BMPs on ephemeral and perennial streams. On the other hand, areas with inactive gullies might be safely ignored. However, further investigation is required as to what rainfall and soil moisture conditions might induce flow and how management circumstances might influence these responses. For example, prescribed burning that consumes the forest floor could trigger re-activation of these gullies.

Presently, the data from this study supports the conclusion found by Harvey et al. (1985) that the mere presence of gullies does not always equate to high sediment yields, especially in a forested watershed. In contrast, however, these data partially contradict the claims by Poesen et al. (2003) that gullies provide continuity of sediment and water flow from the uplands to the valley bottoms, as some of the observed gullies did not exhibit flow. Clearly, the strength of our results are limited by the short observation period of this study and the limited the range of rainfall and soil moisture conditions observed; a condition that will be addressed by continuation of the study.

## CONCLUSION

This study provides information on the hydrologic behavior of gullies in the South Carolina Piedmont under

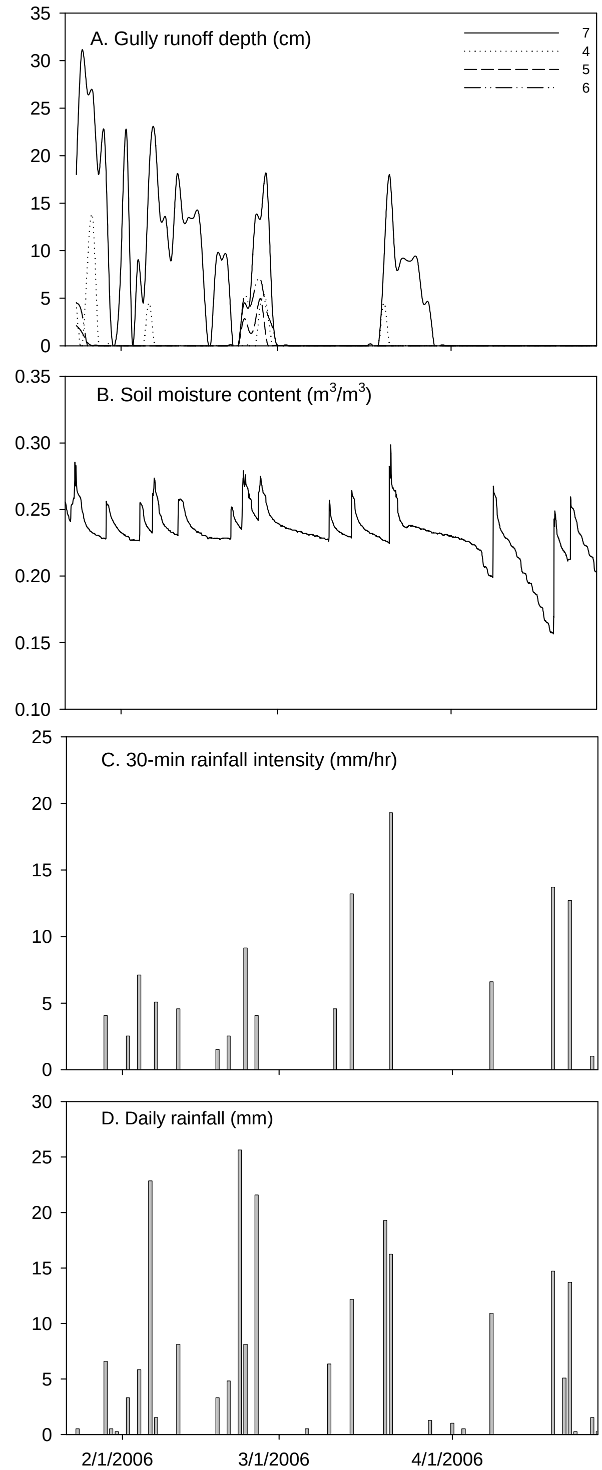


Figure 1. Runoff depth (A) observed in four of eight instrumented gullies within the period of observation as measured in the ponding created at the upstream side of the weir. Soil moisture content (B), daily rainfall intensity (C) and daily rainfall amount (D) are also presented to show the interplay of these factors in producing the observed runoff. Gullies are in the Sumter National Forest in the Piedmont of South Carolina.

undisturbed forested watersheds. We have learned that even under relatively small rain events, some gullies are hyrdologically active. Likewise, not all gullies conduct stormwater during rain events. The percentage of gullies transporting stormwater during high intensity rainfall like hurricane events remains to be determined. With the continuation of this study, insights on the change in behavior induced by prescribed burning will be known.

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