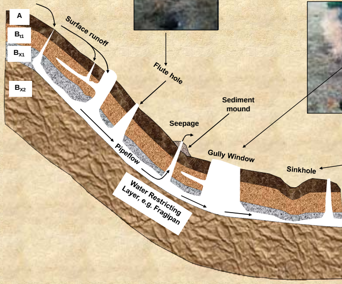
Response of Soil Pipe Collapse Features to Land Management and Soil Hydropedology

G.V. Wilson, J.R. Rigby, and S.M. Dabney
Watershed Physical Processes Research Unit, USDA-ARS National Sedimentation Laboratory

Introduction and Background

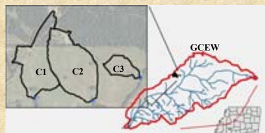
Piping has received considerable attention with regards to its role in extreme erosion events such as landslides, sinkholes, streambank failures, gully erosion, and levee/dam failures. However, the controlling process, i.e. pipeflow, is often overlooked or not obvious because these extreme erosion events tend to remove or bury the evidence of their origin, i.e. the soil pipes

Little is known about the association of soil pipe collapse features to soil properties or land use history. Soil pipes tend to develop in duplex soil in that water restricting horizons cause a proliferation of biopores at the interface and foster lateral subsurface flow by perching water. Internal erosion can enlarge these preferential flow paths to the extent that pipe's collapse, thereby forming flute holes, sinkholes and ephemeral gullies at the surface.



This paper will explore the connections between hydropedologic soil properties and past landuse with soil pipeflow processes using observations of soil pipes in Goodwin Creek Experimental Watershed.

Field Site Description



The 2,132 ha Goodwin Creek Experimental Watershed is located in Panola County, MS.

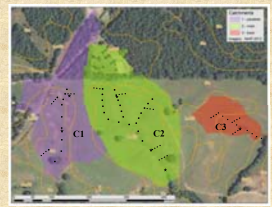
Agriculture (cotton) was historically practiced over the majority of the watershed, but is currently only in flat (slope < 2%) alluvial plains occupying only 6% of the area whereas the hilly forest and pasture lands occupy 39 and 55 %, respectively.

The parcel of interest in GCEW contained three catchments.

The western most catchment (C1) is 5.04 ha, the center catchment (C2) is 6.50 ha, and the eastern most catchment (C3) is 1.36 ha.

All three catchments are mapped as predominantly Loring silt loam soil (fine-silty, mixed, active thermic Oxyaquic Fragiudalf) or gullied (unidentified soil due to erosion) with percentage Loring by area of 72, 98, and 55%, respectively, for C1, C2, and C3.

Field Measurements



In 2013 and 2014 the location of pipe collapse feature was determined by differential GPS. The accuracy was 1 cm in horizontal direction and 1.5 cm in vertical direction. Pipe collapse features were surveyed for their location, dimensions measured manually, and classified by type feature, e.g. sinkhole, flute hole, gully window.

The soil profile was described at six locations (stars) for depth, soil texture, and soil structure. Four undisturbed soil cores were extracted from each horizon along with bulk soil samples. The following *in situ* measurements were made at the soil profile locations as well as at transect locations (solid circles) within each catchment: soil profile description, gravimetric soil water content, shear strength, and soil penetration resistance. The *in situ* locations were generally at 30.48 m intervals along the thalweg of the catchments and 15.24 m intervals along the bottom of the swale of each branch, and 7.62 intervals up selected hillslopes.

Laboratory Measurements

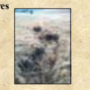
The following properties were determined on the undisturbed soil cores: bulk density (ρ_b), saturated hydraulic conductivity (K_s) by the constant head method (Klute and Dirksen, 1986), water retention by the pressure cell method (Dane and Hopmans, 2002) and erodibility by the pinhole method (ASTM D4647, 1993).

A 2 mm diam pinhole was created through the center of cores and flow of distilled water was established under progressively increasing constants heads of 50, 180, 380, and 1040 mm in 5 minute increments. Outflow samples were collected every 1 minute or less depending upon the flow rate, and all samples that had any visible sediment (Barely Visible rating or higher) were placed in an oven for sediment content determination. The flow rate, sediment concentration and final pin hole enlargement determined the erodibility class.

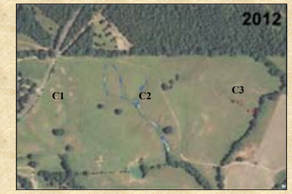
Pinhole Test

Head	Flow Rate $cm^3 s^{-1}$	Effluent color	Pinhole Diameter	Category	Classification
50	>4.8	Very High	>2x	D1	Dispersive
50	>4.8	High	>1.5x	D2	Dispersive
50	<4.8	Medium	>1.5x	ND4	Moderately Dispersive
180	>4.8	Medium	>1.5x	ND4	Moderately Dispersive
180	<4.8	Slight	>1.5x	ND3	Slightly Dispersive
380	>1.8	Slight	>1.5x	ND3	Slightly Dispersive
1020	>3.0	>Barely Visible	<1.5X	ND2	Non-dispersive
1020	<3.0	Clear	<1.5x	ND1	Non-erosive

Results and Discussion



C2 features



C3 features

C2 had more pipe collapse features but density was lower 15.4 # ha^{-1} than in C3=29.4 # ha^{-1}

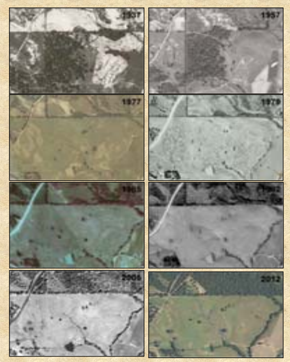
The flute holes and sinkholes were smaller in C2 but gully windows were larger.

Pipe collapse features extended to higher landscape positions in C2.

Feature	Total #	Depth (cm)	Length (cm)	Width (cm)	Vol (m^3)
	Catchment C2				
Flute holes	56	29.2	25.2	20.4	0.137
Sink holes	19	14.8	71.5	62.4	0.059
Small GW	19	33.6	85.1	40.6	2.304
Large GW	6	59.2	3352	163.7	198.912
	Catchment C3				
Flute holes	14	55.5	38.4	31.6	0.102
Sink holes	12	13.7	77.9	72.5	0.044
Small GW	5	44.0	172.4	70.2	2.664
Large GW	9	58.3	601.8	110.7	45.600

The pipe collapse features were significantly deeper, longer, and wider in C3 than C2.

Pipe collapses features in C3 tended to be in lower swale and more actively growing.



1930's The non-piped catchment (C1), which was believed to have been in cotton prior to 1930s, was severely eroded, being described from childhood memories as "pure gullies and raw banks." C2 was primarily an oak/hickory forest. Catchment C3 was primarily in cotton except the area where pipe collapses later appear which was a mature oak/hickory forest.

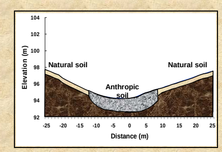
1950's: All three catchments converted to pasture. Using a bulldozer, C1, was "smoothed," the oak/hickories in C2 were cleared, bunched into rows, burnt, then debris pushed into existing gullies, whereas, the trees were just cleared from the swale in C3.

1970's: A plume of sediment was evident in fields below C3 outlet. Gully windows first appear in lower swale of C2 and C3.

1990's: Pipe collapses appear in upper branches of C2.

In total, the edge of field gully that began outside the subwatershed in 1937, had extended at least 105 m by 1957, an additional 125 m by 1977, and only an additional 3 to 4 m by 2007 then remained fairly stable with regards to linear extent until 2013. Between 2013 and 2014 it grew an additional 1.7 m.

The "Natural" Loring pedon was observed in the upper reaches of the three branches of C2, and all locations of C3. The hillslopes in C2 and C3 tended to have shallower depth to fragipan layers than along the swale.



However, the swale locations and along the thalweg to midway up the three branches of C2 the soil was not the Natural Loring. The subsoil layers appeared to be relatively recent sediment deposits containing small eroded aggregates of fragic material that were deposited and lots of charcoal. These Anthropic features were not evident in C3.

This finding of anthropic soils was consistent with the landowner's testimony that the trees cleared from the catchment were burned, then pushed into the pre-existing gullies to fill them.

Horizon	Depth (cm)	Sand %	Clay %	Bulk Density mg m^{-3}	SV kPa	SPR kPa	Pinhole Erodibility
Catchment C1, Anthropic Soil							
A_p	0-5	7.9	16.9	1.062c	191a	1669a	1.5b
1	5-19	6.2	20.2	1.433b	143b	1627a	2.8b
2	19-40	20.3	15.4	1.562a	88b	1266a	4.8a
3	40-	14.0	16.0	1.555a	76b	1104a	5.0a
Catchment C2, Natural Soil							
A_p	0-11	8.1	8.3	1.224b	148cd	1636b	1.0c
B_{t1}	11-30	7.2	11.4	1.383a	126d	1511b	2.2b
B_{t2}	30-48	8.8	15.2	1.362a	147cd	1915ab	3.3a
B_{tx1}	48-62	12.8	21.6	1.380a	175bc	2785a	3.7a
B_{tx2}	67-74	9.5	19.6	1.415a	185ab	2334ab	3.2ab
B_{tx3}	74-	9.4	21.7	1.411a	220a	3022a	2.7ab
Catchment C2, Anthropic Soil							
A_p	0-14	12.1	9.6	1.346c	161a	1972a	1.0d
1	14-33	9.4	9.0	1.566a	97b	1729ab	2.0c
2	32-46	9.6	13.3	1.401bc	83b	1553b	3.3b
3	46-65	9.6	16.0	1.422b	85b	1230b	3.3b
4	64-88	14.1	14.0	1.400bc	99b		4.0a
Catchment C3							
A_p	0-5	7.6	11.8	1.284b	143a	1047c	1.3b
B_{t1}	5-27	6.5	16.4	1.346a	100c	1513b	2.3b
B_{t2}	27-45	6.6	21.8	1.298ab	103bc	1649b	2.0b
B_{tx1}	45-61	6.1	16.2	1.299ab	124abc	2663a	3.5a
B_{tx2}	61-81	7.3	10.6	1.324ab	131ab		3.8a
B_{tx3}	81-	6.6	11.8	1.314ab	139ab		3.5a

Different letters indicate that the variable of interest (i.e. within the column) are significantly different at the 0.05 level among horizons within each respective catchment.

Only 3/20 locations in C1 exhibited the Natural profile-the northern upper most hillslopes. The other locations were missing surface layers-85% of the catchment was severely eroded. 7/20 sites exhibited sediment deposition layers and thus termed Anthropic.

The A_p was similar among catchments for the Natural and Anthropic soil layers.

The fragipan horizons of C2 consistently exhibited the highest shear strength and soil penetration resistance whereas the same horizons in C3 consistently had lower shear strength. These differences would suggest that fragipan layers of C3 are more susceptible to erosion.

The surface layer was non erodible. The subsurface layers were slightly dispersive to dispersive, including the fragipan layers.

The resistance to erosion of the surface layer, thereby, forms a bridge as the soil pipes grow. The lower fragipan layer provides a less-erodible lower boundary that restricts vertical expansion of pipes.

Conclusions

The prevalence of soil piping in the C2 and C3 catchments, in contrast to the C1 catchment, may be attributed largely to the combination of soil properties and landuse history. Soil pipes were closely associated with past management, particularly the presence of historical gullies filled-in (i.e. anthropic soils overlying fragipan horizons) in upper thalweg and lower swale positions.

The C1 catchment did not exhibit soil pipes due to past land use. With the exception of a few locations in C1, the intermediate layers that are susceptible to internal erosion were completely removed by historical rill and sheet erosion when this catchment was under intensive cotton production dating back to early or pre-1900s.

Around three decades after these trees were removed from the historical gully locations, subsurface erosion became evident at the surface.