## SEEPAGE EROSION IMPACTS ON EDGE-OF-FIELD GULLY EROSION

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### 1. Introduction

Concentrated flow is generally considered the controlling mechanism for gully erosion whereas subsurface flow is often overlooked. The two mechanisms of subsurface flow attributed to gully erosion are seepage flow and preferential flow through soil-pipes. Seepage erosion typically occurs in duplex soils in which a perched water table develops above a water-restricting horizon. The effect of seepage is usually considered to be limited to the production of surface runoff and the impact of increasing soil water pressures on reducing soil shear strength. However, recent studies by Wilson et al. (2007), Fox et al (2006, 2007), and Chu-Agar et al. (2007) have demonstrated that seepage erosion can be the controlling process of streambank failure and by analogy may be a significant contributor to gully erosion. Seepage erosion is used to describe the process of sediment transport out of the gully face by liquefaction of soil particles entrained in the seepage. The undercutting of the gully face by seepage erosion results in bank failure which may be a contributing factor to headcut migration and gully widening. This paper will review this recent work on seepage erosion.

### 2. Methodologies

2.1. In situ measurements

Seepage flow and erosion were measured after selected rainfall events at both the Little Topashaw Creek (LTC) and Goodwin Creek (GC) in northern Mississippi using 50- cm wide lateral flow collection pans installed into the streambank face. A time discrete sample was collected at steady-state sediment transport out of the pan.

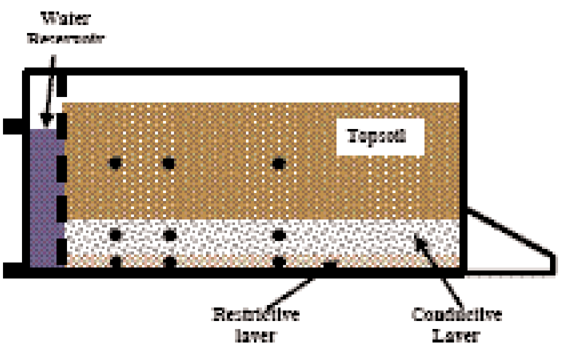


**Fig. 1.** The artificial streambank profile lysimeter (100 cm long by 15 cm wide) with a constant head water reservoir and tensiometers (solid circles) in each layer.

2.2. Lysimeter experiments

Lysimeter experiments were conducted to simulate seepage erosion at LTC. The simulated LTC streambanks consisted of a silt loam topsoil of varying bank height, a 0.10 m conductive loamy sand layer, and a 0.05 m clay loam restrictive layer at the bottom (Figure 1). Lysimeter experiments were performed by varying the inflow water head (30, 40, and 60 cm), bank height of topsoil (30, 50, and 80 cm), and lysimeter slope (0%, 5%, and 10%).

2.3. Stability Modeling

Bank stability with variably-saturated flow modeling was presented by Chu-Agor et al. (2007). SEEP/W, a 2D Richards' equation model, was integrated with SLOPE/W, a bank stability model, to simulate the mass wasting due to seepage erosion. SEEP/W model was calibrated with the measured soil-water pressures and cumulative discharges of the lysimeter experiments by slightly adjusting the hydraulic conductivity, $K_s$, and water retention parameters ($\alpha$ and $n$). Changes in the geometry of the flow domain to reflect the undercutting by seepage erosion was accomplished by changing the material properties of segments, Figure 2. In SEEP/W, the region was treated as a void in the flow domain by not assigning a material property, whereas in SLOPE/W the eroded area was treated as a null region without soil strength properties specified.

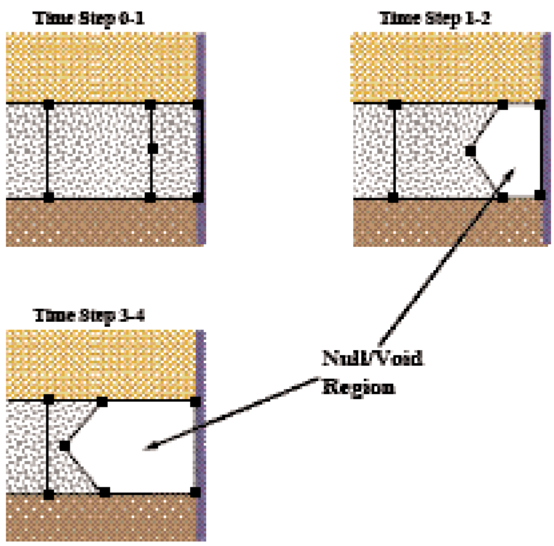


**Fig. 2.** Changes in flow and stability model domains as a result of seepage erosion undercutting banks.

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SLOPE/W uses the theory of limit equilibrium of forces and moments to compute the factor of safety (Fs) against failure:

$$F_s = \frac{\sum \left( (c' \beta \cos \alpha + (N - u\beta) \tan \phi' \cos \alpha \right)}{\sum N \sin \alpha - \sum D \cos \omega} \quad (1)$$

where $c'$ = effective cohesion, $\phi'$= effective angle of internal friction, $\sigma_n$ = total normal stress, $u$ = soil-water pressure, $W$ = slice weight; $D$ = line load; $\beta$ and $\omega$ = geometric parameters; N = normal force at the base of the slice, and $\alpha$ = inclination of the base. Fs< 1.0 indicate mass failure. A probabilistic slope stability approach was used in solving for Fs. A normal probability density function (pdf) was assigned to input parameters based on expected values of cohesion, angle of internal friction, and total unit weight.

## 3. Results and Discussion

### 3.1. In Situ measurements

Seepage flow and erosion were measured after selected rainfall events by Wilson et al. (2007) and Fox et al. (2007) at both the LTC and GC stream sites, respectively. Seepage erosion, due to liquefaction of soil particles, was evident along both streams by locations with undercut banks. In general, average seepage flow rates were significantly greater at GC (388 L $d^{-1}$) than LTC (174 L $d^{-1}$). However, average sediment concentrations at LTC (246 g $L^{-1}$) were significantly greater than at GC (69 g $L^{-1}$) as a result of differences in soil strength of eroding layers.

### 3.2. Lysimeter Experiments

The results of the lysimeter experiments for LTC were reported by Wilson et al. (2007) and Fox et al. (2006). The time to flow initiation and the flow rate were linearly related to the slope of the restrictive layer. Seepage erosion began within minutes of flow initiation with sediment concentrations as high as 4500 g $L^{-1}$. A sediment transport model was derived based on a dimensionless sediment discharge and dimensionless seepage flow shear stress to describe the seepage erosion. Seepage erosion resulted in substantial (7 to 20 cm) undercutting of the banks which was linearly related to the slope. Bank failure occurred when undercutting reached 10 to 20 cm and prior to the removal of negative pore-water pressures in the topsoil layer. This suggests that seepage erosion was the controlling mechanism and not the loss of soil strength. Mass wasting occurred as cantilever failures that averaged 0.2, 25.0, and 29.0 kg for the 30, 50, and 80 cm bank heights, respectively, which is substantial for a 15 cm wide bank.

### 3.3. Stability Modeling

Chu-Agar et al. (2007) demonstrated a procedure for incorporating seepage undercutting into stability models. Undercutting was simulated by changing the geometry of the flow domain based on the measured dimensions and timing of the undercut caused by seepage erosion.

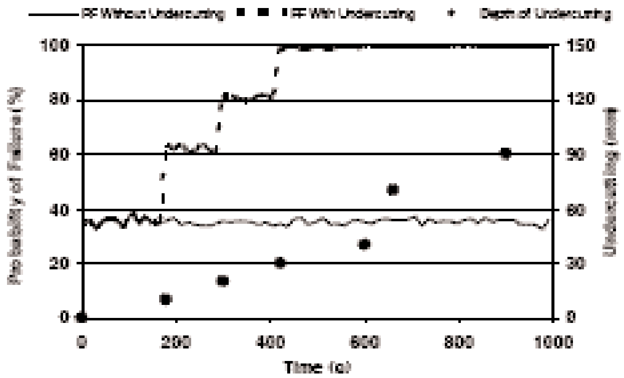


**Fig. 3.** Simulated probability of failure (PF, %) of lysimeter experiments with 0.8 m bank, 0% slope, and a 0.3 m constant head with and without seepage undercutting.

Loss of soil strength by increased soil-water pressures during seepage were not sufficient to contribute to bank failure. However, the mean factor of safety decreased significantly (42 to 91%) as the degree of undercutting increased. Stable banks were shown to become significantly unstable when seepage undercutting was included. For stable banks, the probability of failure reached 100% when the degree of undercutting reached approximately 30 to 50 mm. Bank height and bank slope controlled the initial stability of the bank while the established constant head controlled the degree of undercutting and the mean factor of safety as undercutting progressed.

## 4. Conclusions

These results indicate that the mean factor of safety is related to the degree of undercutting. These results show that mass wasting of gully banks, can be the result of seepage erosion undercutting gully walls. This process was shown to be of equal or greater importance than the impact of seepage on soil strength properties. The question remains as to what role this process plays in ephemeral gully erosion. It is common to observe ephemeral gullies formed on duplex soils, i.e. an erodible surface layer over a water restrictive layer, which are naturally conducive to seepage erosion processes.

## References


Chu-Agor, M.L., G.V. Wilson, and G.A. Fox. 2007. Numerical modeling of bank instability by seepage erosion. J. Hydraulic Engineering. (in review).

Fox, G.A., G.V. Wilson, R.K. Periketi, and R.F. Cullum. 2006. Sediment transport model for seepage erosion of streambank sediment. J. Hydrologic Engineering, 11(6):603-611, ASCE 1084-0699.

Fox, G.A., G.V. Wilson, A Simon, E.J. Langendoen, O. Akay, and J.W. Fuchs. 2007. Measuring streambank erosion due to groundwater seepage: correlation to bank pore water pressure, precipitation and stream stage. Earth Surface Processes and Landforms. (in press).

Wilson, G.V., R.K. Periketi, G.A. Fox, S. Dabney, F.D. Shields, and R.F. Cullum. 2007. Soil properties controlling seepage erosion contributions to streambank failure. Earth Surface Processes and Landforms, 32:447-459. DOI:10.1002/ESP.1405.