Phosphorus transport by surface and subsurface flow pathways in an upland agricultural watershed

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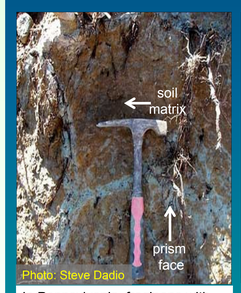
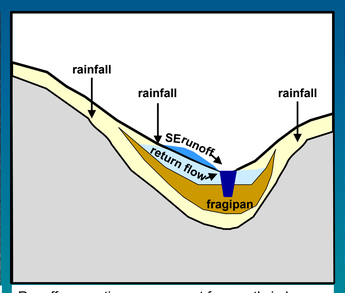
Background

Modern nutrient management strategies for agricultural watersheds depend upon the identification of soils prone to runoff. In the northeast US, soils containing a fragipan generate the largest volumes of overland flow due to saturation excess processes, resulting in the greatest risk of nutrient loss.



In Pennsylvania, fragipans with high bulk density form in colluvial soil at lower landscape positions. These horizons are relatively impermeable to infiltrating water.



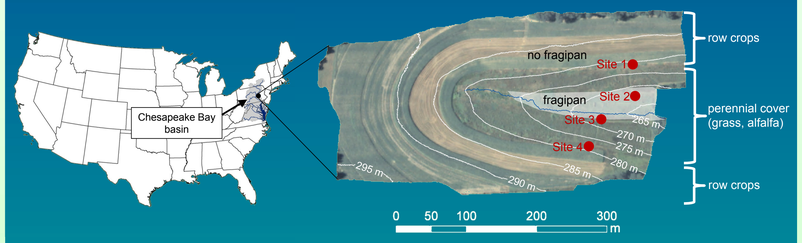
Runoff generation occurs most frequently in lower landscape positions where perched water tables form above the fragipan horizon. During storms, overland flow from fragipan soils is primarily by saturation excess mechanisms.

Residual soils in upslope landscape positions have no fragipan. Overland flow from these soils occurs by infiltration excess mechanisms.

While considerable research has focused on the influence of fragipan soils on overland flow generation, less work has been done to characterize their influence on shallow lateral subsurface flow. In this study, we compare phosphorus (P) loss by overland and subsurface flow pathways on two opposing hillslopes, each with colluvial and residual soils.

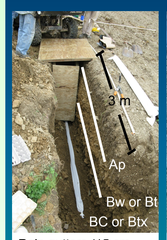
The Mattern Experimental Watershed

We conducted the study in an 11 ha agricultural watershed located in the Ridge and Valley region of the Chesapeake Bay basin.



We installed four monitoring locations on two opposing hillslopes. Upslope sites were located in well-drained soils without a fragipan, while footslope sites were located in somewhat poorly-drained soils possessing a fragipan.

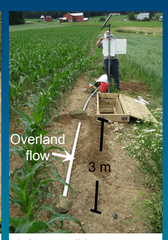
Hydrologic monitoring and instrumentation



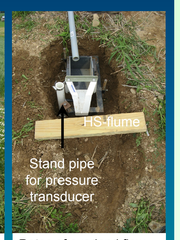
Rain gutters (15 cm wide × 15 cm deep) were installed in each pit to drain subsurface flow from three distinct soil horizons.

The void space above each gutter was back-filled with chemically inert quartzite rock (99% SiO_2). The mean diameter was 1.3 cm.

Tipping buckets were used to measure rates of subsurface flow. Splitters diverted a portion of each tip to a plastic sample bottle.

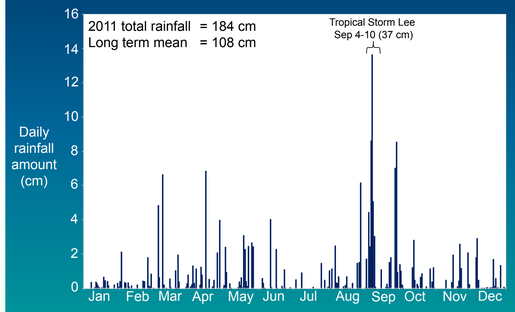


A 25 cm tall berm was used to direct overland flow to a slotted PVC pipe (3 cm diam), which drained water by gravity to an HS-flume.



Rates of overland flow were measured using the HS flume. Samples of runoff water were collected in a plastic tub following each event.

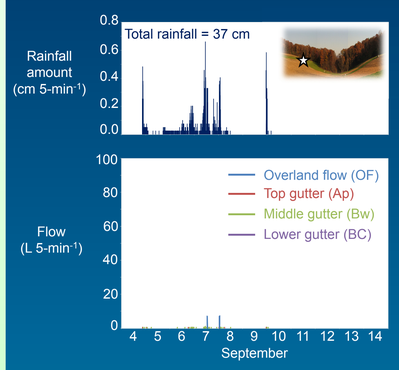
Storm events sampled during 2011



The 2011 calendar year set a record for total rainfall. We sampled a number of storms, each differing in size, duration, and intensity. Here, we focus on the largest event of the year, Tropical Storm Lee, which dumped 37 cm of rain over the course of 6 days.

Hydrologic response during Tropical Storm Lee

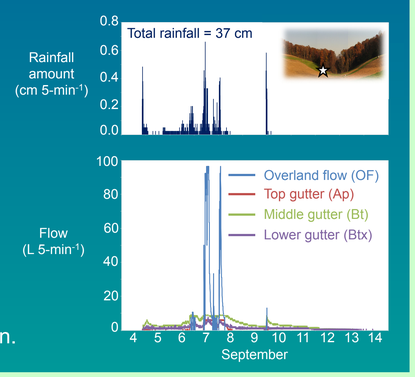
Seepage slope position with no fragipan (Site 1)



- On Sep. 4, 45 min of rainfall produced a small volume of subsurface flow from the the Ap horizon.
- Three days later, on Sep. 7, two bouts of overland flow occurred, coinciding with intense rainfall bursts.
- Over the course of the storm, volumes of shallow lateral flow were small, ending with rainfall cessation.
- Most rainfall appears to infiltrate vertically as opposed to flowing laterally in these well-drained soils.

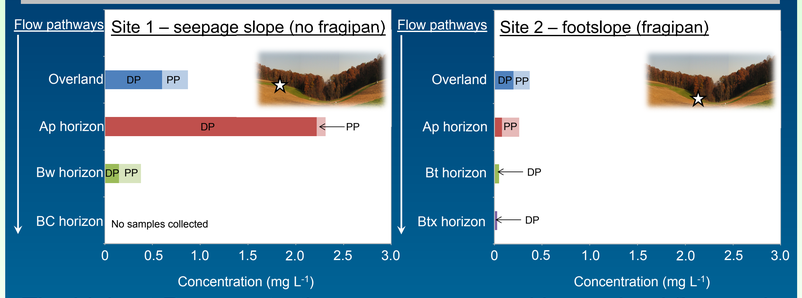
Footslope position with fragipan (Site 2)

- Similar to Site 1, flow was first recorded from the Ap horizon, about 45 min after rainfall began on Sep. 4.
- Flow from the Bt and Btx horizons started <10 min after the Ap horizon.
- Overland flow was tied to the most intense periods of rainfall.
- More than 45% of drainage from the Bt and Btx horizons occurred during periods after rainfall had ended, demonstrating the importance of the fragipan to subsurface flow generation.



P concentrations in runoff

P concentrations measured in surface and subsurface flow

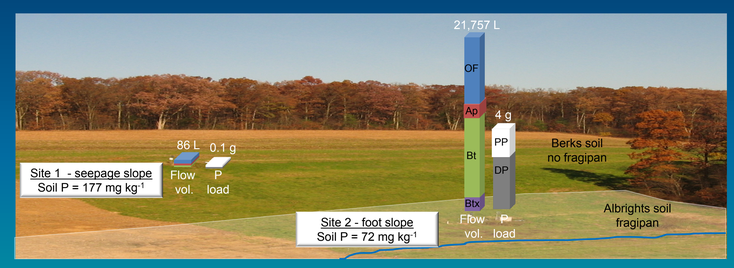


The highest P concentrations were measured in overland flow and in drainage from the Ap horizon, suggesting that high P levels near the soil surface influenced P transfers to these runoff flow paths.

Mean P concentrations in runoff by landscape position

Soil P levels were three times the agronomic optimum at Site 1, leading to higher P concentrations in runoff from this location.

Patterns of runoff P loads



Fragipan soils yielded the majority of observed runoff and P loads during Tropical Storm Lee. Subsurface flow in these soils was the dominant flow path, accounting for 64% of the total runoff volume.

Conclusions and future research

Preliminary results demonstrate the importance of subsurface flow in fragipan soils to P loss from agricultural landscapes in Pennsylvania. Continued monitoring and tracer studies will illuminate seasonal dynamics and link hillslope-scale inferences to P loss patterns at the watershed scale. Monitoring results will also be used to test related research tying short-term weather forecasts to daily overland flow prediction.

Acknowledgments

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