Visualizing the variability of small scale subsurface water flow in the South Tobacco Creek watershed

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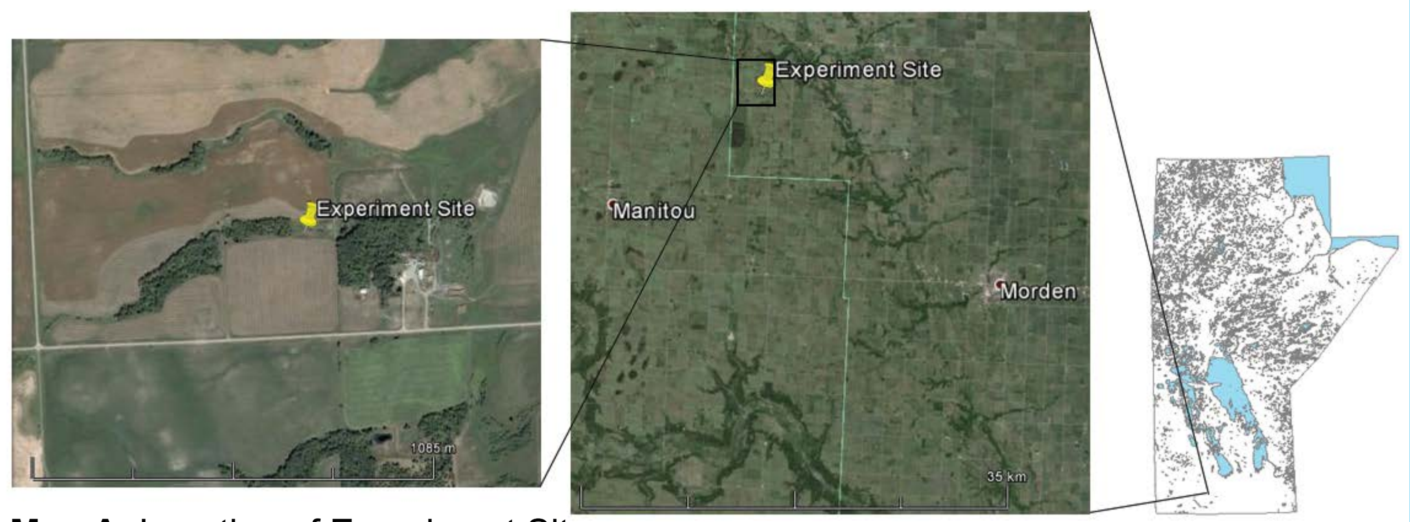
Introduction

Though overland flow is the most dramatic aspect of a flood, a crucial part of quantitatively analyzing the timing, duration, and intensity of a flooding event lies in understanding the effect that subsurface flow has within a watershed. This experiment was conducted in order to observe and analyze subsurface flow patterns in the South Tobacco Creek region of the Manitoba escarpment, which is a sub-watershed of the Morris River watershed and the greater Lake Winnipeg watershed. Previous studies (e.g., Weiler & Hannes, 2003; Bogner et al., 2008; Schlater & Huwe, 2005; Allaire et al., 2009) have successfully sprinkled dyed water onto exposed soil profiles to examine vertical and lateral subsurface flow patterns. In the experiment described here, **Acid Blue #9 dye was dispensed through rainfall simulation and interval flooding in order to examine the variability of subsurface flow patterns at a relatively small (plot) scale.**



Map A: Location of Experiment Site

Field Site

The study plot chosen for this experiment is located in the South Tobacco Creek Watershed at latitude 49° 19' 39.8, longitude 98° 22' 34.1 (Map A). It is situated between an agricultural field and a creek and is 150 cm wide. The study plot had an exposed soil profile face of about 100 cm deep that displayed a topsoil horizon, a layer of sandy-silt and a shale base. Immediately before the rainfall simulation all plant life was cleared away from a 40 cm x 40 cm area in the middle of the study plot to expedite the infiltration of the water and dye.

Experimental Design

Phase 1: Initial flooding and rain simulation

- A rainfall simulator (Clarke & Walsh, 2007) was used to initially wet a 40 cm x 40 cm plot with 20 L of distilled, undyed water, at a rate of approximately 75 mm/hr
- Acid Blue #9 dye mixed with water was then applied through the simulator at the same rate over a two-hour duration.
- Throughout the second hour of rainfall, the plot was also flooded with 1 L of dyed water at ten-minute intervals.
- Upon completion of the 2 hr rainfall simulation the plot was flooded with an additional 20 L of dyed water.

Phase 2: Layered excavation of the study plot three days later

- This was done in order to study the stained subsurface flow patterns.
- Five vertical slices, spaced 8 cm apart, were excavated behind the original profile.
- These sections were individually photographed for further analysis.

Data Processing

The images of the vertical soil profile slices (or excavations) were processed using Adobe Photoshop and MATLAB using a colour clustering code in order to make the (dyed) subsurface flow patterns easier to distinguish visually, and to prepare them for future quantitative analysis. Slices were clustered into 3 different colours, except for the final excavation which required 4 separate clusters to accurately isolate the dye stains from the undyed profile.

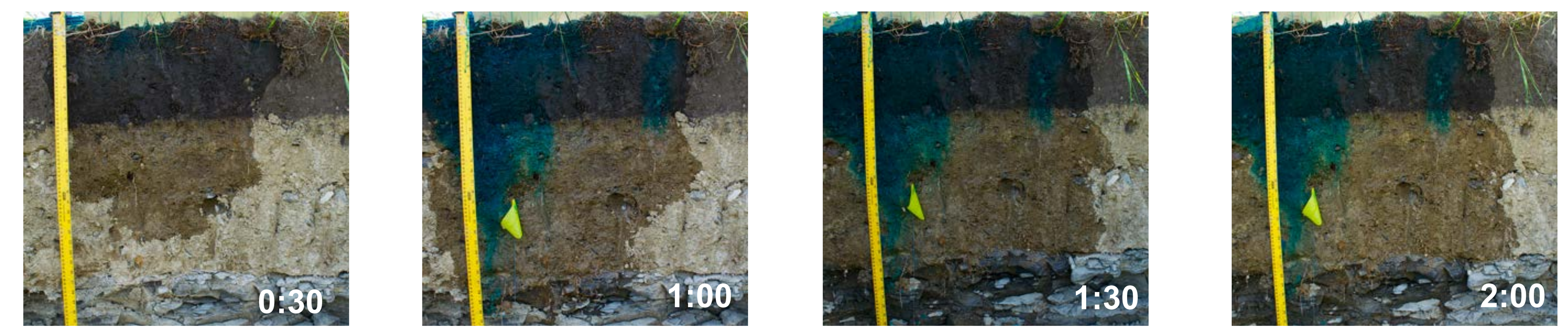


Figure 1: Time lapse of initial flooding and rainfall simulation, meter stick for scale.

Results & Discussion

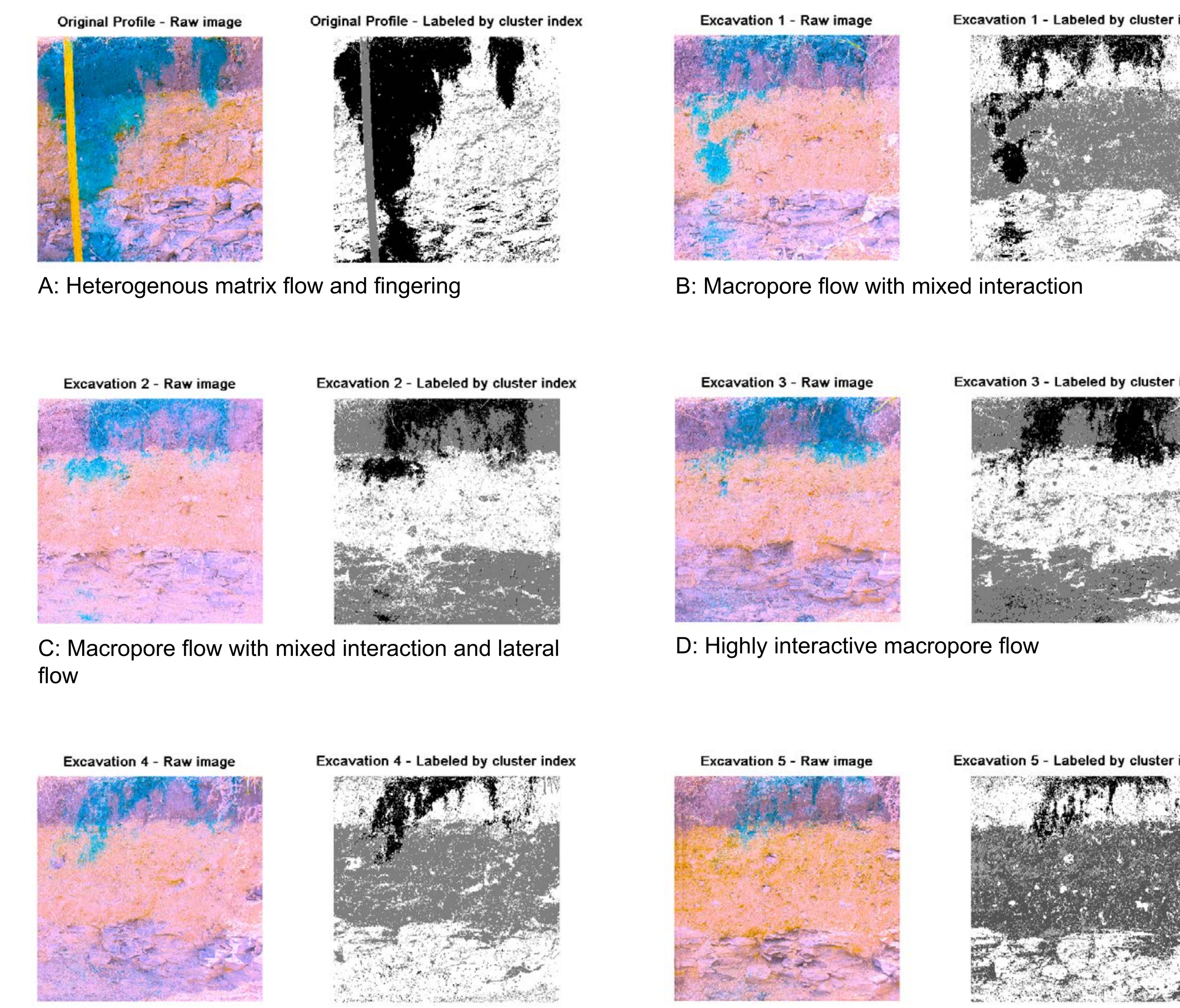
The five excavated vertical slices showed very different stained patterns, indicating that subsurface flow type varied greatly even within such a limited space (40 cm x 40 cm plot). By following the definitions of flow types distinguished by dye pattern laid out by Weiler & Hannes (2003), the distinct flow types present in each excavation were categorized.

- **Original face of the soil profile**: there was evidence of heterogenous matrix flow and fingering, which is indicative of spatially heterogeneous soil properties and somewhat permeable soils (Figure 3A).
- **First, second and fourth slices** (8 cm, 16 cm and 32 cm behind the original face of the soil profile): there was macropore flow with mixed interaction, which Weiler & Hannes (2003) suggest could indicate the presence of macropores within a heterogeneous soil matrix or simply macropores with variable flow (Figure 3B, 3C, 3E).
- **Second slice** (16 cm behind the original profile face): there was evidence of lateral flow, as indicated by the elongated pocket of dye towards the top left of the image (Figure 3C).
- **Third slice** (24 cm behind the original profile face): the dye patterns matched the defined pattern for highly interactive macropore flow in a permeable soil matrix, which contradicts the prior patterns indicating the presence of heterogeneous soil properties (Figure 3D).
- **Fifth slice** (40 cm behind the profile face): patterns indicated macropore flow with low interaction, indicating the presence of a saturated or low permeability soil matrix (Figure 3F).

Despite flooding the study plot with more than 40 L of water, overland flow was never observed at the site. The stains captured in the pictures showed much less staining than would have been expected given the 40 L of dyed water applied to the plot visible in the excavation photos. Given the lack of overland flow noted during the experiment process and since the dye only reached the soil-bedrock (shale) interface in the original profile, it can be hypothesized that (dyed) subsurface water flowed laterally to soil areas that were out of the camera frame. This explanation would be consistent with the lateral flow observed in the second slice.

Figure 2
A: Rainfall simulator and camera setup
B: Experiment plot and excavation
C: Droplet dispenser with blue dye
D: Rainfall simulator system

Figure 3: Excavation images



A: Heterogenous matrix flow and fingering
B: Macropore flow with mixed interaction
C: Macropore flow with mixed interaction and lateral flow
D: Highly interactive macropore flow
E: Macropore flow with mixed interaction
F: Macropore flow with low interaction

Conclusion

The absence of overland flow despite extensive flooding of the study plot is a significant demonstration of the importance of subsurface flow in typical Manitoban unfrozen soils. The fact that there were many different interactions occurring within a 1 m x 1.5 m x 0.4m profile indicates that subsurface flow patterns are extremely variable within the soil matrix in the South Tobacco Creek watershed. This carries the implication that, when analyzing flooding or heavy rainfall events, quantifying watershed-scale dynamics based on information gained from single-point analysis may not accurately represent the subsurface flow dynamics of the greater area. In order to gain a more complete view of the subsurface flow patterns which occur within a watershed, it would be advisable to conduct multiple plot scale tests throughout the watershed in order: **(1) to capture as much of the subsurface flow pattern variation as possible**, and **(2) quantify the volume of water potentially carried by each subsurface flow type (lateral versus vertical, macropore-driven)**. Ongoing research into those issues is underway.

References

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