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Modeling the Impacts of Stream Incision on Water Levels in a Southern Appalachian Fen

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Abstract

Phinneas Fen is a 9.3-hectare (23-acre) mountain wetland located in Cherokee National Forest (Eastern Tennessee, USA). Previous stormwater caused a headcut at Phinneas Fen that has since migrated upstream into the fen. This project was designed to better understand the effects of the incised stream channel on water levels in the surrounding wetland. Field activities included installing a monitoring-well transect perpendicular to the stream channel; stream gauging; and infiltration, slug, and permeameter tests. Field data indicated a two-layer system, with a 2-m thick clayey unit (K=0.0049m/d) above a more permeable sandy unit (K=1.1m/d). The stream channel width is about 0.5-m and baseflow is typically around 3.4E-3 m^3/s (0.12 cfs). These data were then used to construct and calibrate a two-dimensional (cross-sectional) groundwater flow model using MODFLOW and Groundwater Vistas. Parameters including hydraulic conductivity and drain dimensions were then varied to estimate the relative sensitivity of each. For example, a deeper incision depth allowed more water to leave the groundwater system, further drying out the wetland. This was particularly apparent when the drain stage dropped from the upper clayey unit into the deeper higher-K unit.

1. Introduction

Mountain wetlands are unique and rare habitats in the Southern Appalachian mountains. A majority of Southern Appalachian wetlands are fens, meaning the water is supplied predominantly by groundwater discharge. Beyond the intrinsic value of these wetland sites, they provide carbon sinks and habitat for many rare and endangered species [6]. One such species is the bog turtle *Glyptemys muhlenbergii*, which requires a high water table so that there are always wet and flooded portions of land. However, they also need dry areas to lay their eggs and, in winter, prefer woodland habitat for hibernation [5]. One wetland that appears to meet these criteria is Phinneas Fen, a 27-acre site in Cherokee National Forest (Eastern Tennessee). Although there are currently no known bog turtle populations, the site is being considered for reintroduction of turtles hatched in captivity.

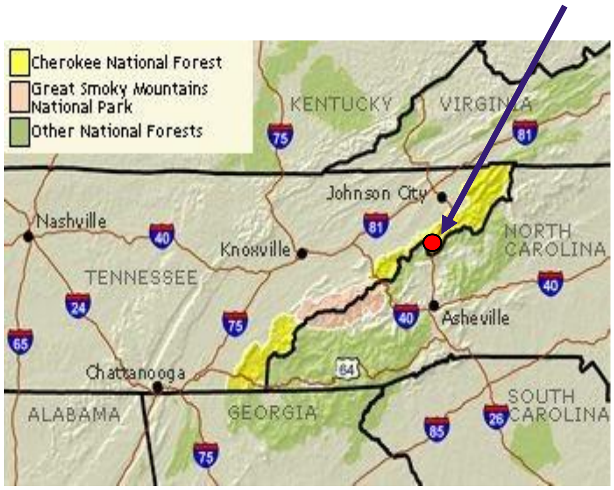


Figure 1:Map of Cherokee National Forest (The Red Dot Representing Phinneas Fen)

Phinneas Fen is located in a valley dominated by perennial wetland vegetation including Marsh Marigold (*Caltha palustris)* and Marsh Bellflower (*Campanula aparinoides*). The valley wetland surrounded by woodland habitat with a variety of tree species:Red Maple (*Acer rubrum*)*,* Yellow Poplar (*Liriodendron tulipifera*)*,* Sourwood (*Oxydendrum arboreum*)*,* White Pine (*Pinus strobus*)*,* Northern Red Oak (*Quercus rubra*), and Eastern Hemlock (*Tsuga Canadensis*) [1]. There is an old logging road that cuts across the middle of the valley and acts as a dam holding back the water above it. During storms excess water flows over the logging road, has cut into the road, and created incisioned channels below the logging road. The incised stream below the logging road has bifurcated into two main branches, allowing water to rapidly drain from the wetland. This project's purpose was to better understand the effects of these incised channels on the water table of this wetland habitat. This information cannot only be used to evaluate the long-term viability of Phinneas Fen for the bog turtles, but it can also be utilized at other mountain fens in the area that also have incised channels.

2. Methods

Ten piezometers were installed at Phinneas Fen to create a cross section perpendicular to the two main branches of incised channels downstream of the logging road. The wells were then surveyed, and groundwater levels were measured. While installing the piezometers, we identified two distinct layers of soil. The top layer (L1) had a higher sand content, while the bottom layer (L2) had a higher clay content. In-situ permeameter tests were conducted to measure the hydraulic conductivity (K) of the top layer (above the water table), while a slug test was performed to measure the K value of the lower layer.

Data collected in the field were used to develop a groundwater model to investigate the impact of stream incision on water levels in the wetland. A two-dimensional cross-section model was created for Modflow [4] using Groundwater Vistas (Figure 6). The model is 174 cells wide with a grid spacing of 0.5. The total thickness of the model is 7m, with the top layer being 2m thick and the bottom layer 5m. An incised channel was simulated using the drain package in Modflow. Water is coming into the system through recharge at a rate of 0.0013m/d per cell, based on estimates by Heath (1994) for the Blue Ridge region of western North Carolina. Wells were added to the 22 cells on either side of the drain (each removing 0.035m^3/d) to account for the groundwater flow through the wetland valley perpendicular to the model domain [2]. For each variation of the model the K values for the two layers were altered. They model worst and best case scenarios as well as estimated hydraulic conductivities from the field investigations. For each combination of hydraulic conductivity values, model simulations were performed at progressively lower drain stages. The lowering of the drain stage represents the channel cutting deeper into the earth. Each time the drain was lowered, model-generated water levels and stream discharge were recorded.

3. Results

3.1 Field Results

A cross section of the fen was constructed using field data (Figure 2). The water table ranged from 4.5m to 5.4m below the ground surface, with drawdown ranging from 0.2m to 0.7m immediately adjacent to the two incised channels.

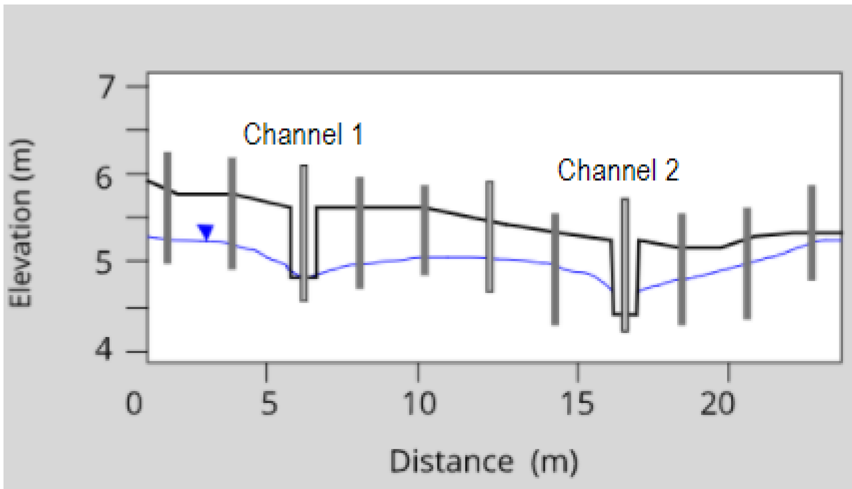


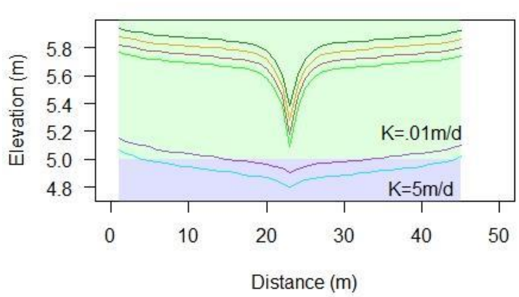
Figure 2: Cross Section from Field Data

The field investigation also provided estimates of hydraulic conductivity that were then used in the model. The permeameter test resulted in a K-value of 0.03m/d for L1, and the slug test yielded a K-value of 0.07m/d for L2. These two parameters were then used as a baseline for the groundwater model. They were also used directly as the K values for the L1 and L2 layers in one variation of the model.

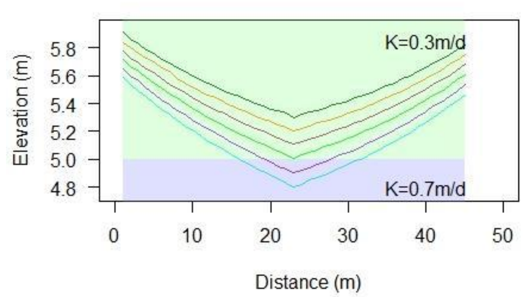
3.2 Groundwater Model Results

Four model trials were simulated, with hydraulic conductivity between 0.01-1.00 m/d for the top layer (L1) and 0.10-5.00m/d for the bottom layer (L2). In each trial, the drain stage was lowered progressively lower from 5.3m (in Layer 1) to 4.8m (in Layer 2) in 0.1m increments. (Figure 3)[redacted][2]. The modeled stream discharge from the drain in the center of the model was also recorded for each simulation as the drain stage was lowered (Figure 4).

Trial 1

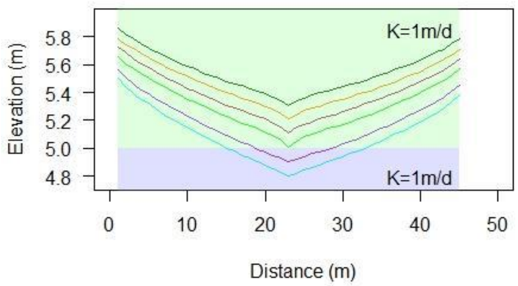


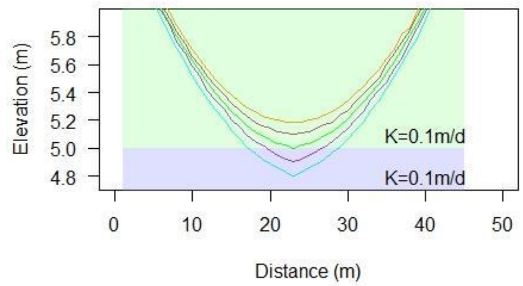
Trial 2



Trial 3

Trial 4





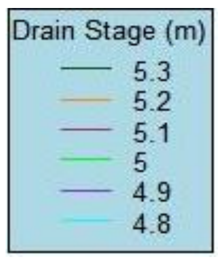
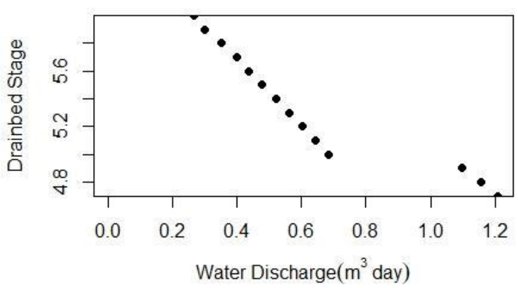
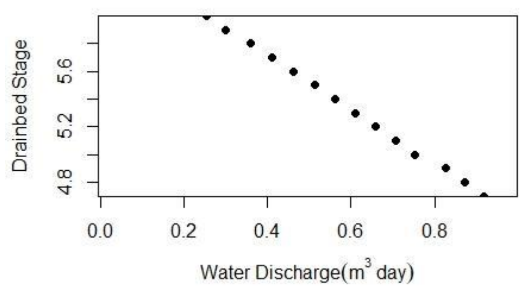


Figure 3: Model results showing the effects of hydraulic conductivity and drain stage on water levels

Trial 1

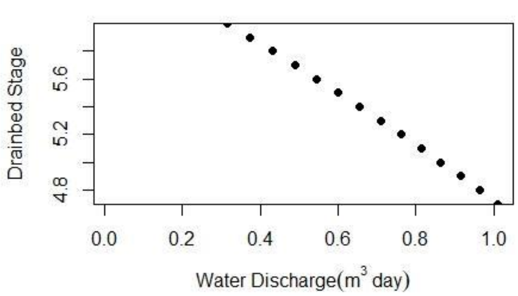
Trial 2





Trial 3

Trial 4



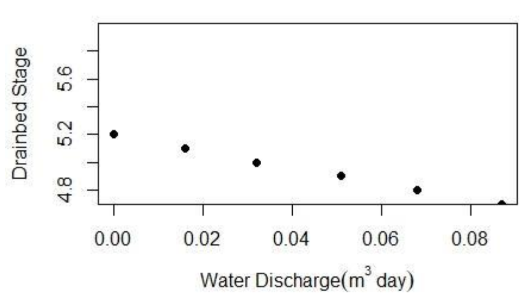


Figure 4: Water Discharge from the Drain (Trials 1-4, Figure 3)

4. Discussion

A trend from Figure 3 is that the drawdown of the water table surrounding the drain is determined by the K value of the L1 layer. With a low K value in the L1 layer the drawdown further from the drain is minimal and the gradient of the water table near the drain is steep (Trial 1, Figure 3). In comparison, if the K value of the L1 layer is higher, then the drawdown of the water table is extended further from the drain, but the gradient of the water table near the drain is shallower (Trials 2-4, Figure 3).

Trial 1 (Figure 4) shows a significant increase in stream discharge when the drain stage is lowered into Layer 2. Discharge increases linearly in the other three trials. Stream discharge is an order of magnitude lower in Trial 4 as compared to Trials 1-3. This supports that the drawdown seen in Trial 1 of Figure 3 is caused by the increased discharge from the drain in Trial 1 of Figure 4.

This study focused on modeling the effects of a single incised channel on the surrounding water table. Therefore, one of the limitations of this study was the effects that multiple incised channels may have on the water table of a mountain wetland. This is of importance due to the fact that many of the incised channels bifurcate and create many branches, as seen at Phinneas Fen. Moving forward with this study, it would be beneficial to model the effects that two or more drains have on the surrounding water table.

Another limitation of this study is that it does not take into account other management practices. While the modeling for this study was underway, there was a management practice called tree girdling taking place. This reduces the amount of water that the trees are uptaking and therefore increases the amount of water in the wetland area. Some clear cutting took place as well. These are factors that could raise the water table. However, they were not included in this model. In the future, it would be beneficial to model the long term effects of these practices.

The two-dimensional groundwater model presented here is insightful , but it would be more informative to have a three dimensional model of the entire fen. This way, individual factors such as stream restoration, forest management practices, and additional incised channels could be modeled and the effects could be tested. This would also allow the individuals involved with the fen to make the best management decisions to preserve the habitat and water levels.

Moving forward, it would be interesting to adapt this model for other fens in the Southern Appalachian Mountains. This would provide more data on how these sites respond to channel incision. A database could then be constructed to compare and contrast these sites and what aspects make them sustainable mountain wetlands, where the water table is retained at a level that is close to the surface. It could also provide data prior to and after restorations or management practices are put in place.

At Phinneas Fen, the incised channel will continue to expand , increasing the amount of stream discharge and lowering the water table surrounding the channel. Due to this fact, channel restoration is recommended for this site. This will help preserve this rare habitat and provide a potential site for reintroduction of the endangered bog turtle.

5. Acknowledgments

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6. References

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