Perched groundwater-wetland systems on ridge tops of the Appalachian Plateau, Daniel Boone National Forest, Kentucky

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Introduction

Ephemeral wetlands on Appalachian ridge tops in the Daniel Boone National Forest, Kentucky are hydrologically connected to shallow perched groundwater. Although these perched groundwater-wetland systems have been shown to support native vegetation and amphibians, the physical controls and hydrologic connectivity are rarely studied due to geographic isolation and sparse occurrence. In this research we determined the hydrologic connectivity of a perched groundwater-wetland system in Daniel Boone National Forest by **(1) Mapping wetland morphology, (2) Monitoring groundwater and surface water, and (3) Quantifying groundwater inputs and outputs.**

Figure 1: Ephemeral wetland (977N) in June 2016. By this time of year many of the ridge top wetlands dry

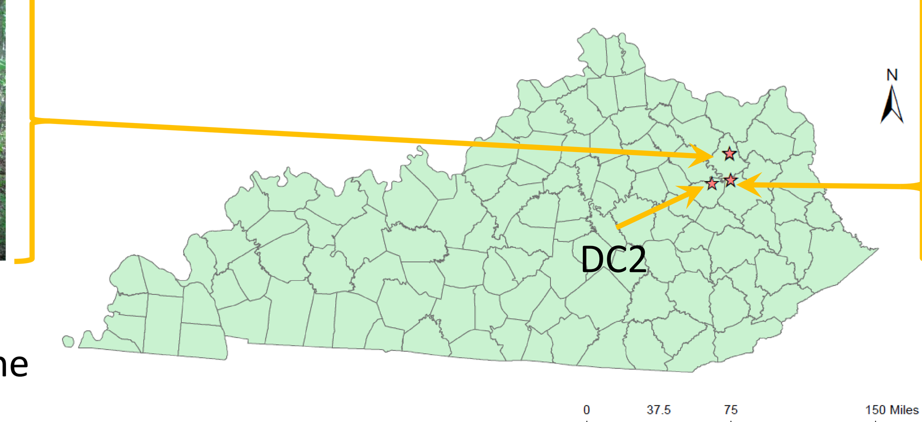
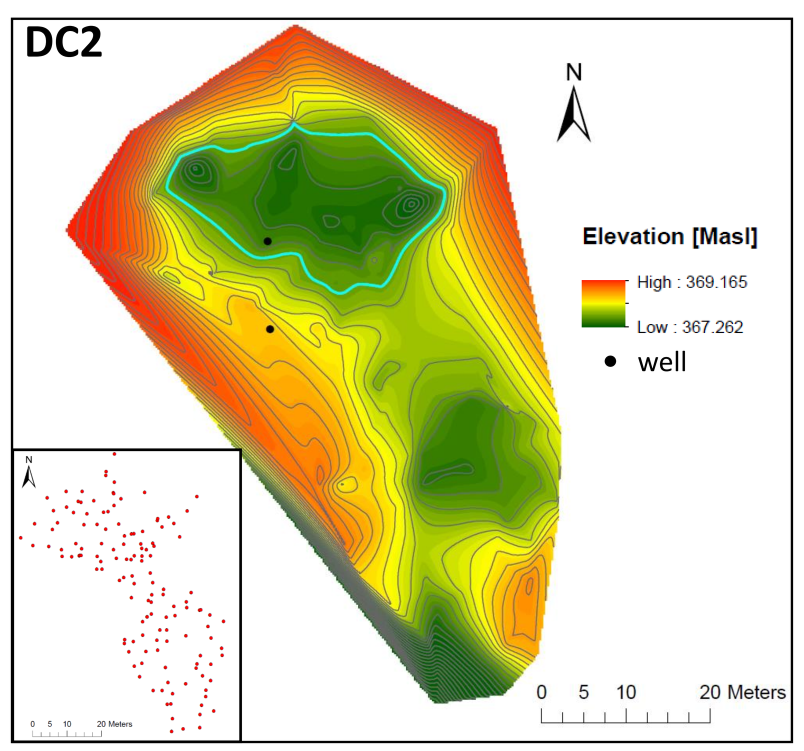


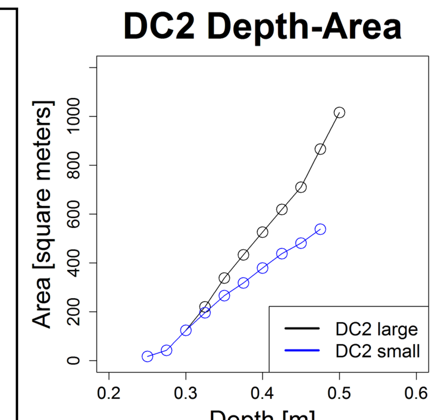
Figure 2: Map of Kentucky with ridge top wetlands from this study marked as stars.

Figure 3: Ephemeral wetland (HEN) in January 2017. By this time heavy rains recharge the area and standing water returns.

Methods

Mapping wetland watersheds: The surface geomorphology of wetland watersheds were mapped using an accurate GPS and optical transit (Figure Below). Points were imported into GIS software and interpolated to create a surface (Figure Right).





Standing water depth and area were calculated from maps (Figure above). The DC2 wetland contained two pools (Figure left). Water was only observed in the larger pool (DC2 small in Figure above).

Water Level Monitoring and Measuring Physical Characteristics:

Wells were installed within wetland pools and in watershed uplands (Figure left). Water levels were measured with a water sounder or pressure transducers. Hydraulic conductivity was calculated with the Bouwer-Rice slug test method.

Soil core samples were taken from each wetland (Figure left). Soil texture was determined via particle settling and sieve analysis. Porosity was determined via loss on ignition.

Water Budget for Groundwater:

Surface maps, monitoring data, and lab analyses were brought together in order to quantify groundwater inputs and outputs. During times of drought the main groundwater input was due to infiltration from wetland basins, while the main groundwater outputs were due to leakage and evapotranspiration.

$$\Delta S = Infiltration - ET_g - Leakage$$

Where ΔS = change in groundwater storage, *Infiltration* = the volume of water recharged from pool to groundwater, and ET_g = the volume of water consumed by evapotranspiration.

$$Q = -K\frac{\Delta h}{\Delta x}A$$

Groundwater inputs were determined using Darcy's Law. Where Q = the volume of groundwater flow, K = hydraulic conductivity, Δh is the hydraulic gradient, and A = the standing water area of the wetland (Figure 4).

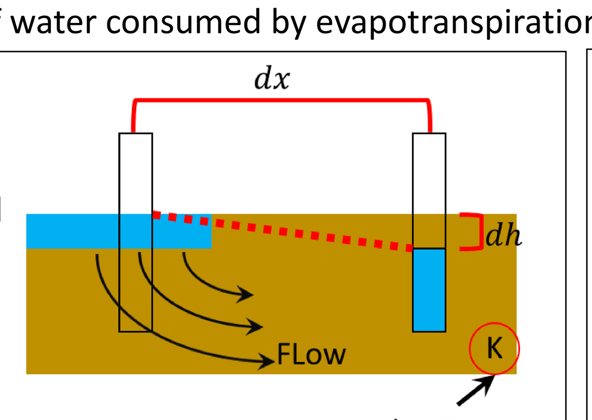


Figure 4: Schematic of Darcy's Law.

$$ET_g = S_y\left(\frac{\Delta s}{t} + R\right)$$

The main groundwater output was due to evapotranspiration (ET_g). ET_g was measured using the White (1932) method. Where Sy = the specific yield of the soil, Δs = t= time, and R = the night recovery rate of the well.

Groundwater Surface Water Interaction

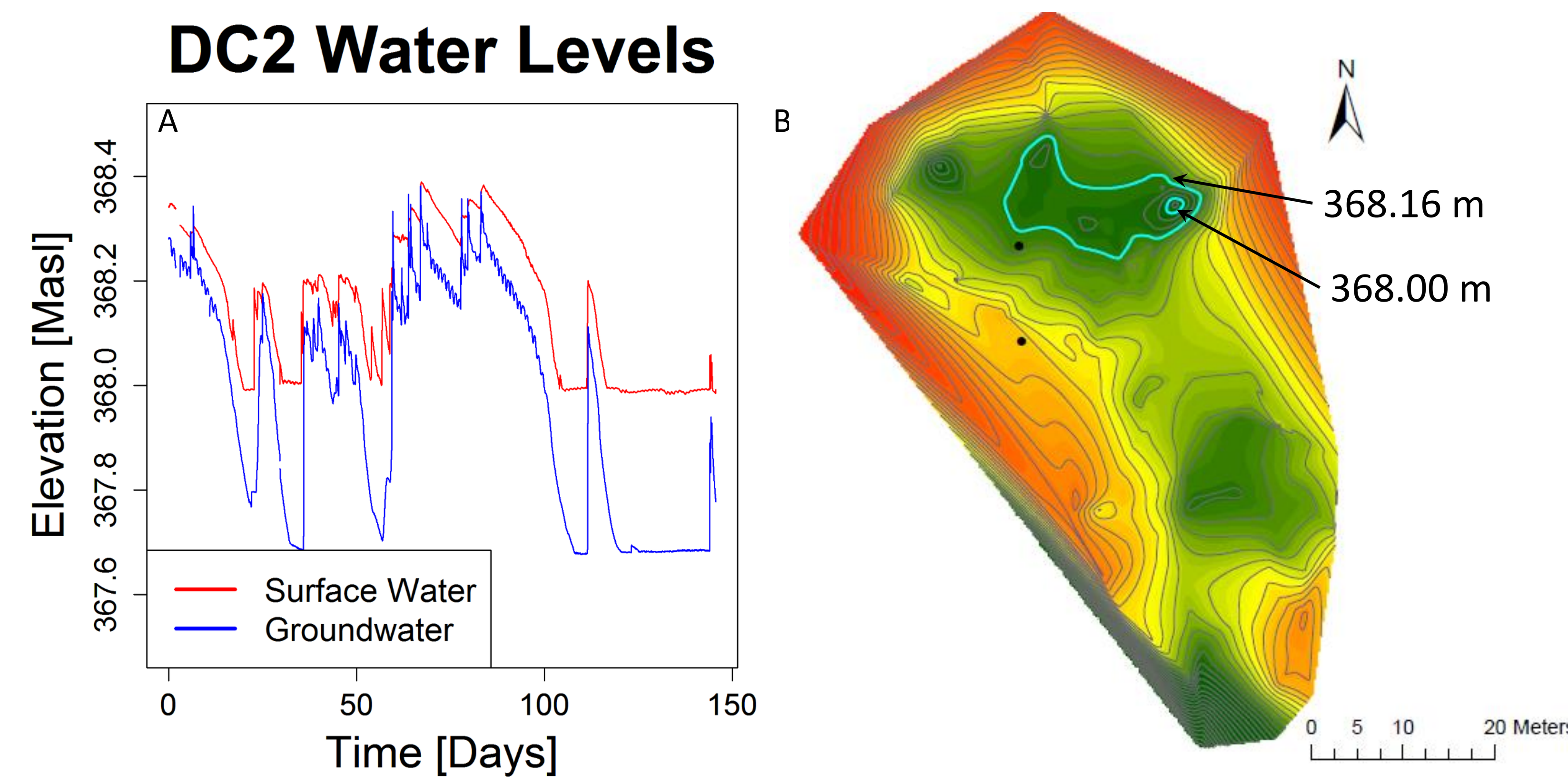


Figure 5: (A) 30 minute interval water level measurements taken with pressure transducers from standing water and groundwater for the DC2 wetland. Time period is May-October 2016. **(B)** Elevation map of the DC2 wetland. Blue contour lines indicate the standing water area for water levels 368.16 m and 368 m. Wells are located as black dots in Figure 5B. Well 1 is located in the wetland depression and Well 2 is developed upslope.

- Surface water has a higher head than groundwater indicating flow from wetland to groundwater (Figure 5A).
- Rainstorms recharge wetland quickly, with a short head reversal during heavy rain (Figure 5A).
- Wetland initially dries out during a drought in June. Heavy July-August rain recharge the wetland before drought in October (Figure 5A).
- Rate of head decline during drought increases as wetland dries to 368 m (Figure 5B).

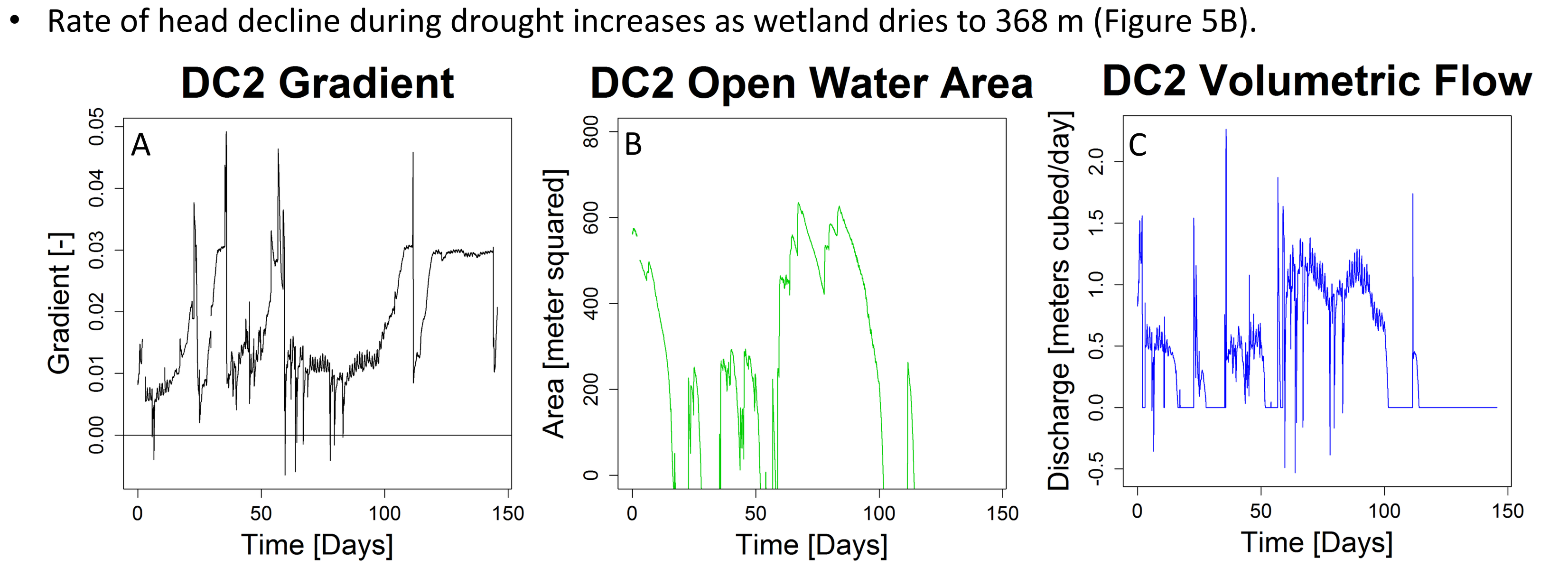


Figure 6: (A) Hydraulic gradient calculated for the time period of May-October 2016 and DC2 wetland. Positive values signify groundwater recharge from wetland to groundwater, while negative values indicate groundwater discharge to wetland. **(B)** Open water area calculated as a function of water level and the DC2 wetland geometry. **(C)** Calculated groundwater volumetric flow rate given the measured hydraulic conductivity of 0.18 m/d, area, and gradient. A positive value indicated flow from wetland to groundwater, while a negative flow indicated groundwater discharge to the wetland.

- During drought periods gradient increases sharply while wetland area decreases sharply. As wetland depth decreases the saturated area for infiltration decreases. The loss of infiltration area has the largest influence on volumetric flow rate.
- Periods of heavy rain create a head reversal where groundwater discharges to wetlands for short durations.

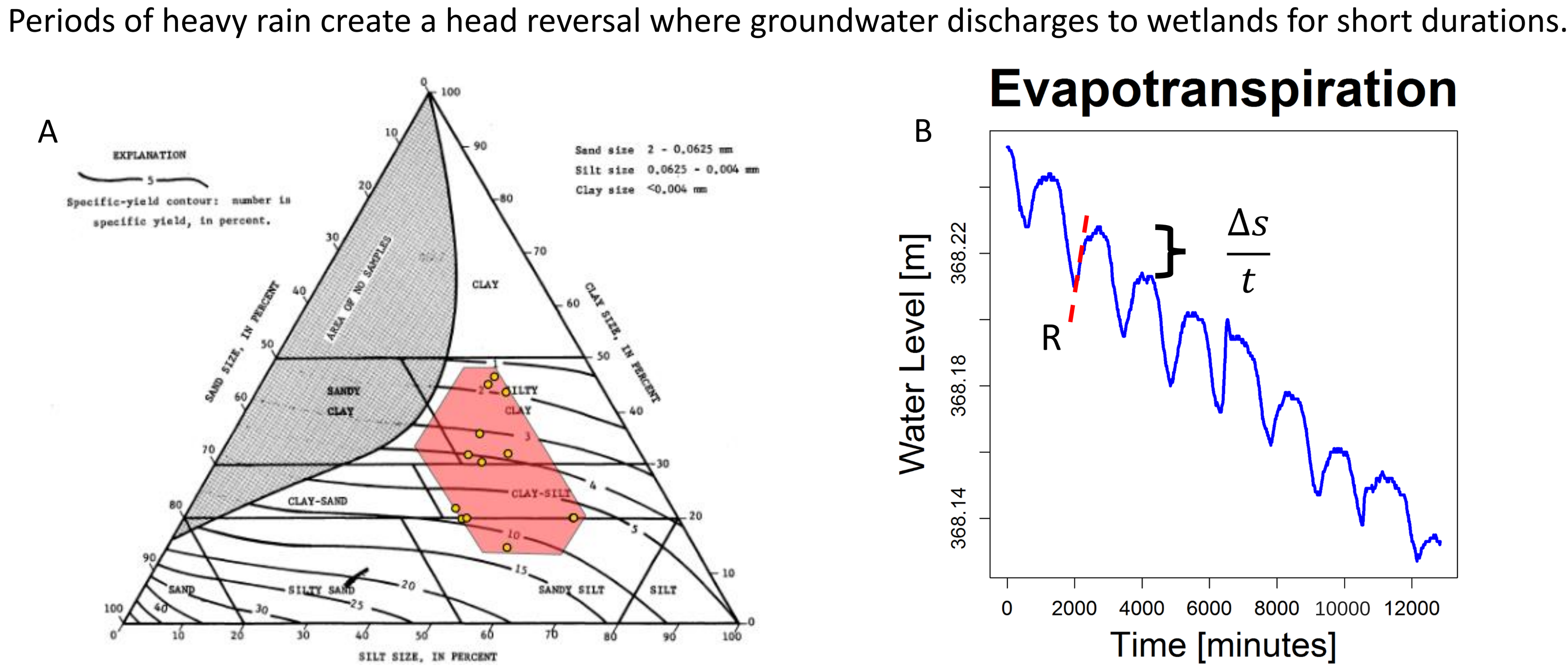


Figure 7: (A) Ternary diagram of soil texture with contours of specific yield modified from Johnson (1963). The yellow points indicate soil textures measured from core samples via particle settling and grain size analysis. The pink area represents a probable range of soil textures. Specific yield was chosen as an estimated range between 0.03 and 0.05 based on soil data. **(B)** Plot of groundwater head during a drought in August showing the diel fluctuation in water level due to evapotranspiration. The red line shows the measurement of the parameter R from the White (1932) method. The bracket shows the measurement of the parameter Δs/t form the White (1932) method.

Water Budget

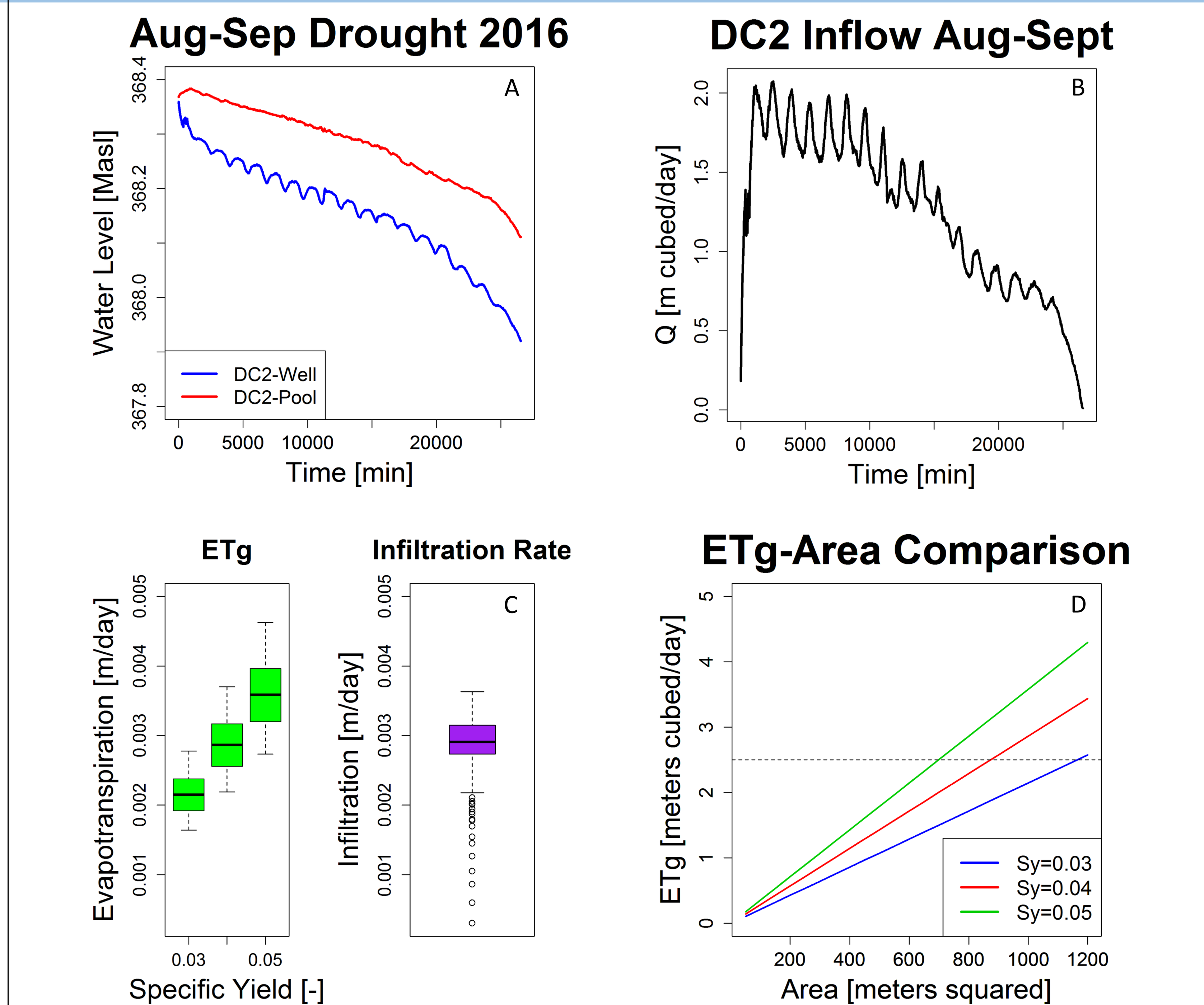


Figure 8: (A) Plot of water levels during the end August-September drought period. This period was chosen for a water budget. **(B)** Calculated volumetric flow rate of infiltration during the drought period. The sinusoidal fluctuation is a result of evapotranspiration. Flow is zero in the beginning due to a reduction in hydraulic gradient to 0 during recharge and at the end due to drying of the wetland area. **(C)** Comparison of evapotranspiration rate and infiltration rate. There is uncertainty inherent in choosing the Sy parameter (Loheide et al. 2005) so a range based on soil type was used. **(D)** The area of the active root uptake zone is unknown at this time. A range of areas were considered to calculate the volumetric flow rate of evapotranspiration. The total area of the watershed is 2500 m^2. The black dashed line represents the highest measured volumetric flow rate of infiltration. This indicates that less than half of the watershed area is necessary for vegetation to completely consume infiltration.

Conclusions and Future Research

Conclusions

- Ephemeral wetlands focus shallow groundwater recharge in the Appalachian ridge tops of the Daniel Boone National Forest. This shallow groundwater recharge supports local forest vegetation.
- Vegetation control the hydraulic gradient between wetland and groundwater, except during periods of intense rainfall.
- Vegetation consume groundwater at a rate that is approximately the same as infiltration rates. Given conservative estimates of aquifer area, evapotranspiration is the primary consumer of groundwater.

Future Research

Modeling groundwater surface water scenarios to determine drought resilience of ridge top wetlands.

Map the aquifer area and reduce uncertainty in estimates.

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