The Long-Term Impacts of Forest Removal on Floodplain Subsurface Hydrology

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Introduction

• Floodplains
  – Interface b/w groundwater and surface water systems
  – Services
    • Transformation of nutrients and pollutants
    • Runoff regulation
    • Flood water mitigation

• Floodplain Forests
  – Services
    • Filter runoff/groundwater
    • Reduce overbank flow velocity
    • Source of coarse woody debris
    • Flood attenuation
  – < 25% of Pre-Columbian bottomland hardwood forest remains
Introduction

• **Groundwater**
  
  – 99% of liquid freshwater
  
  – 30% of U.S. streamflow
  
  – 50% of U.S. drinking water

• **Two Zones**
  
  – Vadose Zone
  
  – Phreatic Zone

• **Shallow Groundwater (SGW)**
  
  – Less than 6 meters below ground surface
  
  – Responsive to changing environmental variables
Introduction

• Shallow Groundwater Temperature
  – Influenced by surface heating and recharge
  – Important physical characteristic
  – Impacts biological activity
  – Affects geochemistry

• Land Use
  – Shown to impact groundwater temperature
  – Previous studies focused on urban land use types
Introduction

• Groundwater Chemistry
  – Important physical characteristic
  – Impacts biological activity
  – Affects resource suitability

• Land Use
  – Shown to impact groundwater chemistry
  – Few comprehensive studies
Objective

Improve understanding of the impacts of agricultural and forest land use types on floodplain subsurface water resources in mixed land use watersheds of the central U.S.
Sub-Objectives

1. Characterize and compare shallow groundwater (SGW) temperatures 1-2 m below the water table at agricultural and forested sites, and relate observed SGW temperature contrasts to differences in estimated groundwater flow and soil temperature at each site.
Sub-Objectives

2. Quantitatively describe and compare groundwater chemical composition using a gridded study design to investigate historic agricultural and forested floodplain sites
Methods

• Hinkson Creek Watershed
  – Contains city of Columbia
  – Mix of land use types
  – Avg. Temp: 12.5° C
  – Avg. PPT: 991 mm/yr.

• Study Sites
  – Agricultural field (Ag)
  – Bottomland Hardwood Forest (BHF)
  – Floodplain landscape
  – Similar aquifer properties
Methods

- Study Design

![Diagram with markers labeled P-1 to P-9, representing various types of instruments like Piezometer, VWC Nest, and Soil Temp. Sensors, distributed across a grid with a scale from 0 to 100 meters in both X and Y axes, with Hinkson Creek Flow indicated.]
Methods

• Groundwater Flow Analysis
  – Devlin (2003) three-point method

• Groundwater Temperature Analysis
  – 9 Piezometers per Site
  – Data collected at 30 minute intervals
  – Data aggregated to row and site levels
  – Wilcoxon Signed-Rank test

Methods

- Soil Heat Flux Analysis
  - 3 microclimate stations per site
  - Soil temperature probes at 30 cm
  - Data collected at 30 minute intervals
  - $A_0 = A_z e^{-z/d}$
  - $d = \sqrt{\frac{2D}{\omega}}$
Methods

- Groundwater Chemical Composition
  - Samples were collected monthly from June 2011 - June 2013
  - Analyzed 50 physiochemical metrics
    - Physiochemical
    - Nitrogen and Carbon
    - Elemental Species
  - Spectrometric methods
  - Mann-Whitney U test
Results: Climate During Study

- Average Ta: 13.4 °C
- Precipitation
  - 762 and 739 mm during 2011 and 2012
  - 960 and 867 mm during 2013 and 2014
- Avg. water table depth
  - Ag: 2.66 m
  - BHF: 3.13 m
  - 18% difference
Results: Climate During Study

- Hinkson Flow
  - Avg.: 1.52 m$^3$ s$^{-1}$
  - Max.: 314.13 m$^3$ s$^{-1}$
  - Min.: < 0.001 m$^3$ s$^{-1}$

- Average Tw: 14.2 °C
Results: Groundwater Flow

- **Ag**
  - Avg.: 0.011 m/day
  - Max.: 0.018 m/day
  - Angle: 76°

- **BHF**
  - Avg.: 0.009 m/day
  - Max.: 0.024 m/day
  - Angle: 41°
Results: Groundwater Temperature

- **Ag**
  - Decreasing temp. range and average with increasing distance from stream

- **BHF**
  - Decreasing temp. range with increasing distance from stream
  - Not temp. average
    - Row 2: greatest avg. temp.
Results: Groundwater Temperature

- Average temp.
  - Ag: 11.1 °C
  - BHF: 11.2 °C
- Significantly (p<0.001) different at 30 min. and daily resolutions
- Temp. range
  - Ag range 72% greater than BHF
Results: Groundwater Temperature

![Graph showing average groundwater temperature over time with two lines representing different sources. The black line represents Ag and the red line represents BHF. The graph shows a cyclical pattern with peaks and troughs.]
Discussion: Groundwater Temperature

• Groundwater flow
  – BHF Avg. was 0.009 m/day
  – Ag Avg. was 0.011 m/day
  – Bundschuh (1993) suggests 0.3 m/day as threshold

• Soil temperature
  – Similar thermal diffusivities and damping depths
  – Amplitude
    • Inconsistent differences of less than 0.5 °C
    • 2012: BHF > Ag
    • 2013: BHF = Ag

• Recharge
  – Zell et al. (2015)
    • 16% greater ET at BHF site
    • 400% greater recharge
Conclusions: Groundwater Temperature

• Average water table depth: 18% greater at the Ag site than BHF

• SGW temperature significantly different (p < 0.001)

• Ag site temperature range 72% greater than the BHF

• Contrasting groundwater recharge rate is the likely mechanistic cause for the observed SGW temperature differences

• Greater temperature range of Ag site SGW suggests the potential for higher baseflow temperatures
  – Temperature sensitive aquatic organisms
  – Thermal refugia
  – Resource suitability

Results: Groundwater Chemical Composition

- 32 metrics significantly (p<0.05) different
- Ag site
  - Higher pH
  - Greater chloride
- BHF site
  - Conductivity
  - Total Dissolved Solids
  - Carbon Species
  - Nitrogen Species

<table>
<thead>
<tr>
<th>BHF</th>
<th>Ag</th>
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<tbody>
<tr>
<td>Sulfur</td>
<td>Arsenic</td>
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<tr>
<td>Potassium</td>
<td>Boron</td>
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<tr>
<td>Sodium</td>
<td>Bismuth</td>
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<td>Cadmium</td>
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<td>Calcium</td>
<td>Copper</td>
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<td>Strontium</td>
<td>Phosphorus</td>
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<tr>
<td>Uranium</td>
<td>Tin</td>
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</tbody>
</table>
Results: Groundwater Chemical Composition
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\textbf{Ca Conc.}

\textbf{Mg Conc.}

\textbf{K Conc.}

\textbf{S Conc.}

\textbf{Nitrate Conc.}

\textbf{TG Conc.}

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Hinkson Creek Flow
Results: Groundwater Chemical Composition

BHF

- Ca Conc.
- Mg Conc.
- S Conc.
- K Conc.
- Nitrate Conc.
- TC Conc.

Distance (m)

Hinkson Creek Flow
Discussion: Groundwater Chemical Composition

- Greater nutrient conc. in BHF SGW
  - Recycling and accumulation by forest vegetation
    - Throughfall, stemflow, and litterfall

- Greater trace element conc. in Ag SGW
  - Phytoremediation
    - Plant uptake, stabilization, sequestration in plant tissues, and volatilization to the atmosphere
  - Seasonal aquifer flushing

- Contrasting stream-aquifer connectivity
  - BHF SGW source of nutrients to Hinkson Creek
  - Ag site retains some floodplain functionality
Conclusions: SGW Chemical Composition

• **BHF SGW**
  – Higher concentrations of nutrients (e.g. Ca, Mg, Na, K)
  – Lower pH, higher electrical conductivity

• **Ag SGW**
  – Higher concentrations of various trace metals (e.g. As, B, Li, Sn)

• **Potential explanations**
  – Contrasting site groundwater flow
  – Greater uptake of trace elements by woody vegetation
  – Accumulation and effective recycling of nutrients by forest vegetation

Synthesis

• Results indicate the influence of forest vegetation as a primary factor controlling observed site differences

• SGW Temperature
  – Similar SGW flow, thermal diffusivities, soil temperature amplitude
  – Contrasting subsurface hydrology
  – Zell et al. (2015)
    • 400% greater groundwater recharge at the Ag
    • 16% greater ET at BHF site

• SGW Chemical Composition
  – Plant uptake and nutrient recycling by forest vegetation
  – Greater hydraulic connectivity of the BHF aquifer to Hinkson Creek
Implications

• Floodplain forests
  – More effectively attenuate floodwaters
  – Better protect the temperature regime of groundwater and adjacent surface water systems
  – More efficiently recycle and accumulate nutrients in the subsurface
  – Promote surface water processing via seasonal aquifer-stream exchange

• Reestablishment of floodplain forests is a valuable alternative/addition to traditional engineering methods of watershed management

• Floodplain forests could be more socioeconomically valuable than marginally productive floodplain agricultural fields
Future Work

• SGW Temperature
  – Comparative mechanistic process research
  – Coupled surface to subsurface heat flux and hydrologic modeling

• SGW Chemical Composition
  – Precipitation chemistry
  – Stable isotope analysis
  – Speciation modeling
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Questions