WATERSHED EFFECTS ON SUCCESS OF STREAM RESTORATION FOR EXCESS NITROGEN MITIGATION

ERICH HESTER[1], DURELLE SCOTT[2], LUKE GOODMAN[2], CARLY FEDERMAN[1], AND NATALIE KRUSE DANIELS[3]

[1]CIVIL AND ENVIRONMENTAL ENGINEERING, VIRGINIA TECH

[2]BIOLOGICAL SYSTEMS ENGINEERING, VIRGINIA TECH

[3]ENVIRONMENTAL STUDIES, OHIO UNIVERSITY


usgs.gov

General Restoration Questions from RFP:

1. What are the cumulative effects of watershed restoration activities within a watershed?
2. What percentage of a catchment needs to be treated…? Does the location of [stream restoration] practices within the catchment make a difference…?

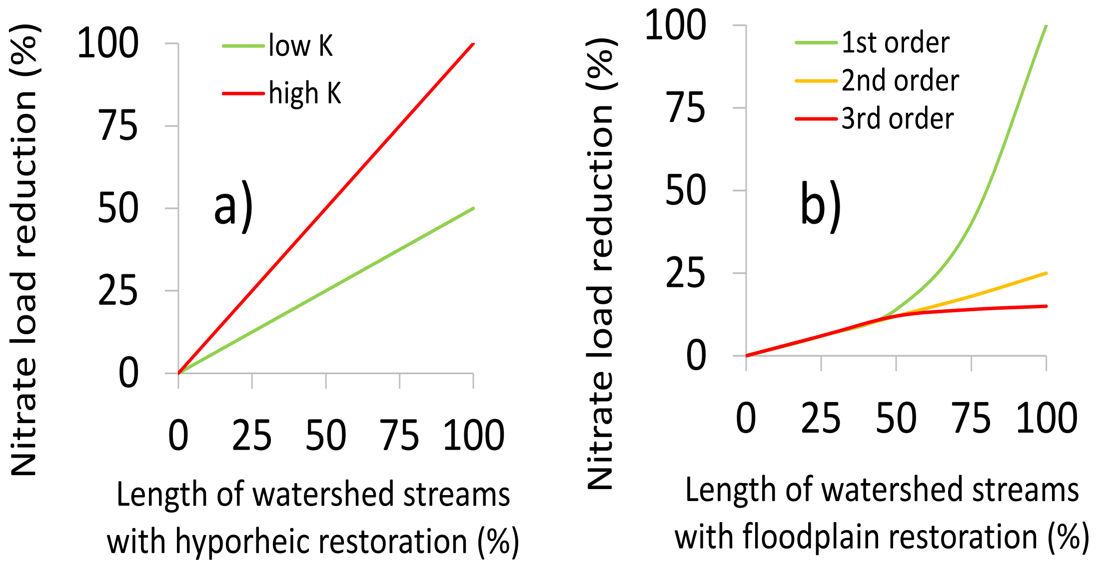
Research Questions and Hypotheses

Restoration Questions from Proposal

1. What is the slope and shape of the relationship between percent of stream network restored and percent nitrate load reduction at the watershed outlet (i.e., linear, exponential, levelling off)?

2. How do the answers to Question #1 above vary with
   - Distribution of nitrate sources in the watershed
   - Restoration technique
   - Restoration location
   - Watershed topography
   - Soil type

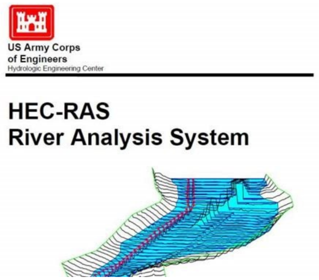
Example Graphic **Hypotheses**



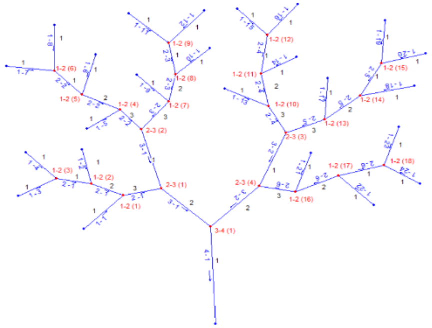
Project Tasks

Task 1 (mostly finished). Generate literature database of nitrate removal rates.

Task 2 (finished). Select model software (1D HEC-RAS w/auxiliary R script).



Task 3 (partly finished). Model generic watershed with literature rates to answer research questions.



Task 4 (not started). Model case study watershed to demonstrate applied value.

Task 1: Nitrate removal database finished, and analysis underway

Database finished

Currently analyzing variation of removal rates with controlling factors

- Restoration status (e.g., restored or not)
- Restoration technique (e.g., channel or floodplain)
- Hydrologic status (baseflow vs stormflow)
- Stream order
- Season
- Sample location (e.g., floodplain or channel)

Task 3: Simulated flood attenuation from Stage 0/ floodplain restoration in 2nd order channel

Started with:

- 2nd-order piece of larger 4th order watershed
- Hydraulics only, effect of restoration on flood wave attenuation

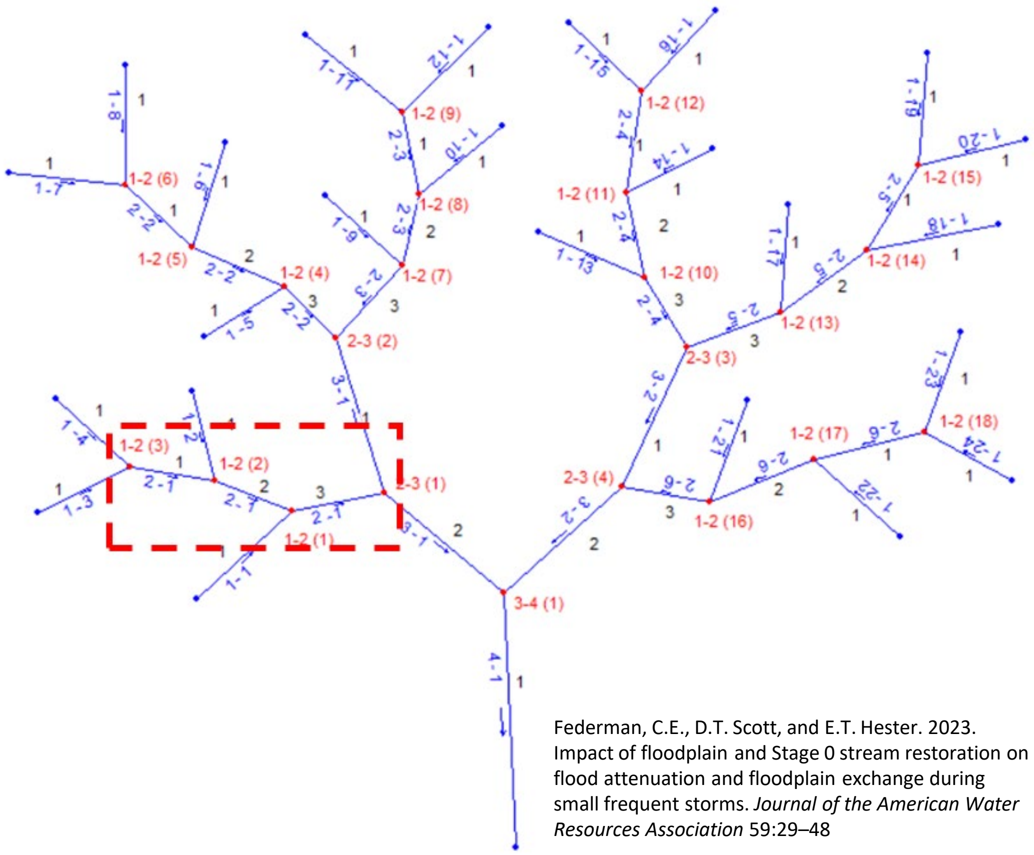
Varied:

- % channel length restored
- Restoration location along channel
- Restored bank height
  - Stage 0: Low bank heights w/frequent floodplain inundation imitating pre-colonization conditions; achieved by legacy sediment removal (LSR) in floodplain or raising the streambed (RSB)
  - Bankfull floodplain restoration: Higher bank heights with floodplain inundation ~1/year
- Restored floodplain width
- Storm size (monthly, 0.5 year, 1 year, and 2 year storms)

Similar study for channel restoration for hyporheic enhancement published earlier

Calfe, M.L., D.T. Scott, Hester, E.T. 2022. Nitrate removal by watershed-scale hyporheic stream restoration: Modeling approach to estimate effects and patterns at the stream network scale. *Ecological Engineering* 175:106498

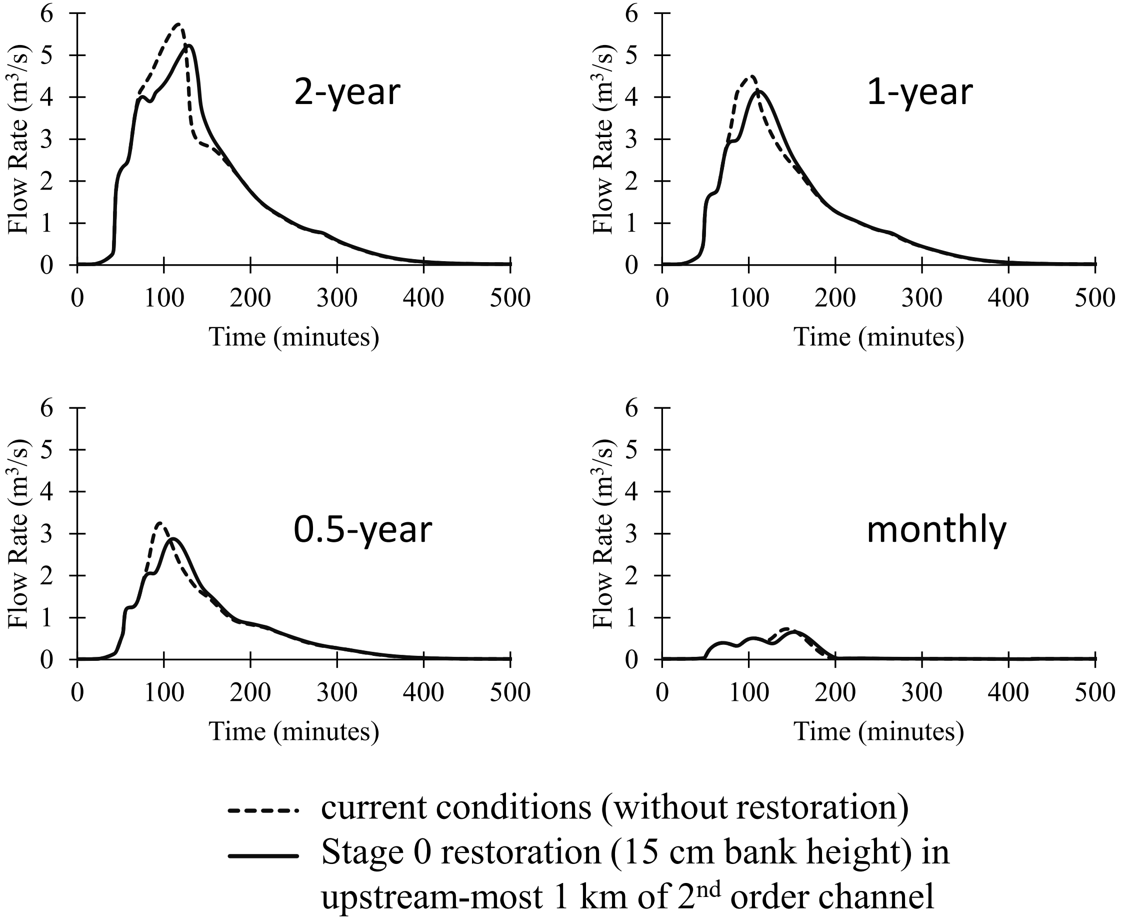
HEC-RAS model channel schematic



Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Task 3: Restoration causes flood attenuation

Flood attenuation = reduced peak flow rate at downstream end of 2nd order channel for restored conditions

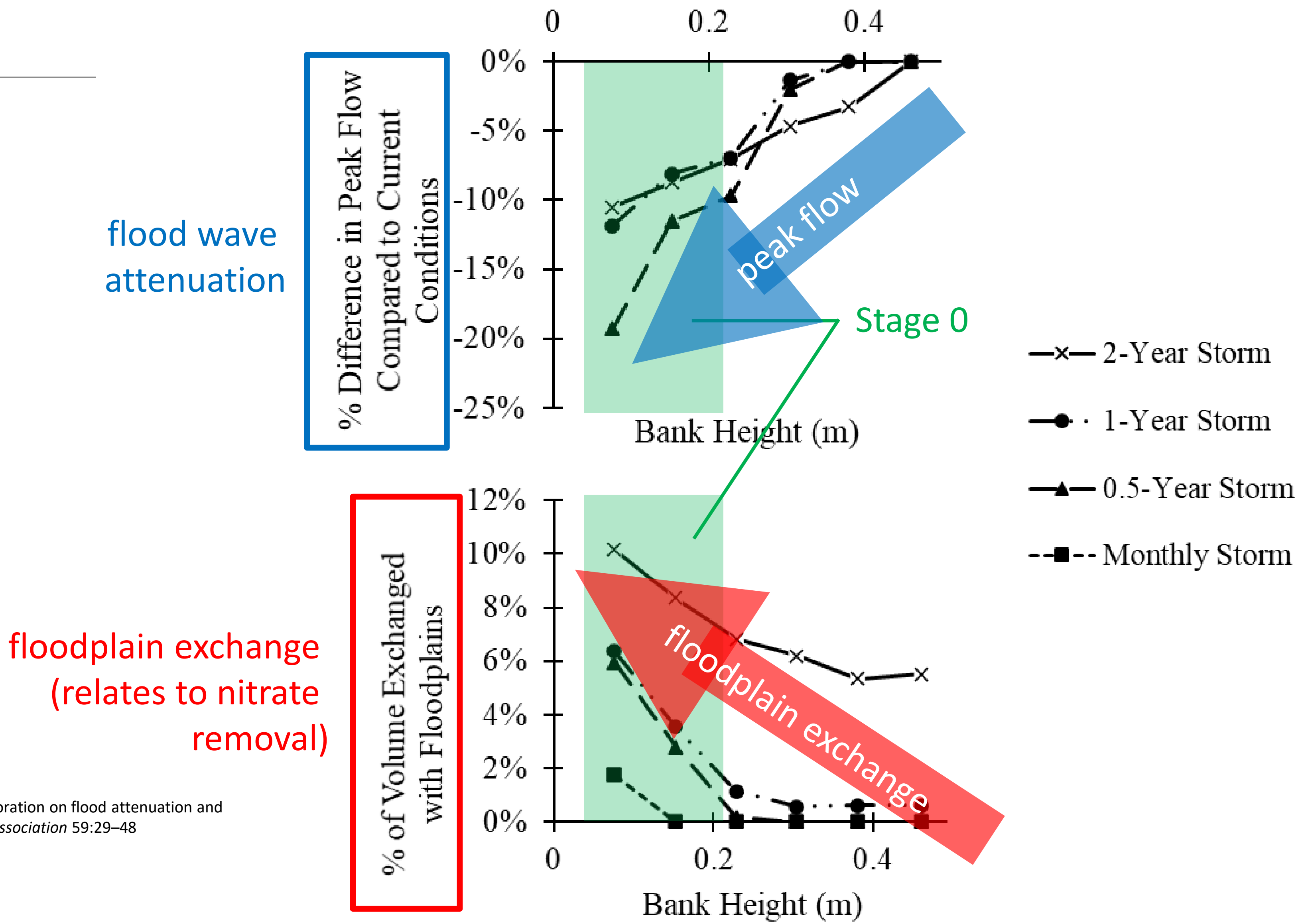


Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Task 3: Project effectiveness varies with restoration technique

Stage 0 (low banks) more effective than high banks (bankfull floodplain)

No tradeoff among restoration benefits; lower banks enhances both flood attenuation and floodplain exchange (water quality)



Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Task 3: Project effectiveness varies with location along channel

Individual projects were more effective if…

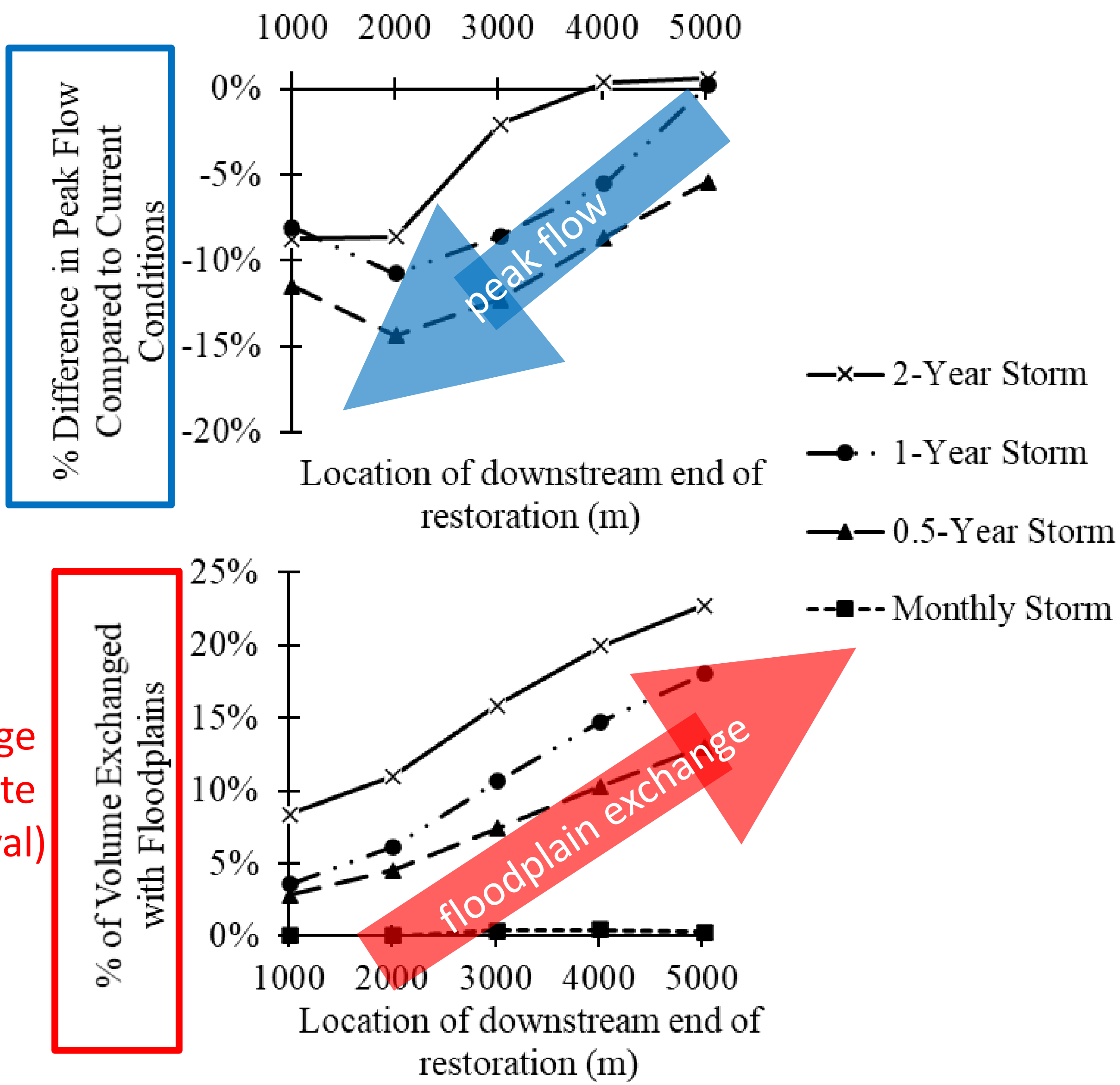
…located upstream along channel (for flood wave attenuation)

…downstream along channel (for floodplain exchange)

Tradeoff between flood attenuation and floodplain exchange

flood wave attenuation

floodplain exchange (relates to nitrate removal)



Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Task 3: Project effectiveness varies with percent of stream network restored

Individual projects were more effective (i.e. greater slope of curve) if…

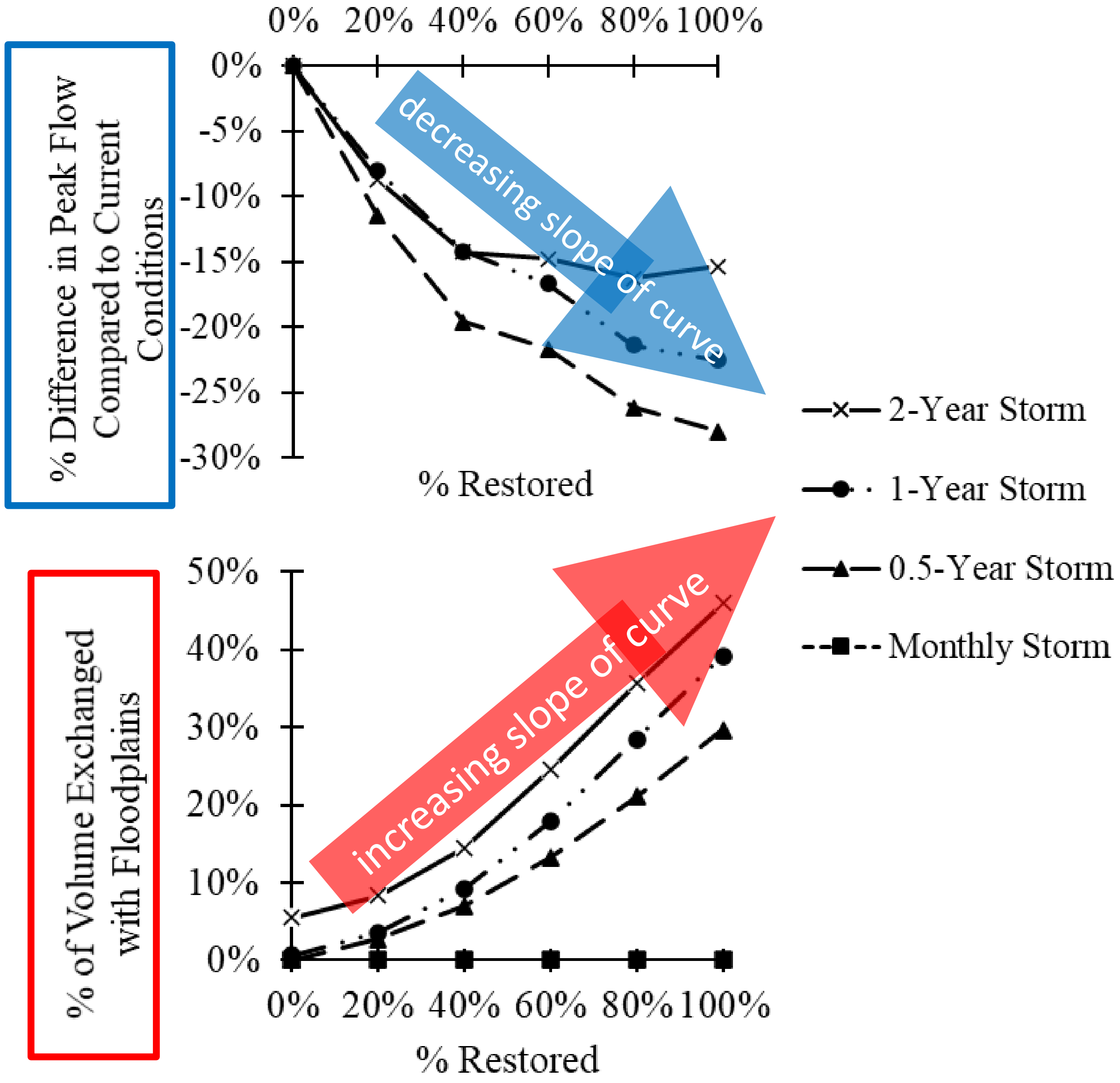
…less prior restoration (for flood wave attenuation)

…more prior restoration (for floodplain exchange)

Tradeoff between flood attenuation and floodplain exchange

flood wave attenuation

floodplain exchange (relates to nitrate removal)

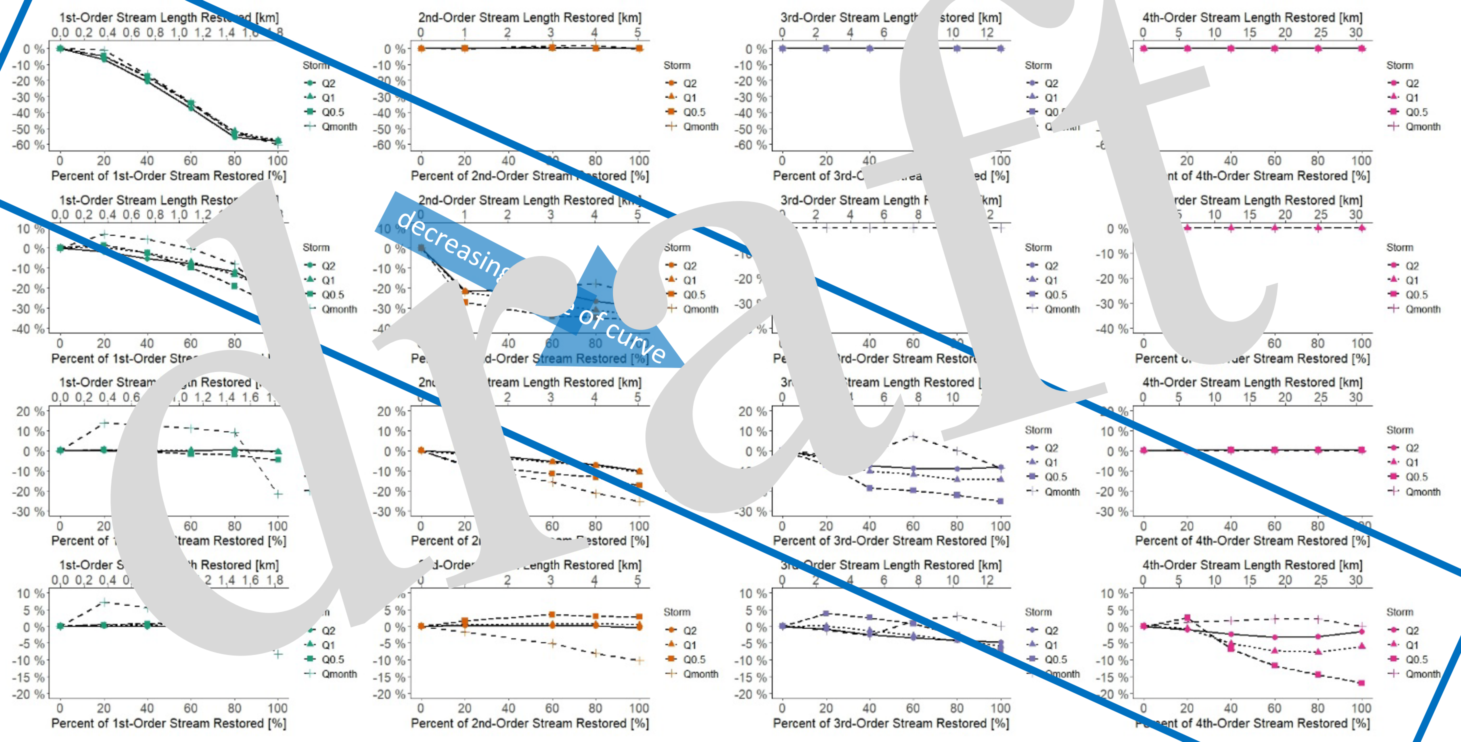


Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Expand storm modeling to 4th order watershed

<u>Preliminary results for flood attenuation</u>

- Answer is more complicated
- Effect greatest at location of restoration
- Diminished effect downstream, no effect upstream
- 2nd order result same as before, but other stream orders different
- Work continues
- Watershed context is critical



Effect of restoration project location (i.e. stream order), percent of prior restoration, and storm size on flood attenuation quantified as percent reduction in peak storm discharge relative to unrestored condition. Rows differ in terms of the location where flood attenuation was quantified (i.e. downstream end of 1st-, 2nd-, 3rd-, and 4th-order channels, respectively.

From here…

Task 1: Finish analyzing variation of rates, use in Task 3 and 4 models

Task 3: Add nitrate transport/removal

Task 4: Select and model case study watershed

Studies already published:

Calfe, M.L., D.T. Scott, and E.T. Hester. 2022. Nitrate removal by watershed-scale hyporheic stream restoration: Modeling approach to estimate effects and patterns at the stream network scale. *Ecological Engineering* 175:106498

Federman, C.E., D.T. Scott, and E.T. Hester. 2023. Impact of floodplain and Stage 0 stream restoration on flood attenuation and floodplain exchange during small frequent storms. *Journal of the American Water Resources Association* 59:29–48

Thank you

The Chesapeake Bay Trust and partners the Maryland Department of Natural Resources, the National Fish and Wildlife Foundation through the Environmental Protection Agency's Chesapeake Bay Program Office, the Maryland Department of Transportation State Highway Administration, and the Montgomery County Department of Environmental Protection

Charles E. Via Endowment at Virginia Tech

Translation Slides

What are the take home points?
What does this mean for me?

TRANSLATION SLIDES BY SHANNON MCKENRICK

MARYLAND DEPT. OF THE ENVIRONMENT

WATERSHED PROTECTION, RESTORATION, AND PLANNING PROGRAM

What does this mean for me?

- Nitrate removal database presents a valuable dataset for evaluating stream restoration effectiveness at varying scales and considering design context
- There are tradeoffs between individual project effectiveness and collective watershed restoration water quality outcomes
- Project location and restoration activity impact on nitrate removal – spatial component to restoration activities

What does this mean for me?

What do I take from this if I am a practitioner:

- All eyes on restoration technique and location – picking the best technique for the location
- Incorporating watershed context during the design process (depending on desired outcome – upstream for flood attenuation, downstream for floodplain exchange?)
- Managing expectations for design results – outcomes are dependent on design type, location related to channel, location within watershed, stream order, etc.

What do I take from this if I am a regulator:

- How do we incorporate *watershed context* into the regulatory process?
- How do we evaluate projects while taking into account cumulative watershed restoration impacts?
- What types of project design information and personnel expertise to we need to examine designs using a more holistic approach?