Pooled Monitoring Forum: Restoration Research to make Science and Regulatory Connections

June 16, 2022, from 9 AM to 3 PM

Zoom/tech leads are Whitney Vong and Lindsay Brubaker (wvong@cbtrust.org, 410-974-2941 xt 122 and lbrubaker@cbtrust.org, 410-974-2941 xt 112)
## Pooled Monitoring Forum Agenda

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<tr>
<td>9 to 9:15 am</td>
<td>Morning Session with opening remarks from <strong>Senator Sarah Elfreth</strong>, Maryland, Anne Arundel County District 30</td>
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<td>9:15 to 11:05 am</td>
<td><strong>Erich Hester</strong> (Virginia Polytechnic Institute and State University), <strong>Arthur Parola</strong> (University of Louisville Research Foundation, Inc.), <strong>Jon Butcher</strong>, Tetra Tech, Inc., and <strong>Theresa Thompson</strong> (Virginia Tech)</td>
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| 11:05 am to 12:05 pm | **PANEL - How are we using the Pooled Monitoring Initiative research?**
Senator Sarah Elfreth (Maryland, Anne Arundel County District 30), Jessica Martinsen (USEPA), Ari Engelberg (MD DNR), Amy Stevens (Montgomery County, MD), Mike Galvin (Maryland Stream Restoration Association), & Sarah Koser (Chesapeake Bay Trust) |
| 12:05 to 1:00 pm | Lunch Break                                                                                 |
| 1 to 3:00 pm    | **Claire Welty & Andy Miller** (University of Maryland Baltimore County), **Sujay Kaushal** (University of Maryland, College Park), **Mark Southerland** (Tetra Tech, Inc.), **Keith Eshleman** (University of Maryland Center for Environmental Science); upcoming research projects and call for sites/data & closing remarks |
Meeting Materials

• Agenda, attendance list, and presentations are at: https://drive.google.com/drive/folders/1dFGF8FPumWlzjR9jhtBxa7lrg4y7AuON?usp=sharing

• This meeting is being recorded and both the recording and presentations will be posted on the Pooled Monitoring Initiative website after the meeting at: https://cbtrust.org/grants/restoration-research/
Morning Session

• Welcome, charge for the day, and Pooled Monitoring Program overview, Sadie Drescher Vice President of Restoration Programs, Chesapeake Bay Trust

• Senator Sarah Elfreth, Maryland, Anne Arundel County District 30, Welcome and opening remarks
Pooled Monitoring Program - Science answers key restoration questions

- Desire to support the best, most cost-effective practices at the most optimal sites, but differences of opinion sometimes exist, and questions about the performance and function of some of these practices persist
- Pool resources to answer restoration questions posed by regulatory community & practitioners
  - **Partnerships and collaborations** - we are all a part of this effort!
- Increase power, objectiveness, and ability to know what works
- Bring science back to those that can use the research/data

Kelsey Wood (UMD) measuring groundwater for "Tree Trade-Offs in Stream Restoration Projects: Impact on Riparian Groundwater Quality" project (PI is Sujay Kaushal)
Regulators prioritize their concerns with input from practitioners

Funders “pool” resources

Top restoration questions issued in the Restoration Research Request for Proposals (RFP) in FY15 administered by the Chesapeake Bay Trust

Scientific teams research these questions and deliver answers back to the regulators

RFP open to any organization – looking for best groups to answer your questions

Results used in decisions, policy, practices, etc.

Claire Welty (UMBC) quantifying the cumulative effects of stream restoration and environmental site design on nitrate loads in nested urban watersheds using a high-frequency sensor network (Baltimore County, MD)
Restoration Research Award Program

- Supported 38 projects since FY 15 at >$7M
- Guided by the Pooled Monitoring Advisory Committee
- Uses scientific reviewers across the world to vet applications
- Runs all applications through a “management review”
- Projects are managed as contracts
- Questions are cycled off/on the RFP each year
- All awards, progress, and program products are online at: https://cbtrust.org/grants/restoration-research/

Keith Eshleman (UMCES) Plum Branch stormwater monitoring station (Ellicott City, Howard County, MD)
Morning Session

- Welcome, charge for the day, and Pooled Monitoring Program overview, Sadie Drescher, Vice President of Restoration Programs, Chesapeake Bay Trust

- **Senator Sarah Elfreth**, Maryland, Anne Arundel County District 30, Welcome and opening remarks
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</table>
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 2\textsuperscript{nd} order channel

Started with:
- Stage 0 and floodplain restoration (channel restoration for hyporheic enhancement coming later)
- 2\textsuperscript{nd}-order piece of larger 4\textsuperscript{th} 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)
Task 3: Restoration causes flood attenuation

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

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<table>
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<th>Event</th>
<th>Stage 0 restoration</th>
<th>current conditions</th>
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<tr>
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<tr>
<td>0.5-year</td>
<td></td>
<td></td>
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<tr>
<td>monthly</td>
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</tbody>
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current conditions (without restoration)
Stage 0 restoration (15 cm bank height) in upstream-most 1 km of 2\textsuperscript{nd} order channel
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)
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
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
From here...

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

Task 3: Expand storm modeling to full 4\textsuperscript{th} order watershed, add nitrate transport/removal, add in-channel restoration techniques

Task 4: Select and model case study watershed
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.
What are the take home points?
What does this mean for me?
What does this mean for me?

- Outcomes vary depending on where restoration takes place along the stream corridor.
- There are trade-offs in thinking about the effectiveness of individual projects vs. cumulative watershed affects.
- Importance of articulating design objectives and achievable outcomes.
What does this mean for me?

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

- Low bank height seems positive, no matter what design methodology is used.
- Design approach should be nested within the watershed context: where, how much restored, optimization of peak flow reduction, watershed storage, water quality, habitat, etc.

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

- How do individual projects fit into a watershed framework.
- What data is needed from the design to determine desired and achievable outcomes?
Reliability of Two-Dimensional (2D) Hydrodynamic Models for Assessing Susceptibility of Stream Restorations to Flood Damage and Potential Effects of Climate Change

Research Question: How can different restoration approaches or techniques reduce the impacts of future climate change?

Presenter: Art Parola, PhD, PE, Director, University of Louisville Stream Institute

Collaborators and contributors: Anne Arundel, County, Prince Georges County, Maryland Department of Natural Resources, Maryland State Highway Administration, RK&K, Greenvest, Underwood & Associates, Berrywood Community
What is a 2D Model
Motivation: Reliable 2D models would be useful under current and future climate conditions

Reliable models can be useful for:

Stable Restoration Design
- Identify components of restoration that are vulnerable to damage
- Determine if rock protection or additional structures are necessary to prevent damage
- Remove unnecessary rock and structures
- Minimize excavation and tree removal necessary for stability
- Compare the stability of restoration alternatives
Motivation: Reliable 2D models would be useful under current and future climate conditions

Reliable models can be useful for:

Climate Change Resilience
  o Identify components that would be vulnerable to increased flow
  o Estimate the increase in extent of damage caused by increased flow
  o Compare resilience of alternative methods to increased flow
Research Approach

• Phase I: Evaluate 2D model reliability at 5 sites

• Phase II: Evaluate the susceptibility of restorations to damage under current and future climate conditions
Phase I: 2D Model Reliability Analysis

1. SELECT SITES
2. SURVEY SITES
3. DEVELOP TERRAIN MODEL
4. INSTALL AND MONITOR SITE INTRUMENTATION
5. COMPILE AVAILABLE SITE DATA FROM PARTNERS
6. DEVELOP INITIAL 2D MODELS
7. COLLECT CLASSIFICATION DATA (DAMAGE/UNDAMAGED)
8. REFINE 2D MODELS
9. DEVELOP INITIAL 2D MODELS
10. CONDUCT RELIABILITY ANALYSIS

Project Status
- COMPLETED
- IN PROGRESS
- NEXT STEPS
Phase I: Refining 2D Models (in progress)

- Direct observations of floods at sites are used to evaluate and refine model parameters
- Also useful for comparing flow patterns predicted by the model to the observed flow patterns

Above: flow during a flood using data collected in partnership with Anne Arundel County

Above: imagery during a flood at CBT research site.
Phase I: Collect classification data for damaged and undamaged areas (in progress)

- Classification data is based on common indicators in the ground and vegetation

**No Surficial Damage - depositional area of floodplain**

**Surficial Damage - Rilled area of floodplain**
Phase I: Collect classification data for damaged and undamaged areas (in progress)

• Classification for structures is based on structure failure modes

Scour and undermining of footer rocks  
Bank erosion and outflanking of structure
Phase I: Collect classification data for damaged and undamaged areas (in progress)

- Structure damage classified by failure mode

*Undamaged beaver dam analog (BDA)*

*Bank rills from floodplain return flow downstream of BDA*
Phase I: Preliminary Results

- Across the 5 sites, 2D model predicted velocities show general agreement with the observed velocity conditions during floods.
Phase I: Preliminary Results

- Across the 5 sites, model low and high velocity regions correspond to undamaged and damaged areas in the classification data.

Above left: depositional area of floodplain
Above right: low velocities predicted correlate with area of deposition and coarse and fine organic material accumulation
Phase II: Current and Future Conditions Analysis (Next Steps)

1. 2D MODELS FOR EACH SITE FROM PHASE I
2. LIMIT TO SITES & COMPONENTS WHERE MODEL IS RELIABLE
3. EVALUATE DAMAGE PREDICTION TO COMPONENTS FROM AN ESTIMATE OF CURRENT 100-YR FLOW
4. EVALUATE DAMAGE PREDICTION TO COMPONENTS FROM ESTIMATES OF 100-YR FLOW WITH CLIMATE CHANGE
5. COMPARE DAMAGE PREDICTIONS UNDER EACH SCENARIO
6. REFINE MODEL THRESHOLDS FOR DAMAGE TO COMPONENTS
Phase II: Very Preliminary Results

Current Climate 100-Year Flow

Estimated Climate Change 100-Year Flow

Velocity Sensitive to Flow Increase

Velocity Less Sensitive to Flow Increase

Wide Floodplain

Pinch Point
Phase II: Very Preliminary Results

Current Climate
100-Year Flow

Estimated Climate Change
100-Year Flow
Phase II: Expected Results

- Increasing flows due to climate change will increase flood velocities
- The % increase in velocity and % damage will vary depending on site conditions and restoration methods
- Some restoration approaches will be more resilient to increased peak flows

Above right: Two observed flows at a CBT research site (typical storm and large storm - Hurricane Ida) shown with a 100-yr event predicted by regional regression equations. Highest flow is the 100-yr event scaled by 30%
Acknowledgements

Thanks to the Chesapeake Bay Trust and all the funding partners for supporting this work. Thanks to Sadie Drescher and the collaborators who are making this project possible.

Partners and collaborators:
MD DOT SHA: Ryan Cole, Nora Bucke, Kevin Wilsey
MDE: Bill Seiger, Deb Cappuccitti, Jeff White
MD DNR: Ari Engelberg
Anne Arundel County: Erik Michelsen, Nasrin Dahlgren, Bryan Perry, Karen Jennings
Prince Georges County: Joanna Smith, Jerry Maldonado, Mark McKibben, Frank Galosi
Montgomery County: Kenny Mack
SERC: Cynthia Gilmour
RK&K: Drew Altland, Jason Coleman
Greenvest: Laura Kelm, David Merkey, Dana Cooper, Brett Berkley
Underwood & Associates: Keith Underwood, Chris Becraft, Keith Binsted, Heather Johnson, Beth Zinecker
Tetra Tech: Mark Sievers, Jasmine DunhamTyson
Berrywood Community: Molly LaChapelle, Bob Royer
Arundel Rivers: Jennifer Carr
McCormick Taylor: Scott Lowe
EQR: Katrina Davis
What are the take home points?
What does this mean for me?

Translation Slides by Erik Michelsen, Anne Arundel County Department of Public Works
What does this mean for me?

• This work continues to demonstrate the utility of 2D modeling as an integral stream and wetland restoration design tool. Not as one that should be applied at the completion of design, but as one that should be used iteratively throughout the initial design process to inform grading and the placement of erosion resistant material, if necessary.

• As storm intensities increase, systems that are designed to allow for a shallow depth of flow across a broad cross section – rather than within a highly armored, narrower cross section – are likely to prove more resilient to higher flows.
What does this mean for me?

What do I take from this if I am a practitioner:
• That 2D modeling can be a powerful tool for more resilient restoration design, and can reduce our adaptive management and repair costs if built into the initial design.
• That in terms of surface stability, we have to consider not only the vegetatively mature “final” product, but the 12-18 months of the temporarily stabilized site (e.g., don’t skimp on matting).

What do I take from this if I am a regulator:
• Ask questions about what sorts of modeling applicants have done on their project surfaces to try to anticipate further instability.
• If applicants are providing 2D model runs, regulatory agencies may want to request some professional development training to be able to better understand those analyses.
Climate Impacts to Restoration Practices

Restoration Research Question B.4 (Grant # 19278)
Chesapeake Bay Trust Pooled Monitoring Forum
June 16, 2022

Jon Butcher, Tetra Tech,
In conjunction with:
Dr. David Sample, Dr. Tess Thompson, Sami Towsif Khan, Virginia Tech
Follow on to prior grant on future changes in storm intensity and potential effects on infrastructure in MD

- Grant # 16928 (Sept 2019 – January 2021):
  - Developed methods and estimated climate-modified intensity-duration-frequency (IDF) curves for all MD NOAA Atlas 14
  - Evaluated impacts on infrastructure, BMPs, channel restoration stability
  - Hypothesis: Designs based on historic weather may be inadequate to achieved desired levels of service under future climate

Conclusions
- Infrastructure such as road culverts likely inadequate to address future large storm events
- Risk to channel stability will increase, should be a factor in restoration design
- Smaller storms (e.g., current 90th percentile event will likely not increase in frequency; Environmental Site Design adequate to address future water quality

Caveats:
- Results depend on downscaled climate product (LOCA)
- Analyses based on design storms may not yield a complete picture
Hypotheses for Current Grant:

• **H1.** Problems in the LOCA methodology introduce biases
  • Test against alternative sources

• **H2.** Current ESD requirements will be sufficient to meet management objectives under future climate
  • Continuous analyses with LOCA and alternative sources

• **H3.** Conclusions based on IDF analysis hold up under continuous simulation on real watersheds
  • Detailed simulations with calibrated flow and sediment transport models
Does LOCA Downscaling Introduce Biases?

- Raw GCM output needs to be downscaled to shorter timestep with local bias correction for IDF analysis
- Training method for LOCA statistical downscaling may underestimate large events
- MACA is an alternative statistical downscaling product that covers most of the same GCMs but uses different training data
- CORDEX experiments with dynamic downscaling using regional climate models (available for a limited number of GCMs)

MACA results for future 10-yr, 24-hr event average 10% higher
Does Downscaling Method Introduce Biases?

- Comparison to CORDEX dynamic downscaling (limited sample) shows LOCA < MACA; CORDEX tends to be in between
- Hierarchical ANOVA shows downscaling effect is statistically significant
- Variance components: Site > GCM > Downscaling
- Downscaling contributes about 10% of variance
H2: Current ESD Sufficiency for Future Climate

- BMPs designed to maximize treatment of 90th percentile 24-hr event that occurs multiple times per year
- Both LOCA and MACA estimate smaller changes in these events
- ESD excess runoff volume target generally achieved in both analyses
- Hypothesis confirmed with non-inferiority test with tolerance of 0.1 inch increase per event

Example results for 30 GCMs, LOCA downscaling, Baltimore, RCP 8.5
Continuous Analyses of Bioretention Performance

- Statewide analysis: Use quantile mapping to modify historic 1-hr rainfall series and unit-area SWMM simulations to evaluate performance across all sites and scenarios.

- Detailed analysis: Created future climate 5-minute time series for use by Virginia Tech collaborators in calibrated SWMM and HEC-RAS models of Tributary 109, Clarksburg, MD.

![Bar graph showing rainfall distribution over years]

![Pie chart showing percentages of underdrain, evaporation, exfiltration, and bypass]

- Underdrain: 57%
- Evaporation: 4%
- Exfiltration: 18%
- Bypass: 21%
Based on continuous simulation for all GCMs at all MD Atlas 14 sites, LOCA and MACA provide similar distribution of untreated bypass from bioretention through end of century.
H3: Response of watershed equipped with ESD under future climate: Null Hypotheses

- Historical duration curve will not change
- Stream will not experience increased channel erosion
- Retrofitting existing stormwater management will protect channel stability for all CC scenarios
H3a: Continuous SWMM Simulation with Future Climate

- All 5-minute flows
- Annual maximum flows
- Flow Duration Curve
- Flood Frequency
Stream discharge will be greater than current conditions for 4% of all flows in Tributary 109.
* Flood peak discharges will likely decrease for recurrence intervals <10 yrs and increase for recurrence intervals > 20 yrs

* Ongoing work by VT: simulating channel stability with HEC-RAS for continuous future-climate time series
Summary

Downscaling methods concur in predicting strong increases in extreme events; small changes in more common events.

Maryland ESD requirements are likely robust against predicted changes.

Infrastructure and stream restoration projects appear at greater risk from extreme events.

Downscaling method does affect results, with intensities on average MACA > CORDEX > LOCA.

Only the more extreme flood events (Recurrence Interval > 20 yrs) will likely increase due to climate change; average stream flows will generally decrease for Clarksburg Tributary 109.
Advice to Regulators and Practitioners

• Future is uncertain, but increase in high intensity storms is likely
• How to adjust design standards depends on risk aversion – cost versus risk from potential future conditions
  ➢ Encourage designs that are adaptable to an uncertain future
  ➢ Seek resilient solutions in which adaptations provide co-benefits (e.g., green space, urban heat island mitigation, carbon sequestration) even if the future turns out different than projected by models
Acknowledgments

• We thank the many partners who support the Restoration Research program for their funding and interest. Major funding for this phase of the work was provided by the U.S. Environmental Protection Agency
Translation Slides

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

Translation Slides by Guido Yactayo
What does this mean for me?

• Downscaling choice matters
• ESD will still meet design objectives
What does this mean for me?

What do I take from this if I am a practitioner: ~2 ideas here
- Downscaling methods can be a source of bias in climate assessments.
- Need for synthesis of research

What do I take from this if I am a regulator: ~2 ideas here
- MDE’s plans to update stormwater management regulations.
- Incorporate resilient design to restoration projects to minimize risk in vulnerable communities.
You are done!

Thank you for your hard work to do the research, communicate it clearly to the audience, and translate this into something the audience can do with the information in their work tasks.
Backup Slides

Use only if needed to answer questions
Efficient Methods Enable Climate-adjusted Estimates of Precipitation and Runoff throughout MD

• Statistical approach to update NOAA Atlas 14 IDF curves based on change in climate models (EQM)
• Application of SWMM5 to convert rainfall to runoff and simulate BMP performance
• Estimate range of futures to which adaptation may be needed
• Database of results for 79 MD stations, mid and late century
Future IDF Curves Show a Range of Possible Conditions, with a Tendency toward More Intense Storms

<table>
<thead>
<tr>
<th>Rainfall Duration</th>
<th>Historic - Atlas14</th>
<th>2085-10th - HadGEM2-ES_rcp45</th>
<th>2085-RCP4.5-50th - MPI-ESM-LR_rcp45</th>
<th>2085-RCP8.5-50th - CanESM2_rcp85</th>
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Runoff Depends on Rainfall and Site Conditions – but the General Trend is Up

• Averages over 20,576 combinations of sites, GCMs, recurrence intervals, imperviousness

• ~14% increase in storm peak runoff rates by late century

• Larger increases for more extreme events
Increasing Flood Risk for Current Designs

- Road culvert designed to pass runoff from 50-year 24-hr storm (minor arterial road)
- Large potential increases in low-recurrence events = greater flood risk

1% slope, 100 ft round culvert, 4.5 ft diameter, 200 cfs design flow, 2 ft freeboard at design flow (matches FHWA Design Guideline 1)
Storm Intensification: Implications for Environmental Design in Maryland

Jonathan B. Butcher, Ph.D., P.H., M.ASCE

Abstract

Extreme precipitation is predicted to increase over the 21st century. Stormwater infrastructure designs based on historic climate experience will have reduced margins of safety and could fail to provide intended levels of services. Climate-adjusted rainfall intensity-duration-frequency curves were estimated at locations throughout Maryland for multiple climate models and land cover assumptions and linked to rainfall-runoff models with green and gray stormwater control measures (SCMs). These data are used to evaluate three classes of responses: highway...
Flood Frequency Analysis – Tributary 109
Droughts (Inter Storm Event Time Period > 5 days) most likely to increase in future. Median Dry Duration to decrease in future – Storms likely to happen more frequently.
For Clarksburg Tributary 109: Total rainfall depth of extreme storm events increases. For 99% of storm events total rainfall depth will decrease.
Effectiveness of stormwater management practices in protecting stream channel stability

Tess Wynn Thompson  Associate Professor  Virginia Tech
David Sample  Professor  Virginia Tech
Mohammad Alsmadi  Adjunct Faculty  Virginia Tech
Sami Towsif Khan  Graduate student  Virginia Tech
Mina Shahed Behrouz  Graduate student  Virginia Tech
Andrew Miller  Professor  Univ. of Maryland, Baltimore County
Acknowledgements
In this talk “sediment” is not a four-lettered word.

- Coarse sediment is naturally transported in suspension and along the channel bed.
- Fine sediment does not play a major role in channel morphology.
The overall study goal is to evaluate the impacts of different stormwater management practices on channel stability.
Watershed changes through time

Tributary 109
Watershed changes through time

Minebank Run
Channel stability is a two-part problem

Water

Sediment

HEC-RAS 6.2
SWMM model development

1. Watershed characteristics and stormwater infrastructure attributes entered into models
2. Models calibrated based on observed USGS flow data
3. Calibrated models used to explore multiple scenarios
4. Modeled stream discharge used in HEC-RAS model
The effect of different stormwater management strategies were modeled for Minebank Run

1. Imperviousness reduced by 50%
2. Depression storage doubled
3. Soil hydraulic conductivity doubled
4. Route all impervious to pervious
5. 12 ponds with a total storage volume of 54 acre-ft
6. Combinations of scenarios of 2-5
Channel stability is a two-part problem

Water

Sediment

SWMM
Storm Water Management Model

HEC-RAS 6.2
HEC-RAS 1-D model development

1. Lidar data and measured cross sections used to create channel geometry
2. Bed particle counts, bulk sediment samples, and USGS suspended sediment data used to parameterize sediment transport routines
3. Bank soil samples and jet tests used to parameterize bank erosion routines
4. Calibrate HEC-RAS to USGS stage data and measured cross section change
5. Modeling channel response to stormwater scenarios modeled using SWMM
Results to date...
With ESD all flows increased.
For small storm events, infiltration practices reduce runoff more than storage practices.
Storage practices are necessary to reduce peak flows from large storm events.
Infiltration practices effectively reduce peak flows from small storm events, but storage practices are necessary to reduce peak flows from large storm events.
Channel stability results coming...
Summary

1. SWMM and HEC-RAS models developed for two watersheds to investigate how much ESD protects channel stability following development.
2. Flow reduction is greatest when using a combination of ESD controlling small storms and SCMs controlling larger events.
3. ESD is more effective for small magnitude, high frequency storms, whereas storage BMPs (ponds) are more helpful in controlling flows from large events.
4. Channel stability findings…
Translation Slides

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

Translation Slides by Sara Weglein
What does this mean for me?

• ESD/infiltration BMPs are more effective in reducing the impacts of smaller, more frequent storms.
• SCMs/storage BMPs are more effective in reducing the impacts of large storm events.
• These BMPs in combination had the greatest impact in reducing the impacts of stormflow overall.

• ESD/infiltration BMPs were also effective in increasing baseflow.
  • This could be an area of additional study; what effect does ESD and increased baseflow have on stream temperature?
What does this mean for me?

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

• Need to apply a combination of infiltration and storage BMPs for the greatest chance of success in reducing stormflow.

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

• Same as above.

• ESD could be utilized to increase the magnitude of baseflows (where a concern), reduce the frequency of dry conditions, and thereby protect biota.
Evaluation of watershed-scale impacts of stormwater management facilities on thermal loads to a Maryland Class IV stream using a high-frequency sensor network

Claire Welty, UMBC
Andy Miller, UMBC
in partnership with
Kevin Brittingham, Baltimore County DEPS
June 16, 2022
Research question to be addressed

What best management practice design and siting methods will reduce thermal impacts to Maryland’s Use III and IV streams?
Hypotheses

H1 High spatial- and temporal-resolution observations of stream water temperature reveal patterns of influence on thermal loading associated with land cover and stormwater management features.

H2 The thermal impact of surface stormwater facilities is comparable to that of directly-connected impervious surfaces at the watershed scale. The relative importance depends on drainage ratio of connected impervious to drainage area treated by stormwater management.

H3 Discharge from underground stormwater management facilities better mitigates thermal impacts to streams compared to drainage from surface stormwater facilities.
Dead Run watershed study area - Use Class IV stream network
Proposed tasks to be undertaken

• Water temperature sensors to be deployed at high spatiotemporal resolution at watershed scale
• Air temperature sensors to be deployed at USGS stream gages
• Data to be recorded every 5 minutes for 2 years/ all flow regimes
• Data to be downloaded periodically
• Spatiotemporal mapping of data at watershed scale to be done
• Statistical analysis of data to be carried out
Deployment design

HOBO TidbiT MX 2203 temperature data loggers (water)

• 160 sensors
  → Every 100 m along all accessible stream segments of the Dead Run, 16 km total

• 140 sensors
  → Longitudinal transects of temperature sensors at ~2-5-10-50 m intervals downstream ~30 stormwater management facilities

HOBO MX2305 temperature sensors (air)

• 6 sensors
  → At 6 USGS stream gaging stations
Status update

• Project started 7/15/2021; sensors ordered immediately
• Sensors arrived Oct 2021 owing to “supply chain issues”
• Air temperature sensors deployed Oct 2021
• 169 water temperature sensors deployed Dec 2021 – March 2022
• Trial download conducted in Jan 2021 for one subwatershed
• First download of all data to be carried out July 2022
• Finer-scale deployments will be made based on watershed-scale data
Deployment challenges

• Bluetooth downloadable sensors will not work through water
• Needed to devise a scheme for secure deployment yet quick release
• Need to be able to find sensors upon return visits
• Stream channel is particularly difficult to navigate owing to downed Ash trees
• Necessary to hike 16 km twice – once for reconnaissance; once for deployment
• Icy weather conditions owing to order delay
Deployment solution
Deployment achieved: 
169 locations over 16 km

Trial download
Stream temperature response to storm runoff

![Graph showing precipitation over time]
Next steps

- Download of entire stream network
- Selection of stormwater facilities for finer-scale deployments
Locations of stormwater management facilities in Dead Run

30 sites to be selected for denser stream temperature instrumentation
Stormwater facilities permitted by Baltimore County located in Dead Run watershed

<table>
<thead>
<tr>
<th>Facility type</th>
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<tr>
<td>Bioretention</td>
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<td>Infiltration basin</td>
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<td>Infiltration trench</td>
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<td>Microbioretention</td>
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<td>Permeable pavement</td>
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<tr>
<td>Sand filter</td>
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<td>Shallow marsh</td>
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<tr>
<td>Submerged gravel wetland</td>
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<tr>
<td>Underground filter</td>
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<tr>
<td>Wet pond/wetland</td>
<td>2</td>
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<tr>
<td>Other</td>
<td>4</td>
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Acknowledgments

CBT/DNR – pooled monitoring fund
UMBC/CUERE staff
  Mary McWilliams, John Lagrosa, Hanna Donovan
USGS - Sarah Queen
Translation Slides

Greg Golden, MD DNR
Karl Berger, MWCOG
What are the take-home points?

• The study will develop addition insight on site conditions and SWM BMP thermal sensitivity that can be considered when designing SWM approaches or retrofits in regulated coldwater systems.

• We can expect useful stream system data and observations that can also be used in stream and riparian restoration efforts.

• Preliminary results from the trial storm on 12/11/2021 show the deployment system’s ability to record fine differences in temperature.

• Study holds great promise for detailing rapid differences in temperature during stormflows.
What are the take-home points?

• Specific site and design cases are important tools for the thermal review field, and several will be developed in this study.

• Reviewers should gain further thermal insight into SWM BMP types, potentially into certain unique design features and options found on specific BMP sites, and for watershed/tributary/riparian condition and influence.

• The study results can be applied to both future specific project reviews, and also will help to identify additional technical details and watershed conditions for further study or observation in coldwater regulatory review.
What does this mean for me?

• Need data like this if we are to mitigate increasing stream temperatures
  ➔ Whether voluntarily or through regulation

• Effort should be expanded to other watersheds
  ➔ Need to determine how much we can mitigate high temperatures based on watershed characteristics
  ➔ The study can inspire more work on not only coldwater system thermal review, but also possible nuanced thermal effects to warmwater aquatic species, and level of thermal influence on restoration ecological uplift potential
Evaluating impacts of freshwater salinization syndrome on mobilization of nutrients and metals from stormwater best management practices

Research Team: Sujay Kaushal\textsuperscript{1}, Joseph Galella\textsuperscript{1}, Ruth Shatkay\textsuperscript{1}, Jenna Reimer\textsuperscript{1}, William Nguyen\textsuperscript{1}, Walter Boger\textsuperscript{1}, and Alexis Yaculak\textsuperscript{1}

Translation: Ken Mack\textsuperscript{2}

\textsuperscript{1}University of Maryland, Department of Geology & Earth System Science Interdisciplinary Center

\textsuperscript{2}Montgomery County, Department of Environmental Protection
Freshwater Salinization Syndrome Impacts Maryland’s Drinking Water
Salinization Mobilizes Metals and Nutrients to Streamwater

Kaushal et al. (2019)
*Philosophical Trans. Royal Society*
Retention and release of chemical cocktails along stream and stormwater flowpaths

Chemical cocktails:
- Atmospheric deposition
- Surface runoff
- Urban karst
- Buried streams

Infiltration (e.g., rain gardens)

- Retained: Ca, Sr, Cu, Zn
- Released: K, As

Hyporheic and floodplain exchange (e.g., stream/floodplain restoration)

- Retained: N, P
- Released: C, Fe

Detention and retention (e.g., stormwater ponds)

- Retained: Cd, Cu, Pb, Zn
- Retained & Released: Na, Cl

Kaushal et al. (In Press)

Freshwater Science
Key Questions

• What are critical thresholds in concentrations of different road salt ions (Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\)) which can mobilize nutrients and metals to surface waters across varying stormwater BMPs?

• What are the concentrations and loads of different road salt ions and associated metals and nutrients in nearby stream outfalls before, during, and after deicing events
Study Sites:

- 4 different stormwater management features (with replicates)
- Sites range from 5 to 33 years in age and were almost always constructed concurrently with a building or large area of impervious surface coverage
- Stream restoration sites and regenerative stormwater conveyance (RSC) systems

Galella et al. (In Prep)
Methods:

1. Collect water and sediment samples
2. Filter water through 0.7-micron GFF
3. Sieve sediment through a 4 mm sieve
4. Add salt (NaCl / CaCl₂ / MgCl₂)
5. Incubate water and sediment on shaker table for 24 hours

Galella et al. (In Prep)
Hold the Salt: How Much Can Be Retained in Sediments?

Retention and Release of Salts, Nutrients, and Metals in Different Stormwater Management Features

Photo courtesy of Kelsey Wood (2019)
High Capacity for Sodium Retention in Restored Stream Floodplain Sediments

Kaushal et al. 2022, Limnology & Oceanography Letters
Sediments and soils can retain substantial amounts of salt ions.

Kaushal et al. (In Press)

Freshwater Science
Mobilization of metals, nutrients, and other salts

Galella et al. (In Prep)
Results: ANOVA Salt type, concentration, and BMP type are significant

- Site type had a significant effect on the concentration of:
  - B, Ba, K, Mn, and Sr
- Salt type was significantly correlated with all major and trace elements save for:
  - B and Fe
- Salt concentration was statistically correlated with mobilization of ALL major and trace elements

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<th>Salt Type</th>
<th>Salt Concentration</th>
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<td>N</td>
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<td>p-value</td>
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<td>X</td>
<td>X</td>
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</table>

Galella et al. (In Prep)
Different Salt Ions Mobilize Different Contaminants

Galella et al. (In Prep)
NaCl Mobilizes More Copper: Implications for Aquatic Ecosystems and Home Plumbing

NaCl mobilizes Cu more than an order of magnitude more efficiently than CaCl$_2$ or MgCl$_2$

Galella et al. (In Prep)
Stream and Stormwater BMP Monitoring

Photos Courtesy: Kelsey Wood
Changes in water quality following road salt events in RSCs

- Decrease in pH
- Increase in conductivity
- Decrease in DOC
- Decrease in TDN
- Increase in ions and metals
- Increase in labile organic matter

Kaushal et al. (In Press)
Freshwater Science
There can be significant recovery and decreases in ion concentrations over years (>50%) depending on amount of road salt use.

Kaushal et al. (In Press)

*Freshwater Science*
New Monitoring Approaches: Specific Conductance as a Proxy for Ions and Metals

Campus Creek

Galella et al. (2021), Kaushal et al. (2021), Kaushal et al. (2022), Kaushal et al. (In Press)
Managing Salinization by the Amounts and Types of Salt Ions along Flowpaths

Kaushal et al. 2022, Limnology & Oceanography Letters
Summary

• Significant retention of salt ions in stormwater sediments

• Mobilization of contaminants depends on concentration of salt ions, type of salt, and BMP type

• New practical monitoring approaches using proxies
Management Implications

• Stormwater sediments/soils can have very high potential to enhance ion retention and ion exchange

• Reducing winter NaCl inputs can lead to rapid and year long recovery in some ions

• Water quality monitoring approaches using inexpensive proxies such as specific conductance can help predict concentrations of multiple ions and metals
Acknowledgments

• Thanks to the Maryland Department of Transportation, and Maryland Department of Natural Resources for funding along with all the funding partners below.

• Special thanks also to Karl Berger, Steve Bieber, Paul Mayer, and Stan Grant
Translation Slides

Ken Mack
Senior Water Quality Specialist
Montgomery County Department of Environmental Protection
Good News Bad News

**Good News**
- BMPs and Stream Restoration are sequestering deicing salts

**Bad News**
- Sequestered deicers are exchanged for other ions (Including environmentally harmful ions)
Good News Bad News

**Good News**  
- Reducing road salt use results in immediate reduction in stream salinization and reduces ion exchange

**Bad News**  
- NaCl results in a likely more harmful chemical cocktail (especially in bioretention)
Good News

- Conductivity monitoring can be a good proxy for several ions (not just Na or Cl)

Bad News

- Exchanged ions result in a broad chemical cocktail possibly reducing biological potential
Additional Management Considerations

• Emphasizes the need to reduce the use of all salts (especially NaCl)

• Many second order effects of deicers (acidification, increase in labile organic matter, reduction in DOC). Potential impacts to:
  • Drinking water
  • Stream biota
  • Infrastructure

• Salt type has a major influence on released chemical cocktail
  • Consider using different salts near bioretention
  • Reduce NaCl where copper export is possible

• BMP type and age influences released chemical cocktail

• Stream restoration results in a pulse of nutrients/ions
Vertebrate Community Trajectory in Regenerative Stream Conveyances

Mark Southerland, Bob Murphy, and Nancy Roth
*Tetra Tech*
Ryan Woodland and Solange Filoso
*UMCES-CBL*

mark.southerland@tetratech.com

Pooled Monitoring Forum
June 16, 2022
Key Research Questions

B. Effectiveness of restoration practices at the project scale

B.4. Biological Community Restoration: Recent research has shown that in many situations, especially in watersheds with relatively high impervious cover, stream restoration may result in improved physical habitats but not restored biological communities (macroinvertebrates, fishes, etc.). ...

D. Trade-offs in resource improvements incurred by restoration practices and the resulting net ecological change as measured by a common “currency”

D.10. Resource trade-offs in different types of restoration projects. The decision to install a restoration project at any given site implies that an existing condition at that site will be modified, replaced, and/or improved. The hypothesis of the restoration practitioner is that the net condition will be improved. However, a value judgment is placed on the existing condition, (e.g., deeming the existing condition to be inferior to the desired “restored” condition) that is often not based on quantification. ...
Outline

• What are RSCs?
• Study Questions and Approach
• Conceptual Model
  ▪ References
• Methods
  ▪ Site Selection
  ▪ Field Sampling
• Results
  ▪ Fish
  ▪ Herpetofauna (amphibians and reptiles)
• Conclusions
What are RSCs?

• **Regenerative stream conveyances (RSCs) typically**
  - transform degraded, single-channel, lower-order streams (some with wetlands)
  - into stream-wetland complexes designed to provide more opportunity for sediment retention and nutrient removal

• **RSCs result in channel widening and partial impoundments that**
  - slow flow rates
  - typically reduce shading
  - create periodic anoxia
  - increase diel dissolved oxygen variation and ecosystem gross primary production (GPP)
What are RSCs?

Wilelinor 2004 and 2020

North Cypress Branch 2010 and 2020

Immediate post-construction

16 and 10 years post-construction
Specific Study Questions

• What trajectory should we expect vertebrate communities to follow in Regenerative Stream Conveyances (RSCs)?

• How can practitioners and regulators more appropriately
  ▪ quantify the biotic resource changes that occur when defined-channel stream systems are transformed into less-defined stream-wetland complexes
  ▪ consider those changes in the context of nutrient reduction benefits expected from restoration
Conceptual Model

**Figure 1.** Graphical comparison of habitat-related differences associated with regenerative stream conveyance (RSC) construction relative to the putative initial condition (LSS: low-quality single channel stream), and reference conditions for three potential vertebrate community trajectories (HSW: high-quality stream-wetland complex; HSS: high-quality single channel stream; LSS).
HSS – High-quality Single Stream
HSW – High-quality Stream Wetland
LSS – Low-quality Single Stream

Conceptual Model
Site Selection for Field Study

• Natural factors were similar among stream types, except for larger catchment sizes that are inherent to HSWs

• 8 HSS  *High-quality Single Streams* = 453–664 acre catchments
• 8 HSW  *High-quality Stream Wetlands* = 552–52,936 acres
• 8 LSS  *Low-quality Single Streams* = 134–669 acres
• 11 RSC  *Regenerative Stream Conveyances* = 30–4550 acres

• Total of 35 sites sampled during August-September 2020
# RSCs with Age and Catchment Areas

<table>
<thead>
<tr>
<th>RSC</th>
<th>RSC Site Name</th>
<th>Date constructed</th>
<th>Age (years)</th>
<th>Catchment (acres)</th>
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<tbody>
<tr>
<td>RSC-1</td>
<td>Bacon Ridge</td>
<td>2018</td>
<td>2</td>
<td>1757</td>
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<tr>
<td>RSC-2</td>
<td>N Branch Cypress Creek</td>
<td>2010</td>
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<td>RSC-3</td>
<td>Crofton Tributary</td>
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<td>Church Creek at Annapolis Harbour Center</td>
<td>2014</td>
<td>6</td>
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</tr>
</tbody>
</table>
Field Sampling Methods

Sampling Protocols

- MBSS for Fish, Herps, Habitat
- Basic Water Quality of Dissolved Oxygen, Temperature, Conductivity
- Stream Metabolism

- High flow days after rain were not sampled
- All sites were sampled in August-September 2020 with sampling of each stream type spread across the calendar
Water Quality is Different in RSCs
Habitat is Similar in RSCs (except for Buffers and Cobble)
FIBI' is Low
RSC Fish Diversity is Low
Fish Field Matches Model
Herpetofauna Diversity is Similar
Frog Abundance in High in RSCs
Herp Field Matches Model
Fish Abundance but not Diversity Increases with Time since RSC Construction

Age_1 = 1.9–4.3 yrs
Age_2 = 5.3–7.4 yrs
Age_3 = 8.9–16.2 yrs
Herp Abundance and Diversity Increases with Time since RSC construction
Herp Abundance takes 8 years to Increase after RSC construction.
Fish Diversity Increases with DO and Decreases with Conductivity
Herpetofauna is Not Reduced by Water Quality
RSC Fish Communities Only Partially Approach High Quality

**LSS reference (baseline condition)**
- RSC
- HSS
- HSW

**Fish community metric value**
- Abundance
- Richness
- Diversity
- FIBI

**Herp. community metric value**
- Abundance
- Richness
- Diversity
Conclusions

1. Overall, fish and herp communities in RSCs are similar to low-quality streams, not to high-quality streams.

2. Fish Index of Biotic Integrity (IBI) was lower in RSCs than high-quality streams, with RSCs non-significantly higher than low-quality streams.

3. Fish and frog abundance in RSCs are higher than both low- and high-quality streams.

4. RSCs recreate stream-wetland structure (such as width and depth) typical of high-order streams in reaches that are low-order, but reference DO, conductivity, and flow levels are not attained.

5. Vertebrate uplift in RSCs appears constrained by continuing poor water quality, but may improve as RSCs mature.

6. Refinements to RSC designs (and stream restoration in general) may improve vertebrate trajectories, but our understanding of ecological states may also limit uplift.
Translation Slides:

Vertebrate Community Trajectories in Regenerative Stream Conveyances (RSCs)

Study by: Mark Southerland et al.

Translation by PMAC member: Chris Ruck, Ecologist
Watershed Assessment Branch
Stormwater Planning Division

Department of Public Works and Environmental Services
Working for You!

A Fairfax County, VA, publication
June 2022
What are the key take-home points?

Two questions:

B.4. Biological community restoration
D.10. Resource trade-offs based upon the type of restoration

• Fish assemblage in RSCs
  – Low diversity & low FIBI scores
  – Affected by water quality (DO and Conductance)
  – Fish abundance increases over time (not diversity or FIBI)

• Herp community in RSCs
  – Herp abundance and diversity increase over time
  – Not affected by water quality (DO, Temp, or Conductance)
  – Take 8-10 years post construction to show community maturation
What does this mean for me?

• As a practitioner
  – Increase pool size for increased numbers of fishes, but maintain sediment transport
  – Increase the amount and diversity of habitat, for biological lift
  – Look to high-quality stream-wetland complexes for designs and biological trajectories

• As a regulator
  – Acknowledge there may be urban/suburban thresholds that limit restorative improvements
  – Fundamentally, RSCs create different habitat/geomorphology from single thread channels
  – Would want to ensure 10+ years of monitoring to see changes to Herp community

• As a PMAC member
  – We may want to fund additional research comparing perennial RSCs with stream-wetland complexes
    and not single thread channels
  – Does landscape composition / water quality affect the assemblages more that the type of
    restoration?
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## Variation in RSCs

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<th>Fish fauna</th>
<th>Fish area metrics</th>
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- RSC 10 (Cowhide Branch to Weems Creek) is most taxonomically diverse with predators (pickerel), several functional groups, and salt tolerants (eel, killifish, stickleback, silverside, mummichog)
- RSC 1 (Bacon Ridge) is next most diverse with lentic character and centrarchids (bluegill, bluespotted sunfish, green sunfish, pumpkinseed)
PCA Clusters of RSCs

• Larger RSCs (1 and 10)
• RSCs more tree canopy and lower temperature (2, 3, 8, 6, and 4)
• RSCs with higher conductivity (9, 12, and 11)
• Variation in design, such as more of less pools and faster or slower flow
Detecting and understanding hydrologic change in developing watersheds: role of ESD

Pooled Monitoring Forum: June 16, 2022

Keith N. Eshleman
UMCES/AL
Outline

• Project objective/hypotheses
• Watersheds (description) and status of development in UTLP
• Project status/timeline
• Hydrologic monitoring, methods to address hypotheses, and preliminary results
  • Continuous stream gaging
  • Stormflow/baseflow sampling
  • Use of NEXRAD areal radar rainfall data (bias-corrected)
  • Paired-watershed analyses: storm event characteristics (pre-development and during-development comparisons)
  • Chemical hydrograph separation: new water contributing area (NWCA) concept
  • Unit hydrographs
  • EMC’s and pollutant load modeling
Paired watershed study (2019 – present)

- **Objective:** determine the spatially-aggregated effectiveness of stormwater BMP’s at the watershed scale (relative to a comparable “control” watershed with conventional stormwater management)
  - lower stormflow runoff
  - higher baseflow runoff
  - lower runoff peaks
  - lower storm runoff coefficients
  - longer centroid lag times
  - more attenuated unit-graphs
  - lower EMC’s and EL’s of N and P

Plumtree Branch (PLBR; area = 2.15 km²; IA = 10.6%)
  - “Developed” watershed: conventional SWM

Unnamed Tributary to Little Patuxent River (UTLP; area = 0.80 km²; IA = 6.8%)
  - “Developing” watershed: green stormwater infrastructure (GSI)/environmentally-sensitive design (ESD)

**Common monitoring equipment:**
- Stilling well (w/intake)/instrument shelter housing digital water level recorder
- In Situ AquaTroll 500 and “tube” for transmitting data to HydroVu website
- Programmable sequential stormwater sampler
- Two unheated tipping bucket rain gauges (located nearby)
CBT Project Status (2019-present)

• Overview
  – Grant awarded (August 2019)
  – Site selection/permitting (fall 2019; winter 2020)
  – PLBR (conventional SWM) instrumented November 2019
  – UTLP (w/ESD) instrumented March 2020

• Slowdown in pace of residential development in the UTLP watershed due in part to COVID forced us to modify the project objectives

• Focus on teasing out impacts of ESD implementation over time: detecting hydrologic change

• Documenting changes in hydrology/water quality during ESD implementation—with comparable data from an adjacent control watershed w/stable land use (rare dataset)

• Timeline: NCE to extend monitoring through WY’23
UTLP Watershed (2020 imagery)
UTLP Watershed Development status (Spring 2022): imagery from April 2020
CBT Project Status (2019-present)

- Hydrologic/water quality monitoring
  - Solid rating curves (w/minor shifts); complete 5-min stage/discharge records; hourly rainfall data (2 stations); annual water balances
  - Sterling VA NEXRAD Level III data used to estimate areal rainfall
  - Monthly baseflow concentrations (both sites)
  - 44 major stormflow-producing events characterized: 41 common events (17 with intensive water quality sampling)
    - Max. one-hour rainfall mostly < 1-year R.I.
    - June 20, 2020: one-hour rainfall of ~2.3” at UTLP (5-year R.I.)
    - June 22, 2020: one-hour rainfall of ~2.5” at both sites (20-year R.I.)
  - 5-min in situ conductivity, turbidity, temperature, water level data
  - 800+ discrete water samples analyzed for TSS, TN, TP, nutrients, major anions, SC, etc. (“pre” and “during” phases of GSI implementation at UTLP) of 1,050 proposed
Rating Curves/Water Balances

Plumtree Branch Rating Curve (composite)

\[ y = 1.6051x + 0.637 \]
\[ R^2 = 0.9928 \]

UTLP Rating Curve

\[ y = 3.9046x + 1.5076 \]
\[ R^2 = 0.99 \]

\[ y = 6.1518x + 3.2296 \]
\[ R^2 = 0.97 \]

Annual Runoff

*partial water year data (3/10/20 – 9/30/20)

**partial water year data (10/1/21 – 5/31/22)

- Highly flashy streams gaged over 3 orders of magnitude
- Highest discharge measurements exceeded <0.05% of the time!
- PLBR annual runoff agrees well with data from nearby USGS watersheds
- UTLP runoff is much lower (esp. in WY’21)
Hydrographs/runoff anomaly

- Similar hydrographs: area-normalized mean daily discharge (log scale)
- Slightly greater range at PLBR mostly due to lower summer baseflows
- Large UTLP runoff anomaly of -22 cm in WY’21
Storm Event Runoff

One way ANCOVA: $p < 0.001$

One way ANCOVA: $p = 0.92$ (NS)

- Paired data analysis (ANCOVA) with/without 7 “outlier” events
- Statistically significant difference in adjusted mean event runoff (UTLP < PLBR) in WY’21 and ‘22 compared to the “pre”-development period ONLY with “outliers” removed
Storm Event Runoff Ratio

One way ANCOVA: $p = 0.37$ (NS)

One way ANCOVA: $p = 0.03$

• Same statistical result as for storm event runoff
Peak Mean Hourly Runoff

One way ANCOVA:  $p = 0.86$ (NS)

- No statistically significant difference in adjusted means even with “outlier” events removed
New Water Contributing Areas (NWCA’s)

One way ANCOVA:  $p < 0.01$

• Same statistically significant difference as for event runoff and runoff ratio (UTLP < PLBR during development)
• %NWCA’s often much larger than %IA’s
Unit Hydrographs (UH’s)

- PLBR unit-graph is double-peaked: two different sources of overland flow ("new" water)?
- Area-normalized unit-graphs based on field data: PLBR is more attenuated than UTLP
- Greater attenuation than synthetic hydrograph for 7/30/2016 event from HEC-RAS

*From 2017 Valley Mede Drainage Study: HEC-RAS
Insufficient no. of events for “pre” period to use ANCOVA
Statistically significant differences in median TSS, TN, and nitrate-N between watersheds
N Load Modeling

Event V

Event P

PLBR TN Models

Nash-Sutcliffe Efficiency

Bias (%)
P Load Modeling

Event K

TP Load (g)

Event F

PLBR TP Models

Nash-Sutcliffe Efficiency

Bias (%)

Base Model

Storm Model
Summary of *(Tentative!)* Findings

• Integration of conventional and newer field/analytical methods allowed us to detect and quantify some significant watershed-scale hydrologic changes apparently brought about through implementation of ESD/GSI including:
  - Reduction in total runoff
  - Reduction in storm event runoff
  - Reduction in new water contributing areas

• While we have observed *differences* between the watersheds, we have *not yet* detected any significant changes in:
  - Peak event runoff (tested)
  - Event mean pollutant concentrations (insufficient data)
  - Event pollutant loads (TBD)

• Are the observed changes *transient* in nature or will they, or other hydrologic signals, *persist* beyond the active development period?
Acknowledgments

• Chesapeake Bay Trust/Maryland DNR: sponsorship
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  ▪ Katie Kline
  ▪ Briana Rice
  ▪ Jim Garlitz
  ▪ Ev Demott
• Joel Bostic: GIS support; load modeling
• Neal Eshleman
• Elizabeth Eshleman
Translation Slides

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

Translation Slides by Ari Engelberg
What does this mean for me?

• The developing watershed (UTLP) produced less runoff during development than it did before development began. This result is more apparent for smaller runoff events than larger runoff events.
  • We don’t know why yet; possibly due to increased groundwater storage associated with ESD and the ESD being more effective during smaller rain events.

• So far, the paired watersheds have exhibited different hydrologic responses (e.g., PLBR double-peaked unit hydrograph). Still working out why. Event mean concentrations were also fairly different between watersheds (except for phosphorus).

• There has been considerable spatial variability in precipitation between the two adjacent catchments. Understanding these differences requires the use of spatially explicit precipitation data such as NEXRAD Level III to assess.
What does this mean for me?

What do I take from this if I am a practitioner:
• Need to account for the significant spatial variability in rainfall when monitoring or designing restoration projects.

What do I take from this if I am a regulator:
• Same as above regarding rainfall variability.
• Also, there seems to be a potential hydrologic signal from active development which can be detected at the watershed scale. More research is needed to discern the reason/implications of this.
  • Runoff anomaly associated with GSI implementation: temporary signal OR will it persist beyond the immediate construction phase?
Wet vs Dry Construction Research

• **WHO are we:** The Team - Ecosystem Planning and Restoration (EPR), Center for Watershed Protection (CWP), Ecosystem Services (ES), and Katrina Emery

• **WHAT are we doing:** conducting research on the difference in effects on water quality (turbidity) and total suspended sediment loads delivered downstream between stream restoration work “in the wet” (construction without diverting the stream) vs work “in the dry”

• **WHY we are doing this:** The overall goal of this research is to quantify turbidity and suspended sediment loads downstream of stream construction sites to inform regulatory decisions on stream construction requirements.
The study will evaluate three (3) stream restoration reaches, each study reach being approx. 1,000 feet in length.

Reach/site criteria includes:

- Similar hydrologic watershed and geomorphic characteristics
- 2nd or 3rd order streams
- Located in the Piedmont physiographic area
- Sufficient base flow rate to ensure that stream flow characteristics and sediment suspension mixing typical (continuous) during construction
- Similar stream restoration practices including type and number of structures, area of disturbance, etc. (we will make this determination).
Wet vs Dry Construction Research

• If you have a potential candidate site and would like to participate in this study, please contact Erin Knauer at eknauer@eprusa.net