Quantifying the cumulative effects of stream restoration and environmental site design on nitrate loads in nested urban watersheds using a high-frequency sensor network

Restoration Research Question Addressed:

What are the cumulative effects of watershed restoration activities within a watershed?

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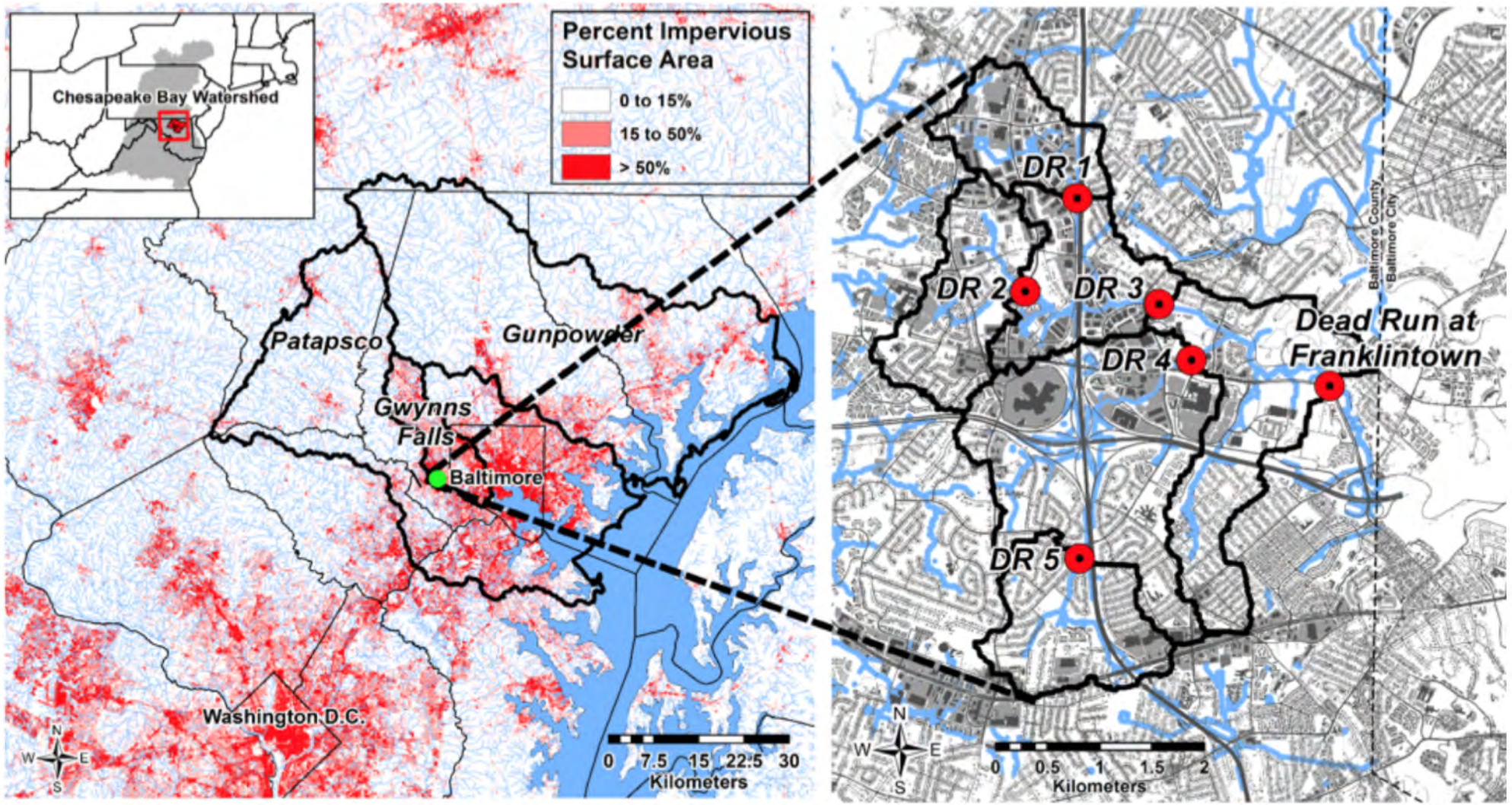
Research question and expected findings

- ***What are the cumulative effects of watershed restoration activities within a watershed?***
- We expected to find that
  - Nitrate loads are reduced by a restored stream reach.
  - Distributed stormwater management reduces peak storm flow at the small watershed scale.

Part 1
How are nitrate loads reduced across a restored stream reach?

Dead Run watershed study area

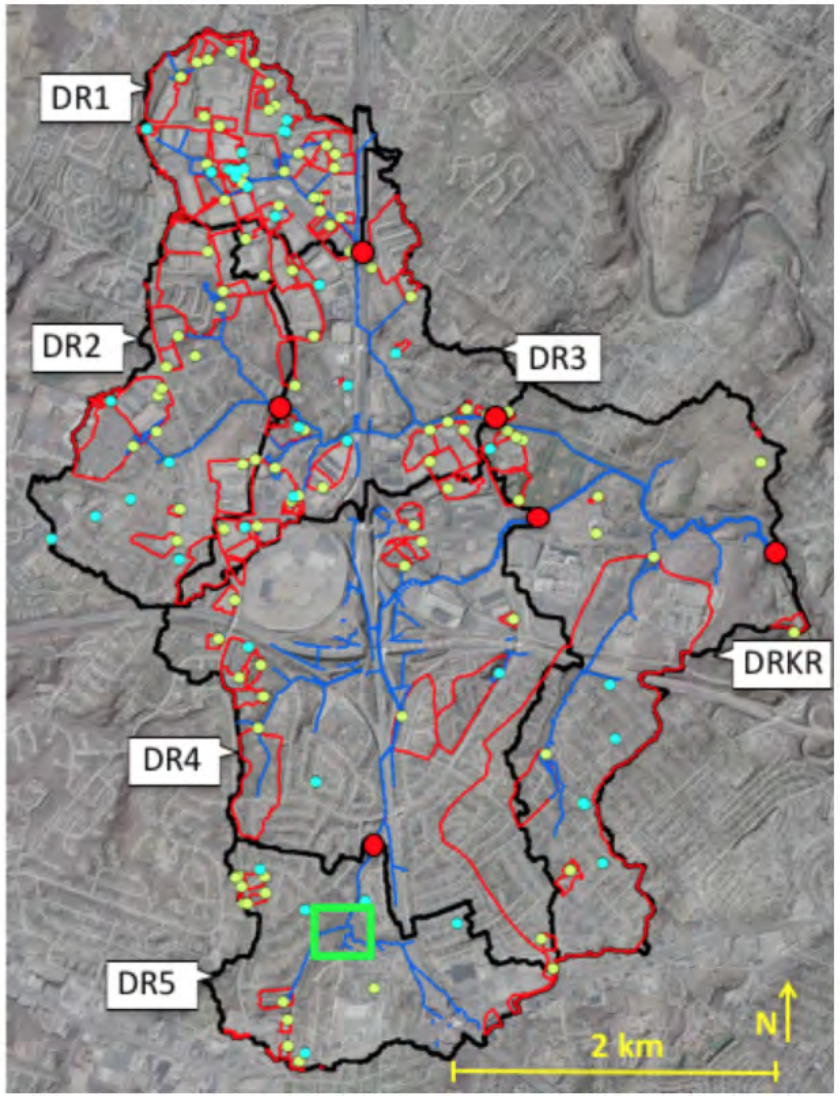


Stream restoration in headwaters of Dead Run, 2017-2018

- Stream restoration was originally designed for stream stabilization and to protect infrastructure.
- Plans were revised to include installation of a wet pond with additional water quality credits.
- Nitrogen credits: stream restoration 60 kg TN/yr
  water quality pond 100 kg TN/yr
- The project was built in a watershed that was already highly instrumented.
- The project provided an opportunity to add instrumentation to assess effectiveness of restoration on N removal.

Before and after restoration

Extent of restoration; new sensor stations



Instrumentation installed

- Satlantic/Seabird SUNA
  Submersible Ultraviolet Nitrate Analyzer
  - Ultraviolet absorption spectroscopy
  - In-situ measurement of NO_3-N
  - Range: 0.007 - 28 mg N/L
  - Precision: 0.028 mg N/L
  - Accuracy: ~ +/- 10% of reading
- Onset Hobo U20-001-04 water level loggers
- Blue Siren ultrasonic depth sensors & microvelocity acoustic doppler sensors

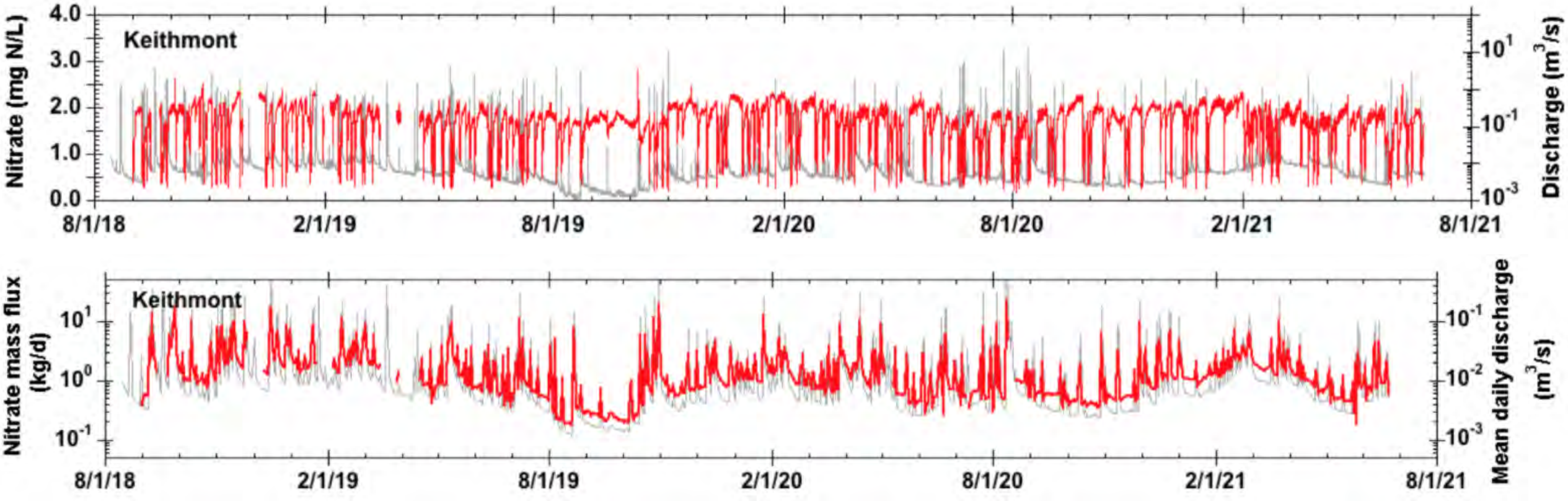
Example instrumentation deployment: stream

Example instrumentation deployment: stream

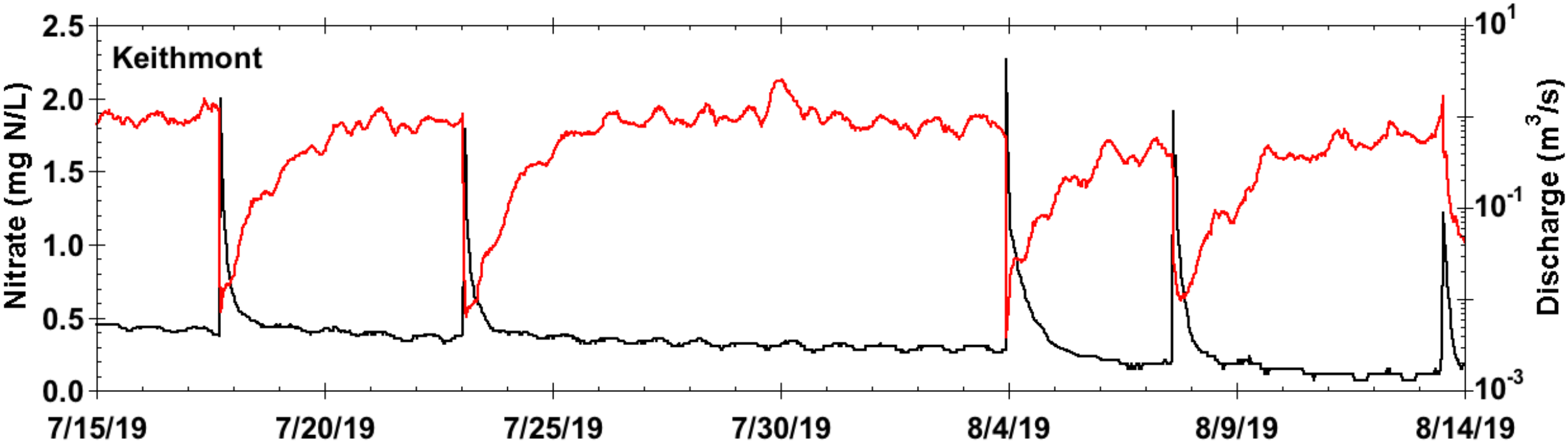
Example instrumentation deployment: pipe

Example instrumentation deployment: pipe

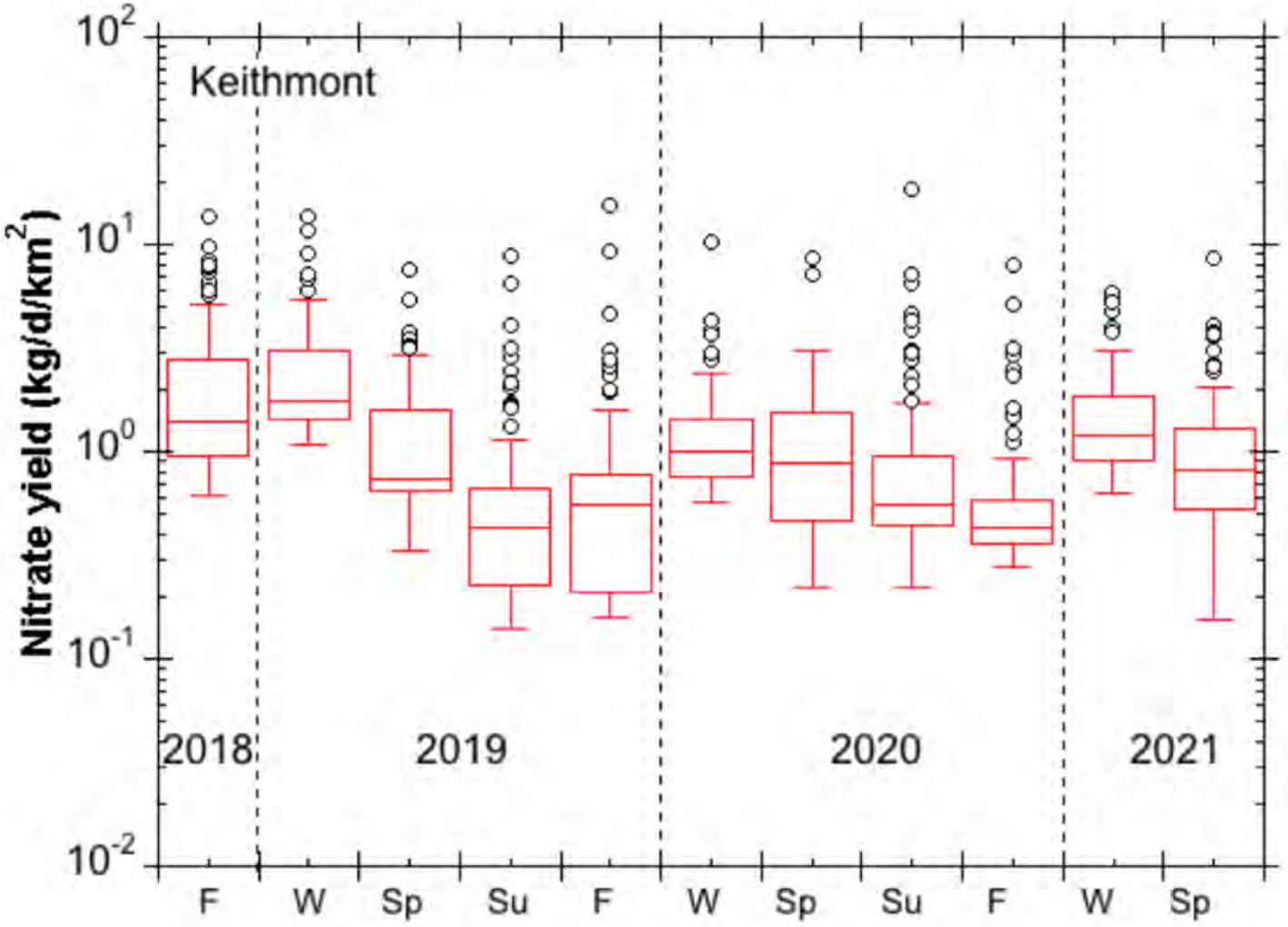
Sensors provide high-frequency nitrate & discharge data for calculating loads.



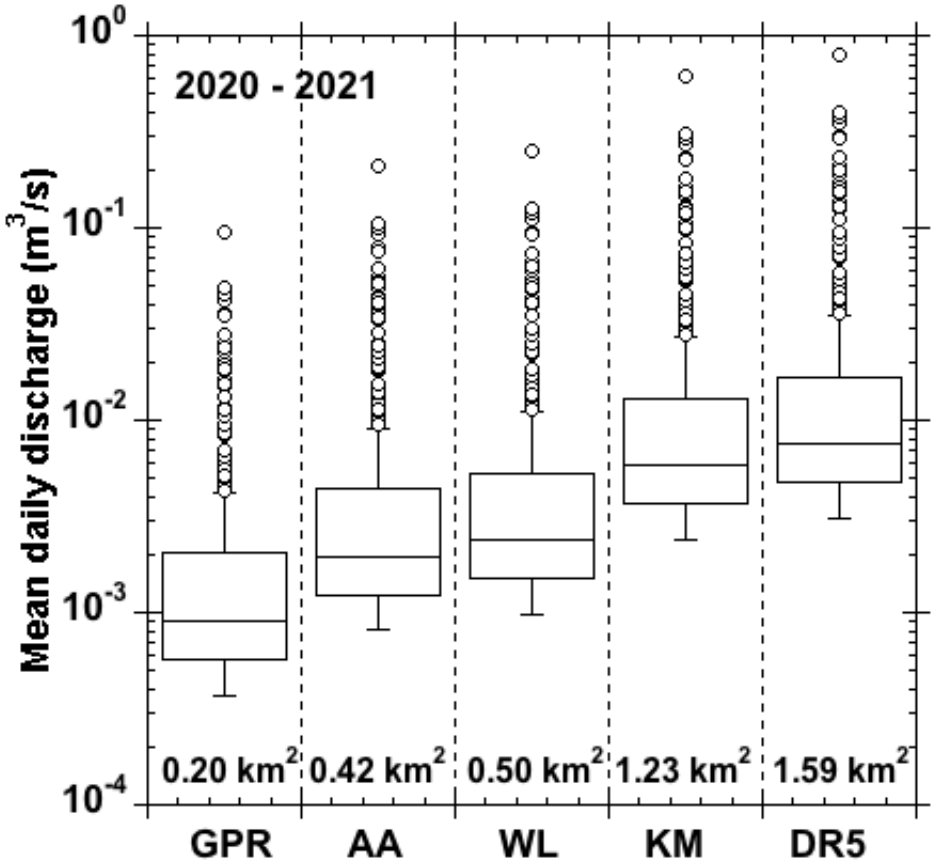
High-frequency data illustrates process details.

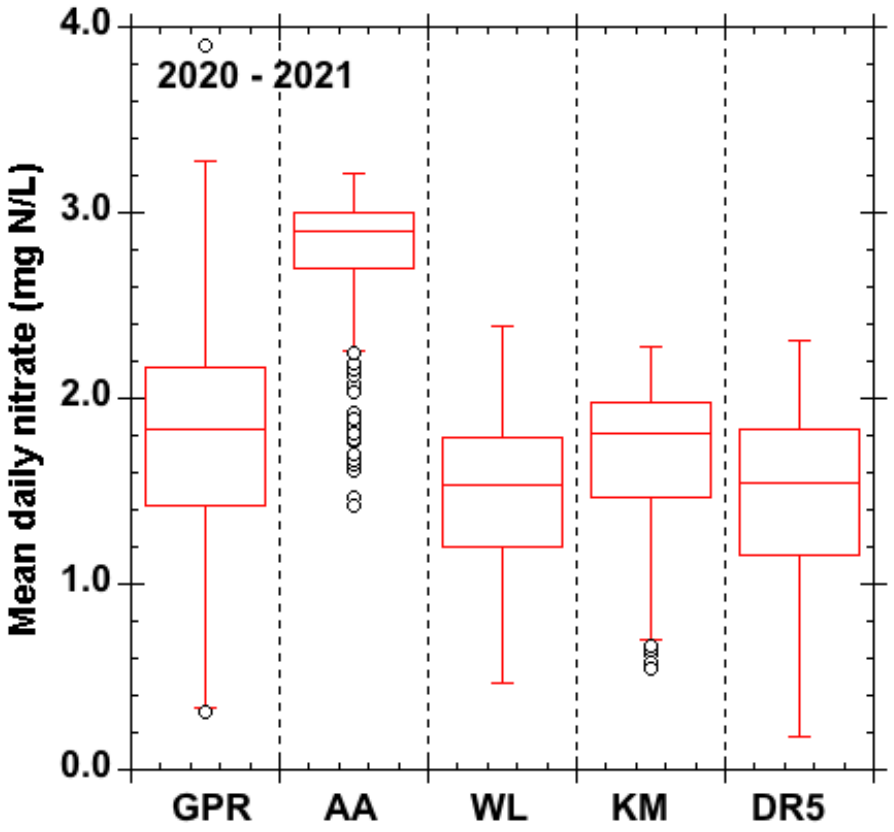


Seasonal and interannual variability of nitrate yield can be quantified.



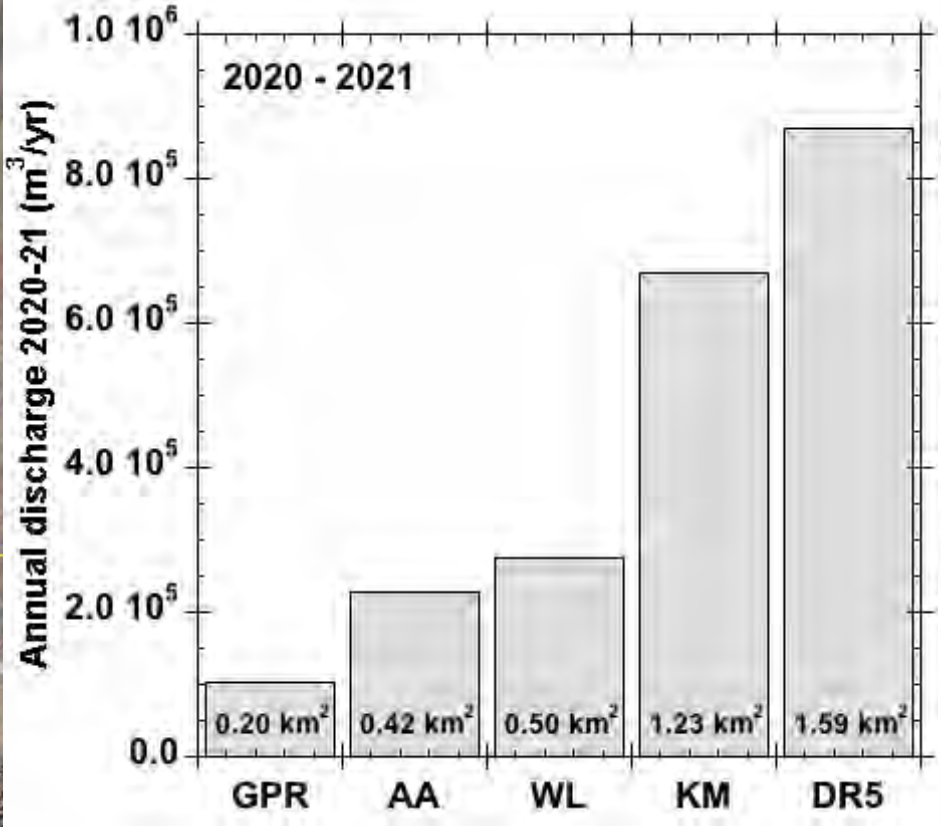
Variability in mean daily concentration across stations can be calculated.



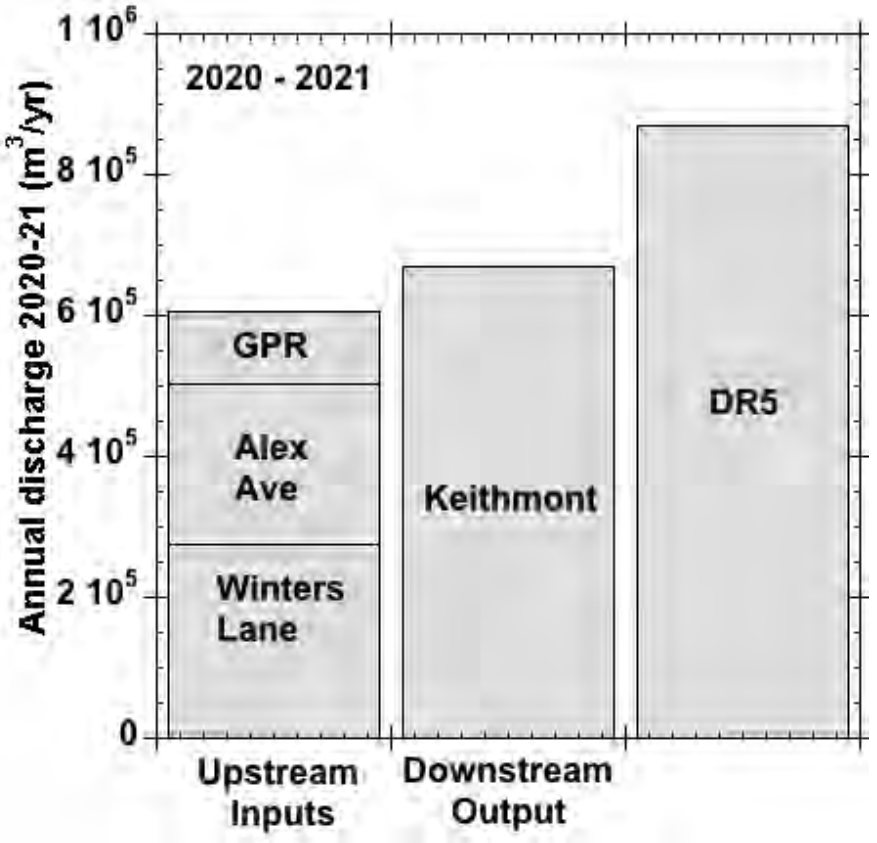


Mass balance of restored reach can be estimated.

Annual discharge

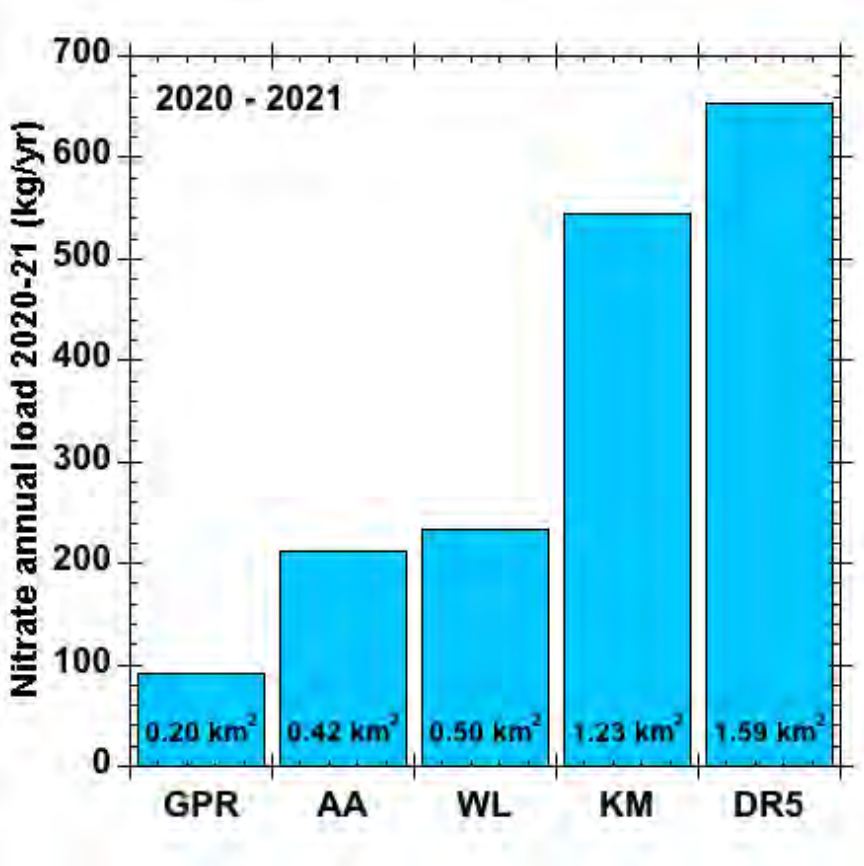


Inputs vs output

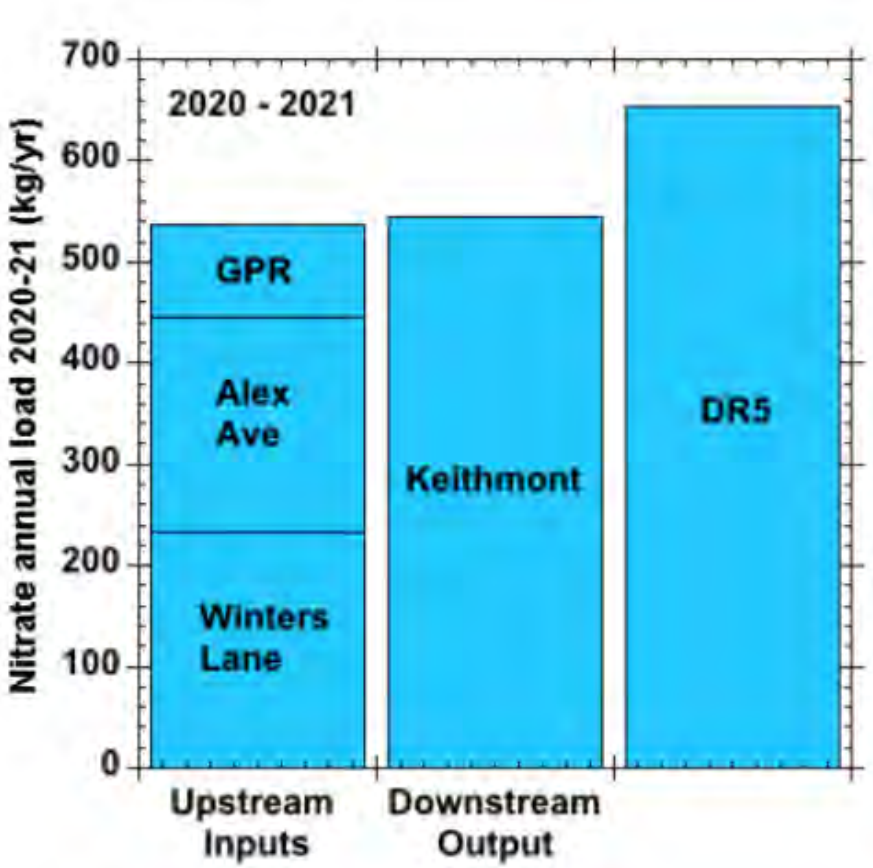


Mass balance of restored reach can be estimated.

Annual nitrate load



Inputs vs output



Part 2
How does distributed stormwater management reduce peak storm flow at the small watershed scale?

Hydrological Processes

RESEARCH ARTICLE

Assessing urban rainfall-runoff response to stormwater management extent

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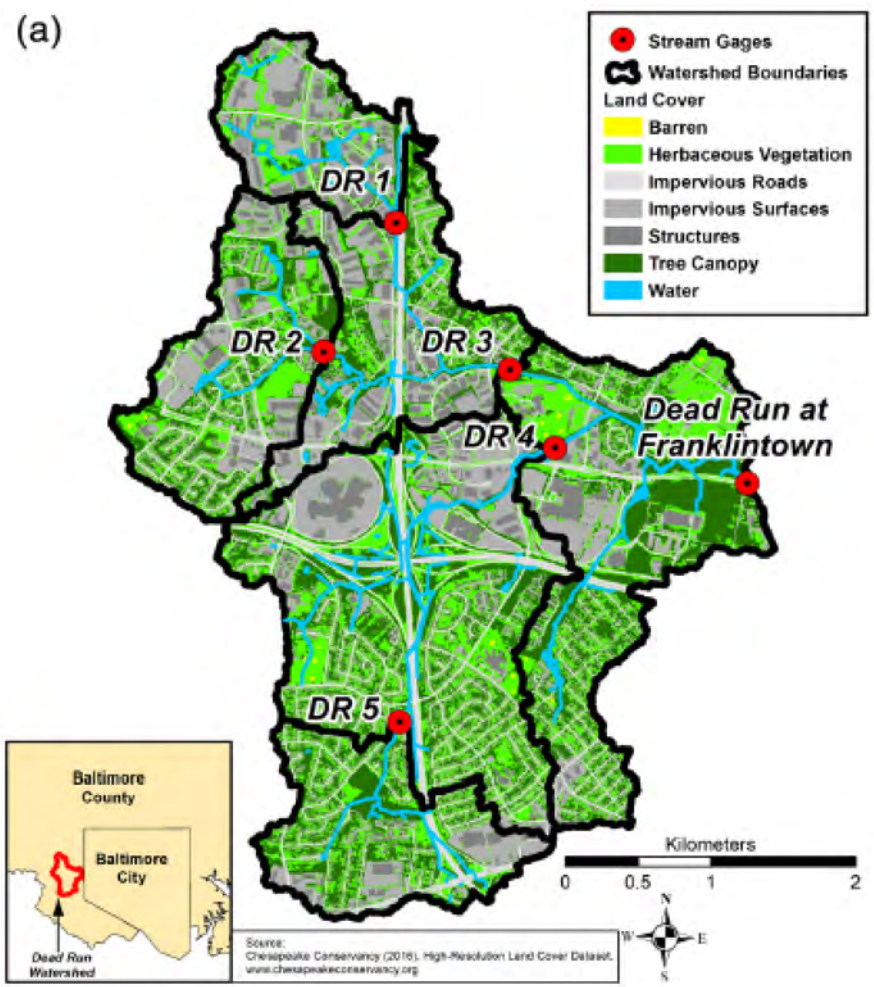
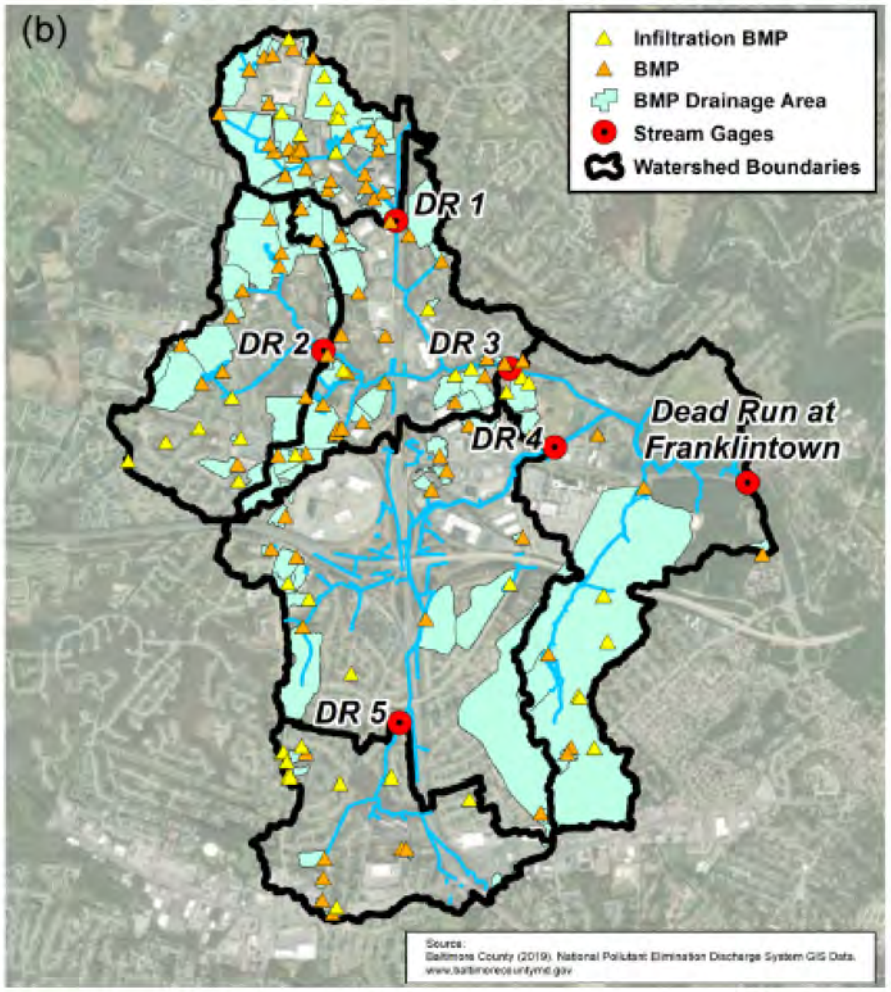
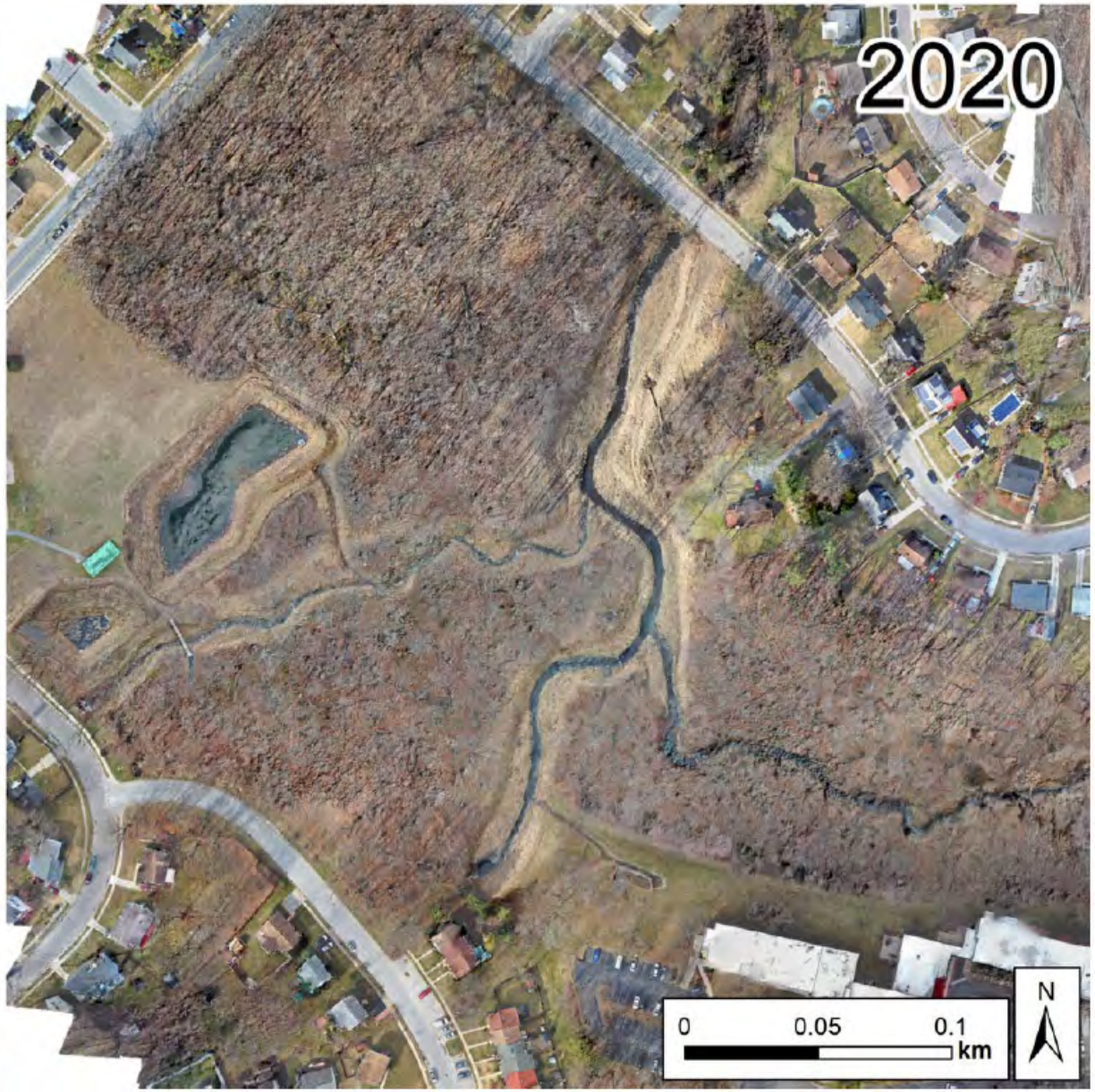
Dead Run land cover and areas draining to SWM

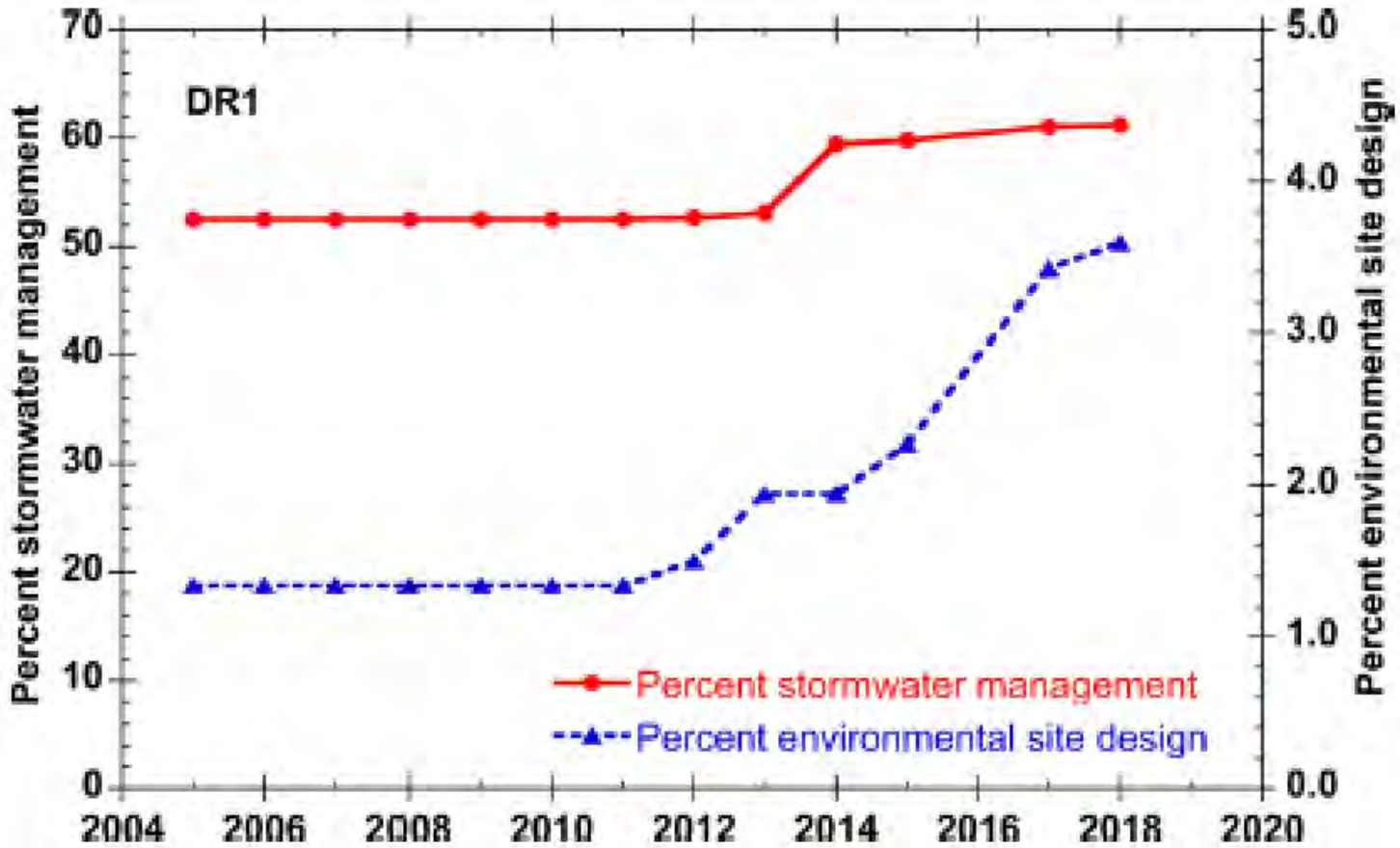




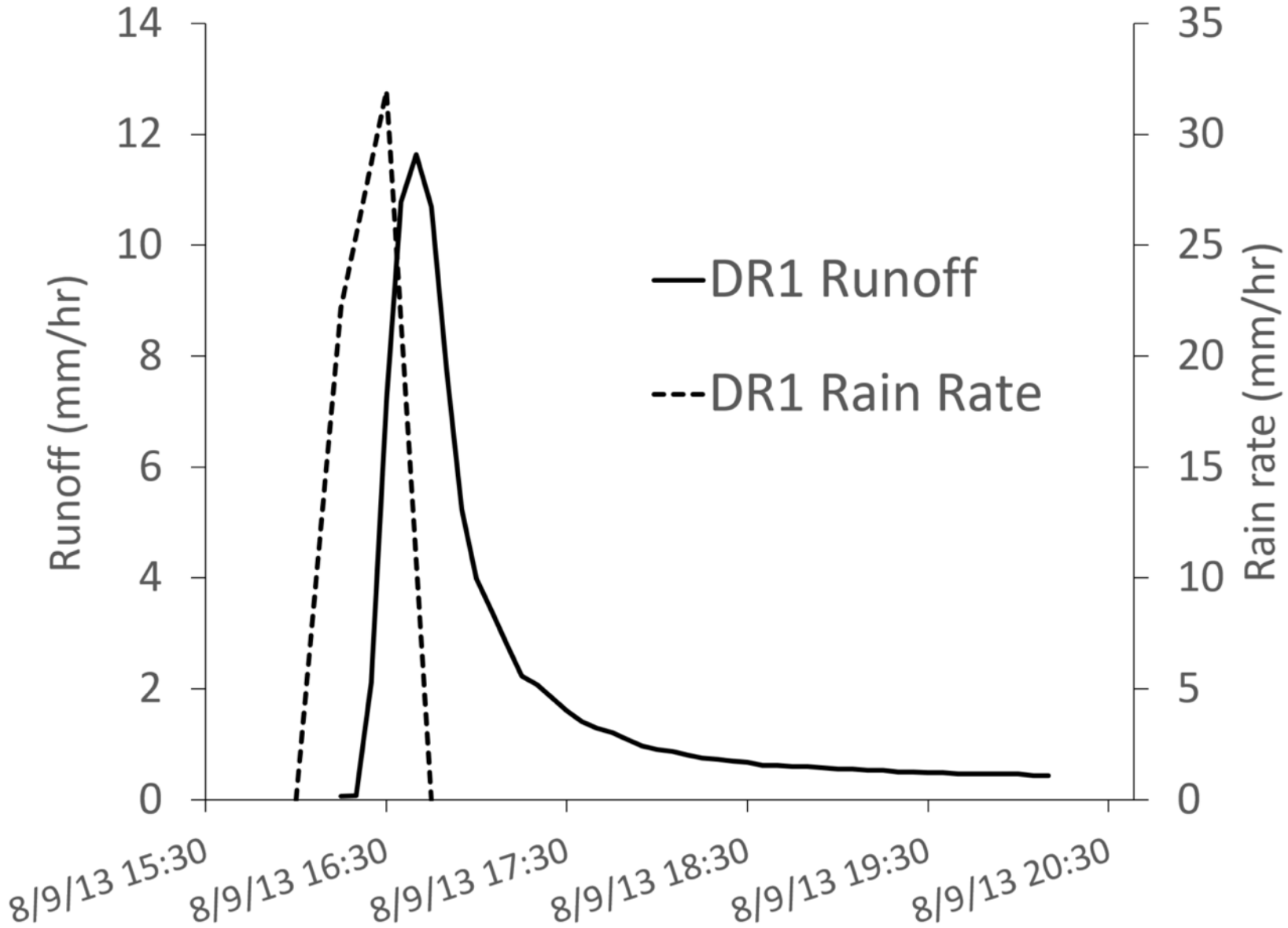
DR5 before and after restoration



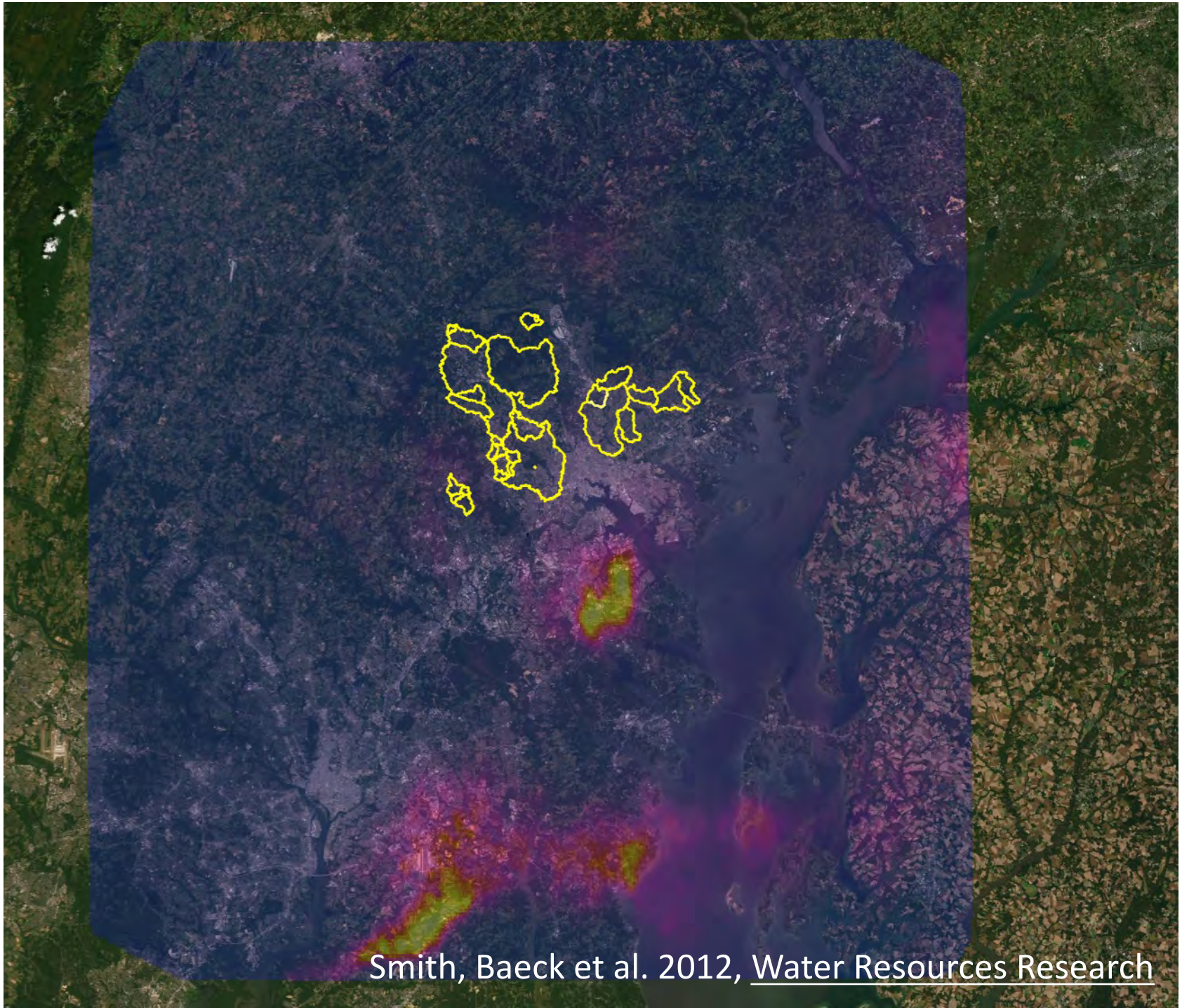
DR1 SWM and ESD features, 2004-2018



Example pulse rainfall event with runoff response



Long-term radar rainfall data set

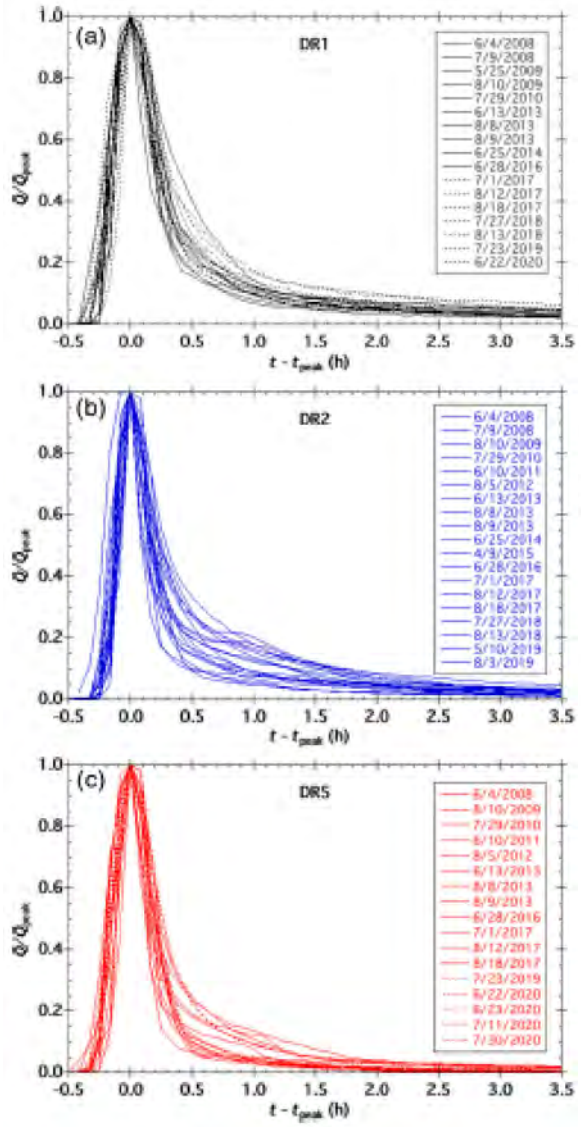


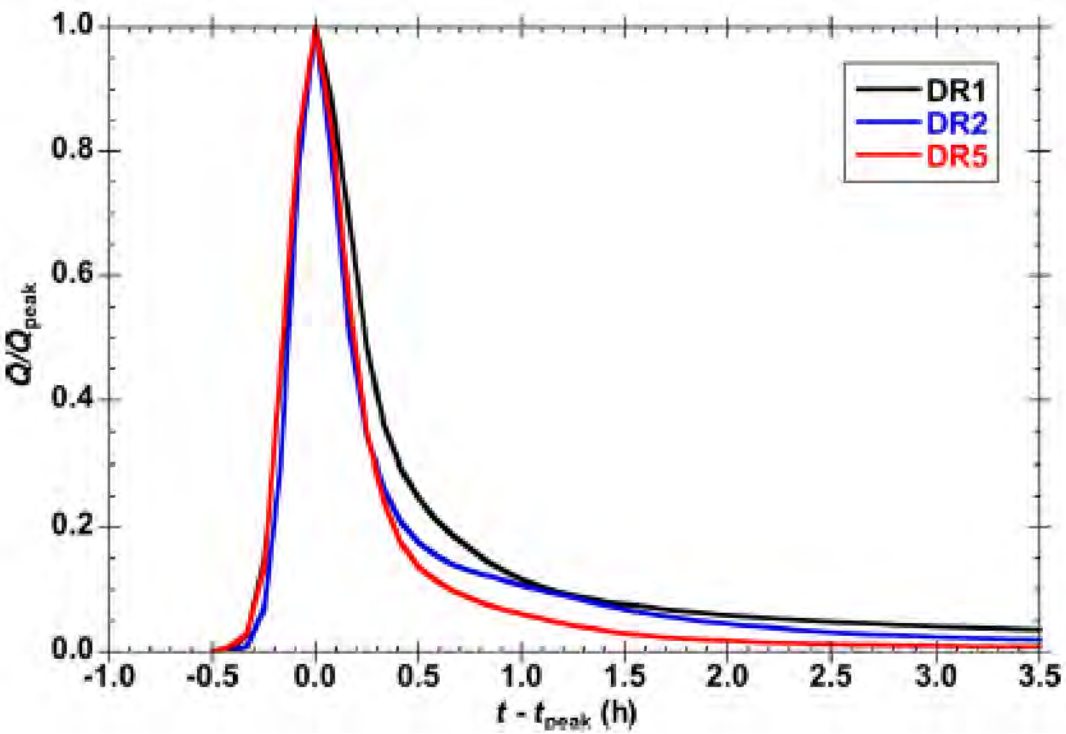
Comparison of pulse hydrographs 2008-2020

DR1
61.1% drainage
to SWM

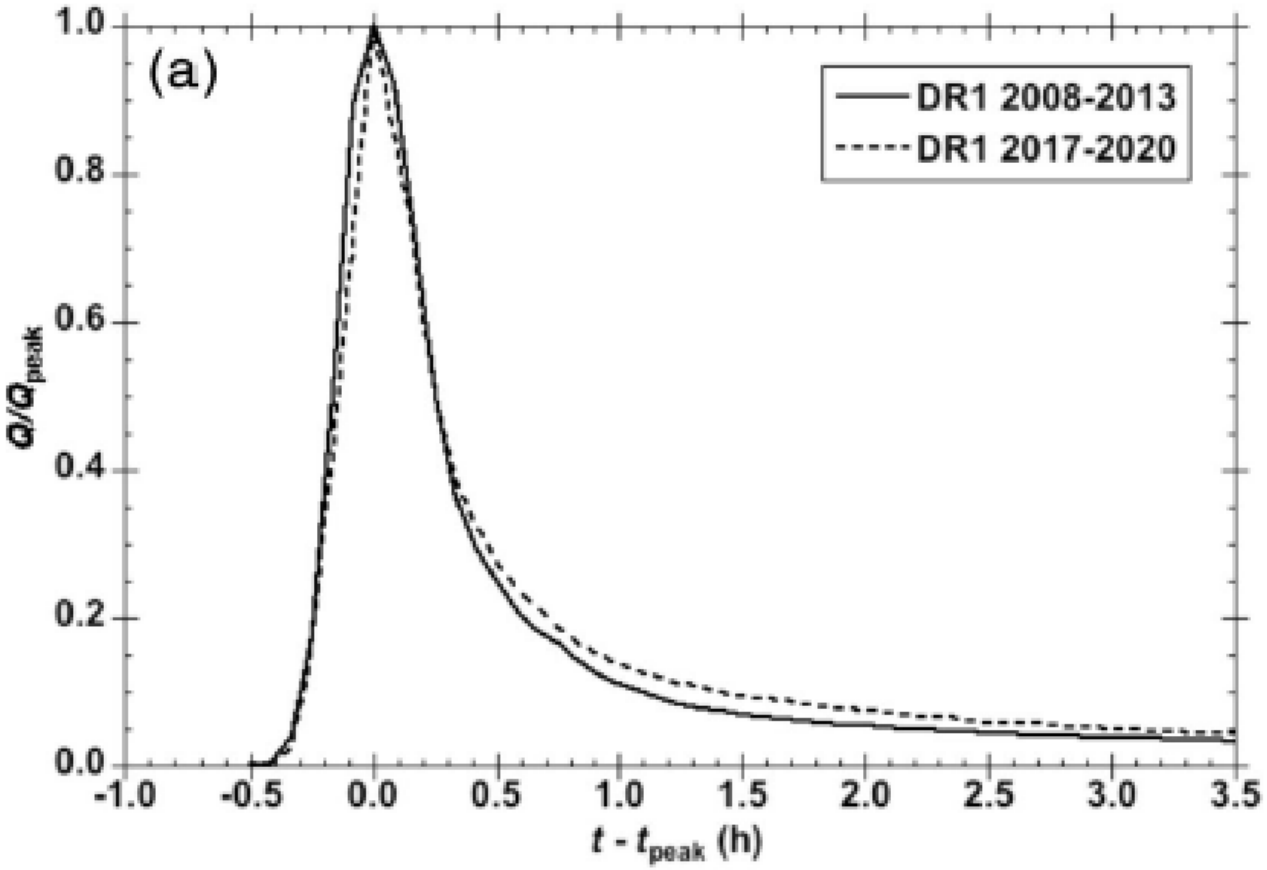
DR2
33.0% drainage
to SWM

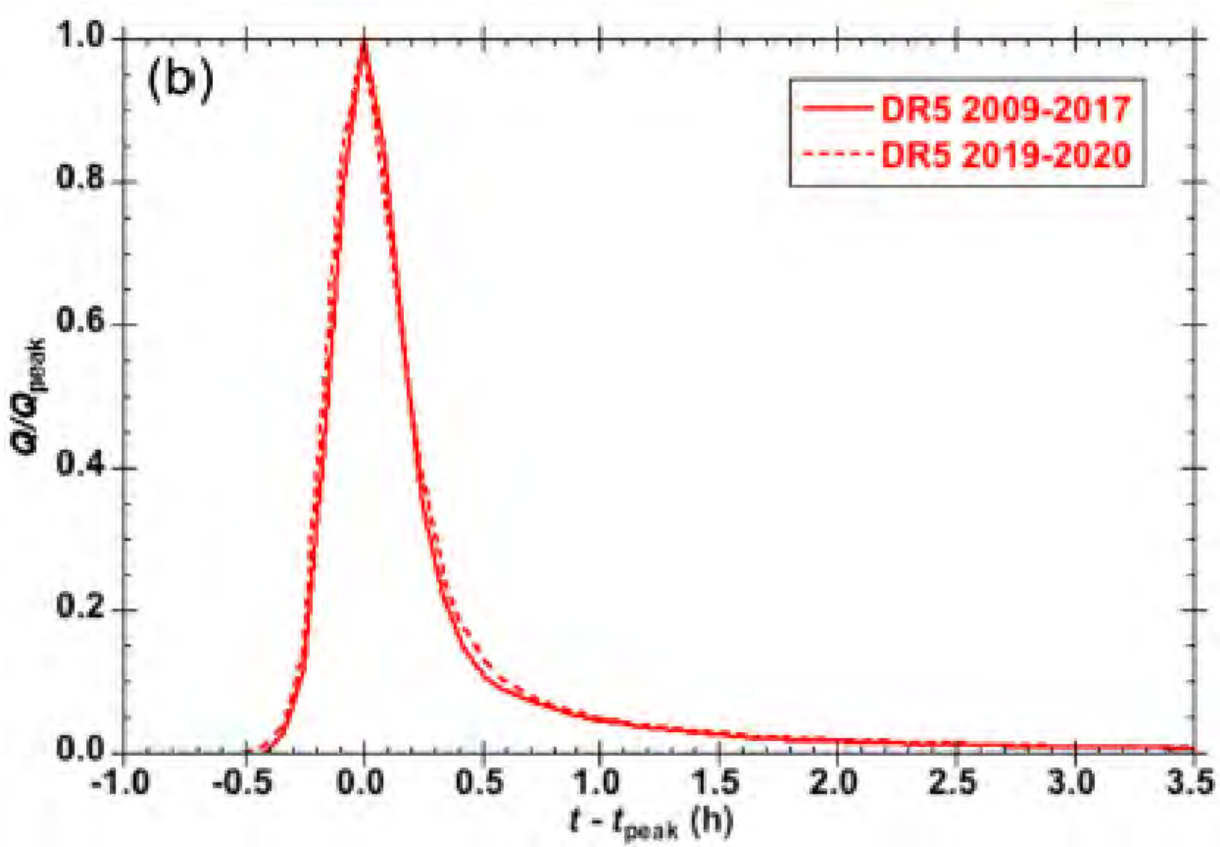
DR5
4.5% drainage
to SWM





DR1 before/after ESD; DR5 before/after restoration

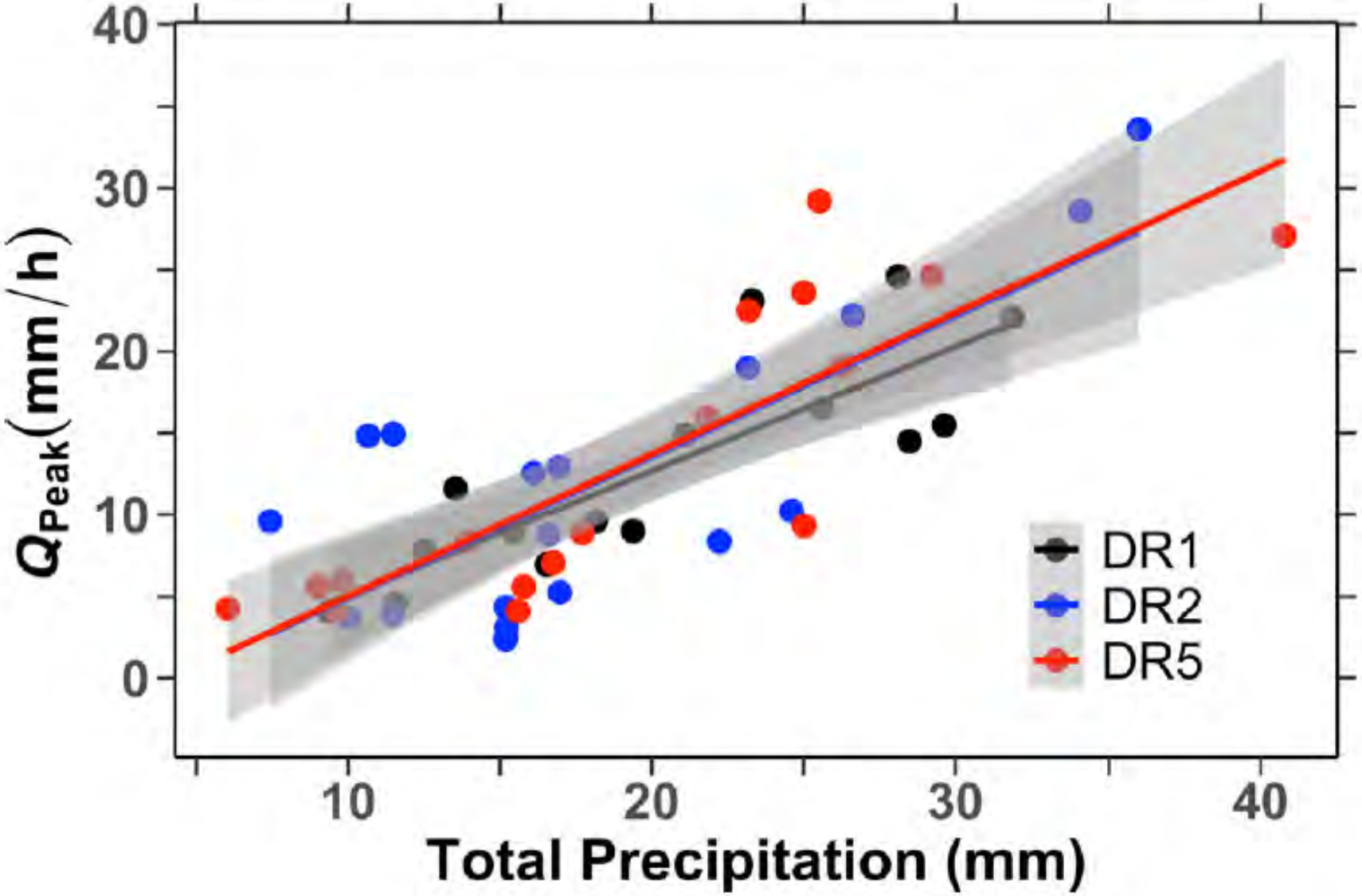




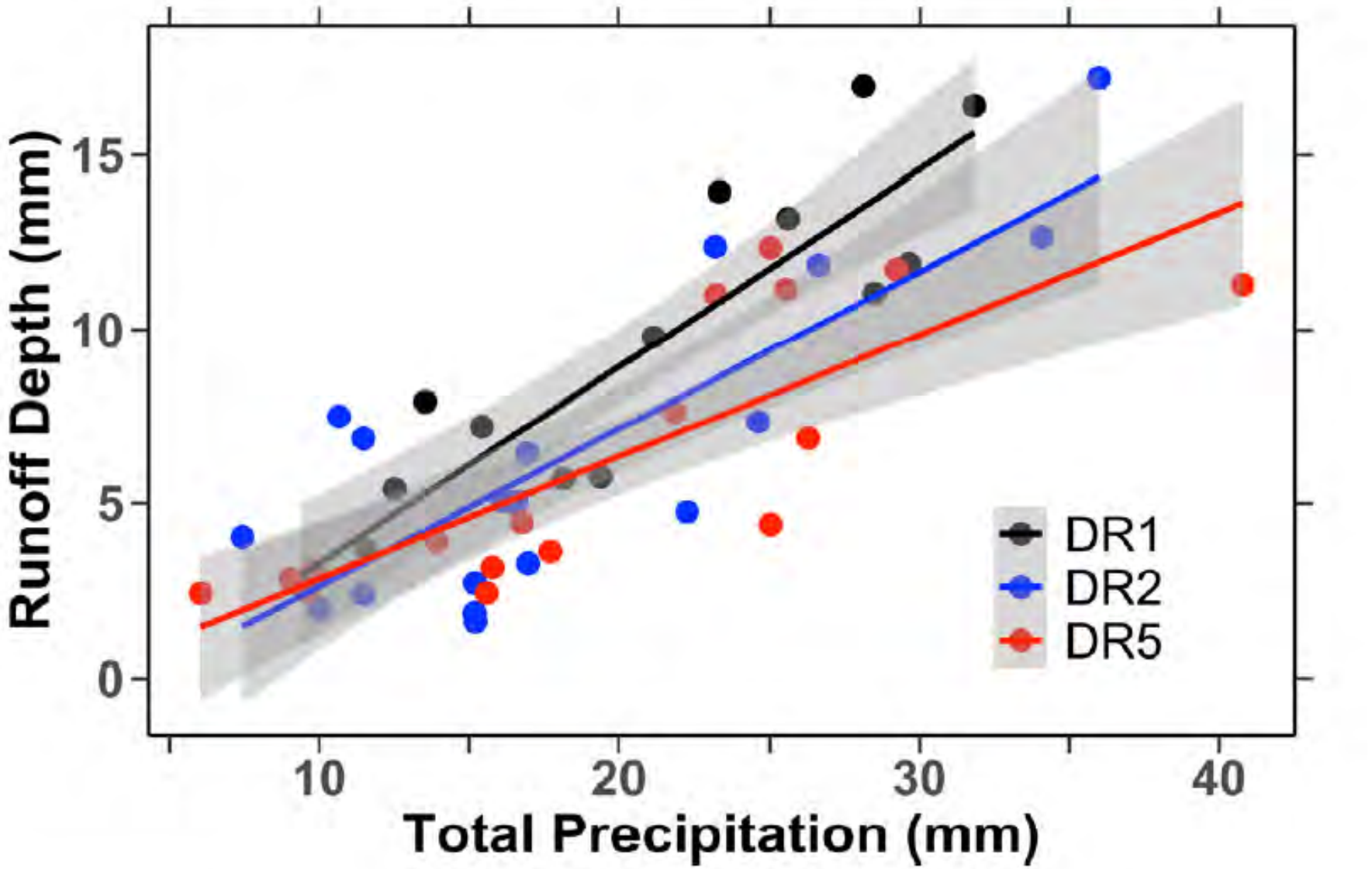
Watershed properties for headwater tributaries

Watershed	Drainage area (km^2)	% Impervious cover	% Drainage to SWM	Peak runoff intensity, median (mm/h)	Runoff ratio, median
DR1	1.19	67.0	61.1	9.6	0.40
DR2	1.92	49.1	33.0	9.9	0.31
DR5	1.63	45.9	2.7	8.9	0.28

Analysis of peak runoff response as a function of storm-total precipitation



Analysis of runoff depth as a function of storm-total precipitation



Summary: Part 1, Nitrate

- High-frequency data illustrates process details.
- Seasonal and interannual variability of nitrate concentrations, loads, and yields can be quantified across nested watersheds.
- For the restored stream reach instrumented, results so far (2020-21) do not demonstrate a reduction in nitrate load between upstream inputs and downstream output at Keithmont.

Summary: Part 2, Stormwater

- Comparison of composite hydrographs shows no difference in rising limb of hydrograph and time of peak flow, slightly longer recession curve for watersheds with more SWM.
- Comparison of composite hydrographs before and after restoration shows no change.
- Analysis of trends in peak runoff response to storm-total rainfall shows no significant difference for watersheds with large differences in SWM coverage.
- Analysis of runoff depth as a function of storm-total precipitation shows differences that are not statistically significant, with more runoff for the watershed with the highest SWM coverage and highest impervious cover.

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