

Detecting and understanding hydrologic change in developing watersheds: role of ESD

Pooled Monitoring Forum: June 16, 2022

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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%)

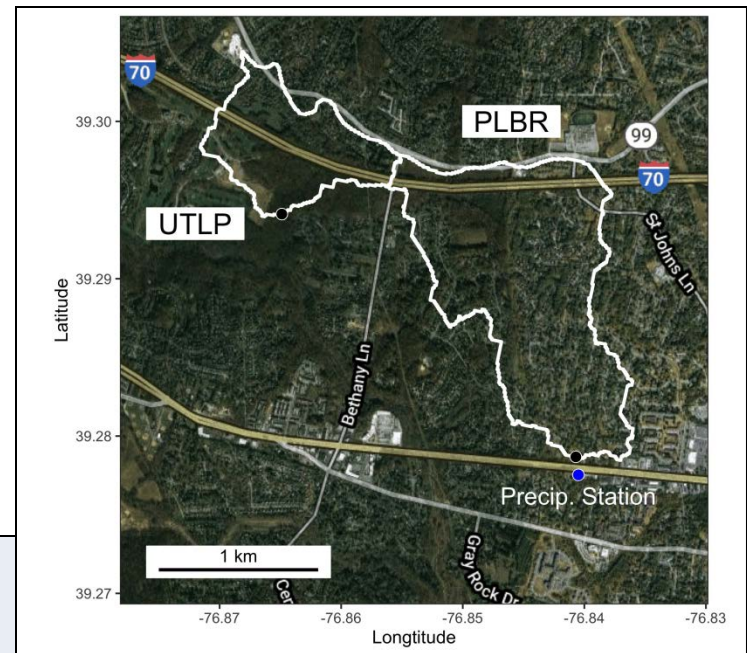
- “Developed” watershed: conventional SWM

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



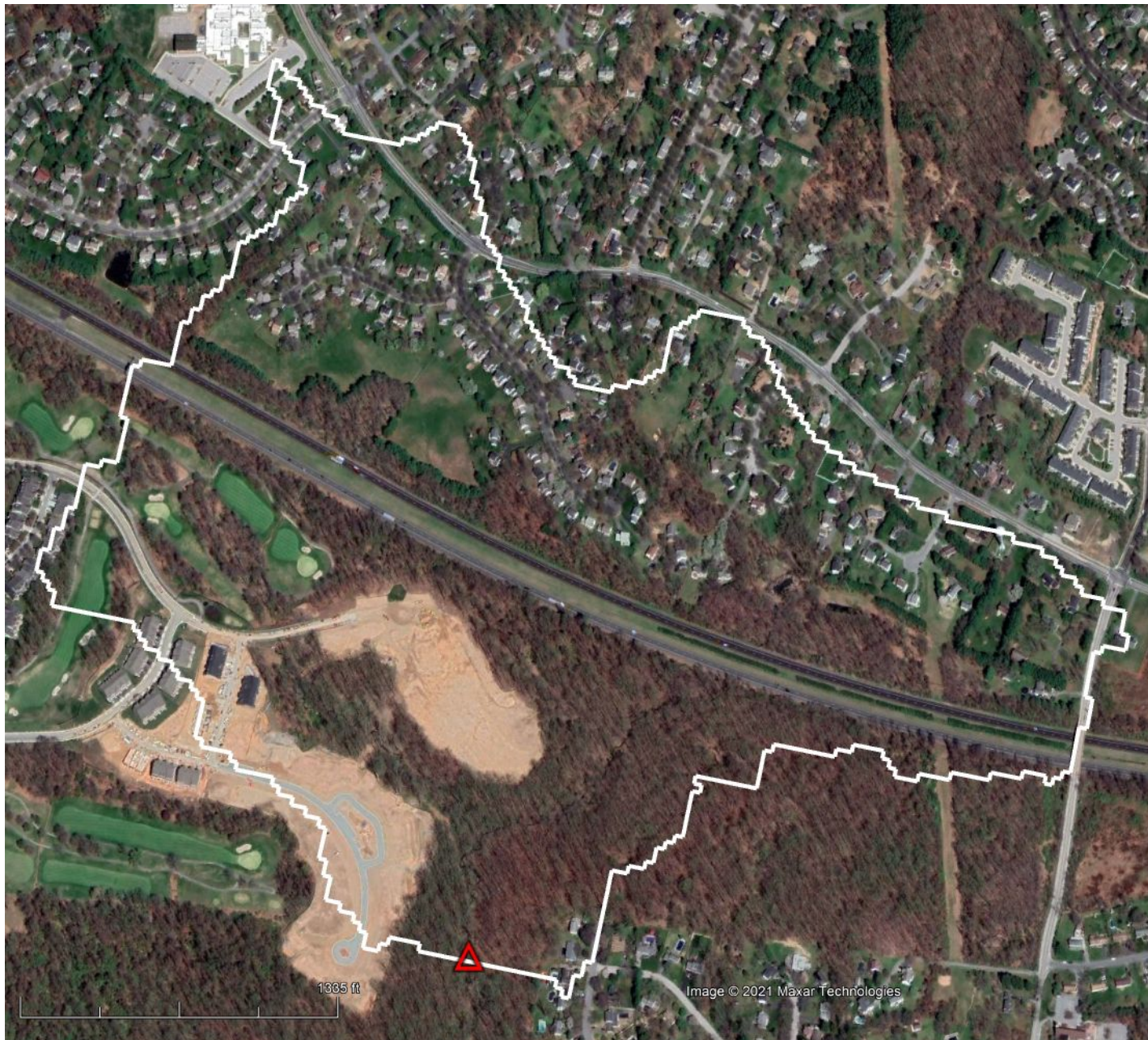
UTLP Watershed (2015 Google Earth imagery)



UTLP Watershed (2019 imagery)



UTLP Watershed (2020 imagery)



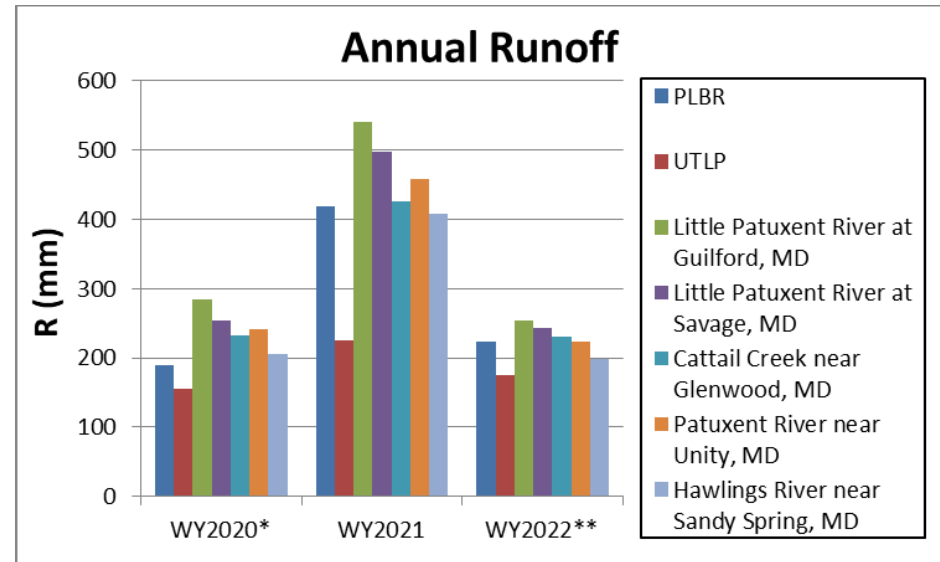
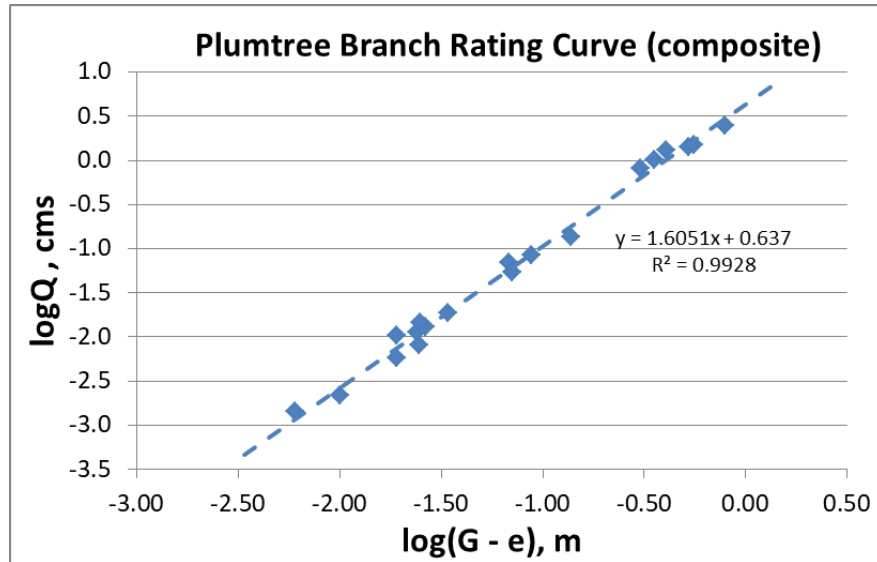
UTLP Watershed Development status (Spring 2022): imagery from April 2020



CBT Project Status (2019-present)

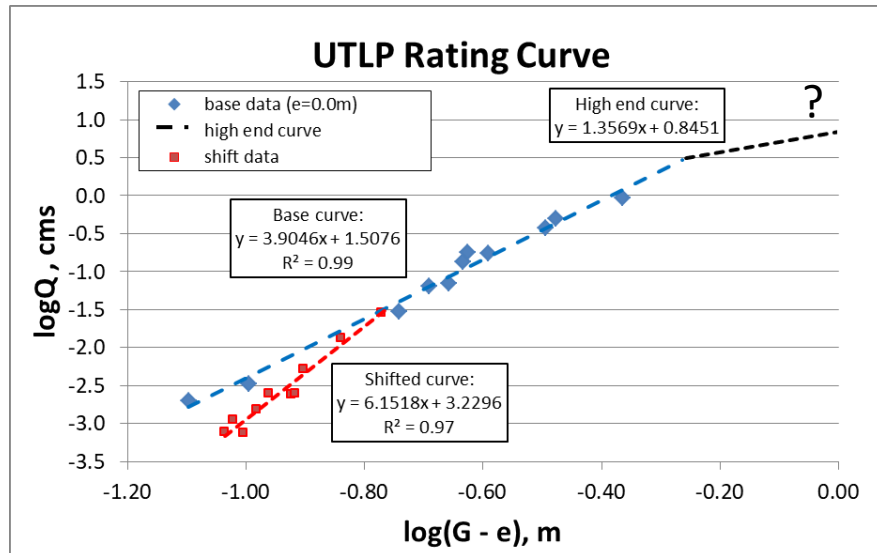
- Hydrologic/water quality monitoring
 - Solid rating curves (w/minor shifts); complete 5-min stage/discharge records; hourly rainfall data (2 stations); annual water balances
 - Sterling VA NEXRAD Level III data used to estimate areal rainfall
 - Monthly baseflow concentrations (both sites)
 - 44 major 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



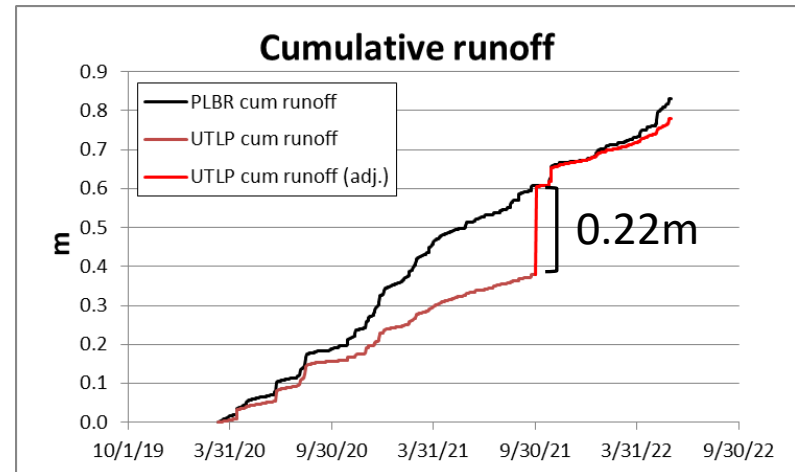
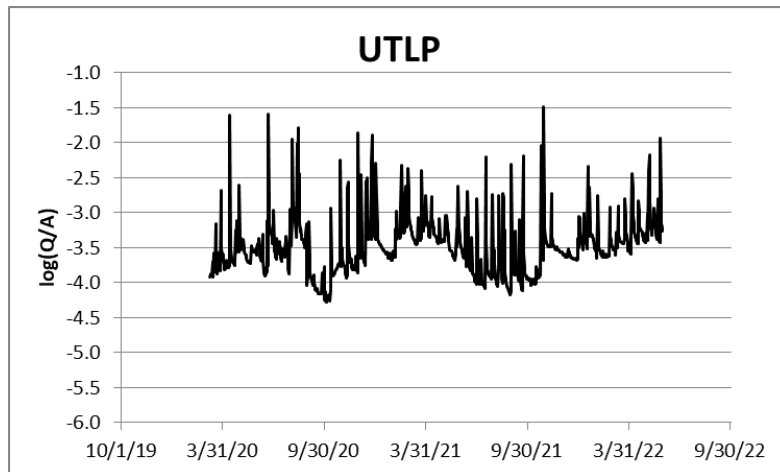
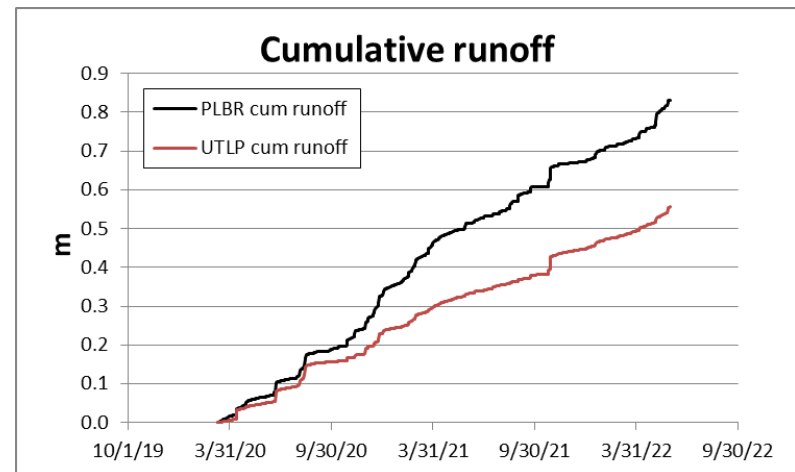
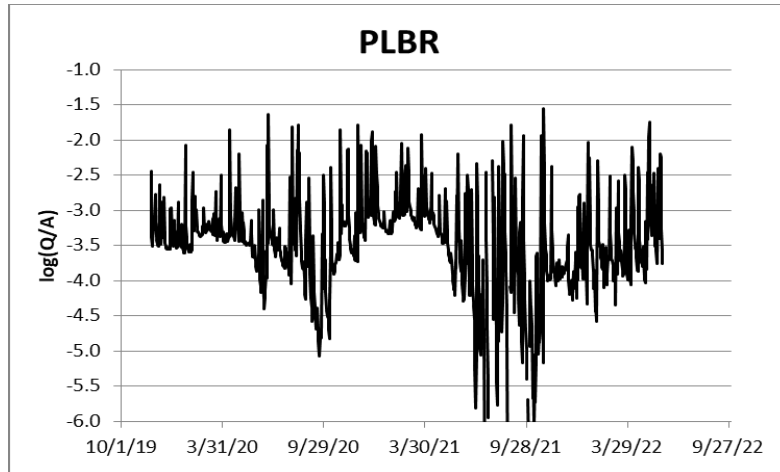
*partial water year data (3/10/20 – 9/30/20)

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



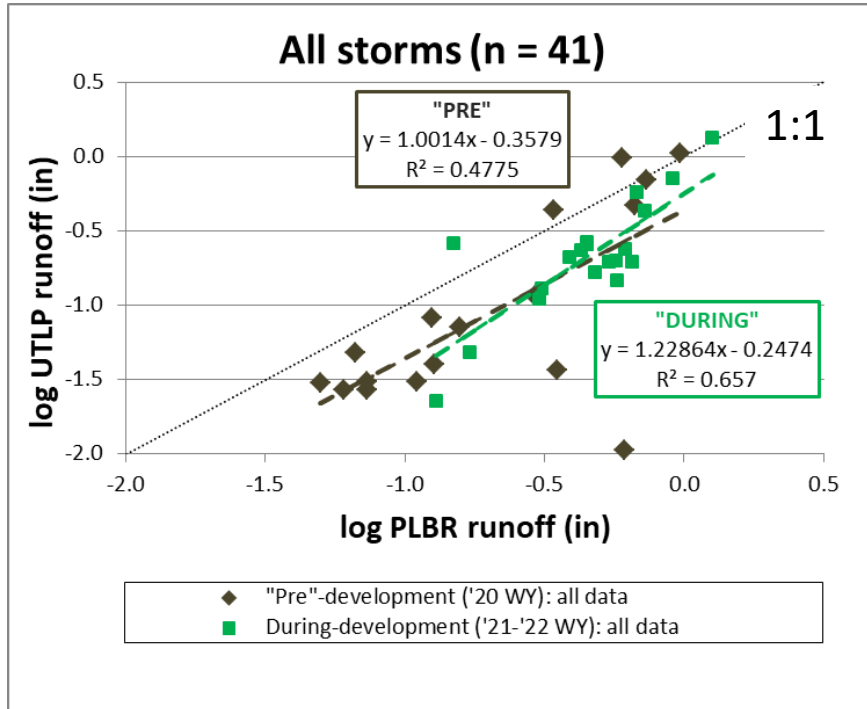
- Highly flashy streams gaged over 3 orders of magnitude
- Highest discharge measurements exceeded <0.05% of the time!
- PLBR annual runoff agrees well with data from nearby USGS watersheds
- UTLP runoff is much lower (esp. in WY'21)

Hydrographs/runoff anomaly

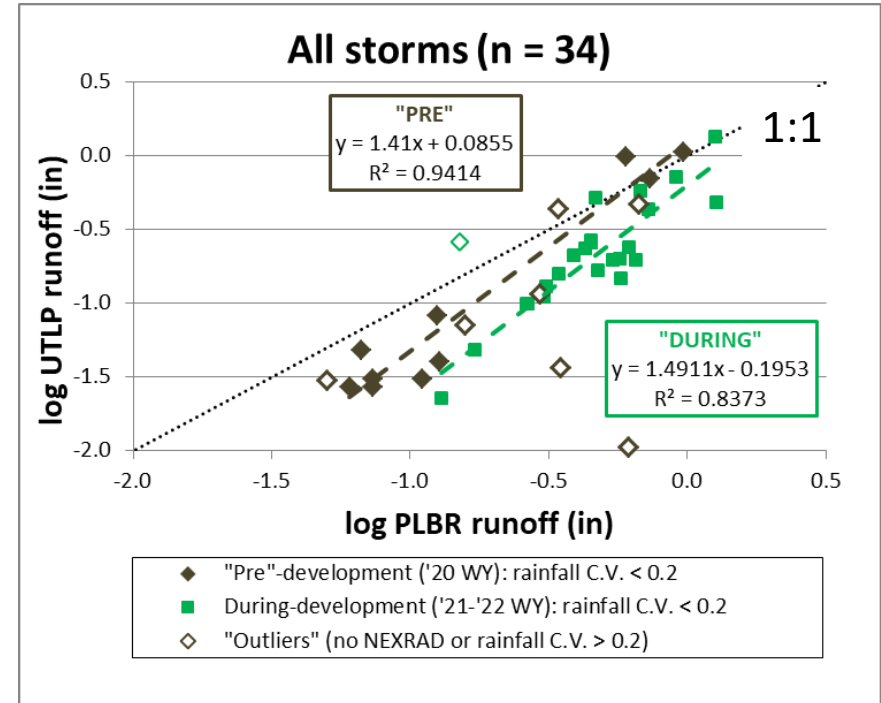


- Similar hydrographs: area-normalized mean daily discharge (log scale)
- Slightly greater range at PLBR mostly due to lower summer baseflows
- Large UTLP runoff anomaly of -22 cm in WY'21

Storm Event Runoff



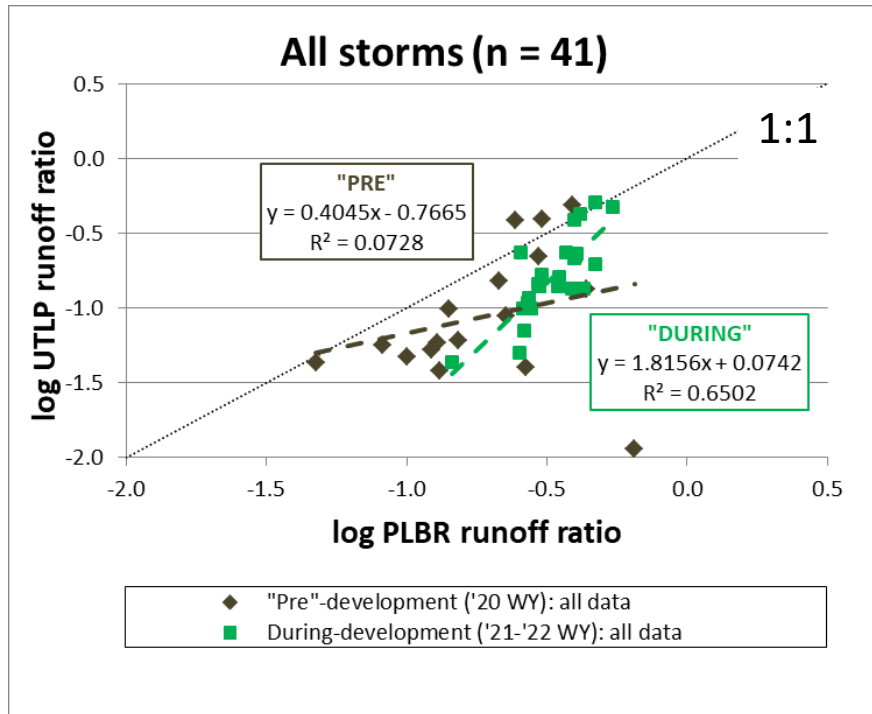
One way ANCOVA: $p = 0.92$ (NS)



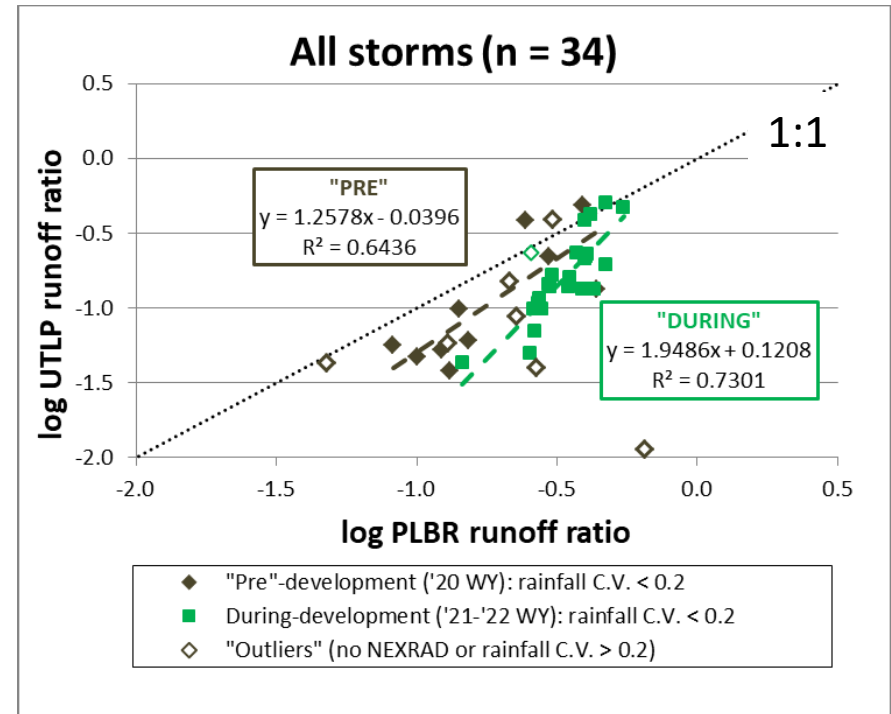
One way ANCOVA: $p < 0.001$

- 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



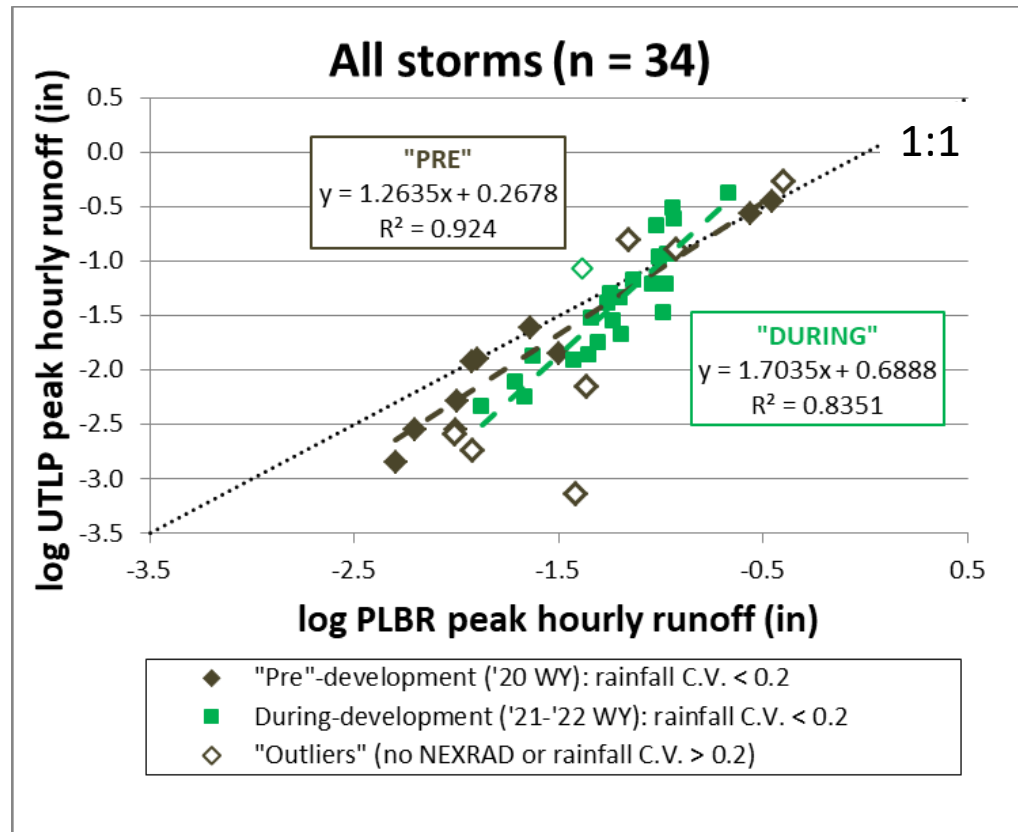
One way ANCOVA: $p = 0.37$ (NS)



One way ANCOVA: $p = 0.03$

- Same statistical result as for storm event runoff

Peak Mean Hourly Runoff

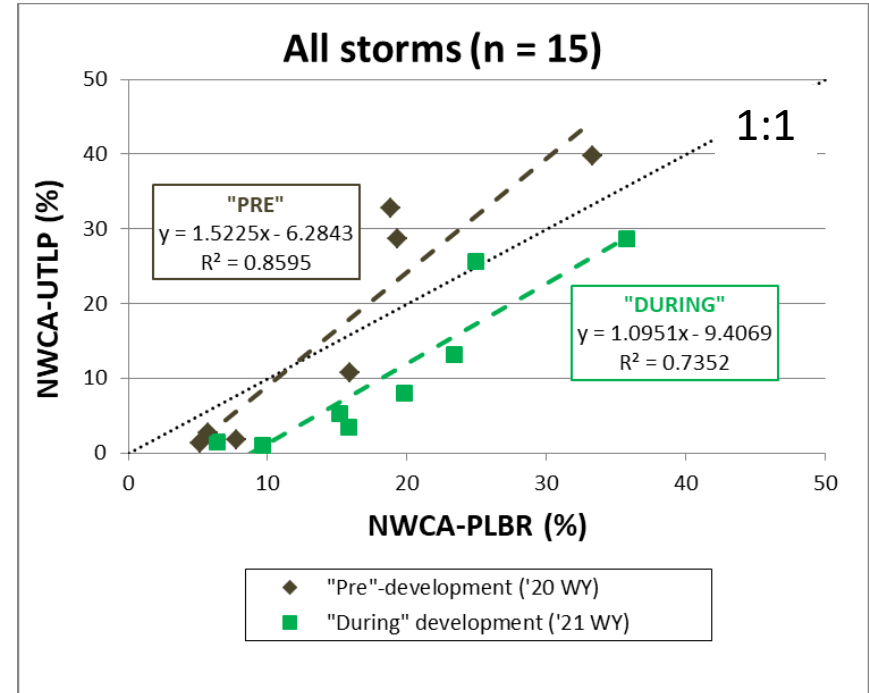
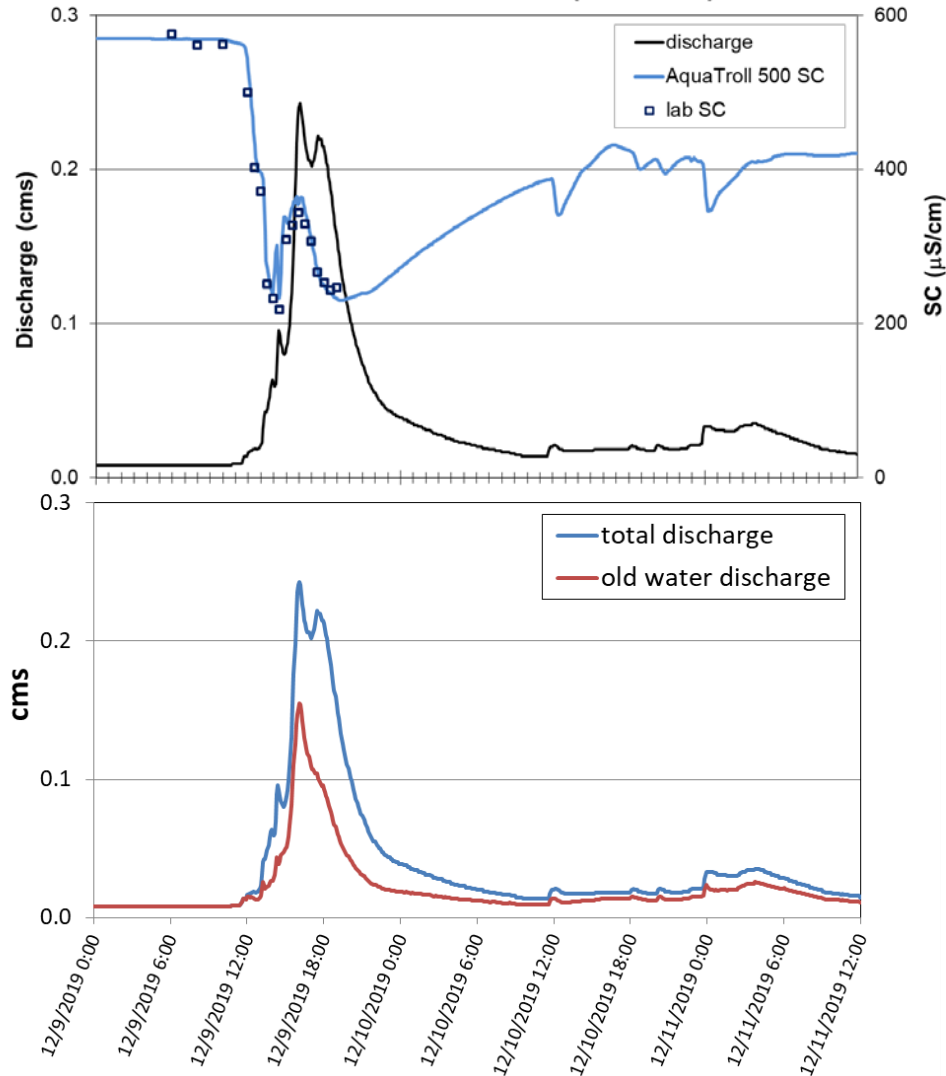


One way ANCOVA: $p = 0.86$ (NS)

- No statistically significant difference in adjusted means even with "outlier" events removed

New Water Contributing Areas (NWCA's)

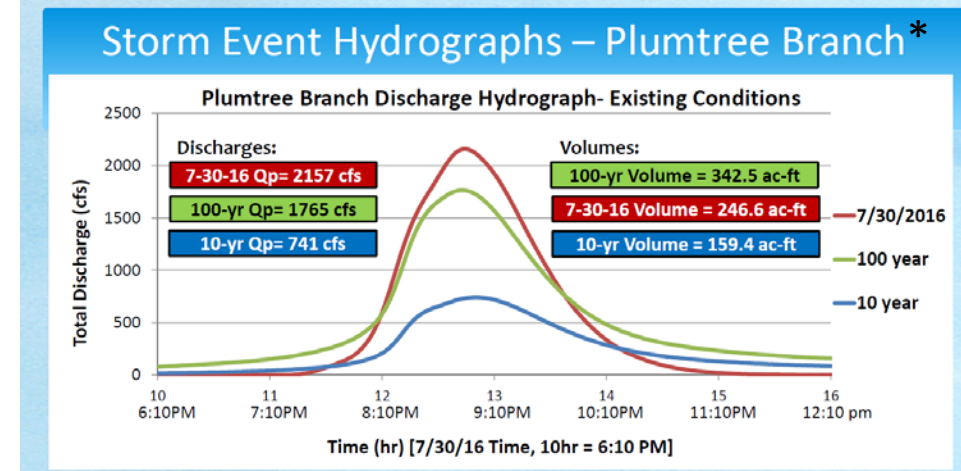
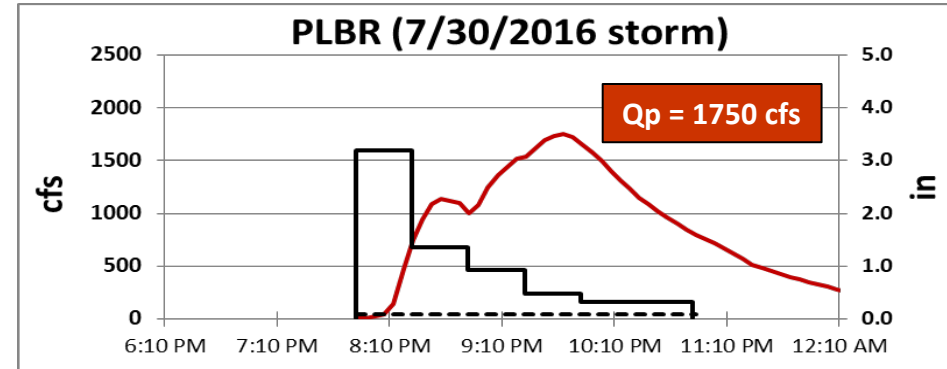
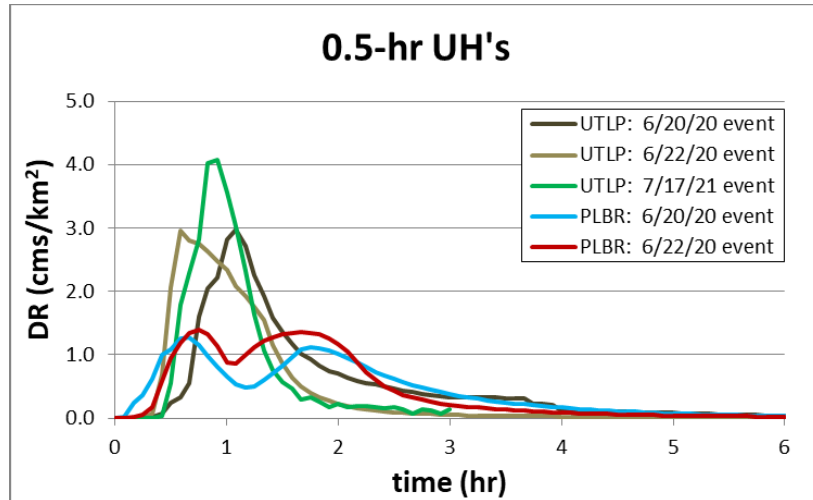
Plumtree Branch (Event A)



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

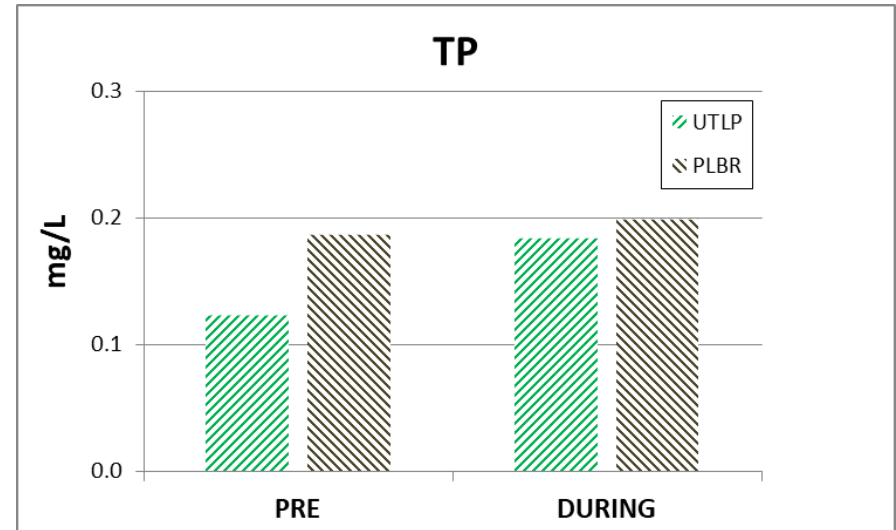
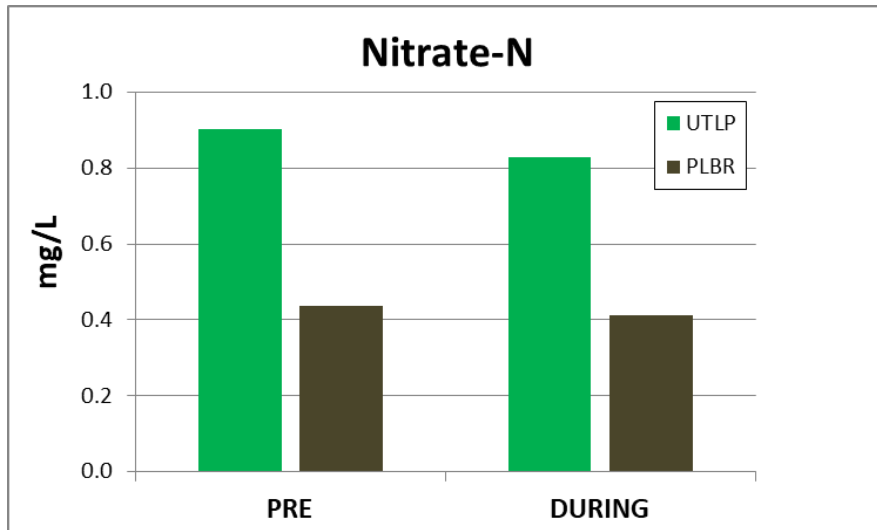
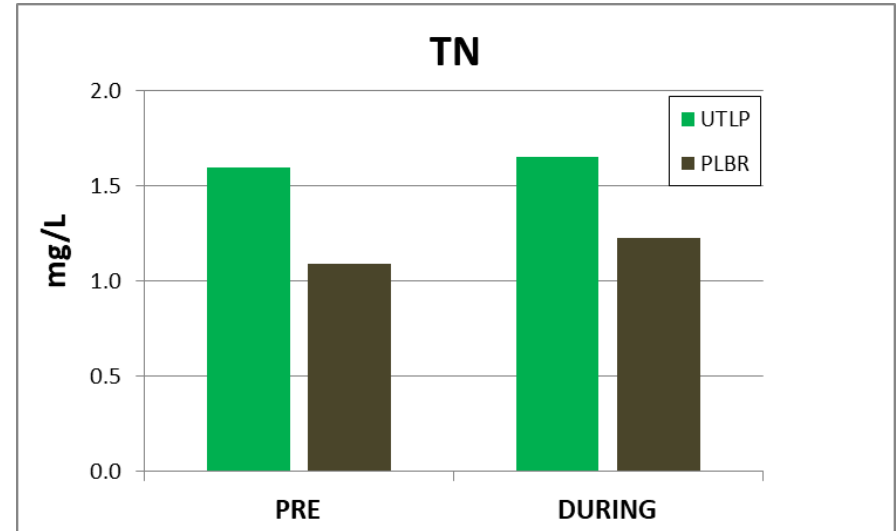
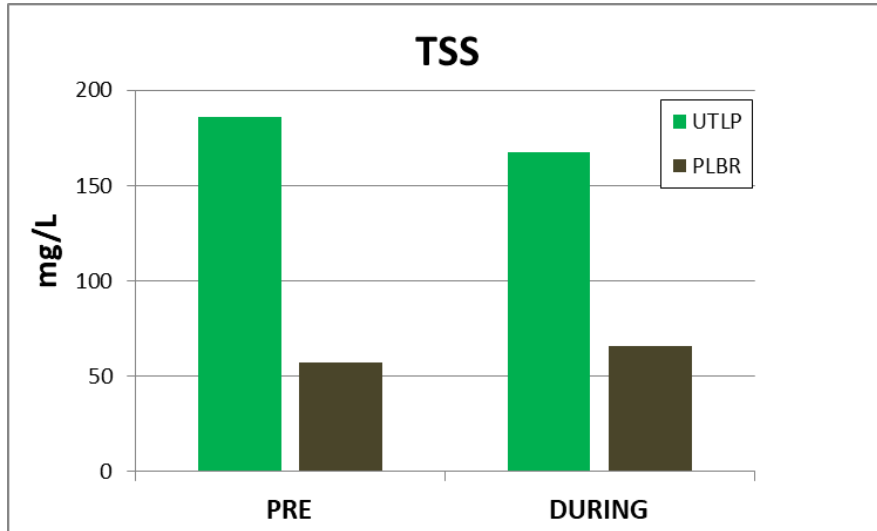
Unit Hydrographs (UH's)



*From 2017 Valley Mede Drainage Study: HEC-RAS

- 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

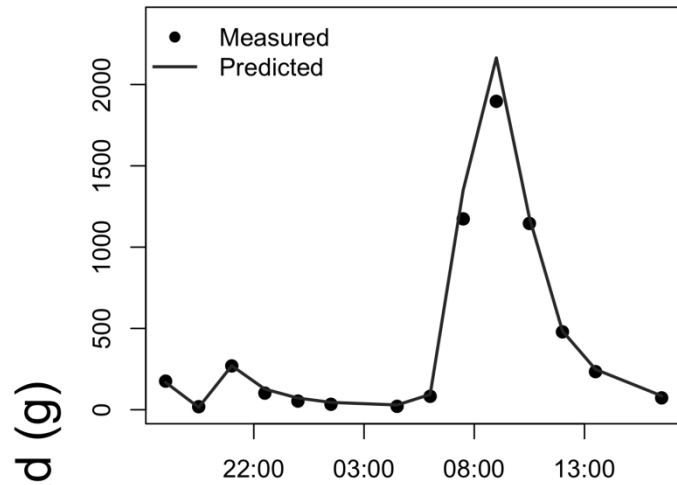
EMC's



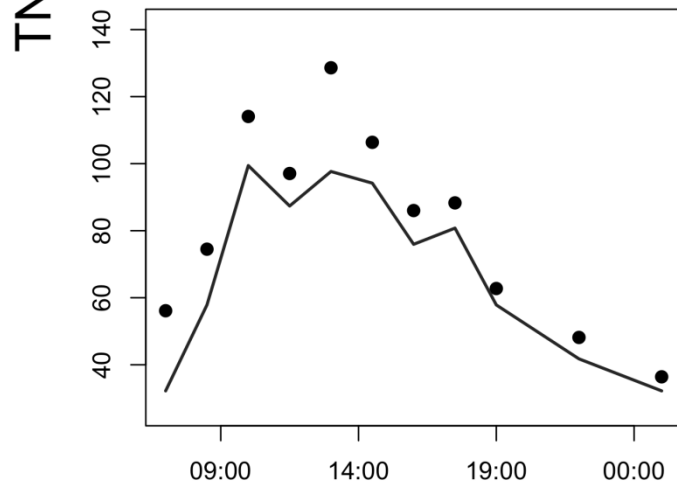
- Insufficient no. of events for “pre” period to use ANCOVA
- Statistically significant differences in median TSS, TN, and nitrate-N between watersheds

N Load Modeling

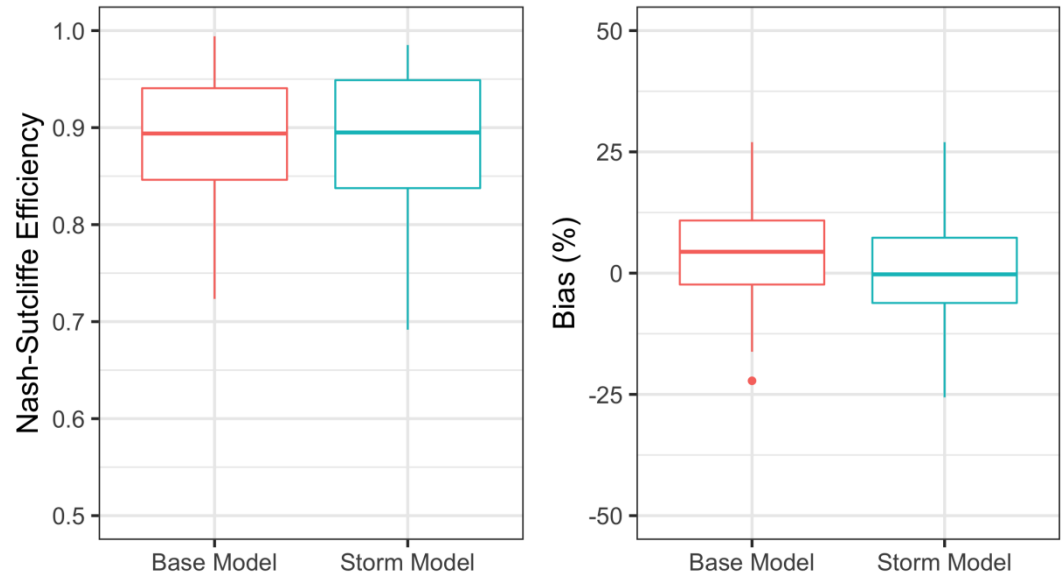
Event V



Event P

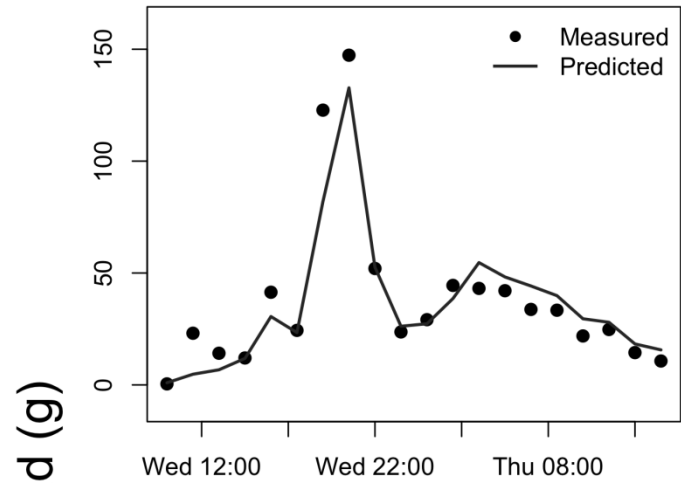


PLBR TN Models

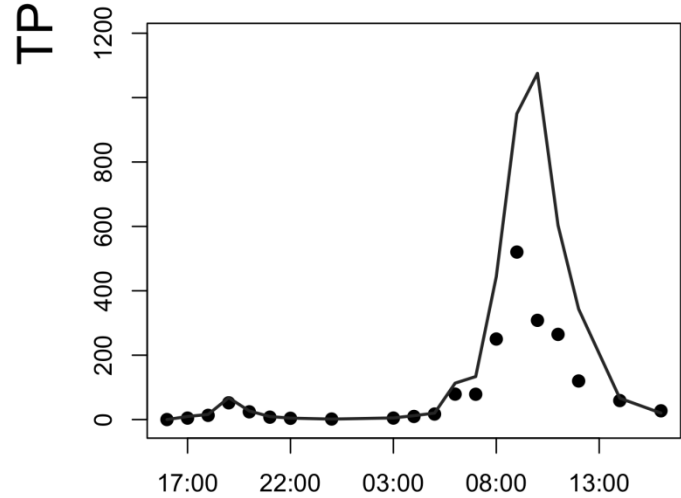


P Load Modeling

Event K



Event F



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
- Howard County (Mark Richmond *et al.*): ROE permits; site development plans
- UMCES Appalachian Lab Water Chemistry Lab
 - 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?