# Phase 1 – Modeling and Development of Flow Duration Curves (FDC 1 Project)

## Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

## Task 5 TSC Meeting

Prepared for

U.S. EPA Region 1

Prepared by:

Paradigm Environmental

Great Lakes Environmental Center

Support for Southeast New England Program (SNEP) Communications Strategy and Technical Assistance

April 22, 2021

# Meeting Agenda

# April 22, 2021

- Project Overview
- Data Review and Flow Metrics For Taunton River Basin and Wading River Watershed
- Pilot Sub-watershed Selection
- HRU Development
- Proposed Modeling Approach
- Discussion
- Conclusion/Next Steps

**Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers**

# Project Overview

# Project Milestone & Timeline

| Project Elements/Sub-Tasks | Delivery Date | Status |
|---|---|---|
| **Task 1: Prepare Quality Assurance Project Plan** | 12/31/2020 | Complete |
| **Task 2: Project Management and Administration** | - | On going |
| **Task 3:  Technical Steering Committee Meetings** | - | On going |
| **Task 4. Coordinate with TSC to Finalize Phase 1 Project Approach** | 12/31/2020 | Complete |
| **Task 5. Compile Available Data/Information for Taunton River Watershed Modeling Analyses** | 4/30/2021 | In Progress |
| **Task 6. Phase 1 Hydrologic Streamflow Modeling Analyses** | 6/30/2021 | - |
| **Task 7. Phase 1 Stormwater/Hydrologic Management Optimization Analyses** | 9/30/2021 | - |
| **Task 8. Phase 1 Project Webinar to SNEP Region** | 9/30/2021* | - |

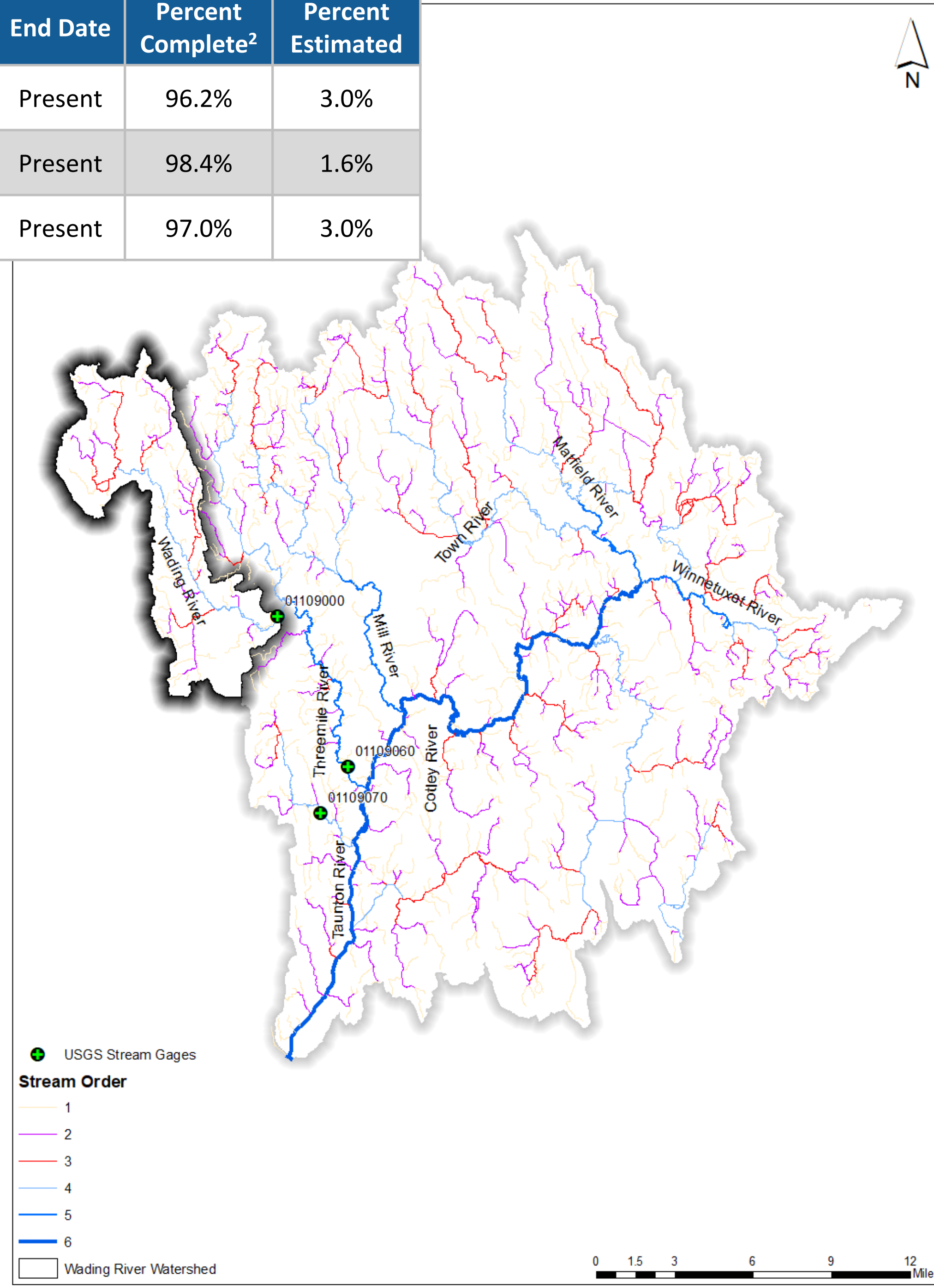
Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

# Data Review and Flow Metrics

Data Review

- Landscape
  - Landuse/landcover
  - Elevation/Slope
  - Soils
  - Surficial Geology
- Dams/Reservoirs
- Meteorology Data
- Streamflow and metrics
- Existing Models

| Location | USGS-ID | Drainage Area ($mi^2$) | Start Date | End Date | Percent Complete[2] | Percent Estimated |
|---|---|---|---|---|---|---|
| Segreganset River near Dighton, MA | 01109070 | 10.6 | 7/1/1966 | Present | 96.2% | 3.0% |
| Wading River near Norton, MA | 01109000 | 43.3 | 6/1/1925 | Present | 98.4% | 1.6% |
| Threemile River at North Dighton, MA | 01109060 | 84.3 | 7/1/1966 | Present | 97.0% | 3.0% |



USGS
science for a changing world

# User Guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R Packages for Hydrologic Data

Chapter 10 of
Section A, Statistical Analysis
**Book 4, Hydrologic Analysis and Interpretation**

Techniques and Methods 4–A10
Version 2.0, February 2015

**U.S. Department of the Interior**
**U.S. Geological Survey**

RStudio

File Edit Code View Plots Session Build Debug Profile Tools Help

Untitled1* R_code.R

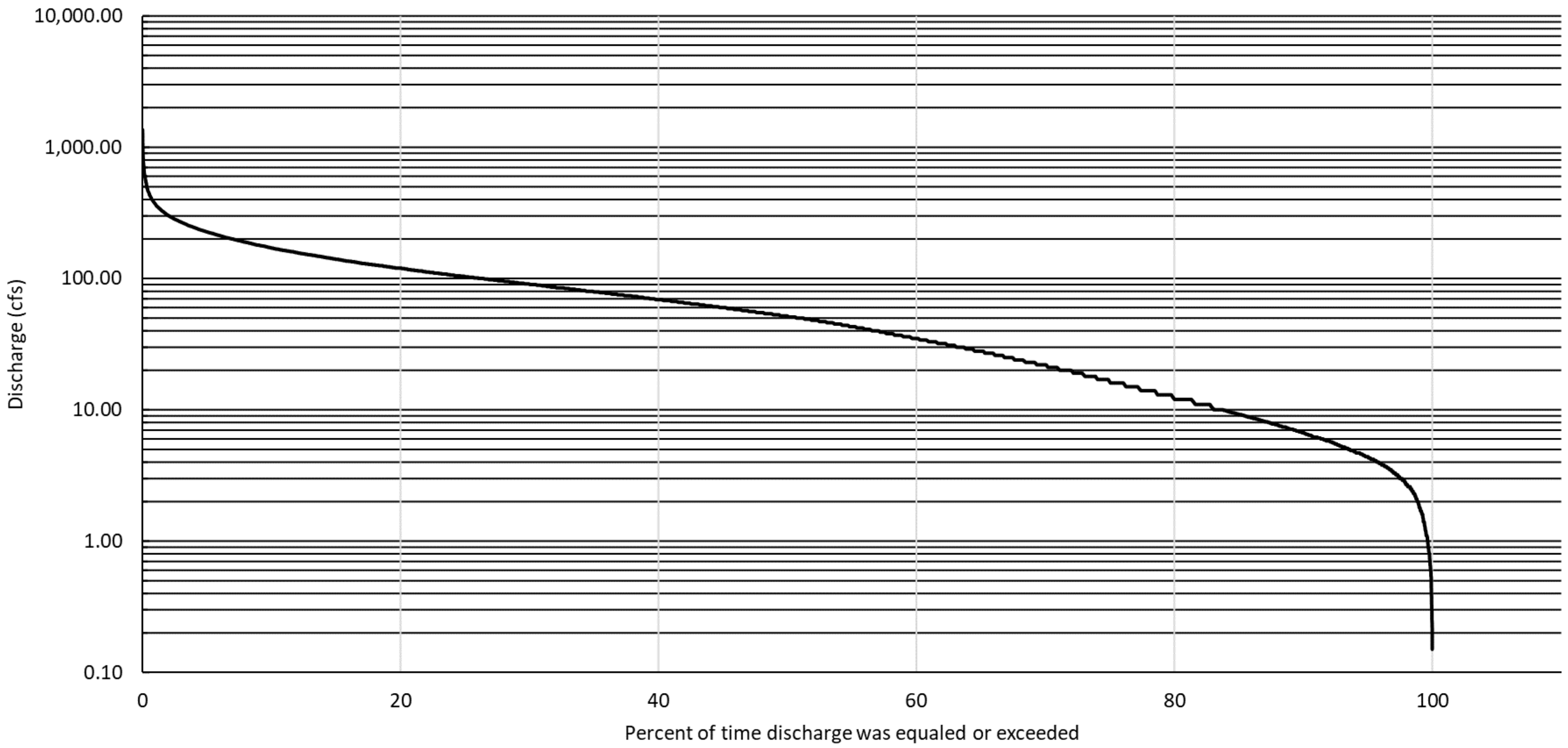
Source on Save Run

```
plotFour(eList, qUnit=1)
plotFourStats(eList, qUnit=1)
#
seriesResult <- printSeries(eList, istat=3, qUnit=3)
tableFlowChange(eList,istat=3,qUnit=1,yearPoints=c(1940,1950,1960,1970,1980,1990,2000,2010,2020))
library(rkt)
library(zyp)
library(lubridate)
#make plot, see here for more details http://usgs-r.github.io/EGRET/articles/streamflow_trend.html
plotQuantileKendall(eList)

flowDuration(eList, "06-25", qUnit = 1, span = 30)
#Quantile for summer
plotQuantileKendall(eList, paStart = 6, paLong = 3)
#Quantile for fall
plotQuantileKendall(eList, paStart = 9, paLong = 3)
#Quantile for winter
plotQuantileKendall(eList, paStart = 12, paLong = 3)
#Quantile for spring
plotQuantileKendall(eList, paStart = 3, paLong = 3)


# Gather discharge data:
siteID <- "01491000" #Wading River
startDate <- "" # Get earliest date
```

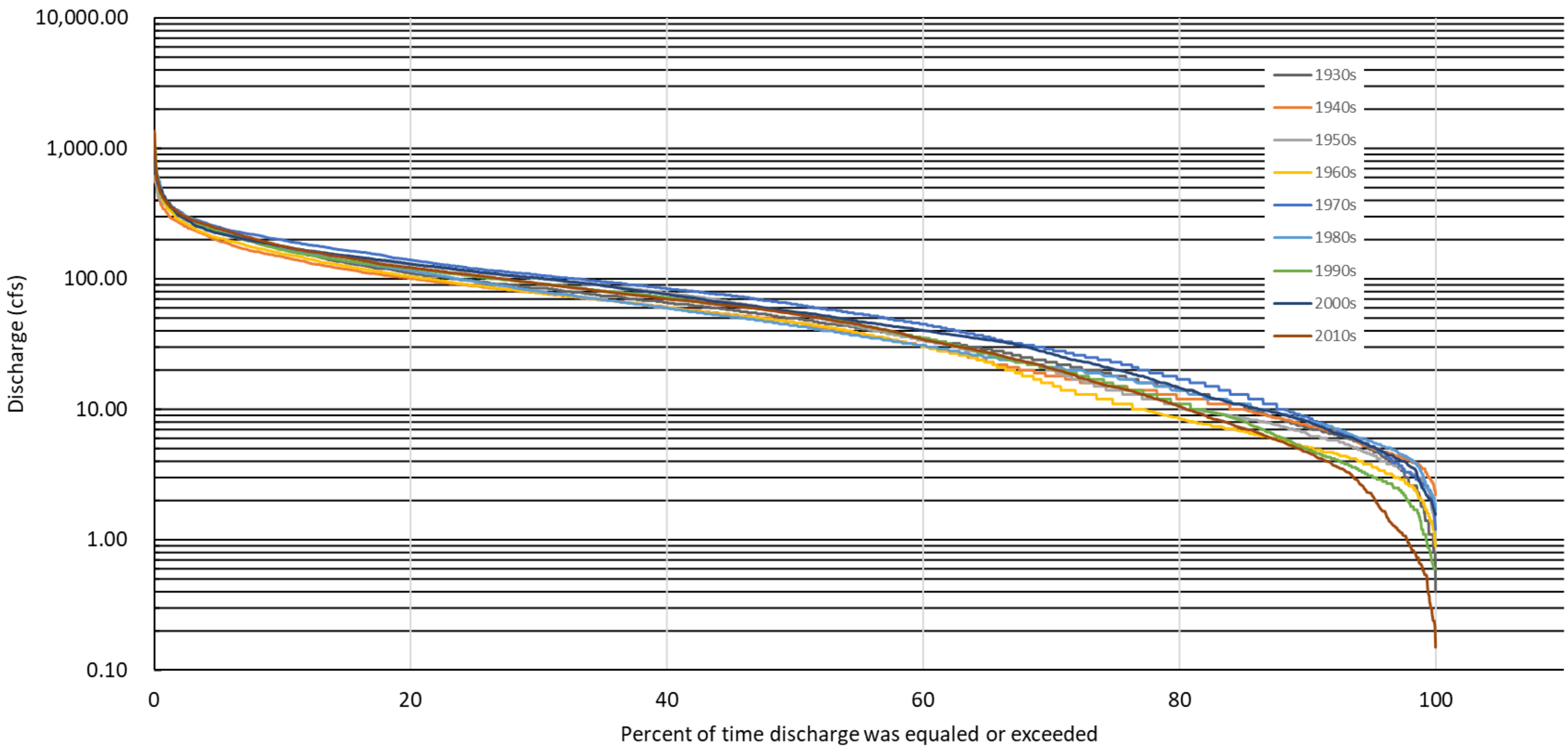
| Group | IHA parameter | Figure | Examples of Ecosystem Impact |
|---|---|---|---|
| Group 1<br>Magnitude and timing (12 parameters) | Average monthly flow (1 value for each of the 12 months) | Figure 17 | Increased flow variations may lead to wash out or stranding of sensitive species |
| Group 2<br>Magnitude and duration<br>(12 parameters) | Average annual 1-day minimum flow | Figure 18 | Prolonged low flows, prolonged base flow spikes, and altered inundation period may lead to a change in the concentration of aquatic organisms, reduction or elimination of plant cover, diminished plant species diversity, and loss of floating eggs |
| | Average annual 3-day minimum flow | Figure 19 | |
| | Average annual 7-day minimum flow | Figure 20 | |
| | Average annual 30-day minimum flow | Figure 21 | |
| | Average annual 90-day minimum flow | Figure 22 | |
| | Average annual 1-day maximum flow | Figure 18 | |
| | Average annual 3-day maximum flow | Figure 19 | |
| | Average annual 7-day maximum flow | Figure 20 | |
| | Average annual 30-day maximum flow | Figure 21 | |
| | Average annual 90-day maximum flow | Figure 22 | |
| | Number of days per year with zero flow | N/A | |
| | 7-day minimum flow divided by mean flow in each year | Figure 23 | |
| Group 3<br>Timing (2 parameters) | Julian date of the minimum flow | Figure 24 | Loss of seasonal flow peaks may disrupt cues for spawning, egg hatching, and migration and lead to loss of fish access to Julian date of the maximum flow wetlands or backwaters |
| | Julian date of the maximum flow | Figure 24 | |
| Group 4<br>Frequency and duration<br>(4 parameters) | Number of low pulses | Figure 25 | Flow stabilization may lead to invasion of exotic species and reduced water and nutrients to floodplain plant species |
| | Average duration of low pulse | Figure 26 | |
| | Number of high pulses | Figure 25 | |
| | Average duration of high pulses | Figure 26 | |
| Group 5<br>Rate of change and frequency (3 parameters) | Rise rate (mean of all positive differences) | Figure 27 | Rapid changes in river stage and accelerated flood recession may cause wash out and stranding of aquatic species, failure of seedling establishment |
| | Fall rate (mean of all negative differences) | Figure 27 | |
| | Number of flow reversals | Figure 28 | |

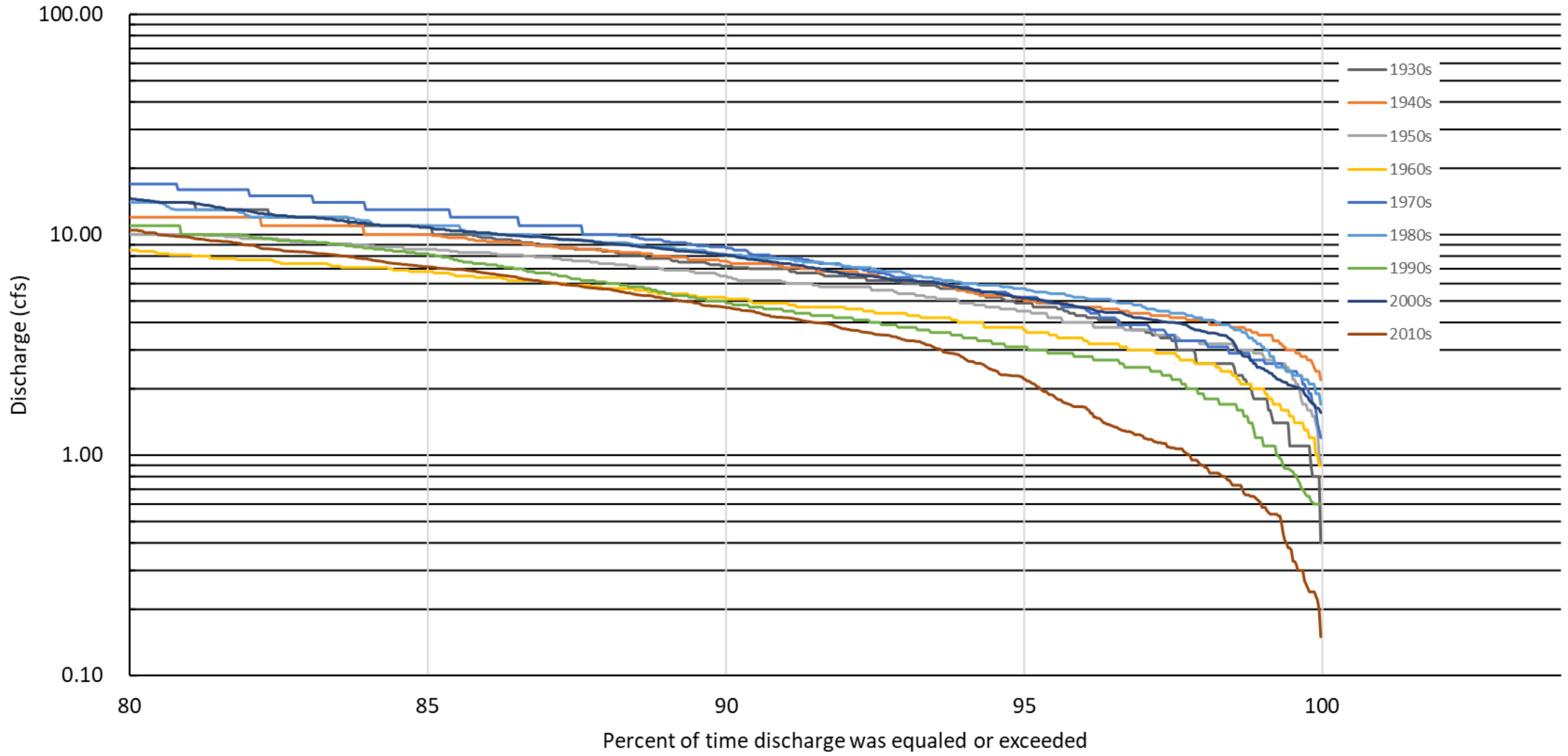
| Evaluation Metric | Description | Source | Figure | Unit |
|---|---|---|---|---|
| Trend Slope | Quantile-Kendall plot | EGRET | Figure 30 & Figure 31 | % per year |
| Variability | Discharge variability over time | EGRET | Figure 29 | Unitless |
| Annual Nutrient (P&N) load export (excluding channel processes) | Pollutant load Export rates | TSC | N/A – will be presented with modeling results in Task 6 | lbs/acres/year |
| Annual surface runoff volume | Runoff yields | TSC | Figure 33 | inches/year |
| Annual Groundwater recharge | Infiltration | TSC | N/A – will be presented with modeling results in Task 6 | inches/year |
| Ecodeficit/Ecosurplus | Flow Duration Curve | TSC | Figure 35 | Dimensionless |
| Composite IHA | Flow Duration Curve | | N/A – will be presented with modeling results in Task 6 | Dimensionless |
| $Q_{Bankfull}$ | Flooding | TSC | Figure 34 | cfs |
| Richard-Baker Flashiness index | Quicker routing of storm flows to streams and rivers relative to natural conditions | TSC | Figure 32 | Dimensionless |
| Critical Shear Stress (mobilization of particles) | Streambed Mobility/Stability | TSC | N/A – will be presented with modeling results in Task 6 | lb-force/ft$^2$ |
| Evapotranspiration rate | Ecohydrology | TSC | N/A – will be presented with modeling results in Task 6 | mm day$^{-1}$ |
| Latent heat flux | Ecohydrology | TSC | N/A – will be presented with modeling results in Task 6 | MJ m$^2$ day$^1$ |

# Wading River Flow Duration Curve

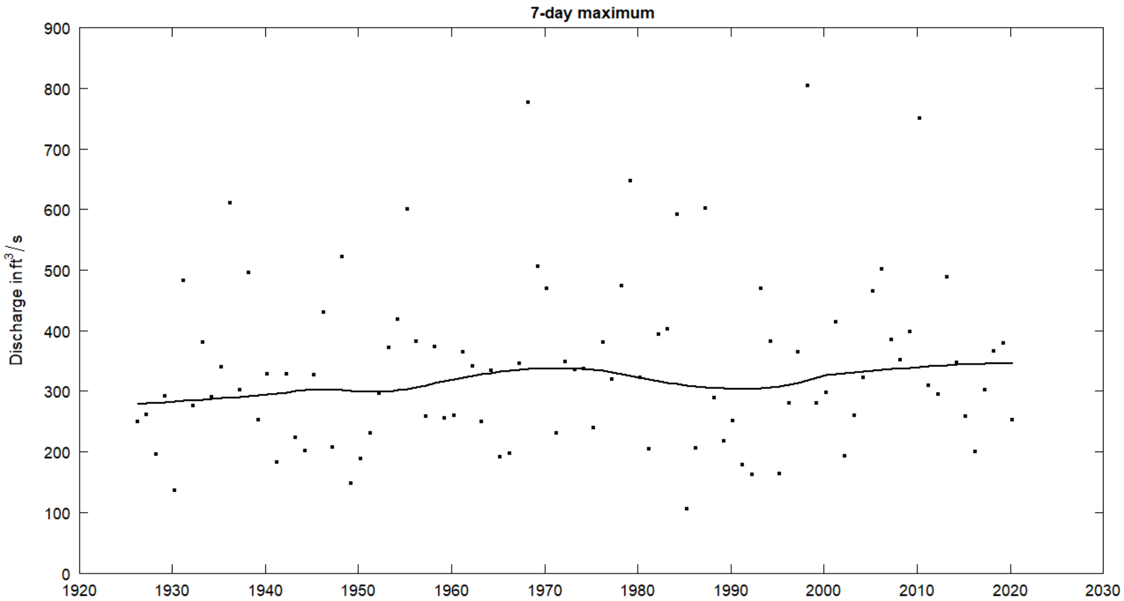


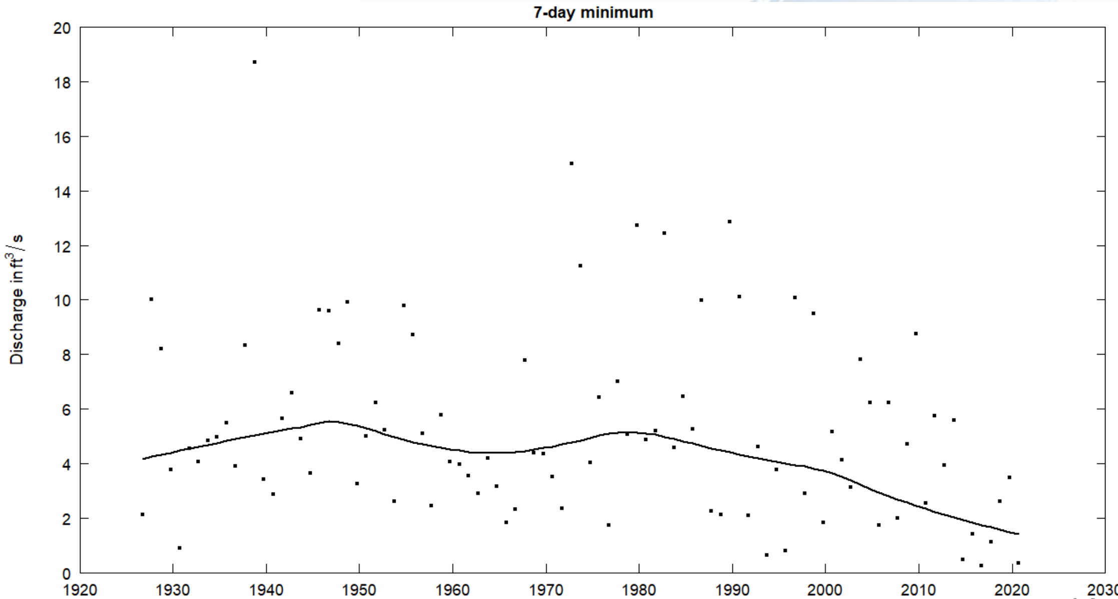
# Wading River Rating Curve – by decade




100.00
10.00
1.00
0.10
Discharge (cfs)
80
85
90
95
100
Percent of time discharge was equaled or exceeded
1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
2010s

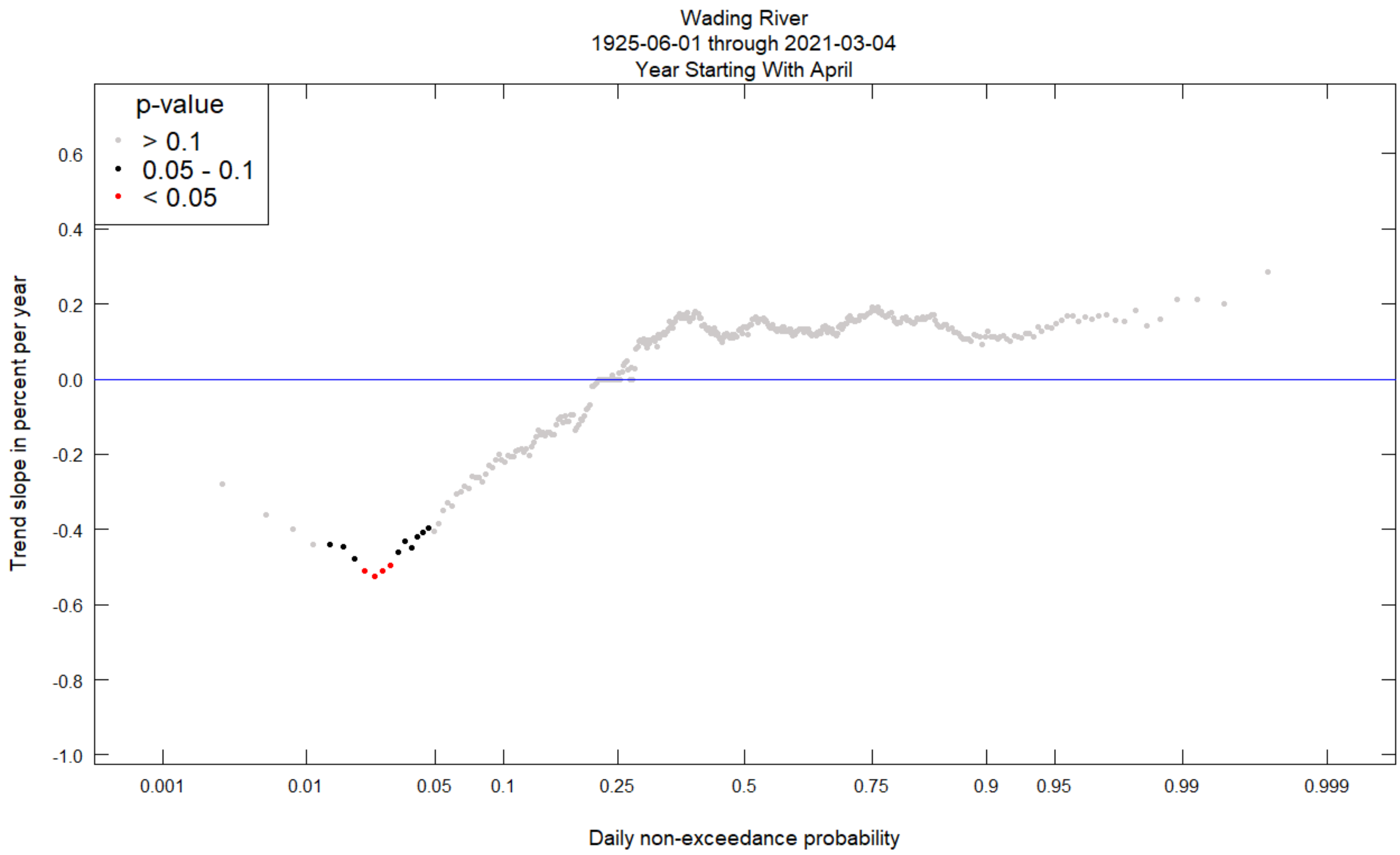
# 7-day maximum and minimum flows



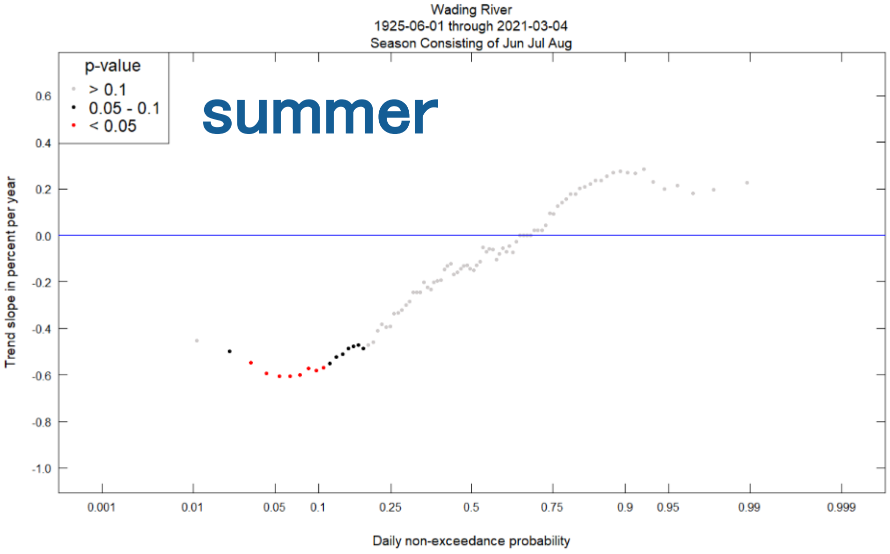

Similar results for 1, 7, 30, and 90 day graphs

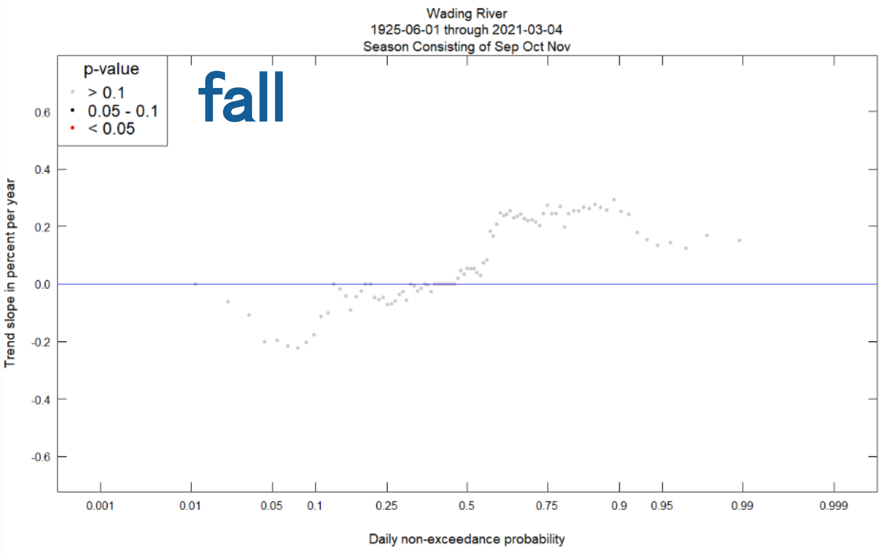
# Quantile–Kendall plot

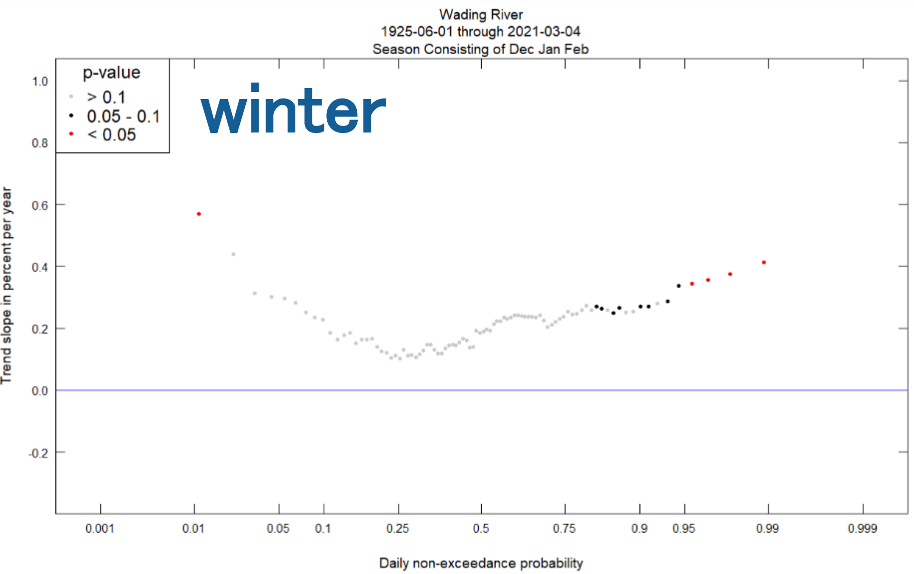


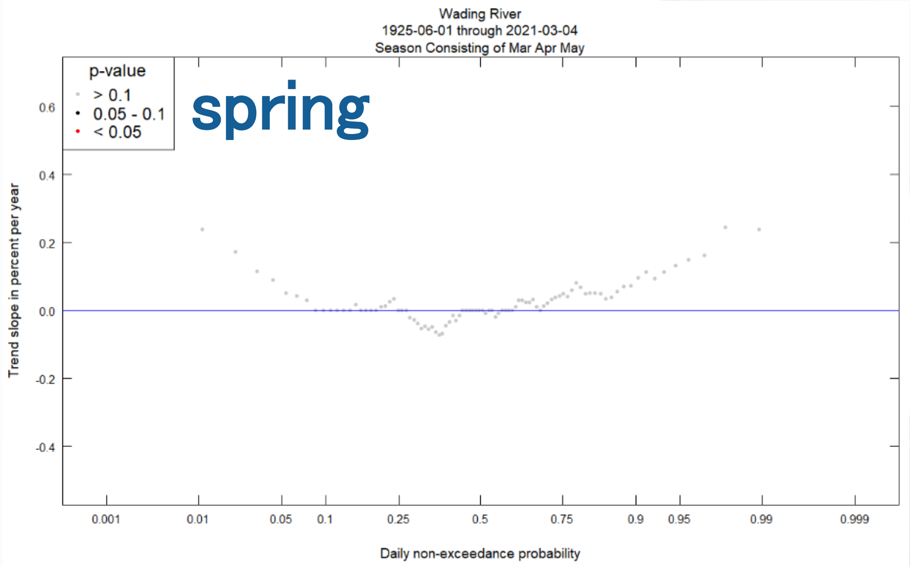

Each point in the graph represents the estimated trend slope, expressed in percent change per year, for discharge values of the given rank. The x-axis presents daily non-exceedance probability with low flows and their trends on the far left of the graph and high flows and their trends on the far right. The black and red points indicate that the trend is statistically significant at the given p-value. Many of the lowest flows in the Wading River are becoming significantly ($p < 0.05$-1, $p<0.05$) lower, reducing by between 0.4% to 0.6% a year.

# Quantile–Kendall plots

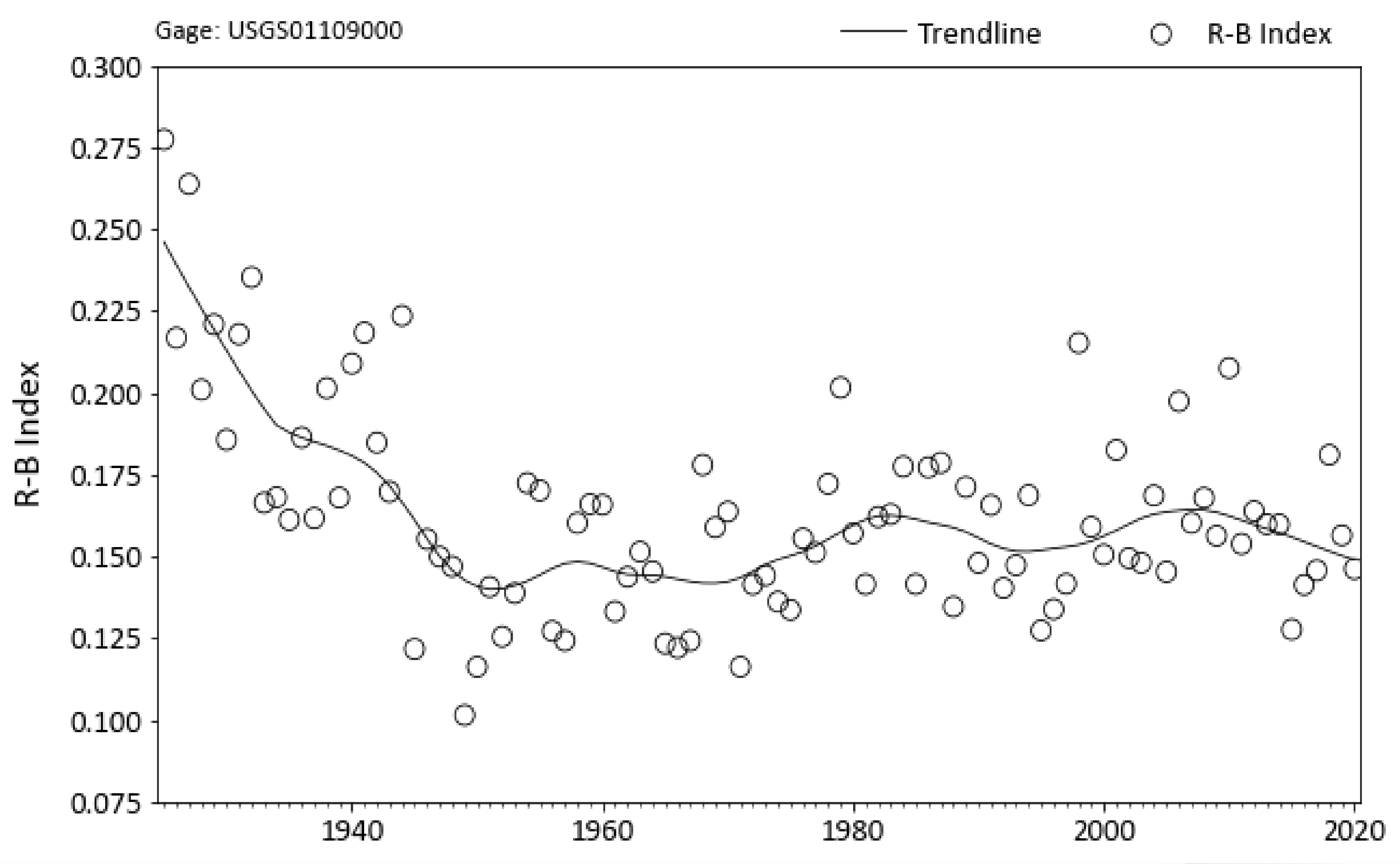


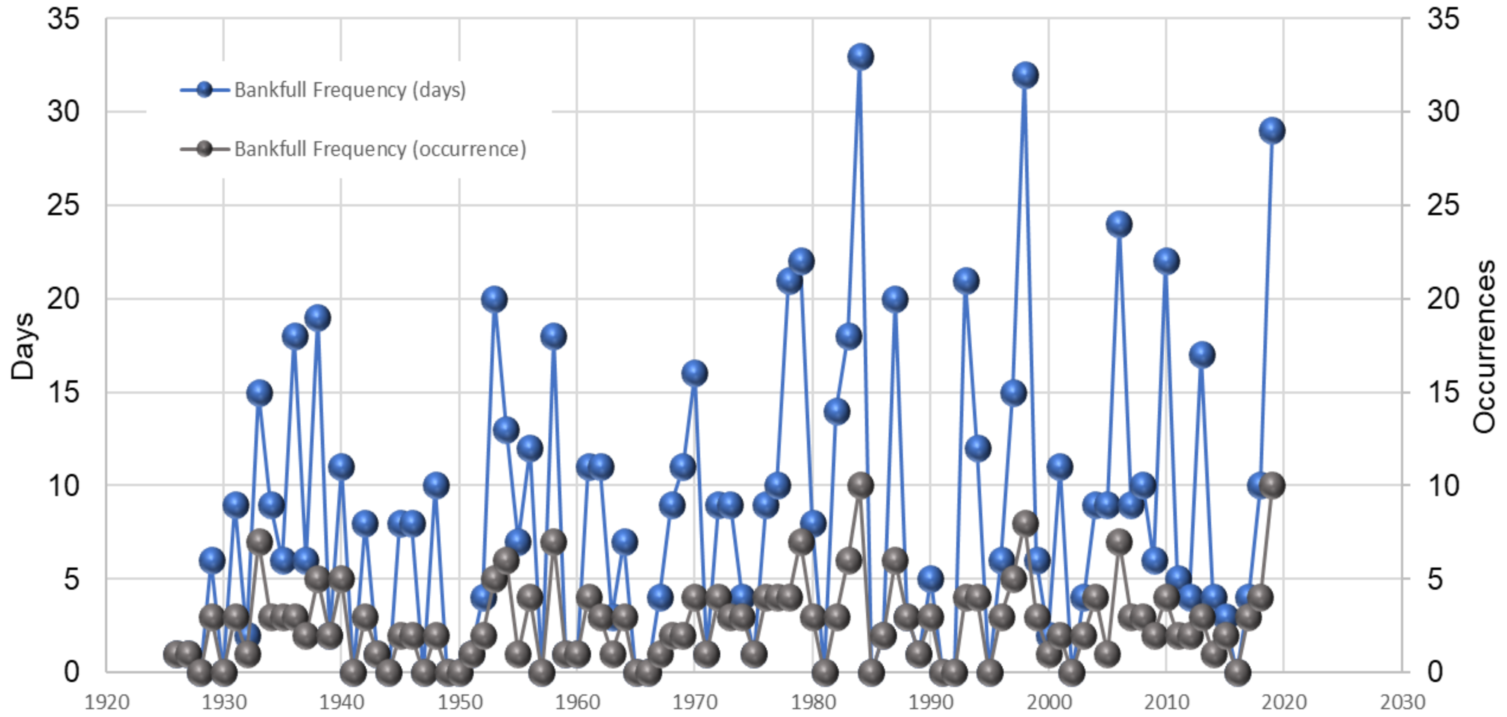



# Richard-Baker flashiness index



# Bankfull




Bankfull frequency by occurrence and total days >= bankfull. Based on a bankfull flow of 295 $ft^3/s$ (Bent and Waite, 2013).

Bankfull discharge often associated with channel forming flows – i.e sediment mobilization

# Sediment Mobilization

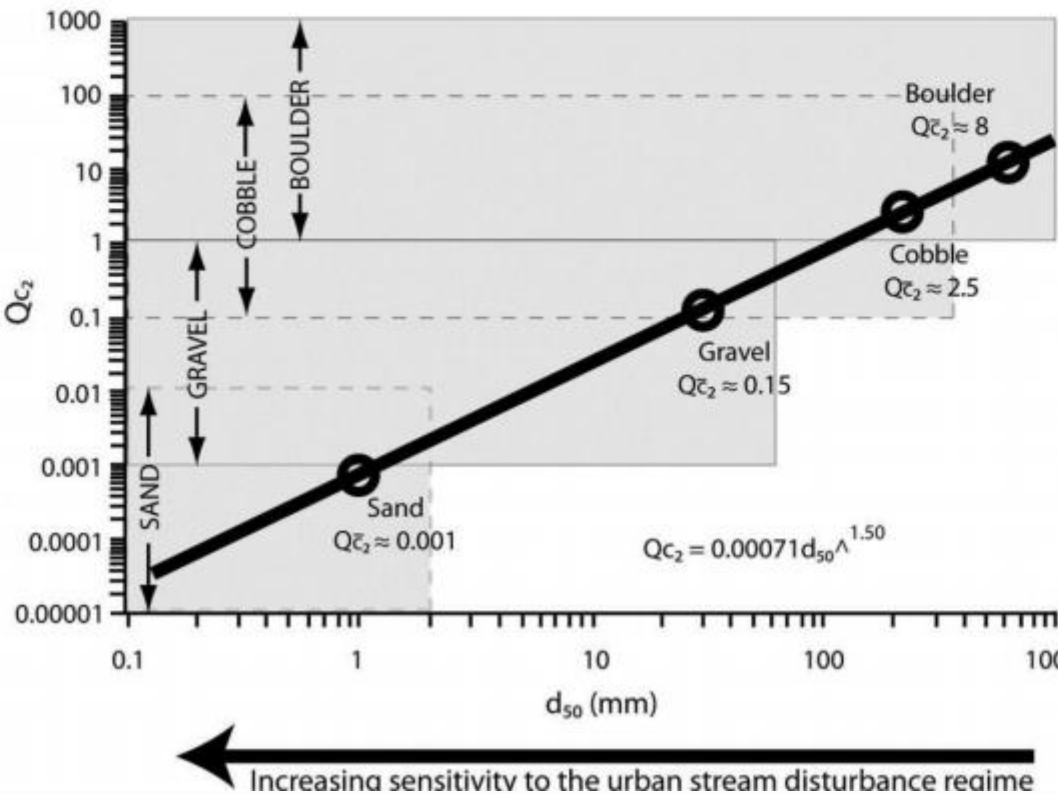
URBAN STREAMS

## Addressing the urban stream disturbance regime

**R. J. Hawley**[1,2,4] **and G. J. Vietz**[3,5]

[1]Sustainable Streams, LLC, 1948 Deer Park Avenue, Louisville, Kentucky 40205 USA
[2]Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado 80523 USA
[3]School of Ecosystem and Forest Sciences, The University of Melbourne, Burnley, Victoria 3121 Australia

**Abstract:** Thresholds for particle entrainment and natural disturbance frequency vary across hydrogeomorphic settings, but urbanization increases the rate and extent of channel erosion and sediment transport in alluvial channels. The *urban disturbance regime* is a change in the frequency, magnitude, and duration of hydrologically induced disturbance on the stream channel and ecosystem that can lead to geomorphic and ecological degradation. To preserve stream stability and ecological function, storm-water management systems should be optimized to maintain the natural disturbance regime of streambed material within the



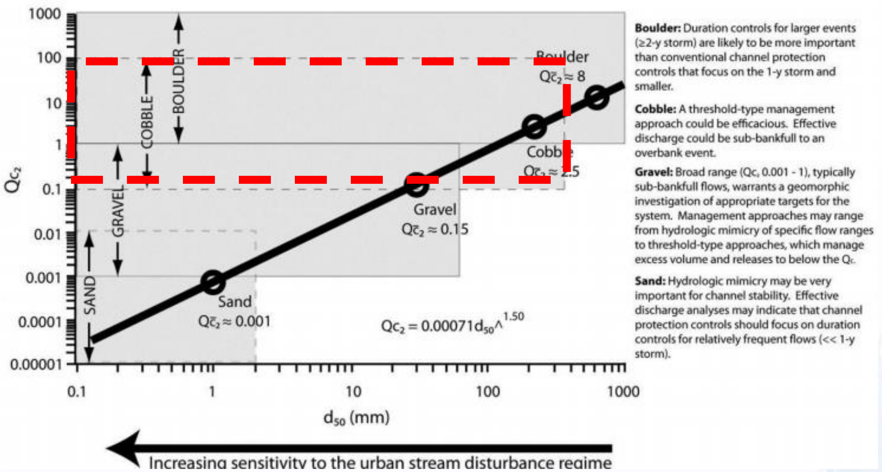

**Boulder:** Duration controls for larger events (≥2-y storm) are likely to be more important than conventional channel protection controls that focus on the 1-y storm and smaller.

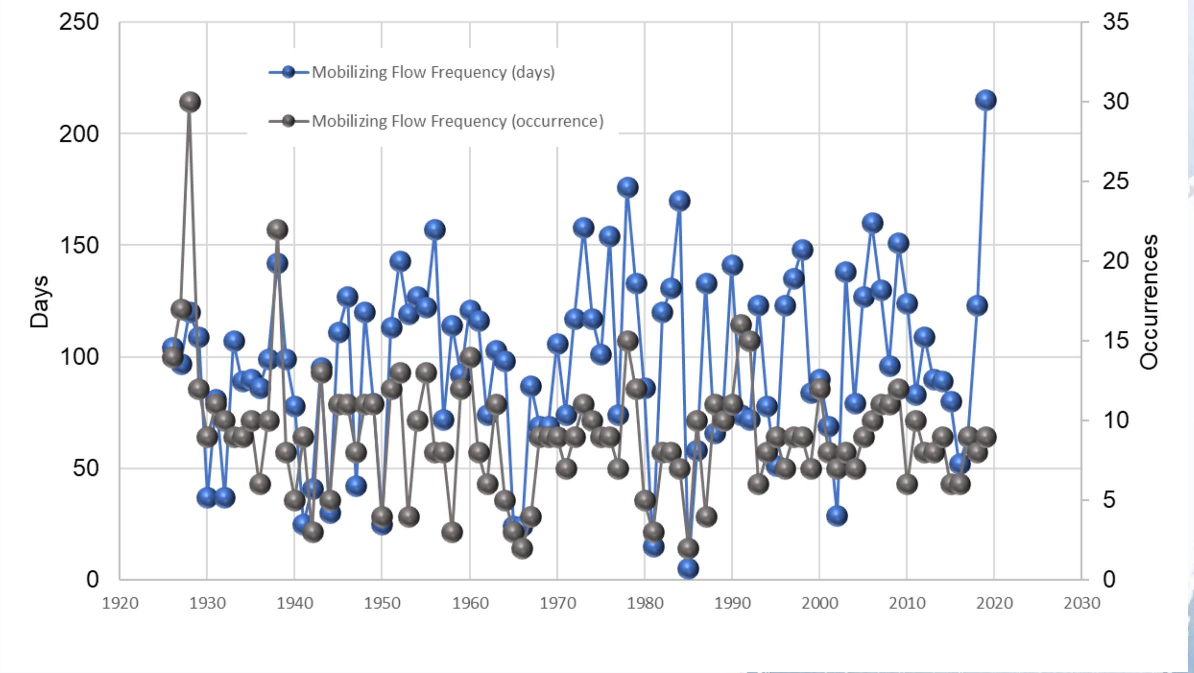
**Cobble:** A threshold-type management approach could be efficacious. Effective discharge could be sub-bankfull to an overbank event.

**Gravel:** Broad range ($Q_c$ 0.001 - 1), typically sub-bankfull flows, warrants a geomorphic investigation of appropriate targets for the system. Management approaches may range from hydrologic mimicry of specific flow ranges to threshold-type approaches, which manage excess volume and releases to below the $Q_c$.

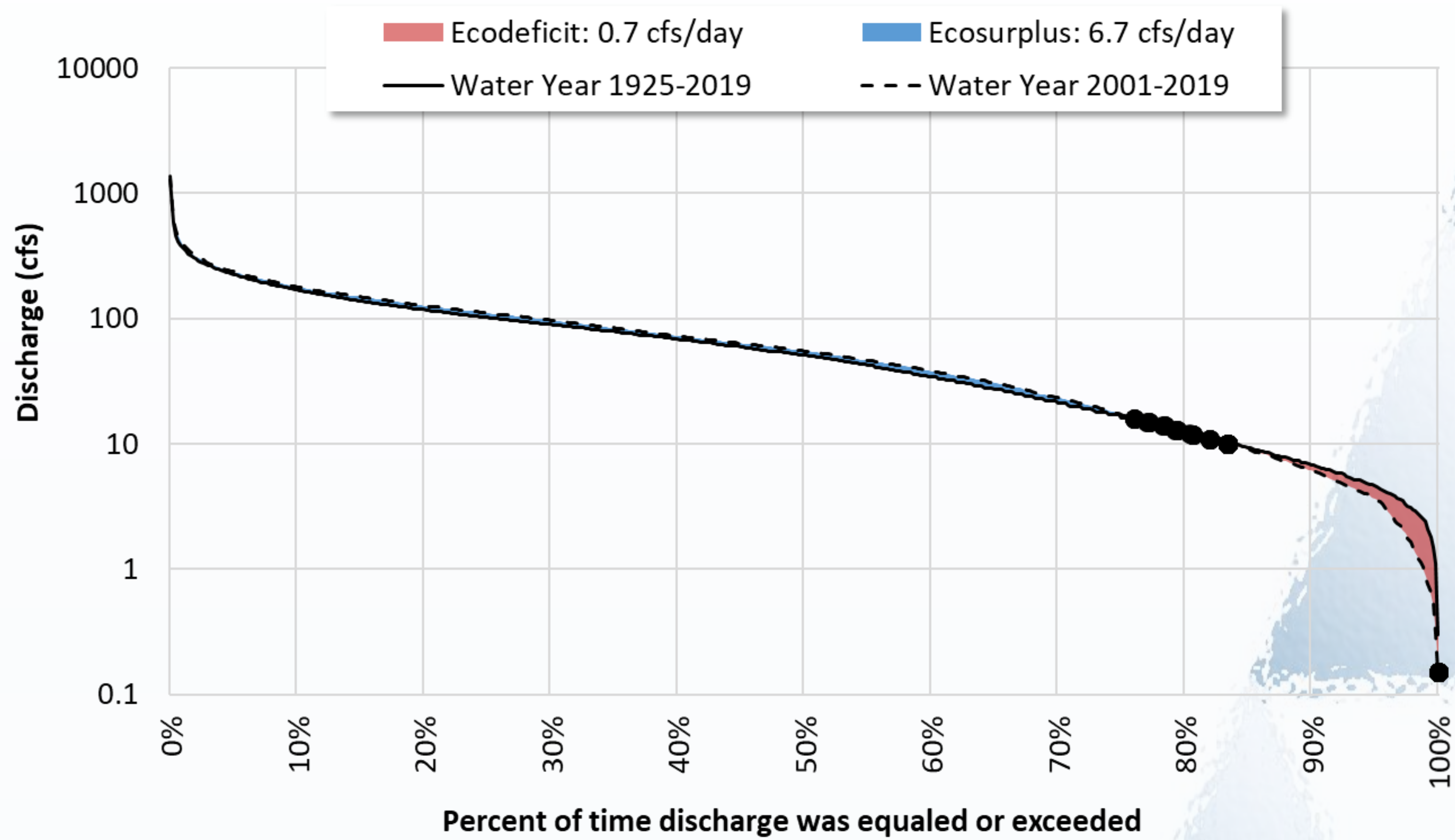
**Sand:** Hydrologic mimicry may be very important for channel stability. Effective discharge analyses may indicate that channel protection controls should focus on duration controls for relatively frequent flows (<< 1-y storm).

# Based on some [observed data](): assumed Taunton has a cobble bottom

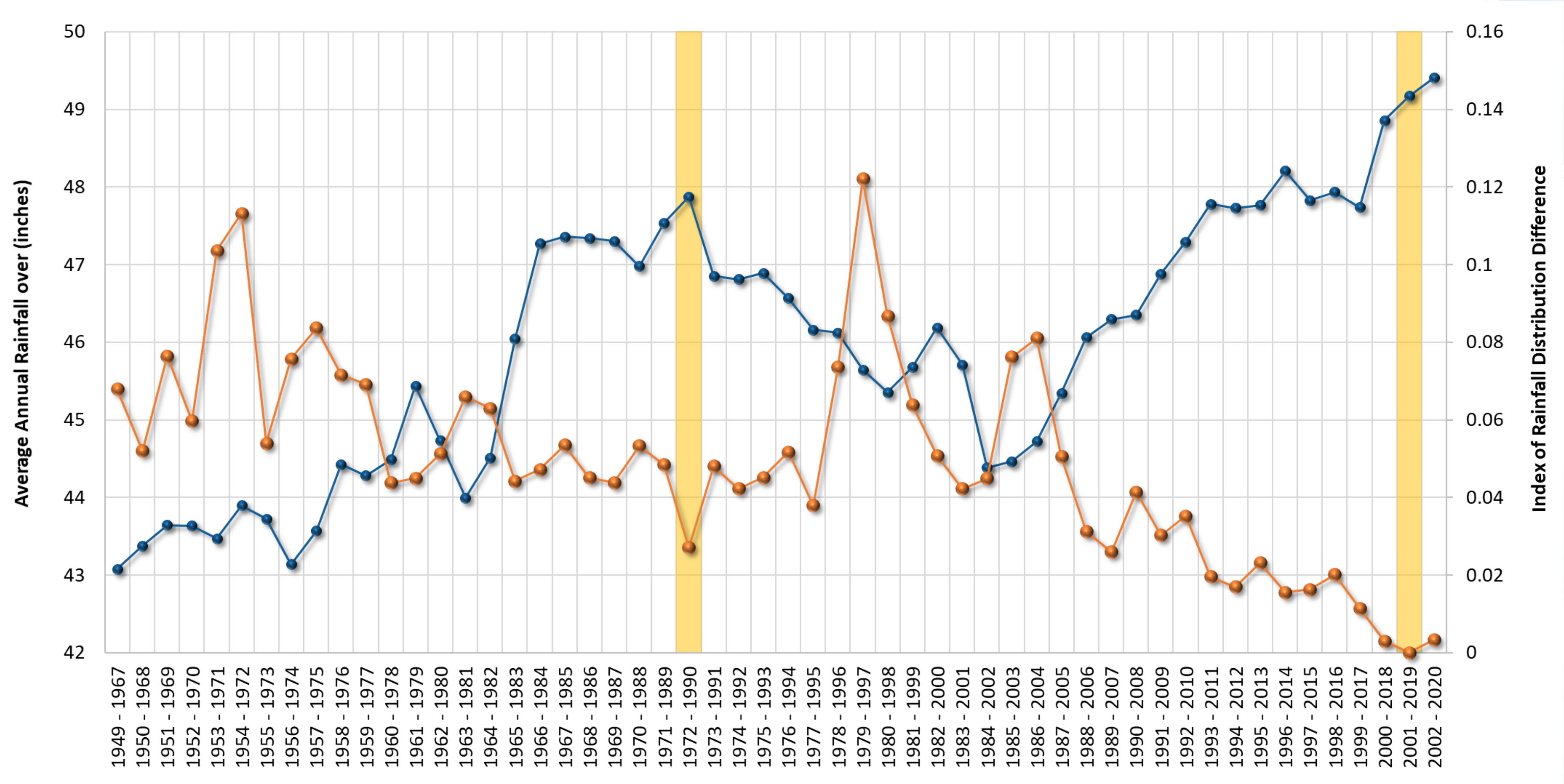


# Eco-deficit and eco-surplus



# Average annual rainfall depth and distribution



# Group 1 IHA parameter comparisons

| | 1972-1990 | 2001-2019 | % difference |
|---|---|---|---|
| Group 1. Magnitude and timing | **Average (cfs)** | | |
| January | 116.19 | 102.66 | -11.65% |
| February | 117.82 | 104.57 | -11.25% |
| March | 143.77 | 151.01 | 5.04% |
| April | 140.82 | 147.19 | 4.52% |
| May | 89.20 | 82.37 | -7.66% |
| June | 66.84 | 69.24 | 3.58% |
| July | 23.91 | 28.51 | 19.22% |
| August | 31.25 | 17.77 | -43.15% |
| September | 23.54 | 20.07 | -14.77% |
| October | 44.21 | 45.98 | 4.02% |
| November | 75.90 | 74.35 | -2.05% |
| December | 107.81 | 105.47 | -2.17% |

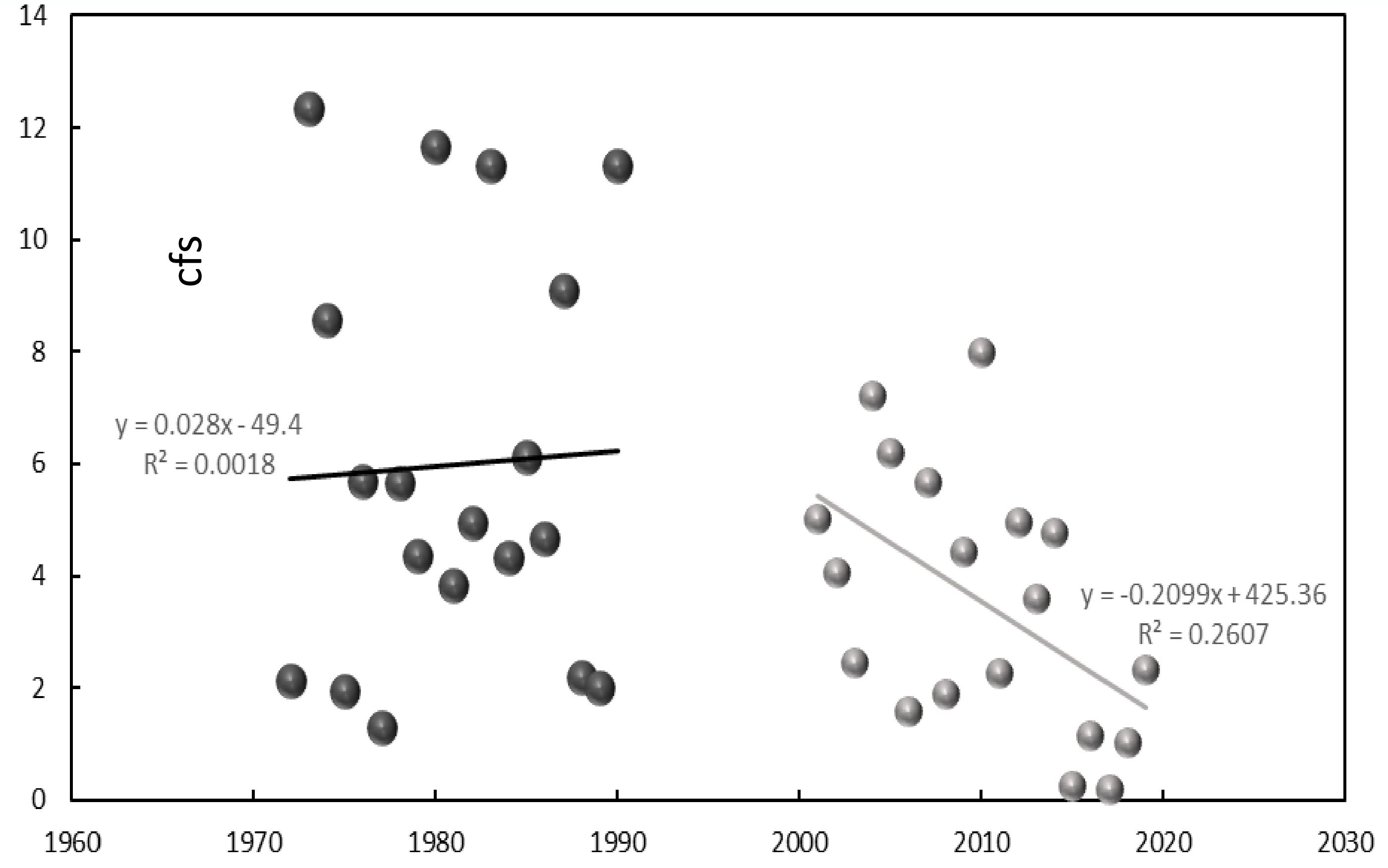
# Group 2 IHA parameter comparisons

| Group 2. Magnitude and duration of annual extremes | 1972-1990 Average (cfs) | 2001-2019 | % difference |
|---|---|---|---|
| 1 day minimum | 5.20 | 3.44 | -34.0% |
| 1 day maximum | 501.32 | 544.25 | 8.6% |
| 3 day minimum | 5.98 | 3.54 | -40.8% |
| 3 day maximum | 431.72 | 453.63 | 5.1% |
| 7 day minimum | 6.92 | 3.85 | -44.4% |
| 7 day maximum | 351.07 | 361.91 | 3.1% |
| 30 day minimum | 11.32 | 7.48 | -33.9% |
| 30 day maximum | 222.61 | 233.40 | 4.8% |
| 90 day minimum | 18.73 | 13.82 | -26.2% |
| 90 day maximum | 159.32 | 156.19 | -2.0% |

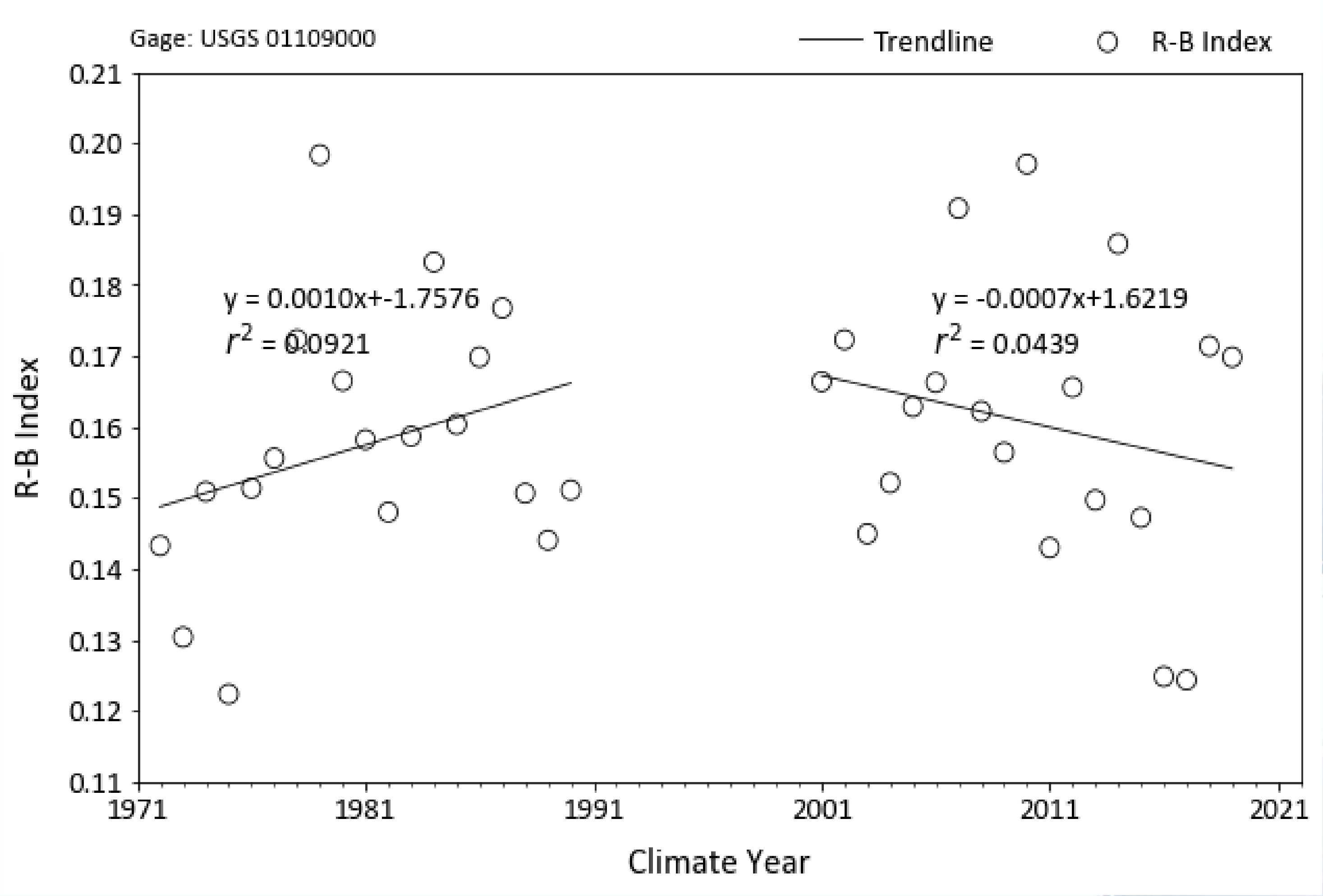
# Groups 3,4,5 IHA parameter comparisons

| | 1972-1990 | 2001-2019 | |
|---|---|---|---|
| Group 3. Timing of annual extremes | **Average Julian Day** | | % difference |
| Julian date of annual minimum | 230 | 249 | 8.30% |
| Julian date of annual maximum | 511 | 529 | 3.51% |
| Group 4. Frequency and duration of high (90th percentile) and low (10th percentile) pulses | **Average Count/Average # Days** | | % difference |
| Low pulse count | 453 | 771 | 70.20% |
| Low pulse duration (days) | 7.95 | 12.44 | 56.47% |
| High pulse count | 825 | 756 | -8.36% |
| High Pulse duration (days) | 6.11 | 5.77 | -5.57% |
| Group 5 Rate and frequency of change | **Average Count/ Average cfs** | | % difference |
| Fall rate (cfs) | 4569 | 4826 | 5.62% |
| Fall count | 22.58 | 22.69 | 0.48% |
| Rise rate(cfs) | 1956 | 1982 | 1.33% |
| Rise count | 4569 | 4826 | 5.62% |

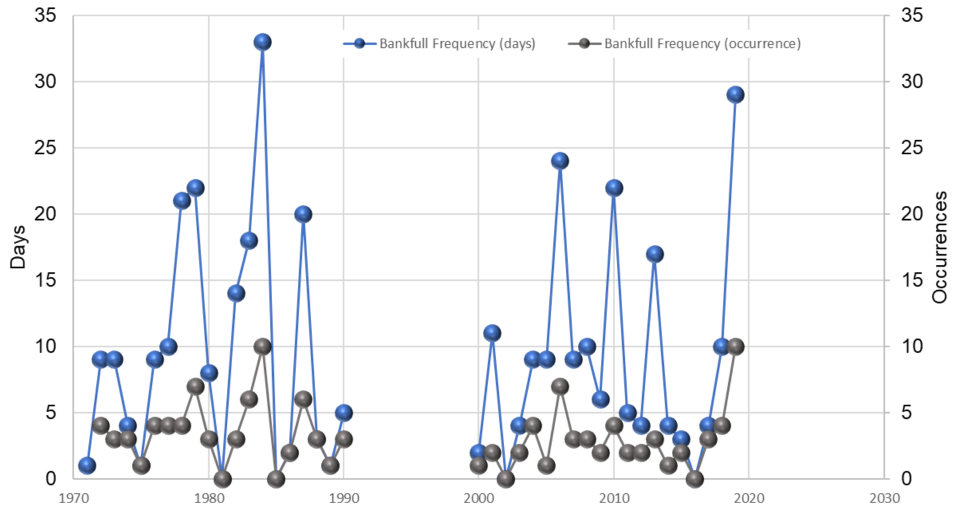
# 3-day minimum flows

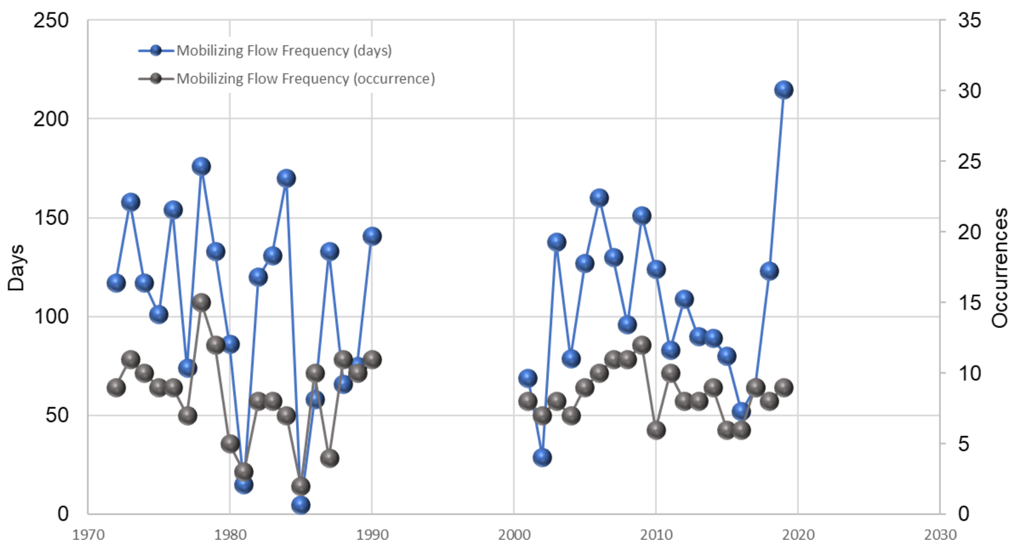


# Richard–baker flashiness

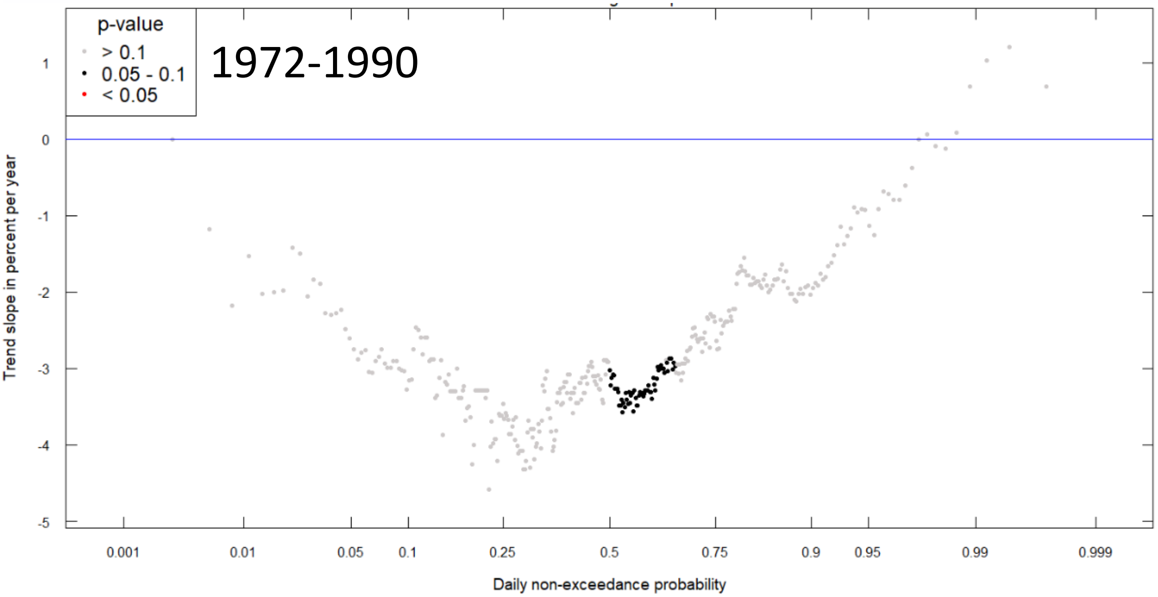


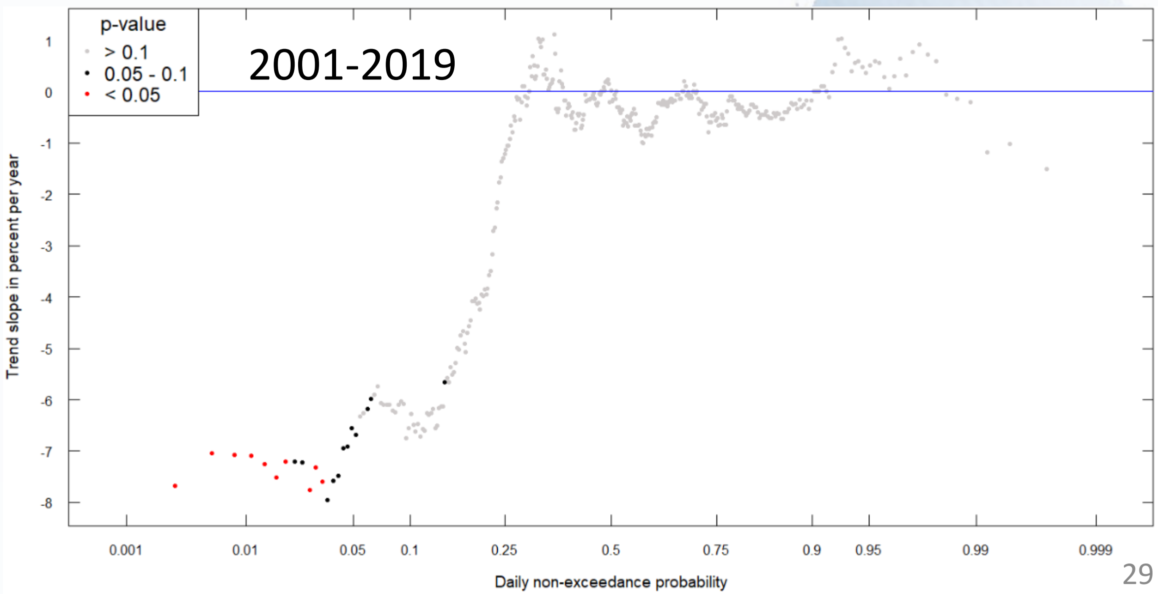
# Bankfull and mobilizing flows



# Quantile–Kendall



# Precipitation vs Streamflow

Landscape Ecology **17:** 471–489, 2002.



## Changes in anthropogenic impervious surfaces, precipitation and daily streamflow discharge: a historical perspective in a mid-atlantic subwatershed

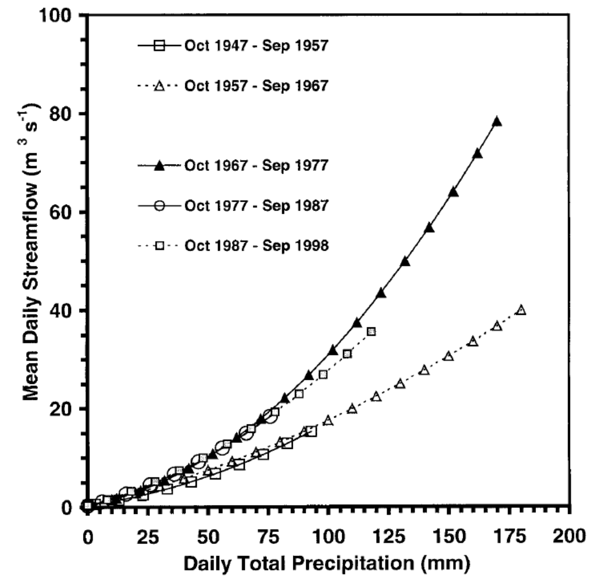
David B. Jennings* and S. Taylor Jarnagin
*US Environmental Protection Agency, 12201 Sunrise Valley Dr., Reston, VA 20192, USA; *Author for correspondence (e-mail: jennings.david@epa.gov)*

Received 28 August 2001; accepted in revised form 6 February 2002

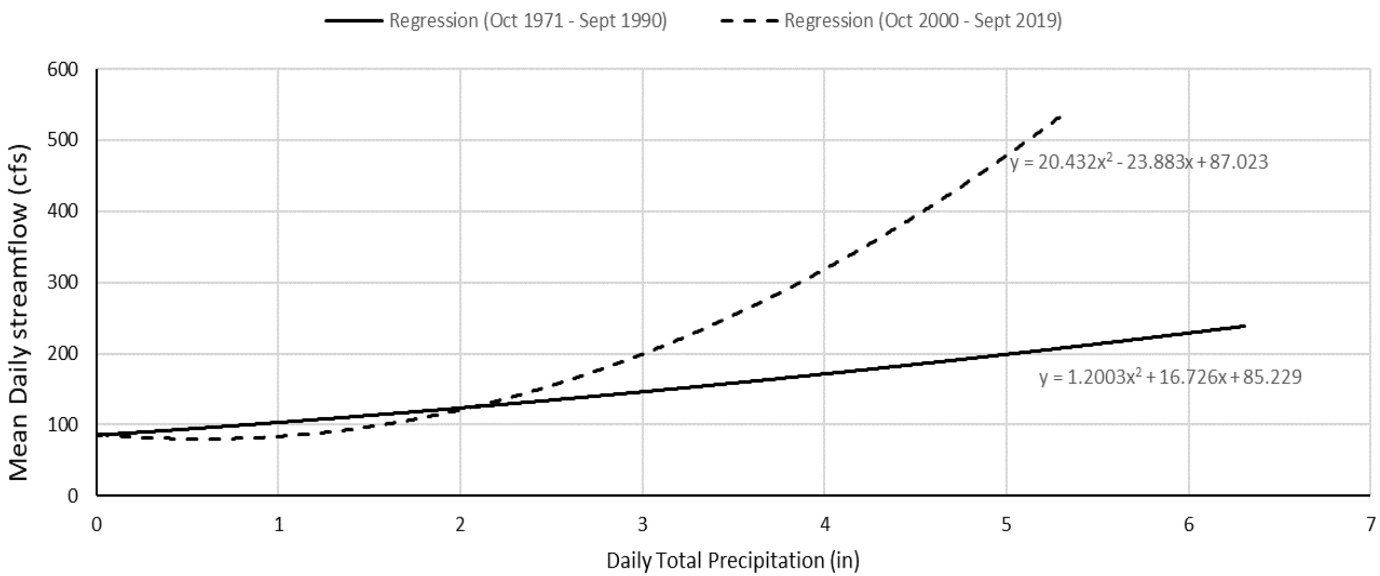
*Key words:* Historical aerial photography, Impervious surfaces, Precipitation, Streamflow, Urban landscape change

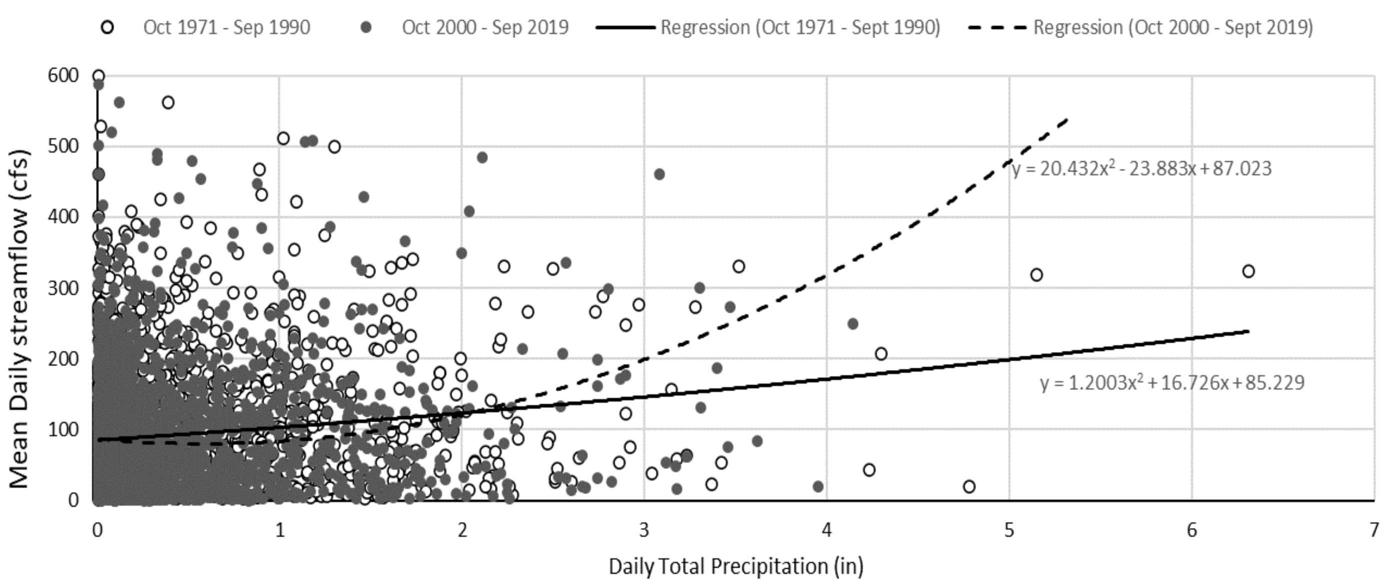
**Abstract**

Aerial photography provides a historical vehicle for determining long-term urban landscape change and, with concurrent daily streamflow and precipitation records, allows the historical relationship of anthropogenic impervious surfaces and streamflow to be explored. Anthropogenic impervious surface area in the upper Accotink Creek subwatershed (near Annandala, Virginia, USA) was mapped from six dates of rectified historical aerial photography ranging from 1949 to 1994. Results show that anthropogenic impervious surface area has grown from approximately 3% in 1949 to 33% in 1994. Coincident to this period, analysis of historical mean daily streamflow shows a statistically significant increase in the streamflow discharge response (per meter of precipitation) associated with "normal" and "extreme" daily precipitation levels. Significant changes were also observed in the frequency of daily streamflow discharge at given volumes above and below the historical daily mean. Simultaneously, the historical magnitude, frequency and pattern of precipitation values ⩾ 0 mm, ⩾ 6.0 mm and ⩾ 35.0 mm show either no statistically significant change or influence on streamflow. Historical changes in streamflow in this basin appear to be related to increases in anthropogenic impervious surface cover. Historical aerial photography is a viable tool for revealing long-term landscape and ecosystem relationships, and allows landscape investigations to extend beyond the temporal and spatial constraints of historical satellite remote sensing data.



# Streamflow vs precipitation

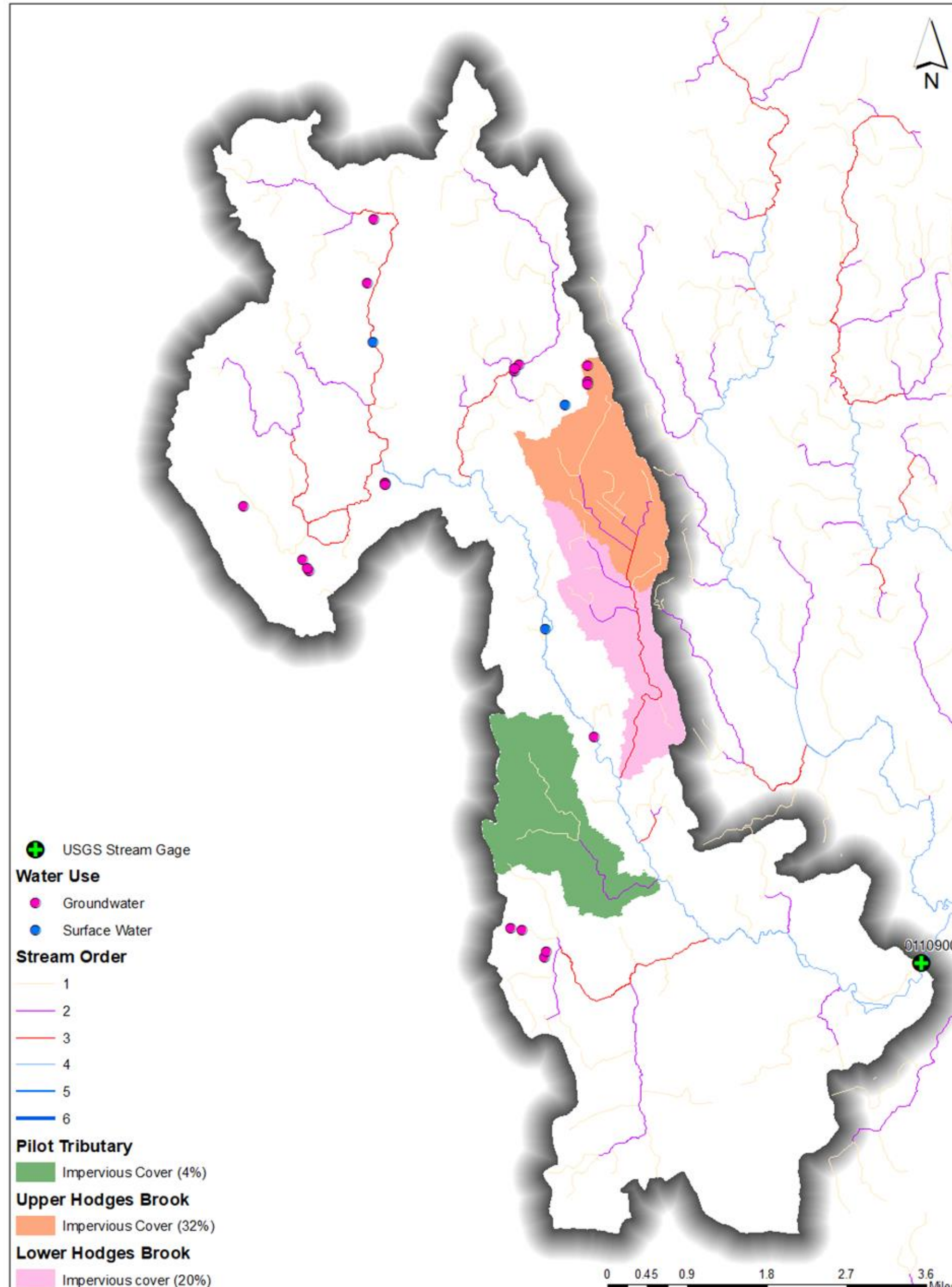


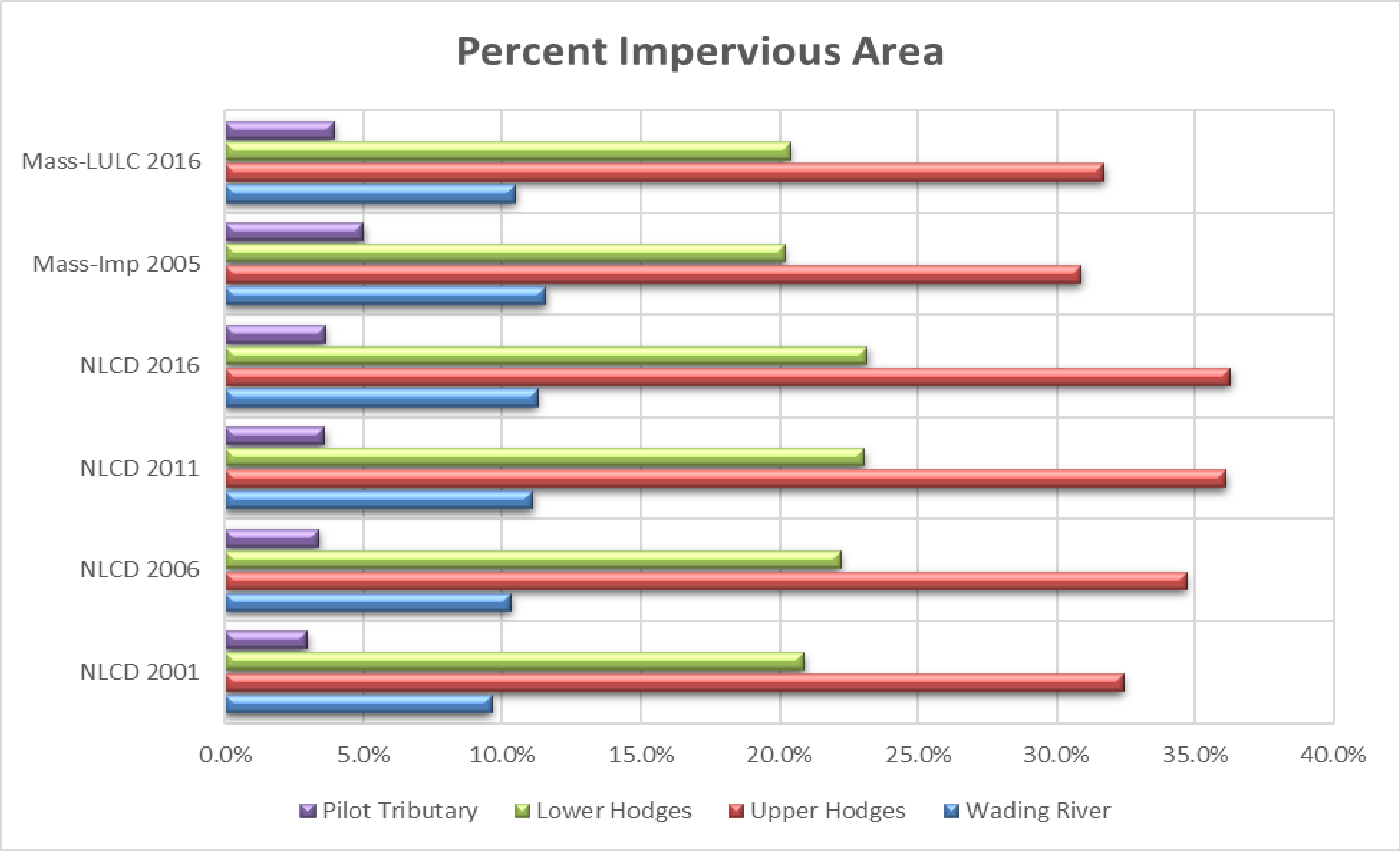
Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

# Pilot Sub-watershed selection

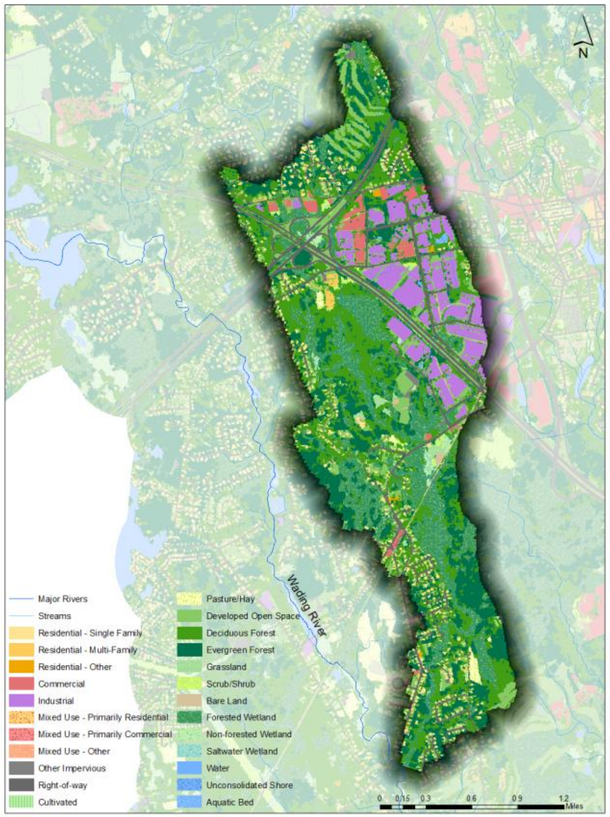
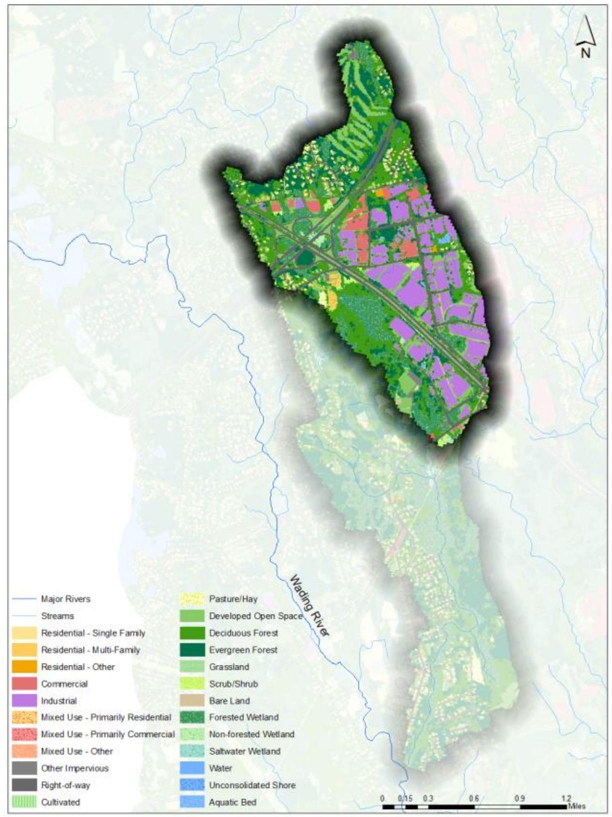
# Sub-watersheds



# Impervious Cover

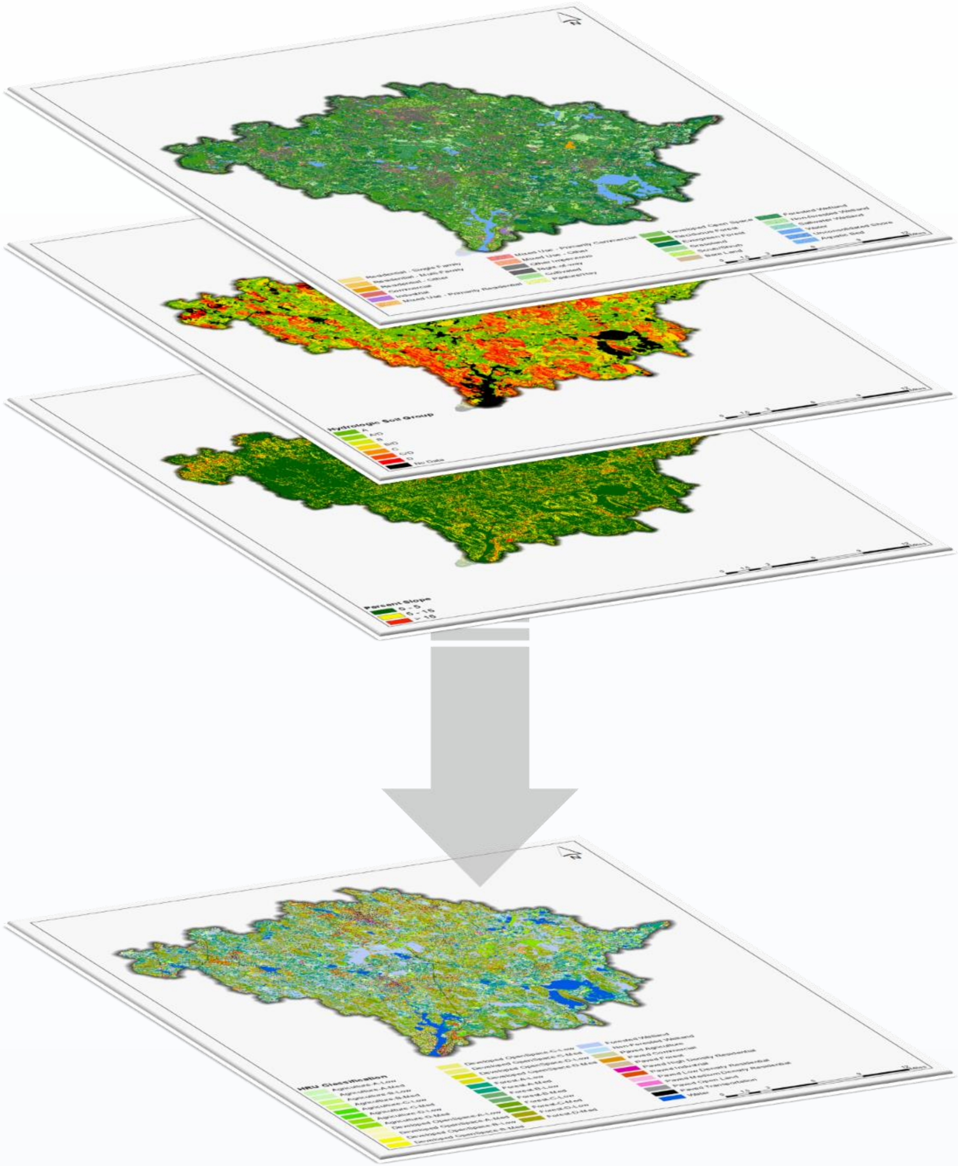


# Landuse

| Lower Hodges Brook | Upper Hodges Brook | Pilot Tributary |
|---|---|---|
|  |  |  |
| Area = 2,507 acre (3.9 mi$^2$)<br>IC = 20% | Area = 1,337 acre (2.1 mi$^2$)<br>IC = 32% | Area = 1,458 acre (2.3 mi$^2$)<br>IC = 4% |

Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

# HRU Development



Land Use / Land Cover

×

Hydrologic Soil Group

×

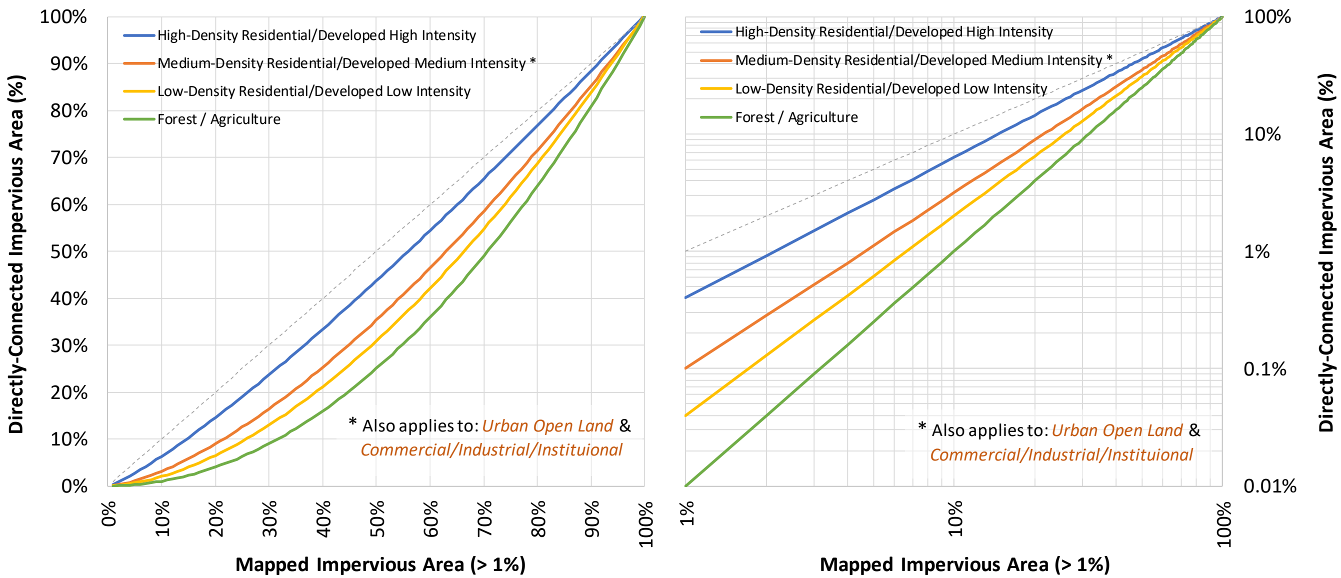
Slope

Hydrologic Response Unit

HRU Classification Table

| HRU Code | HRU Description | Land Use | Soil | Slope | Land Cover |
|---|---|---|---|---|---|
| 1001 | Paved Forest | Paved Forest | N/A | N/A | Impervious |
| 2001 | Paved Agriculture | Paved Agriculture | N/A | N/A | Impervious |
| 3001 | Paved Commercial | Paved Commercial | N/A | N/A | Impervious |
| 4001 | Paved Industrial | Paved Industrial | N/A | N/A | Impervious |
| 5001 | Paved Low Density Residential | Paved Low Density Residential | N/A | N/A | Impervious |
| 6001 | Paved Medium Density Residential | Paved Medium Density Residential | N/A | N/A | Impervious |
| 7001 | Paved High Density Residential | Paved High Density Residential | N/A | N/A | Impervious |
| 8001 | Paved Transportation | Paved Transportation | N/A | N/A | Impervious |
| 9001 | Paved Open Land | Paved Open Land | N/A | N/A | Impervious |
| 10110 | Developed OpenSpace-A-Low | Developed OpenSpace | A | Low | Pervious |
| 10120 | Developed OpenSpace-A-Med | Developed OpenSpace | A | Med | Pervious |
| 10210 | Developed OpenSpace-B-Low | Developed OpenSpace | B | Low | Pervious |
| 10220 | Developed OpenSpace-B-Med | Developed OpenSpace | B | Med | Pervious |
| 10310 | Developed OpenSpace-C-Low | Developed OpenSpace | C | Low | Pervious |
| 10320 | Developed OpenSpace-C-Med | Developed OpenSpace | C | Med | Pervious |
| 10410 | Developed OpenSpace-D-Low | Developed OpenSpace | D | Low | Pervious |
| 10420 | Developed OpenSpace-D-Med | Developed OpenSpace | D | Med | Pervious |
| 11000 | Forested Wetland | Forested Wetland | N/A | N/A | Pervious |
| 12000 | Non-Forested Wetland | Non-Forested Wetland | N/A | N/A | Pervious |
| 13110 | Forest-A-Low | Forest | A | Low | Pervious |
| 13120 | Forest-A-Med | Forest | A | Med | Pervious |
| 13210 | Forest-B-Low | Forest | B | Low | Pervious |
| 13220 | Forest-B-Med | Forest | B | Med | Pervious |
| 13310 | Forest-C-Low | Forest | C | Low | Pervious |
| 13320 | Forest-C-Med | Forest | C | Med | Pervious |
| 13410 | Forest-D-Low | Forest | D | Low | Pervious |
| 13420 | Forest-D-Med | Forest | D | Med | Pervious |
| 14110 | Agriculture-A-Low | Agriculture | A | Low | Pervious |
| 14120 | Agriculture-A-Med | Agriculture | A | Med | Pervious |
| 14210 | Agriculture-B-Low | Agriculture | B | Low | Pervious |
| 14220 | Agriculture-B-Med | Agriculture | B | Med | Pervious |
| 14310 | Agriculture-C-Low | Agriculture | C | Low | Pervious |
| 14320 | Agriculture-C-Med | Agriculture | C | Med | Pervious |
| 14410 | Agriculture-D-Low | Agriculture | D | Low | Pervious |
| 14420 | Agriculture-D-Med | Agriculture | D | Med | Pervious |
| 15000 | Water | Water | N/A | N/A | Pervious |

# Mapped vs Effective Impervious




(Sutherland 2000).

## Wading River Results *

| HRU Description | Total Impervious Area (acre) | Effective Impervious Area (acre) | EIA (%) |
|---|---|---|---|
| Paved Forest | 0.3 | 0.0 | 0% |
| Paved Agriculture | 3.4 | 0.0 | 0% |
| Paved Commercial | 375.8 | 96.5 | 26% |
| Paved Industrial | 366.2 | 103.5 | 28% |
| Paved Low Density Residential | 778.4 | 147.4 | 19% |
| Paved Medium Density Residential | 20.5 | 5.6 | 27% |
| Paved High Density Residential | 147.4 | 122.3 | 83% |
| Paved Transportation | 956.5 | 793.7 | 83% |
| Paved Open Land | 245.7 | 61.9 | 25% |
| **Total** | **2,894.2** | **1,330.9** | **46%** |

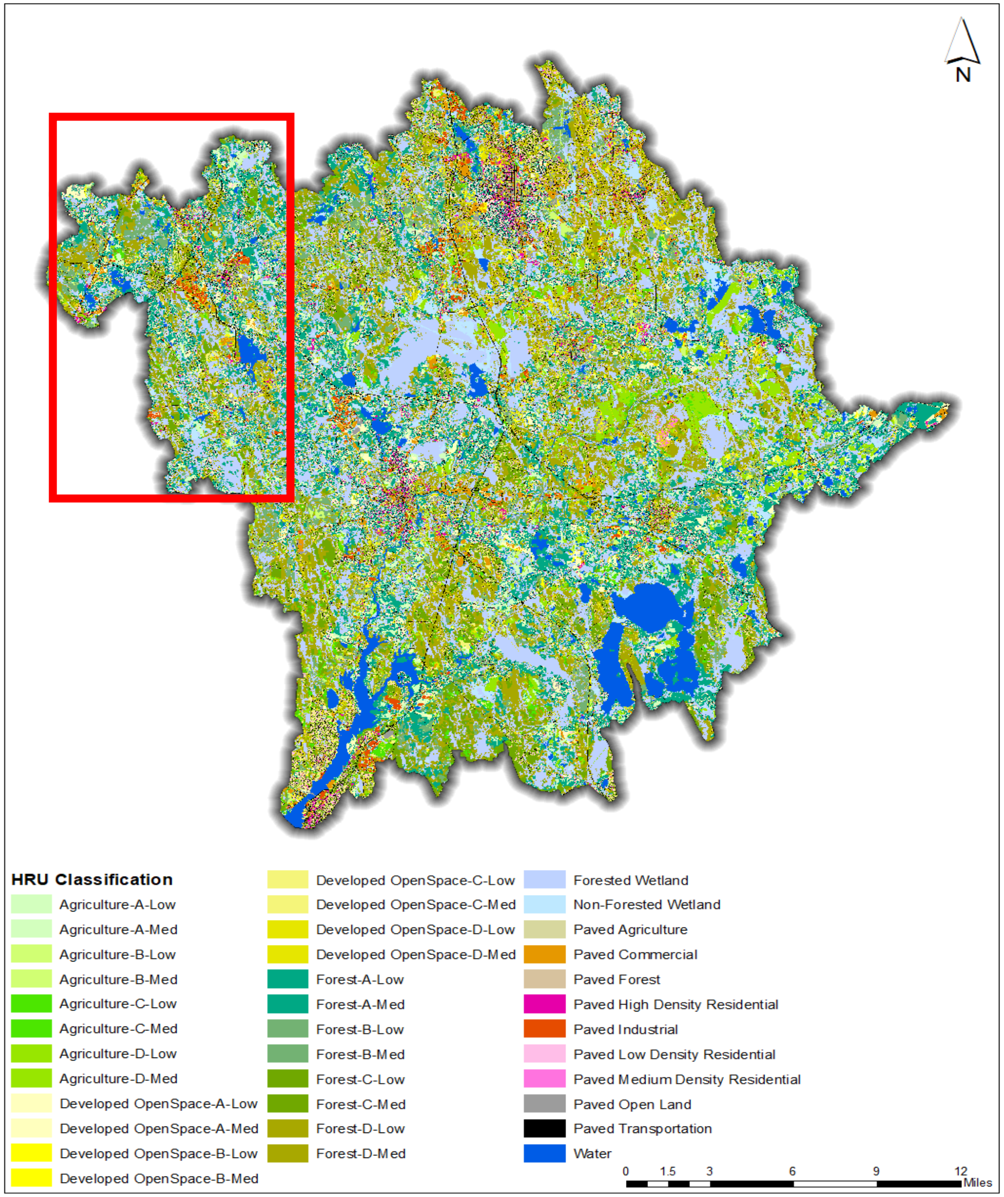
* *Basinwide summary. Distributions vary by sub-watershed*

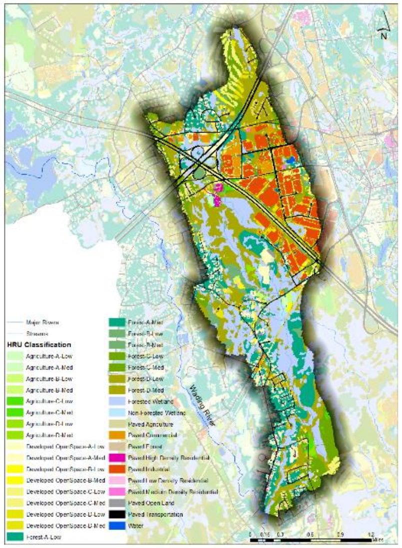
# Comparison to HSPF Model

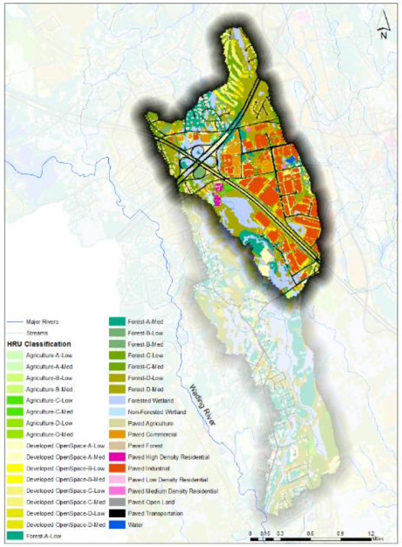
| Wading River Model | HSPF Model* (acre) | LSPC Model (acre) | Difference (%) |
|---|---|---|---|
| Total Impervious Area | 1,367.2 | 1,330.9 | -2.65% |
| Total Pervious Area | 26,231.4 | 26,270.3 | 0.15% |
| **Total** | **27,598.6** | **27,601.2** | **0.01%** |

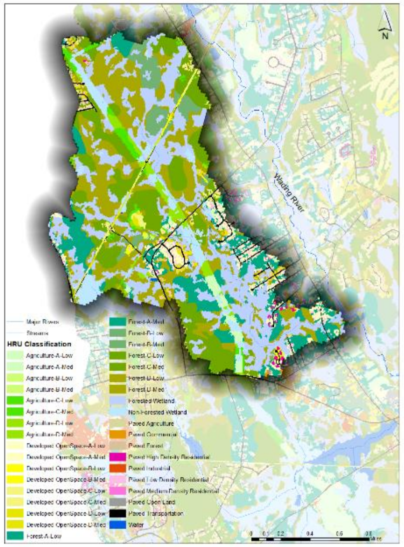
* USGS published HSPF models for the Taunton basin (Barbaro and Sorenson, 2013)

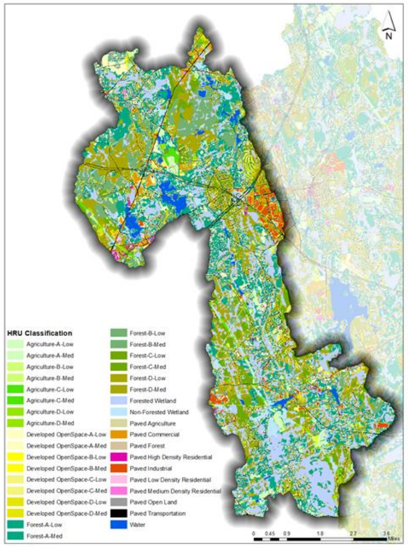
# HRUs for Taunton Basin





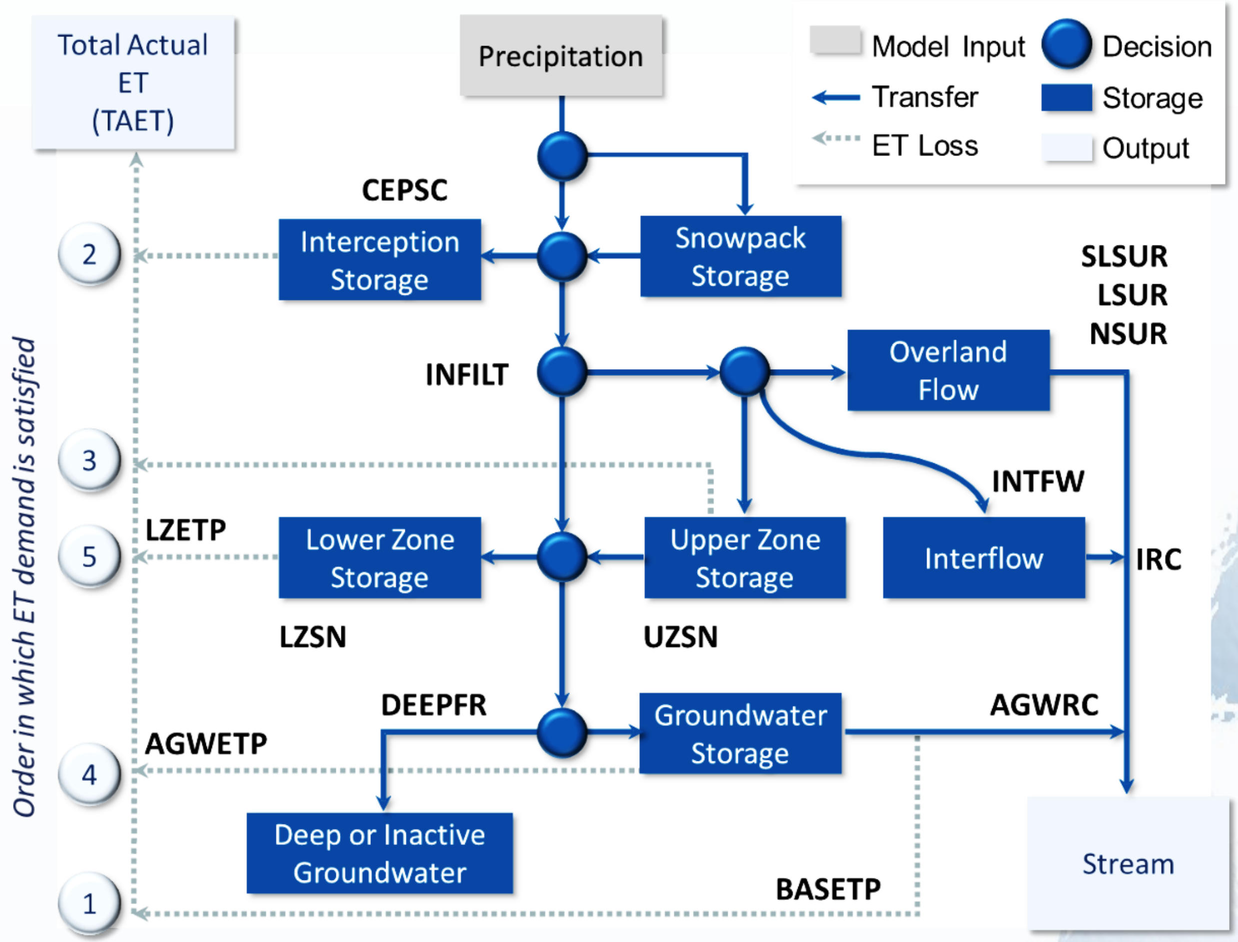




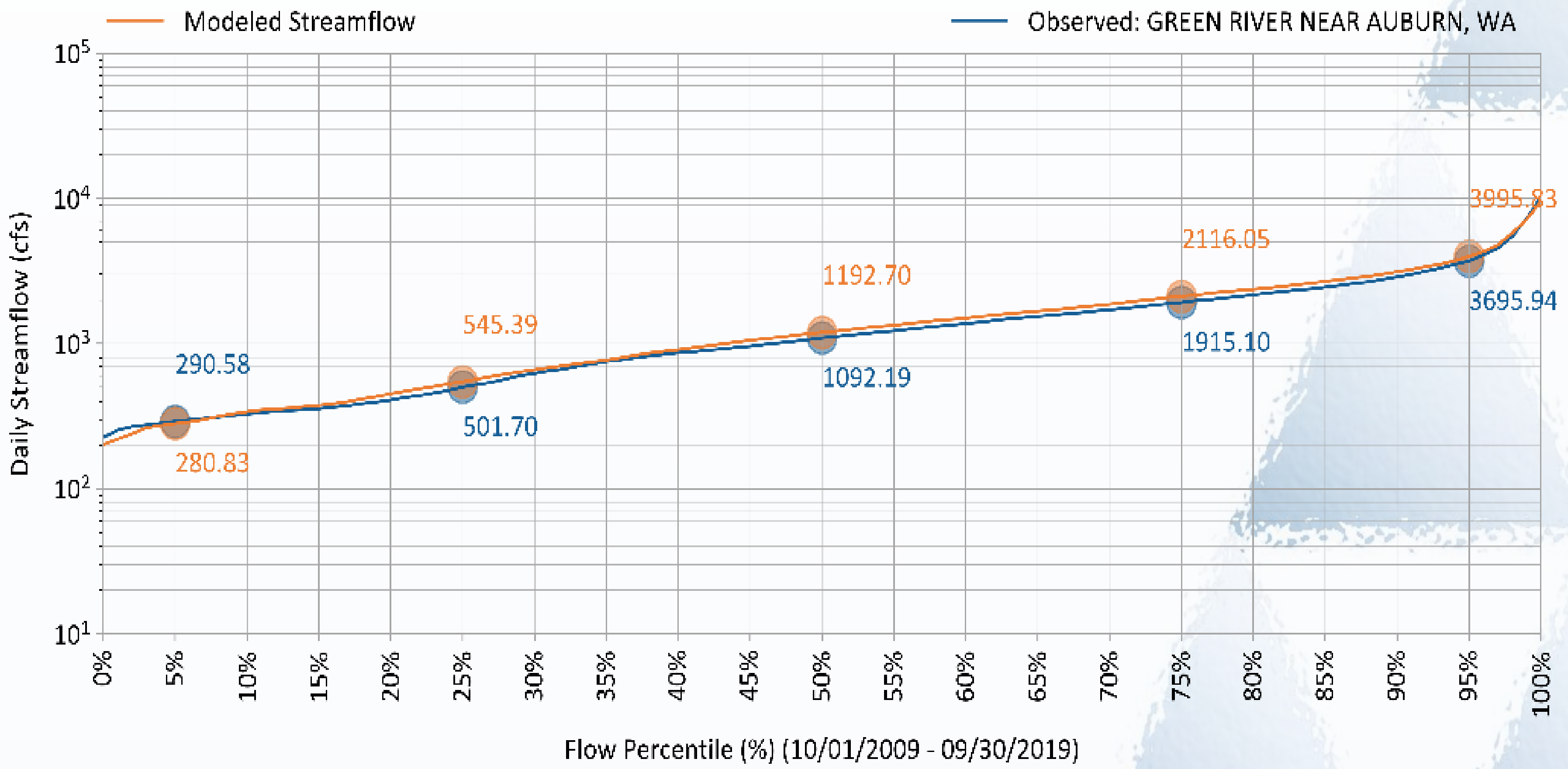
Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

# Proposed Modeling Approach

# Model schematic for hydrology



# Observed vs predicted FDCs



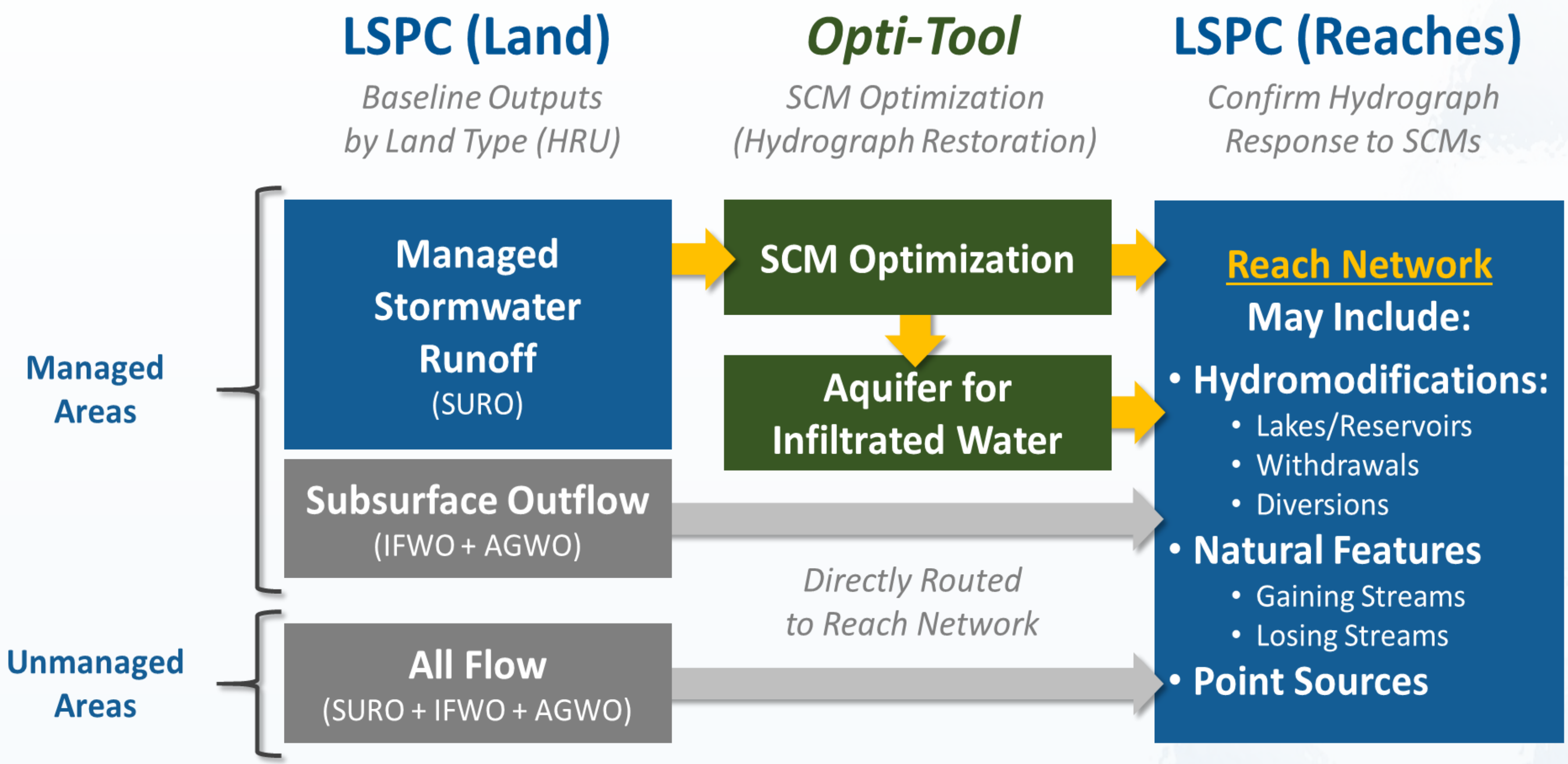
# Calibration metrics

| Hydrology Monitoring Locations | Performance Metrics (Seasonal) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PBIAS | | | | | R-squared | | | | | Nash-Sutcliffe E | | | | |
| | All | Winter | Spring | Summer | Fall | All | Winter | Spring | Summer | Fall | All | Winter | Spring | Summer | Fall |
| GREEN RIVER NEAR AUBURN, WA | - | - | + | - | - | | | | | | | | | | |
| GREEN RIVER AT 200TH STREET AT KENT, WA | - | - | - | - | - | | | | | | | | | | |
| CEDAR RIVER BELOW DIVERSION NEAR LANDSBURG, WA | + | + | + | + | - | | | | | | | | | | |
| CEDAR RIVER AT RENTON, WA | - | + | + | + | - | | | | | | | | | | |
| WHITE RIVER AT R STREET NEAR AUBURN, WA | + | + | + | + | + | | | | | | | | | | |

| Calibration Metrics | Recommended Error Criteria (PBIAS) | | | | Reference |
|---|---|---|---|---|---|
| | Very Good | Good | Satisfactory | Unsatisfactory | |
| All Conditions | <5% | 5% - 10% | 10% - 15% | >15% | Moriasi et al. (2015) |
| Seasonal Flows | <10% | 10% - 15% | 15% - 25% | >25% | |
| Highest 10% of Daily Flow Rates | | | | | |
| Lowest 50% of Daily Flow Rates | | | | | |
| Days Categorized as Storm Flow | | | | | |
| Days Categorized as Baseflow | | | | | |

| Calibration Metrics | Recommended Error Criteria ($R^2$) | | | | Reference |
|---|---|---|---|---|---|
| | Very Good | Good | Satisfactory | Unsatisfactory | |
| All Conditions | >0.85 | 0.75 - 0.85 | 0.60 - 0.75 | ≤0.60 | Moriasi et al. (2015) |
| Seasonal Flows | >0.75 | 0.60 - 0.75 | 0.50 - 0.60 | ≤0.50 | |
| Highest 10% of Daily Flow Rates | | | | | |
| Lowest 50% of Daily Flow Rates | | | | | |
| Days Categorized as Storm Flow | | | | | |
| Days Categorized as Baseflow | | | | | |

| Calibration Metrics | Recommended Error Criteria (E) | | | | Reference |
|---|---|---|---|---|---|
| | Very Good | Good | Satisfactory | Unsatisfactory | |
| All Conditions | >0.80 | 0.70 - 0.80 | 0.50 - 0.70 | ≤0.50 | Moriasi et al. (2015) |
| Seasonal Flows | >0.70 | 0.50 - 0.70 | 0.40 - 0.50 | ≤0.40 | |
| Highest 10% of Daily Flow Rates | | | | | |
| Lowest 50% of Daily Flow Rates | | | | | |
| Days Categorized as Storm Flow | | | | | |
| Days Categorized as Baseflow | | | | | |


LSPC (Land)
Baseline Outputs
by Land Type (HRU)
Opti-Tool
SCM Optimization
(Hydrograph Restoration)
LSPC (Reaches)
Confirm Hydrograph
Response to SCMs
Managed
Areas
Managed
Stormwater
Runoff
(SURO)
SCM Optimization
Aquifer for
Infiltrated Water
Reach Network
May Include:
• Hydromodifications:
• Lakes/Reservoirs
• Withdrawals
• Diversions
• Natural Features
• Gaining Streams
• Losing Streams
• Point Sources
Subsurface Outflow
(IFWO + AGWO)
Directly Routed
to Reach Network
Unmanaged
Areas
All Flow
(SURO + IFWO + AGWO)

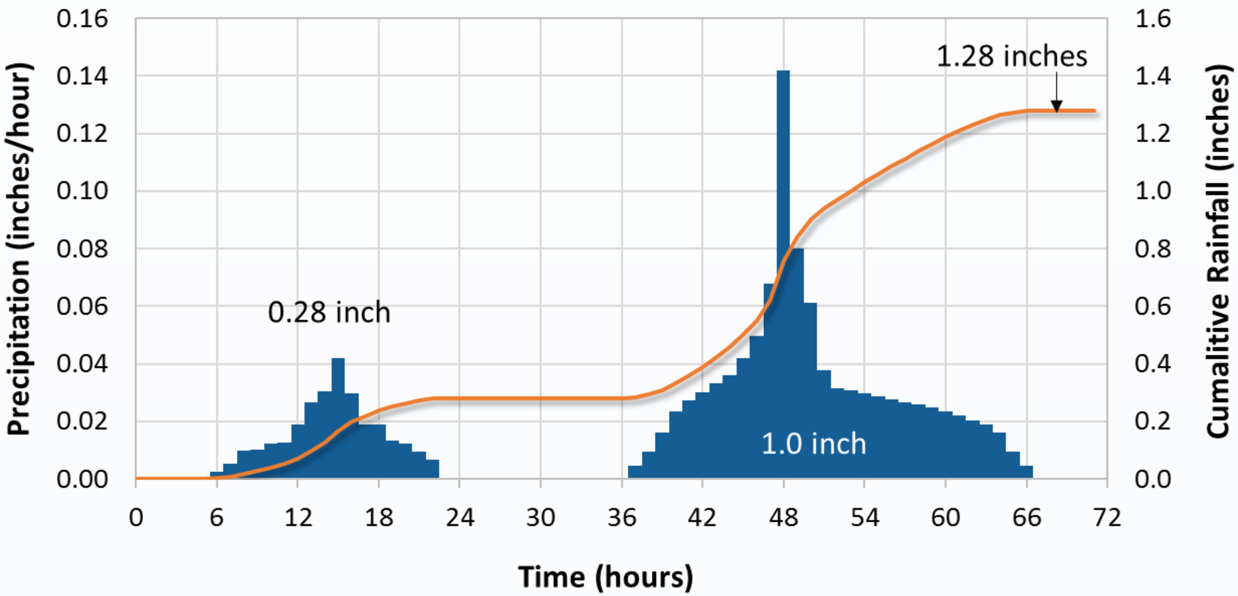
# Management Questions addressed through SCM optimization modeling

| Competing Management Questions | |
|---|---|
| Who? | Which agencies need to cooperate to address hydrology and water quality impairment? |
| What? | What types of and how many SCMs are needed to restore an impaired hydrograph? |
| When? | How should agencies prioritize, sequence, and build SCMs in a watershed of interest? |
| Where? | Where in the system do SCMs yield the most benefit toward management objectives? |
| Why? | What is the most cost-effective strategy that also has the highest likelihood of successful adoption and implementation? |
| How? | A multi-objective inclusive solution technique (MOIST) can help address competing management objectives |

# Multi-Objective Inclusive Solution Technique (MOIST)

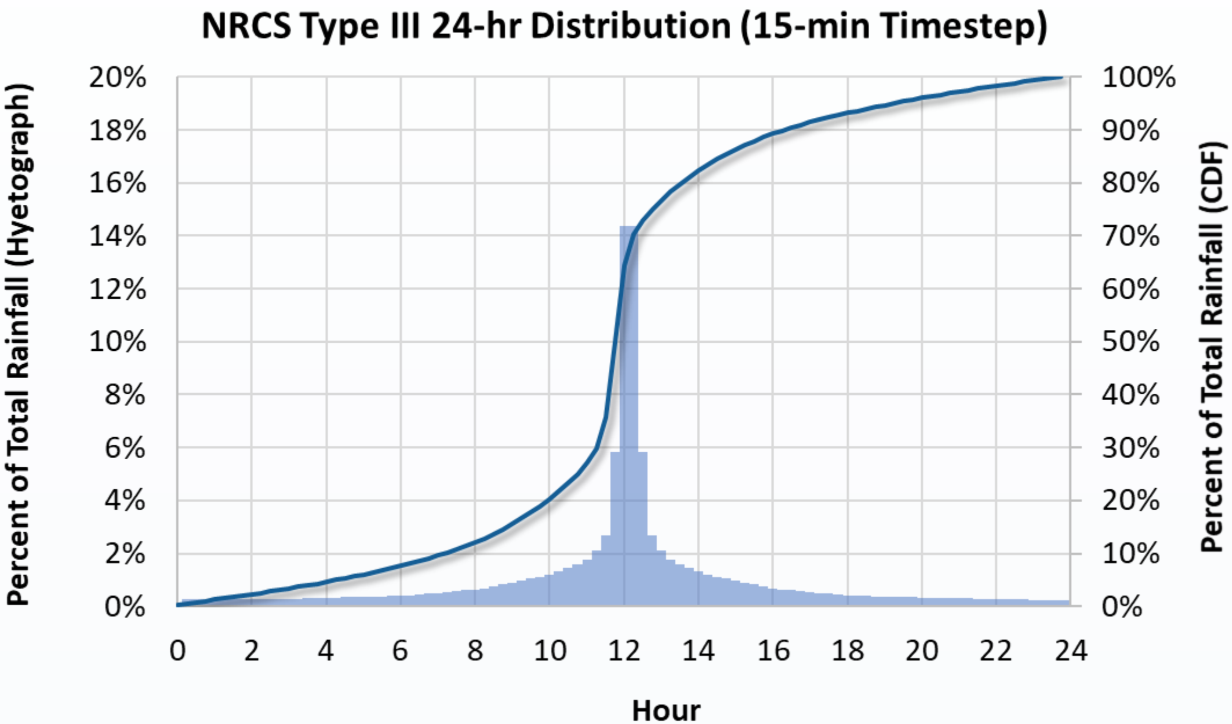
- Multi-Objective
  - Optimize BMP opportunities using a range storms (1-,2-,5-,10-,25-,50-year return periods)
  - Optimize for different desired outcomes and target constituents (e.g., minimize runoff volume, maximize pollutant load reduction)
- Inclusive
  - BMPs considered optimum for managing smaller storms should be part of the solution set for managing larger storms
- Solution Technique
  - Construct a Composite Objective Sequentially Tabulated (COST) curve that inclusively layers optimized BMP capacities from small to large storm.
  - Do a production run to generate CE curve using the new composite curve

# Example rainfall distributions and magnitudes




| Storm Description | | 72-hour Rainfall Volume | 72-hour Runoff Volume |
|---|---|---|---|
| 1 | "Average" Storm[1] | 2 inches | 1.25 inches |
| 2 | "Extreme" Condition[1] | 6.5 inches | 6.0 inches |
| 3 | "Flood" Scenario[2] | 40 inches | 39.5 inches |

# Representative Hyetal Distribution for this Region



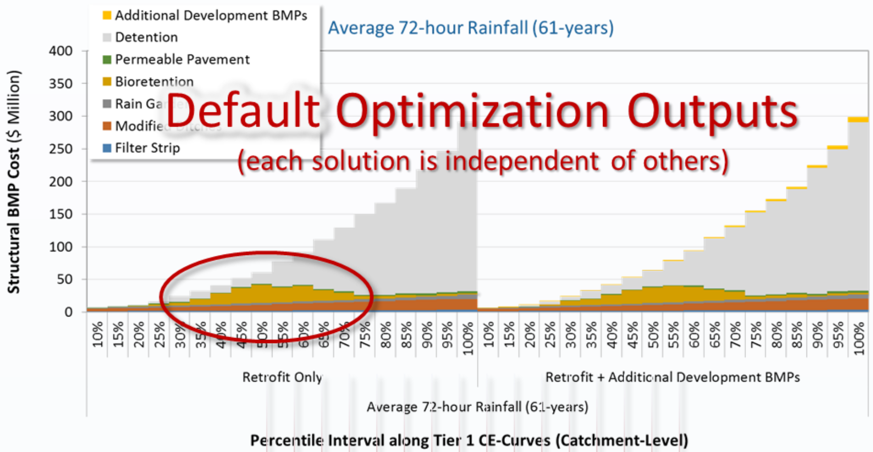

| Storm/Description | | Return Period | 24-hour Rainfall Volume |
|---|---|---|---|
| 1 | Small | 1-yr | 2.1 |
| 2 | | 2-yr | 2.8 |
| 3 | Medium | 5-yr | 3.3 |
| 4 | | 10-yr | 3.9 |
| 5 | Large | 25-yr | 5.1 |
| 6 | | 50-yr | 6.5 |

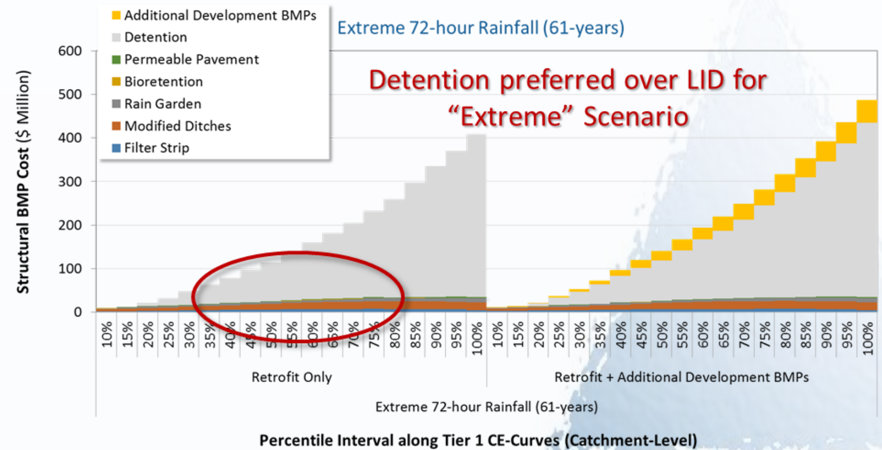
# Example analysis of "Average," "Extreme" and "Flood" scenarios

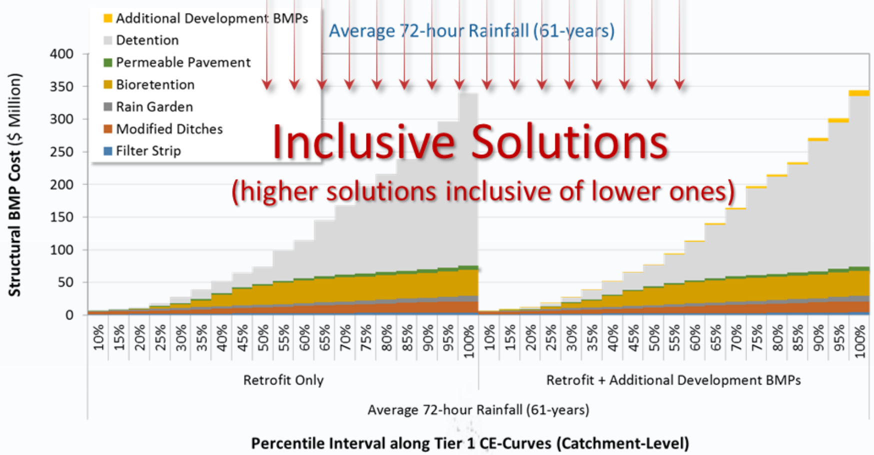
| | Storm Description | 72-hour Rainfall Volume | 72-hour Runoff Volume |
|---|---|---|---|
| 1 | "Average" Storm | 2 inches | 1.25 inches |
| 2 | "Extreme" Condition | 6.5 nches | 6.0 inches |
| 3 | "Flood" Scenario | 40 inches | 39.5 inches |

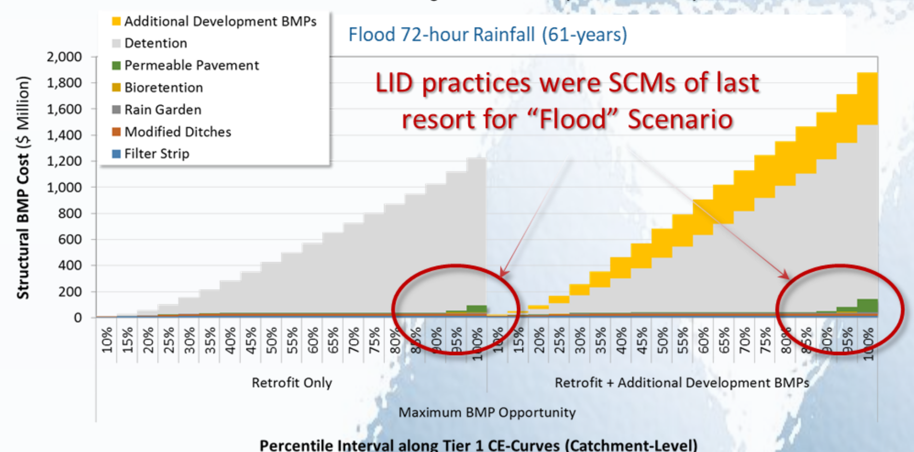
"Average" Storm

"Extreme" and "Flood" Storms

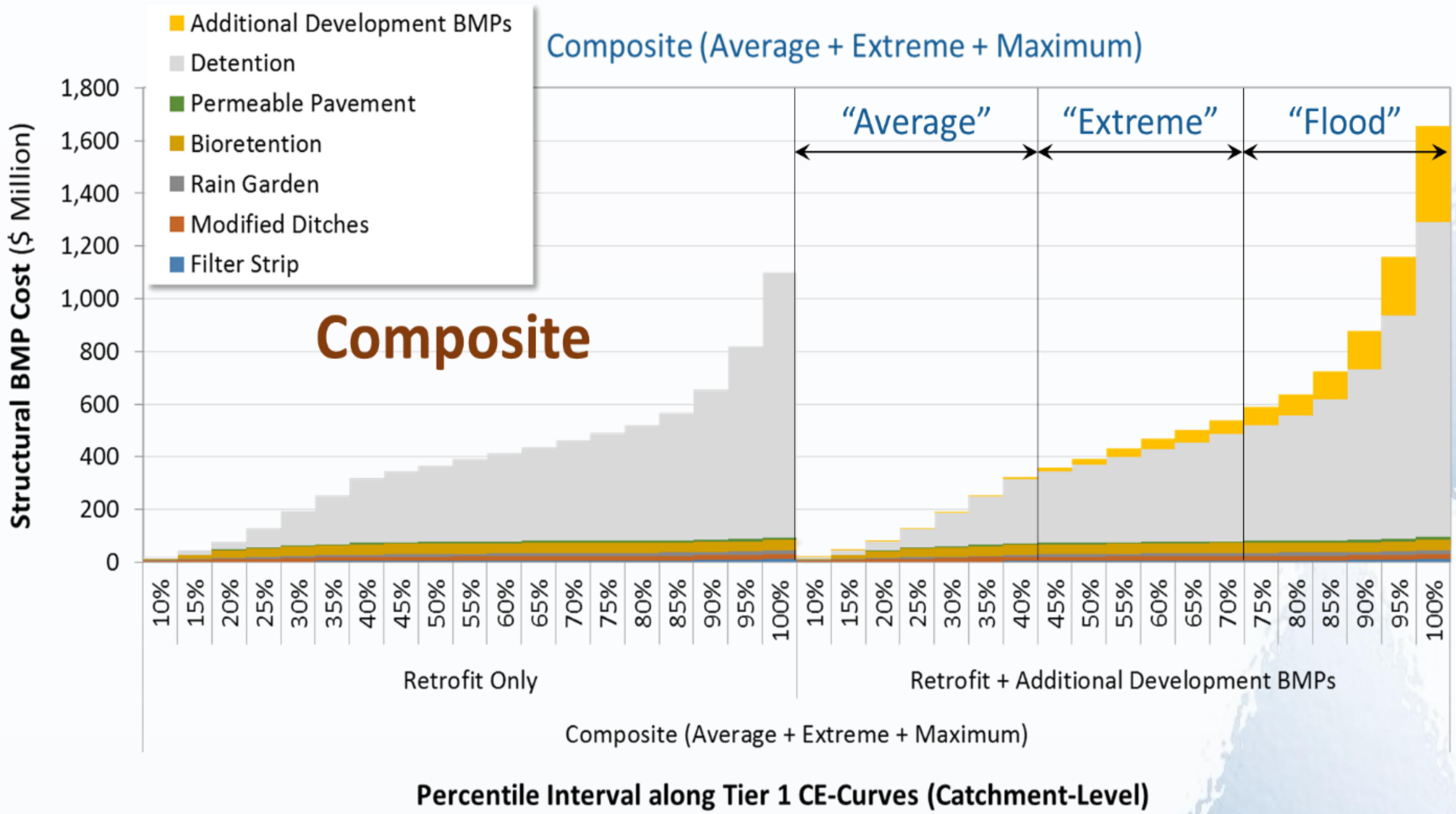


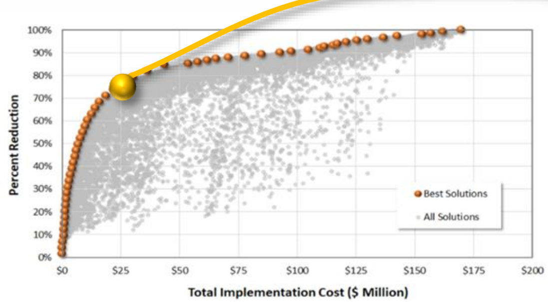



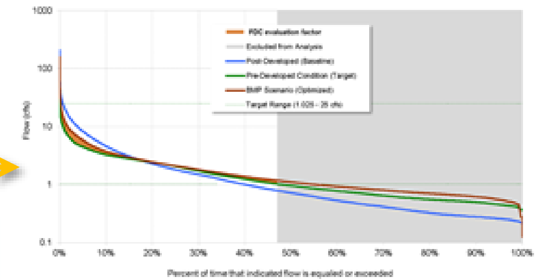
# Composite Curve



# Simulation Sequence




Each point on the curve has a unique FDC



**Step 1:** **Opti-Tool**

*SCM Optimization (Stormwater Infiltration)*

**Identify Shorter Representative Time Period(s)**
e.g., [Wet Year]

*LSPC: SURO*

**Optimize SCMs: Derive Tier 1 CE-Curves**

*SUSTAIN*

*Optimally sized SCM capacities from Tier 1 are locked down for the full FDC Simulation Run.*

*IFWO +AGWO + Infiltrated Stormwater are added back in here*

**Step 2:**

*FDC Simulation (Hydrograph Restoration)*

**Long-term Continuous Simulation**
e.g., [25-years]

**Cost-Optimal Sizes for SCM Network**

**Generate FDC and Compute Hydrograph IHA Metrics**

**Step 3:**

*Validation*

**FDC Validation**

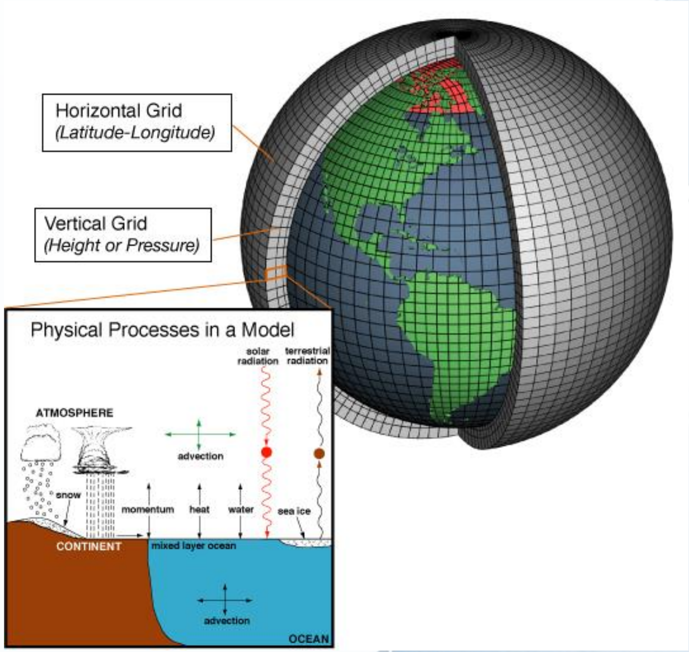
*Evaluate FDC curves at a downstream assessment point to demonstrate that SCMs achieve long-term instream management objectives*

# Future Climate

## General circulation models (GCMs)

– Provide climate change predictions, but output is at relatively coarse temporal and spatial resolutions.

– Most hydrological and water quality models require data at hourly timesteps or finer, and higher spatial resolutions depending on watershed size.



## Solution:

Downscale climate data for Taunton watershed using Local Constructed Analogs (LOCA). More info here

Use historical hourly data to identify "analog days" that can be used to disaggregate the future daily precipitation.

## Previous work: WMOST

Temperatures were adjusted based on absolute value of change and precipitation was adjusted based on percentage of change. Therefore, if the overall temperature was predicted to increase 2 degrees and precipitation was expected to increase 10%, every hourly record of temperature and precipitation was adjusted by those values, respectively.

| Climate Change | | 6-hour Storm Size (in.) | | | | | |
|---|---|---|---|---|---|---|---|
| Scenario | Model | 2-yr | 5-yr | 10-yr | 25-yr | 50-yr | 100-yr |
| Current (Historical) | | 1.91 | 2.38 | 2.77 | 3.31 | 3.74 | 4.18 |
| All | Median (All) | 2.07 | 2.65 | 3.13 | 3.84 | 4.49 | 5.16 |
| | Mean (All) | 2.11 | 2.72 | 3.25 | 4.01 | 4.65 | 5.35 |
| RCP 4.5 | Median (4.5) | 2.05 | 2.59 | 3.04 | 3.71 | 4.27 | 4.89 |
| | Mean (4.5) | 2.08 | 2.66 | 3.16 | 3.88 | 4.48 | 5.13 |
| | ACCESS1-0 | 2.07 | 2.59 | 3.05 | 3.76 | 4.36 | 5.03 |
| | CanESM2 | 2.20 | 2.93 | 3.54 | 4.42 | 5.15 | 5.95 |
| | CCSM4 | 2.02 | 2.58 | 3.00 | 3.53 | 3.91 | 4.28 |
| | CESM1-BGC | 2.18 | 2.75 | 3.31 | 4.20 | 5.02 | 5.97 |
| | CMCC-CMS | 2.16 | 2.72 | 3.12 | 3.61 | 3.95 | 4.27 |
| | CNRM-CM5 | 2.49 | 3.38 | 4.14 | 5.24 | 6.16 | 7.17 |
| | GFDL-CM3 | 1.98 | 2.41 | 2.78 | 3.31 | 3.73 | 4.18 |
| | HadGEM2-CC | 1.88 | 2.49 | 3.00 | 3.72 | 4.31 | 4.93 |
| | HadGEM2-ES | 1.92 | 2.38 | 2.85 | 3.61 | 4.29 | 5.10 |
| | MIROC5 | 1.87 | 2.41 | 2.84 | 3.45 | 3.92 | 4.42 |
| RCP 8.5 | Median (8.5) | 2.12 | 2.73 | 3.31 | 4.22 | 4.97 | 5.79 |
| | Mean (8.5) | 2.16 | 2.81 | 3.38 | 4.21 | 4.91 | 5.68 |
| | ACCESS1-0 | 2.04 | 2.59 | 3.12 | 3.99 | 4.78 | 5.71 |
| | CanESM2 | 2.41 | 3.31 | 4.07 | 5.18 | 6.11 | 7.12 |
| | CCSM4 | 2.08 | 2.64 | 3.09 | 3.69 | 4.14 | 4.60 |
| | CESM1-BGC | 2.27 | 2.88 | 3.47 | 4.40 | 5.23 | 6.19 |
| | CMCC-CMS | 2.30 | 3.09 | 3.69 | 4.47 | 5.05 | 5.64 |
| | CNRM-CM5 | 2.54 | 3.48 | 4.30 | 5.52 | 6.57 | 7.75 |
| | GFDL-CM3 | 1.97 | 2.46 | 2.85 | 3.37 | 3.77 | 4.16 |
| | HadGEM2-CC | 2.04 | 2.72 | 3.34 | 4.28 | 5.10 | 6.04 |
| | HadGEM2-ES | 2.14 | 2.71 | 3.28 | 4.20 | 5.04 | 6.03 |
| | MIROC5 | 1.76 | 2.22 | 2.56 | 2.99 | 3.30 | 3.60 |

Yellow highlighted are instances where the return period storm exceeds the historical 100-yr storm.

# Discussion

Holistic Watershed Management for Existing and Future Land use Development Activities: Opportunities for Action for Local Decision Makers

Flow metrics to prioritize?

Existing stormwater management practices in the area?

Use of regression equations for bankfull discharge in pilot streams?

Bed material in pilot streams?

Other local information that we’re missing?

# Next Steps

- Task 6
- TSC Meeting #3
- June 24, 2021

# Task 6. Model Development

- Model Refinements
  - **Convert HSPF to LSPC**
    - Adopt hydrology parameters from HSPF model
    - Adopt water quality parameters from Opti-Tool HRU-SWMM model
  - **Update Opti-Tool**
    - GI SCM groundwater recharge linkage to local surface water
    - FDC evaluation factors for GI SCM optimization
- Model Calibration/Validation
  - **Verify the model prediction at the instream gage using the long-term observed continuous flow data**
    - Wading River Watershed
    - USGS gage 01109000
    - Baseline (2001-2019)
    - Historic (1972-1990) EIA as calibration parameter?

# Task 6. Model Results

- FDC for Baseline Climate Condition (3 Sub-watersheds)
  - Pre-development
  - Historic development (1972-1990)
  - Existing development conditions (2001-2019)
- FDC for Future Climatic Condition (3 Sub-watersheds)
  - Pre-development
  - Historic development (1972-1990)
  - Existing development conditions (2001-2019)
- Quantify Impacts of IC Conversion
  - Critical streamflow regimes / metrics (e.g., flooding, channel scouring, baseflow depletion, etc.)
  - Stormwater runoff pollutant load export
  - Groundwater recharge
  - Evapotranspiration
  - Carbon sequestration and heat loss exchange