09/10/2020

Fine-scale Chesapeake Regional Hydrologic Model (CRHM)

Modeling Workgroup Conference Call – September 2020

Gary Shenk[1], Gopal Bhatt[2], Isabella Bertani[3]

[1] USGS, [2] Penn State, [3] UMCES – Chesapeake Bay Program Office

Presentation Outline

1. Overview – Gary Shenk
2. CRHM 2020 – Gopal Bhatt
3. CRHM 2020 | 2023 Data – Isabella Bertani

Chesapeake Regional Hydrologic Model (CRHM 2020 Version)

Gopal Bhatt[1], Lewis Linker[2], Gary Shenk[3], Isabella Bertani[4], Cuiyin Wu[5], Peter Claggett[3], Jeffery Chanat[3]

[1] Penn State, [2] US EPA, [3] USGS, [4] UMCES , [5] CRC – Chesapeake Bay Program Office

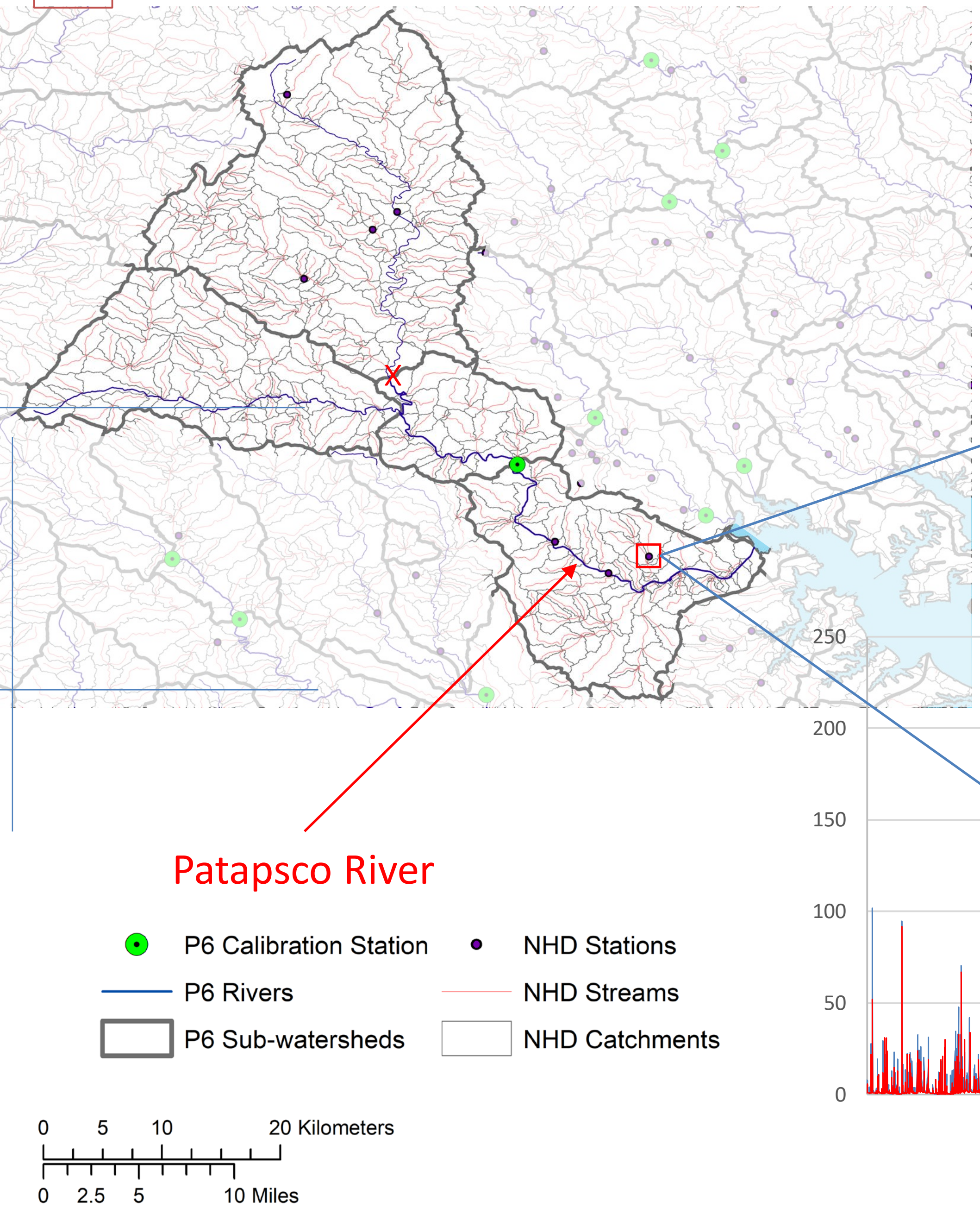
A. Model Performance Statistics

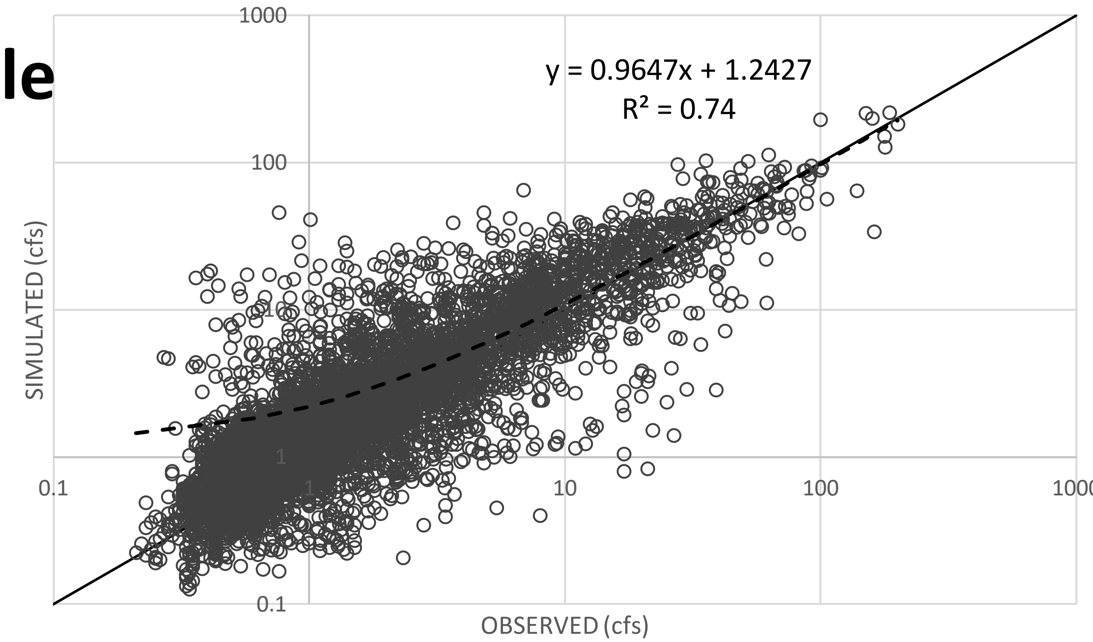
B. Verification of Downscaling at P6 Calibration Station

C. Modeling Team’s Discussions on the Next Steps

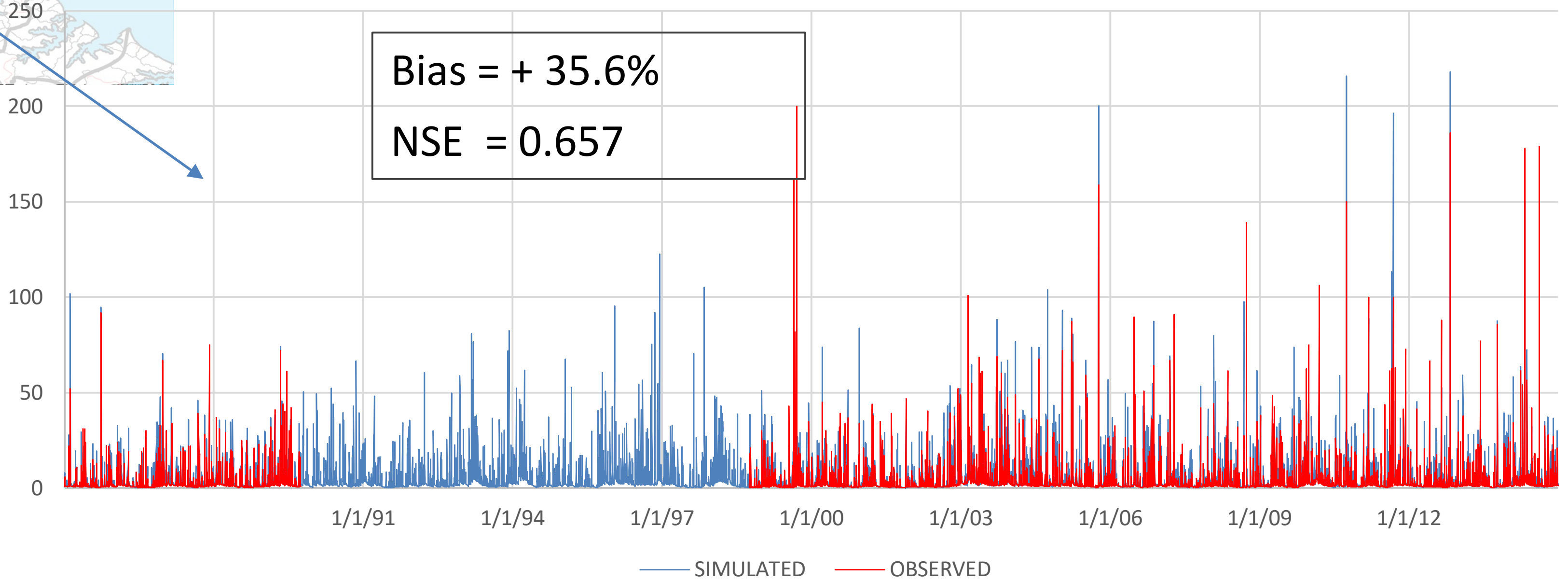
A

Downscaled streamflow at NHDplus scale

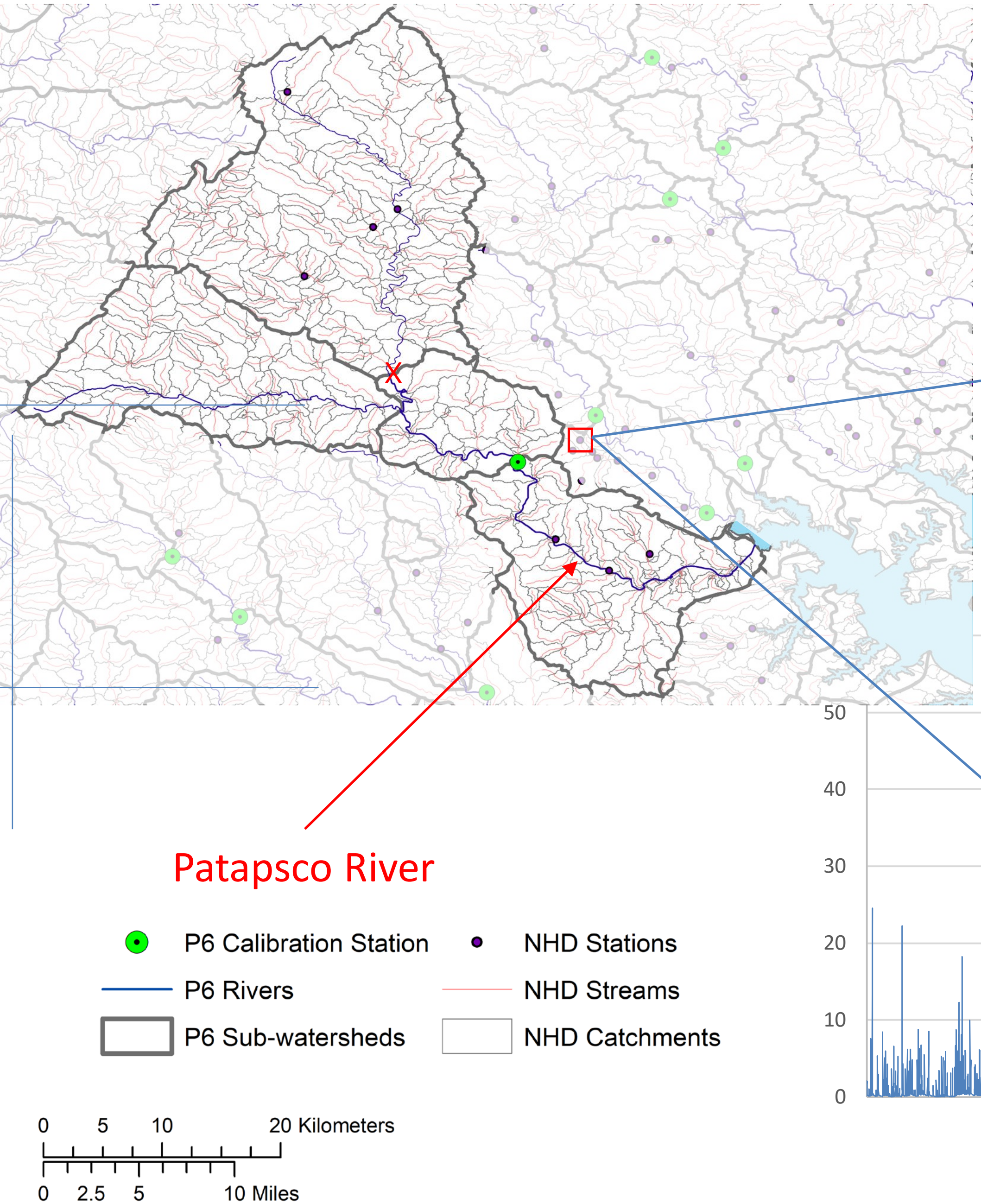


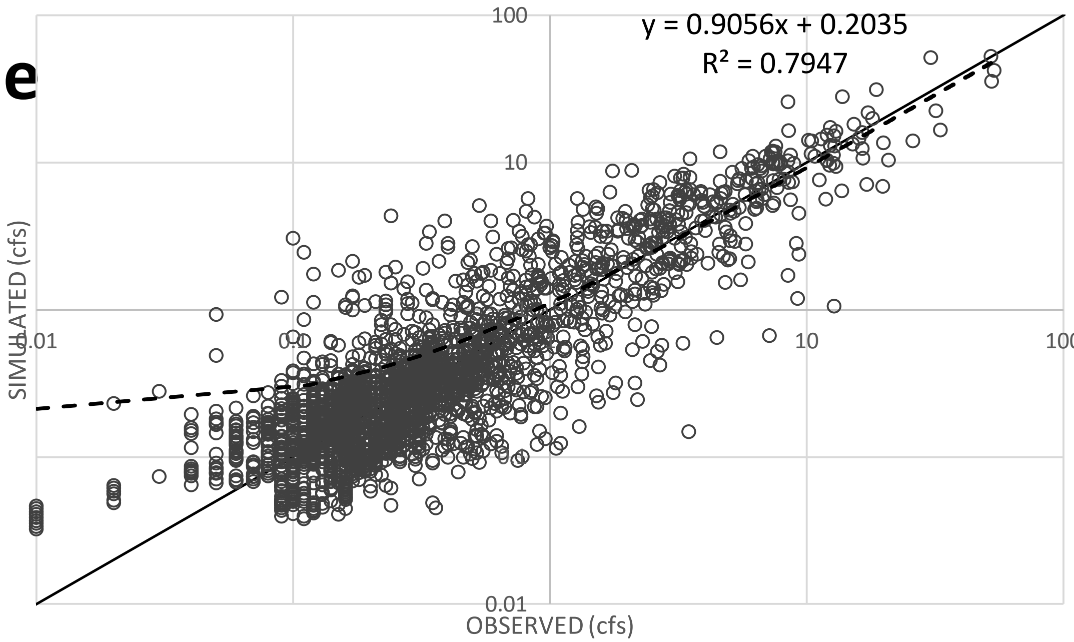


DAILY FLOW (cfs): USGS 01589100 EAST BRANCH HERBERT RUN AT ARBUTUS, MD; **DA = 2.47 mi^2; Flow = 3.6 ft^3/s**

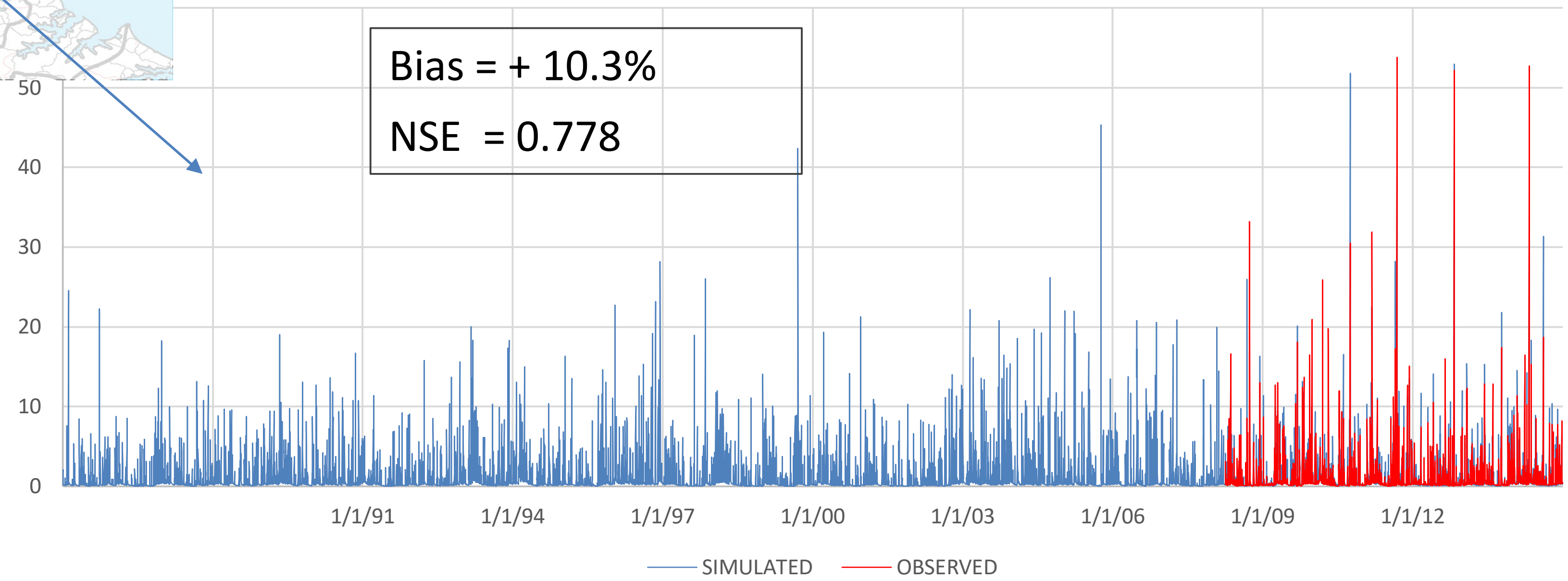


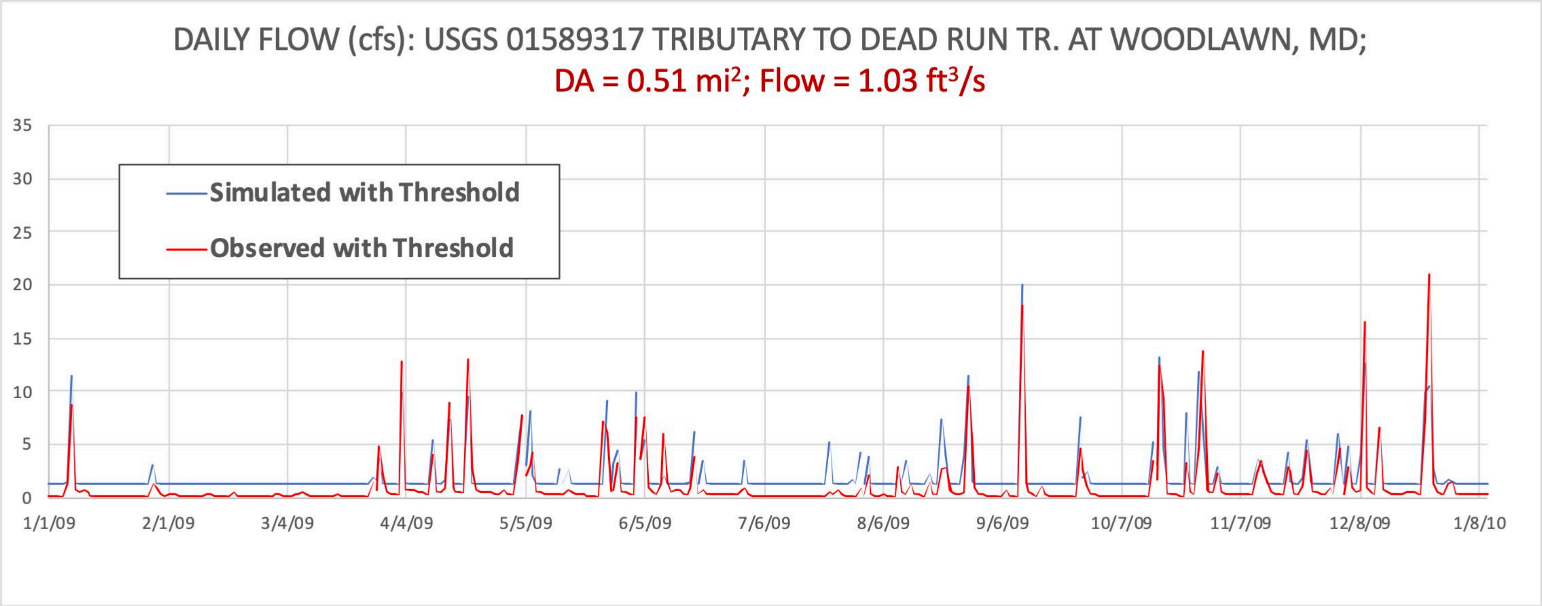
Downscaled streamflow at NHDplus scale

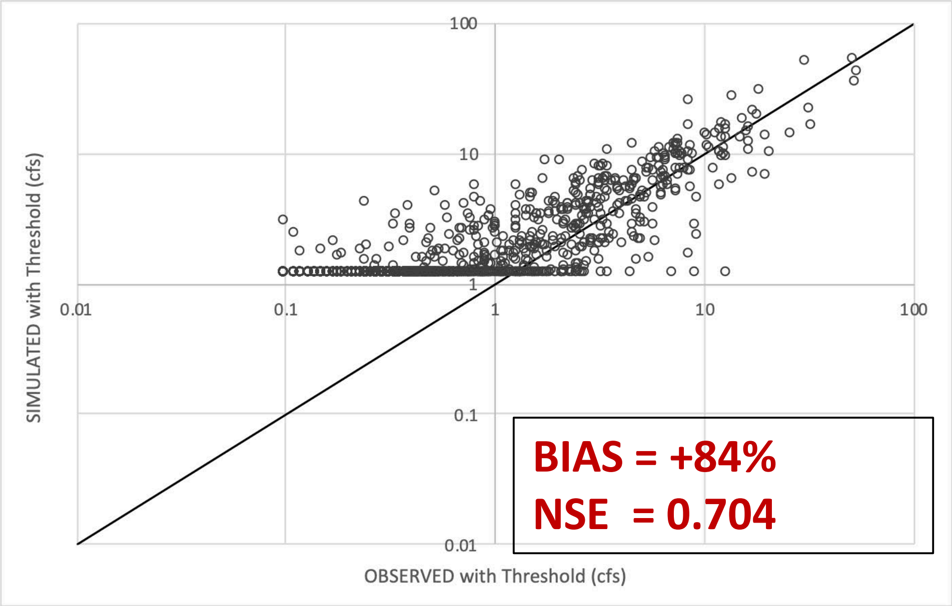


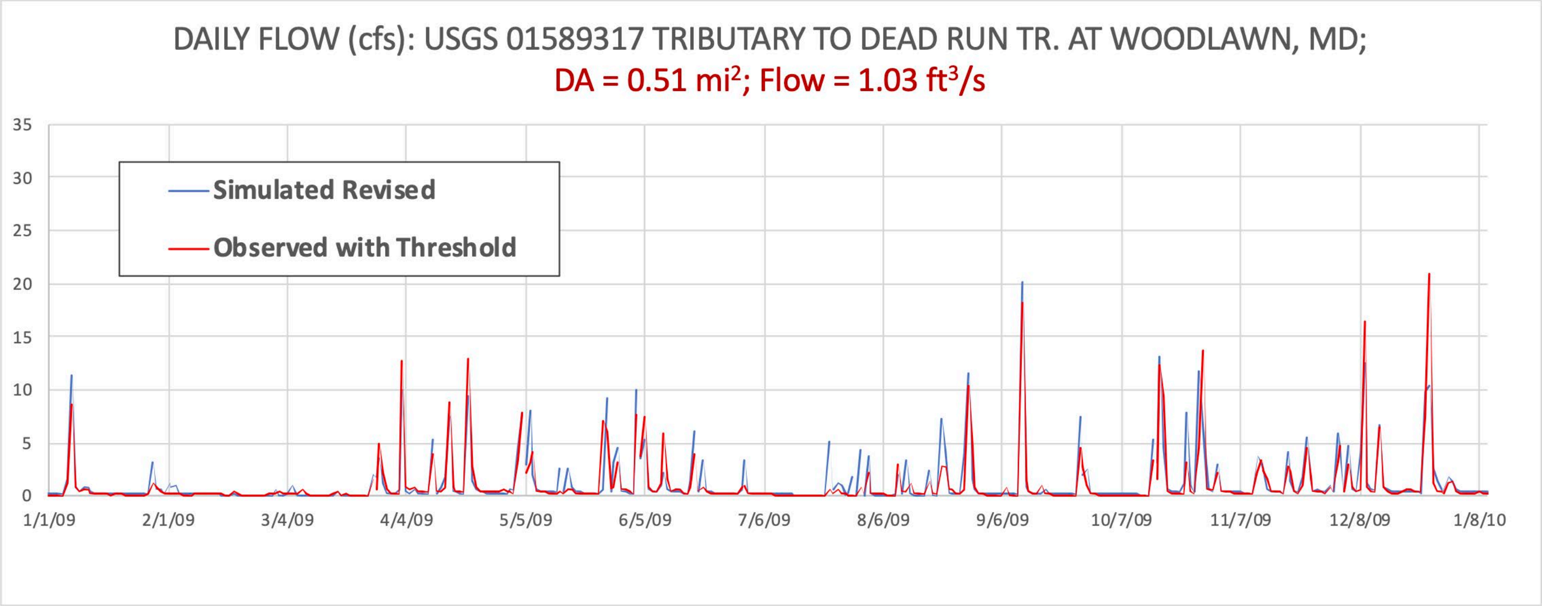


DAILY FLOW (cfs): USGS 01589317 TRIBUTARY TO DEAD RUN TR, AT WOODLAWN, MD; DA = 0.51 mi^2; Flow = 1.03 ft^3/s




DAILY FLOW (cfs): USGS 01589317 TRIBUTARY TO DEAD RUN TR. AT WOODLAWN, MD;
DA = 0.51 mi²; Flow = 1.03 ft³/s
Simulated with Threshold
Observed with Threshold
35
30
25
20
15
10
5
0
1/1/09
2/1/09
3/4/09
4/4/09
5/5/09
6/5/09
7/6/09
8/6/09
9/6/09
10/7/09
11/7/09
12/8/09
1/8/10


SIMULATED with Threshold (cfs)
OBSERVED with Threshold (cfs)
100
10
1
0.1
0.01
BIAS = +84%
NSE = 0.704


DAILY FLOW (cfs): USGS 01589317 TRIBUTARY TO DEAD RUN TR. AT WOODLAWN, MD;
DA = 0.51 mi²; Flow = 1.03 ft³/s
Simulated Revised
Observed with Threshold
35
30
25
20
15
10
5
0
1/1/09
2/1/09
3/4/09
4/4/09
5/5/09
6/5/09
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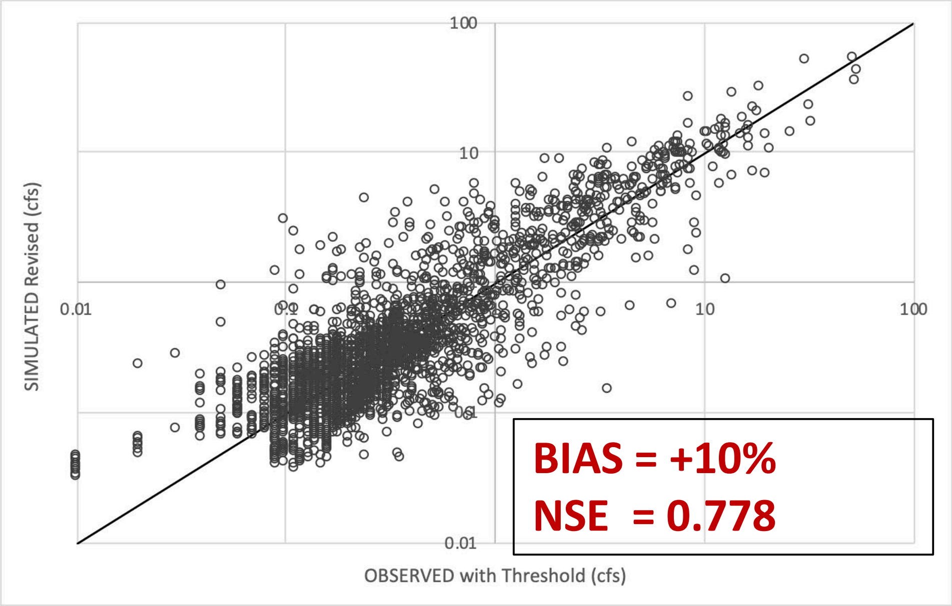
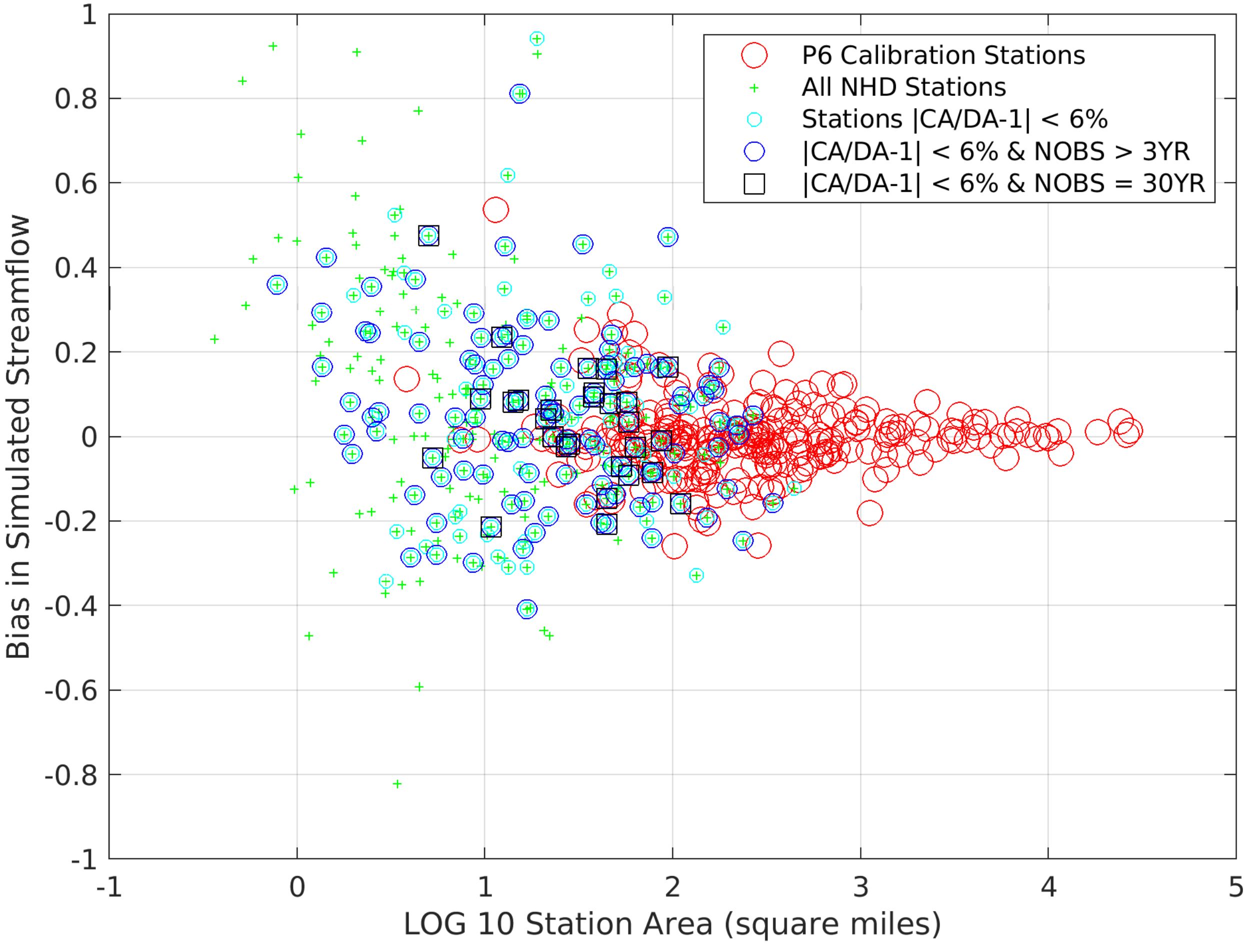
10/7/09
11/7/09
12/8/09
1/8/10

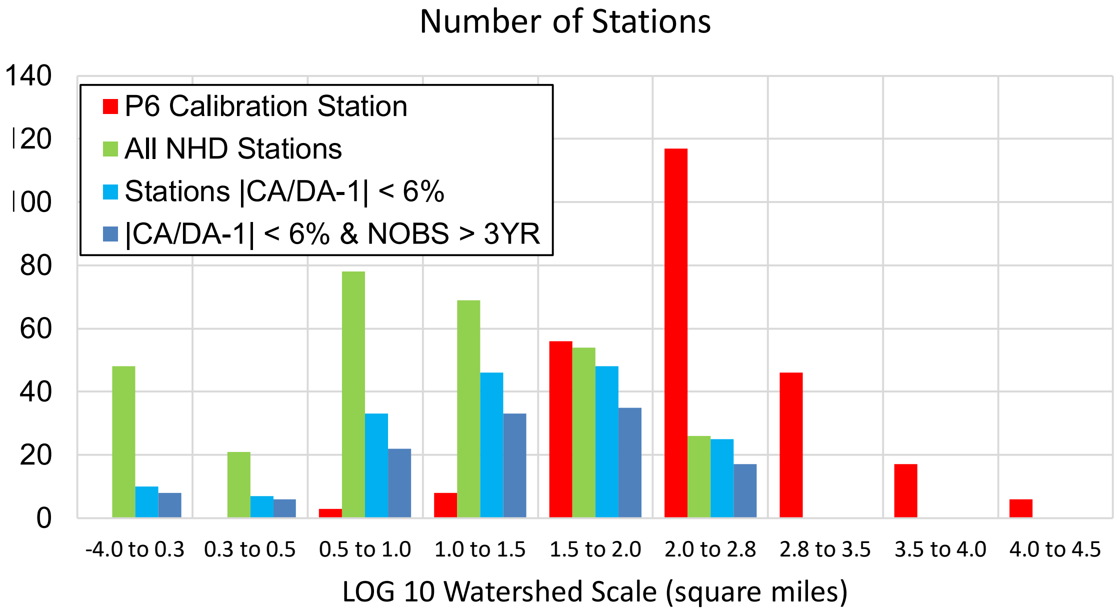

SIMULATED Revised (cfs)
OBSERVED with Threshold (cfs)
100
10
0.01
BIAS = +10%
NSE = 0.778

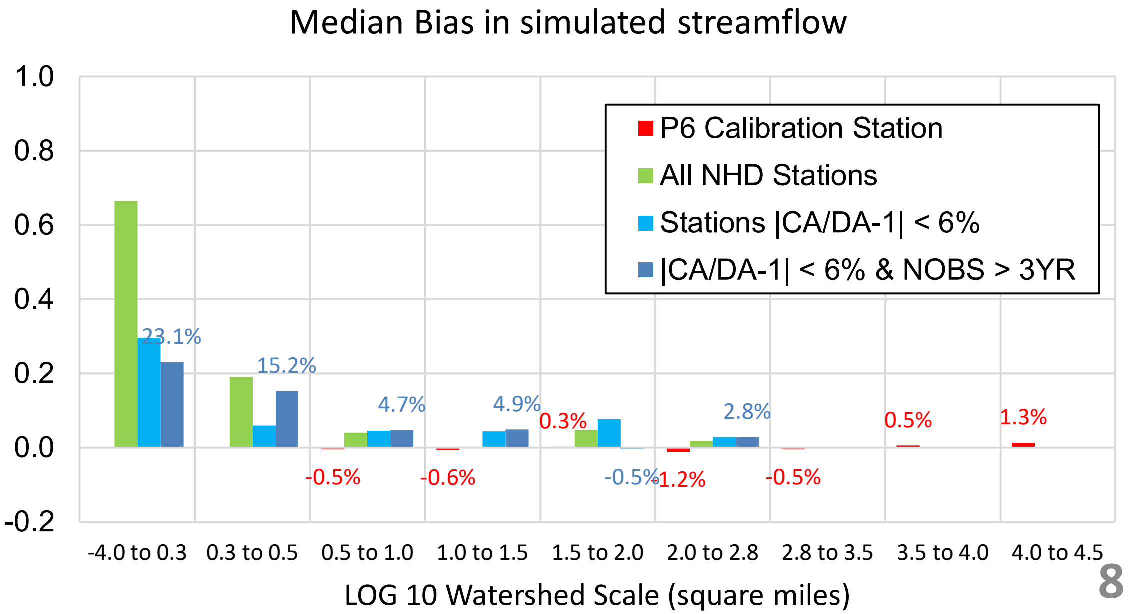
OLD

Bias in simulated streamflow

Bias closer to 0 is better



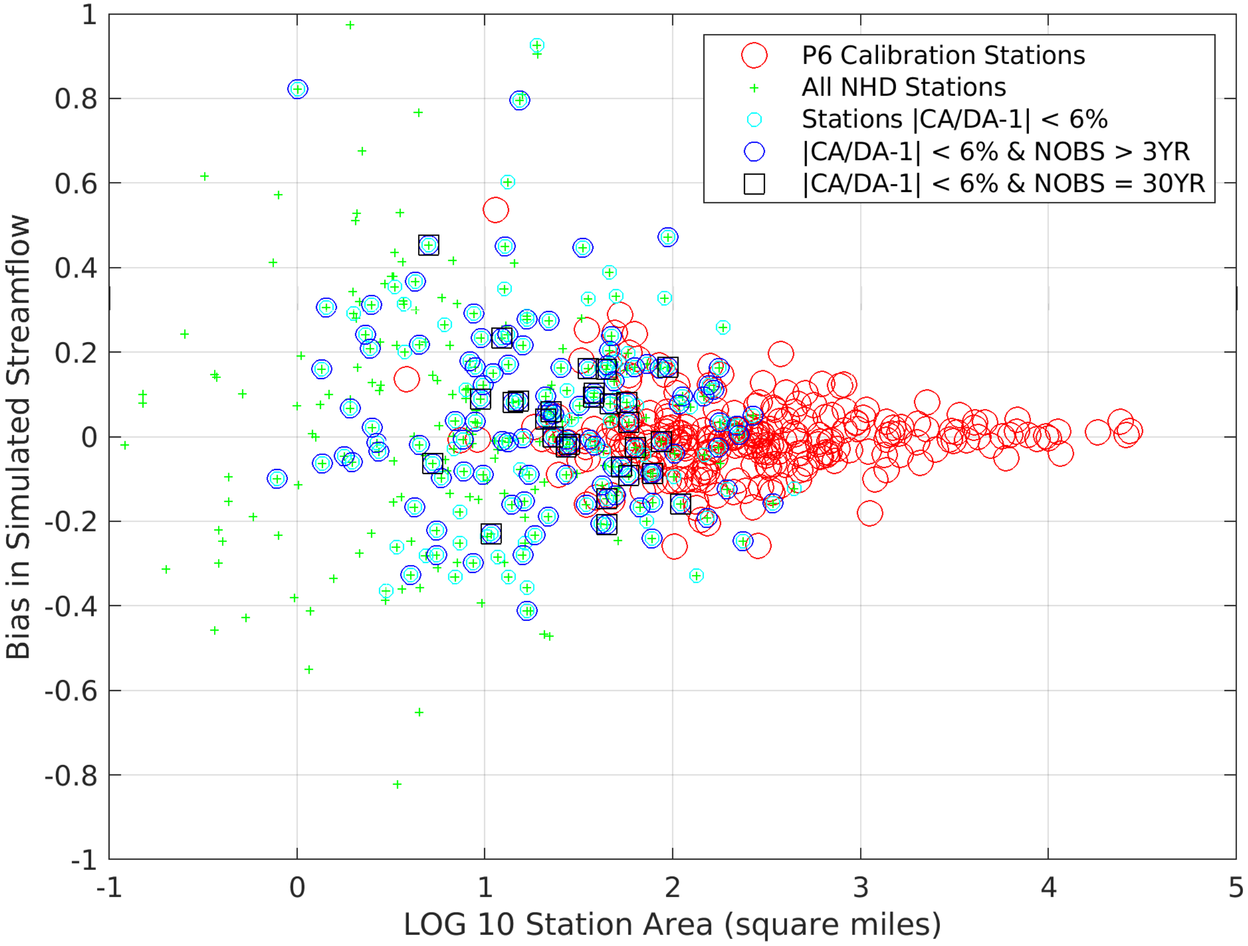




"downscaled" streamflow had degradation in biases with watershed scale/size but it showed comparable skill at P6 watershed scale.

Bias in simulated streamflow

Bias closer to 0 is better

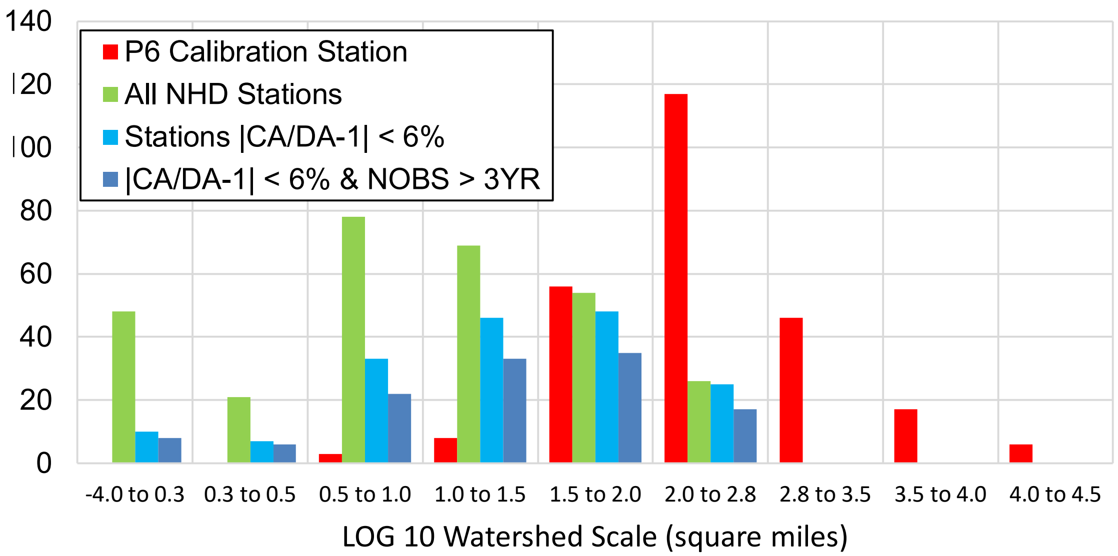


Out of 297

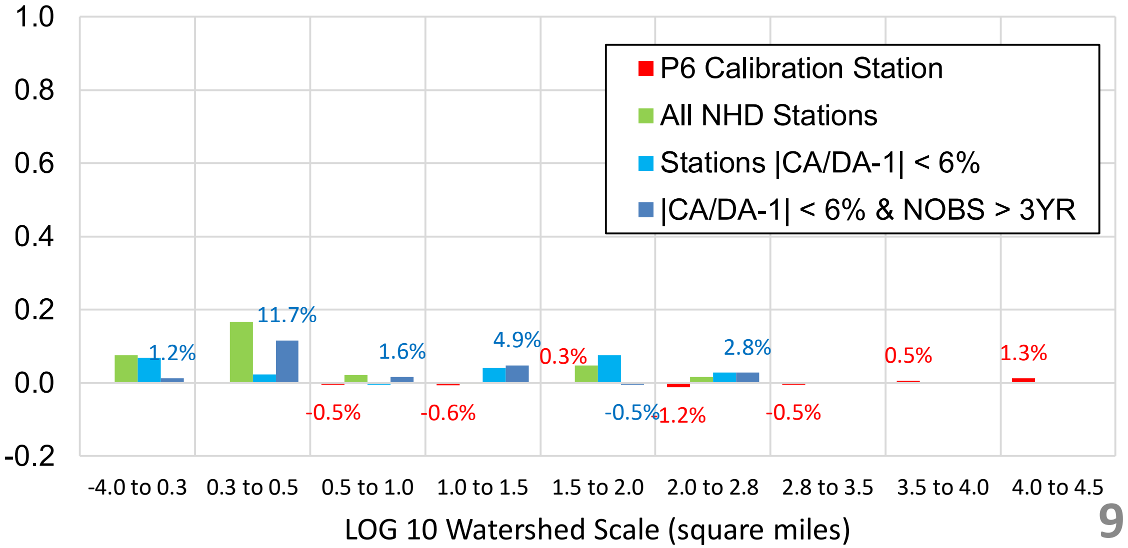
#stations with >±30% bias changed from 87 ($71^{+}|16^{-}$) to 71 ($47^{+}|24^{-}$)

#stations with >±100% bias changed from 23 ($23^{+}|0^{-}$) to 5 ($5^{+}|0^{-}$)

Number of Stations



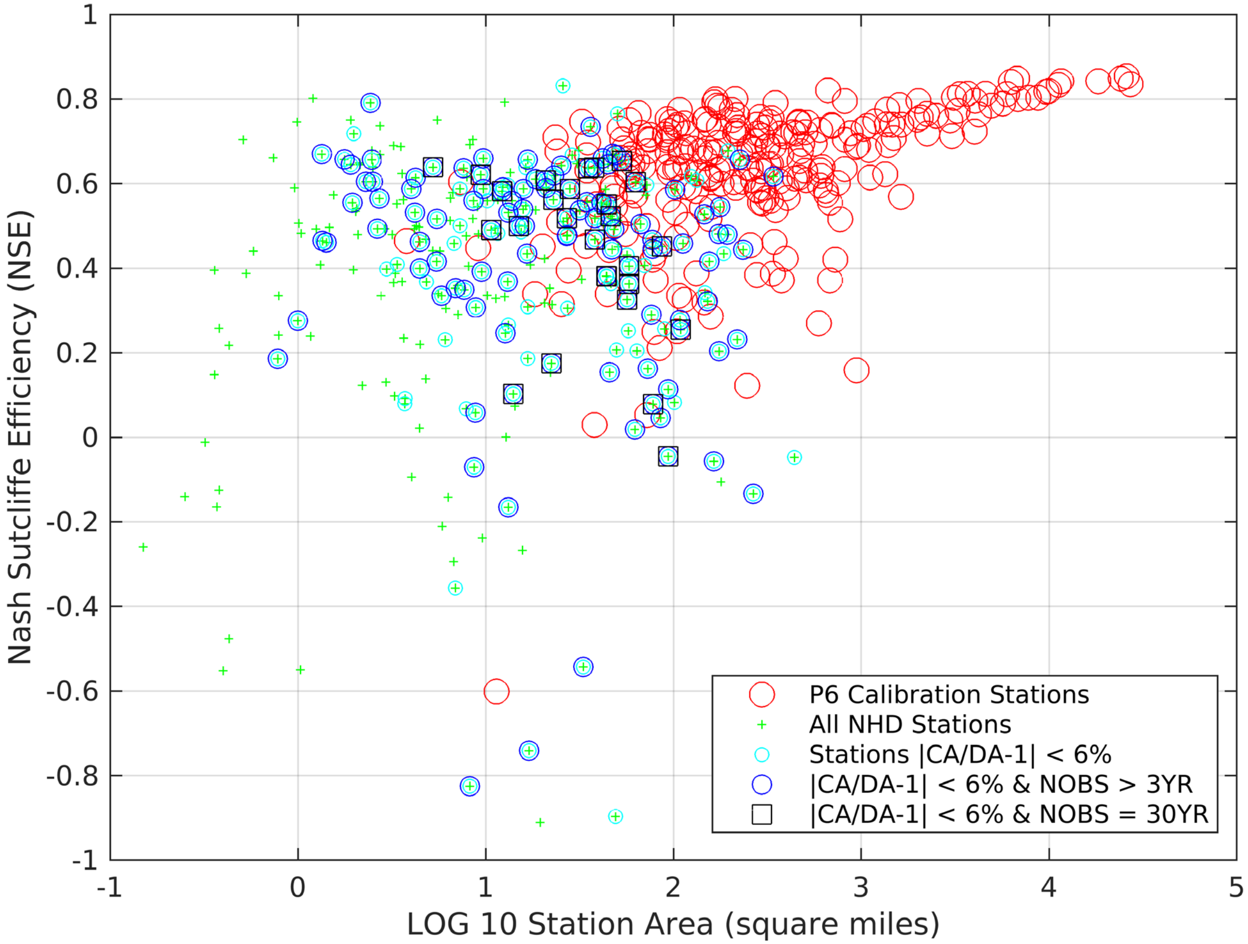
Median Bias in simulated streamflow



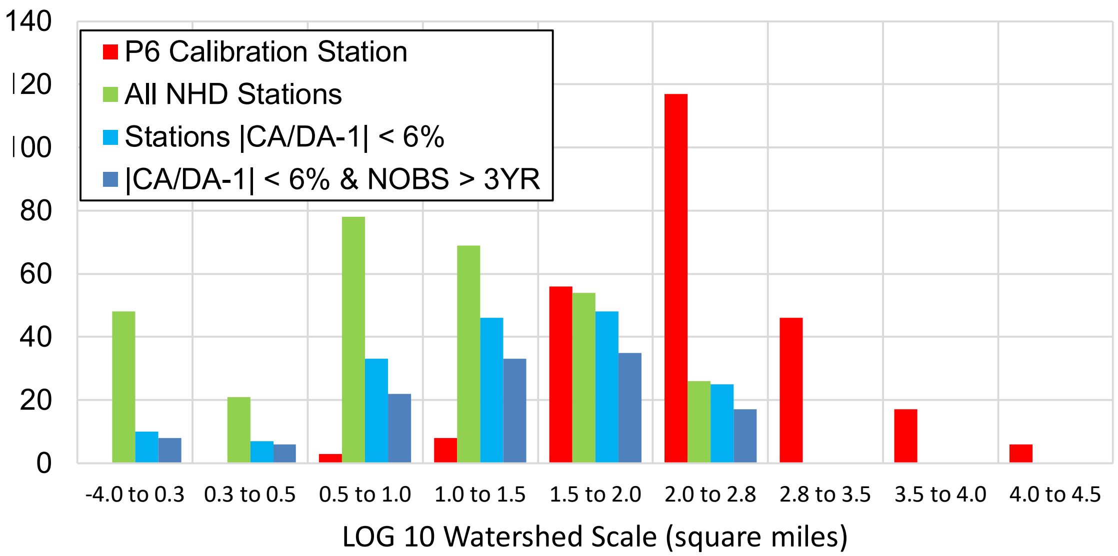
OLD

Nash Sutcliffe Efficiency (NSE) of simulated daily streamflow

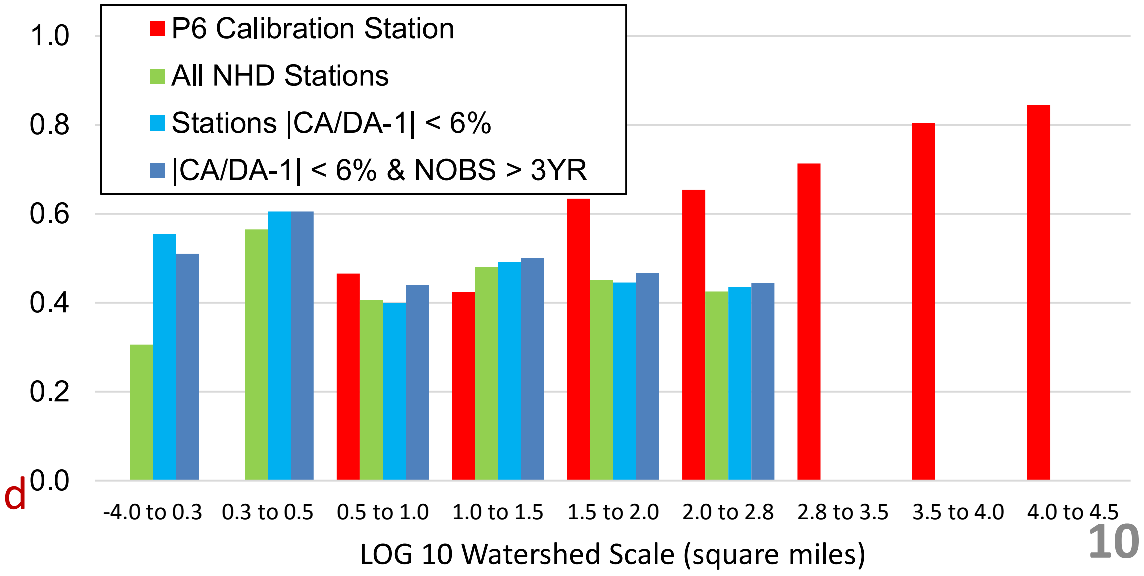
NSE closer to 1 is better



Number of Stations



NSE of simulated daily streamflow

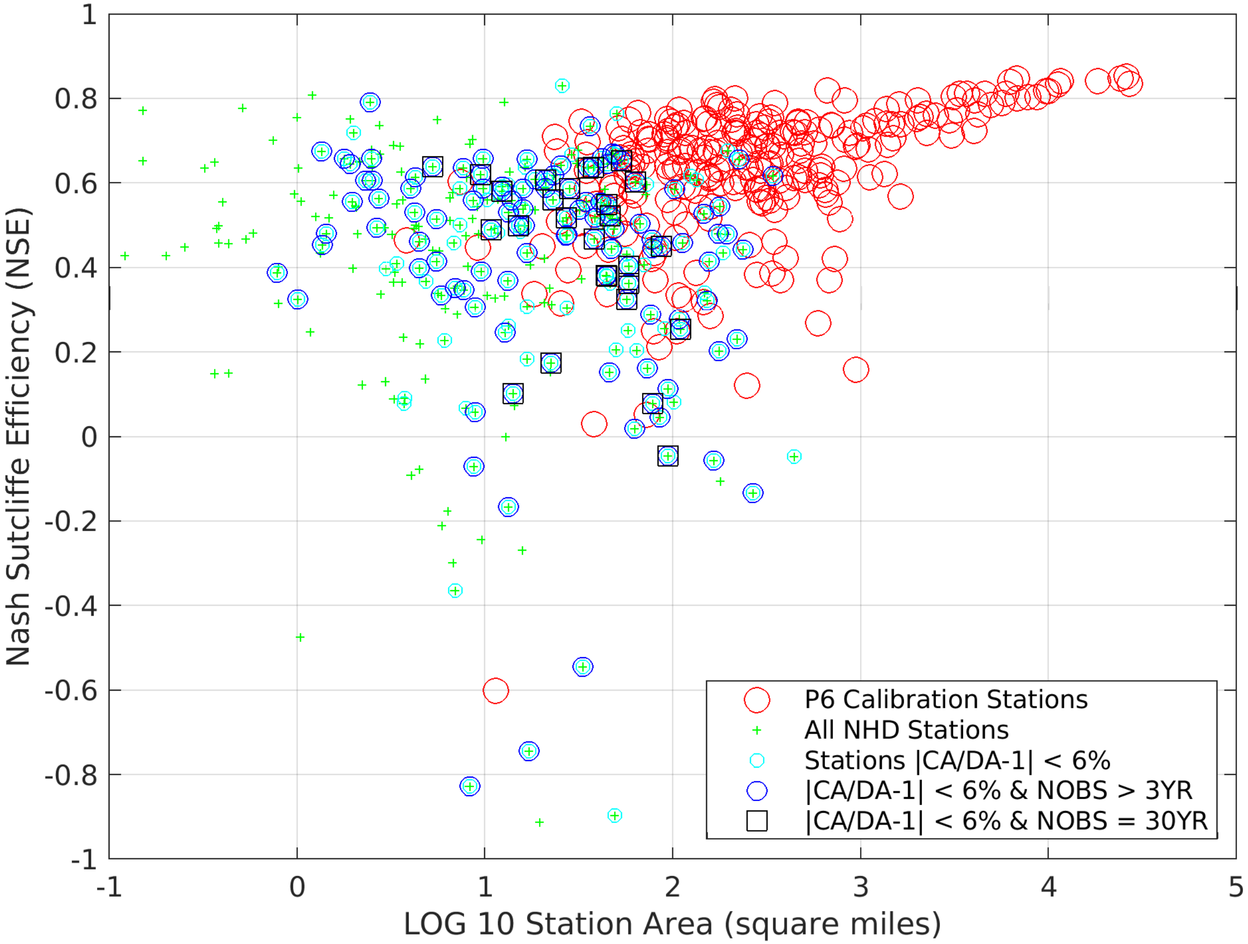


Although “downscaled” streamflow had an overall lower NSE but it did not show significant degradation in model skill with “downscaling”.

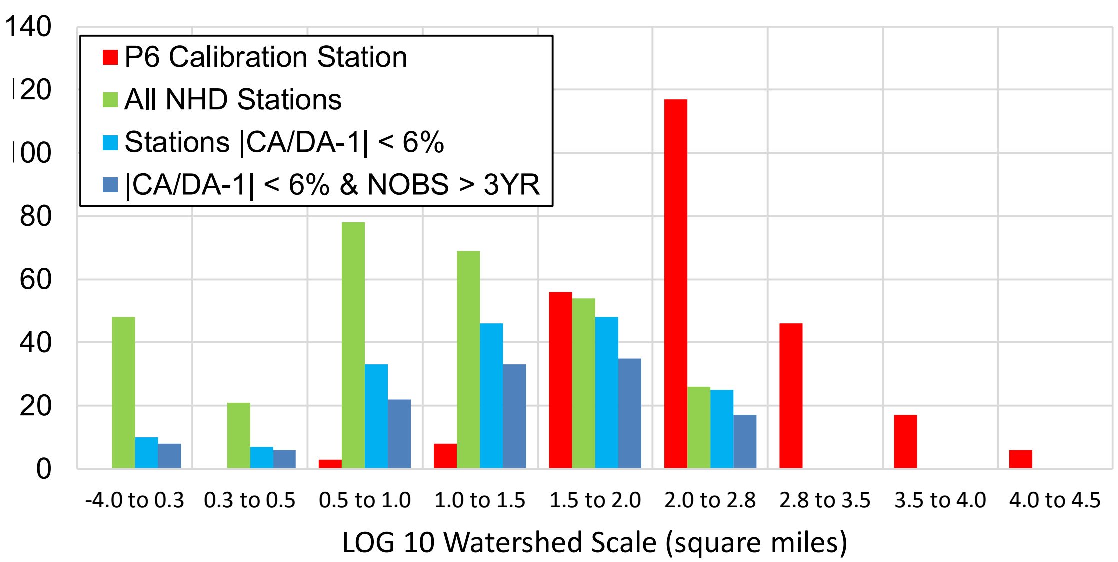
NEW

Nash Sutcliffe Efficiency (NSE) of simulated daily streamflow

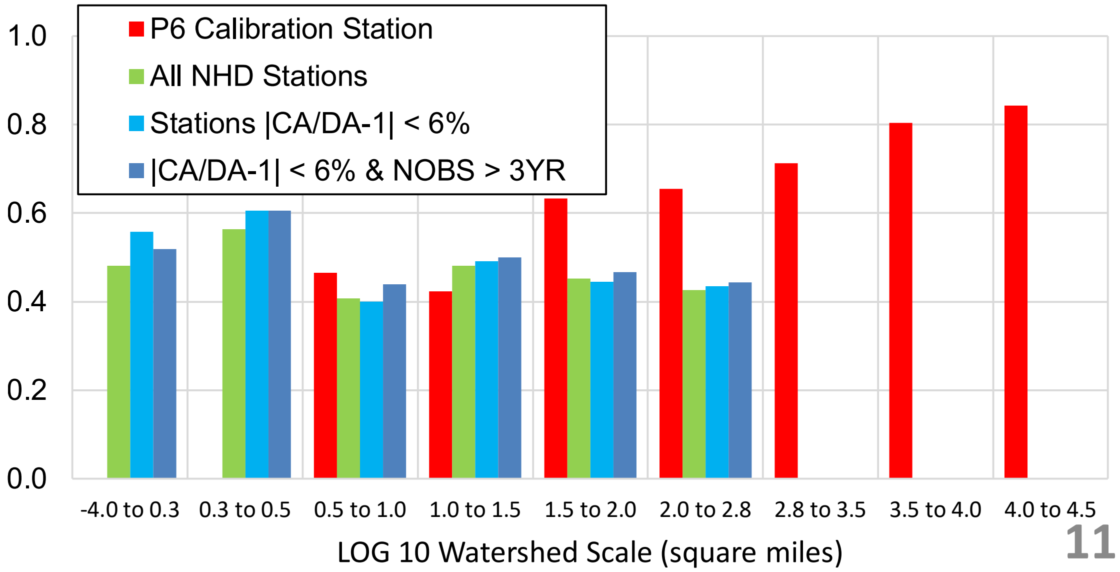
NSE closer to 1 is better



Number of Stations



NSE of simulated daily streamflow



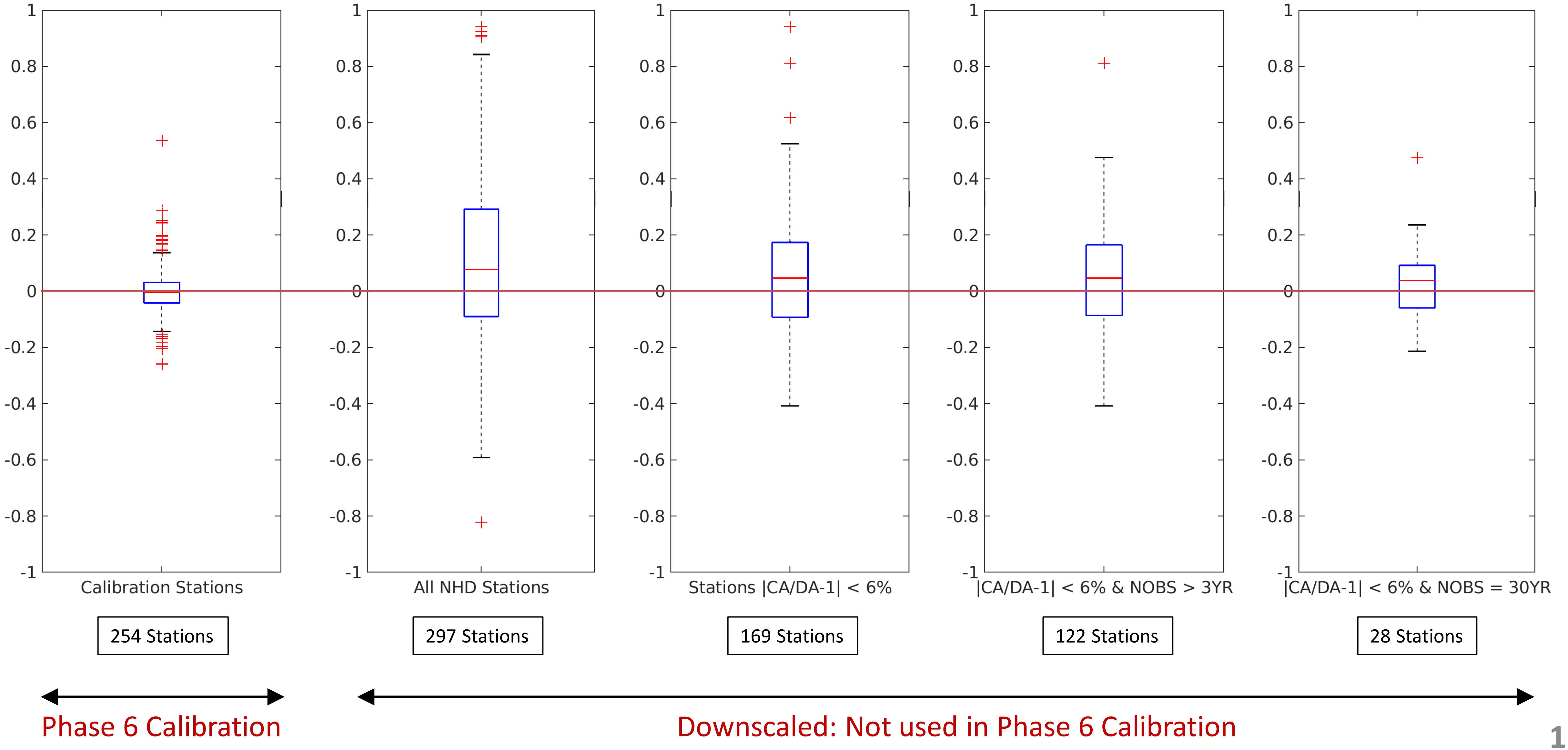
Out of 297

#stations with NSE <0 changed from 52 to 43

#stations with NSE <-1 changed from 25 to 22

Bias in simulated streamflow

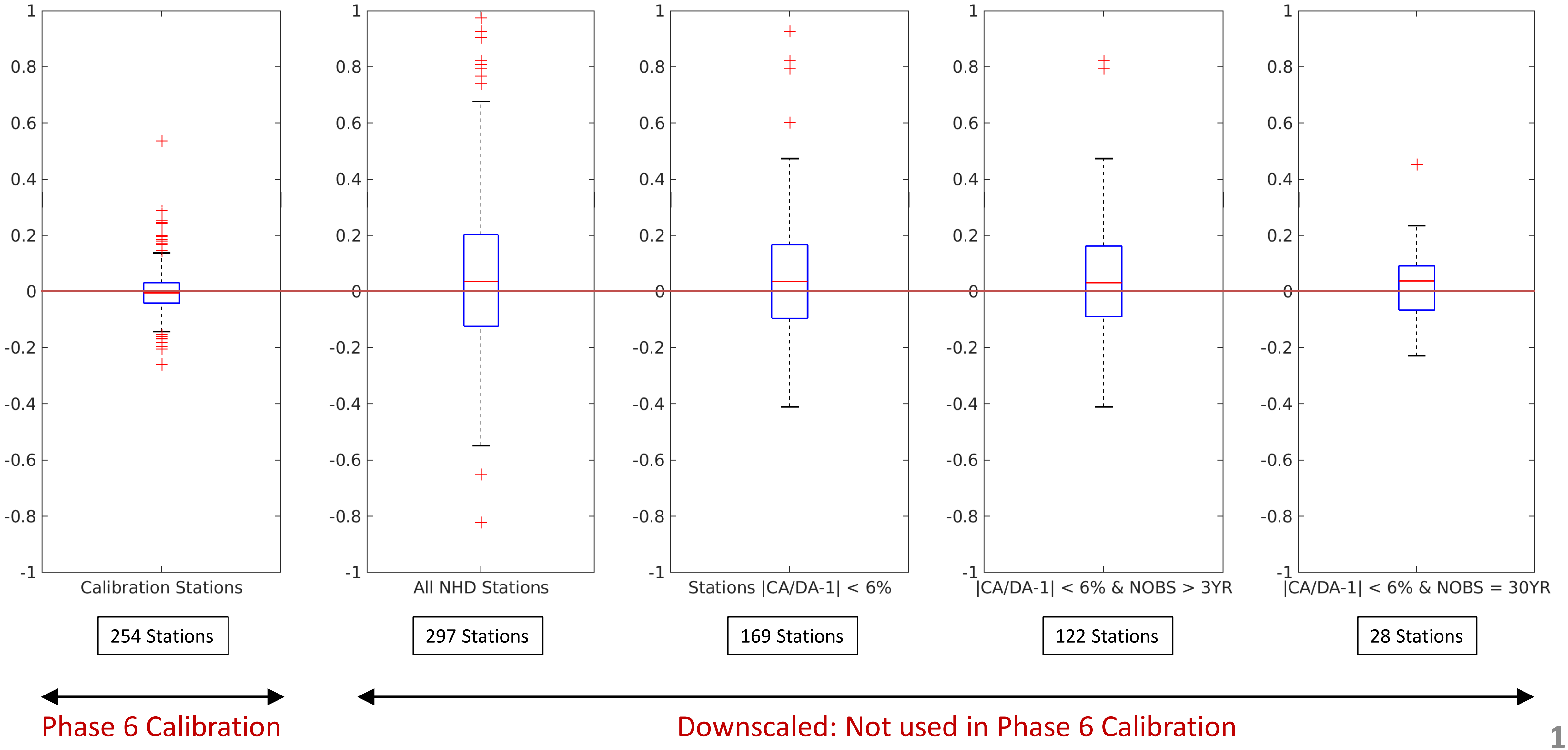
Bias closer to 0 is better



Bias in simulated streamflow

NEW

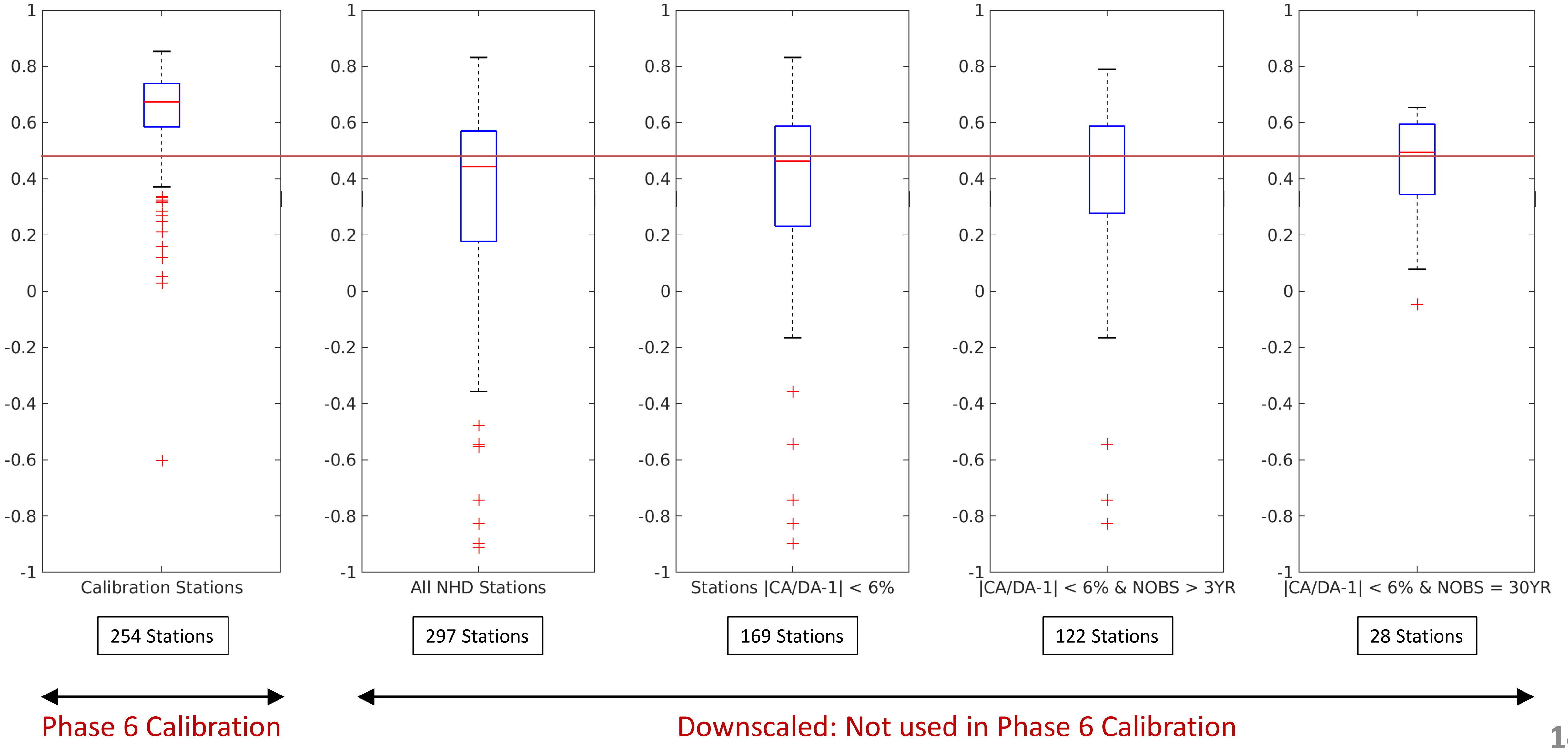
Bias closer to 0 is better



Nash Sutcliffe Efficiency (NSE) of simulated daily streamflow

OLD

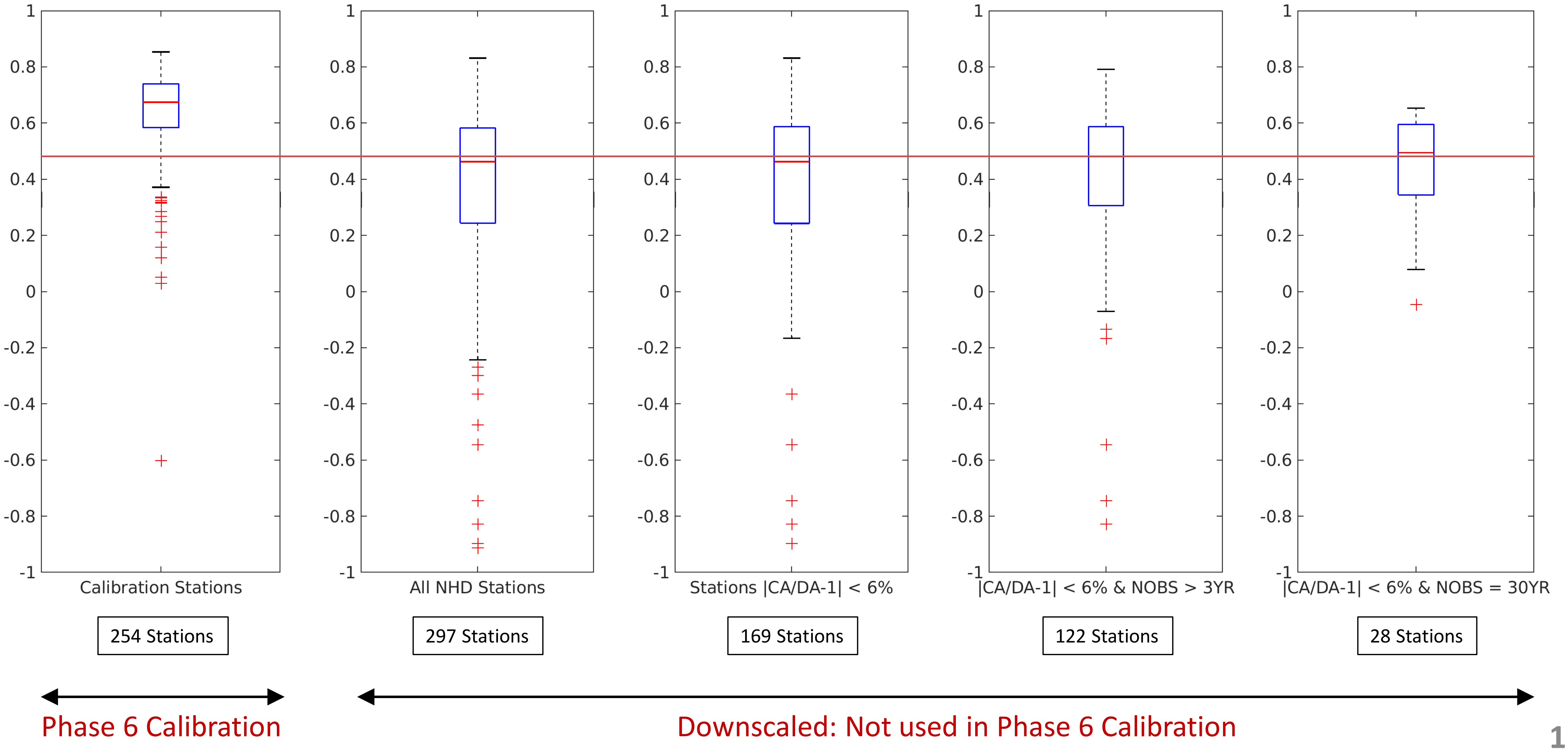
NSE closer to 1 is better



Nash Sutcliffe Efficiency (NSE) of simulated daily streamflow

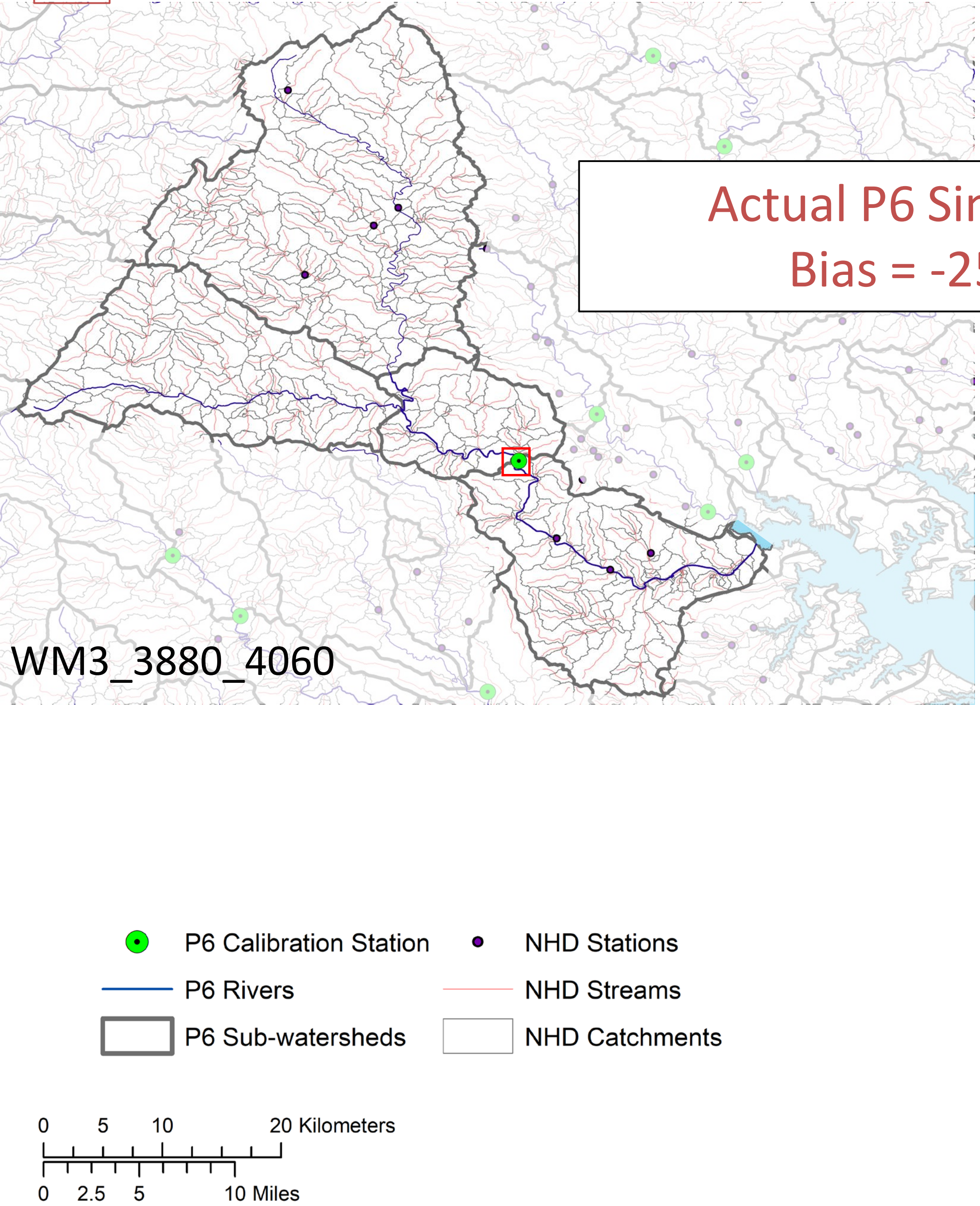
NEW

NSE closer to 1 is better

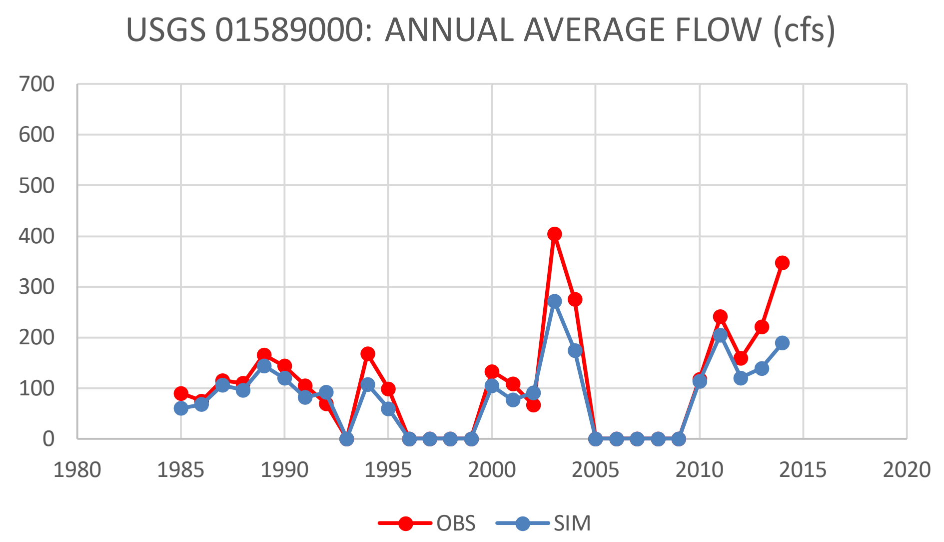


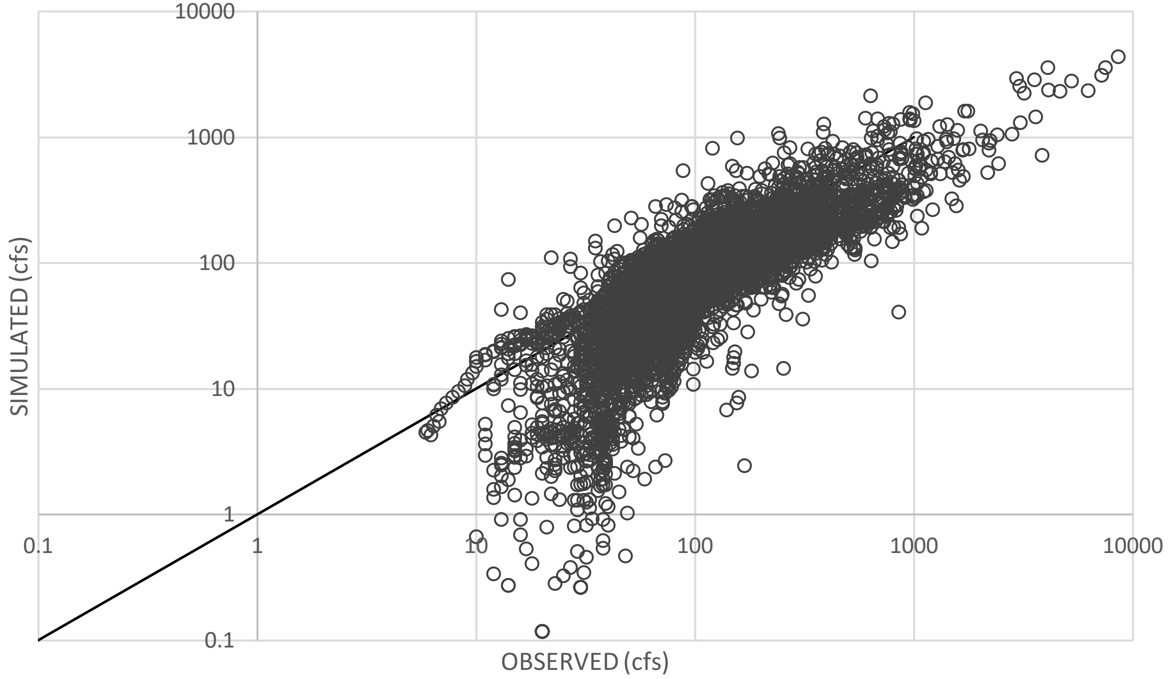
B

Verification of Downscaling at P6 Calibration Station

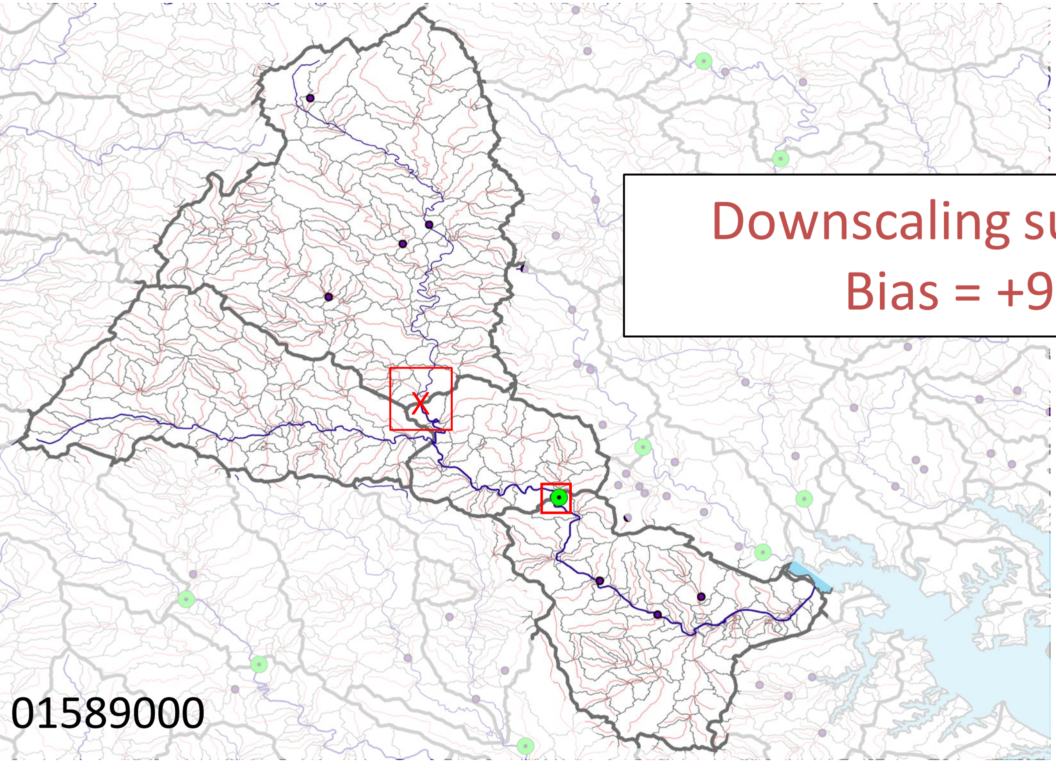


Actual P6 Simulation
Bias = -25.6%





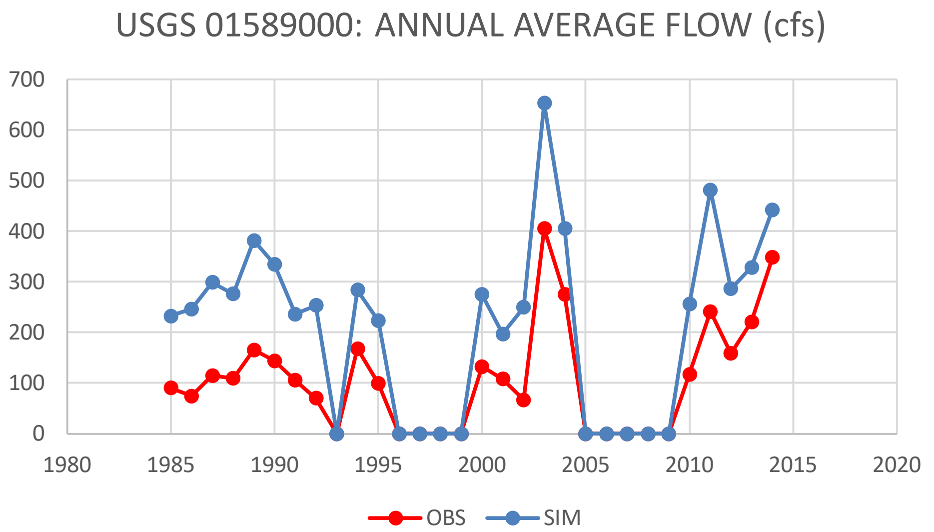
Verification of Downscaling at P6 Calibration Station

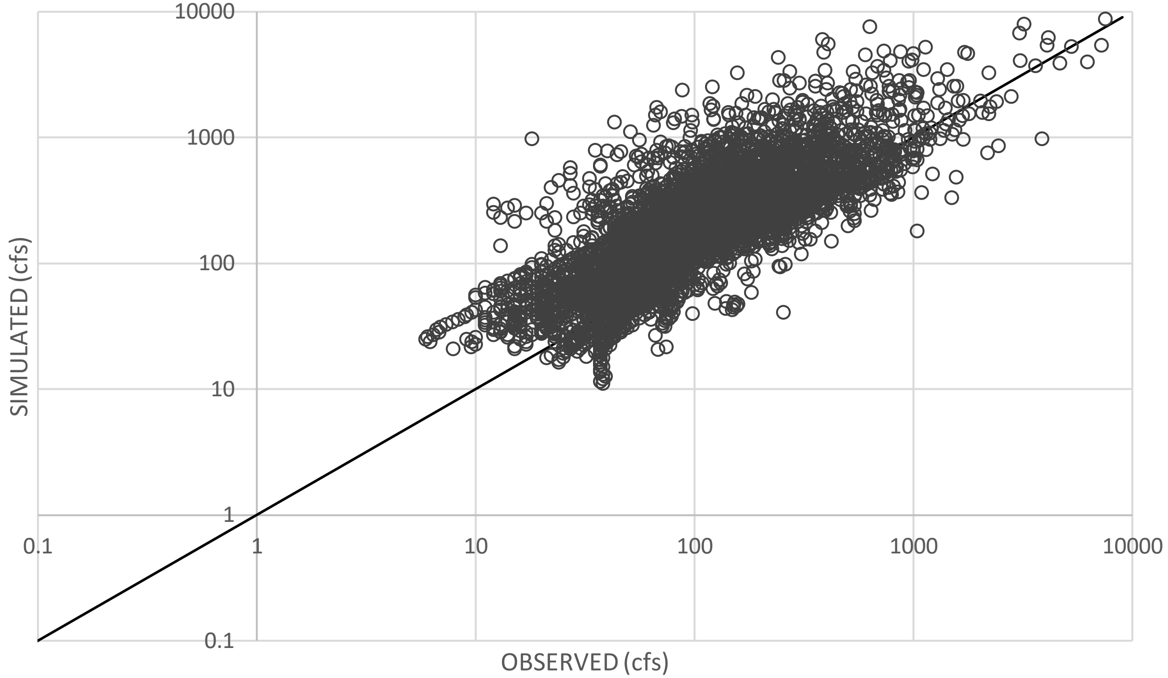


Downscaling subroutines
Bias = +94.7%

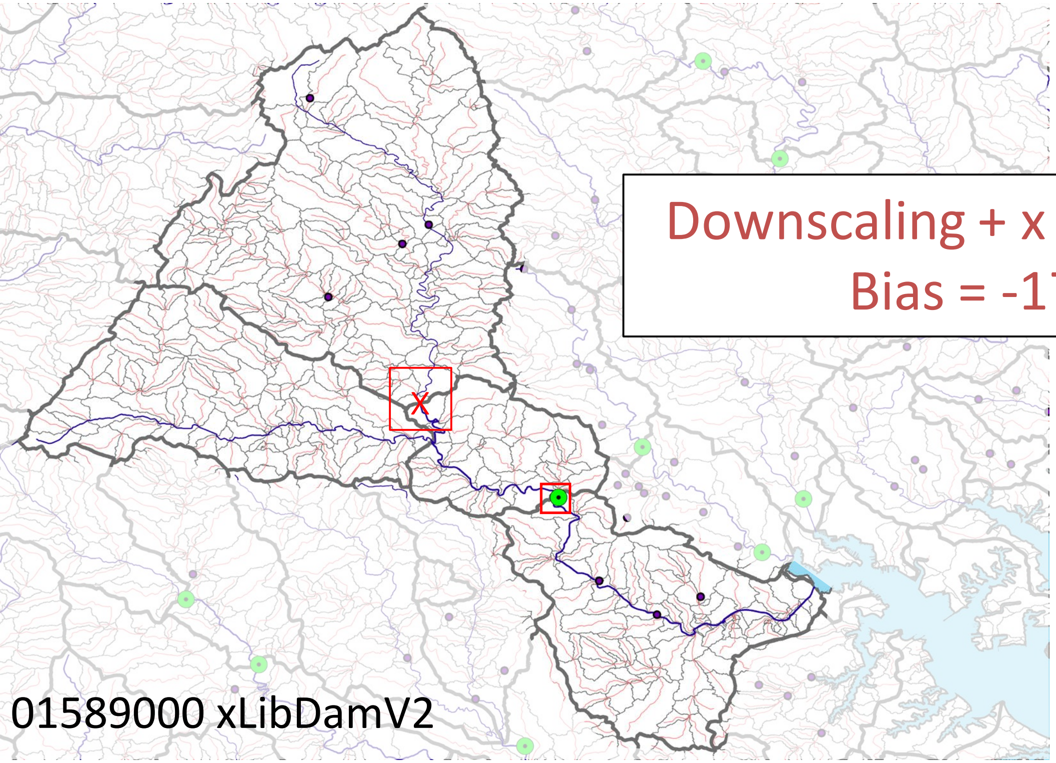
P6 Calibration Station
NHD Stations
P6 Rivers
NHD Streams
P6 Sub-watersheds
NHD Catchments

0 5 10 20 Kilometers
0 2.5 5 10 Miles





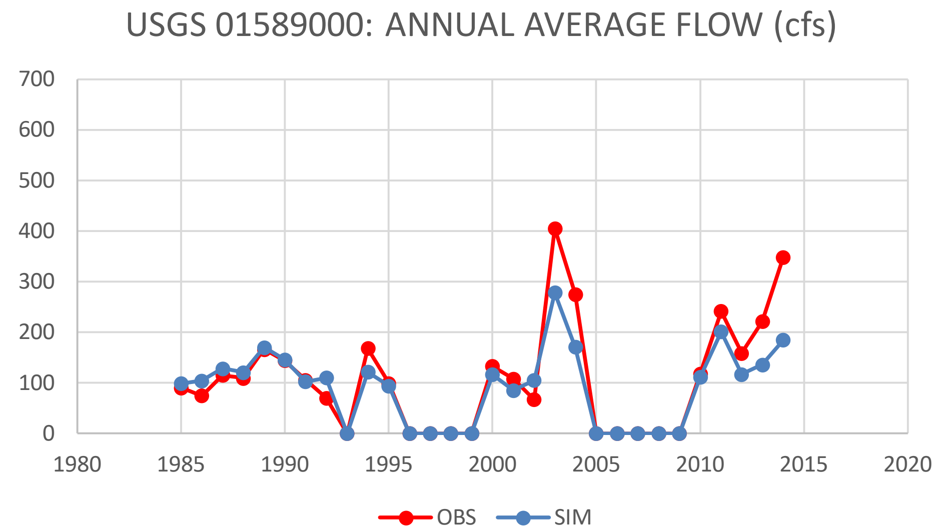
Verification of Downscaling at P6 Calibration Station

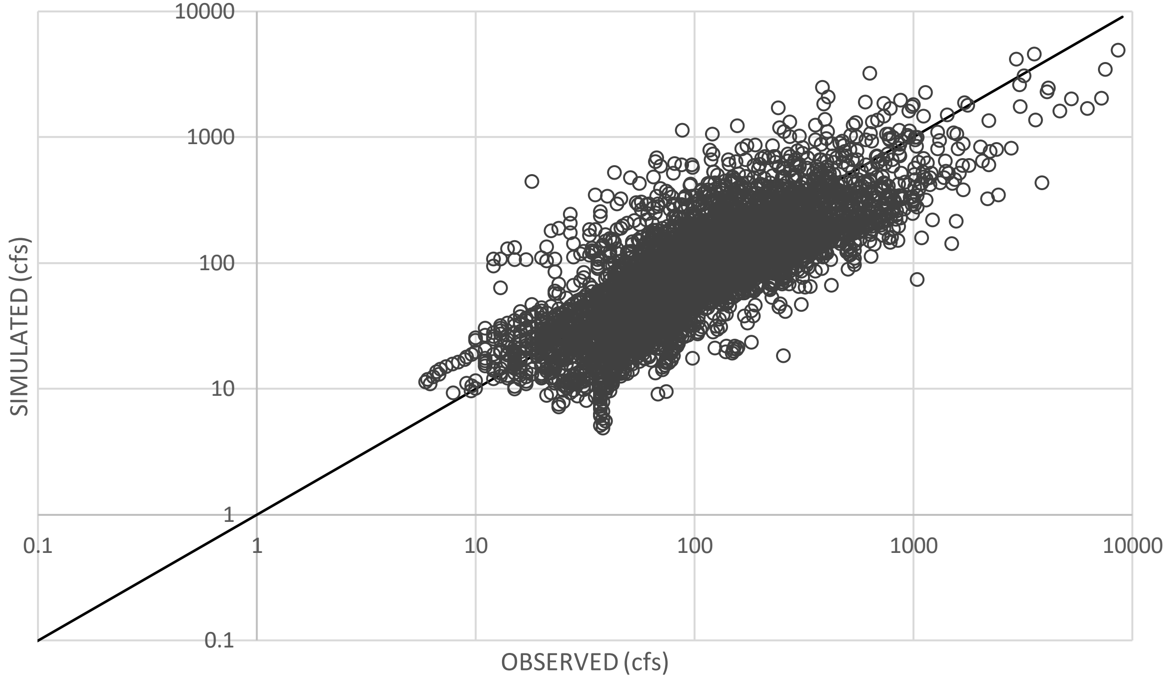


Downscaling + x Liberty Dam
Bias = -17.3%

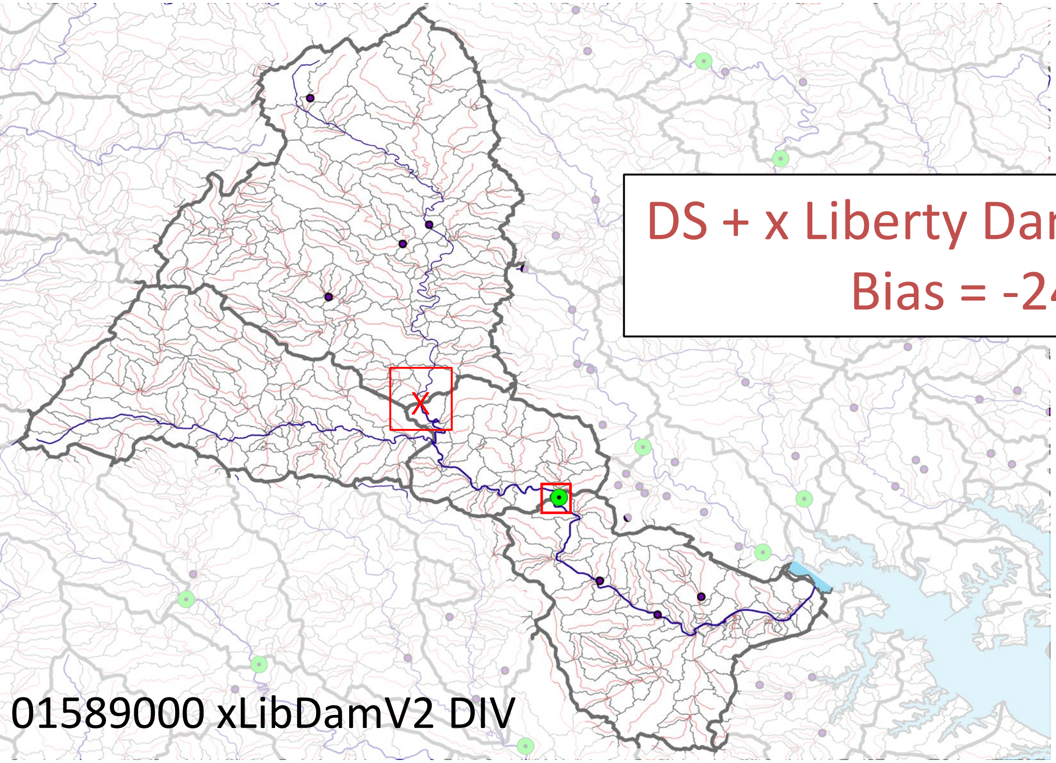
P6 Calibration Station
NHD Stations
P6 Rivers
NHD Streams
P6 Sub-watersheds
NHD Catchments

0 5 10 20 Kilometers
0 2.5 5 10 Miles





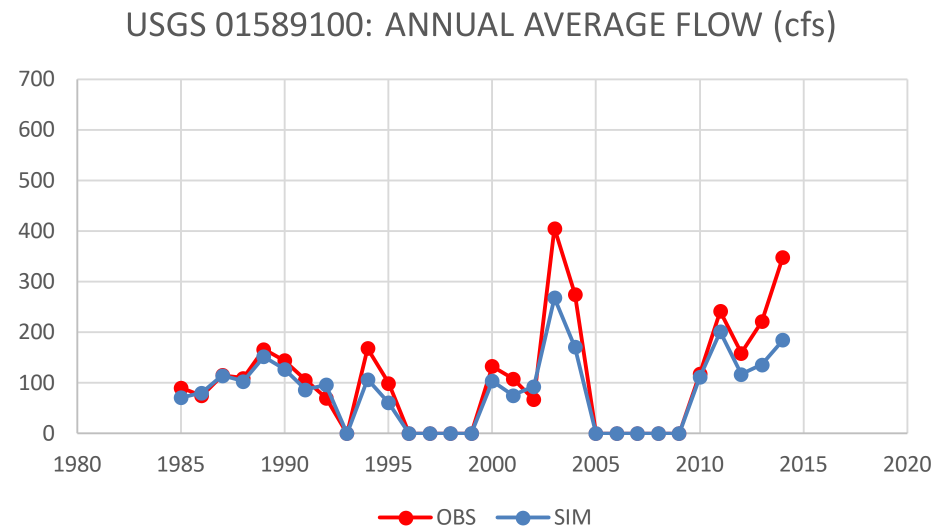
Verification of Downscaling at P6 Calibration Station

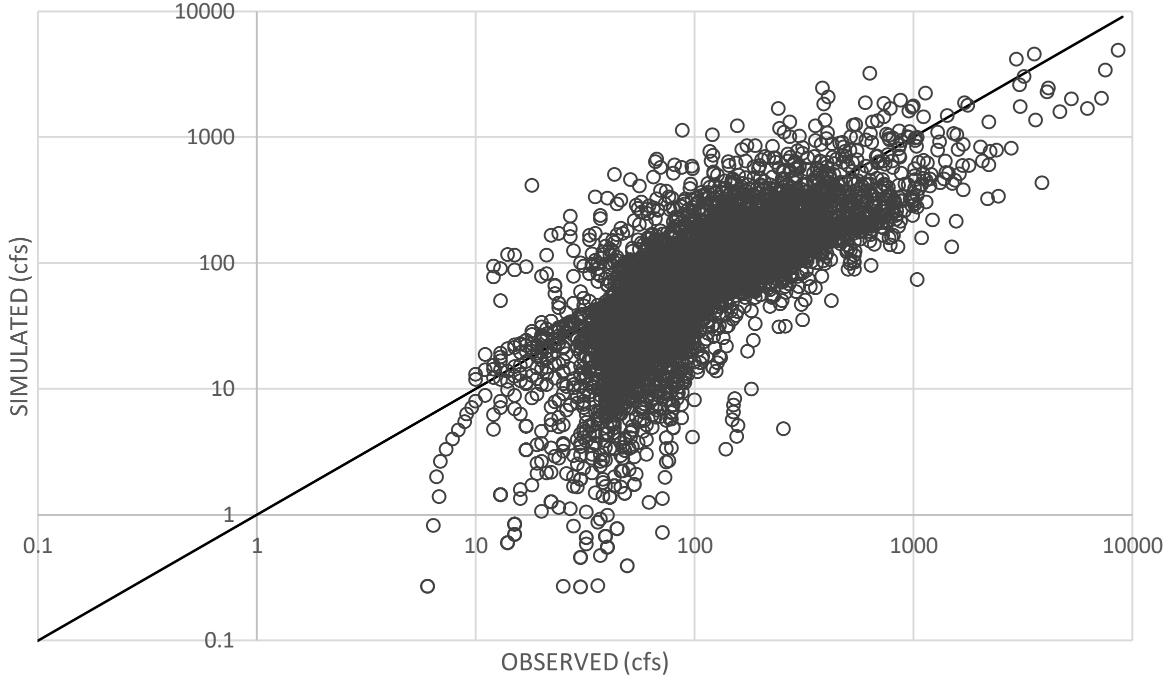


DS + x Liberty Dam + Diversion
Bias = -24.6%

P6 Calibration Station
NHD Stations
P6 Rivers
NHD Streams
P6 Sub-watersheds
NHD Catchments

0 5 10 20 Kilometers
0 2.5 5 10 Miles





C

Modeling Team's Discussion on the Next Steps

Methods and Results – CRHM 2020 Version 1

- Limitations of the current approach
  - Point-source (Wastewater & CSO) discharges ← Can be done
  - Surface water withdrawals (water supply and irrigation) ← Progress but not possible until end of the year
  - Spatial variability in rainfall and meteorology
  - Flow routing through small streams

    ← Possible but some decisions are needed, e.g., NHD segmentations
  - Spatial variability in watershed properties ← Longer term unless a breakthrough
  - Others ← Calibration methods, Penman Monteith PET

+ other minor issues such as static land cover, exclusion of water land use, etc.

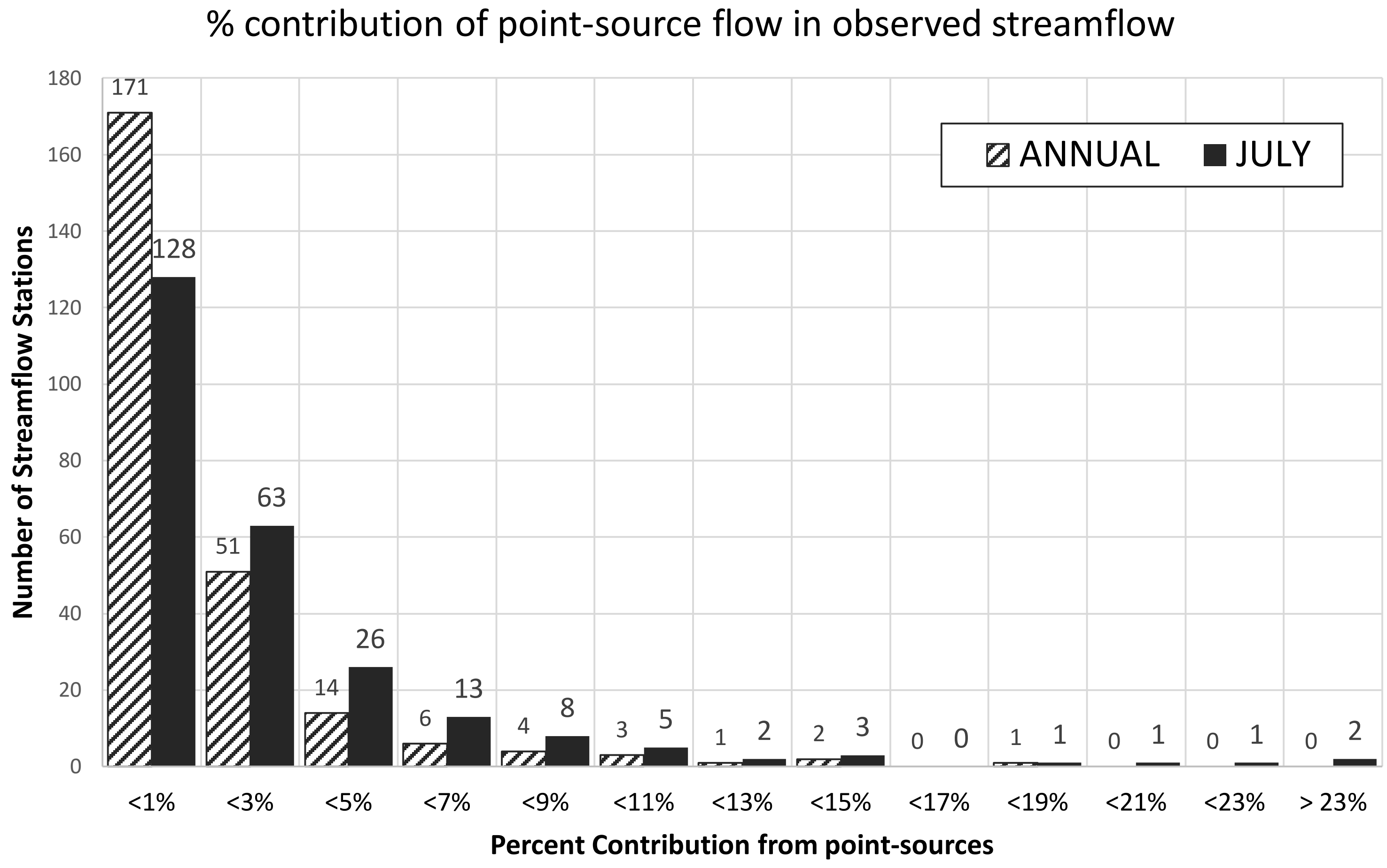
Potential approaches to downscale monthly wastewater flow to hourly/daily

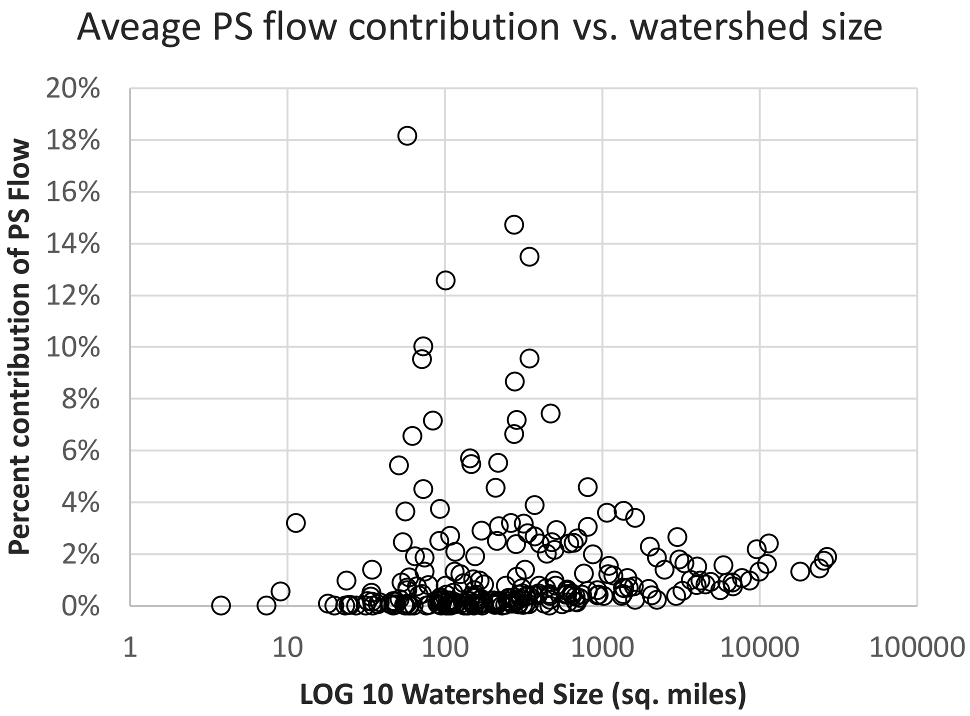
Municipal wastewater production varies with **season**, **day of the week**, **hour of the day**, and **precipitation**

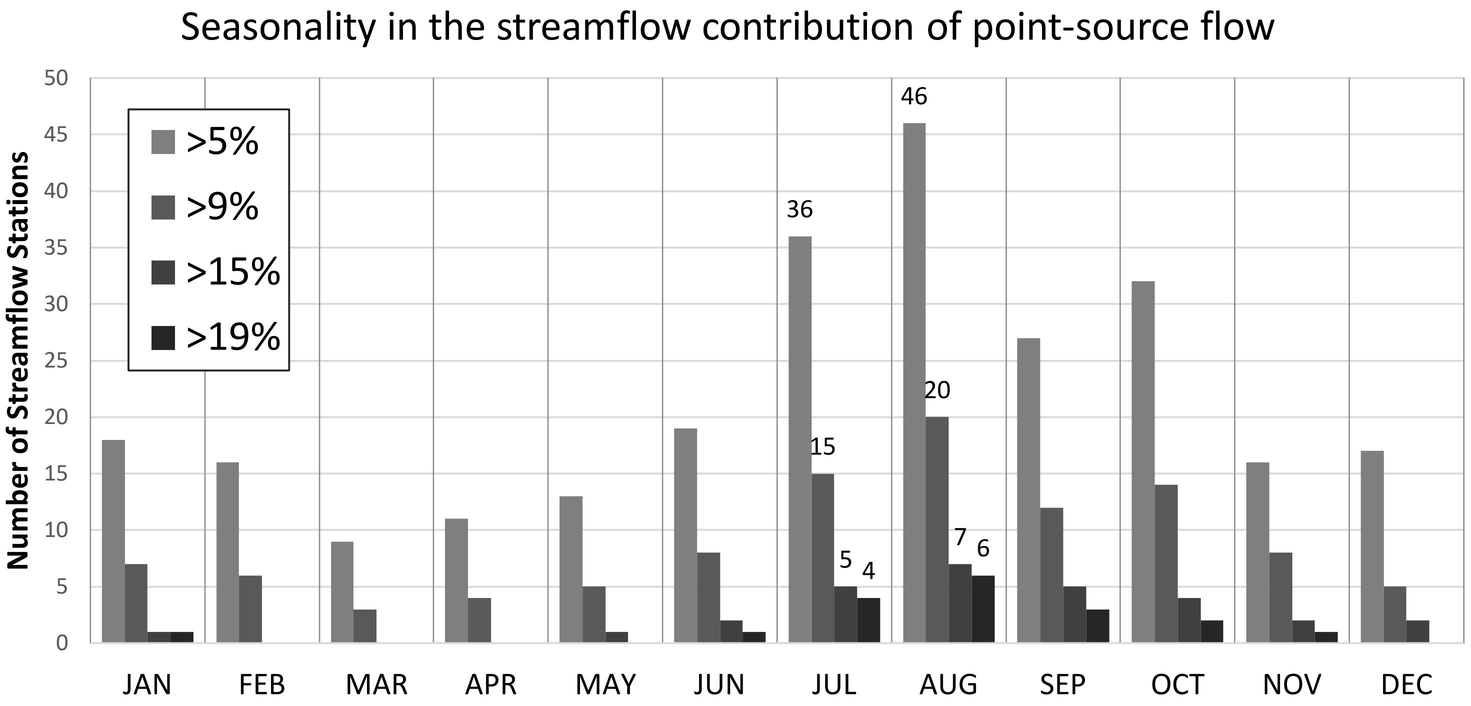
Such variations were not considered at the coarser Phase 6 scale, but they may play a non-negligible role at the finer NHDPlus scale, especially in smaller streams

We did some preliminary explorations of what our options would be to incorporate temporal variability in municipal wastewater flow patterns into the next generation hydrology model

Point Source Flow Contributions at 254 P6 Calibration Stations






Seasonality in the streamflow contribution of point-source flow
Number of Streamflow Stations
0
5
10
15
20
25
30
35
40
45
50
>5%
>9%
>15%
>19%
36
15
5
4
46
20
7
6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Potential approaches to downscale monthly wastewater flow to hourly/daily

Two potential approaches:

1. Use hourly/daily flow **monitoring data** from a subset of representative WWTPs capturing a range of plant sizes and develop a simple statistical model that predicts WWTP flow as a function of hour of the day, day of the week, season, size of the plant, and precipitation

2. Use **“textbook” curves** that describe typical diurnal variations in WWTP flow as a function of WWTP size and are typically used in the WWTP design phase

Potential approaches to downscale monthly wastewater flow to hourly/daily

1. Use hourly/daily flow **monitoring data**

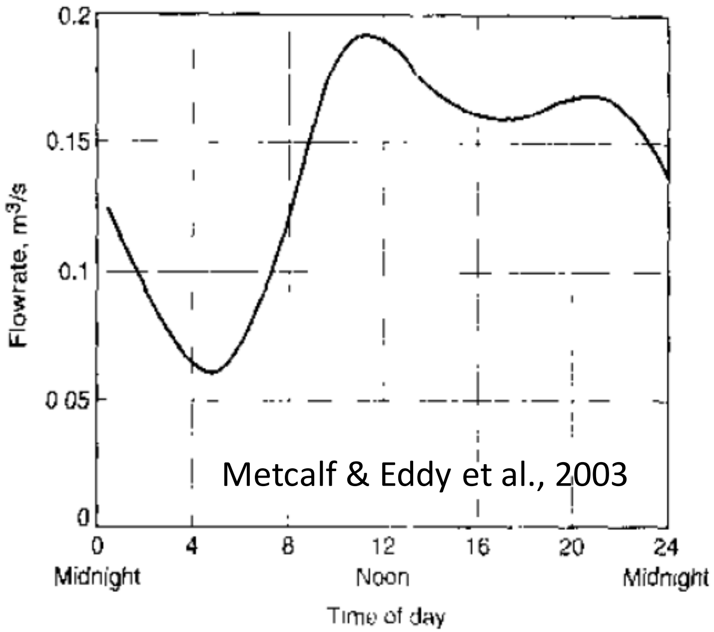
    - Did extensive search of EPA`s **ICIS-NPDES DMR** database to look for daily WWTP flow data – FOUND NOTHING

    - Should receive hourly flow data from a subset of WWTPs managed by **HRSD**. Once we get those, we might consider having an undergrad work with us to explore development of a simple statistical model

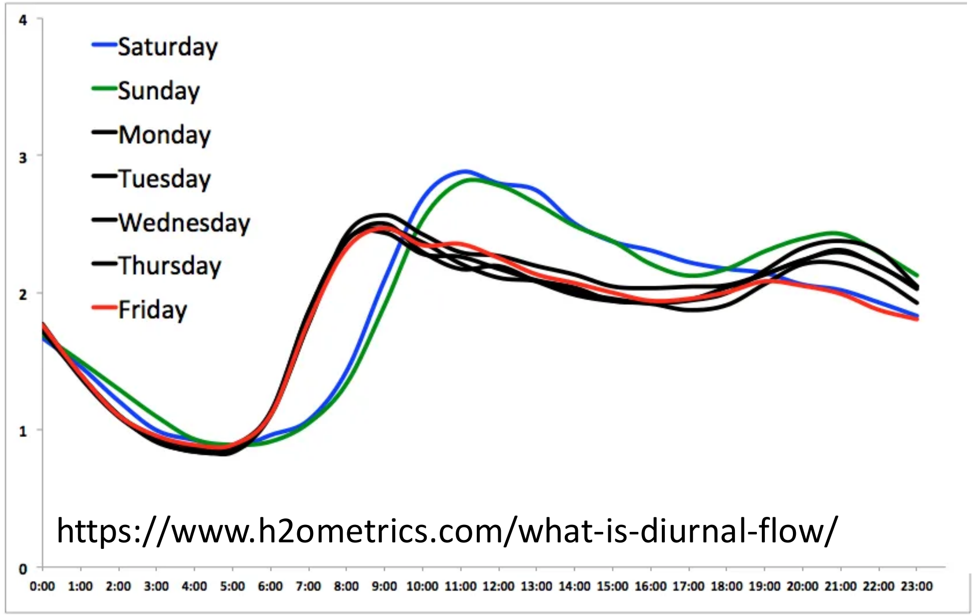
Potential approaches to downscale monthly wastewater flow to hourly/daily

2. Use **“textbook” curves** that describe typical diurnal variations in WWTP flow as a function of WWTP size

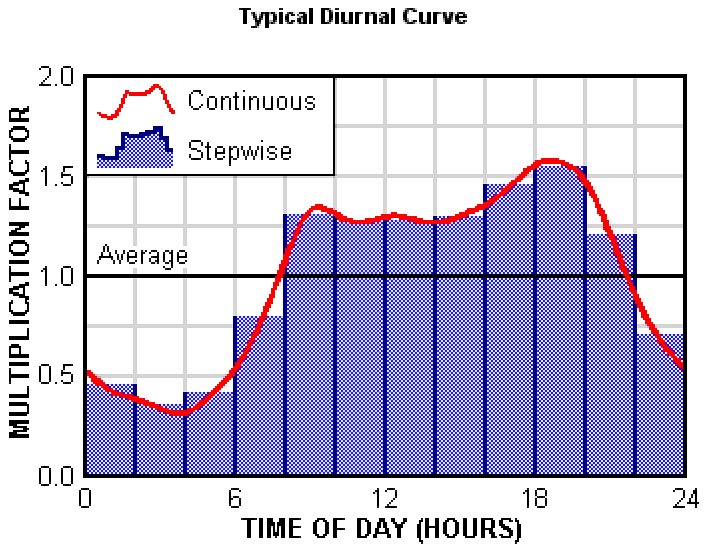
Typical Diurnal Pattern of municipal WWTP Flow



Metcalf & Eddy et al., 2003



https://www.h2ometrics.com/what-is-diurnal-flow/



https://docs.bentley.com/

Potential approaches to downscale monthly wastewater flow to hourly/daily

How accurate are **"textbook" curves**?

Examples of observed WWTP flow diurnal patterns

San Jose/Santa Clara WWTP

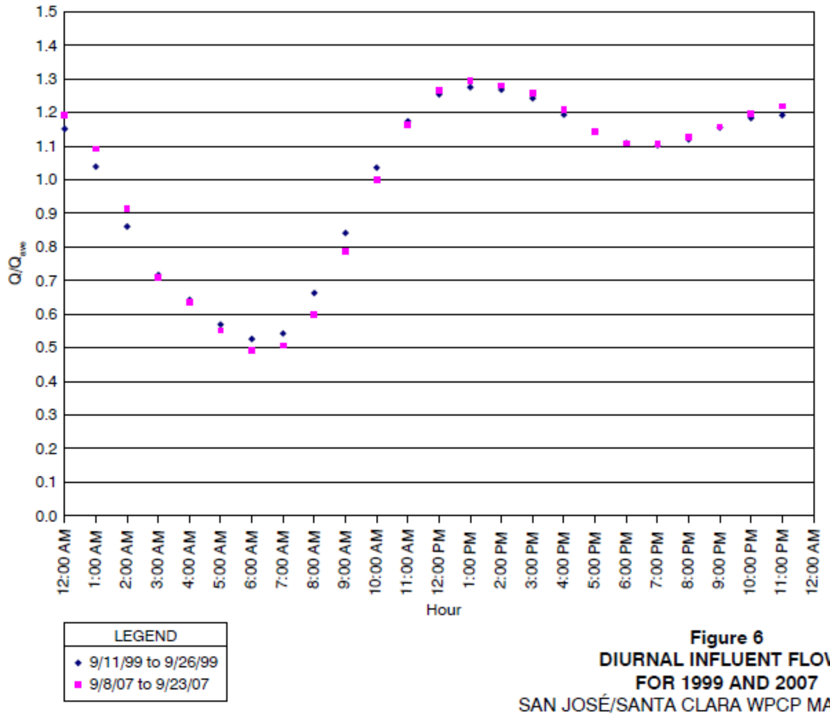


Figure 6
DIURNAL INFLUENT FLOWS
FOR 1999 AND 2007
SAN JOSÉ/SANTA CLARA WPCP MASTER PLAN
CITY OF SAN JOSÉ

"Confidential" WWTP

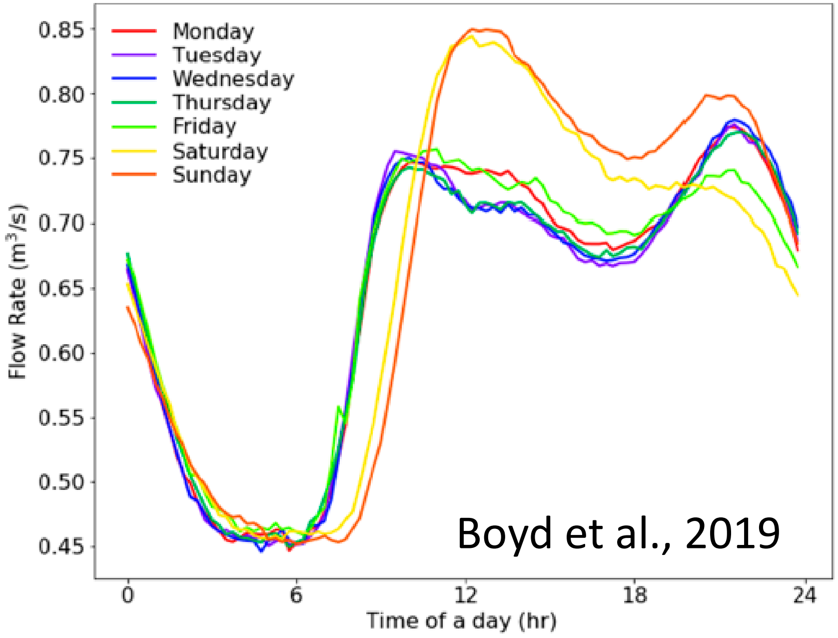
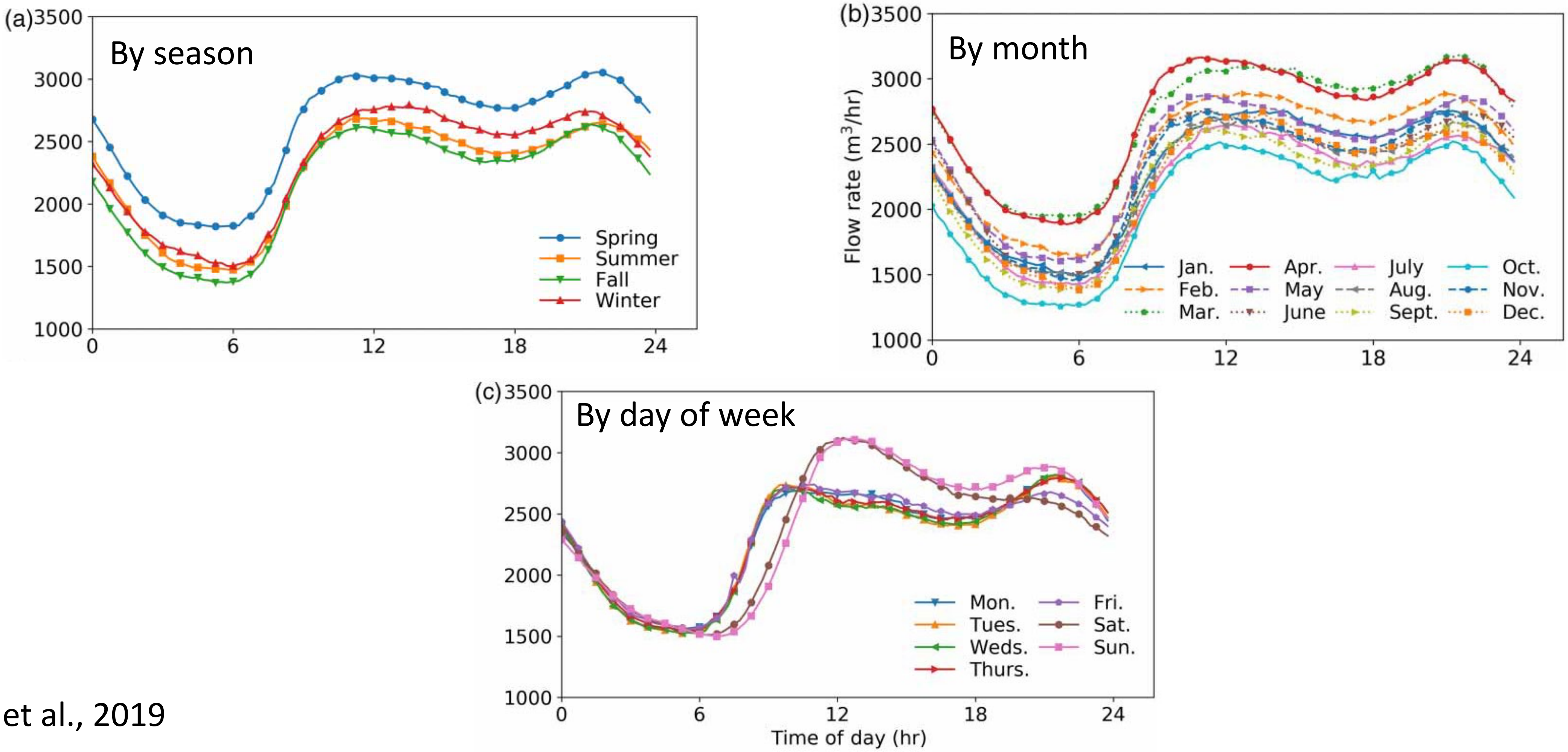


Figure 4. Weekday hourly pattern for Confidential Plant II.

Potential approaches to downscale monthly wastewater flow to hourly/daily

WWTP in Barrie, Ontario



Zhang et al., 2019

Potential approaches to downscale monthly wastewater flow to hourly/daily

Timing of diurnal variations in municipal WWTP flow well captured by textbook curves (though length of collection system might cause delay in peak flows)

Amplitude of textbook curves varies with the size of the community/WWTP (larger plants typically have smaller fluctuations due to larger storage capacity of the collection system)

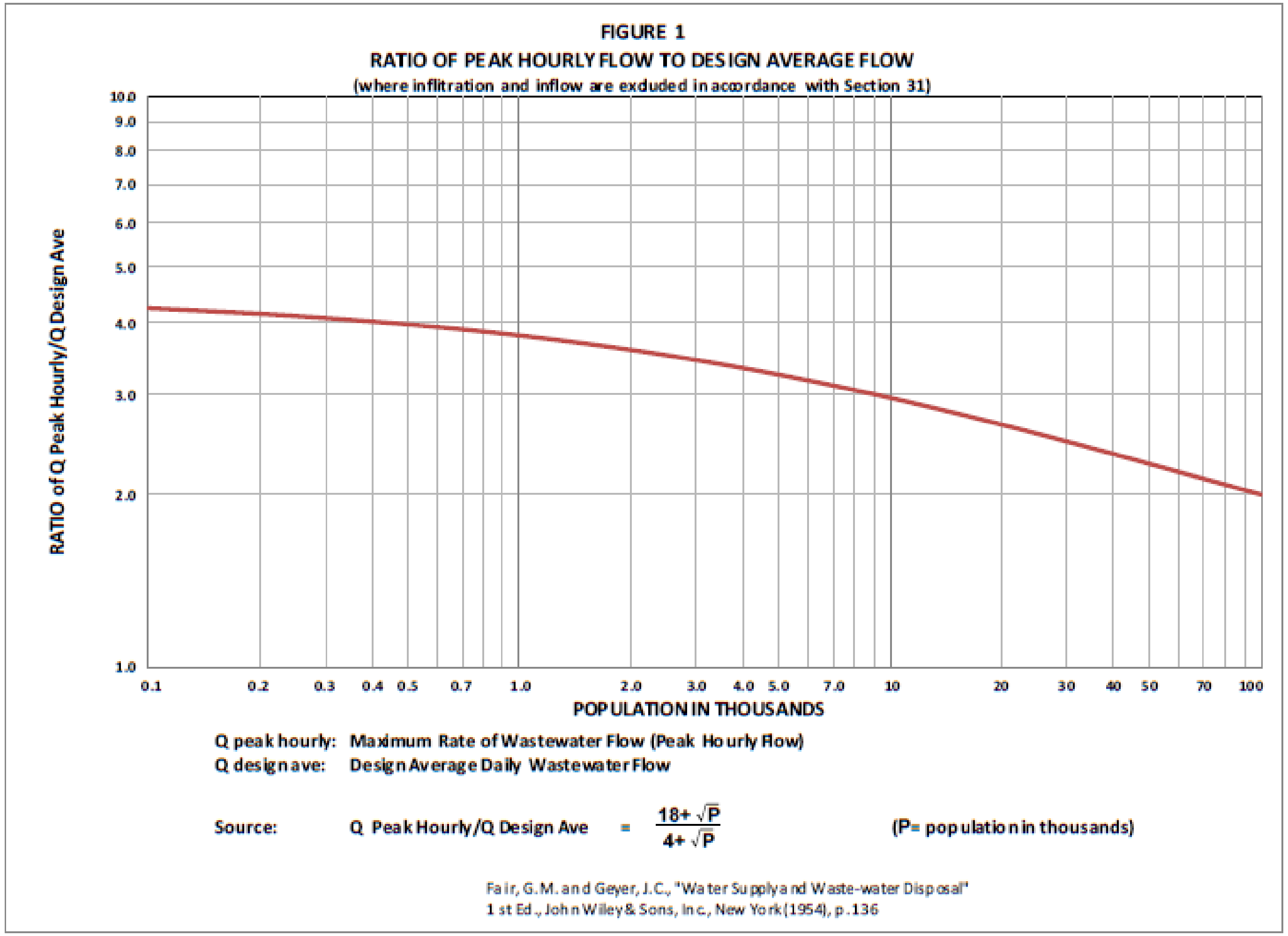
"**Peaking factor curves**" describe relationship between plant size and expected peak flow rates

Potential approaches to downscale monthly wastewater flow to hourly/daily

Peaking factor (PF):

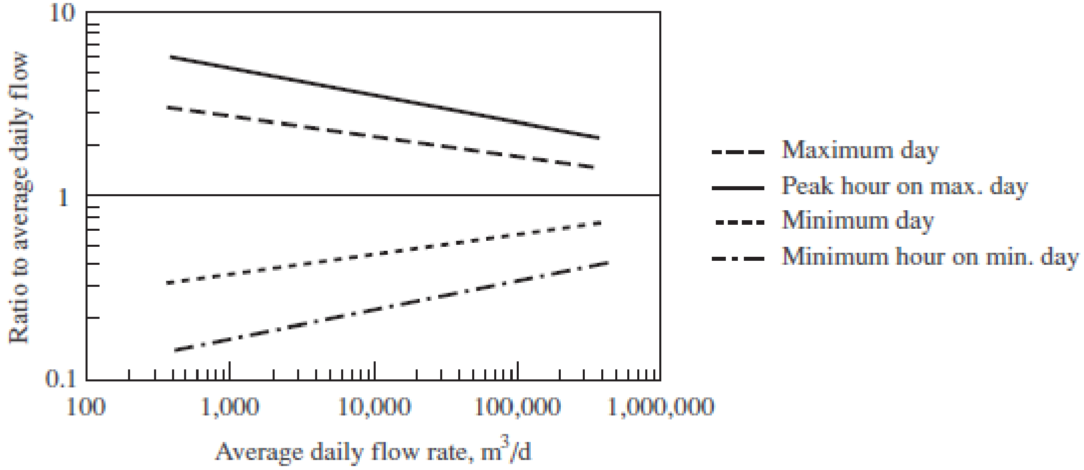
$$PF = \frac{\text{peak flow rate (hourly, daily, monthly, etc)}}{\text{average long-term flow rate}}$$

Peaking factor curves can be used to estimate peak hourly flow rates from domestic sources as a function of plant size



Recommended Standards for Wastewater Facilities for Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (10-State Standards)

Potential approaches to downscale monthly wastewater flow to hourly/daily



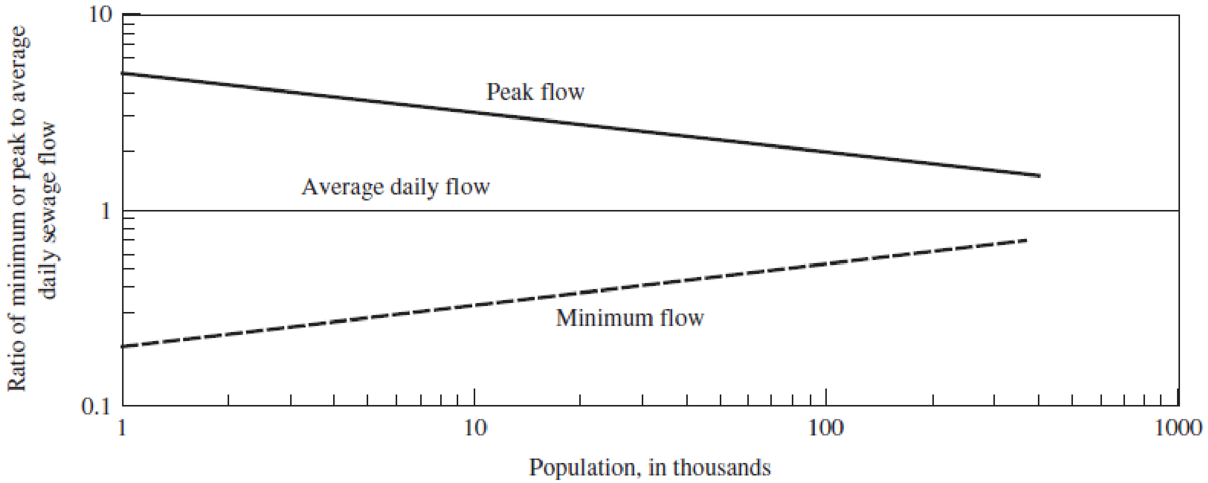
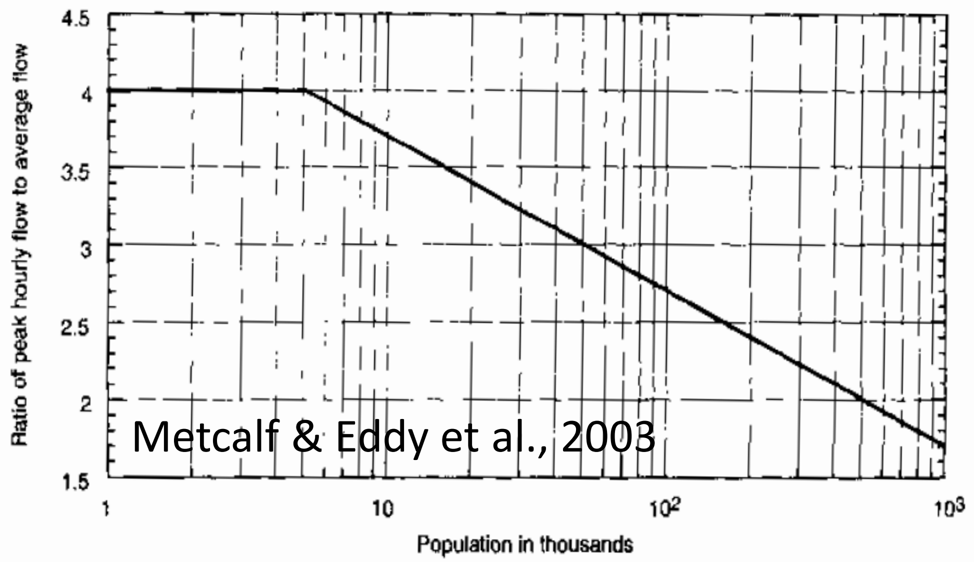


FIGURE 2-1
Ratio of extreme flows to average daily flow

Davis, 2010

Figure 3–13
Peaking factor curve (ratio of peak hourly to average daily flow).



Metcalf & Eddy et al., 2003

Potential approaches to downscale monthly wastewater flow to hourly/daily

$$\text{Peaking Factor (PF)} = \frac{\text{current peak flow (hourly, daily, monthly)}}{\text{Current average daily flow}}$$

Peak Flow = PF calculated above X Proposed Design Capacity

New facilities may use data from other plants of the similar size and condition (preferred method), or may use the following typical Peaking Factors (PF):

Design Capacity Range	Hourly PF	Daily PF	Monthly PF
0 to 0.25 MGD	4	3	2
0.25 to 16 MGD	$\frac{3.2 \times \text{Design Capacity}^{5/6}}{\text{Design Capacity}}$	75% of Hourly PF	50% of Hourly PF, but not below 1.2
More than 16 MGD	2	1.5	1.2

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Conclusions

Potential approaches to downscale monthly WWTP flow to hourly/daily may include:

- **Observed data** (particularly useful to explore influence of seasonality and precipitation)

- **Textbook engineering curves** (timing and amplitude of diurnal flow patterns as a function of plant size)

This was a preliminary exploration of feasible approaches, assessment of costs/benefits will dictate whether worth pursuing.