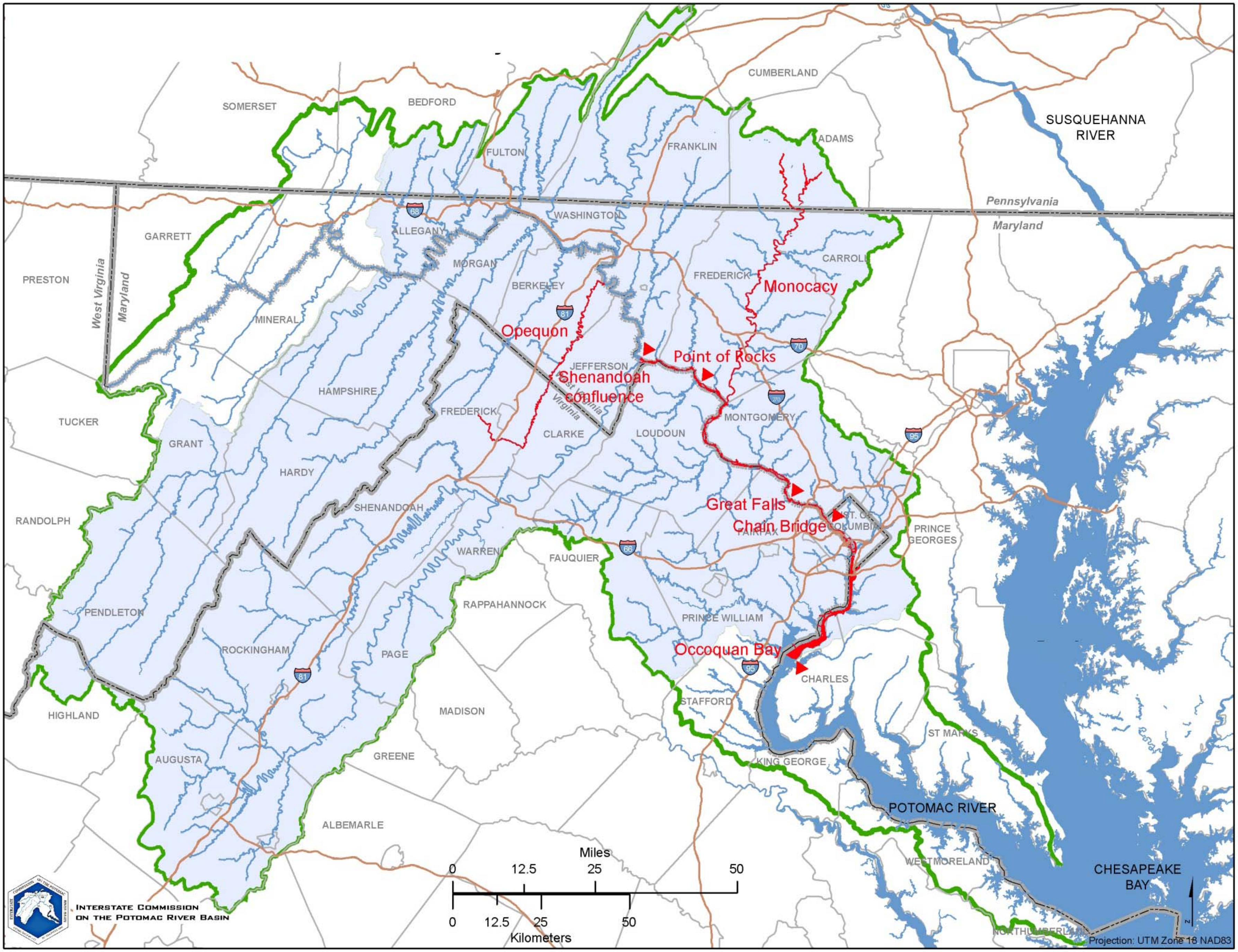
Potomac R. at Great Falls
Sep. 1966, ~100 cfs
Sep. 2003, ~123,000 cfs

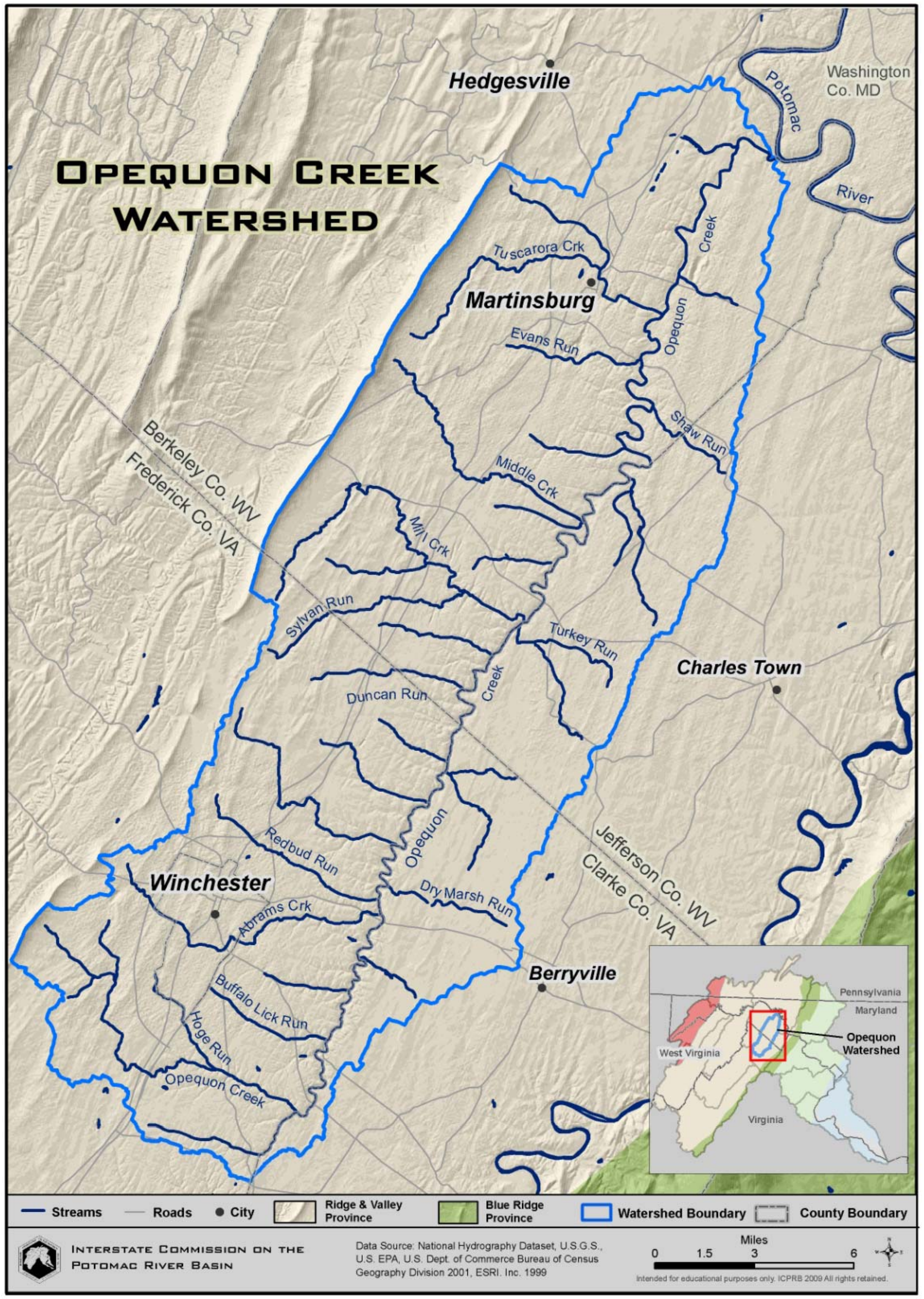
Potomac Large River Environmental Flow Needs Expert Workshop

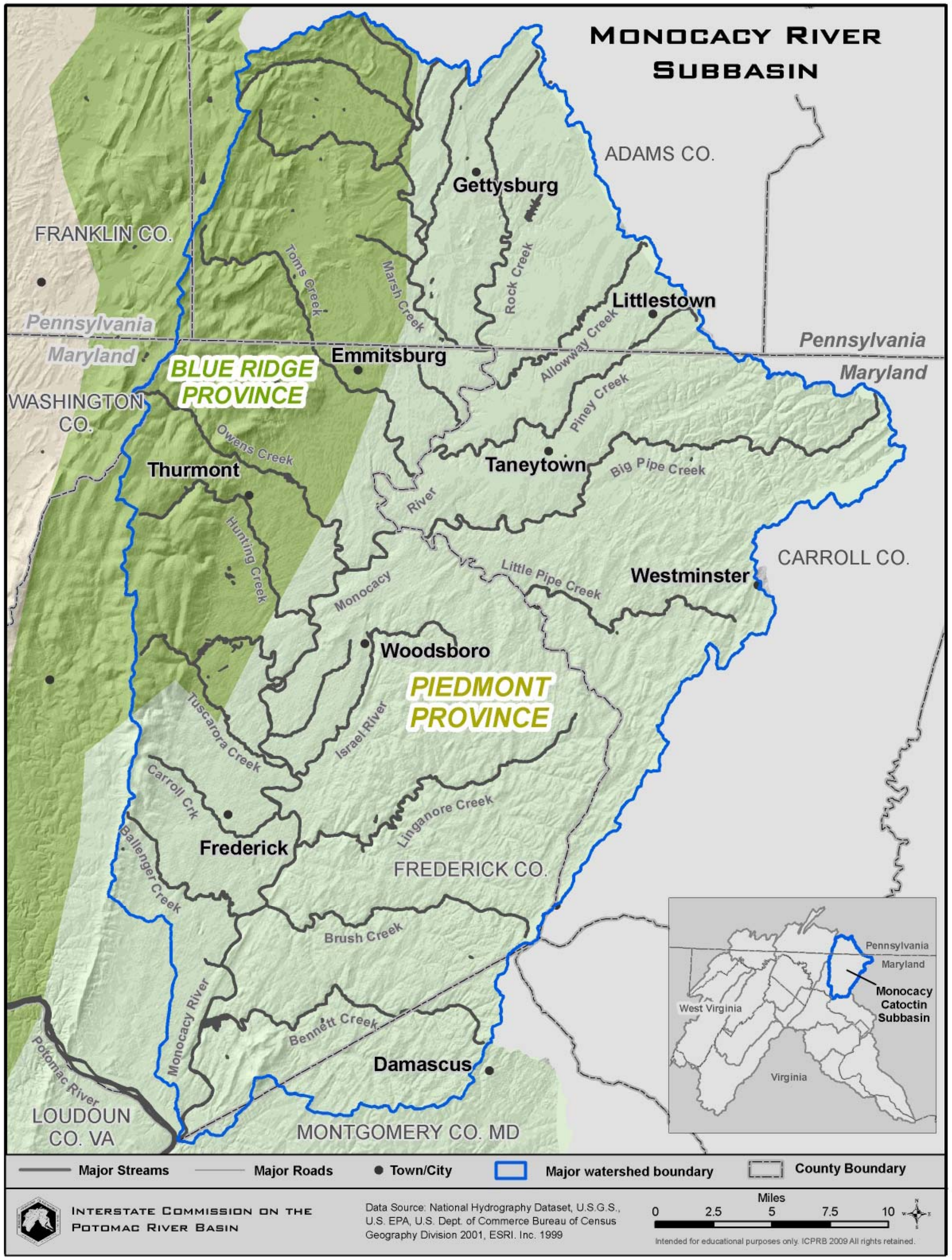
The Hydrologic Context

Carlton Haywood, ICPRB, 22 Sep 2010



SOMERSET
BEDFORD
FULTON
FRANKLIN
CUMBERLAND
ADAMS
SUSQUEHANNA RIVER
Pennsylvania
Maryland
GARRETT
PRESTON
West Virginia
Maryland
ALLEGANY
WASHINGTON
MORGAN
BERKELEY
FREDERICK
CARROLL
Monocacy
MINERAL
Opequon
Point of Rocks
JEFFERSON
Shenandoah confluence
HAMPSHIRE
FREDERICK
CLARKE
LOUDOUN
MONTGOMERY
TUCKER
GRANT
HARDY
RANDOLPH
SHENANDOAH
Great Falls
Chain Bridge
FAIRFAX
PRINCE GEORGES
WARREN
FAUQUIER
RAPPAHANNOCK
PENDLETON
PRINCE WILLIAM
ROCKINGHAM
PAGE
Occoquan Bay
CHARLES
HIGHLAND
MADISON
STAFFORD
ST MARYS
AUGUSTA
GREENE
KING GEORGE
POTOMAC RIVER
ALBEMARLE
WESTMORELAND
CHESAPEAKE BAY
Miles
0
12.5
25
50
0
12.5
25
50
Kilometers
Interstate Commission on the Potomac River Basin
Projection: UTM Zone 18 NAD83


Opequon Creek Watershed
Hedgesville
Washington Co. MD
Potomac
River
Tuscarora Crk
Martinsburg
Creek
Opequon
Evans Run
Shaw Run
Middle Crk
Mill Crk
Berkeley Co. WV
Frederick Co. VA
Sylvan Run
Turkey Run
Charles Town
Duncan Run
Creek
Opequon
Redbud Run
Winchester
Abrams Crk
Dry Marsh Run
Jefferson Co. WV
Clarke Co. VA
Berryville
Buffalo Lick Run
Hoge Run
Opequon Creek
Pennsylvania
Maryland
Opequon Watershed
West Virginia
Virginia
Streams
Roads
City
Ridge & Valley Province
Blue Ridge Province
Watershed Boundary
County Boundary
Interstate Commission on the Potomac River Basin
Data Source: National Hydrography Dataset, U.S.G.S., U.S. EPA, U.S. Dept. of Commerce Bureau of Census Geography Division 2001, ESRI, Inc. 1999
Miles
0
1.5
3
6


Monocacy River Subbasin
ADAMS CO.
FRANKLIN CO.
Gettysburg
Rock Creek
Toms Creek
Marsh Creek
Littlestown
Alloway Creek
Pennsylvania
Maryland
BLUE RIDGE PROVINCE
Emmitsburg
WASHINGTON CO.
Piney Creek
Owens Creek
Thurmont
Taneytown
Big Pipe Creek
River
Hunting Creek
Monocacy
Little Pipe Creek
Westminster
CARROLL CO.
Woodsboro
PIEDMONT PROVINCE
Tuscarora Creek
Israel River
Carroll Crk
Linganore Creek
Frederick
Ballenger Creek
FREDERICK CO.
Brush Creek
Monocacy River
Bennett Creek
Damascus
Potomac River
LOUDOUN CO. VA
MONTGOMERY CO. MD
Pennsylvania
Maryland
West Virginia
Monocacy Catoctin Subbasin
Virginia
Major Streams
Major Roads
Town/City
Major watershed boundary
County Boundary
Interstate Commission on the Potomac River Basin
Data Source: National Hydrography Dataset, U.S.G.S., U.S. EPA, U.S. Dept. of Commerce Bureau of Census Geography Division 2001, ESRI. Inc. 1999
Miles
0 2.5 5 7.5 10
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Basin characteristics

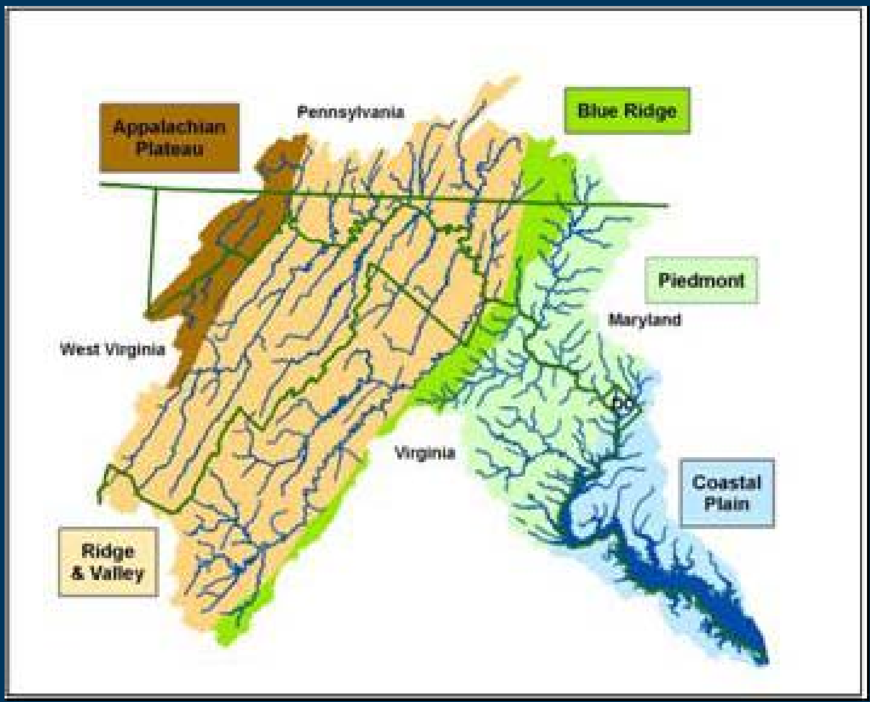


Fig. 5. Physiographic Provinces

US Army Corps of Engineers

The Nature Conservancy

Basin characteristics

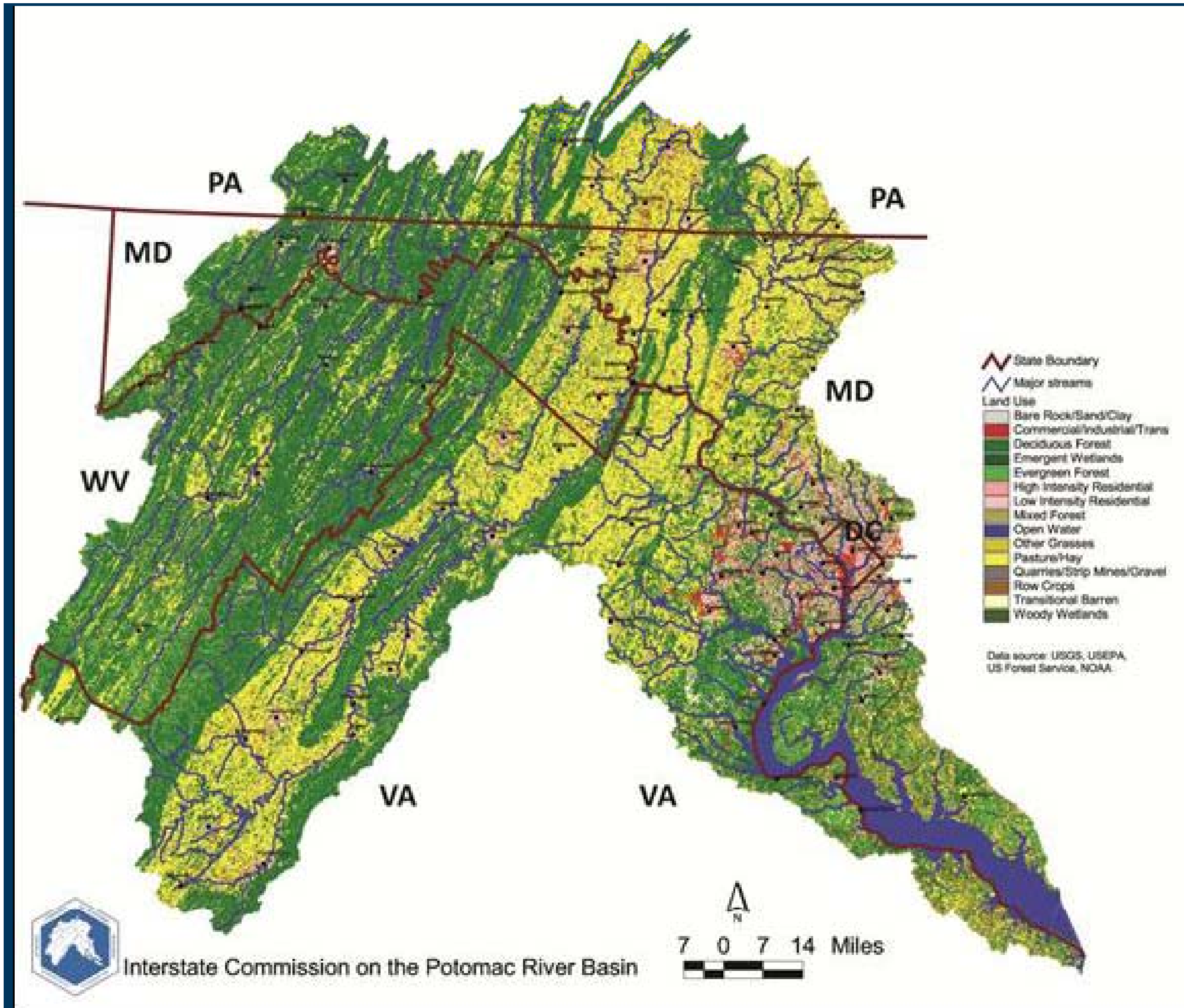
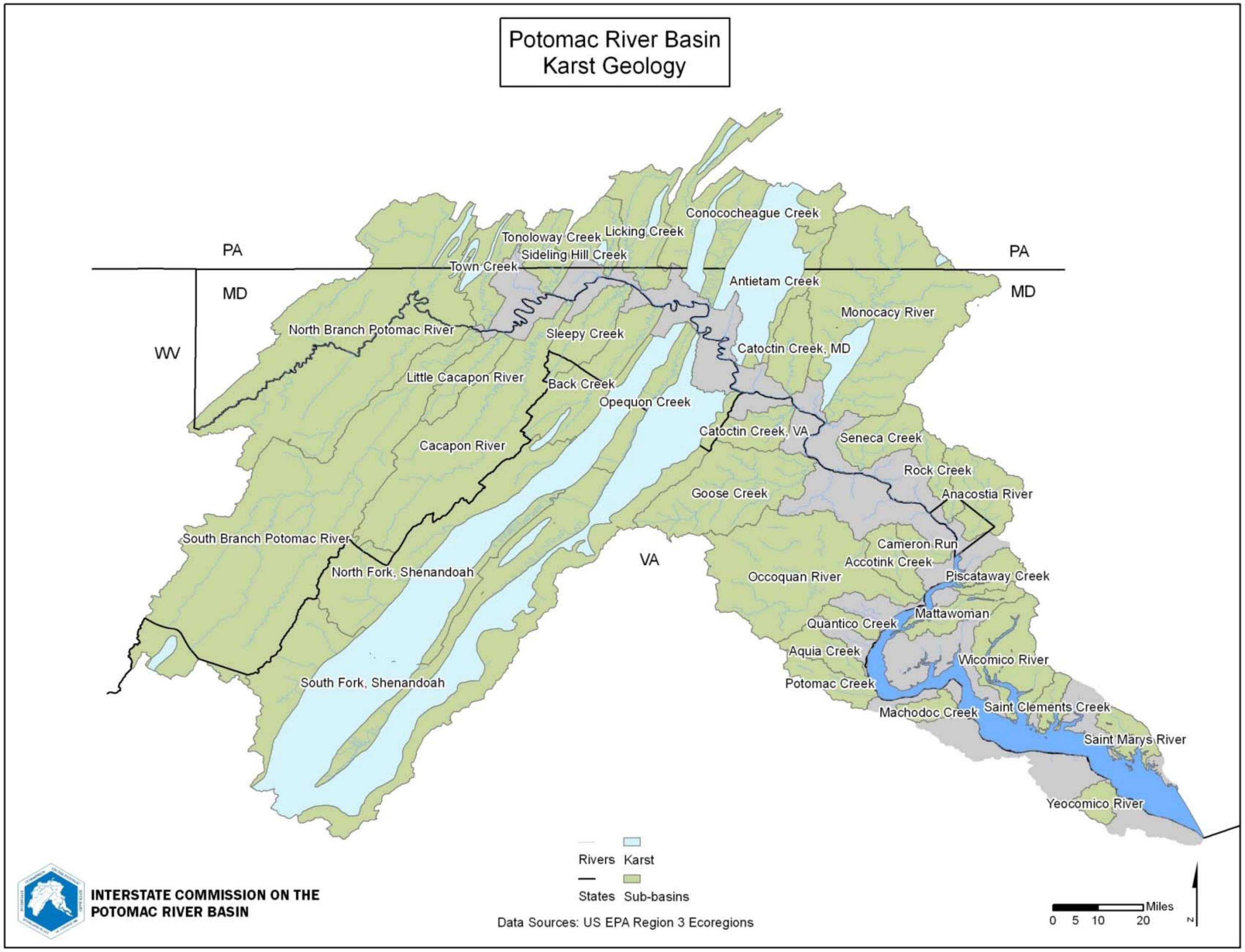


Fig. 7. Land Use in Potomac Basin

Basin Characteristics



Opequon
63% karst

Monocacy
6% karst

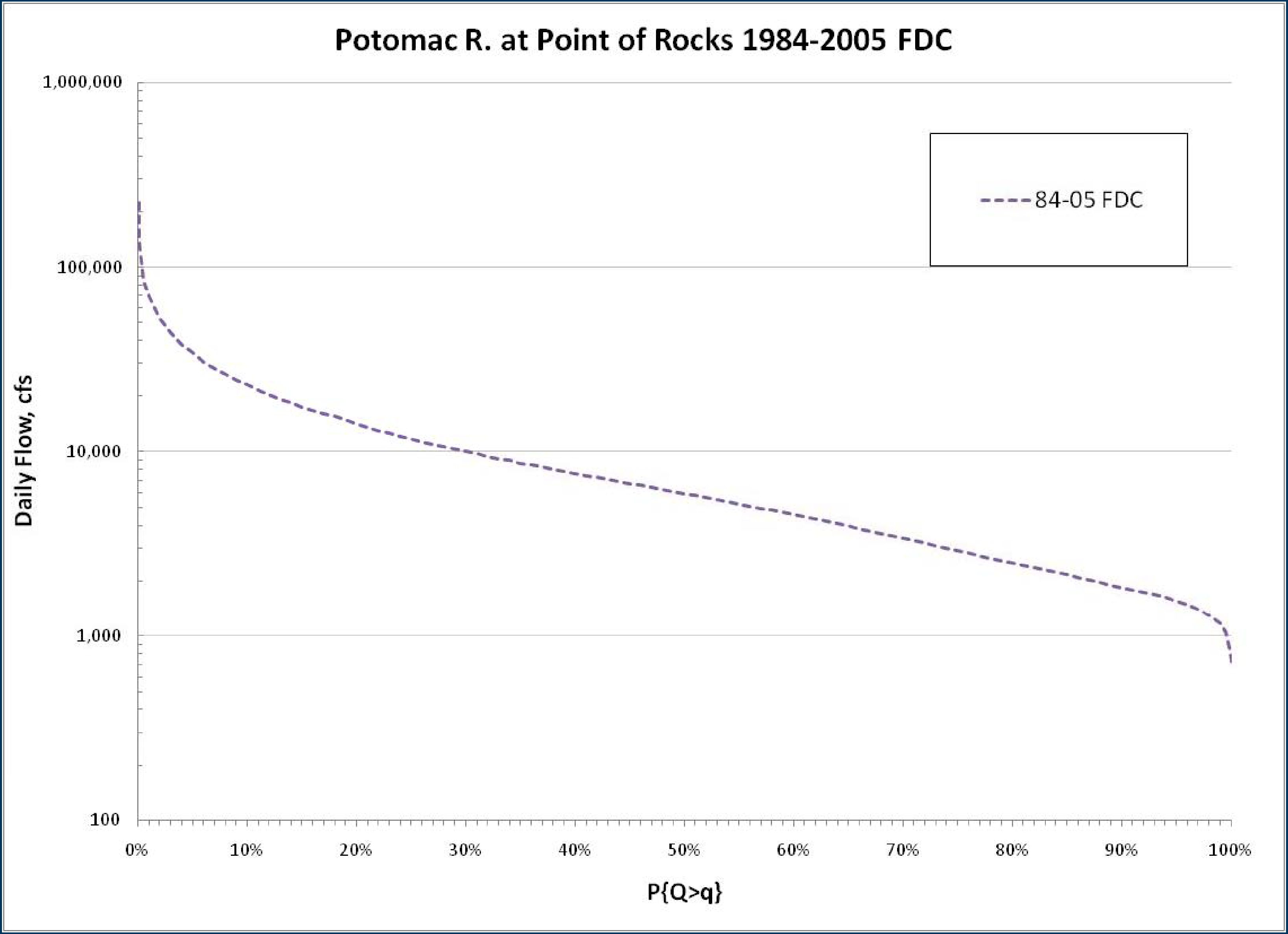
Basin characteristics

Table 2. Land and water uses in Opequon Creek, Monocacy River, and the areas laterally bordering each of the four Potomac River mainstem segments of interest and the upstream basin (shown in Figure 11).

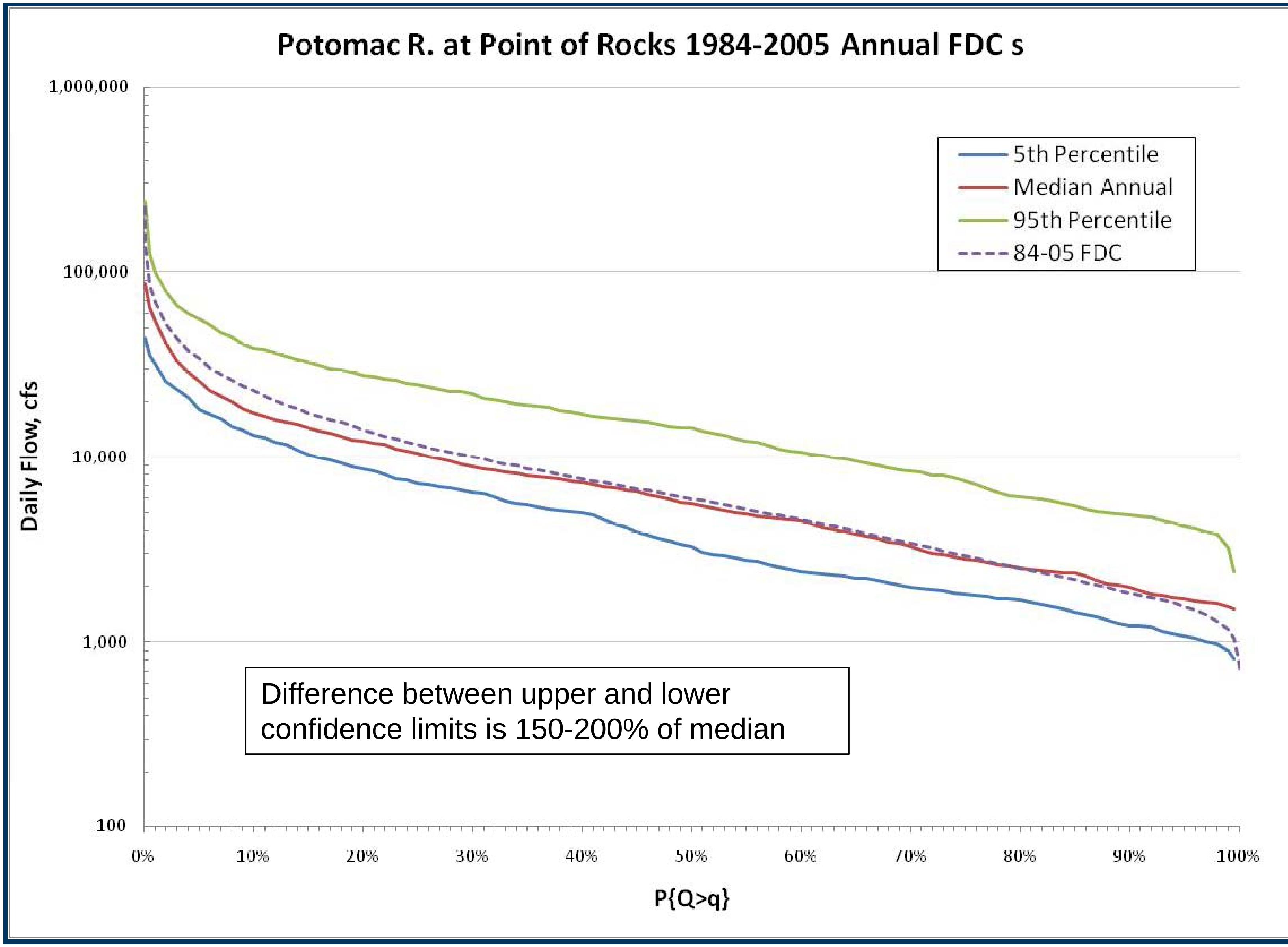
	Area of bordering watershed, mi^2	Agri-culture area, mi^2 (%)	Urban area, mi^2 (%)	Forest area, mi^2(%)	Total withdrawal, billion gallons per year	Consump. use, billion gallons per year
Opequon & Monocacy Watersheds						
Opequon Creek	344	128 (37%)	38 (11%)	165 (48%)	7.3	2.0
Monocacy River	965	455 (47%)	144 (15%)	309 (32%)	16	4.4
Potomac River Mainstem Segments						
Basin upstream of Shenandoah River confluence	9,360	2,108 (23%)	605 (6.5%)	6,507 (70%)	570	30
Shenandoah River confluence to Point of Rocks	288	126 (44%)	32 (12%)	125 (44%)	0.81	0.23
Point of Rocks to Great Falls	1,796	778 (43%)	336 (19%)	618 (34%)	340	47
Great Falls to Chain Bridge (Little Falls)	119	8.6 (7%)	72 (61%)	33 (28%)	1.6	0.44
Chain Bridge (Little Falls) to Occoquan River confluence	1,397	206 (15%)	584 (42%)	504 (36%)	114	8.7

Values were obtained as follows: area or volume/year calculated for the entire basin above the upstream end of each segment is subtracted from that calculated for the entire basin above the downstream each of each segment.

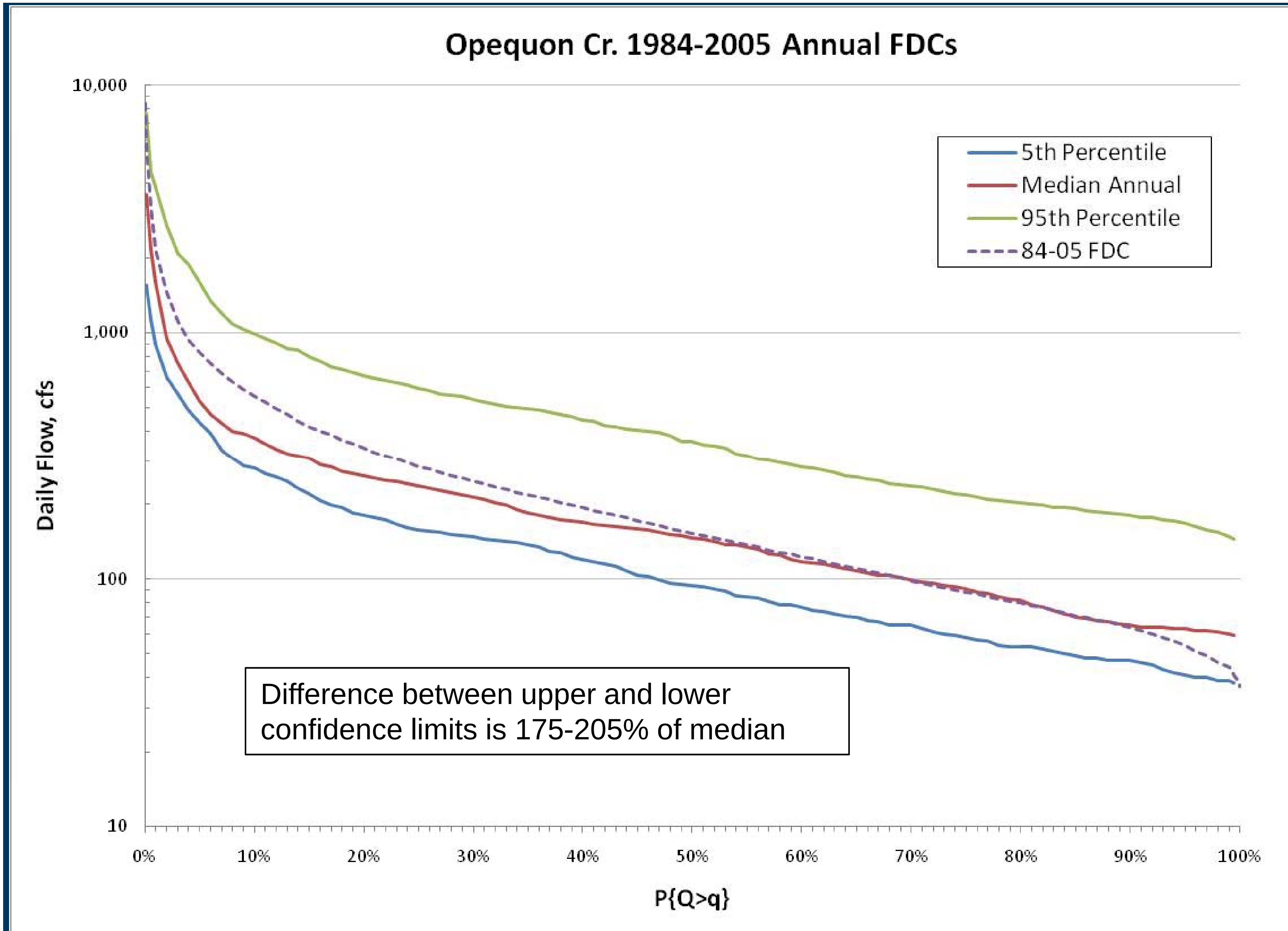
Flows are variable



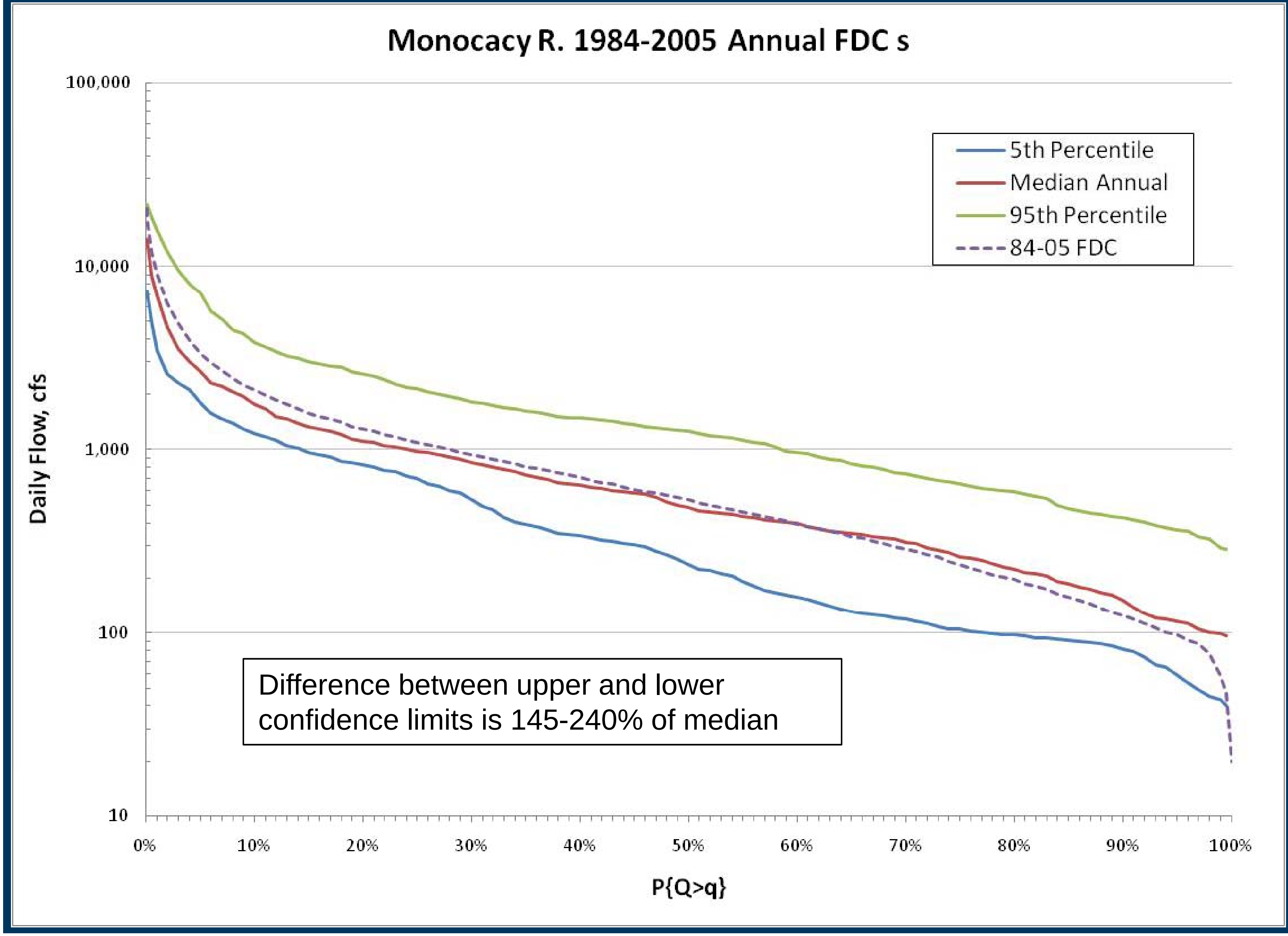
Flows are variable



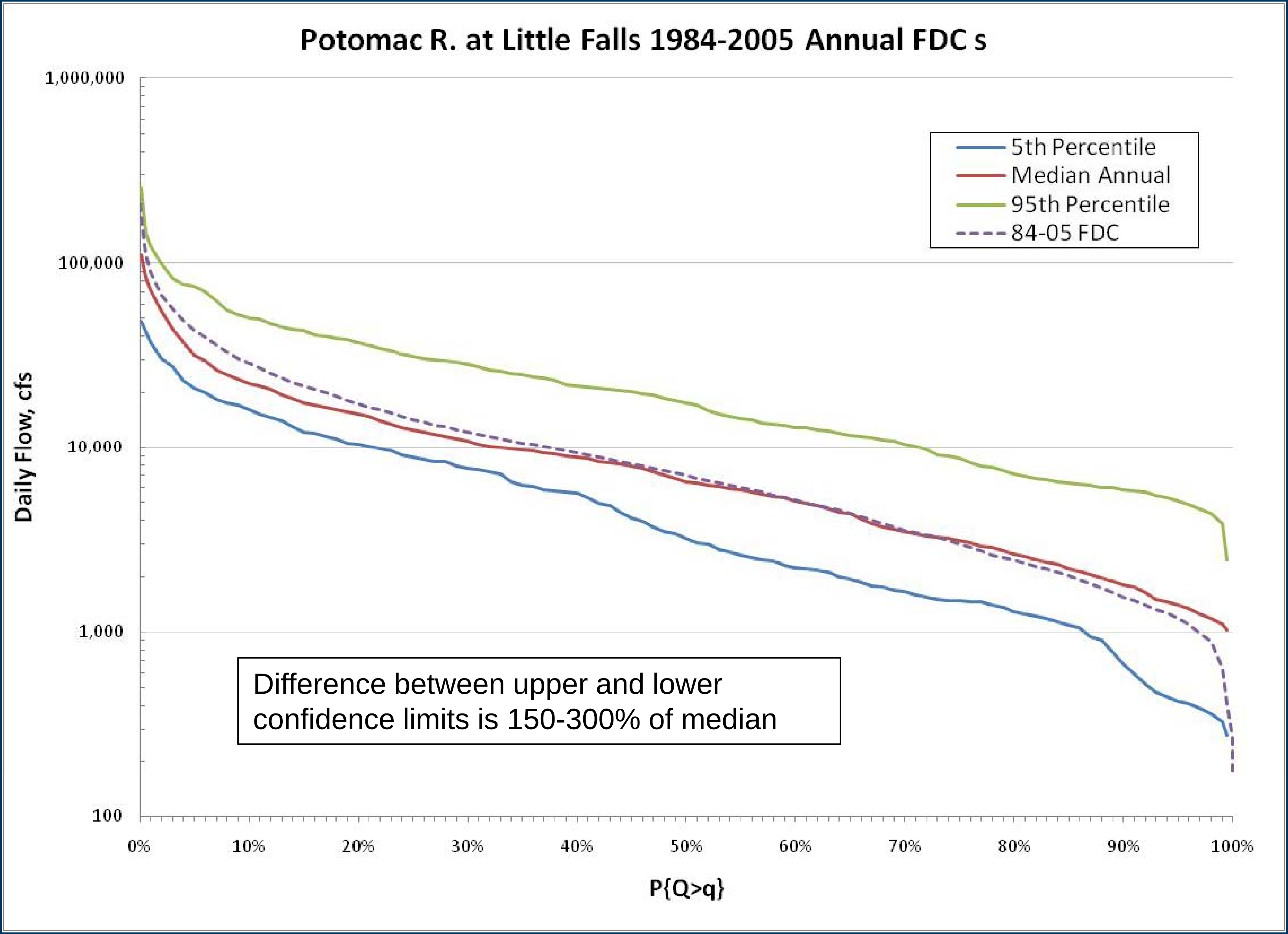
Flows are variable



Flows are variable

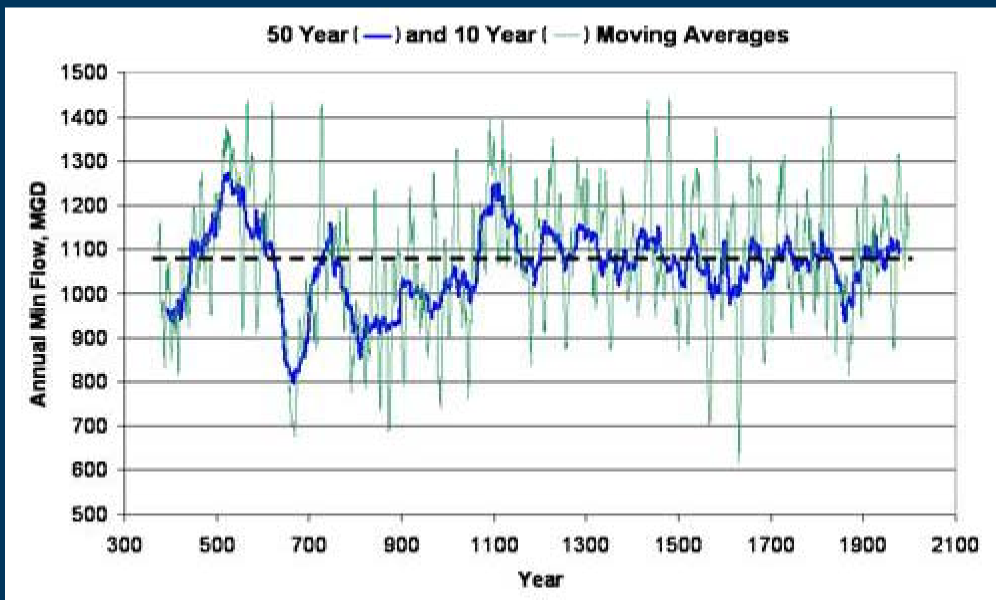


Flows are variable



Long term variability in flows

- Climate cycles? Climate change? Land cover change?



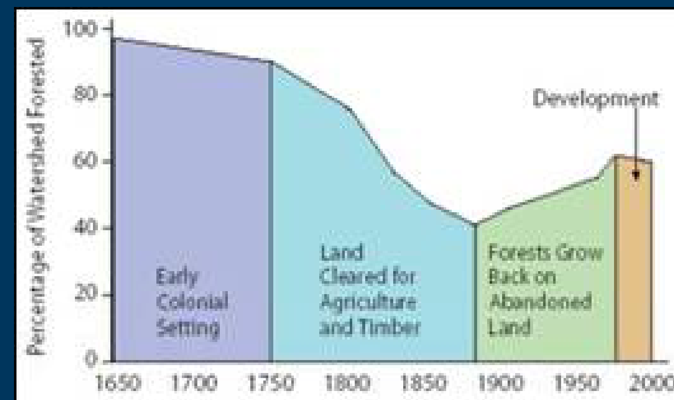
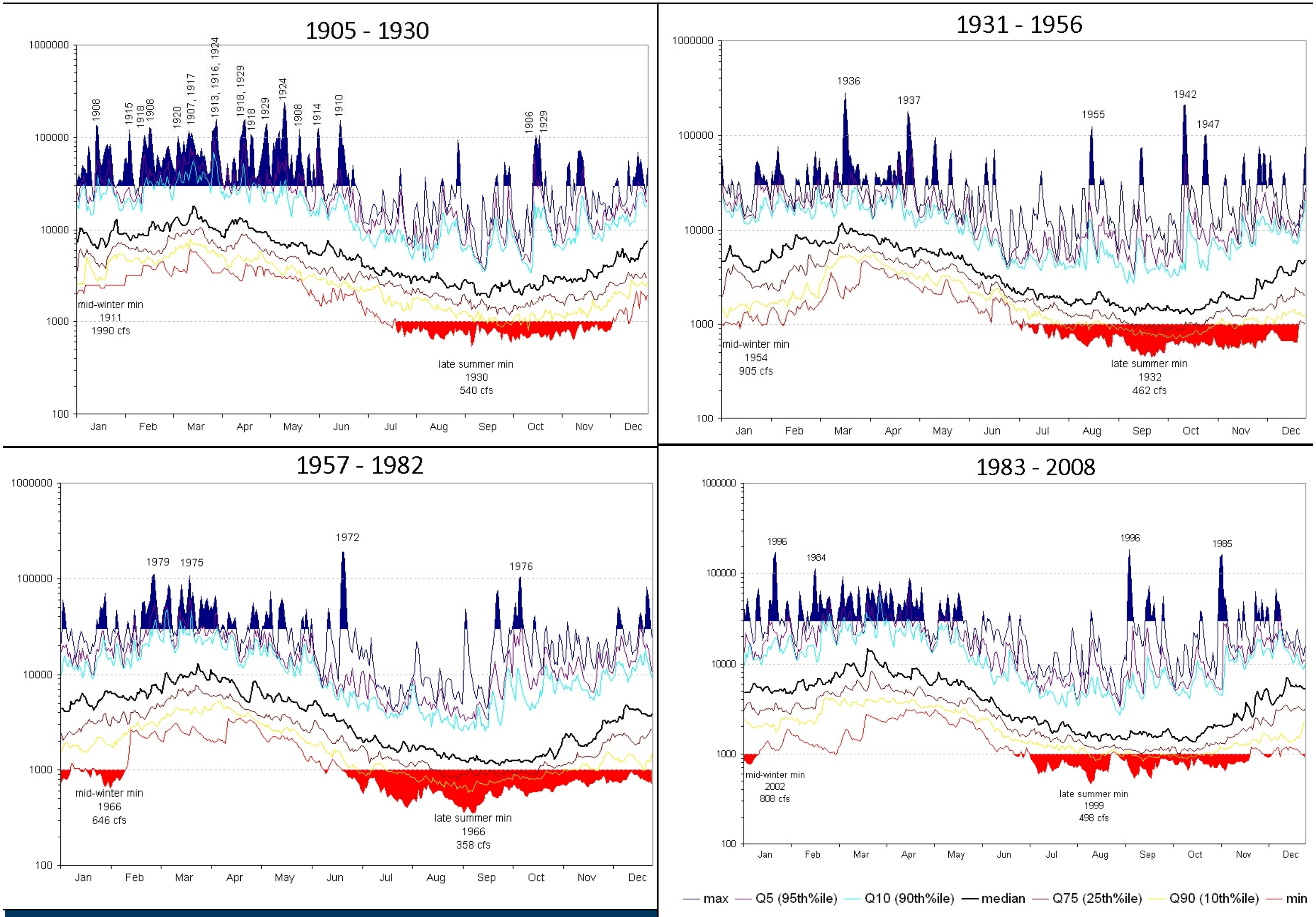


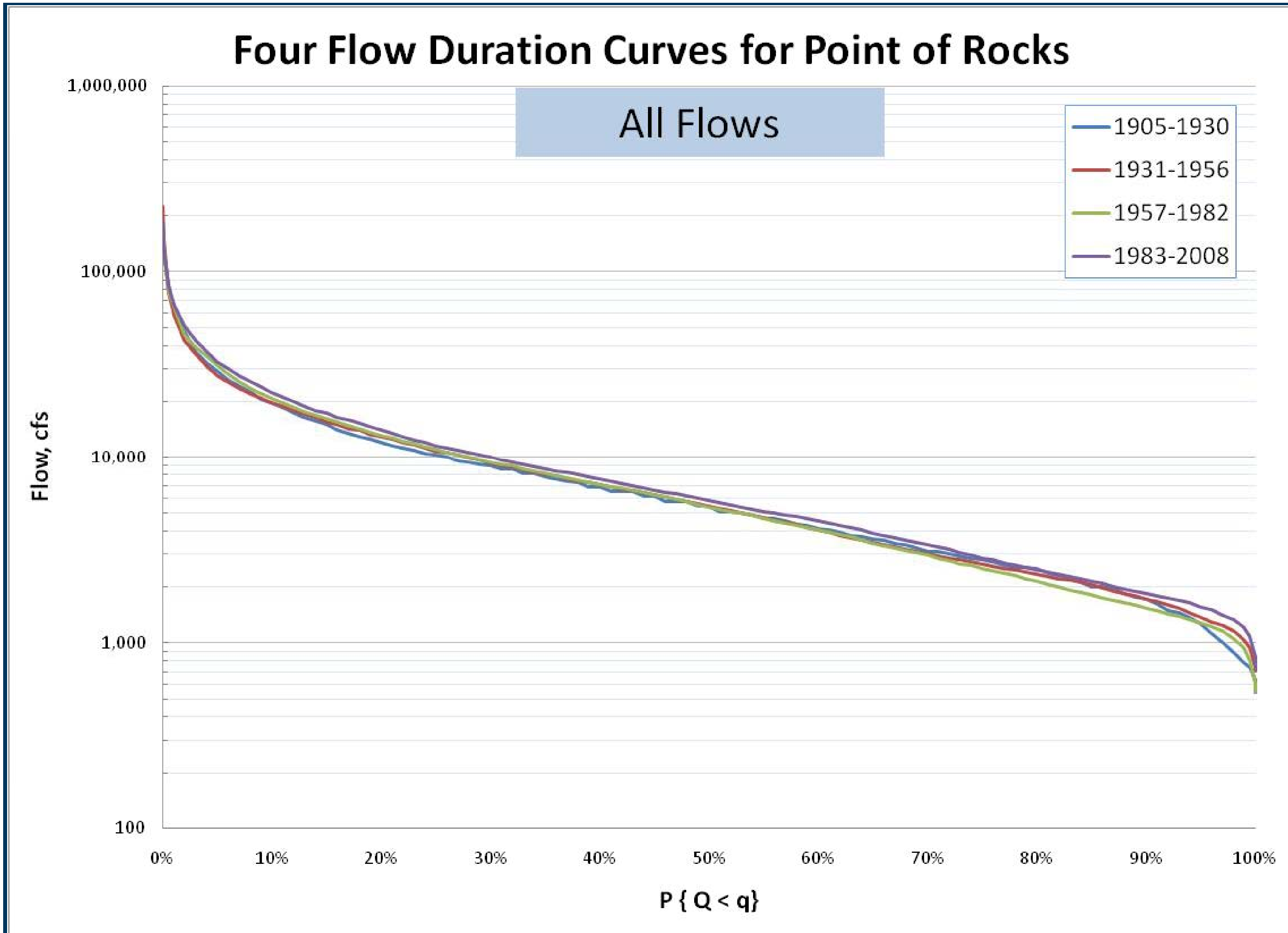
Figure 8. Changes in Chesapeake forest cover

Figure 4. … annual minimum flows from tree-rings …

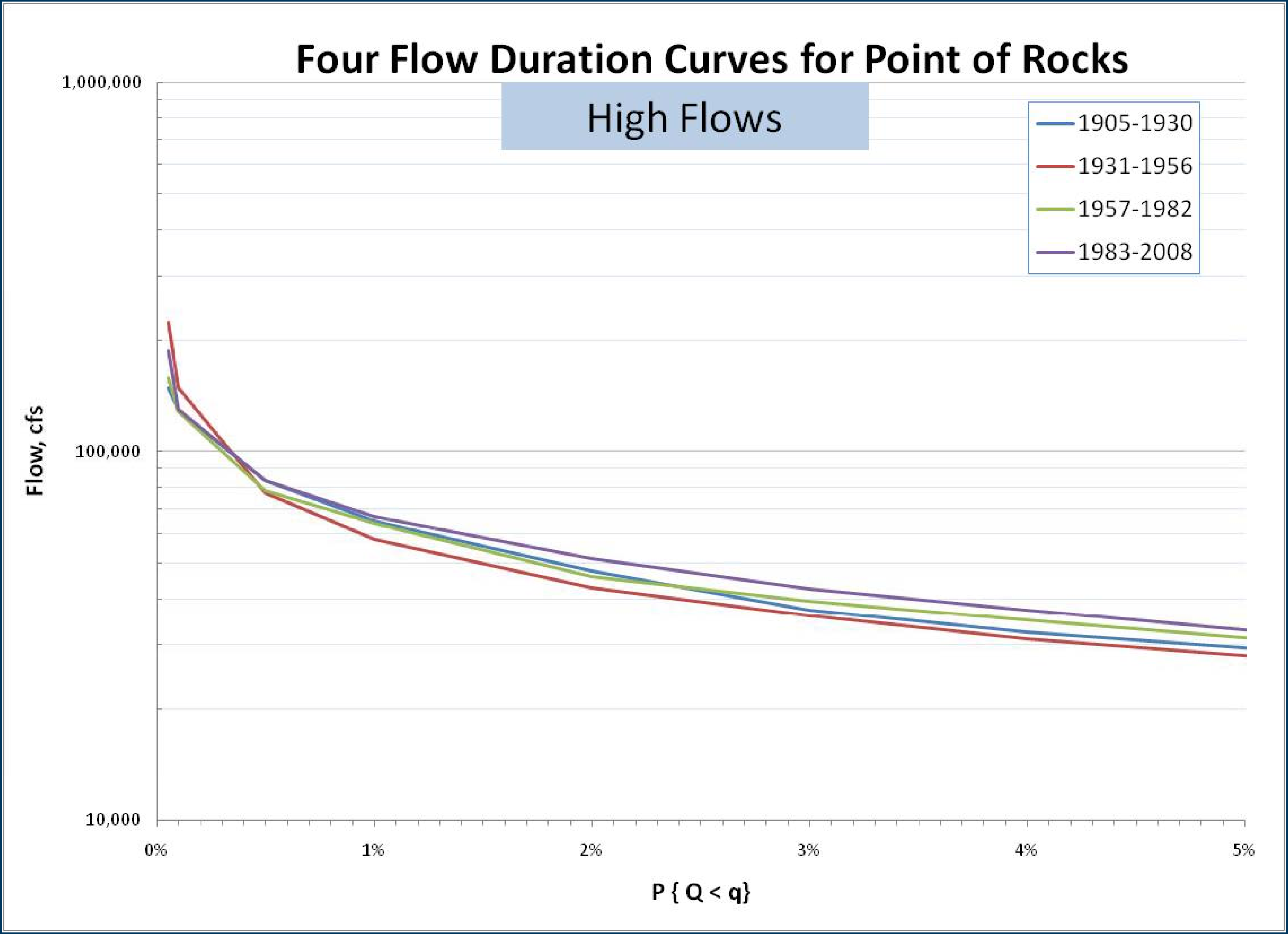


Report Figure 38

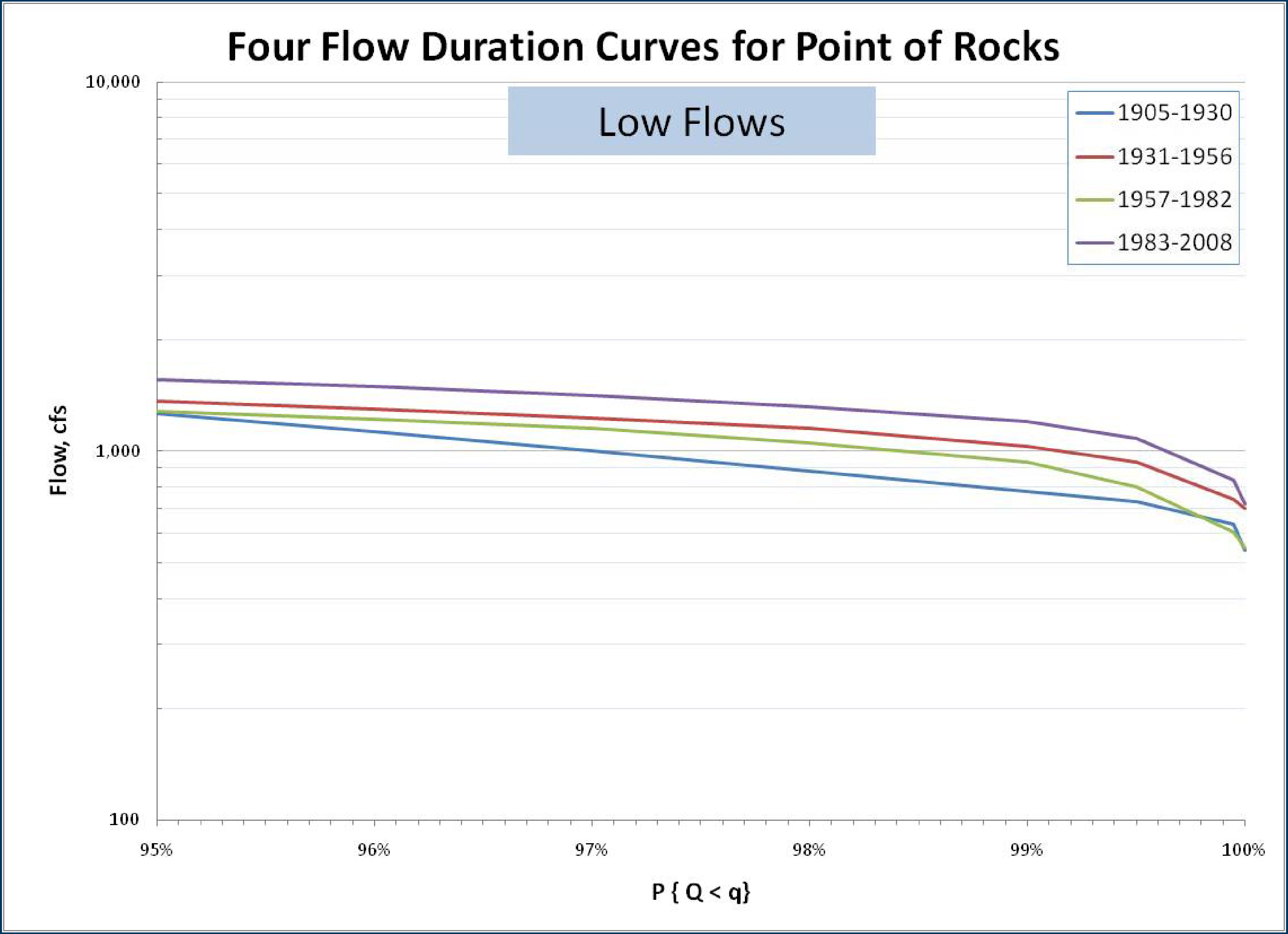
Variability in 104 year flow record



Variability in 104 year flow record

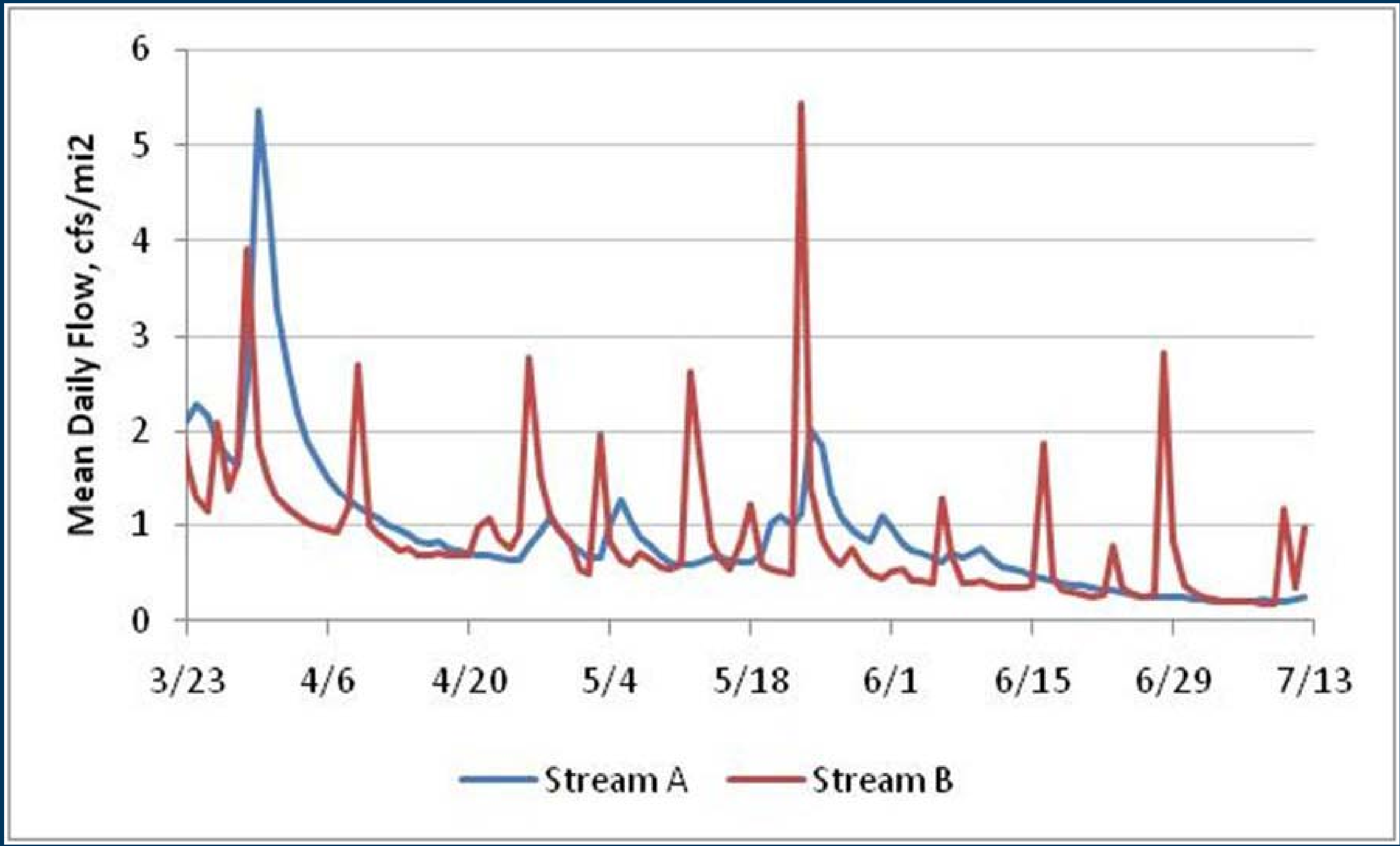


Variability in 104 year flow record



Stream Flashiness

In this context, stream flashiness refers to the amount of variability in flow per unit of time.

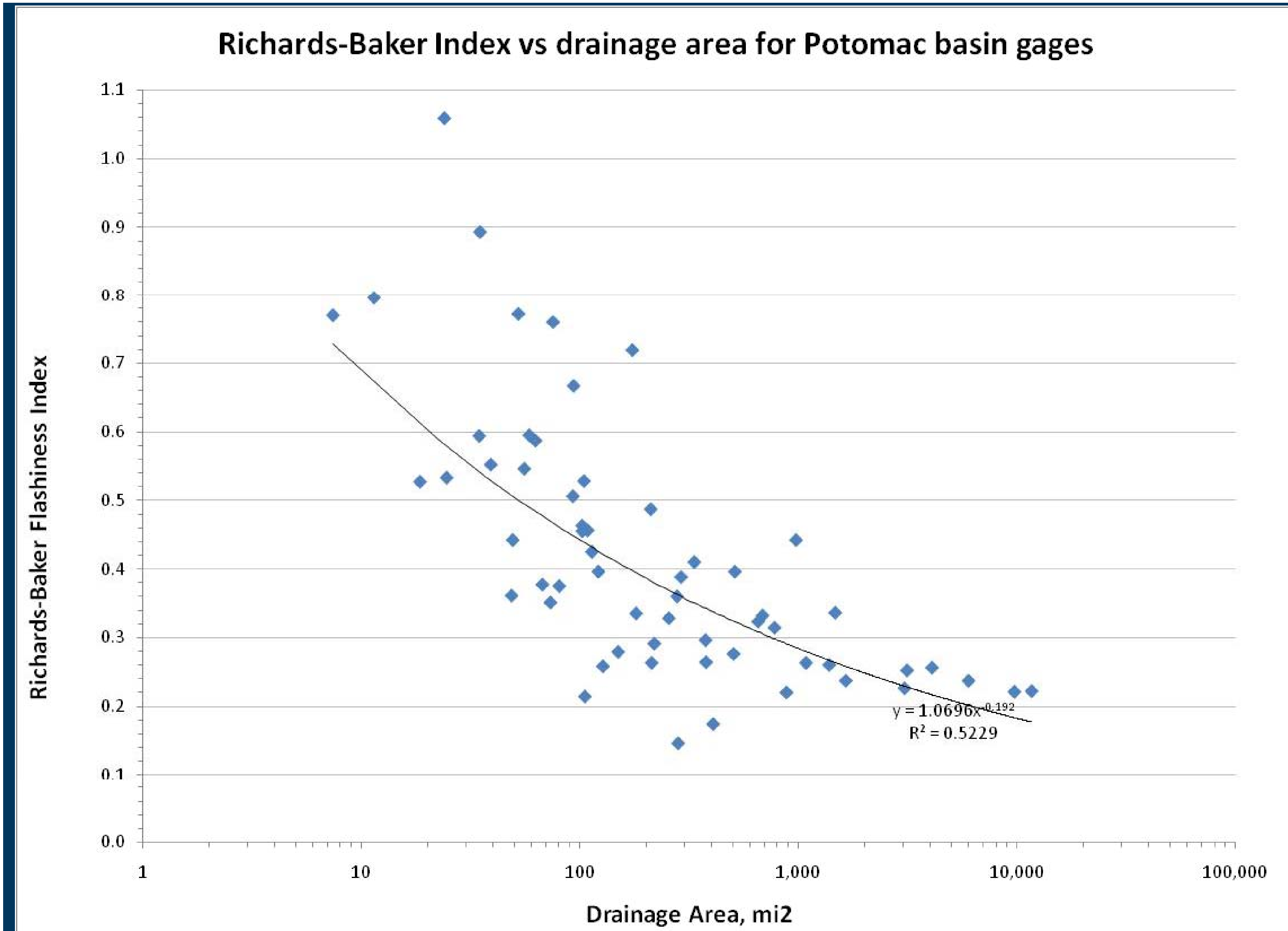


Stream Flashiness

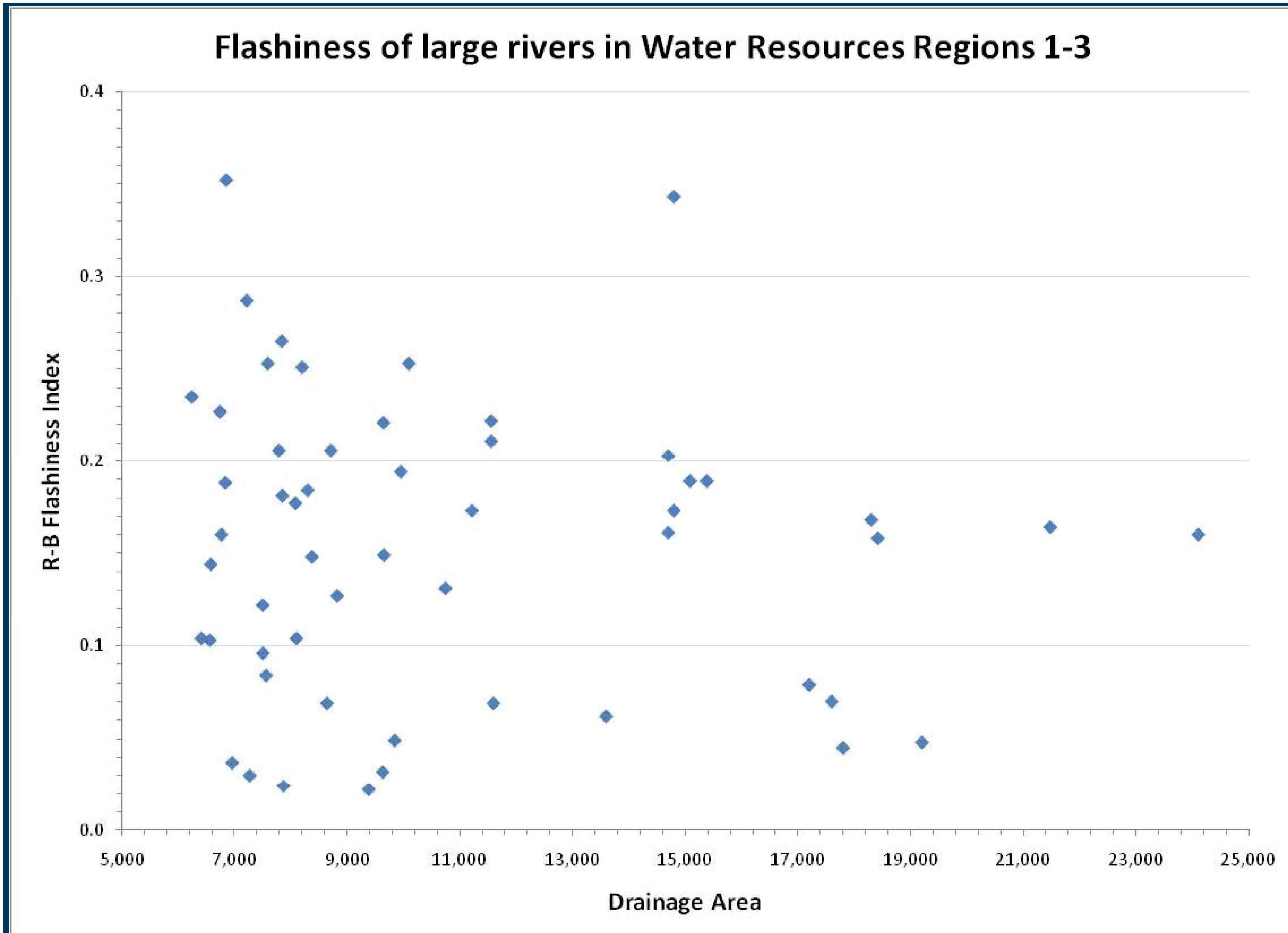
Richards – Baker Index, Baker et al (2004), Journal of the AWRA

$$R - B\ Index = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

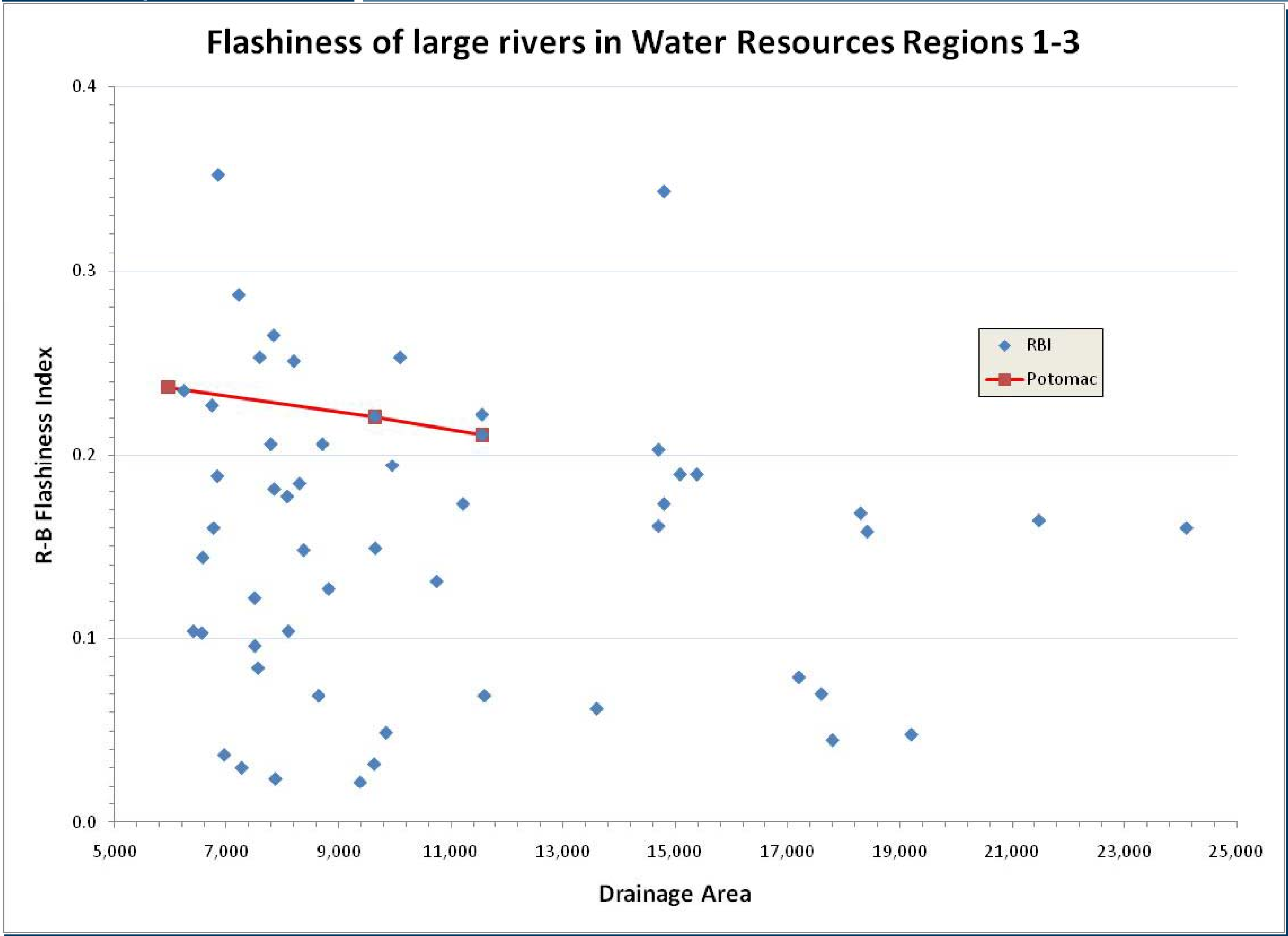
Flashiness decreases as D.A. increases



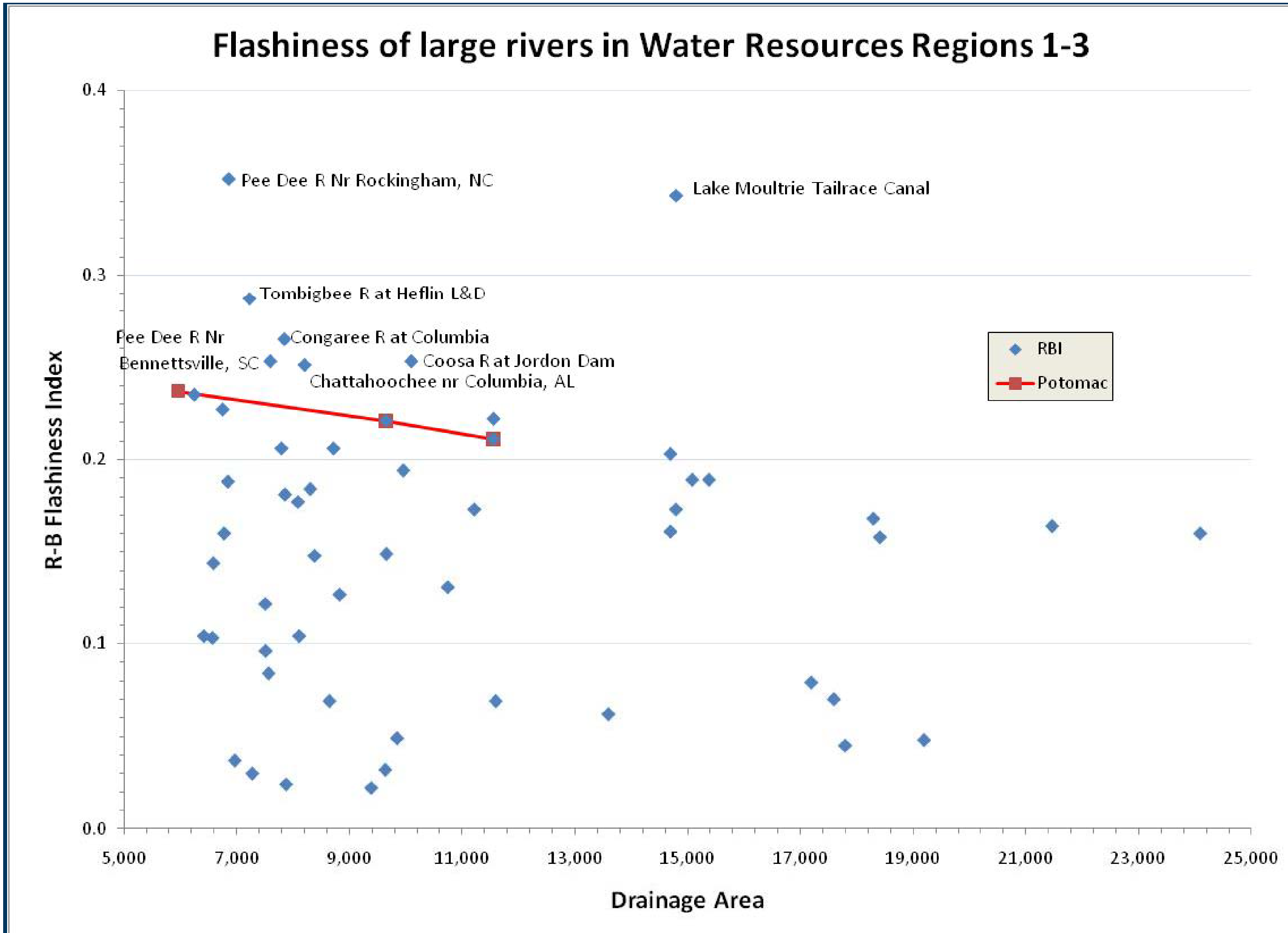
Flashiness of East Coast Large Rivers



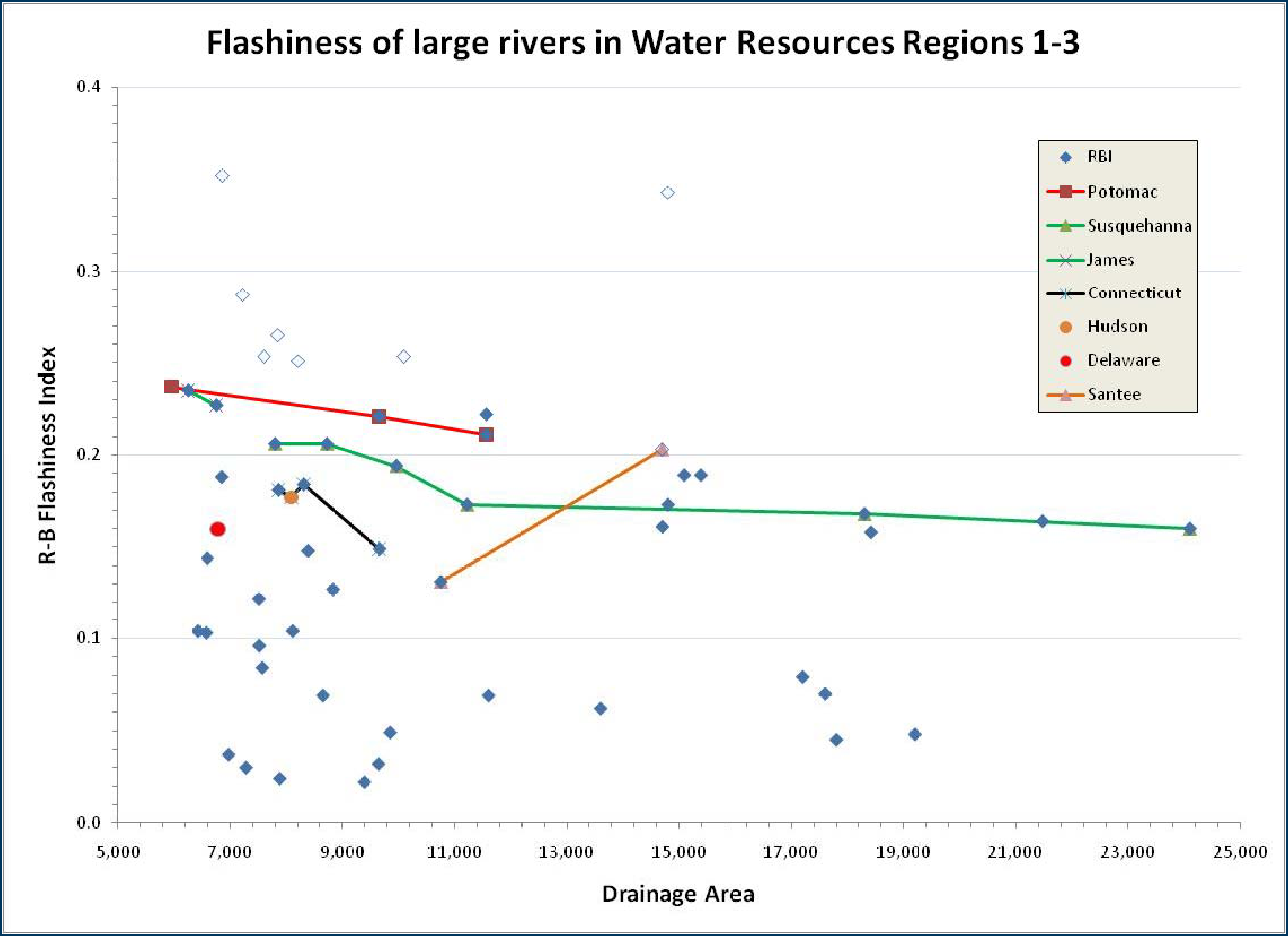
Potomac River is “flashy”



Potomac River is "flashy"



Potomac River:
The “flashiest” river in the East



How we picked river reaches to study

1) A Priori selection
    a) Potomac R. Great Falls to Little Falls
    b) Tidal Potomac to Occoquan Bay
2) Hydrologic alteration risk assessment
    a) Monocacy
    b) Opequon
    c) Potomac R. Point of Rocks to Great Falls

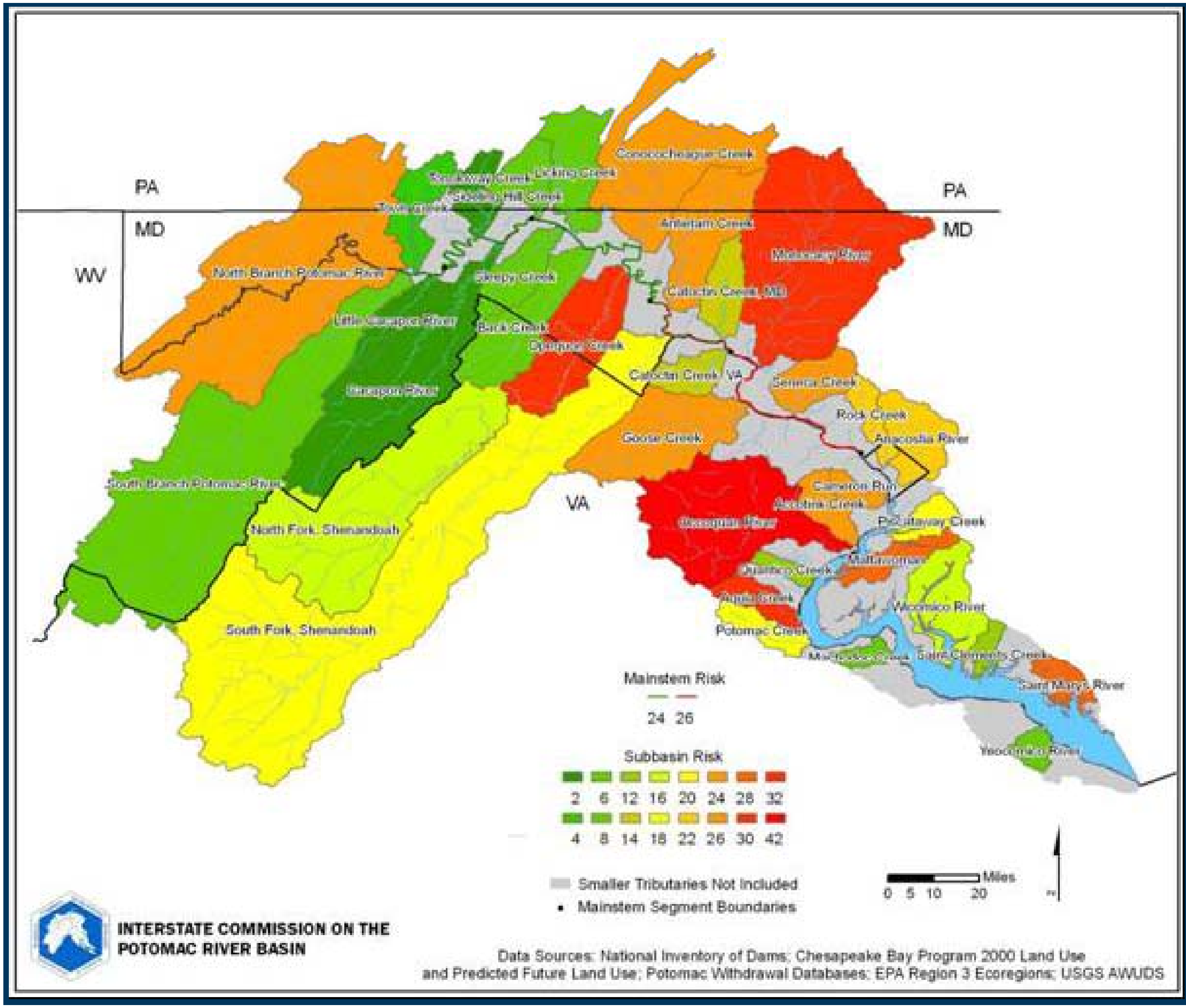
Hydrologic alteration risk assessment

- Ten risk factors selected for evaluation based on their ability to influence one or more Indicators of Hydrologic Alteration.

- The ten risk factors were categorized as low, medium, high, and severe, risk based on results of a Classification and Regression Tree (CART) analysis, on literature values, and on the frequency of risk factor values in the basin.

- Risk index is a count of risk factors, weighted by relative severity of each factor.

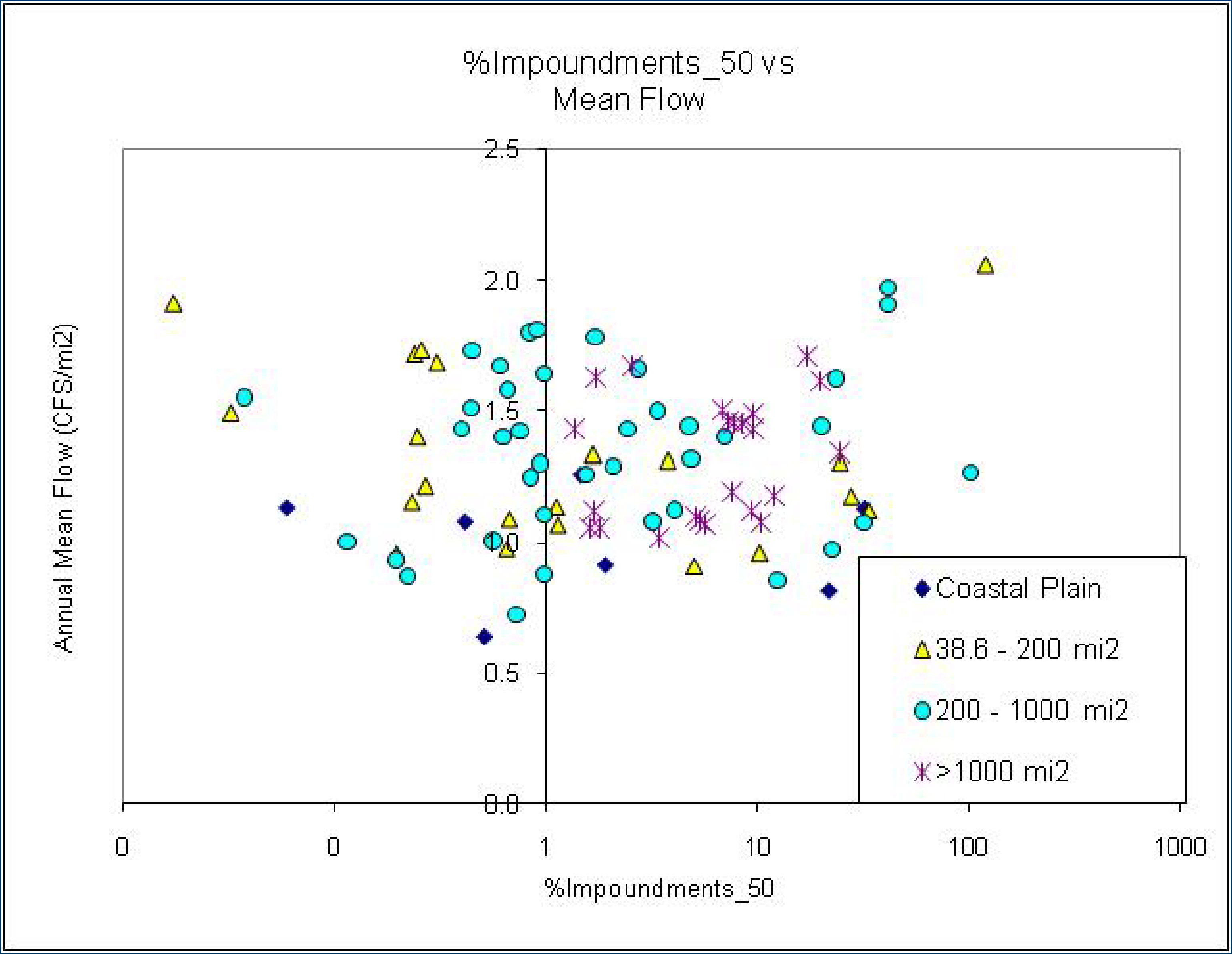
Watersheds / reaches most at risk of hydrologic alteration



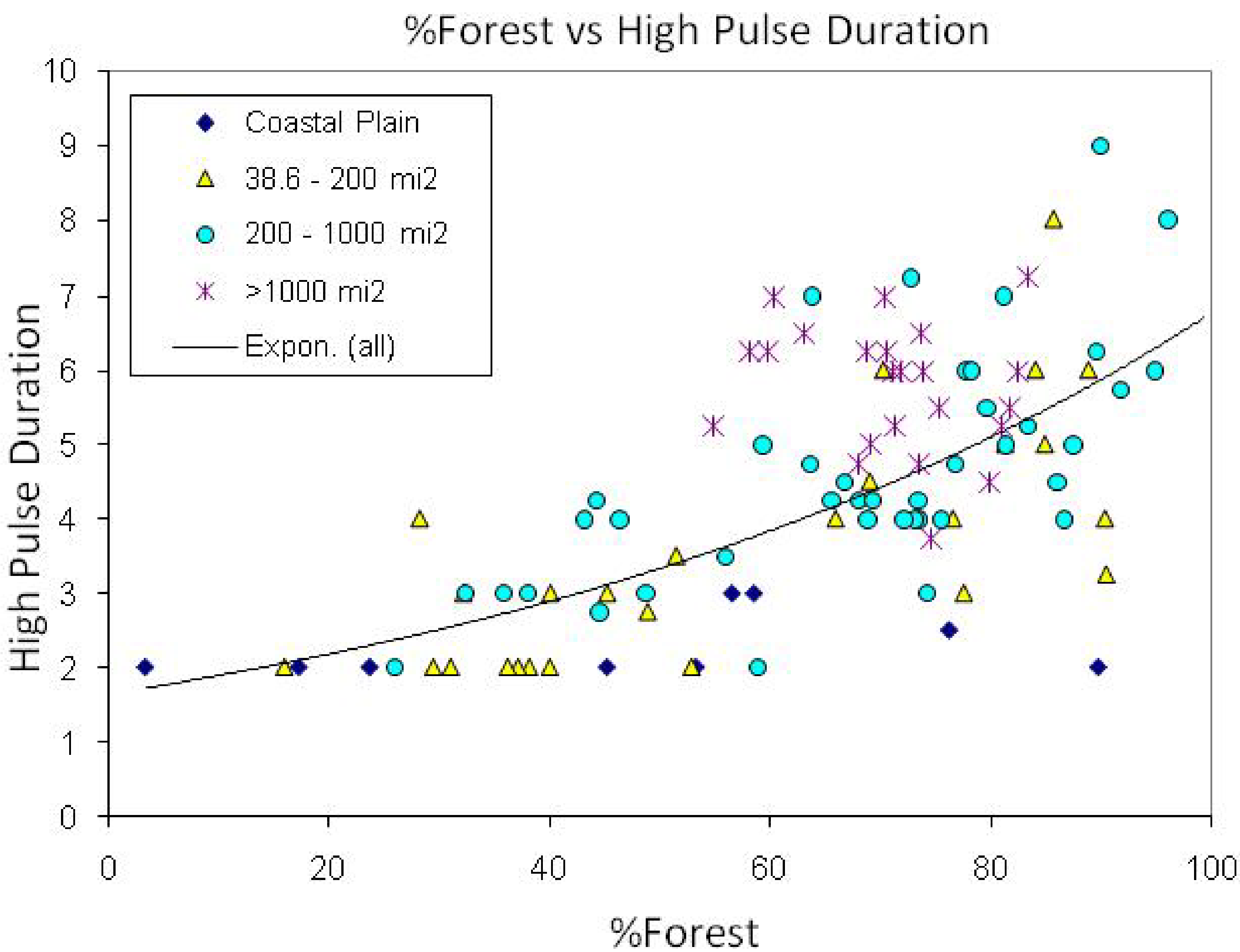
Preliminary General Findings: risk factors and impact on Indicators of Hydrologic Alteration

- Findings come from analysis of Potomac (incl. North Branch) + Susquehanna watersheds done for Middle Potomac Watershed Assessment
- Watershed size >38 mi^2 apparently not important for IHAs representing *lower half of hydrograph*
- % Forest cover is most significant discriminator
- % Impervious Surface next most important
- % Agriculture next most important
- % Karst geology (a natural risk factor) important for several IHAs

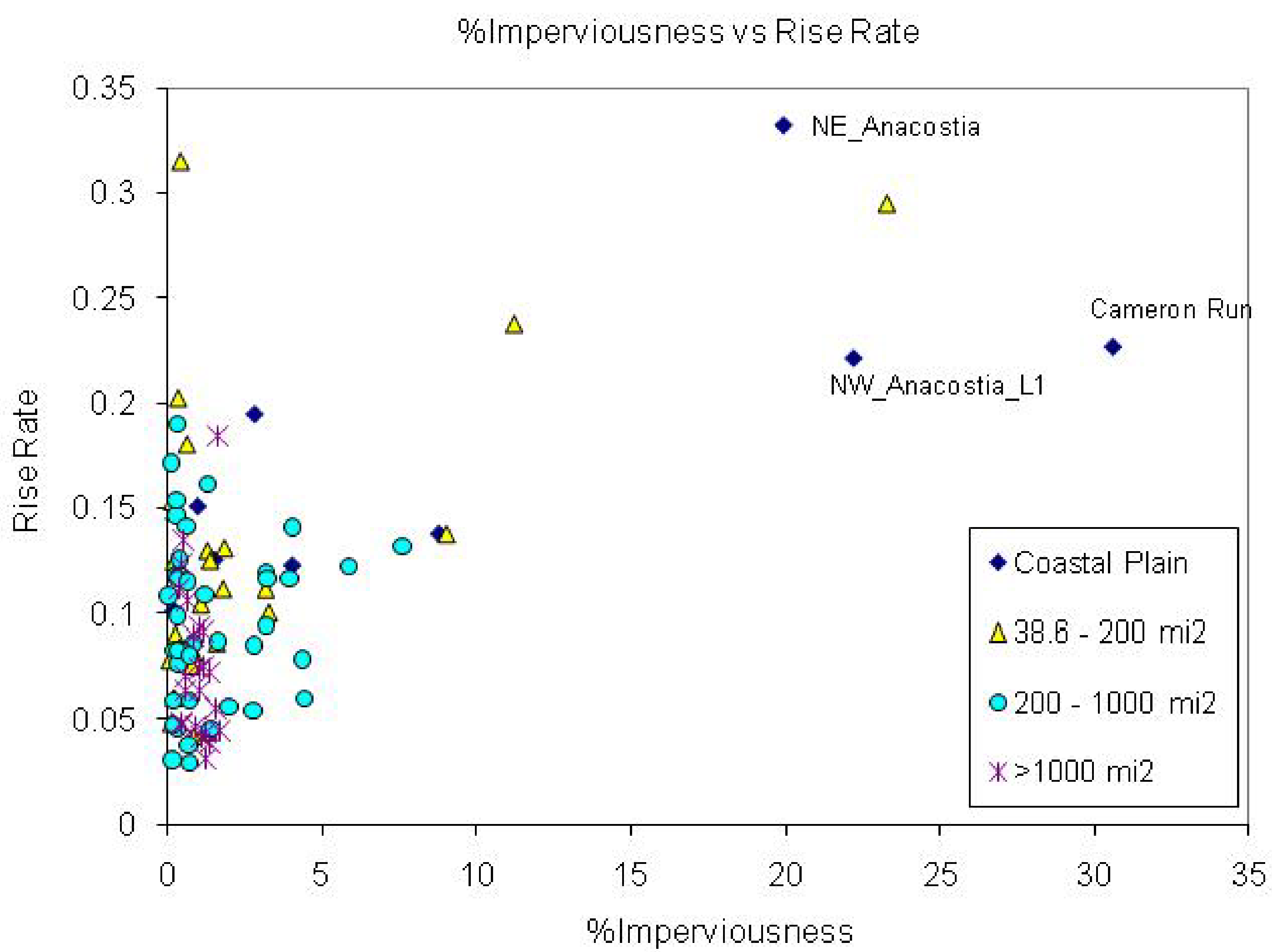
Examples: Risk factors and impact on IHAs – Impoundment vol. vs mean flow



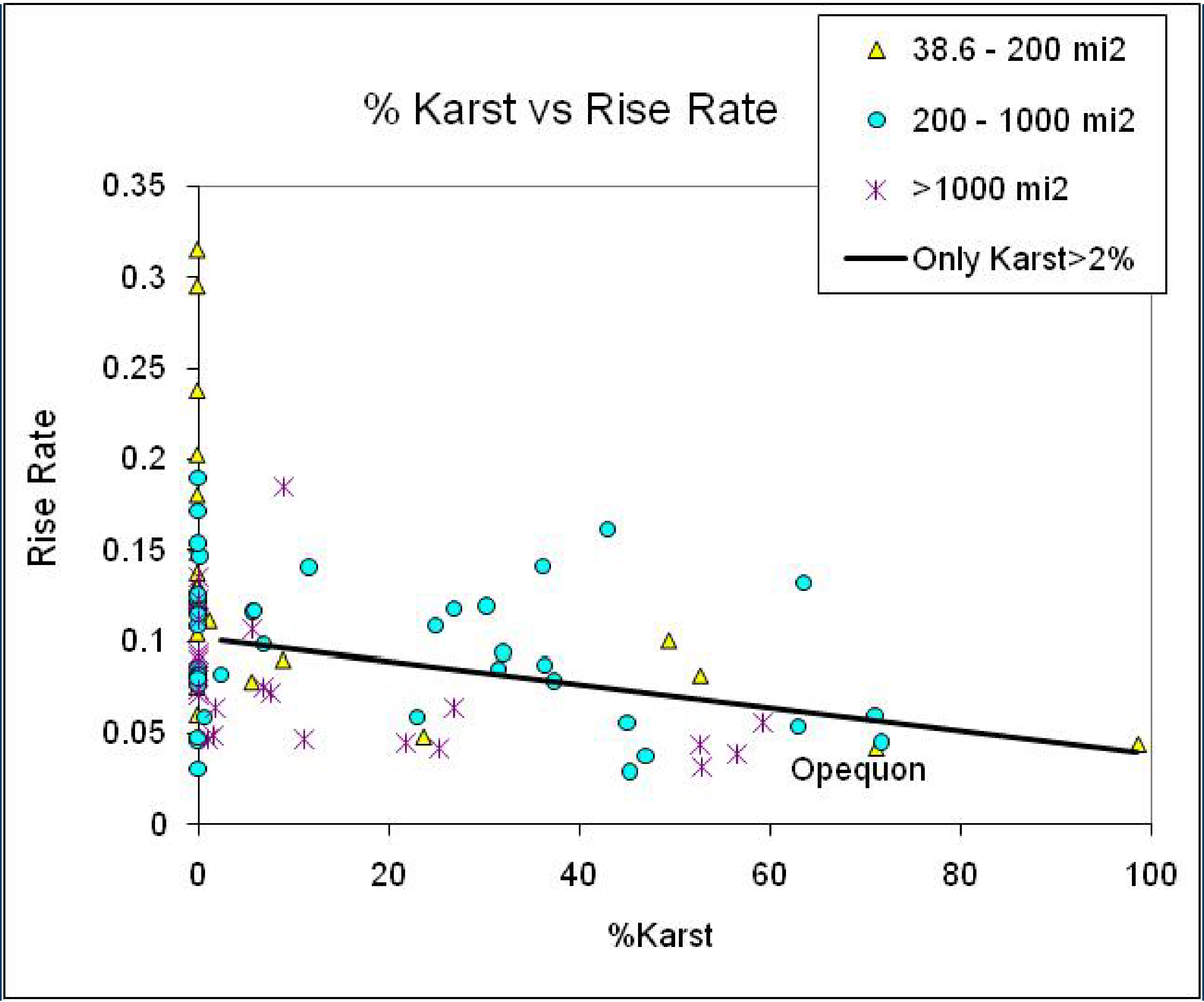
Examples: Risk factors and impact on IHAs – % Forest vs High Pulse Duration



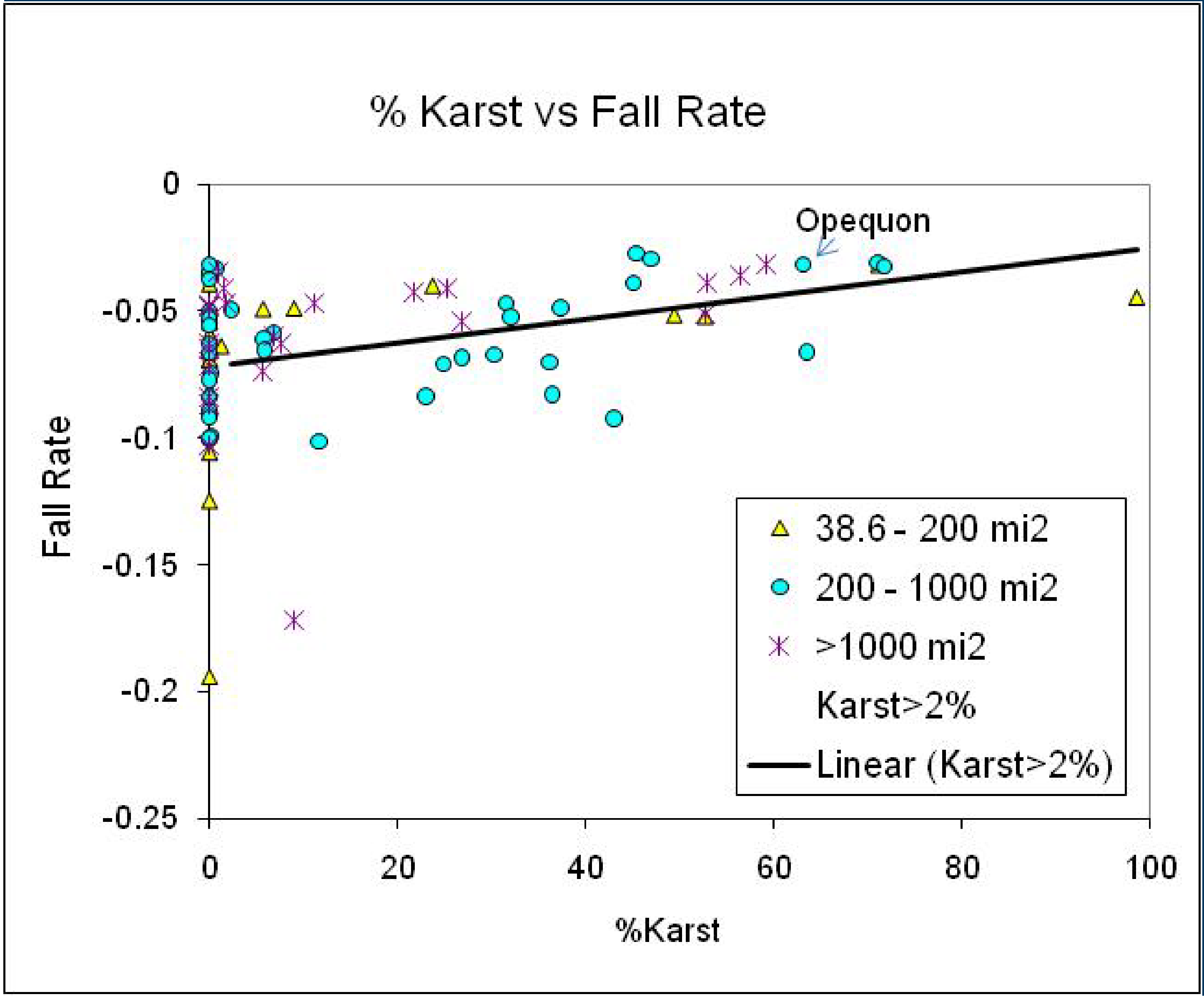
Examples: Risk factors and impact on IHAs – % Impervious vs Rise Rate



Examples: Risk factors and impact on IHAs – Impoundment vol. vs Rise Rate



Examples: Risk factors and impact on IHAs – % Karst vs Fall Rate



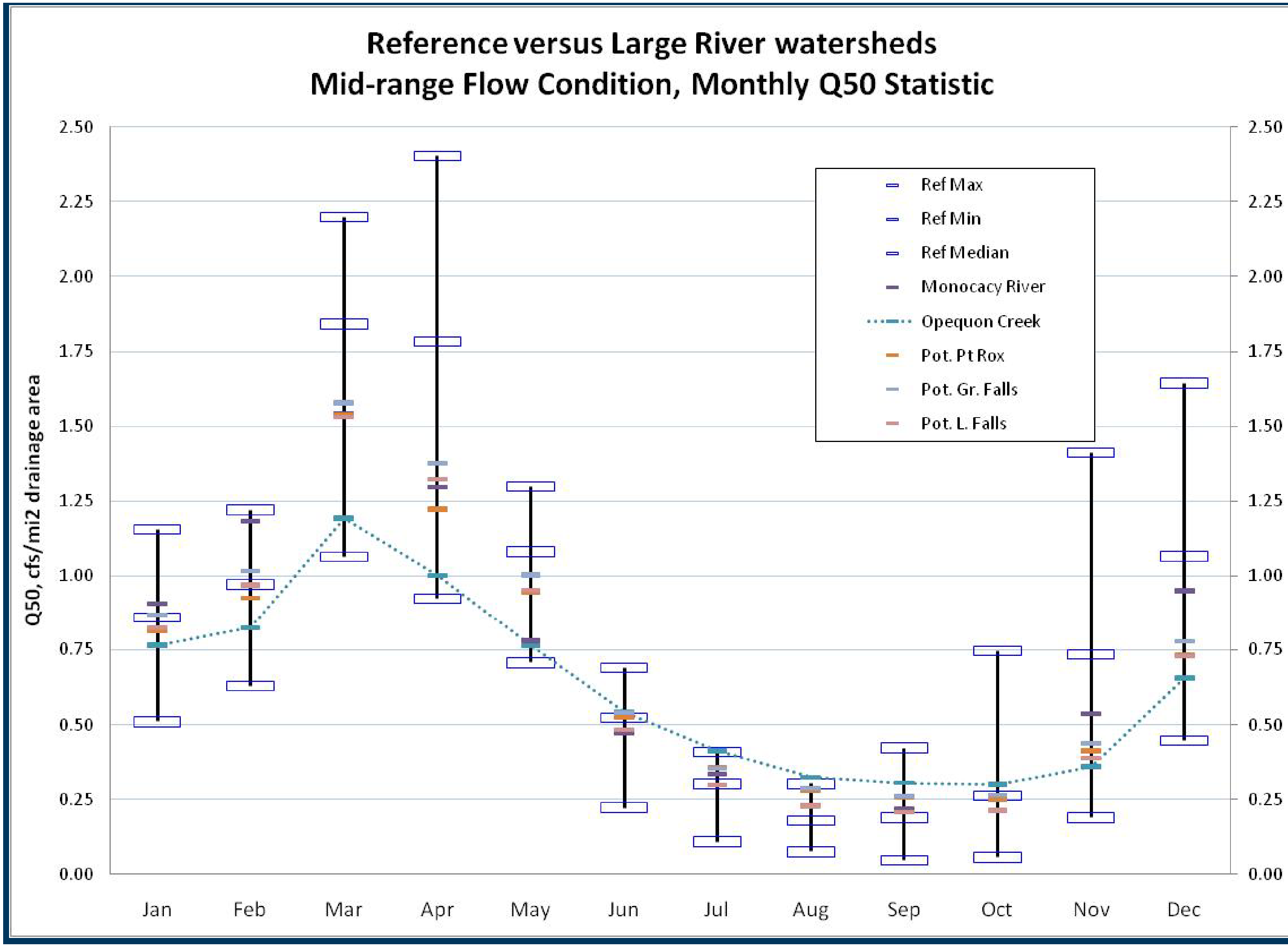
How do current flows compare with “Natural” flows?

We don’t know what “natural” is (e.g. slides on long term flow records), but we addressed the question in two ways.

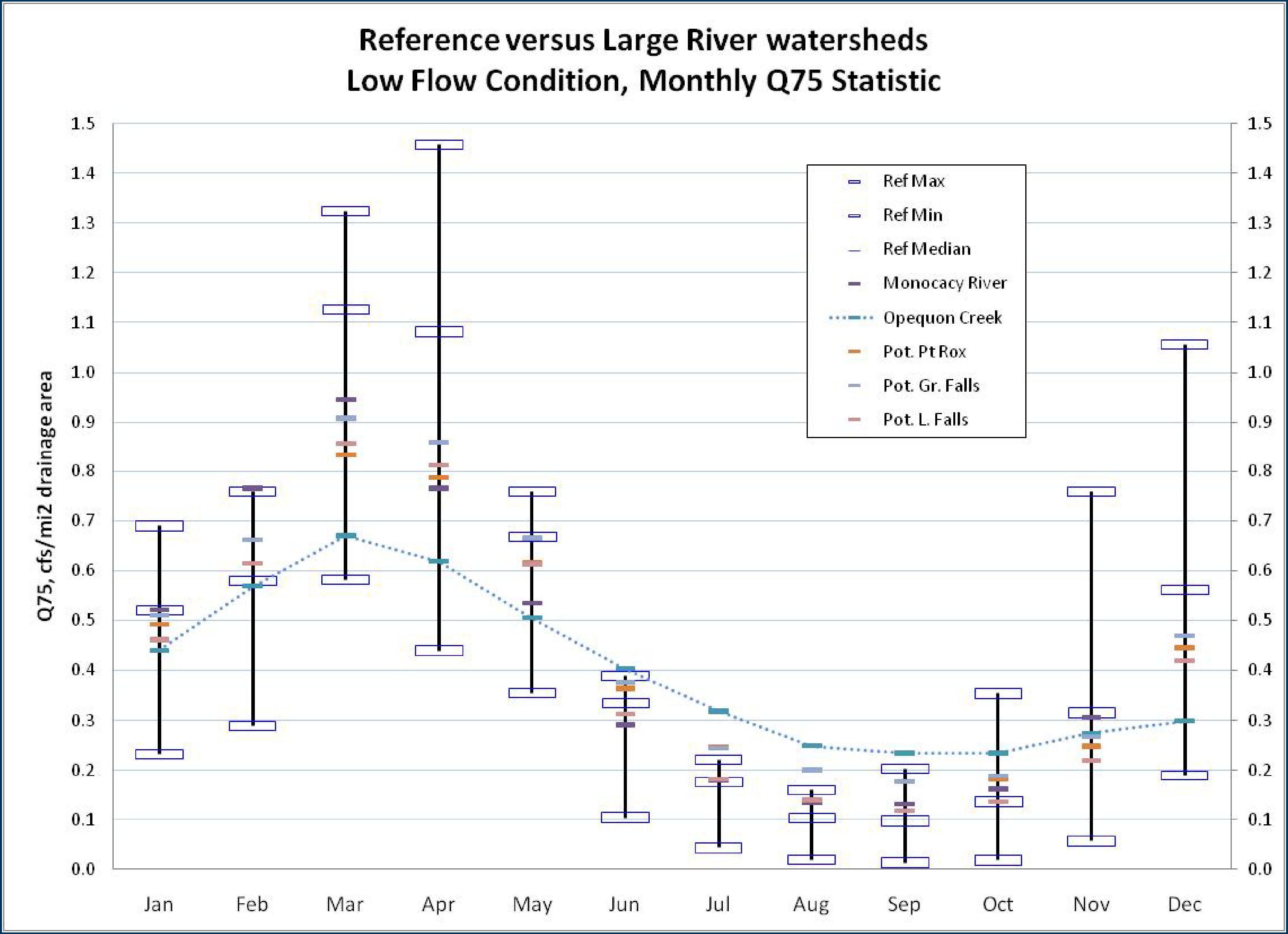
1) Compare flow statistics for Monocacy, Opequon, and Potomac with those for reference watersheds.
   a) Reference watersheds, selected from across Potomac and Susquehanna, have minimal to no impact from factors shown to affect IHAs.

2) Use flow simulation model to compare simulated flows at current conditions versus a “baseline”, or minimally impacted condition.

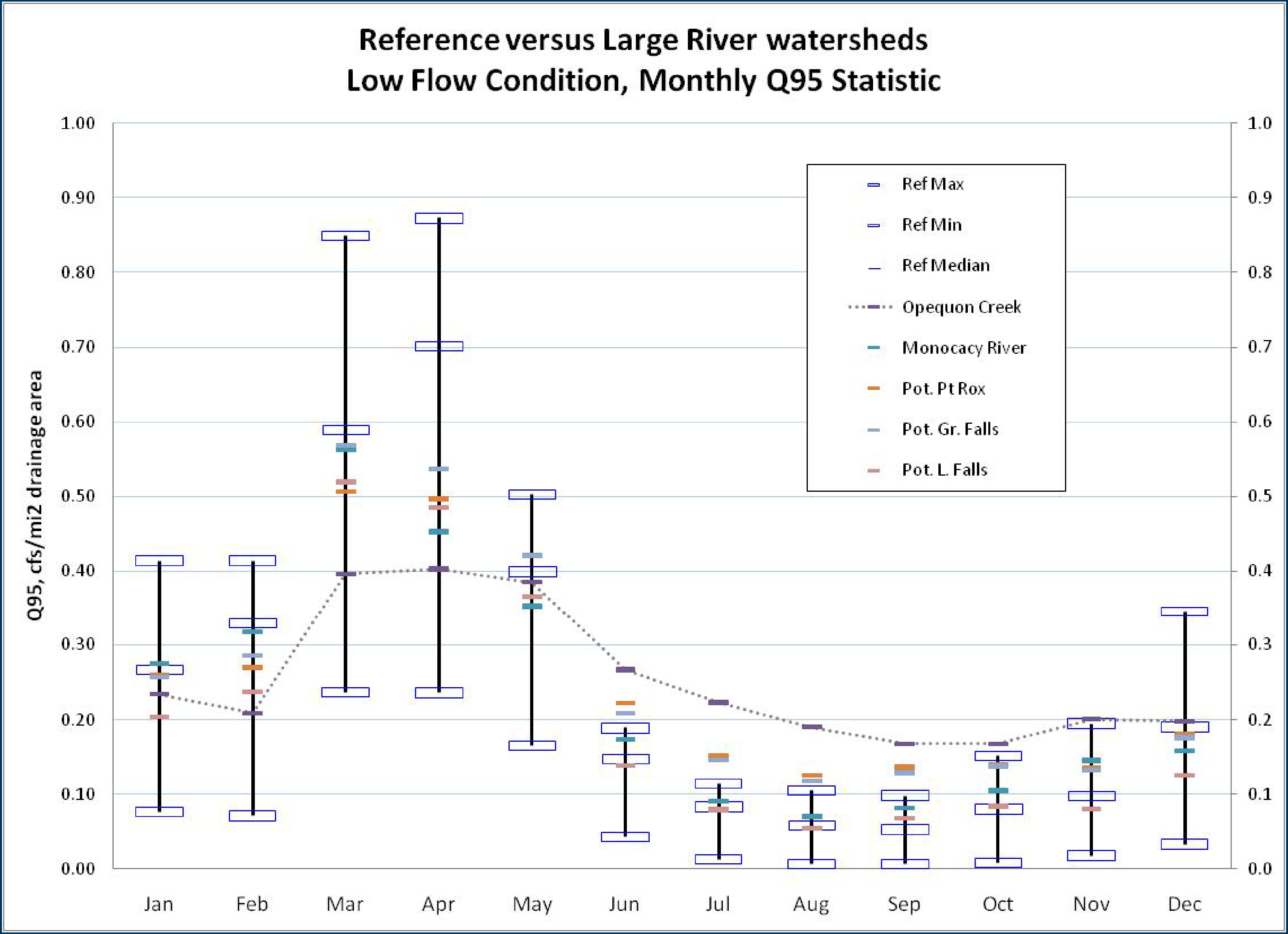
Reference vs Large River Watersheds



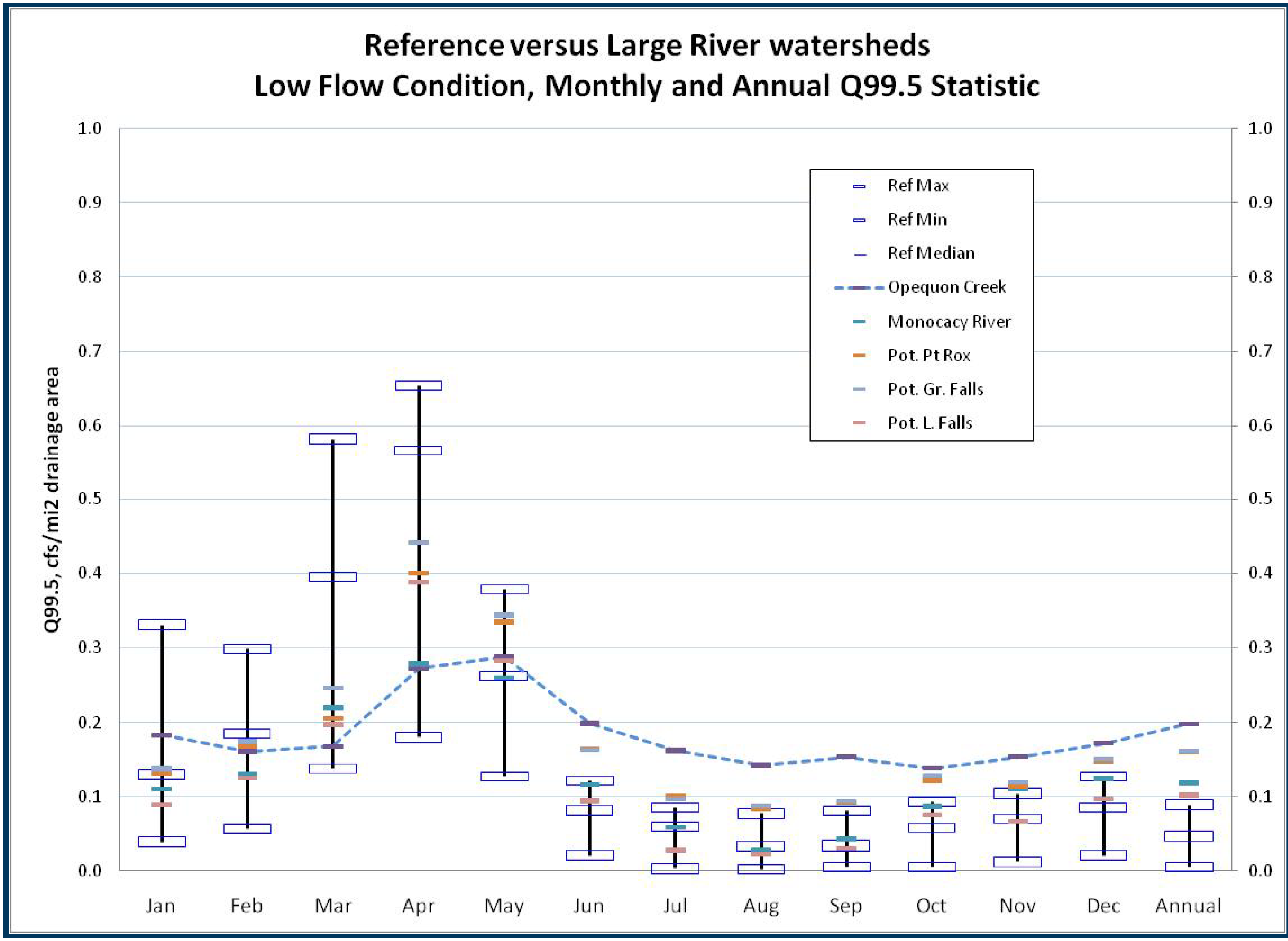
Reference vs Large River Watersheds



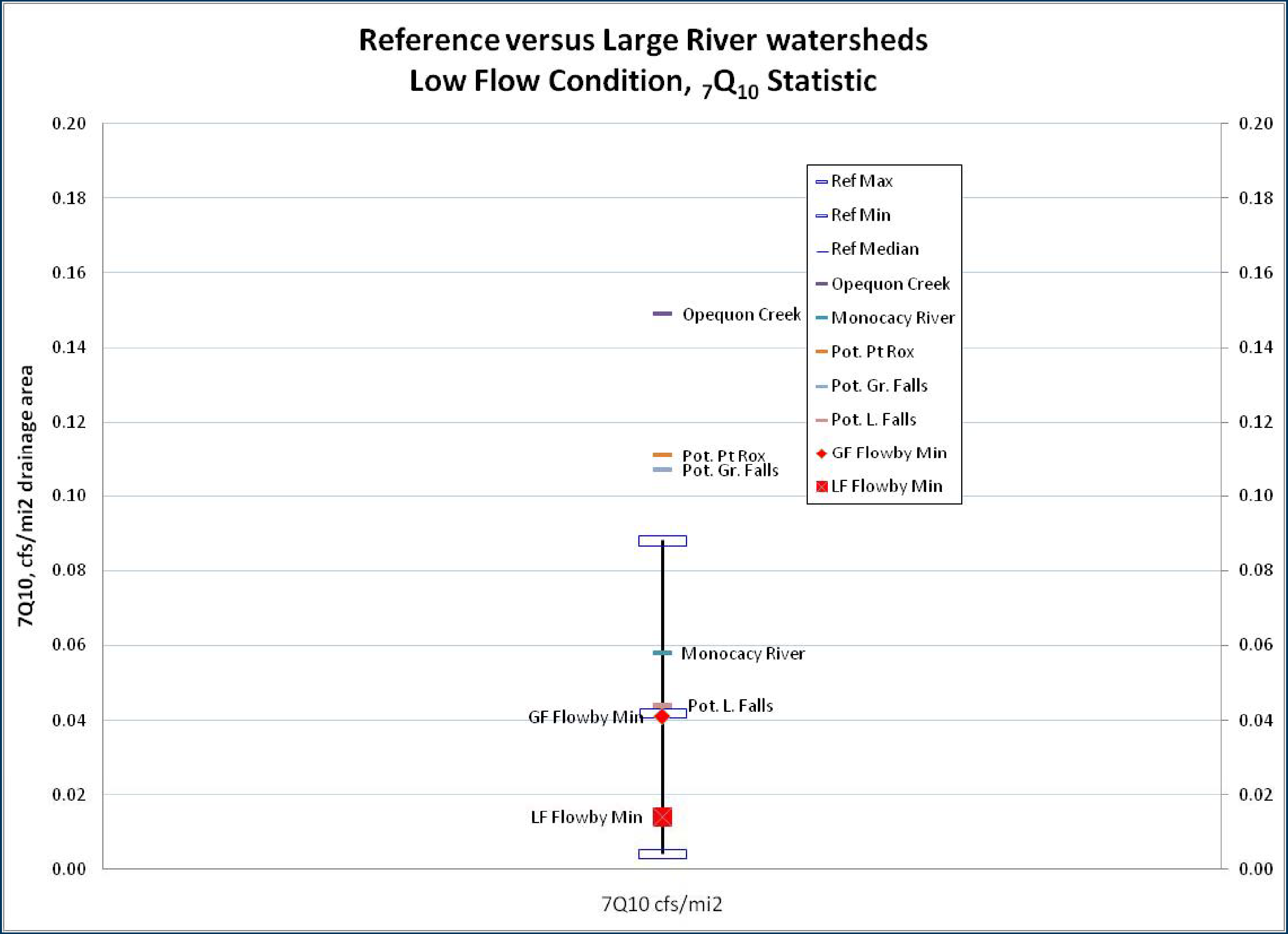
Reference vs Large River Watersheds



Reference vs Large River Watersheds



Reference vs Large River Watersheds



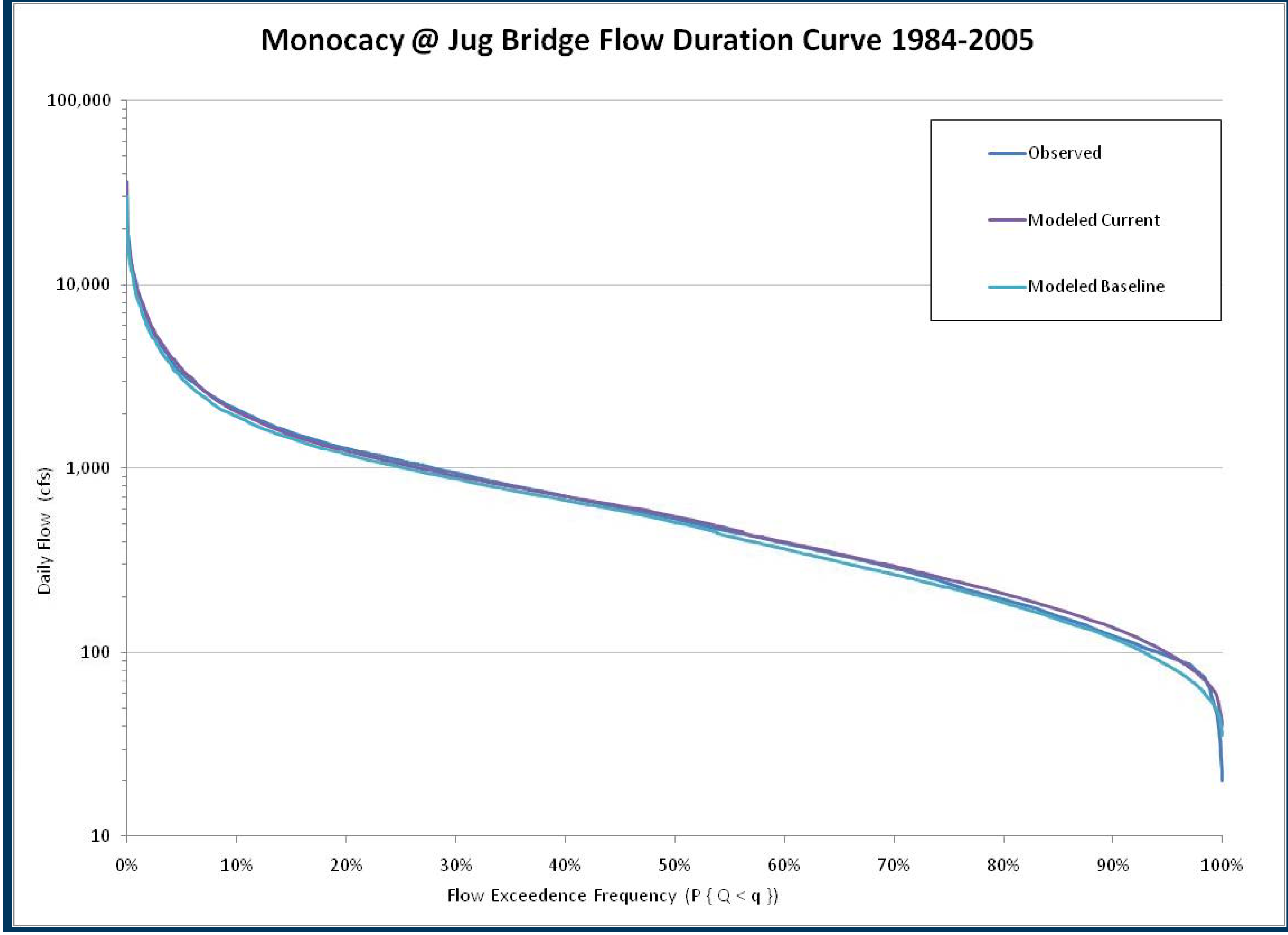
A flow simulation model for the Potomac Basin

1) Under development for the Middle Potomac Watershed Assessment
2) Based on the Chesapeake Bay Watershed Model
3) With some added segments to improve flow simulation below impoundments not in Bay Model.
4) With improved baseflow recession simulation
5) Calibrated to gaged flows for period 1984 – 2005
6) When coupled with VA DEQ WOOOMM model, can generate a synthetic flow time series at any point in basin
7) Will be used to establish relationships between biological health and selected flow statistics (ELOHA), and to quantify change in flow statistics predicted as watershed characteristics change.

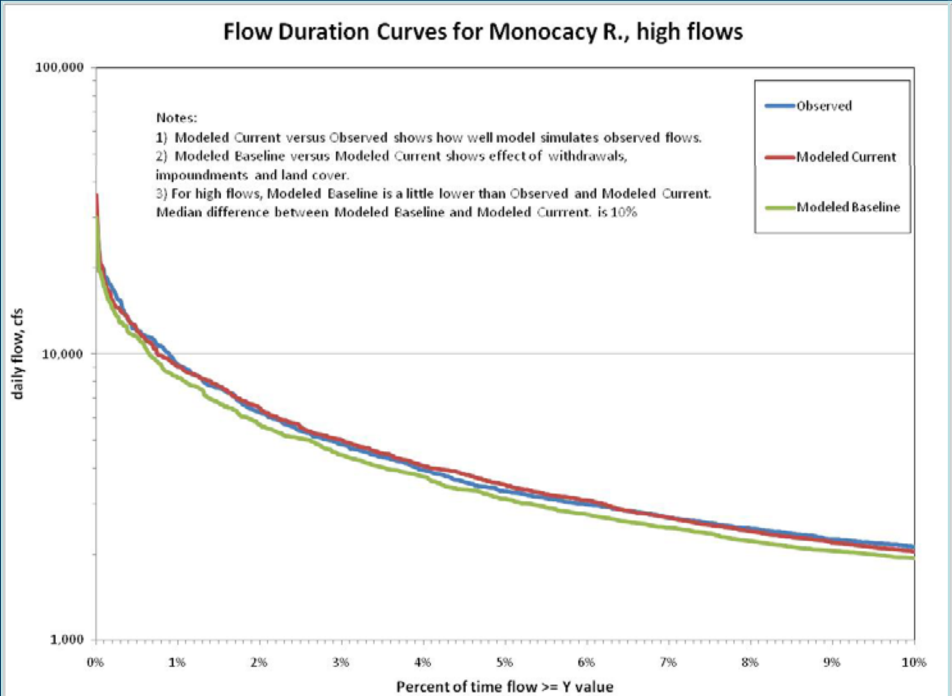
Current Conditions vs Baseline

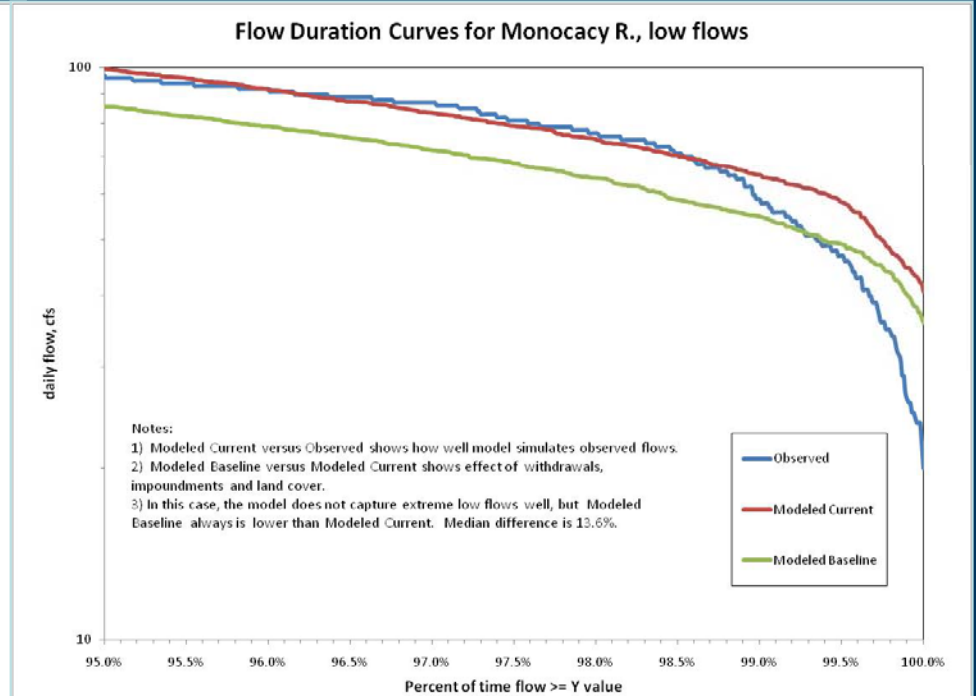
- Analysis of risk factors showed that where forest cover >= 78% there is negligible change in IHAs.
- Similarly, negligible change in IHAs where impervious surface <= 0.35%
- Therefore, for Baseline conditions, watershed characteristics are modified so that
  - Forest cover = 78%
  - Impervious surface = 0.35%
  - Other land covers adjusted proportionally
  - Impoundments, Withdrawals, Consumptive use = 0
- Current Conditions = 2005

Current Conditions vs Baseline: Monocacy



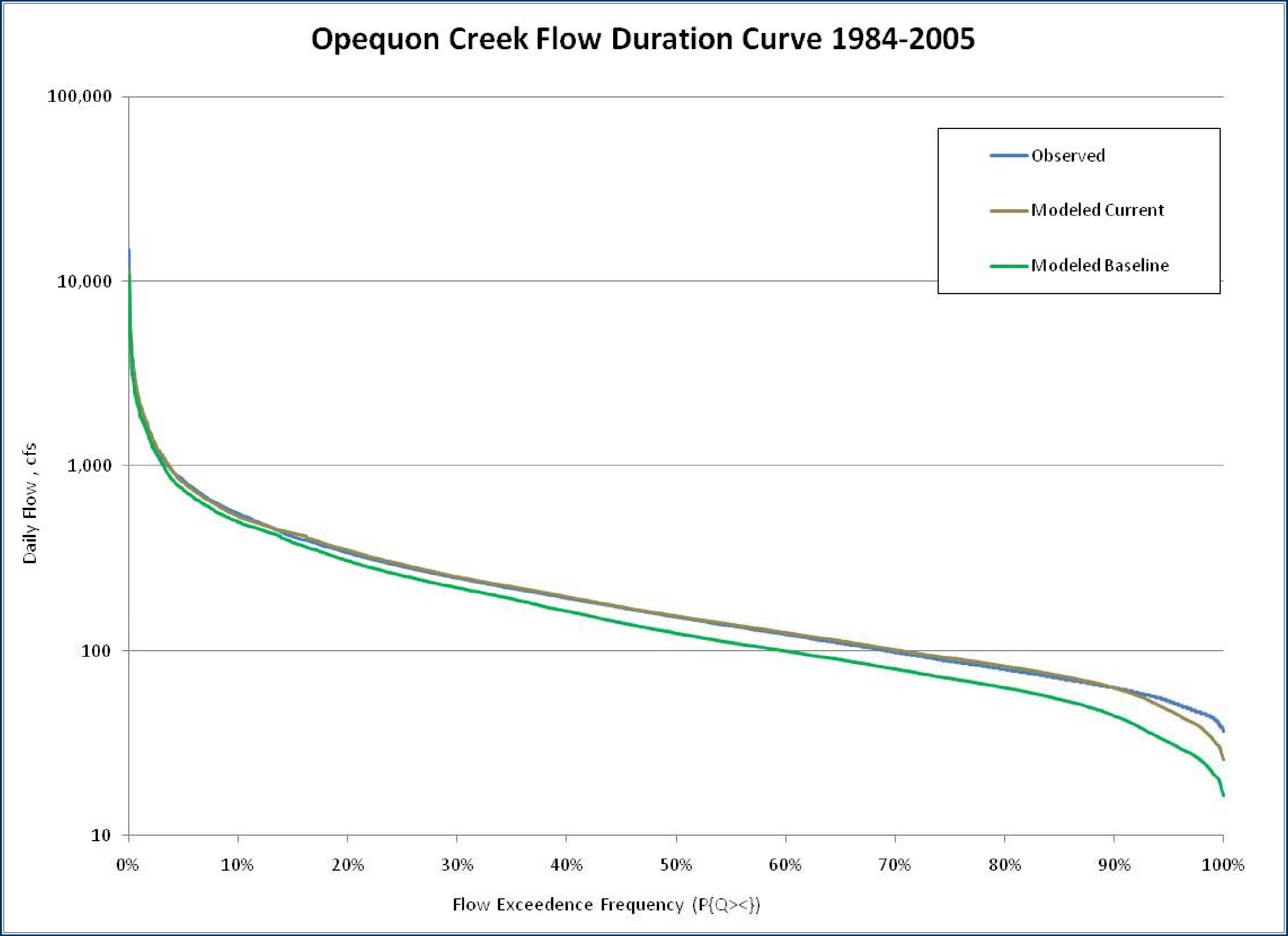
Current Conditions vs Baseline: Monocacy



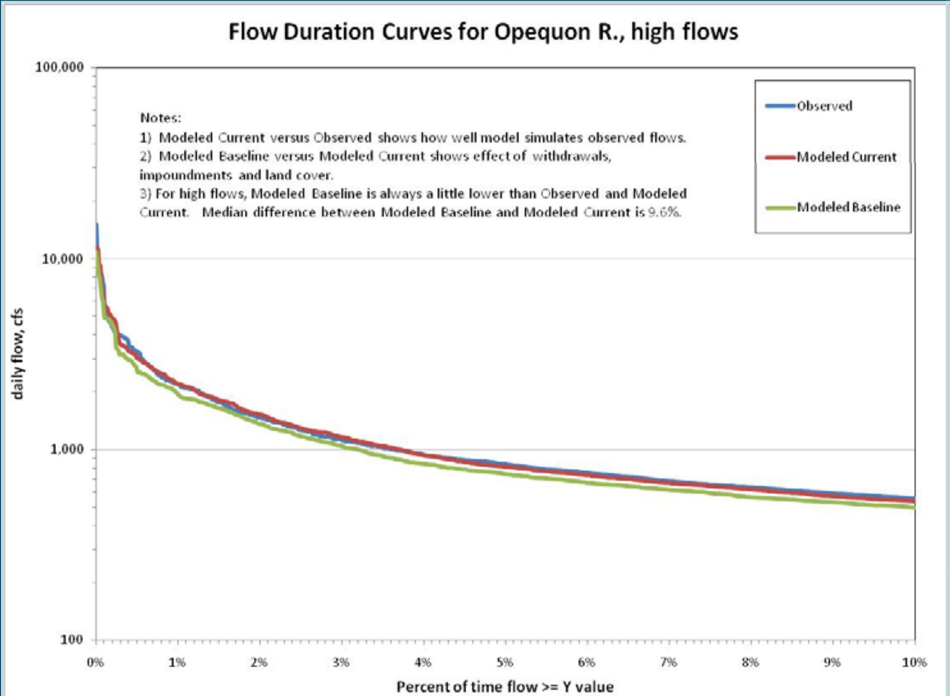


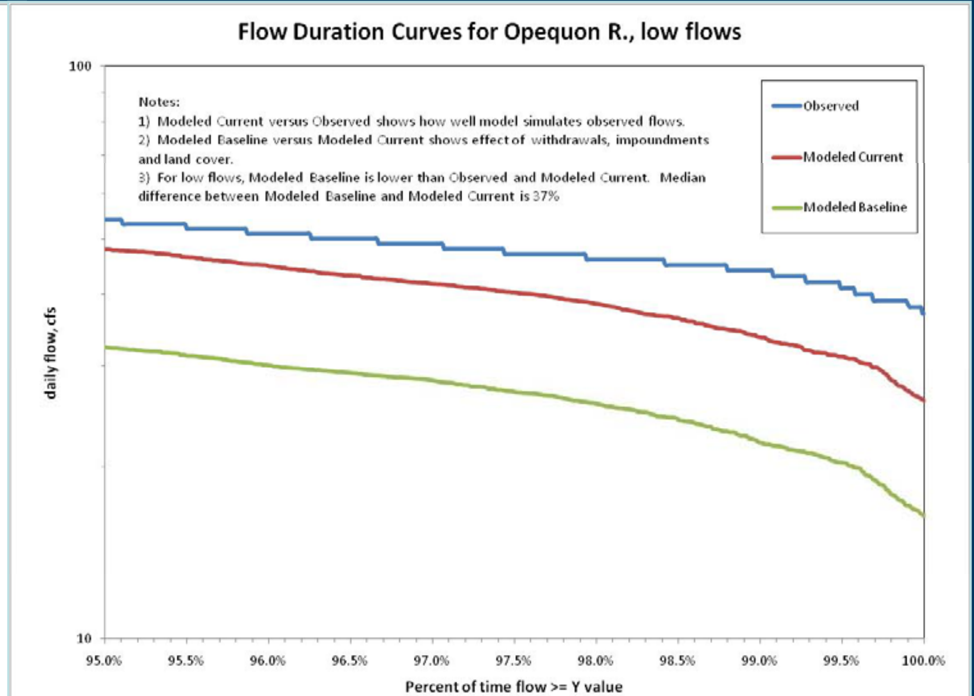
- Baseline is always lower than Current Conditions
- At high flow, median difference is 10%
- At low flow , median difference is 14%

Current Conditions vs Baseline: Opequon



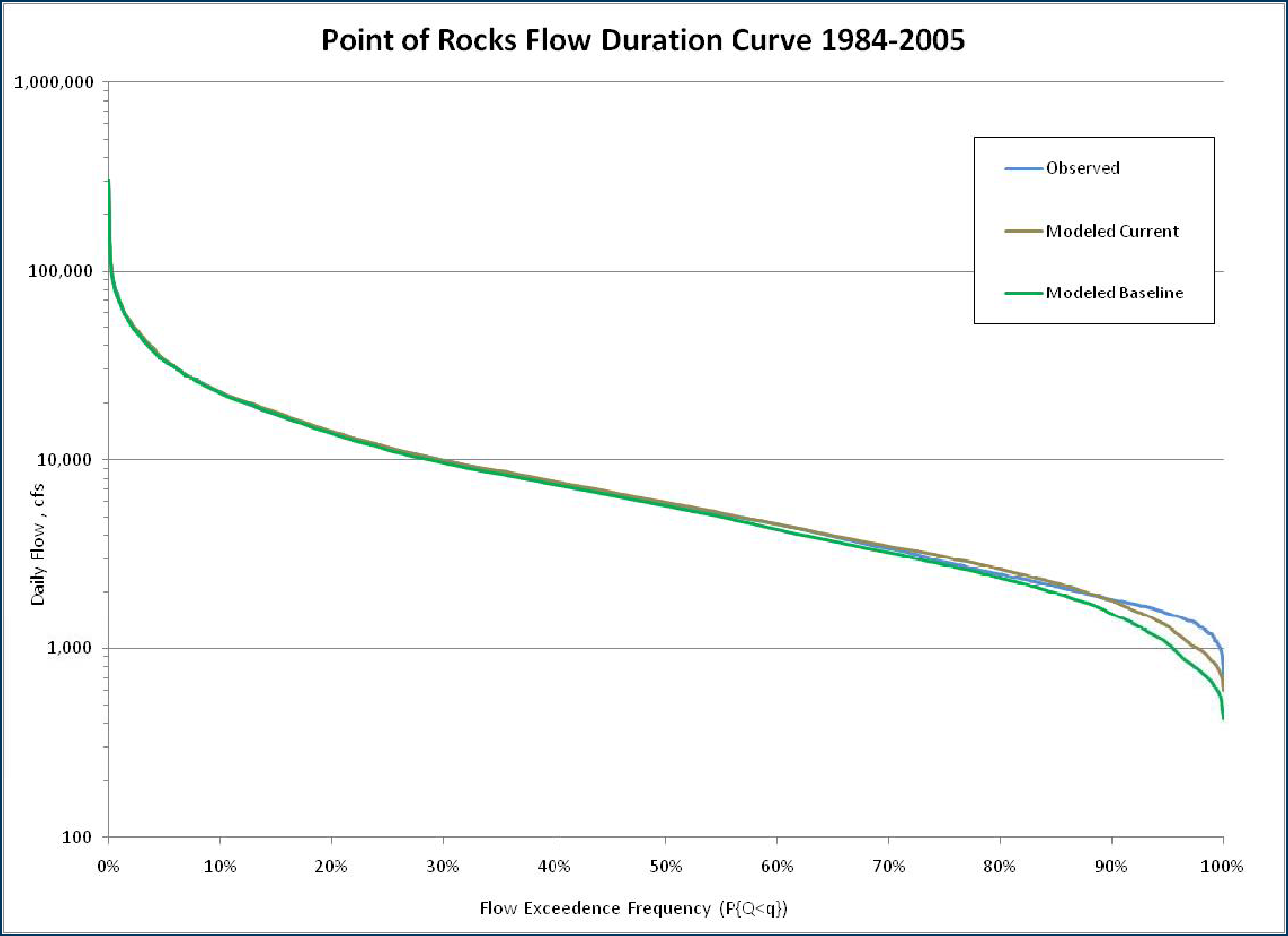
Current Conditions vs Baseline: Opequon



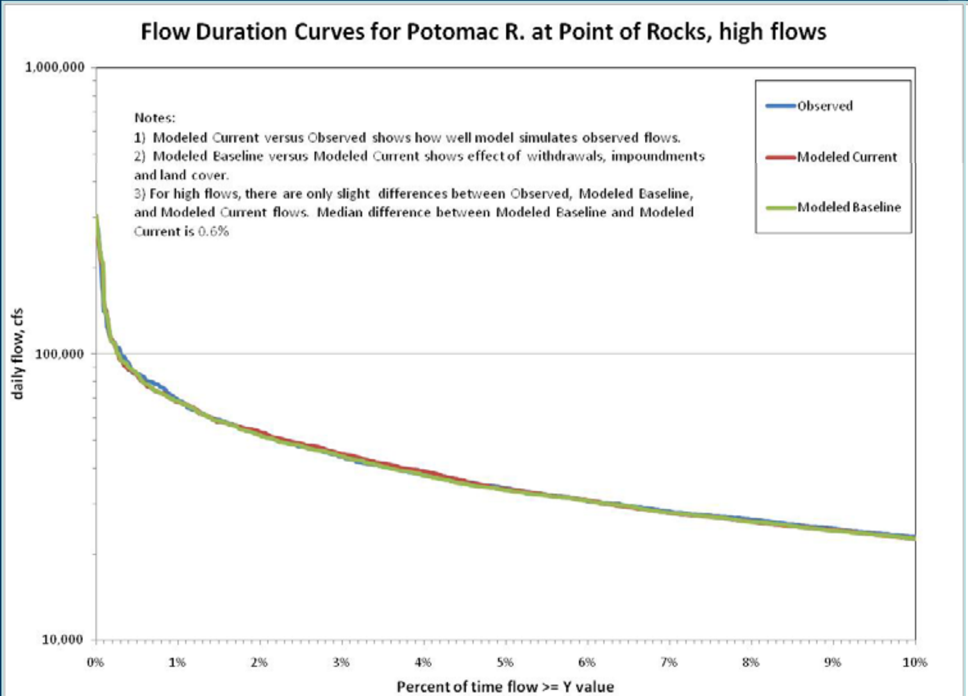


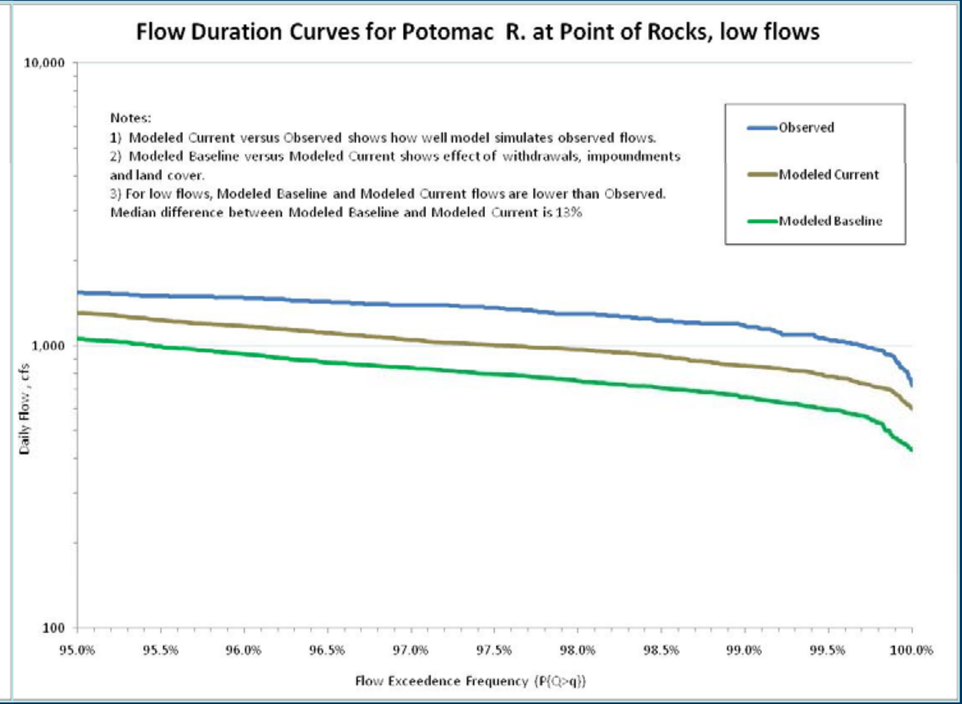
- Baseline is always lower than Current Conditions
- At high flow, median difference is 10%
- At low flow , median difference is 37%

Current Conditions vs Baseline: Potomac Point at Point of Rocks



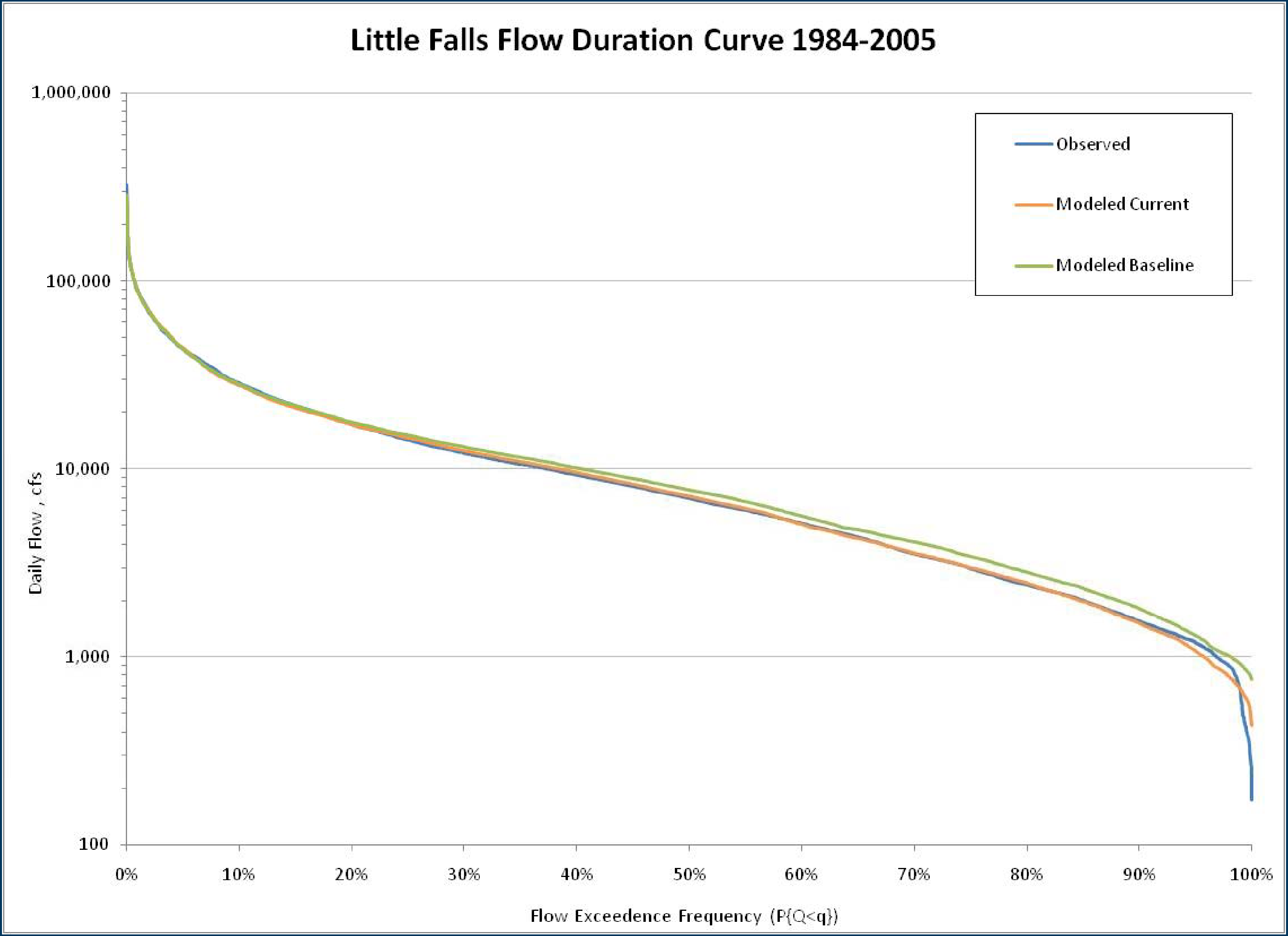
Current Conditions vs Baseline: Potomac at Point of Rocks



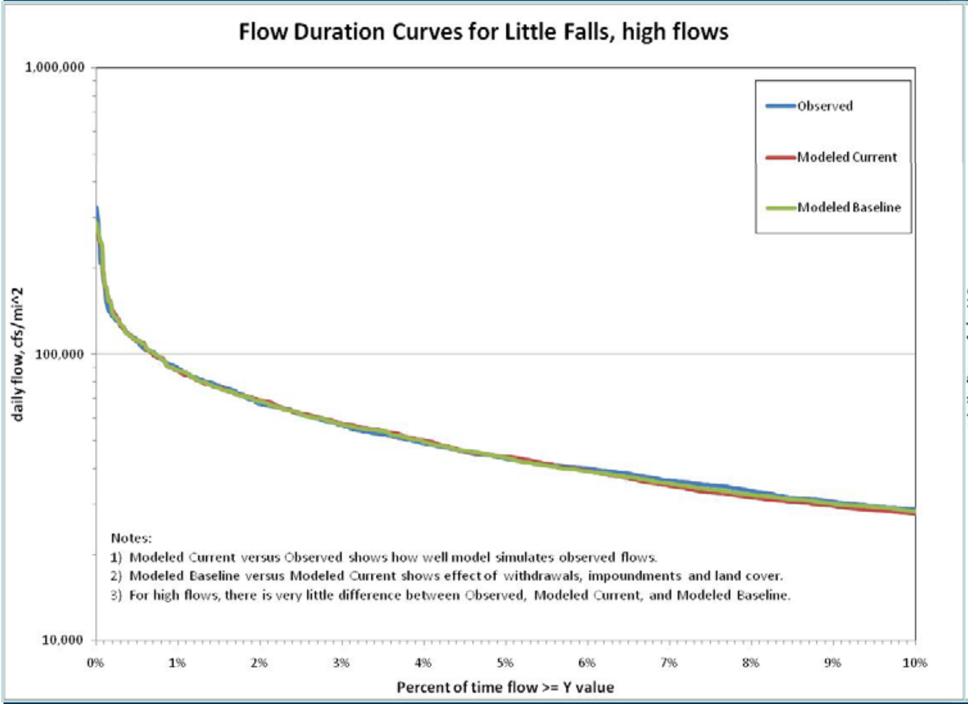


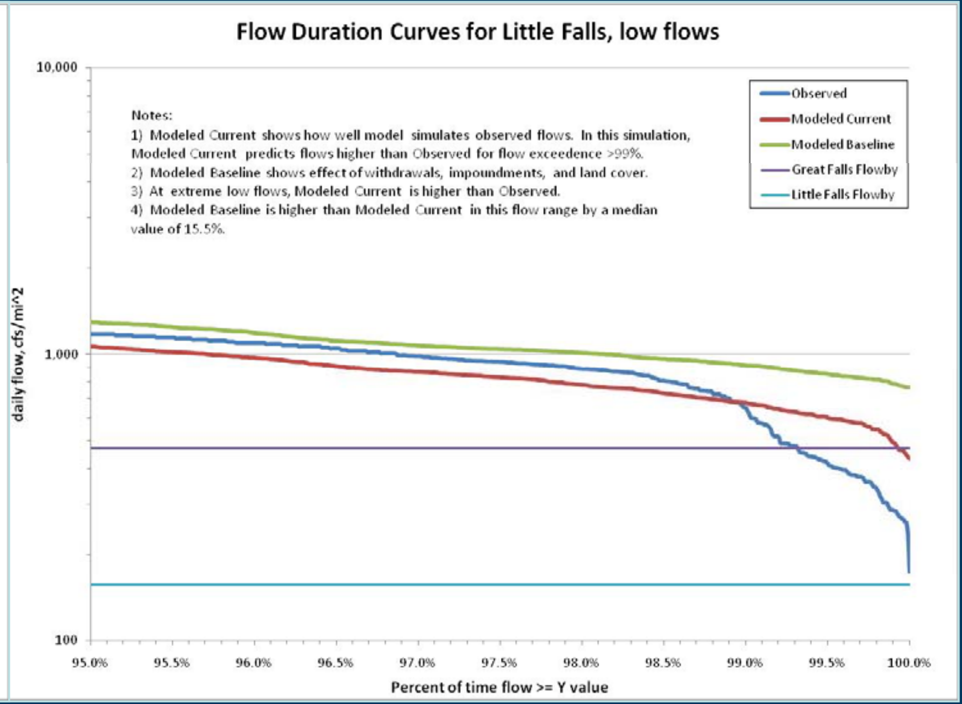
- Baseline is always lower than Current Conditions
- At high flow, median difference is 0.6%
- At low flow , median difference is 13%

Current Conditions vs Baseline: Potomac River at Little Falls



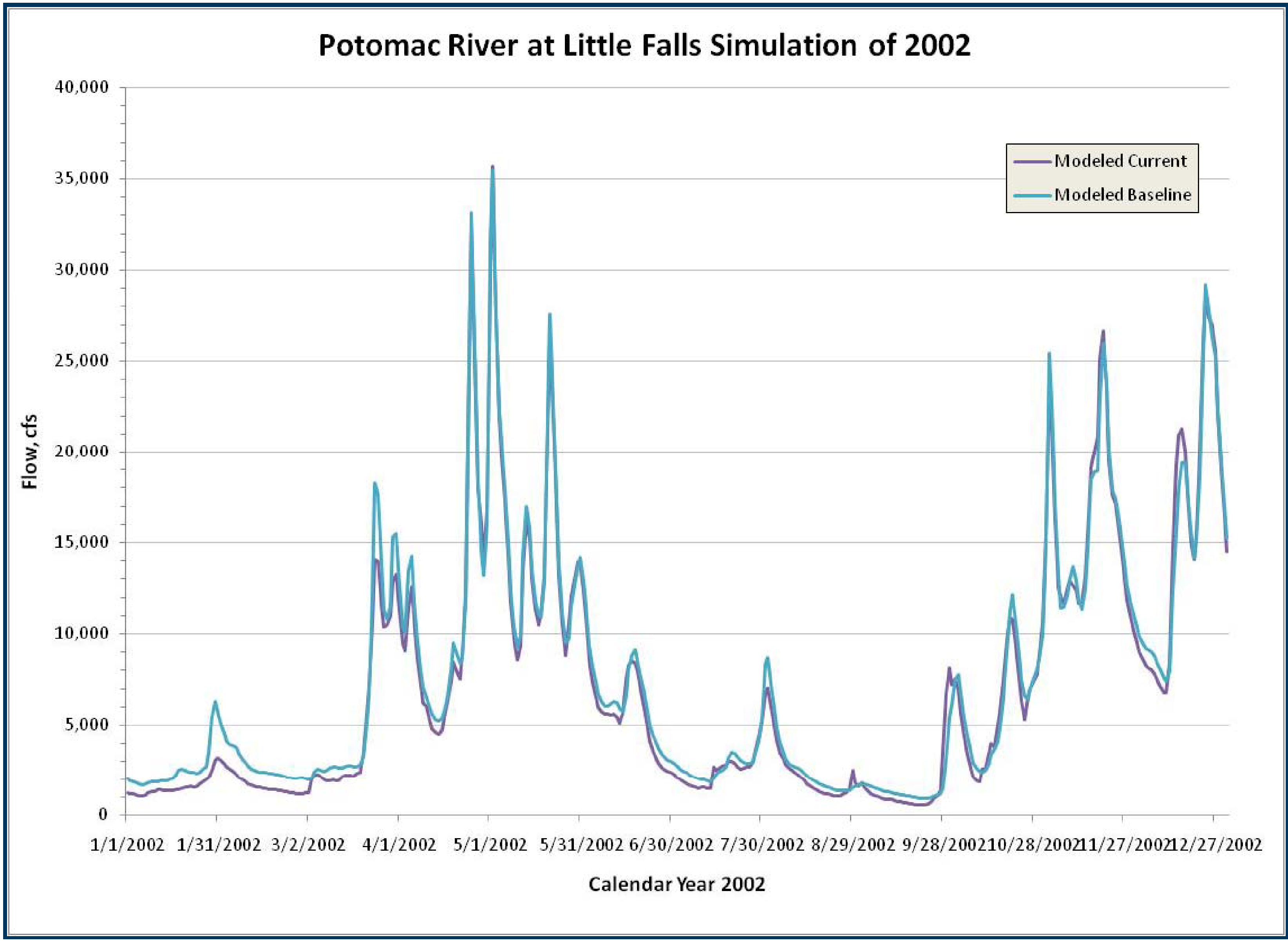
Current Conditions vs Baseline: Potomac at Little Falls



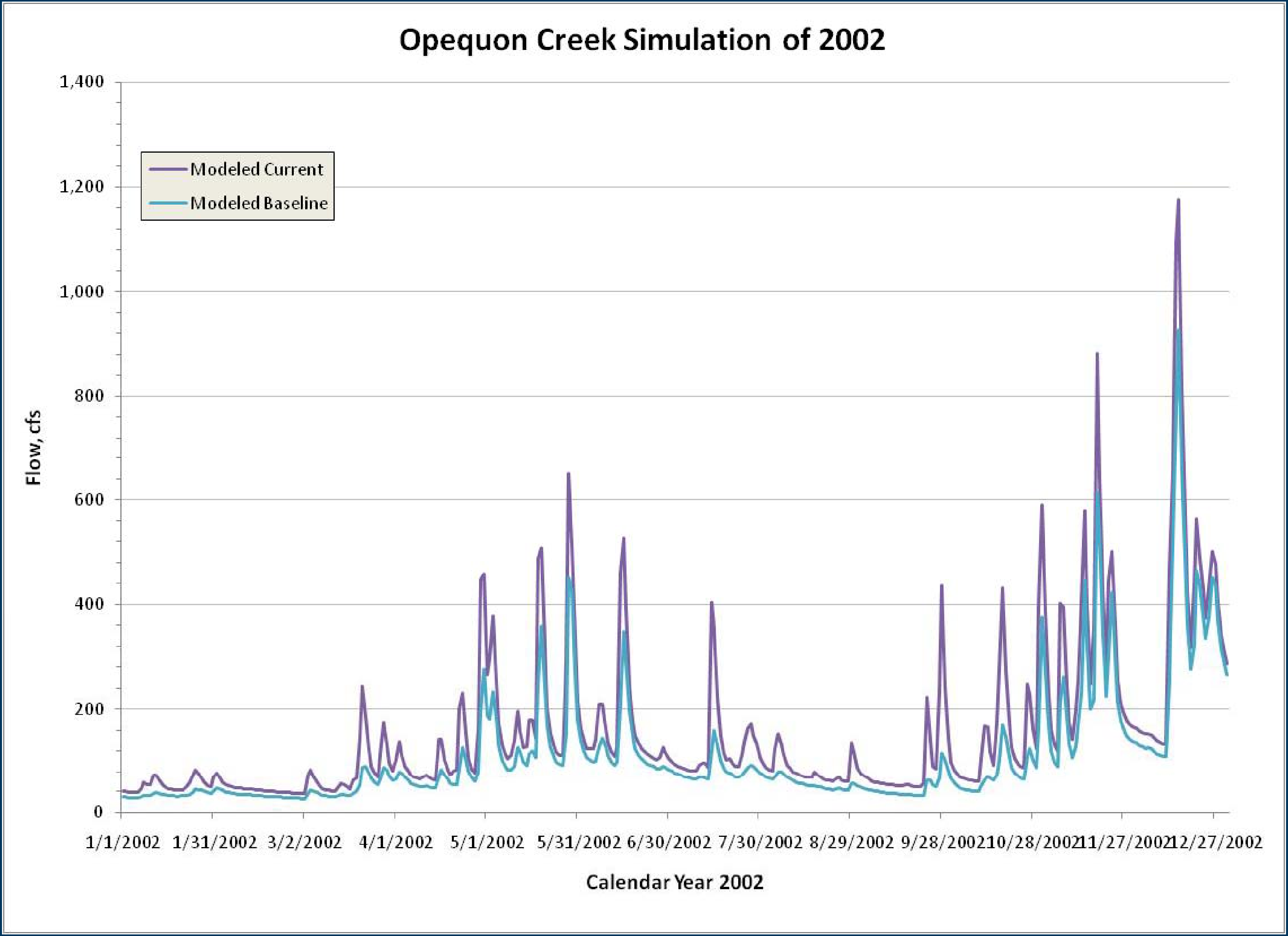


- At high flow, no real difference between Baseline and Current
- At low flow , Baseline is higher than Current by median 15.5%
- Note location of G.F. 300 mgd and L.F. 100 mgd minimum flow recommendations.

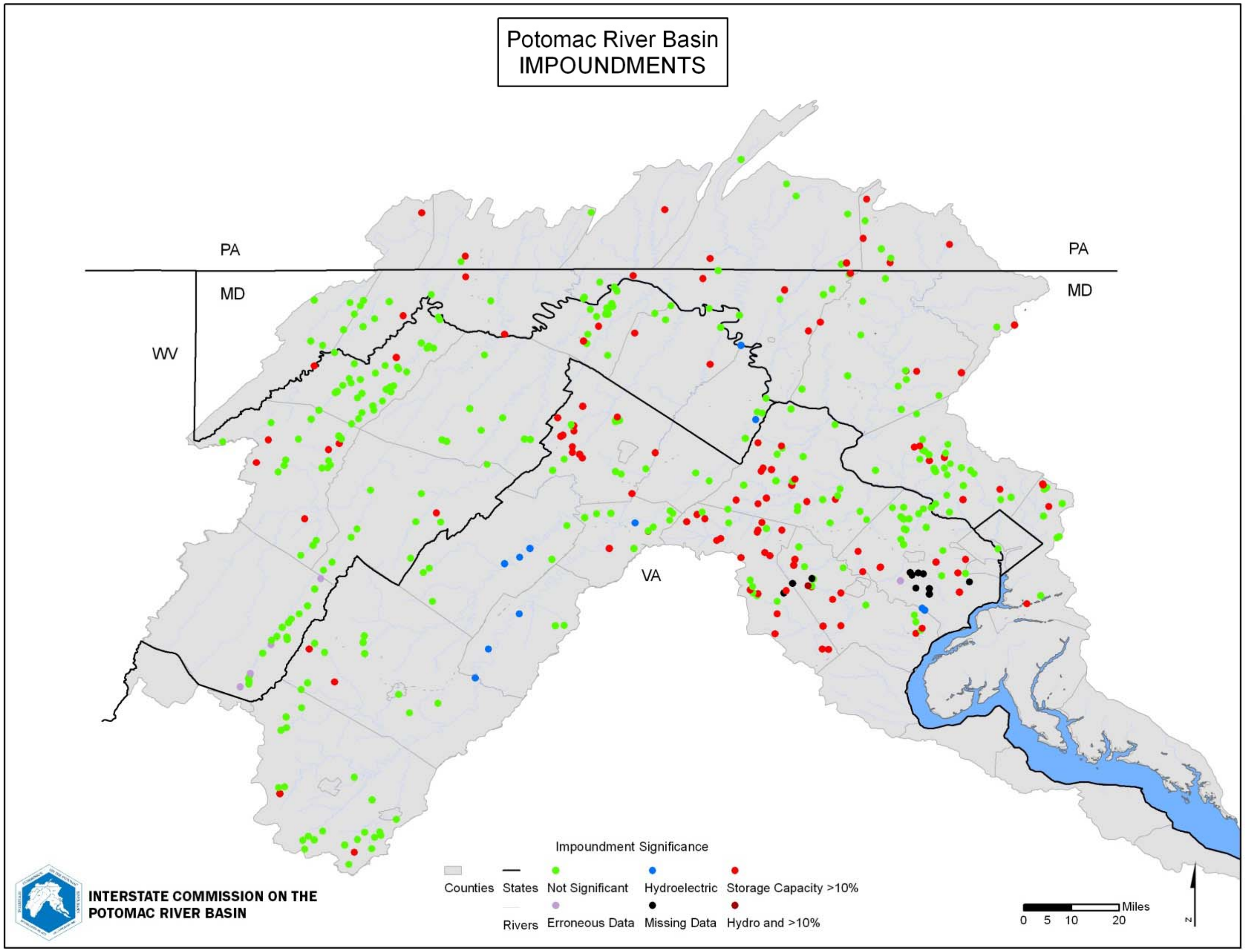
Current Conditions vs Baseline: Simulate a Drought Year



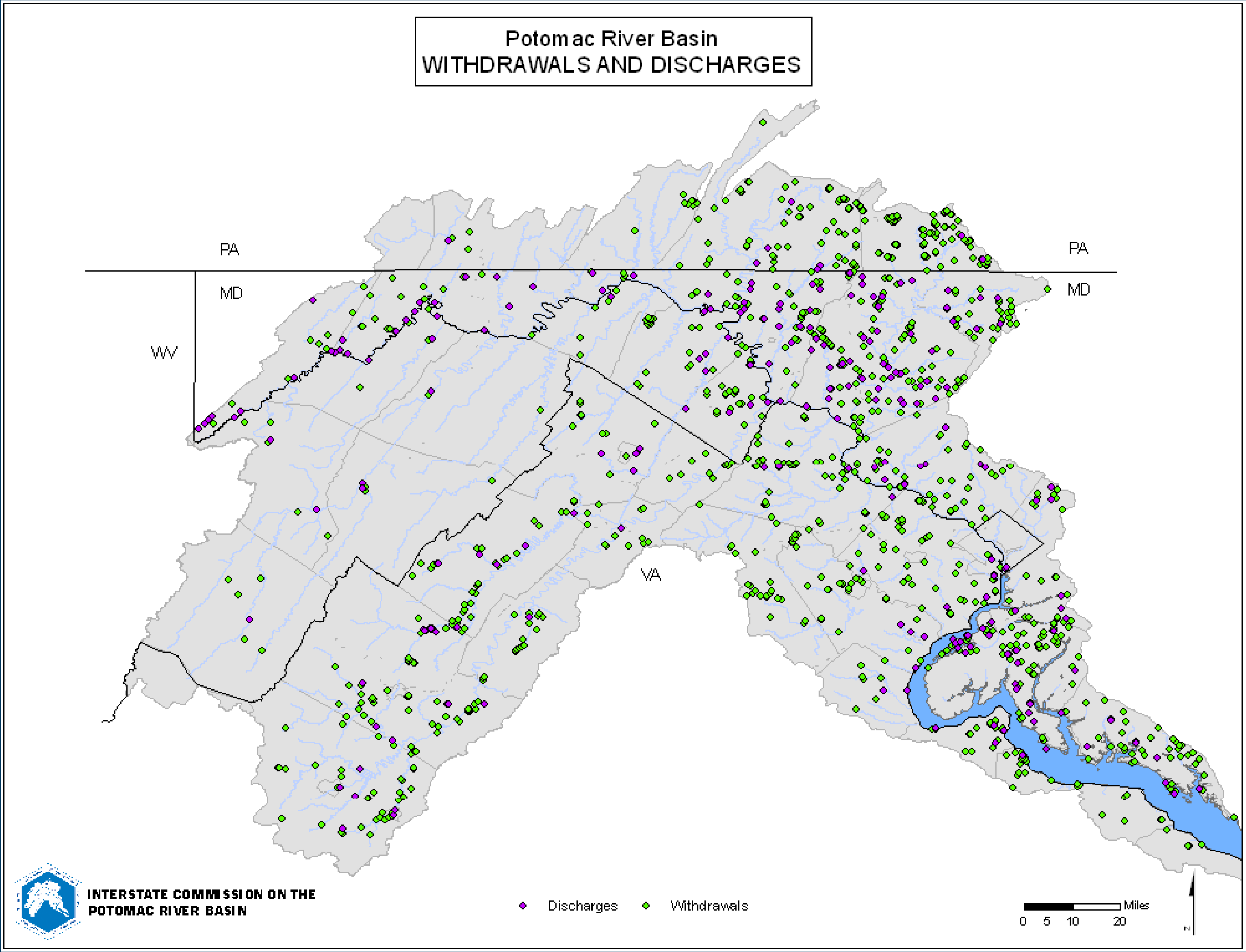
Current Conditions vs Baseline: Simulate a Drought Year



Current river management impacts on flow regimes: Impoundments



Current river management impacts on flow regimes: Withdrawals



Current river management impacts on flow regimes

1) Although over 400 impoundments in watershed, only a handful have actively managed releases
2) For Monocacy, Opequon, and lower Potomac River, essentially no impact on mid and high range flows
3) Jennings Randolph / Savage reservoirs provide some low flow augmentation for Potomac mainstem
4) Withdrawals and consumptive demands are widespread and have some impact on low flows in all watersheds, but for Monocacy, Opequon, and Potomac to Seneca Creek current low flows are higher than Baseline.
5) Only for the Potomac from Seneca to Great Falls and Little Falls are current withdrawals pushing very low flows below the Baseline simulation.

Preliminary withdrawal and consumptive use forecast.

Drainage Basin	2010 With-drawal (MGD)	2010 Cons. Use (MGD)	2030 With-drawal (MGD)	2030 Cons. Use (MGD)
Opequon Creek	22	2	39	4
Monocacy	52	6	121	14
PawPaw	1242	43	1500	54
Hancock	1242	43	1501	54
Shepherdstown	1556	58	1909	74
PointOfRocks	1653	71	2117	99
LittleFalls	3122	849	5194	1850

Climate change forecast

1) Middle Potomac Watershed Assessment Task
2) Climate change to 2030 will have a negligible effect (1% increase) on water withdrawals and consumptive use.
3) Beyond 2030, forecasts for withdrawals highly uncertain.
4) Long range forecasts for climate change also uncertain.

From the climate change literature

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

Climate Change and Water

Edited by

Bryson Bates, CSIRO, Australia
Zbigniew W. Kundzewicz, Polish Academy of Sciences, Poland and Potsdam Institute for Climate Impact Research, Germany
Shaohong Wu, Chinese Academy of Sciences, China
Jean Palutikof, Met Office Hadley Centre, United Kingdom

This is a Technical Paper of the Intergovernmental Panel on Climate Change prepared in response to a decision of the Panel. The material herein has undergone expert and government review, but has not been considered by the Panel for possible acceptance or approval.

June 2008

This paper was prepared under the management of the IPCC Working Group II Technical Support Unit

In the absence of reliable projections of future changes in hydrological variables, adaptation processes and methods which can be usefully implemented in the absence of accurate projections, such as improved water-use efficiency and water-demand management, offer no-regrets options to cope with climate change. [WGII 3.8]

Climate Change 2007: Synthesis Report

Summary for Policymake

An Assessment of the Intergovernmental Panel on Climate Change

This summary, approved in detail at IPCC Plenary XXVII (Valencia, Spain, 12-
formally agreed statement of the IPCC concerning key findings and uncertainti
contributions to the Fourth Assessment Report.

Based on a draft prepared by:

Lenny Bernstein, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunl
Huq, David Karoly, Vladimir Kattsov, Zbigniew Kundzewicz, Jian Liu, Ulrike Lohma
Bettina Menne, Bert Metz, Monirul Mirza, Neville Nicholls, Leonard Nurse, Rajen
Parry, Dahe Qin, Nijavalli Ravindranath, Andy Reisinger, Jiawen Ren, Keywan
Rusticucci, Stephen Schneider, Youba Sokona, Susan Solomon, Peter Stott, Ronald
Dennis Tirpak, Coleen Vogel, Gary Yohe

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised

Key Point 7: Current expectations about future climate may indicate a need to supplement historical climate information. Planning assumptions might instead be related to projections of future temperature and precipitation. This can be accomplished using a multitude of approaches; a best approach has yet to be determined.

USGS science for a changing world

Climate Change and Water Resources Management: A Federal Perspective

Circular 1331

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

More from Climate Change Literature

ASSESSING URBAN WATER USE AND THE ROLE OF WATER CONSERVATION MEASURES UNDER CLIMATE UNCERTAINTY

JOHN J. BOLAND
Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD, USA 21218-2686

Climatic Change **37**: 157–176, 1997.
©1997 *Kluwer Academic Publishers. Printed in the Netherlands.*

This study provides no clear argument for focusing on climate change as a variable that must be addressed decades in advance of the planning horizon. In a study area such as the WMA, demand management measures are more than adequate to deal with plausible climate-induced deviations, should supply management approaches later prove unavailable or excessively costly.

Another way to view these results is to compare the outcomes associated with different Conservation Policy Options, using a single climate scenario as a basis. The scenario with the largest water use increase is Scenario F, using the UK Hadley GCM. Table XI shows Scenario F summer results for each of the Policy Options, as well as the stationary climate forecast (Scenario A). While the possibility of a significant warming of climate (as expressed by Scenario F) can increase summer water use dramatically, plausible policy interventions (such as Policy Options II or III) can reduce water use back to and below stationary climate levels.

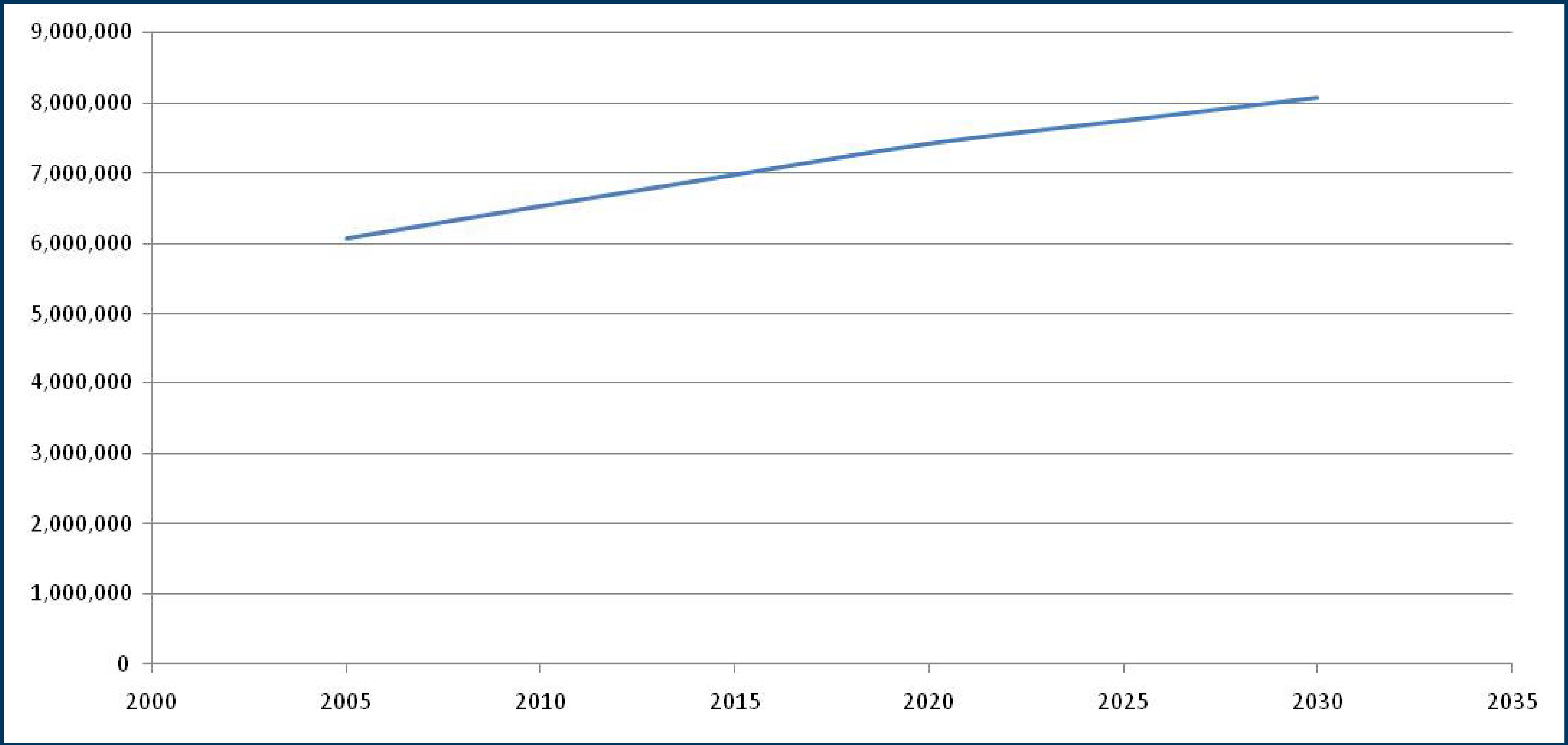
What are significant causes of changes in flow characteristics?

1) Natural factors not subject to our control
   a) Climate variability and cycles
   b) Physiography and geology (karst)

2) Anthropogenic factors
   a) Land use change is most significant
   b) Impoundments – not significant
   c) Withdrawals can impact extreme low flows
   d) Climate change – minor impacts

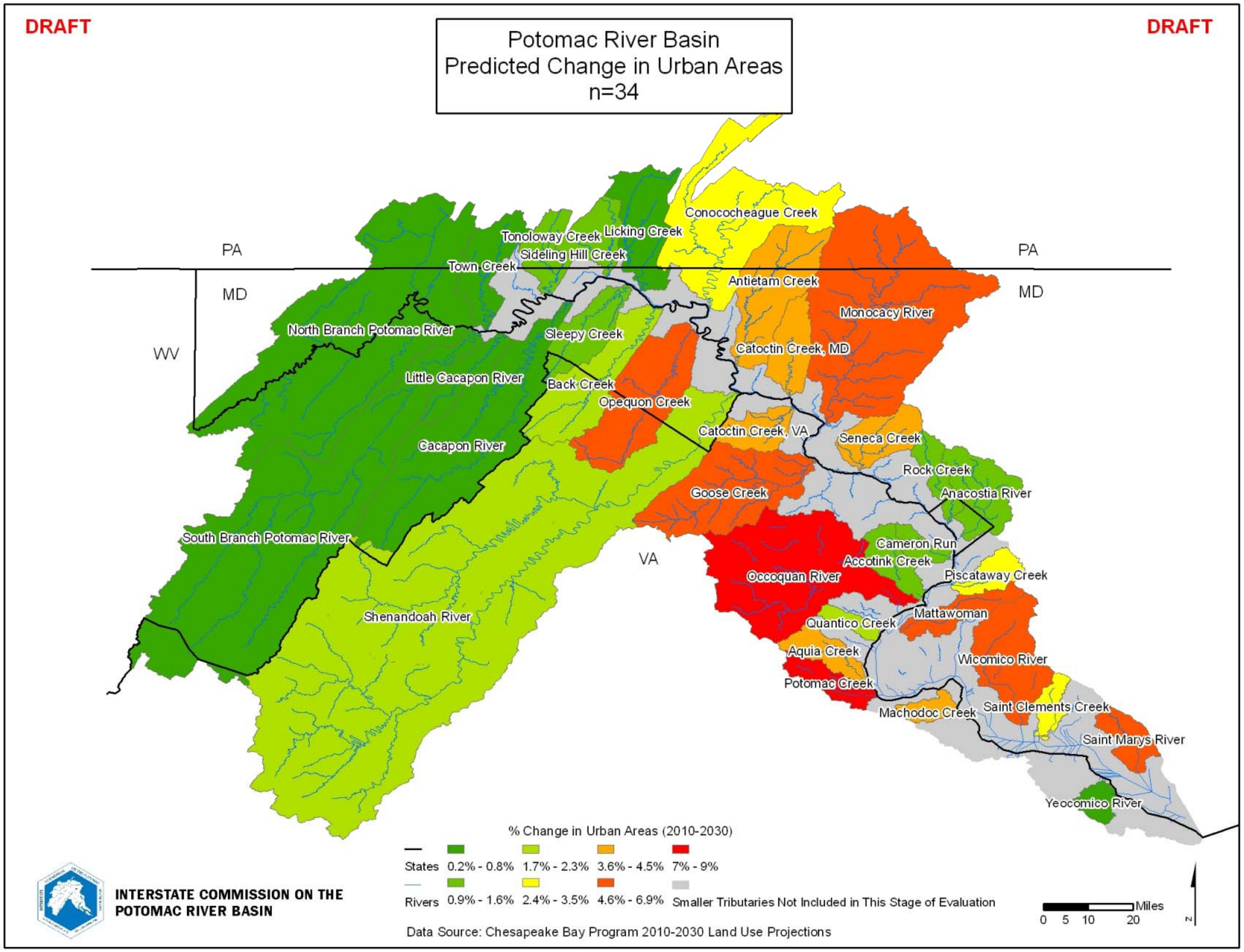
3) Time scales for change in flow characteristics
   a) Rate of land use change / rate of population growth

Potomac Basin Population Forecast

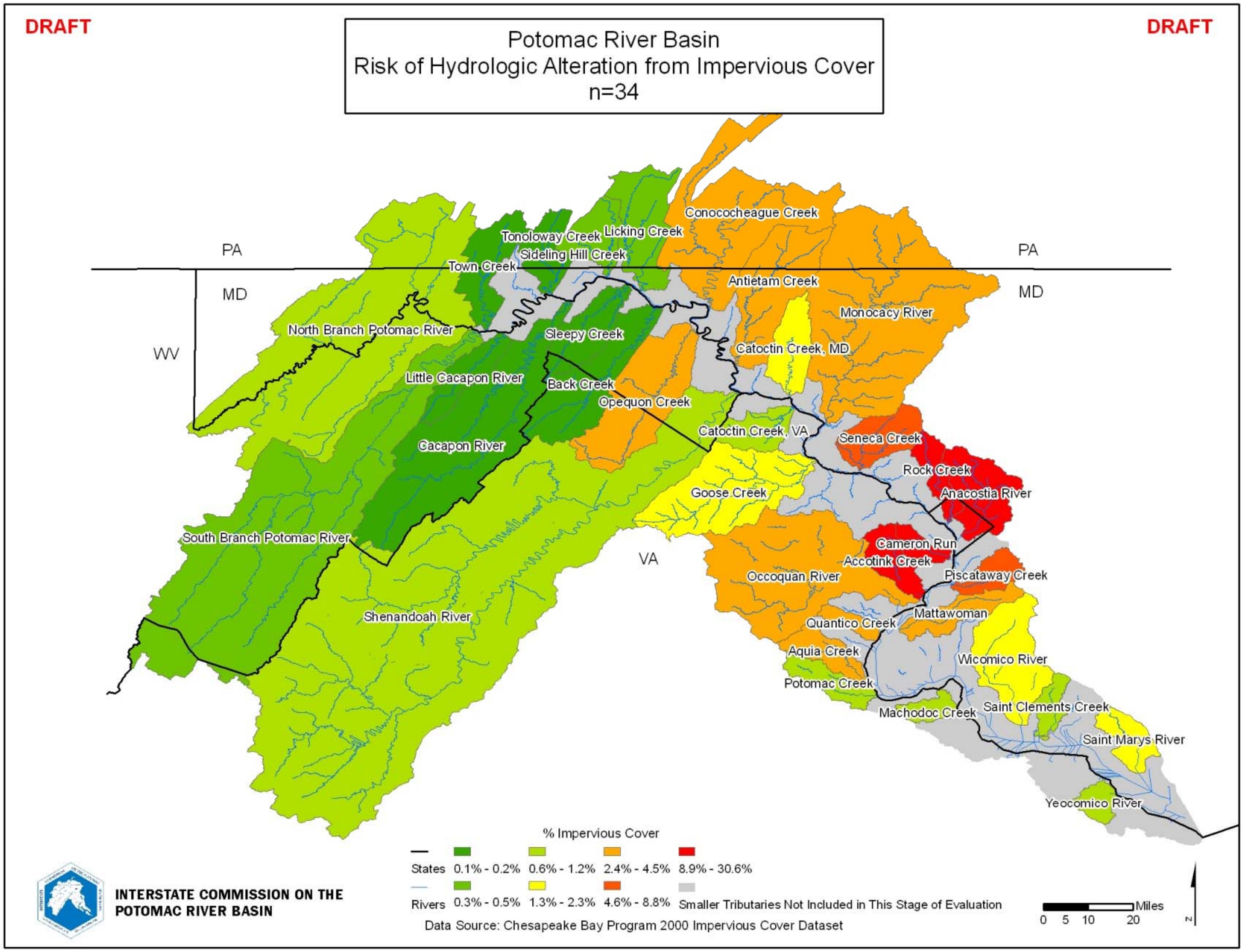


From P. Claggett, USGS, Chesapeake Bay Program (2009)

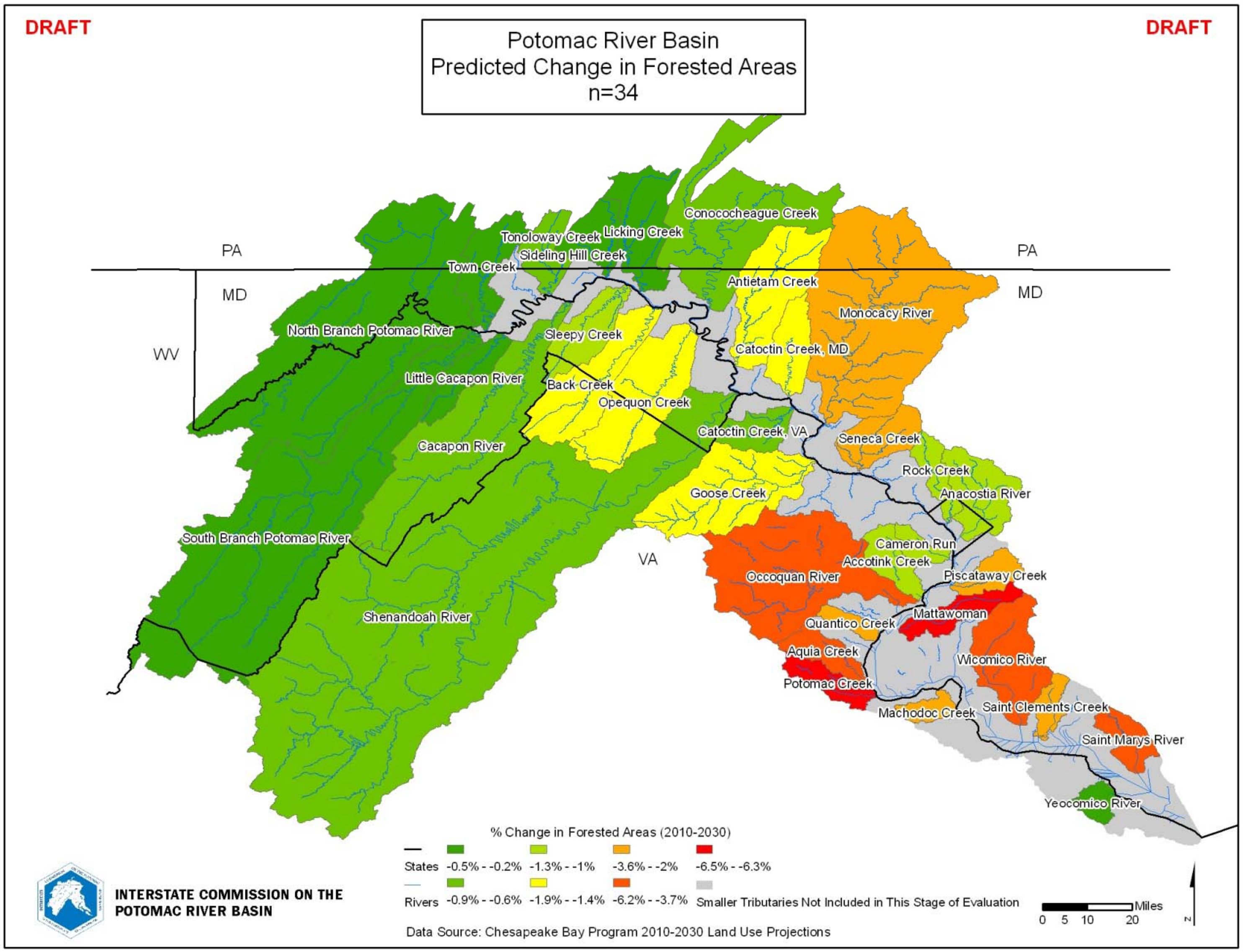
Land Use Change Projections



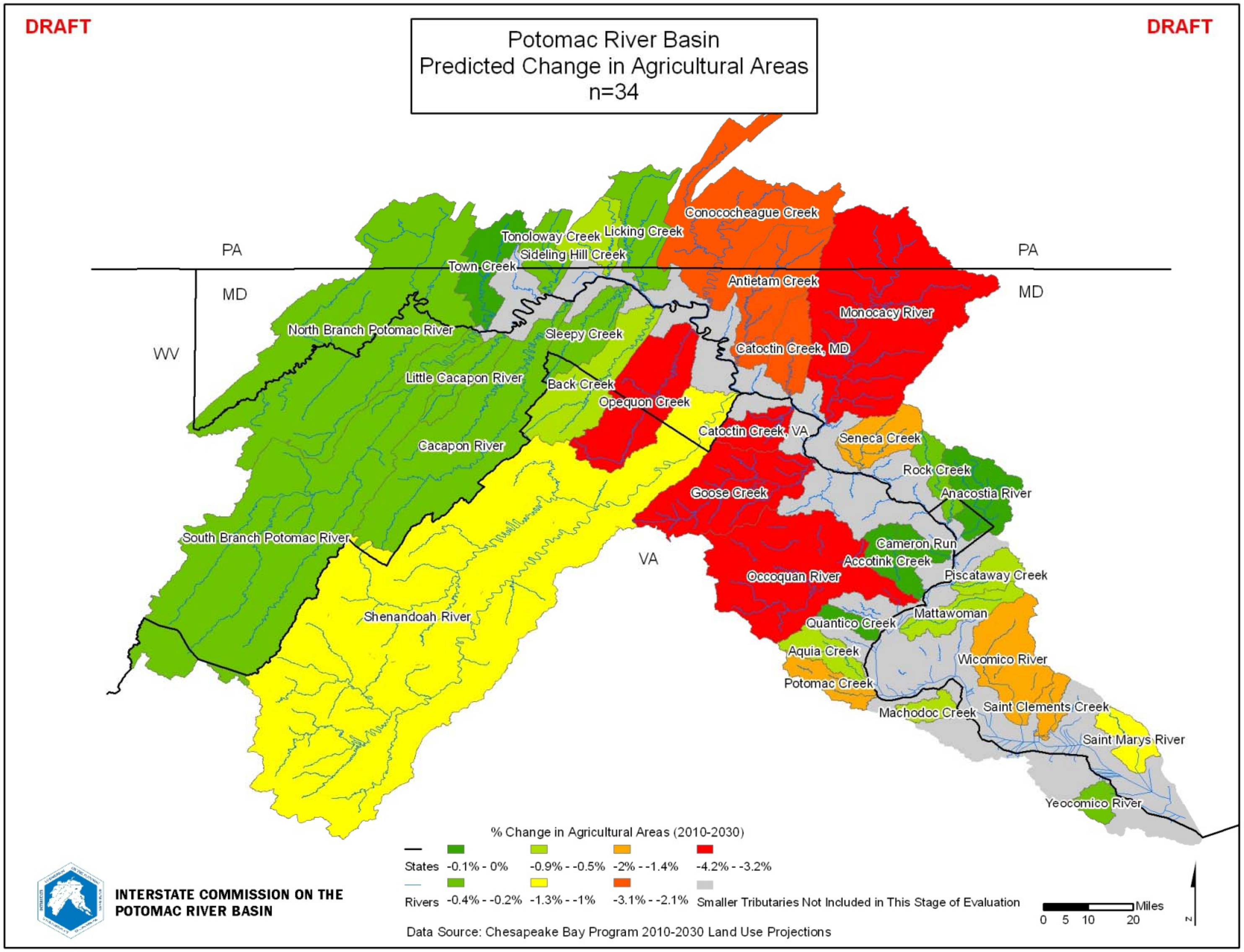
Land Use Change Projections



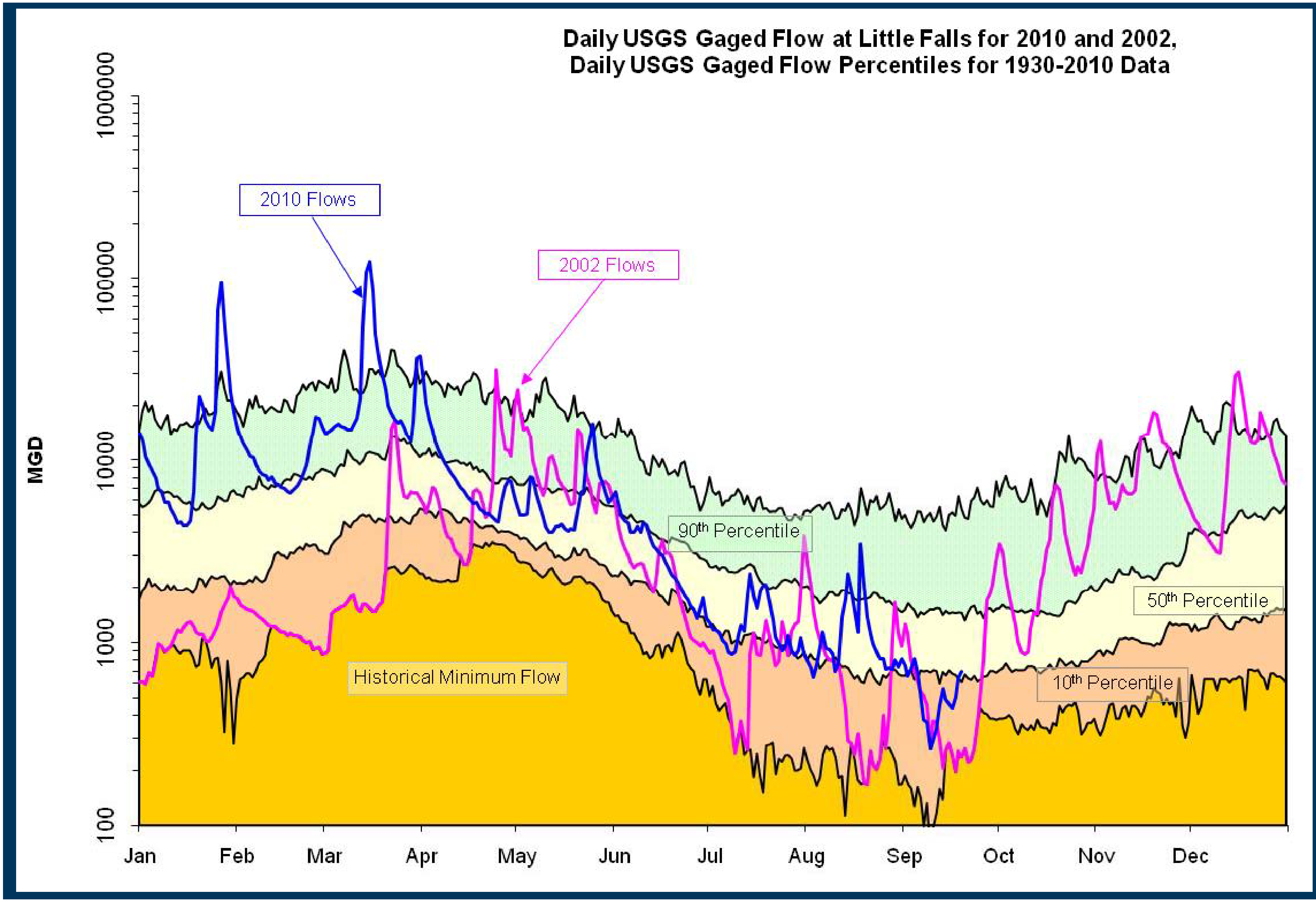
Land Use Change Projections



Land Use Change Projections



What's happening on the river right now?



Credits

Special thanks to Claire Buchanan, Heidi Moltz, Jim Palmer, and Olivia Devereux for contributions to the hydrologic analysis.

And to the USGS. Without the stream gage network, this project would not be possible.