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
Basin characteristics

Fig. 5. Physiographic Provinces
Fig. 7. Land Use in Potomac Basin
Basin Characteristics

Potomac River Basin
Karst Geology

Opequon
63% karst

Monocacy
6% karst

Data Sources: US EPA Region 3 Ecoregions
### 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).

<table>
<thead>
<tr>
<th>Area of</th>
<th>Agriculture</th>
<th>Urban</th>
<th>Forest</th>
<th>Total</th>
<th>Consump.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m²</td>
<td>%</td>
<td>m²</td>
<td>%</td>
<td>m²</td>
</tr>
<tr>
<td>Watershed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opequon Creek</td>
<td>344</td>
<td>128 (37%)</td>
<td>38 (11%)</td>
<td>165 (48%)</td>
<td>7.3</td>
</tr>
<tr>
<td>Monocacy River</td>
<td>965</td>
<td>455 (47%)</td>
<td>144 (15%)</td>
<td>309 (32%)</td>
<td>16</td>
</tr>
<tr>
<td>Potomac River Mainstem Segments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin upstream of Shenandoah River confluence</td>
<td>9,360</td>
<td>2,108 (23%)</td>
<td>605 (6.5%)</td>
<td>6,507 (70%)</td>
<td>570</td>
</tr>
<tr>
<td>Shenandoah River confluence to Point of Rocks</td>
<td>288</td>
<td>126 (44%)</td>
<td>32 (12%)</td>
<td>125 (44%)</td>
<td>0.81</td>
</tr>
<tr>
<td>Point of Rocks to Great Falls</td>
<td>1,796</td>
<td>778 (43%)</td>
<td>336 (19%)</td>
<td>618 (34%)</td>
<td>340</td>
</tr>
<tr>
<td>Great Falls to Chain Bridge (Little Falls)</td>
<td>119</td>
<td>8.6 (7%)</td>
<td>72 (61%)</td>
<td>33 (28%)</td>
<td>1.6</td>
</tr>
<tr>
<td>Chain Bridge (Little Falls) to Occoquan River confluence</td>
<td>1,397</td>
<td>206 (15%)</td>
<td>584 (42%)</td>
<td>504 (36%)</td>
<td>114</td>
</tr>
</tbody>
</table>

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 end of each segment.
Flows are variable

Potomac R. at Point of Rocks 1984-2005 FDC

- 84-05 FDC
Flows are variable

Potomac R. at Point of Rocks 1984-2005 Annual FDCs

Difference between upper and lower confidence limits is 150-200% of median
Flows are variable

Opequon Cr. 1984-2005 Annual FDCs

Difference between upper and lower confidence limits is 175-205% of median
Flows are variable

Monocacy R. 1984-2005 Annual FDC s

Difference between upper and lower confidence limits is 145-240% of median
Flows are variable

Potomac R. at Little Falls 1984-2005 Annual FDCs

Difference between upper and lower confidence limits is 150-300% of median
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 ...
Flows are variable.

---

**Report Figure 38**
Variability in 104 year flow record

Four Flow Duration Curves for Point of Rocks

- All Flows
- 1905-1930
- 1931-1956
- 1957-1982
- 1983-2008
Variability in 104 year flow record
Variability in 104 year flow record

Four Flow Duration Curves for Point of Rocks

Low Flows

Flow, cfs

1000

100

95%

96%

97%

98%

99%

100%

P \{ Q < q \}
In this context, stream flashiness refers to the amount of variability in flow per unit of time.

$$R - B \text{ Index} = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$
Flashiness decreases as D.A. increases
Flashiness of East Coast Large Rivers

Flashiness of large rivers in Water Resources Regions 1-3
Potomac River is “flashy”
Potomac River is “flashy”
Potomac River: The “flashiest” river in the East

Flashiness of large rivers in Water Resources Regions 1-3

- RBI
- Potomac
- Susquehanna
- James
- Connecticut
- Hudson
- Delaware
- Santee

Drainage Area

R:B Flashiness Index
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 mi² 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

% Karst vs Rise Rate

- ▲ 38.6 - 200 mi²
- ◦ 200 - 1000 mi²
- • >1000 mi²
- ▲ Only Karst > 2%

Rise Rate

% Karst

Opequon
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 versus Large River watersheds
Mid-range Flow Condition, Monthly Q50 Statistic
Reference vs Large River Watersheds

Reference versus Large River watersheds
Low Flow Condition, Monthly Q75 Statistic

Q75, cfs/m² drainage area

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

Ref Max
Ref Min
Ref Median
Monocacy River
Opequon Creek
Pot. Pt Rox
Pot. Gr. Falls
Pot. L. Falls
Reference vs Large River Watersheds

Reference versus Large River watersheds
Low Flow Condition, Monthly Q95 Statistic
Reference vs Large River Watersheds

Reference versus Large River watersheds
Low Flow Condition, Monthly and Annual Q99.5 Statistic

- Ref Max
- Ref Min
- Ref Median
- Opequon Creek
- Monocacy River
- Pot. Pt. Rox
- Pot. Gr. Falls
- Pot. L. Falls

Q99.5, cfs/mi2 drainage area

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Annual
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.
• Analysis of risk factors showed that where forest cover $\geq 78\%$ there is negligible change in IHAs.
• Similarly, negligible change in IHAs where impervious surface $\leq 0.35\%$
• 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

Monocacy @ Jug Bridge Flow Duration Curve 1984-2005

- Observed
- Modeled Current
- Modeled Baseline
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

Opequon Creek Flow Duration Curve 1984-2005

- Observed
- Modeled Current
- Modeled Baseline
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 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

Potomac River at Little Falls Simulation of 2002

Flow, cfs

Calendar Year 2002

Modeled Current
Modeled Baseline
Current Conditions vs Baseline: Simulate a Drought Year

Opequon Creek Simulation of 2002

Flow, cfs

Modeled Current
Modeled Baseline

Calendar Year 2002
Current river management impacts on flow regimes: Impoundments

Interstate Commission on the Potomac River Basin

Potomac River Basin
IMPOUNDMENTS

PA
PA
VA
MD
WV

Legend:
- Impoundment Significance
  - Counties
  - States
  - Not Significant
  - Hydroelectric
  - Storage Capacity >10%
  - Rivers
  - Erroneous Data
  - Missing Data
  - Hydro and >10%

Distance: 0 5 10 20 Miles
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.

<table>
<thead>
<tr>
<th>Drainage Basin</th>
<th>2010 Withdrawal (MGD)</th>
<th>2010 Cons. Use (MGD)</th>
<th>2030 Withdrawal (MGD)</th>
<th>2030 Cons. Use (MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opequon Creek</td>
<td>22</td>
<td>2</td>
<td>39</td>
<td>4</td>
</tr>
<tr>
<td>Monocacy</td>
<td>52</td>
<td>6</td>
<td>121</td>
<td>14</td>
</tr>
<tr>
<td>PawPaw</td>
<td>1242</td>
<td>43</td>
<td>1500</td>
<td>54</td>
</tr>
<tr>
<td>Hancock</td>
<td>1242</td>
<td>43</td>
<td>1501</td>
<td>54</td>
</tr>
<tr>
<td>Shepherdstown</td>
<td>1556</td>
<td>58</td>
<td>1909</td>
<td>74</td>
</tr>
<tr>
<td>PointOfRocks</td>
<td>1653</td>
<td>71</td>
<td>2117</td>
<td>99</td>
</tr>
<tr>
<td>LittleFalls</td>
<td>3122</td>
<td>849</td>
<td>5194</td>
<td>1850</td>
</tr>
</tbody>
</table>
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

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]

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.
More from Climate Change Literature

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

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


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

Potomac River Basin
Predicted Change in Urban Areas
n=34

% Change in Urban Areas (2010-2030)
- States: 0.2% - 0.8%
- 1.7% - 2.3%
- 3.6% - 4.5%
- 7% - 9%
- Rivers: 0.9% - 1.6%
- 2.4% - 3.5%
- 4.6% - 6.9%

Smaller Tributaries Not Included in This Stage of Evaluation

Data Source: Chesapeake Bay Program 2010-2030 Land Use Projections
Land Use Change Projections

Potomac River Basin
Predicted Change in Forested Areas
n=34

% Change in Forested Areas (2010-2030)

- States: -0.9% - 0.6% - 1.3% - 1.9% + 1% - 3.8% - 5.2% - 6.5% - 8.3%
- Rivers: -0.9% - 0.6% - 1.9% - 2.6% - 3.7% - 5.2% - 6.5% - 8.3%

Smaller Tributaries Not Included in This Stage of Evaluation

Data Source: Chesapeake Bay Program 2010-2030 Land Use Projections
Land Use Change Projections

Potomac River Basin
Predicted Change in Agricultural Areas
n=34

% Change in Agricultural Areas (2010-2030)

- States: -0.1% - 0%
  -0.9% - -0.5%
  -2% - -1.4%
  -4.2% - -3.2%

- Rivers: -0.4% - -0.2%
  -1.3% - -1%
  -3.1% - -2.1%

Smaller Tributaries Not Included in This Stage of Evaluation

Data Source: Chesapeake Bay Program 2010-2030 Land Use Projections
What’s happening on the river right now?
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.