Climate Change Effects on Forest Hydrology

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The Hydrology of Forested Watersheds
Pennsylvania Hydrologic Budget

precipitation = 41 inches

evapotranspiration = 21 inches

recharge = 13 inches

groundwater discharge = 13 inches

runoff = 7 inches

stream flow = 20 inches
Hydrologic Budget by Land Cover

- **Evapotranspiration**
  - Forest: ~60%
  - Cropland: ~70%
- **Stream Flow**
  - Forest: ~30%
  - Cropland: ~40%
  - Pavement: ~70%
Forests = High Water Infiltration Rates
High Infiltration Results in Subsurface Flow

What is the average age of water in small streams at low flow?

A buffer to rapid climate effects

(Graphic by William Gburek)
Modeling Forest Watershed Residence Time

Figure 5. Seasonal oxygen-18 variations in baseflow on Fernow catchments WS3 and WS4 (March 1989–March 1990). Sine waves fitted to precipitation and baseflow data are shown for reference.

Residence Time = many months to a year or more

Low flow = 100% groundwater

Stormflow = subsurface flows
Forest Hydrological Processes

- High rate of evapotranspiration
- High recharge rates
- Mostly subsurface flow
- Moderated flows, cool water
- Stable banks
- Good water quality

Streamflow = 30-40%

Evaporation
Transpiration
60-70%

Recharge

Runoff

Discharge
Mid-Atlantic Changing Temperature and Precipitation

Mean Annual Temperature – increasing 0.016°F per year.

Mean Annual Precipitation – increasing 0.04 inches per year.

Evapotranspiration Trends

Overall, Increased ET due to:
- Increased air temperature throughout the year
- Increasing moisture availability
- Lengthening of the growing season

Evapotranspiration in winter will decrease with a decreasing snowpack and hence reduced sublimation (Hayhoe et al., 2007).

(PA Climate Impacts Assessment, 2013).
Precipitation Trends

• Increase in winter precipitation (but less snow)

• Small to no overall increase in summer precipitation. Potential increase in extreme heavy precipitation events

• More extreme precipitation is already occurring

(PA Climate Impacts Assessment, 2013).
Number of Days >2" Precipitation (all PA Global Historical Climatology Network Sites per Year)

Webinar – Is PA Becoming Drought Resistant?
Paul Knight, PA State Climatologist
National Climate Assessment
released on May 6, 2014

Observed Change in Very Heavy Precipitation

Source: Paul Knight, PA State Climatologist
Precipitation Controls Streamflow
(Buskill Creek, Pennsylvania)

So, increasing precipitation will result in higher streamflow.
**Stream Flow Changes**

- Overall **INCREASE** due to
  - Higher winter runoff (rain instead of snow)
  - Increase in groundwater from greater recharge (infiltration of rainfall) due to reduced frozen soil and higher winter precipitation when plants are not active and evapotranspiration is low
  - More extreme flows from higher intensity storms

- Somewhat offset by
  - Increased evapotranspiration from longer growing season and more moisture
  - Decrease of large rain on snow events in spring

(Pennsylvania Climate Impacts Assessment, 2013)
Substantial Decrease in Snow Cover Extent and Duration

• Reduced rain on snow floods!

• More rapid groundwater recharge in winter/spring

Figure 5.1. Results of HadCM3 and PCM GCM-output driven simulations with the VIC land-surface model. Plots show snow-covered days per month from December to February averaged over 30-year periods. ‘Change’ refers to the difference between the period 1961-1990 and future periods (Hayhoe et al., 2007).

(PA Climate Impacts Assessment, 2013)
Water Temperature Increases Will Occur

Delaware River at Philadelphia, PA

- Air Temperature (deg. C)
- Water Temperature (deg. C)
Forested Watershed Temperature Sensitivity

Figure 5.6. Stream order (SO) versus thermal sensitivity, across 57 Pennsylvania streams. Color highlights baseflow contribution, in terms of BFI. Sites where thermal sensitivity is influenced by a unique site condition are noted on the figure. General controls on thermal sensitivity and their influence relative to stream size are conceptualized at the bottom of the figure (Kelleher et al., 2011).
Native Brook Trout Stressors

Source: Shawn Rummell, Trout Unlimited
Changing Stream Hydrographs

- Early peaks (no snow)
- More extreme flows
- Higher water temperature
- Lower low flows
Climate Change on Forested and Urbanizing Watersheds
(Funded by U.S. Environmental Protection Agency)

• 39 urbanizing watersheds
• 21 forested (rural) watersheds
• Analyzed 1930-1990

• Concept – past period of record provides climatic variability that will provide clues to future changes

• How do urbanizing watersheds respond relative to forested watersheds?
Forest Watershed
Bushkill Creek

Stream Flow Trend

Stream Flow = 3.6 + 0.27 * Precip – 1.18 Temp
Urbanizing Watershed
Chester Creek Example

Stream Flow = -10.8 + 0.20*Precip + 0*Temp + 1.58*Population
Percent Change in Mean Annual Flow for Climate Change Scenarios

- Greater response to higher precipitation on urban watersheds
- Lower response to temperature on urban watersheds
- Higher precip effect muted on rural watersheds due to higher ET

More ET on rural watersheds

Climate Change Scenario

+20%  +20%  +10%  +10%  +0%  +0%  +0%
+2°C  +4°C  +2°C  +4°C  +0°C  +2°C  +4°C
Summary

• Change to forested watershed hydrology will include:
  o Increased precipitation including more extreme events and less snow
  o Increased evapotranspiration due to more moisture, higher temperature, and longer growing season
  o Overall increased streamflow and more extreme flows resulting from greater groundwater and higher precipitation
  o Increased stream temperatures

• Water impacts on urbanizing watersheds will be more extreme but dominated by land use changes