Washington’s water resources in a changing climate

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April 20, 2007: State Legislature of Washington passed HB 1303 which mandated *the preparation of a comprehensive assessment of the impacts of climate change on the State of Washington* to be performed by the UW Climate Impacts Group.

The assessment was to be focused on the impacts of global warming generally, and specifically in relation to:

- public health,
- Agriculture (partner: WSU)
- the coastal zone
- forestry
- Infrastructure (specifically stormwater)
- water supply and management (partner: PNNL)
- Salmon and ecosystems
- energy
Projected annual changes in precipitation for PNW (averaged over 111° – 124° W, 41.5° – 49.5° N)

Changes in annual precipitation averaged over all models are small—but some models show large seasonal changes, especially toward wetter autumns and winters and drier summers.
Projected annual changes in surface air temperature for PNW (averaged over 111° – 124° W, 41.5° – 49.5° N)
Assessment Overview: Study Region
Global Climate Models
2 different emissions scenarios
20 models using A1B (medium scenario)
19 models using B1 (low scenario)

Downscaled to regional projections of P and T for the 2020s, 2040s, 2080s

Hydrologic Models
Projections of future changes in snowpack, streamflow, soil moisture, etc.

Energy
Forests
Water Management
Infrastructure
Agriculture
Salmon
Hydrologic Simulations

Variable Infiltration Capacity (VIC)
Macroscale Hydrologic Model

Grid Cell Vegetation Coverage

Cell Energy and Moisture Fluxes

Canopy
Layer 0
Layer 1
Layer 2

P E L S R_s R_L E_c E_G

Variable Infiltration Curve

i = L[1 - (1 - A)^n]

Point Infiltration Capacity, i

Fraction of Area

0 As dA

Baseflow Curve

Baseflow, B

D_Down

D_Up

Layer 2 Soil Moisture, W_2

Large Scale Model (VIC)
~12mi^2 per cell

Fine Scale Model (DHSVM)
~6 acres per cell
Climate Change Projections (using “delta method”)

39 Climate Change Scenarios
- each is a monthly timeseries of $P$ and $T$ from 2000-2099

3 chosen projection windows

- Mean $\Delta P$ & $\Delta T$ for 2020s (2010-2039)
- Mean $\Delta P$ & $\Delta T$ for 2040s (2030-2059)
- Mean $\Delta P$ & $\Delta T$ for 2080s (2070-2099)

Historical daily timeseries (1916-2006) perturbed by mean monthly $\Delta P$ & $\Delta T$
(same mean $\Delta P$ and $\Delta T$ applied to each day in a given month)

New daily timeseries which incorporates historical daily patterns and future projections of precipitation and temperature
Focus Watersheds

- Columbia River
  - Washington portion
- Puget Sound
  - Green River
  - Snohomish River
  - Cedar River
  - Tolt River
- Yakima River
Implications of 21st century climate change on Washington’s watersheds
April 1
Snow-Water Equivalent

Weekly Snowpack Projections

Cedar River

Yakima River

Low

Medium
Watershed Classification

Ratio of April 1 SWE to October - March Precipitation
- < 0.1  Rain dominant
- 0.1 - 0.4  Transition
- > 0.4  Snow dominant

Historical

2020s

2040s

2080s

A1B

B1
Monthly Streamflow Projections

Rain dominant watershed

Transient rain-snow watershed

Snowmelt dominant watershed

Chehalis River (at Porter)

Yakima River (at Parker)

Columbia River (The Dalles)
Weekly Streamflow Projections

Cedar River - inflow to Chester Morse Reservoir

Yakima River at Parker
Case study 1: Puget Sound Basin

- Precipitation in fall-winter, water demand in summer
- Water management systems:
  - Seattle: municipal, fish
  - Tacoma: municipal, flood control
  - Everett: municipal, hydropower
- Reservoir capacities small relative to annual flow
Puget Sound Basin

Seattle

Tacoma

Everett

Variations in impacts within and between systems (A1B)

- Seattle, M&I and environmental flows
- Tacoma, flood control, more constrained storage
- Everett, hydropower, more interannual variability
Puget Sound Basin
municipal supply - current demand

- M&I reliability measures, differ for all systems
- Current demand, reliability little impact from future change (A1B)
- Tacoma, water allocations closer to current system capacity
- Everett, largest system capacity
- Note: simulations prior to adaptations

![Graph showing current demand in Puget Sound Basin municipalities.](image-url)
Puget Sound Basin
municipal supply - changing demand

With demand increases, climate change has more impact on reliability. The importance of conservation measures/reduced demand is highlighted. Systems respond differently depending on storage capacity, basin transitions, system demands, and adaptive capacity. Note: simulations prior to adaptations.

Seattle M&I Reliability

- Current demand: 1% at 100%, 5% at 125%, 23% at 150%

Tacoma FDWR Reliability

- Current demand: 7% at 100%, 9% at 125%, 9% at 150%

Everett M&I Reliability

- 0% difference, all 100%
Puget Sound Basin
operations beyond municipal supply

Tacoma Likelihood of Flood Control Years

Tacoma MIF at Palmer Reliability

32% diff

36% diff
Case study 2: Yakima River Basin

- Irrigated crops largest agriculture value in the state
- Precipitation (fall-winter), growing season (spring-summer)
- Five USBR reservoirs with storage capacity of ~1 million acre-ft, ~30% unregulated annual runoff
- Snowpack sixth reservoir
- Water-short years impact water entitlements
Key Findings: Puget Sound Basin

1) Primary impacts of climate change will be a shift on average in the timing of peak river flow from late spring to winter.
2) With current demands, system reliability able to accommodate changes.
3) With demand increases, system reliability reduced, conservation measures matter.
4) Other aspects of system performance complicate management decisions such as environmental flows, flood control, and hydropower.

Photo courtesy of http://www.seattle.gov
Yakima Basin Methods
Yakima River Basin

Unregulated
Yakima River Basin

Unregulated
Yakima River Basin

Unregulated

Regulated
Yakima River Basin

- Basin shifts from snow to more rain dominant
- Water prorating, junior water users receive 75% of allocation
Yakima River Basin

- Basin shifts from snow to more rain dominant
- Water prorating, junior water users receive 75% of allocation

Junior irrigators less than 75% prorating (current operations):
- Historically 14% 
- 2020s A1B: 32% (15% to 54% range of ensemble members) 
- 2040s A1B: 36% 
- 2080s A1B: 77%
Crop Model - Apple Yields

• Yields decline from historic by 20% to 25% (2020s) and 40% to 50% (2080s)
Key Findings
Yakima River Basin

1) Future projections indicated that reservoir system will be less able to supply water to all users, especially those with junior water rights
2) Earlier and shorter growing season - apples 12 days earlier, cherries 22 days earlier season start, month earlier harvest
3) Yields decline - under A1B emissions scenario, average apple and cherry yield are likely to decline by 20% to 25% (2020s) and 40% to 50% (2080s) for junior water holders
4) Crop values decline - value of apple and cherry production is likely to decline by 5% ($20 million) in 2020s, 16% ($70 million) in the 2080s
Shifts in energy production and demand
Changes in precipitation maxima

Comparison of 25-Year 24-Hour Design Storms
Based on Observed and Modeled Data at SeaTac Airport

- Observed
- ECHAM5-WRF
- CCSM3-WRF

Precipitation (inches)

1956-1980
1981-2005
1970-2000
2020-2050
• Models project **more winter flooding** in sensitive “transient runoff” river basins that are common in the Cascades

  – Likely reducing survival rates for incubating eggs and rearing parr

![Ratio of 20-year Flood Statistics (21st Century ÷ 20th Century)](image)
• **Summer base flows are projected to drop substantially** (5 to 50%) for most streams in western WA and the Cascades
  
  – The duration of the summer low flow season is also projected to increase in snowmelt and transient runoff rivers, and this reduces rearing habitat
Warming trends of air and water temperatures across Washington State
August Mean Surface Air Temperature and Maximum Stream Temperature

2020s

2040s

2080s

A1B

Historical

WACCIA 12 Feb 2009
Average Number of Weeks per Year
Stream Temperatures Exceed 21°C/70°F

Historical

- 0: 13
- 1: 15
- 3: 17
- 5: 19
- 7: 9
- 9: 11
- 11:

2020s
2040s
2080s

A1B
Conclusions

• Broad consensus among models that PNW temperatures will rise, continuing (and amplifying) 20th C trends
• Precipitation changes less clear, both historically and projected, although some indication of slightly wetter conditions in coming decades, esp. in winter
• Dominant hydrologic signal is reduction in SWE, and streamflow timing shifts – esp. in transient basins
• Direct effects of warming on western WA water supply systems are nonetheless modest, mostly because of demand reductions achieved over last ~10-20 years
• Impacts on the already-overallocated Yakima basin are more severe than on westside water systems
• Other water-related sectors (fish habitat, energy, infrastructure) are generally negatively impacted, although specifics vary