Meeting Water Utility Needs: Translating Climate Science into Hydrology

Julie Vano, National Center for Atmospheric Research
Classic “Top-Down” Chain of Models

- **Emissions Scenario(s)**
  - e.g. RCP8.5

- **Global Climate Model(s)**
  - e.g. CESM

- **Downscaling Method(s)**
  - e.g. BCSD

- **Hydrologic Model(s)**
  - e.g. Sac-SMA
  - e.g. WEAP

- **Decision**
  - e.g. ...

- **Management?**
What type of hydrologic models do you use?
Why Do We Need Hydrology Models?

What we have: precipitation, temperature, other atmospheric values

What we would like: streamflow (highs, lows), water demand from vegetation, water temperature

Hydrology models represent energy and water fluxes in watersheds, combine measurements and physical processes to encapsulate our understanding.

Important in filling gaps since measurements are not available in most places.
Benefits of Hydrology Models

Portland Water Bureau

- Land surface values from GCMs measures not helpful
- Worked with University of Washington to select and set up in-house hydrologic model
- Model allows PWB to understand how changes in streamflow affect future supply conditions
- Included in Supply System Master Plan
Hydrologic Modeling Cautions

- Models built to represent many landscapes, spatial configurations
- May miss key elements
  - Snow redistribution
  - Groundwater interactions
- Important to be a savvy user
Hydrologic Modeling in the Colorado River

Variable Infiltration Capacity (VIC) model

Historical

Temperature perturbations

Precipitation perturbations

mm/day

Historical

Temperature perturbations

Precipitation perturbations

P ET Q
Hydrologic Modeling in the Colorado River

**Historical**

**Precipitation perturbation**

**Temperature increase**

VIC  Catchment  CLM  Noah 2.7  Noah 2.8  Sac
Hydrologic Model Choice

Flows at Lees Ferry using six different Hydrologic Models

- Hydrologic models provide a range of results
Hydrologic Model Choice

- Hydrologic models provide a range of results
- Change signal across hydrologic models also differs
- How sensitive a model is depends on hydrologic model choice!
- Some signals are less sensitive to model choice than others
Hydrologic Model Spatial Structures

a) GRUs

b) HRUs

i) lump

ii) grid

iii) polygon

c) Column organization
Hydrologic Model Process Structure

Looking under the hood...

- Canopy radiation
- Beer's Law 2-stream broadband 2-stream vis+nir
- Soil water characteristics
- Supercooled liquid water

Water
- Canopy evaporation
- Snow storage
- Canopy temperature
- Soil temperature
- Aquifer storage

Energy
- Evapotranspiration
- Infiltration
- Surface runoff
- Evapotranspiration

Physical processes
- Canopy storage
- Aquifer storage
- Water table (TOPMODEL)
- Xinanjiang (VIC)
- Rooting profile
- Ball-Berry
- Soil Stress function

Conservation equations
- Louis Obukhov
- Boussinesq
- Kinematic
- Conceptual aquifer

- Gravity drainage
- Richards'
- Multi-domain

- Darcy
- Green-Ampt
- Frozen ground

- Explicit overland flow
- Water table (TOPMODEL)

- Lincoln
- Capacity limited
- Wetted area
- Liquid drainage
- Linear above threshold
- Melt drip Linear reservoir
- Topographic drift factors
- Blowing snow model

- Horizontal redistribution
- Vertical redistribution
- Gravity drainage

- Instant outflow
- Gravity drainage

- Phase change
- Snow Unloading
- Snow drifting

- Soil water content

- Snow temperature

- Soil temperature

- Canopy interception

- Canopy radiation

- Canopy evaporation

- Snow Unloading

- Snow drifting

- Water flow through snow

Clark et al. (WRR 2015) 12

Looking under the hood…
Hydrologic Model Construction

Conservation equations, the order they are solved and time step matter

Clark et al. (WRR 2015)
Hydrologic Model Construction

Equations to calculate model fluxes (e.g., evapotranspiration)

Clark et al. (WRR 2015)
Conservation equations

Water

Energy

Physical processes

XXX

Model options

Evapotranspiration

Infiltration

Surface runoff

Solver

Canopy storage

Snow storage

Soil water content

Snow temperature

Canopy temperature

Canopy radiation

Net energy fluxes

Atmospheric stability

K-theory

L-theory

Louis

Obukhov

Capacity limited

Linear above threshold

Wetted area

Canopy interception

Canopy evaporation

Liquid drainage

Snow Unloading

Snow drifting

Water flow through snow

Instant outflow

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Horizontal redistribution

Vertical redistribution

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Clark et al. (WRR 2015)
Hydrologic Model Parameters

• Parameters represent real-world vegetation, soil type
• Often calibrated to streamflow
• Calibrated parameters can compensate for other errors
• Compensating errors can respond differently to climate change
• Check robustness by exploring multiple “calibrated” and uncalibrated parameter sets
Response Not Always Obvious

• Many responses are “obvious”

• But hydrology-climate interactions not always linear
  • Rain-on-snow events
  • Slower snow melt in a warmer world
  • Decreased snowpack sublimation/evaporation in a warmer world

• Tipping points hard to detect

• Hydrologic models encapsulate our understanding of the system, but far from perfect
Revealing Uncertainties

- Emissions Scenario(s)
- Global Climate Model(s)
- GCM Initial Conditions
- Downscaling Method(s)
- Combined uncertainty projections
- Hydrologic Model Structure(s)
- Hydrologic Model Parameter(s)
- Combined uncertainty
- Calibration
- PDF
- PDF
- PDF
- PDF
- PDF
Revealing Uncertainties

Key Uncertainties from:
- Human activities
- Physical processes
- Natural variability
What Data are Available Now?

- Hydrology focused Green Data Oasis (GDO) portal
  - BCSD (12km), LOCA (6km)
  - VIC streamflow

- Dynamical
  - NARCCAP (50km),
  - CORDEX (limited 25km)
  - Others over regional domains or limited time periods

- USGS GeoDataPortal
  - Collection of different archives

- Northwest Knowledge Network
  - MACA (6 km, 4 km)

- Many others (NASA NEX, ARRM)
Classic “Top-down” Impacts Modeling Chain

Emissions Scenario(s)
e.g. RCP8.5

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e.g. Sac-SMA

Decision
e.g. ...

Management?
e.g. WEAP
Revised “Top-down” Impacts Modeling Chain

- Emissions Scenario(s)
  - e.g. RCP8.5
- Global Climate Model(s)
  - e.g. CESM
- Downscaling Method(s)
  - e.g. BCSD
- Hydrologic Model(s)
  - e.g. Sac-SMA

Decision
- e.g. ...

Managed?
- e.g. WEAP
Key Takeaways

• Hydrologic modeling can help understand local water resources
• Some change signals are more certain than others
• Some uncertainty is unavoidable
  – Representation of uncertainties is hard but necessary
  – Uncertainties have always been there; just understanding them now
  – Previous climate impact studies possibly over-confident
• Approaches being developed to select representative set of scenarios useful for water resources planning
• It is critical to understand important processes and uncertainties involved in your system
EXTRA SLIDES
Climate Change Study Choices

- Approach type (e.g. scenarios, paleo, vulnerability analysis):
- Emission scenarios used:
- GCMs used:
- Number of initial conditions for each GCM used:
- Downscaling methods used:
- Hydrologic models and parameter sets used:
- Time period of interest (transient or delta):
- Project timeline:
- Impacts evaluated:
- Results reported (ensembles, individual simulations):

Clark et al. 2016
Model Set Up

GIS data = soil, vegetation, elevation maps

Portland Water Bureau

NRCS STATSGO2 and SSURGO$^{2,3}$
Record heat put thousands of Californians in the dark Friday. Scientists predicted this from climate change.

By Jason Samenow  July 9  Email the author

“Temperatures shot up over 110 degrees in Southern California on Friday, obliterating all kinds of long-standing heat records, and the lights went out for tens of thousands of customers. Californians were powerless, without air conditioning, in the hottest weather many had ever experienced.”
Figure 3. Normalized distance from observations in the CMIP2, CMIP3, and CMIP5 models. The distance metric is calculated as the root mean square of the surface temperature and precipitation distance as in Figure 1 but relative to observations (NCEP, ERA40, and MERRA for temperature; GPCP and CMAP for precipitation, see MK11). Mean and medians for the different ensembles are indicated by red solid and dashed lines, respectively. Note that most models in CMIP2 (including HadCM2, but not HadCM3) used flux corrections.
Hydrologic Model Choice

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