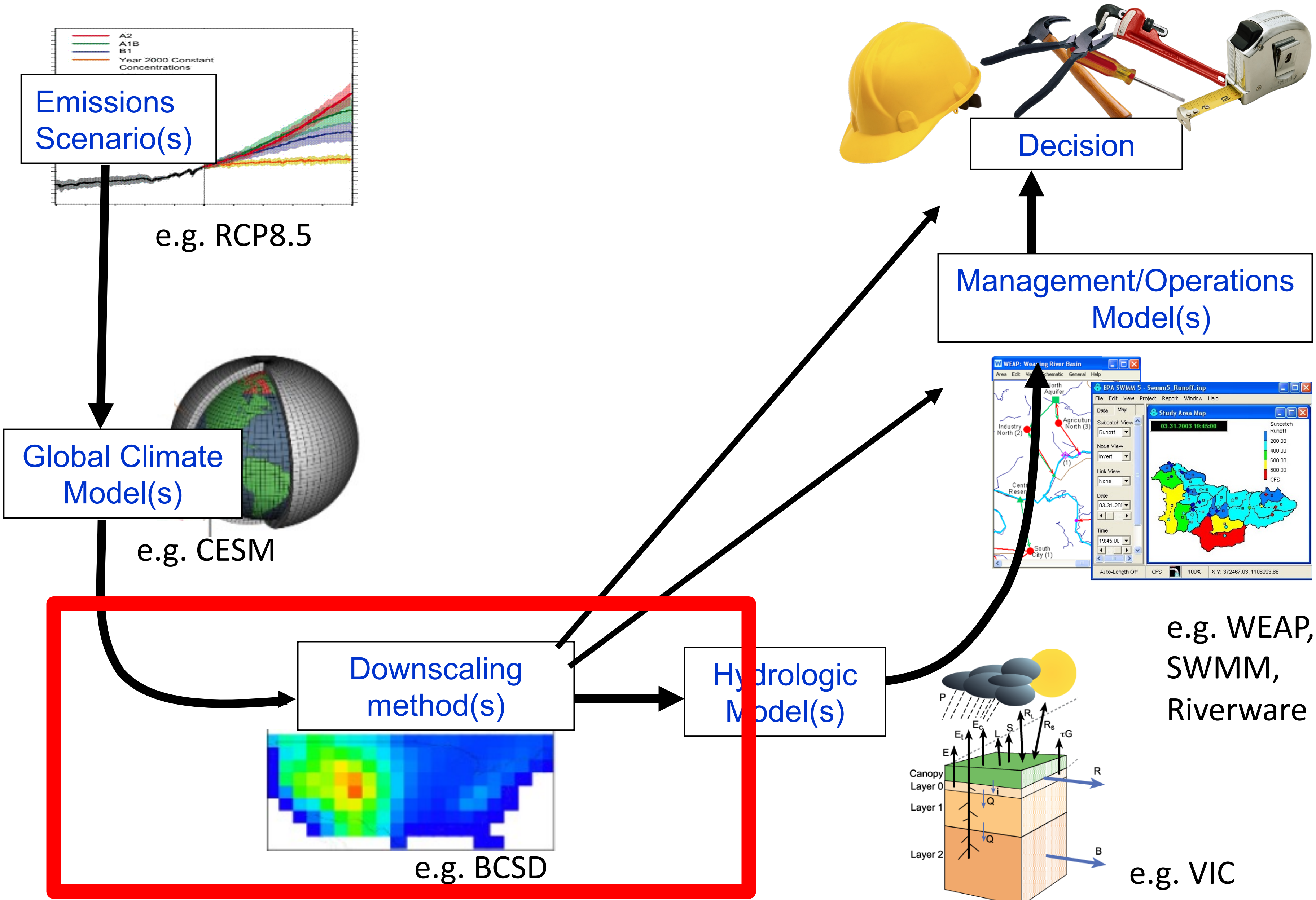
Building Resilience to a Changing Climate:
A Technical Training in Water Sector
Utility Decision Support

WUCA
Water Utility Climate Alliance

A Practical Look at Downscaling, Bias Correction, and Translating Climate Science into Hydrology in the Colorado River Basin

Julie Vano, Aspen Global Change Institute

Classic "Top-down" Impacts Modeling Chain



Why Downscale?

Global models:

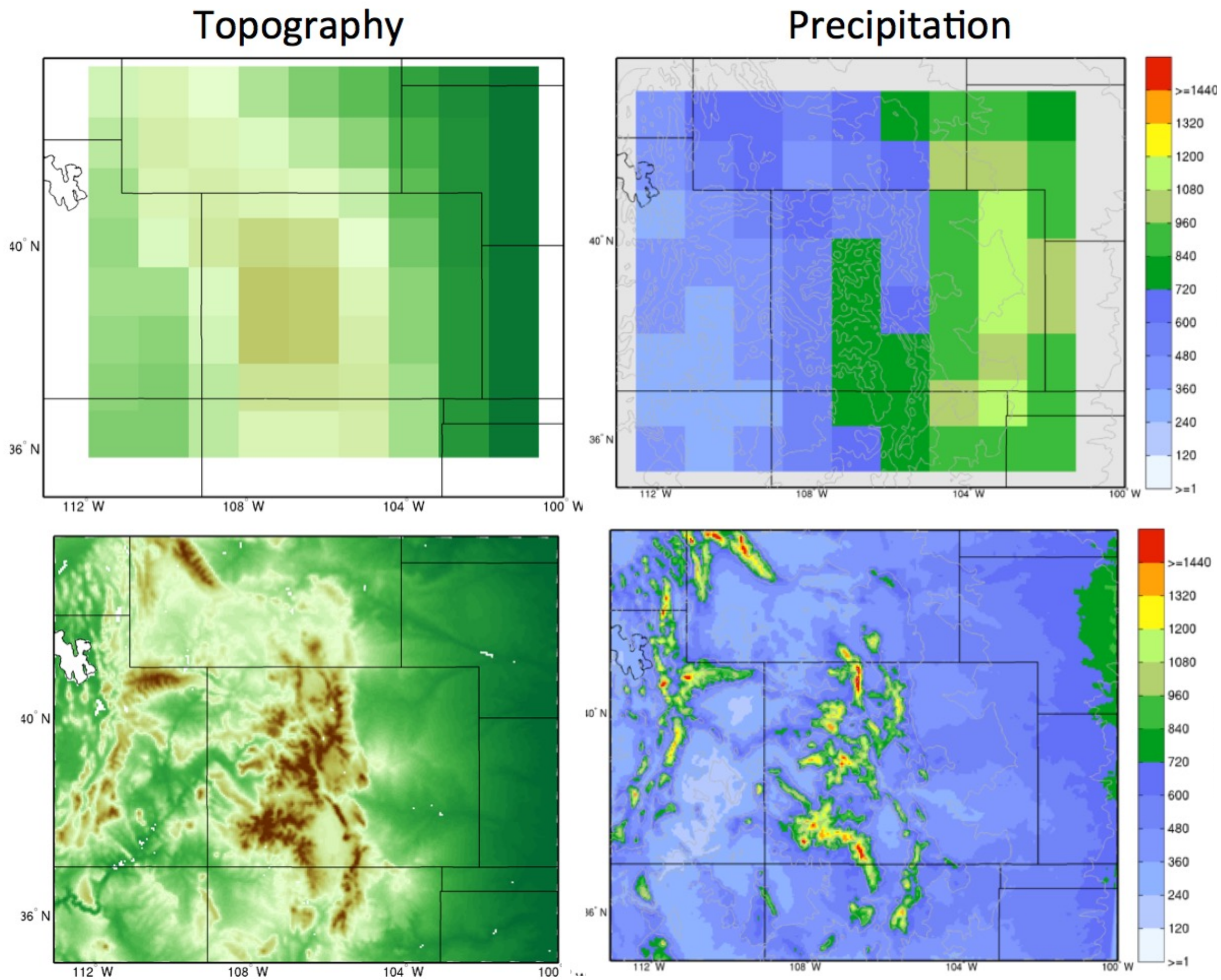
- Resolution does not capture topography
- Inaccurate in simulating orographic precipitation, temperature gradients, cloud, snow, etc.

Regional models:

- High resolution topography
- More accurate local physics and dynamics

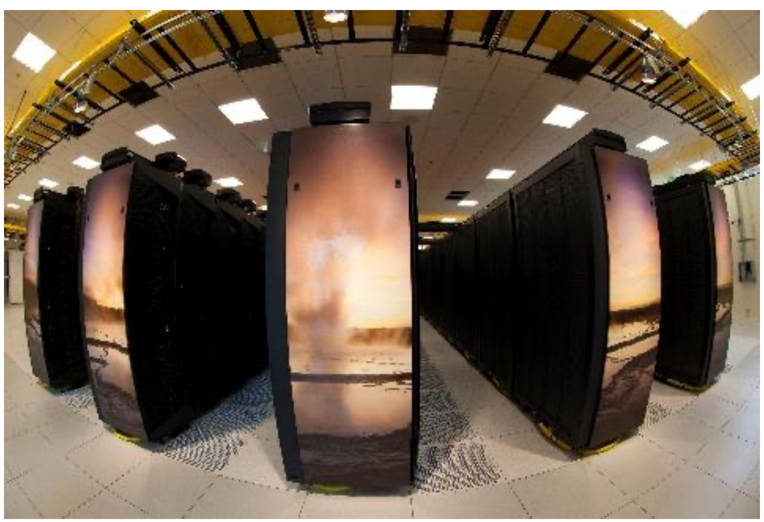
Benefits of downscaling:

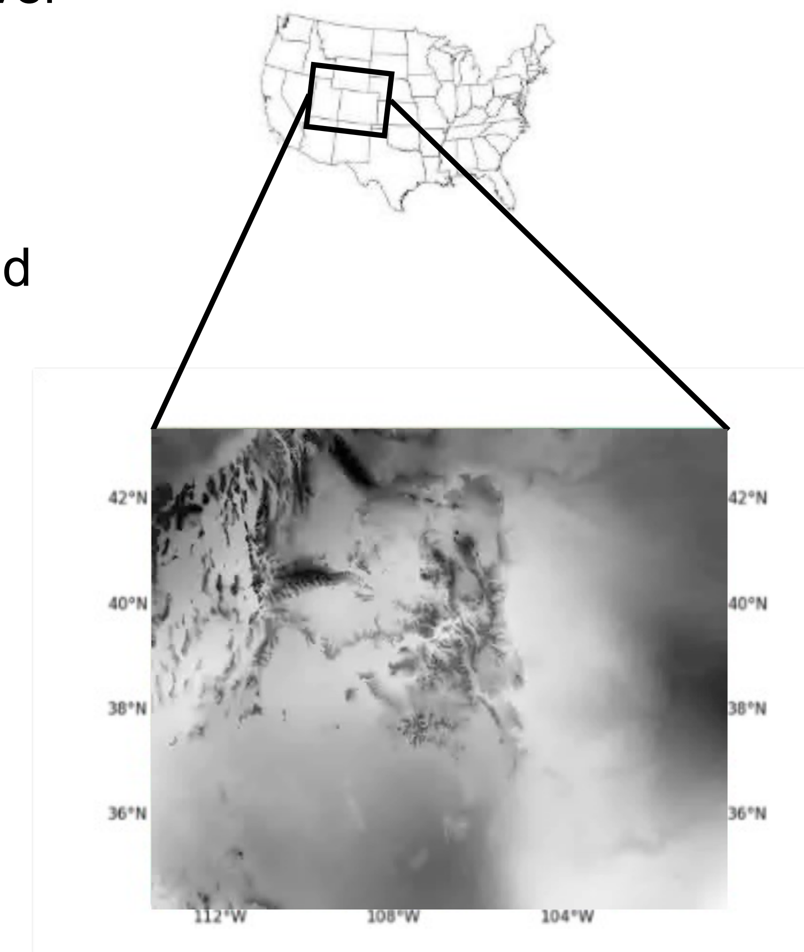
- Local-scale insights
- Fine-scale, high-temporal inputs (e.g., precip, temp) for impacts models
- Can correct certain biases of global models



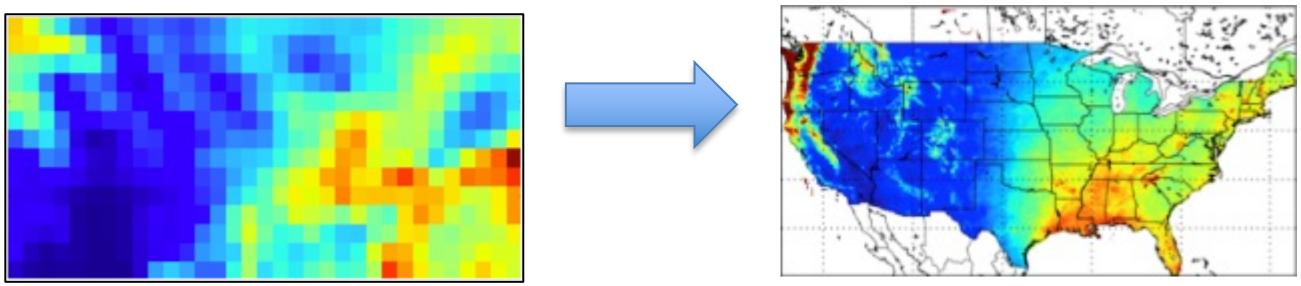
Types of Downscaling: Dynamical

- Uses a high-resolution regional climate model to simulate local dynamics over the area of interest
- Global model output applied along boundaries and as initial conditions
- Computationally expensive, time and supercomputers (usually) required

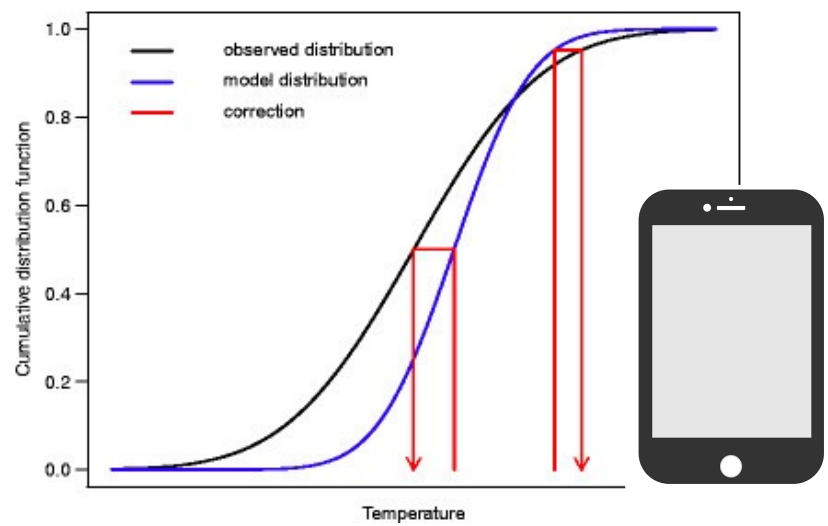




Types of Downscaling: Statistical



- Uses statistical relationships that relate coarse to fine resolution from historical record
- Stationary statistical relationships then applied to future global model output
- Output usually for subset variables (precipitation, temperature)
- Computationally cheap, quick and can be done anywhere
- Statistical relationships reproduce historical data well



Example: Bias correction with spatial disaggregation (BCSD)

Tradeoffs Between Dynamical and Statistical Downscaling

Dynamical

Pros

- **Represents physical processes**
- No stationarity assumptions
- Physically consistent across variables

Cons

- **Computationally expensive**
- Data set availability is limited
- Introduces need for additional ensembles
- Produces climate change signals that still must analyzed for credibility

Statistical

Pros

- **Computationally tractable for large GCM ensembles**
- Large high-resolution data sets publicly available
- Consistent with observations

Cons

- **May not represent climate change signal correctly** (often is effectively just interpolated GCM signal)
- Statistical nature often introduces artifacts

A Continuum of Downscaling Options

increasing physical representation

- Dynamical downscaling using state-of-the-art RCMs
  e.g., RSM-ROMS, Water Research and Forecasting (WRF) model

- ”Hybrid” (dynamical + statistical) downscaling
  e.g., build statistical emulator using limited set of dynamical runs
- Physically-based “quasi-dynamical” atmospheric models
  e.g., Intermediate Complexity Atmospheric Research model (ICAR)
- Statistical downscaling based on GCM dynamics (wind, humidity, stability, etc.)
  e.g., regression-based, analog, pattern scaling, En-GARD
- Methods to relate downscaled fields to synoptic scale atmospheric predictors
  e.g., self-organized maps, weather typing

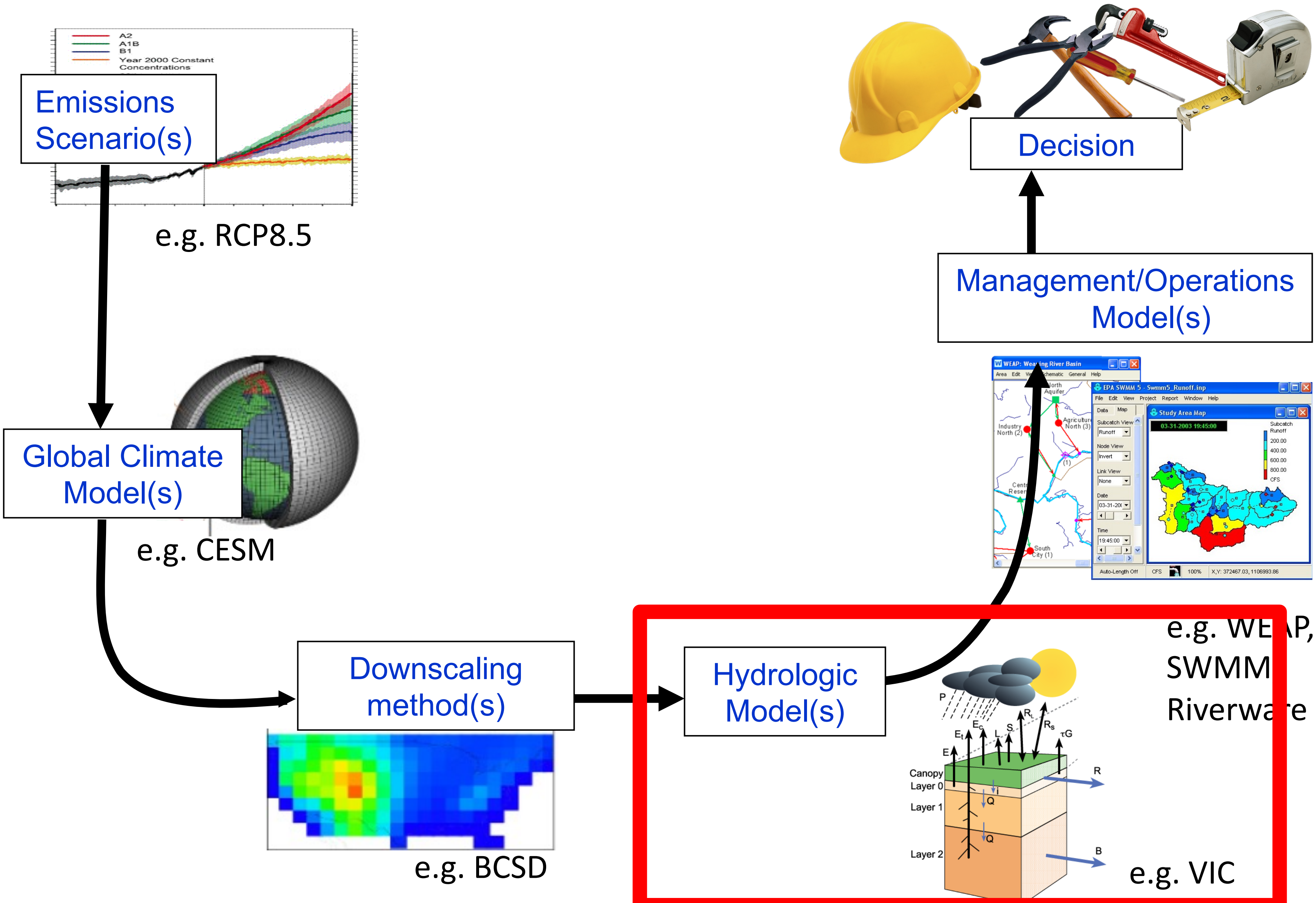
- Statistical downscaling based on rescaling GCM outputs
  e.g., BCSD, BCSA, LOCA, BCCA, linear regression, and more

Questions to help determine most appropriate downscaling techniques

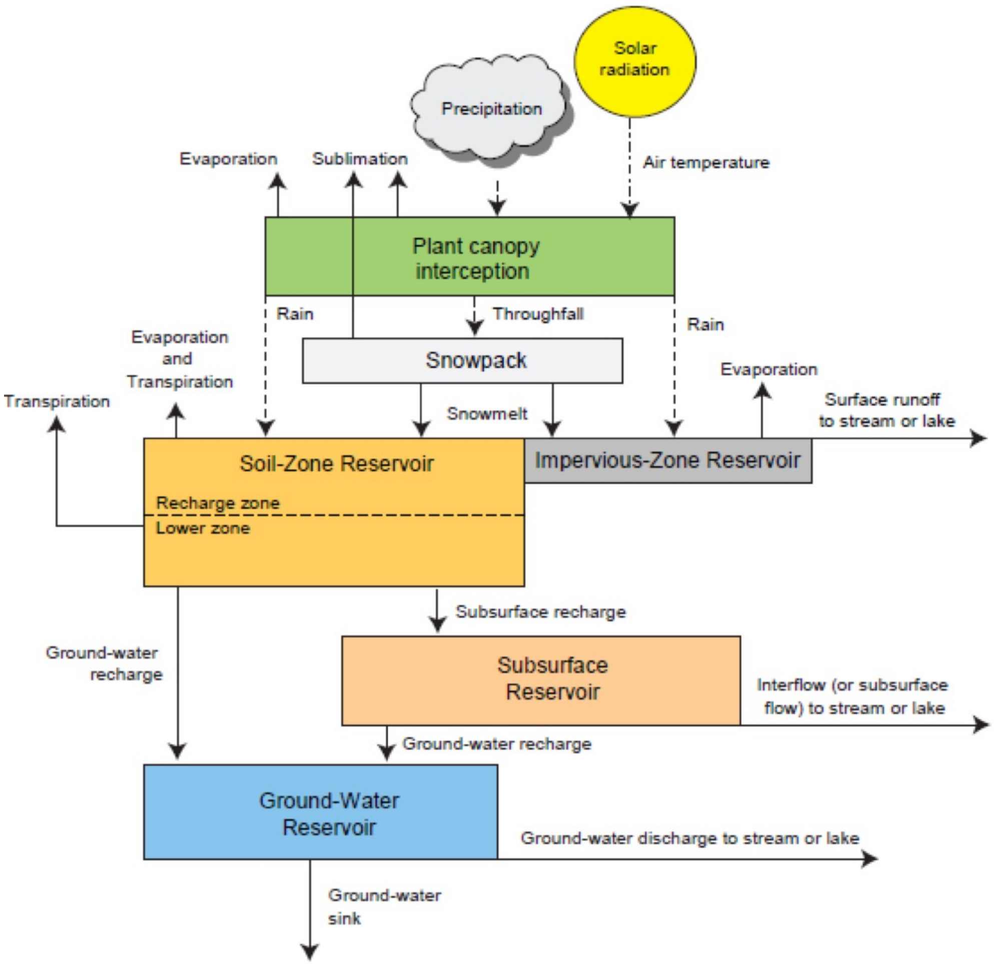
- Where is it?
- How large is the area of interest?
- What is the impact of interest?
- When in the future?
- Does the sequencing of weather events matter?
- What type of climate change uncertainty is important?
- What is available?

Source: J. Vano, Dos and Don'ts

Classic "Top-down" Impacts Modeling Chain



Why We Need Hydrology Models



We have: precipitation, temperature, other atmospheric values

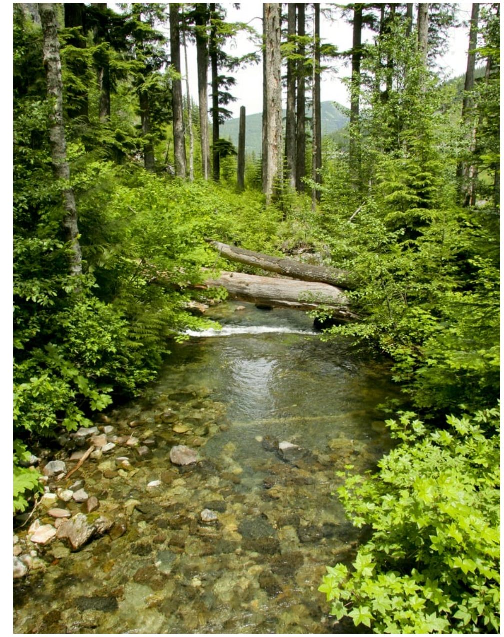
We want: streamflow (highs, lows), water demand from vegetation, water temperature

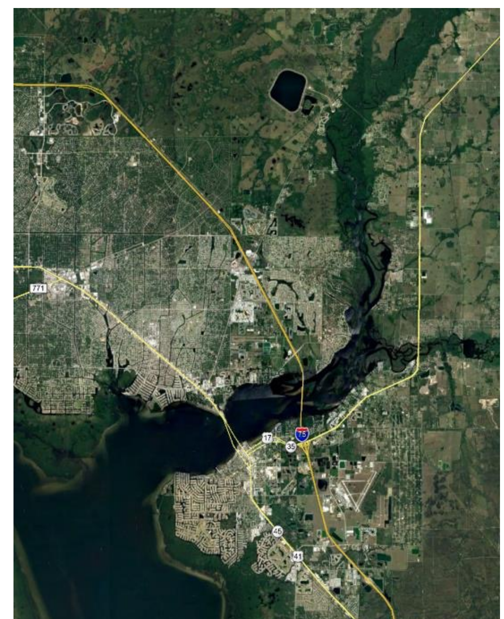
Hydrology models represent energy and water fluxes in watersheds, encapsulate our best understanding

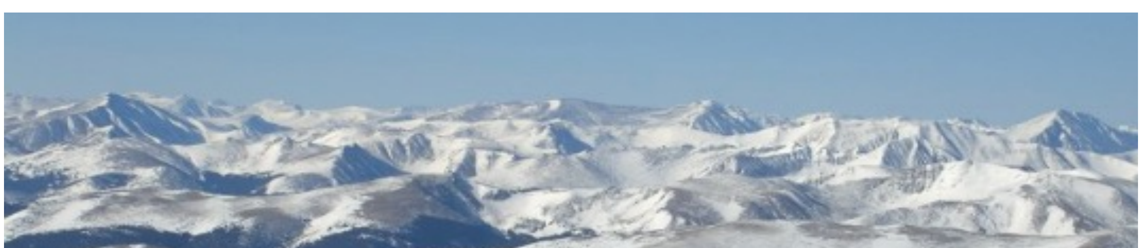
Fill gaps since measurements unavailable in most places

Modeling Cautions

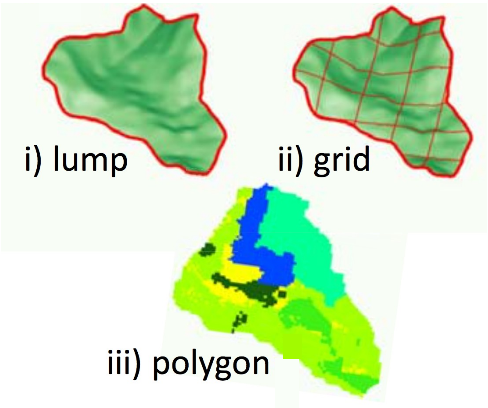
- Models built to represent many landscapes, processes, spatial configurations+
- May miss key elements
  - Groundwater interactions
  - Salt-water intrusion
- Important to be a savvy user





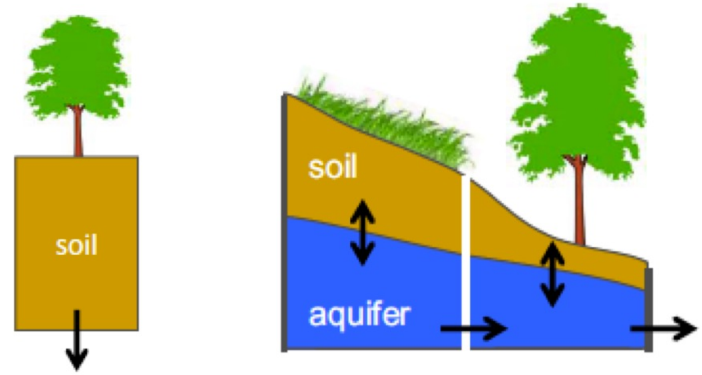


Model Spatial Structures



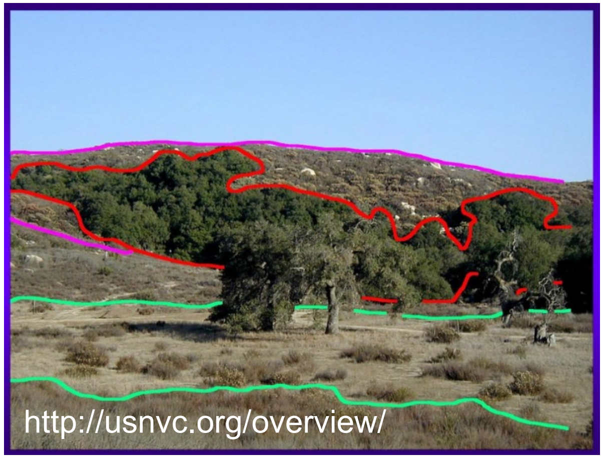
Lumped, gridded or hydrologically similar areas

Figures from Clark et al., WRR, 2015

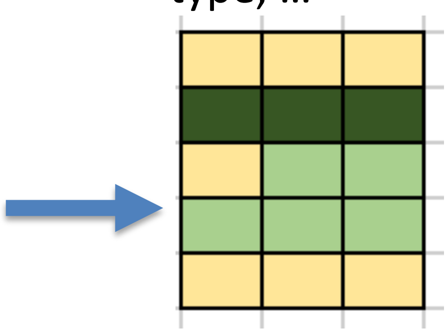


Connections between soil and aquifer

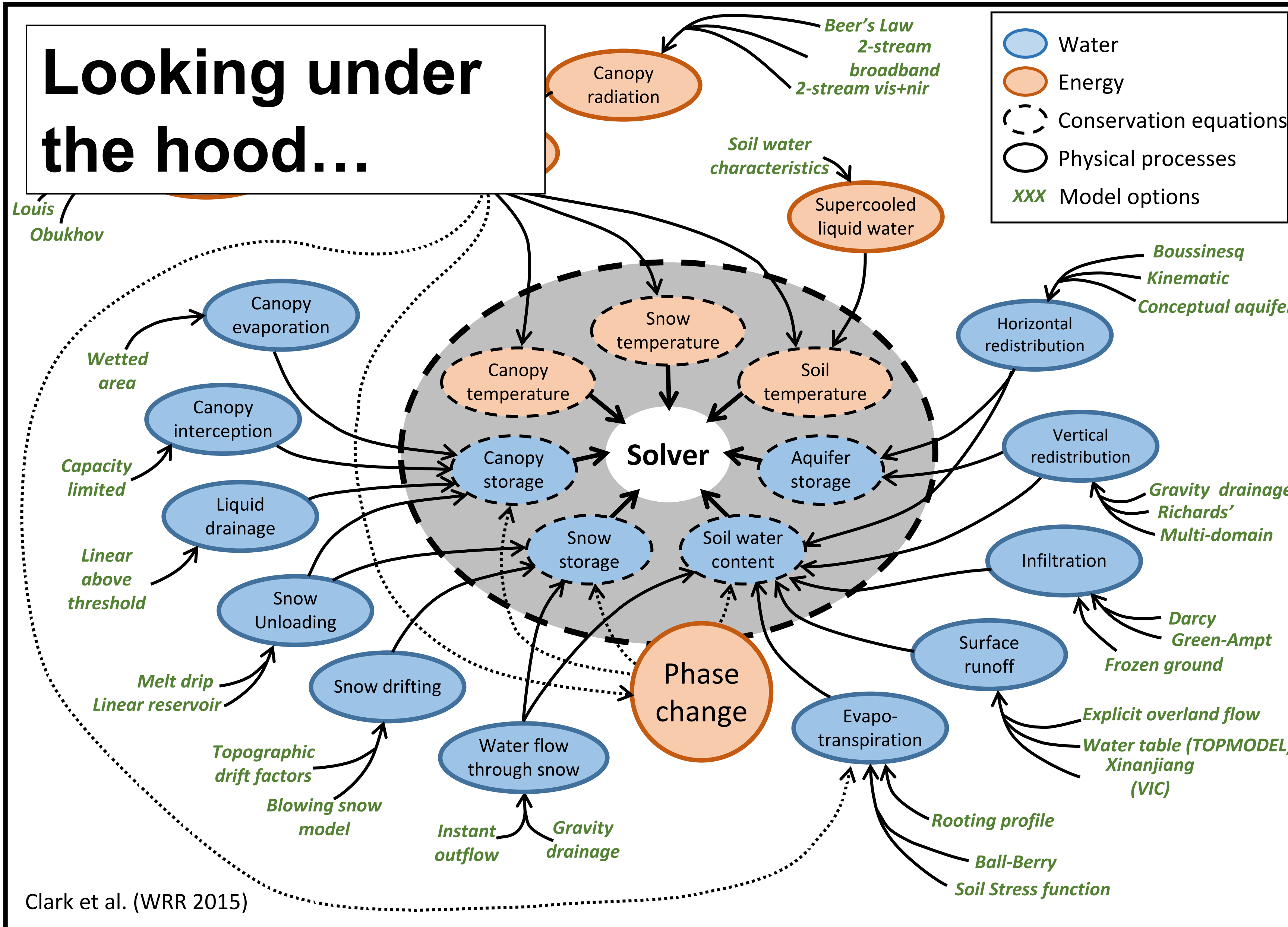
Model Parameters



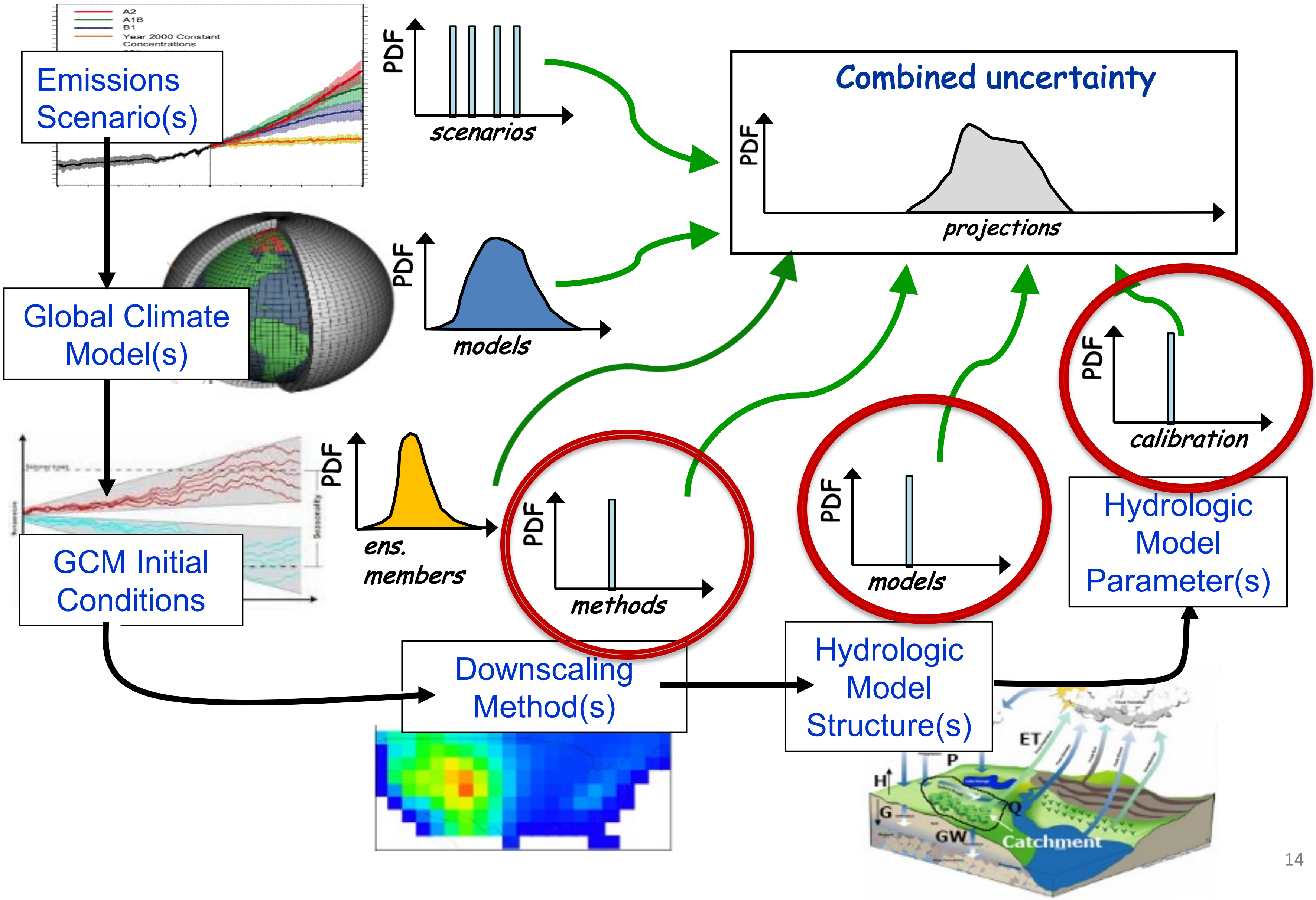
Vegetation, Soil type, …



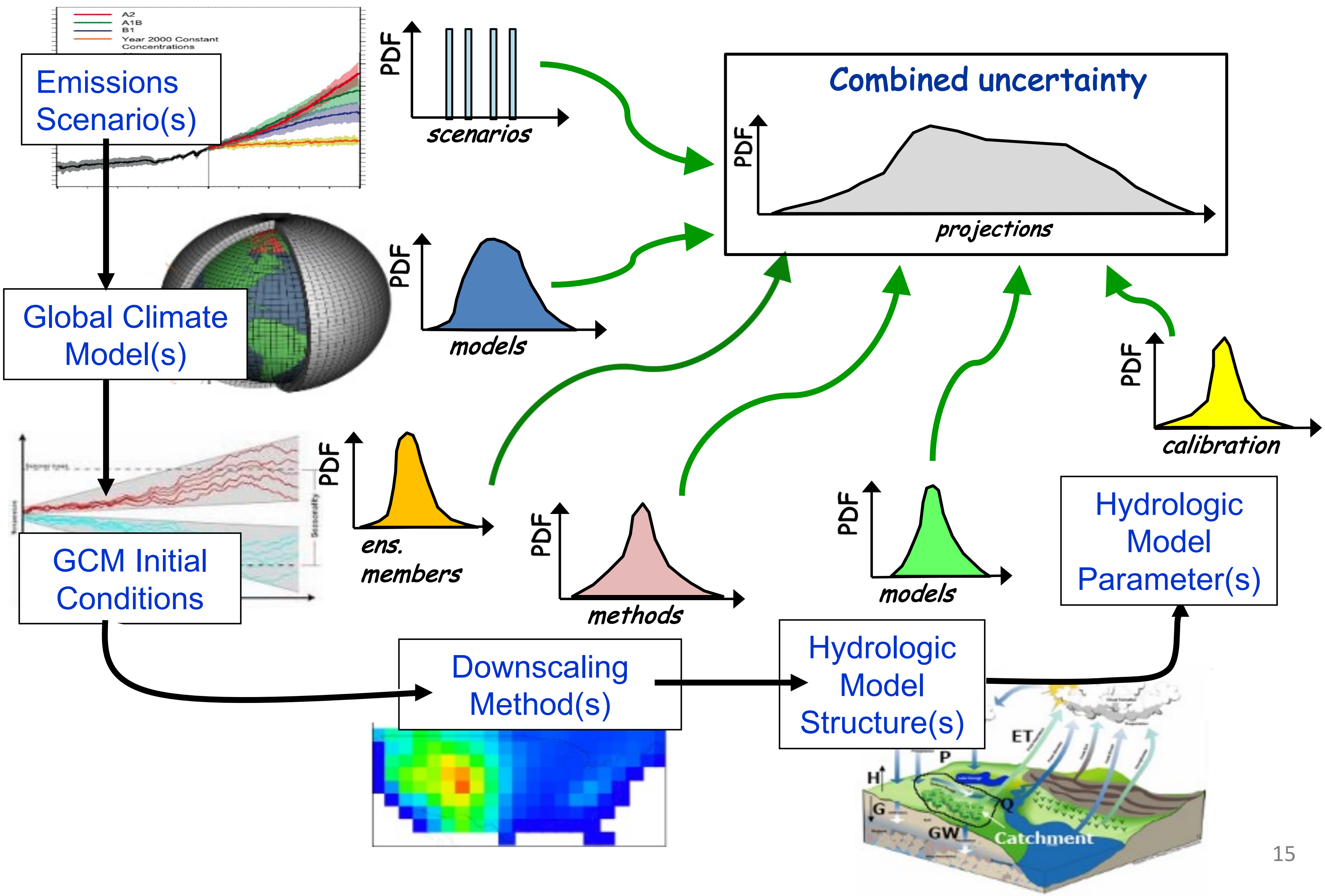
Hydrologic Model Processes



Revealing Uncertainties



Revealing Uncertainties



Real-world context…

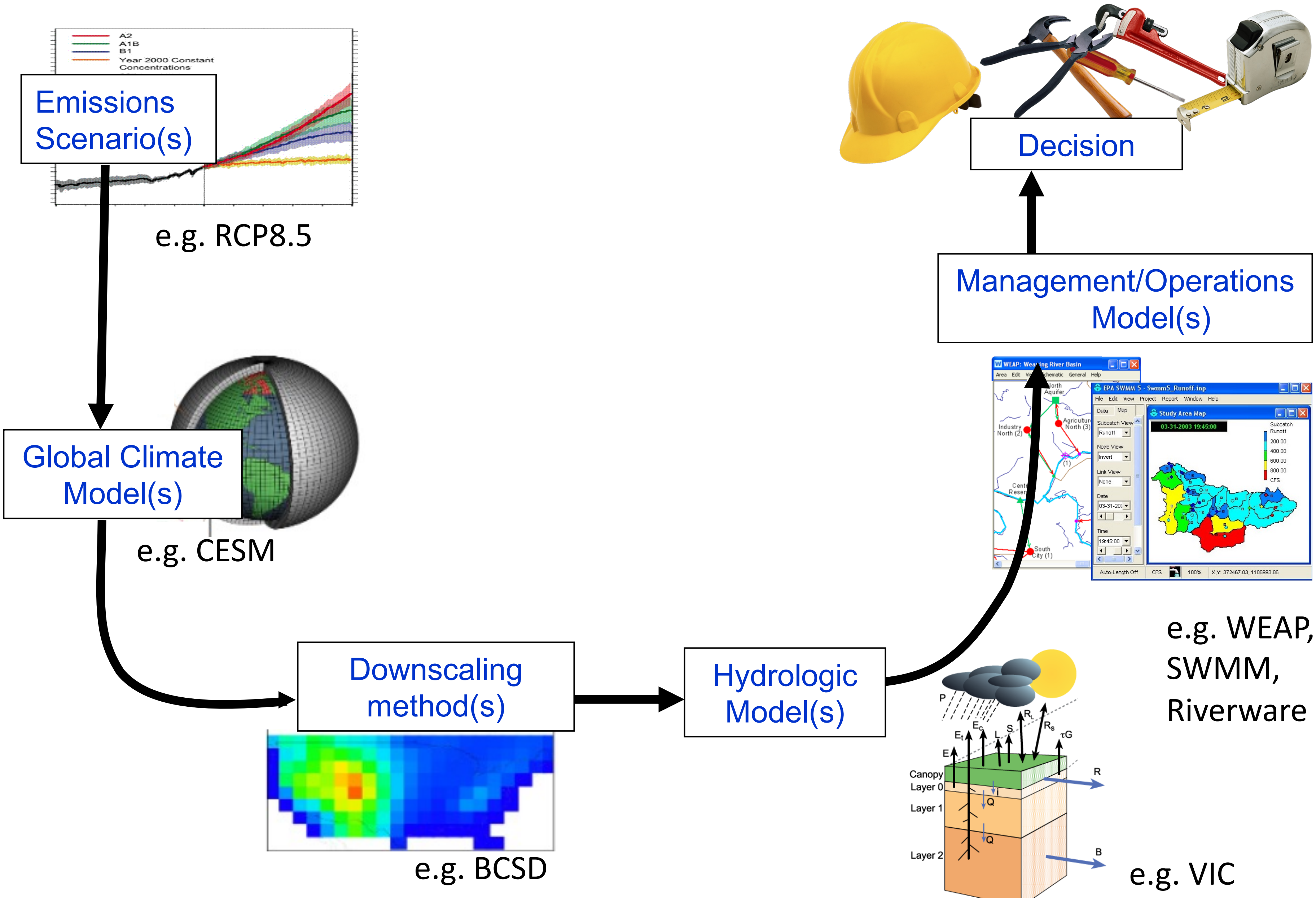
BUREAU OF RECLAMATION

Downscaling Approaches & Hydrologies developed for the Colorado River Simulation System

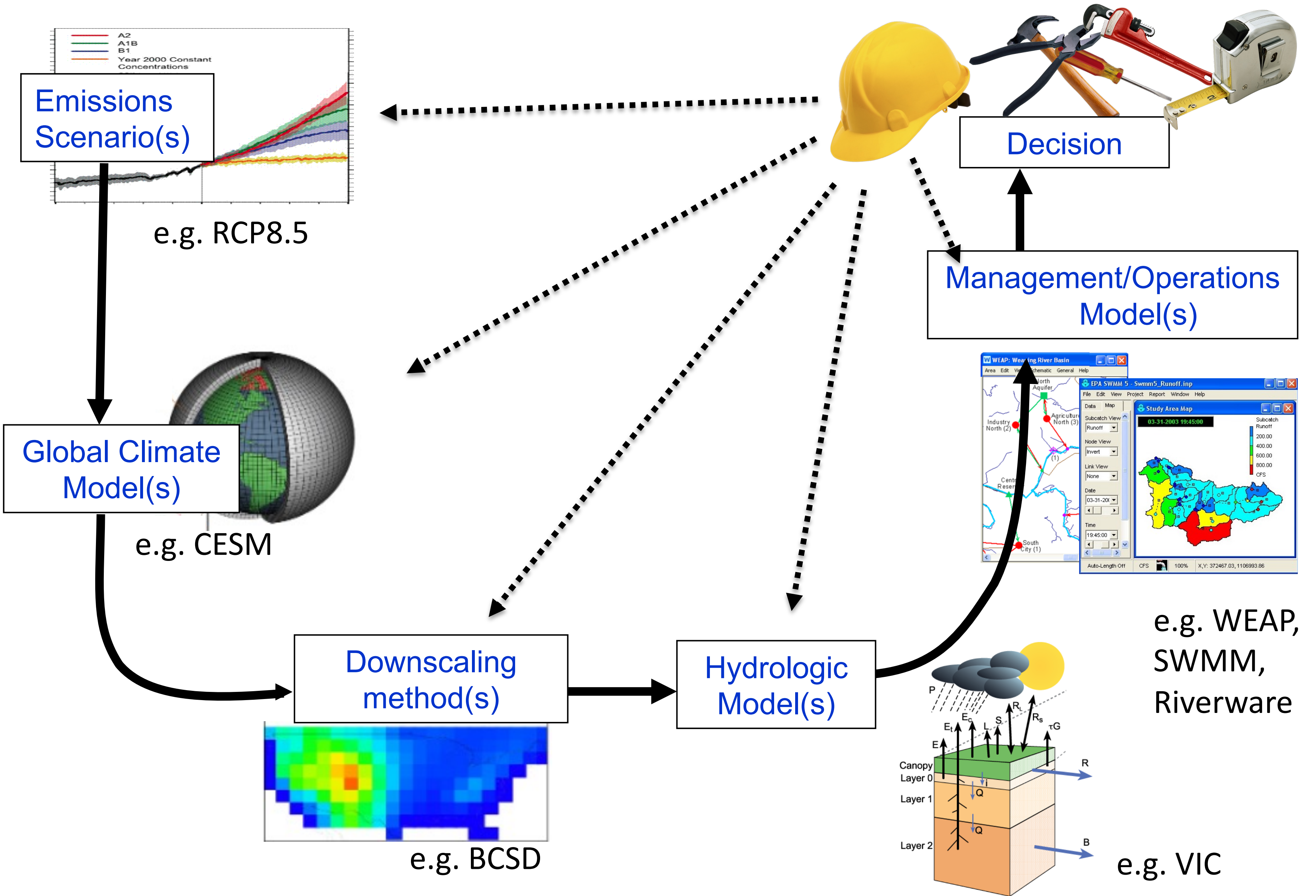
Water Utility Climate Alliance
July 20, 2022

James Prairie, PhD, Modeling and Research Group Chief, Upper Colorado Basin Region

Classic "Top-down" Impacts Modeling Chain



Revised "Top-down" Impacts Modeling Chain



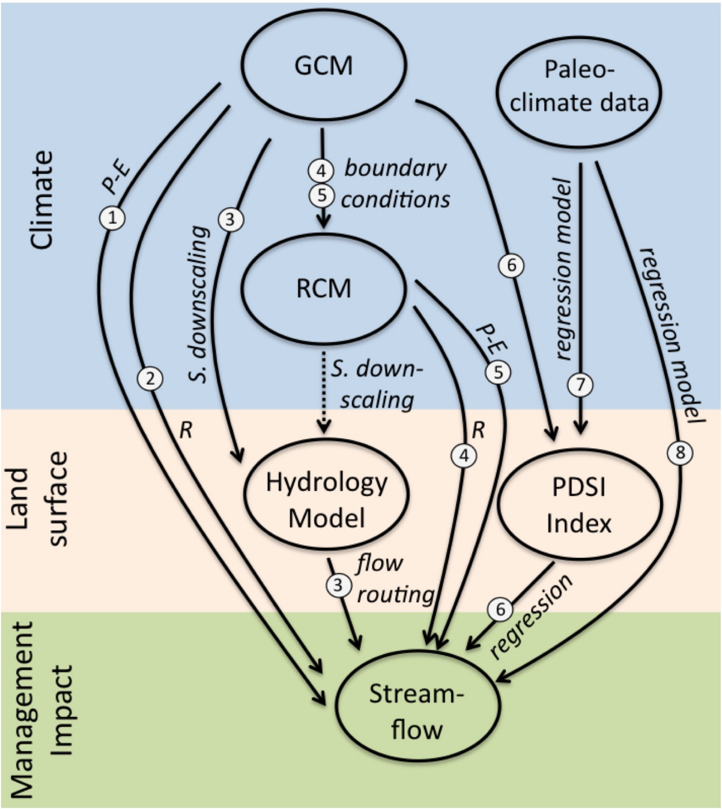
Events We Care About

- Intensifying Heat Waves
- Diminished Snowpack
- Long-Duration Drying (Sustained Declines in Runoff Efficiency)
- Extensive Wildfire
- Short-duration intense wet and dry system shocks
- Amplified Wet and Dry Swings
- Decline in Monsoons

Colorado River Conversations Conference, October 2019

McCoy et al. JAWRA 2022, Read paper here: https://onlinelibrary.wiley.com/doi/epdf/10.1111/1752-1688.13021
photo from: https://ccass.arizona.edu/colorado-river-conversations-program

<u>DON'T</u> treat all future projections or methods equally



Different: GCMs, emission scenarios, spatial resolution, hydrology, +

- Certain models and methods are more appropriate
- Certain spatial and temporal scales are more appropriate for certain questions
- Realize some questions may not be possible to answer with current knowledge
- Finer resolution in space and time is not necessarily better
  - Higher Resolution ≠ Higher Accuracy
  - Most models do better on averages than on extremes

Be a savvy consumer and remember

Figure from Vano et al., BAMS, January 2014

No Model is Perfect

“The accuracy of streamflow simulations in natural catchments will always be limited by simplified model representations of the real world as well as the availability and quality of hydrologic measurements.” (Clark et al., WRR, 2008)

- **Don’t expect perfect results,**
  - Not prediction, but a tool to test how system responds (what if scenarios)
- **BUT we can make better choices…**
  - Seek simple yet defensible models (don’t need a Cadillac)
  - Be aware of model shortcomings

DON'T wait until new information is available, there will always be new research and models coming soon

- Research will continue to evolve (sustained assessment)
- Often the biggest challenge is the first time through
- Automate when possible

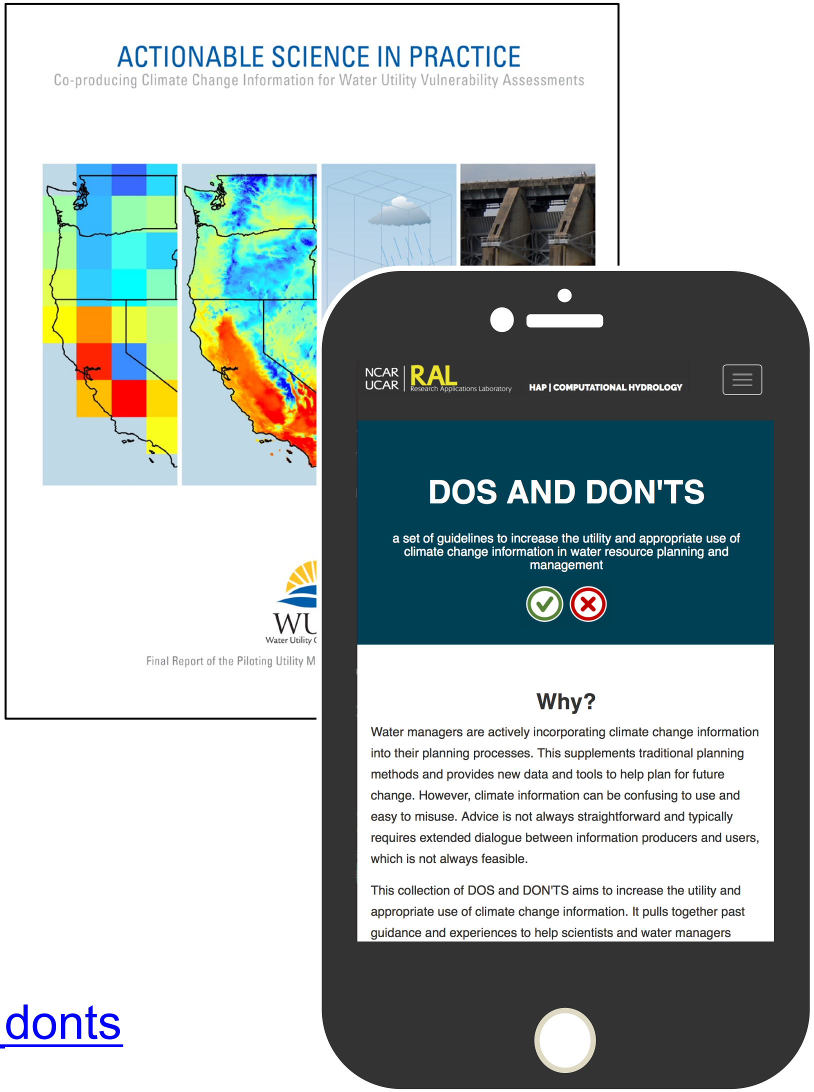
Common challenges the first time through:

- learning where and how to download the data
- using unfamiliar data formats (e.g., NetCDF)
- slicing data for a particular region or time period
- converting from one data format to another
- automating the process
- running new extremes through a reservoir model
- defining evaluation criteria
- displaying results in meaningful ways

Image from http://www.activatedesign.co.nz

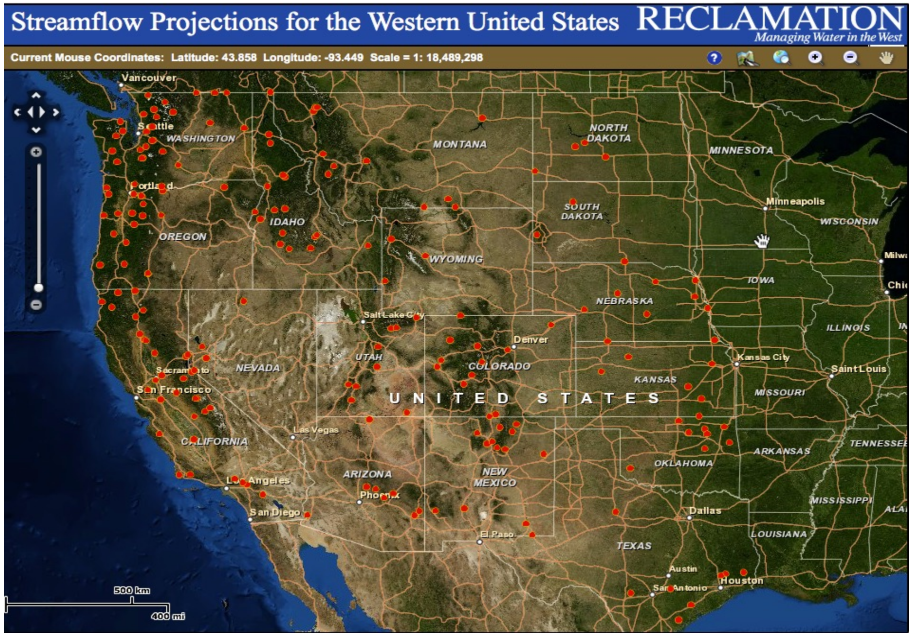
Available Resources

- WUCA products
  - PUMA project examples
  - Leading Practices & other case studies
  - www.wucaonline.org
- Federal Agency Guidance
  - Bureau of Reclamation
  - U.S. Army Corps of Engineers
  - Environmental Protection Agency
  - U.S. Climate Resilience Toolkit
- Professional Societies
  - American Society of Civil Engineers
- Dos and Don’ts Guidelines
  - Reviews other guidance
  - https://global-change.github.io/dos_and_donts
- Many others, including each other

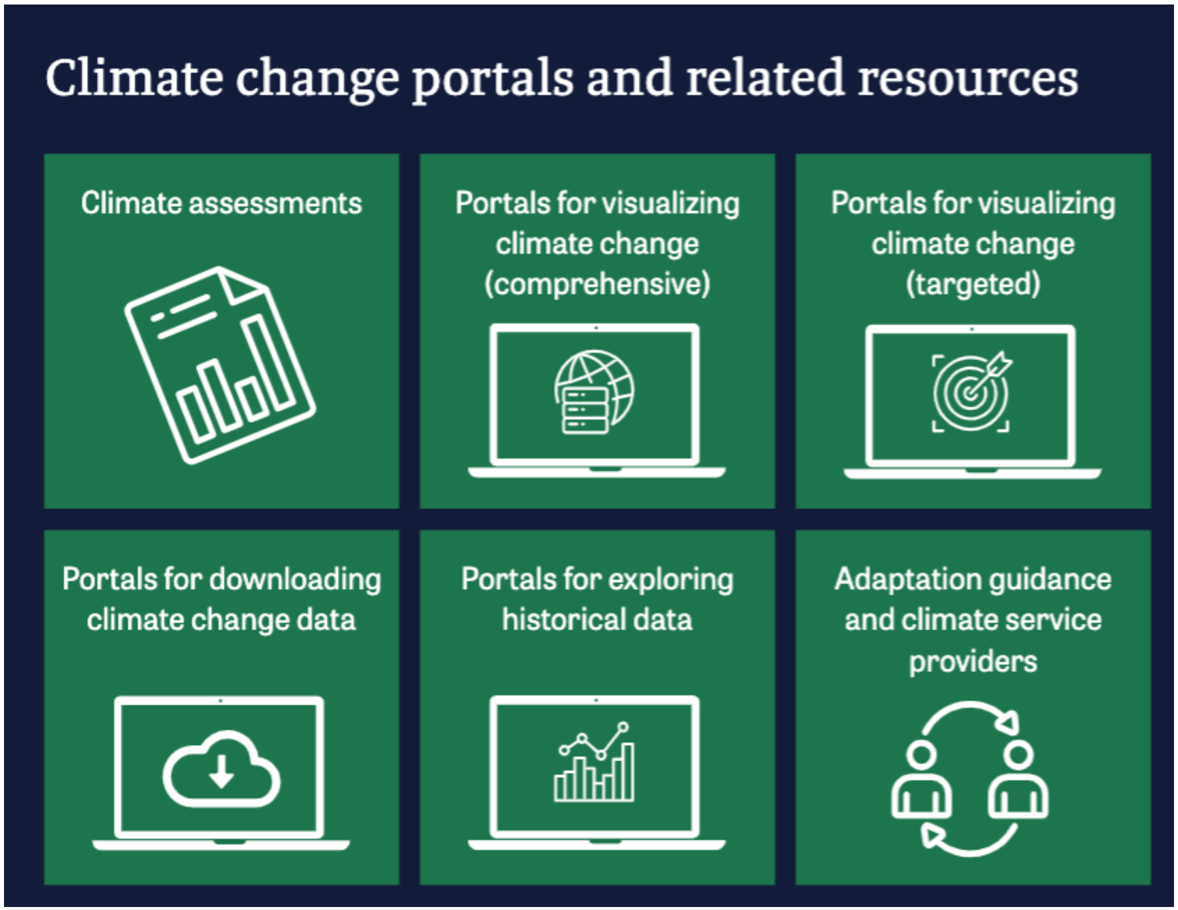


Available Data

- Hydrology on Green Data Oasis portal
  - BCSD (12km), LOCA (6km)
  - VIC streamflow
- MACA Download Tool
- Dynamical
  - NARCCAP (50km),
  - CORDEX (limited 25km)
  - Others over regional domains or limited time periods
- Many others (NASA NEX, ARRM…)



New Guide to Available Resources



A User Guide to Climate Change Portals

and other resources that support planning and adaptation in the Mountain West

Places to go for climate change information

To match the need for climate change information (left) with the type of resources (right; Boxes 1–4).
All resources named in the numbered boxes are described in the guide, available online at: <web link>

What climate change information do you need?

Here's where to find it:

Summary statements about projected future climate changes for your state or multi-state region

Static maps and charts for projected climate changes for your state or multi-state region

1. CLIMATE ASSESSMENTS

- U.S. National Climate Assessment (NCA4)
  - SW, NW, N Great Plains Chapters
  - **State** Summaries (few graphics)
- Climate Change in **New Mexico**
- **Greater Yellowstone** Climate Assessment
- Fifth **Oregon** Climate Assessment
- **California**'s Fourth Climate Change Assessment
- **Montana** Climate Assessment
- Climate Change in **Colorado**
- Climate Change Impacts and Adaptations in **Washington State**

Interactive maps, charts, and analysis: Projected climate changes for many variables, for a specific location, county, state, or watershed, anywhere in the contiguous U.S.

2. DATA VISUALIZING PORTALS (COMPREHENSIVE)

- Climate Explorer (T + P only)
- Climate Toolbox
- National Climate Change Viewer

Need additional variables, datasets, visualizations?

Interactive maps, charts, and analysis: Projected climate changes for a region, state, watershed, fewer options in each portal than the 3 above

3. DATA VISUALIZING PORTALS (TARGETED)

- Climate Impact Map
- NOAA Climate Change Web Portals
- IPCC AR6 Interactive Atlas
- CONUS Climate Console
- Pacific Northwest Climate Projection Tool
- AdaptWest Watershed Climate Data Explorer
- KNMI Climate Change Atlas
- Cal-Adapt Climate Tools
- EPA CREAT

Climate change projection data to allow you to conduct your own analyses, and generate maps and charts not available elsewhere

4. DATA DOWNLOADING PORTALS

- GDO-DCHP
- MACA Download Tools

Easier to use / Fewer choices / More context for data

Harder to use / More choices / Less context for data

Public release in August 2022

If interested in a sneak peak, contact jvano@agci.org

Colorado River Science Wiki

- www.coloradoriverscience.org
- Clearinghouse for scientific and technical information relevant to the Colorado River Basin
- Pages specific to climate change, hydrology, and more
- Opportunity to add and/or request information be added
- **Work in progress!** Some content not yet live. “Add this!” seeks additional info and feedback on priorities. Public release this fall.

JAWRA Featured Collection

On Severe Sustained Drought in the Colorado River Basin

Lots of articles already available, and more coming soon…

Commentary Open Access

Decision Science Can Help Address the Challenges of Long-Term Planning in the Colorado River Basin

Rebecca Smith, Edith Zagona, Joseph Kasprzyk, Nathan Bonham, Elliot Alexander, Alan Butler, James Prairie, Carly Jerla

Research Article Open Access

The Press and Pulse of Climate Change: Extreme Events in the Colorado River Basin

Amy L. McCoy, Katharine L. Jacobs, Julie A. Vano, J. Keaton Wilson, Season Martin, Angeline G. Pendergrass, Rob Cifelli

Research Article

The Three Colorado Rivers: Hydrologic, Infrastructural, and Economic Flows of Water in a Shared River Basin

Richard R. Rushforth, Nicolas P. Zegre, Benjamin L. Ruddell

Research Article

Tree-Ring Perspectives on the Colorado River: Looking Back and Moving Forward

David M. Meko, Connie A. Woodhouse, Anabel G. Winitsky

Research Article

Colorado Basin Incentive-Based Urban Water Policies: Review and Evaluation

Bonnie G. Colby, Hannah Hansen

Research Article

Colorado River Water Use and Climate: Model and Application

James F. Booker

Research Article Open Access

The Colorado River Basin Operational Prediction Testbed: A Framework for Evaluating Streamflow Forecasts and Reservoir Operations

Sarah A. Baker, Andy W. Wood, Balaji Rajagopalan, James Prairie, Carly Jerla, Edith Zagona, Robert A. Butler, Rebecca Smith

Open Access

Impacts and Opportunities at the Climate–Land Use–Energy–Water Interface: An Urgent Call for Dialogue

Kathy Jacobs, Jim Holway, Ellen Hanak, Ray Quay, Faith Sternlieb, Brad Udall

Key Takeaways

- Models can be used in a variety of ways to think about the future.
- Downscaling and hydrology modeling provide local-scale insights of global-scale information.
- Downscaling exist on a continuum of tradeoffs between computational efficiency and method complexity.
- Model uncertainty is unavoidable and important to acknowledge.

Key Takeaways

- It is critical to understand important processes and uncertainties in **your** system.
- Models are tools that can be useful, if used appropriately. **Be a savvy consumer.**
- Lots of resources available. Consult local experts and national resources.

Poll #4

Do you view downscaling techniques as applicable and valuable to your organization's long-range planning?