A Framework for Analysis of Energy Water Interdependency Problems

Development of an Object-Oriented System Dynamics Hydrology Simulator

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Image courtesy of U.S. Bureau of Reclamation

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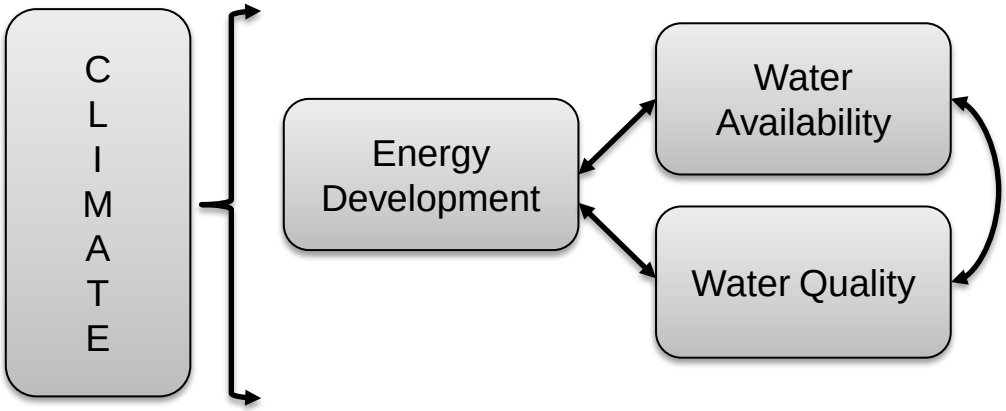
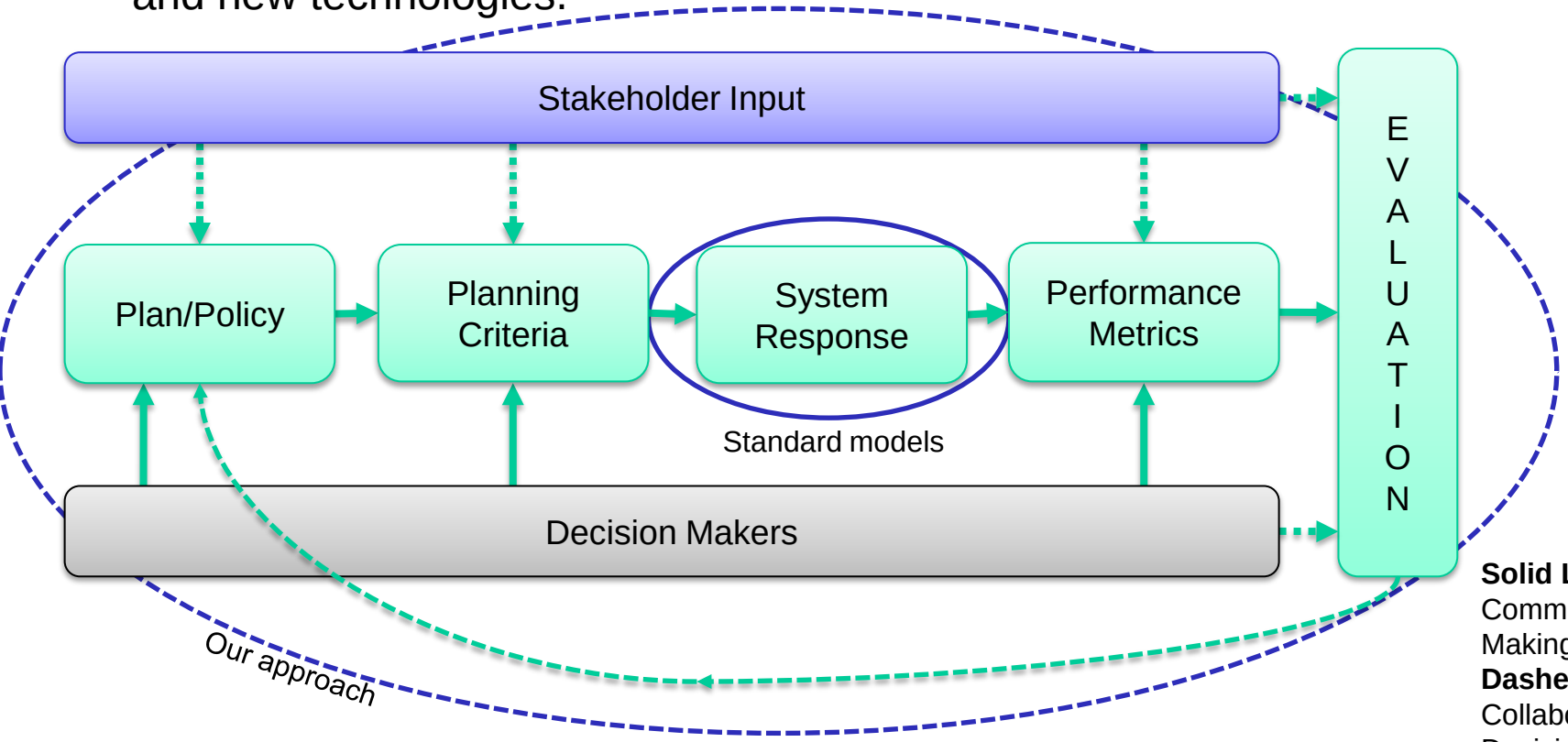
Problems that drive our research:



- How much water is being withdrawn and/or consumed for which purposes?
- How does this compare with the amount and timing of readily available, clean water in these basins?
- How can water users work together to plan the development of energy and water resource systems with their collective interests in mind?

Goals of the current project:

- Enable holistic thinking for energy and water system planning with the inclusion of basin-scale water resource feedbacks.
- Simulate multiple intersecting scenarios that highlight the interdependency of energy and water in a basin, then simulate solutions such as policy changes and new technologies.



Solid Lines: Common Decision Making
Dashed Lines: Collaborative Decision Making

Policy Inputs

- FERC relicensing constraints
- Aquifer management plans
- TMDLs
- Renewable portfolio standards
- Pollutant trading

Climate Inputs

20 years of monthly inputs for precipitation and temperature

Informed by Global Climate Models (GCM's)

WEST

Water and Energy Scenarios Testing

Computer-aided simulation for improved stakeholder understanding and involvement

20 year simulations with monthly results

Highlights change in electricity generation due to change in water availability and consumption

A game-like environment where user input is encouraged during runtime

Electric Power Inputs

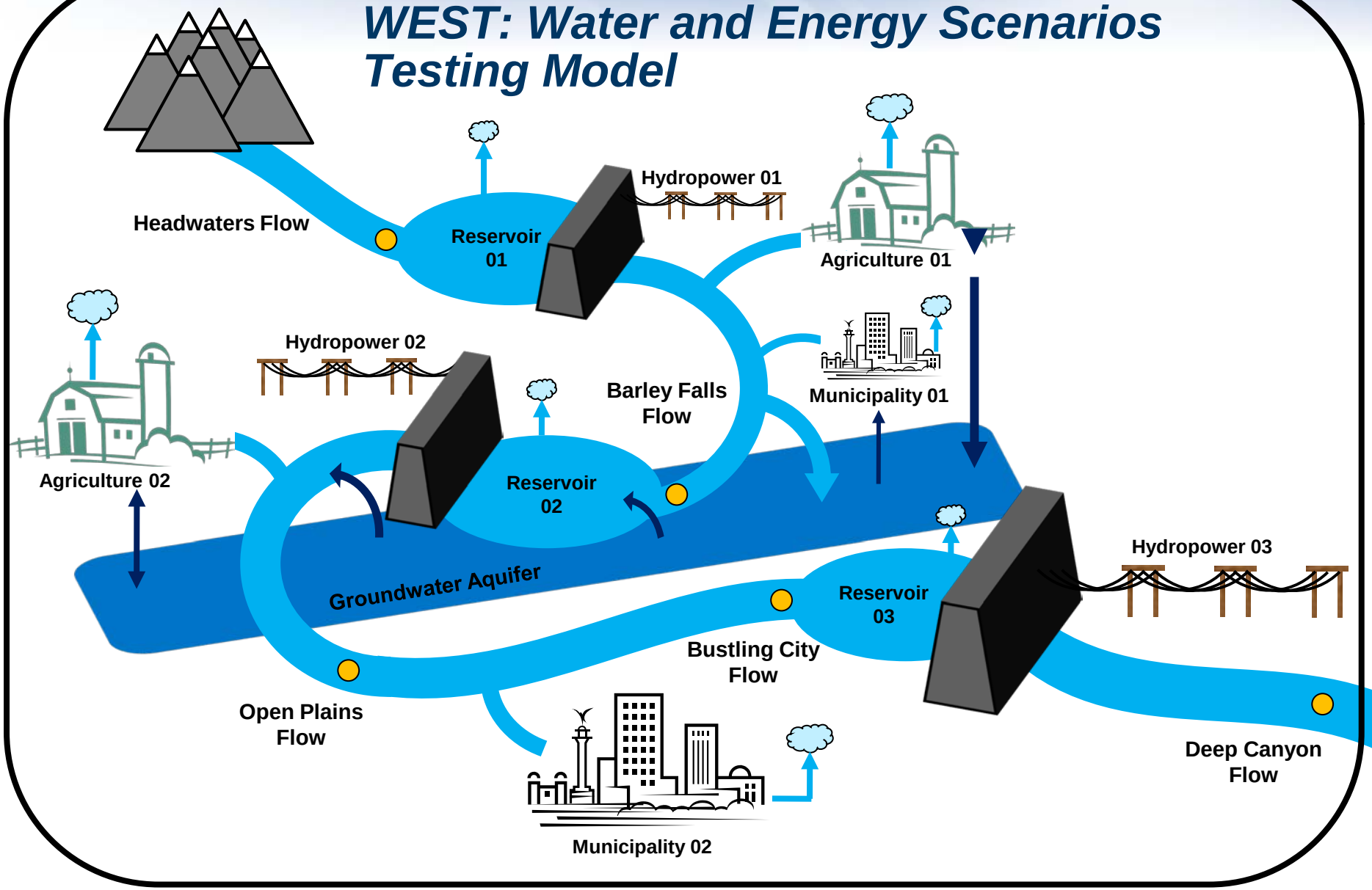
20 years of monthly inputs for generation dispatch, wholesale prices, and agricultural retail rates

ITERATION: Informed by daily and monthly patterns in hydro generation, and trends in electricity demand within WEST

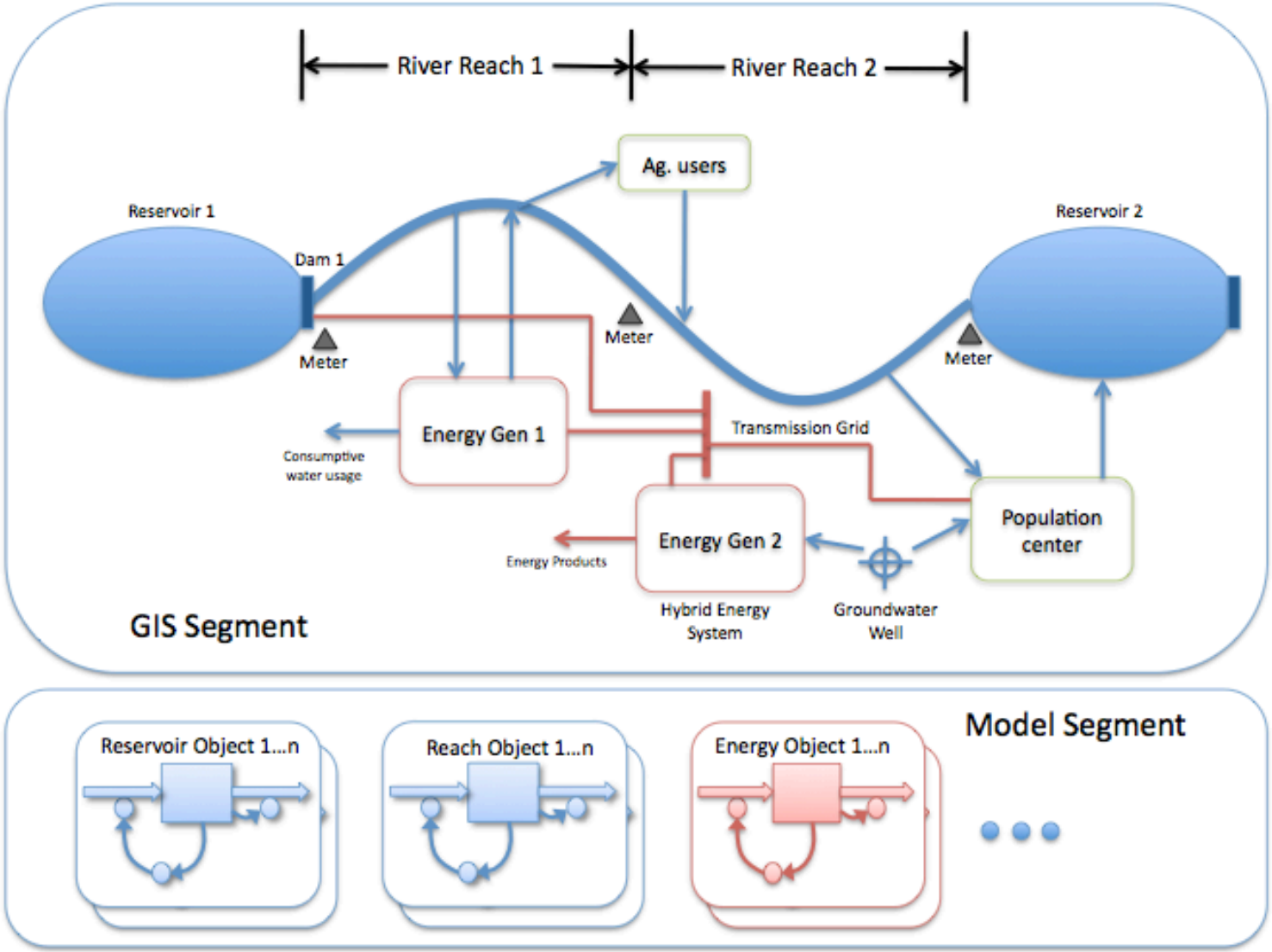
Water Demand Inputs

- Agricultural demand
- Municipal demand
- Industrial demand

WEST: Water and Energy Scenarios Testing Model



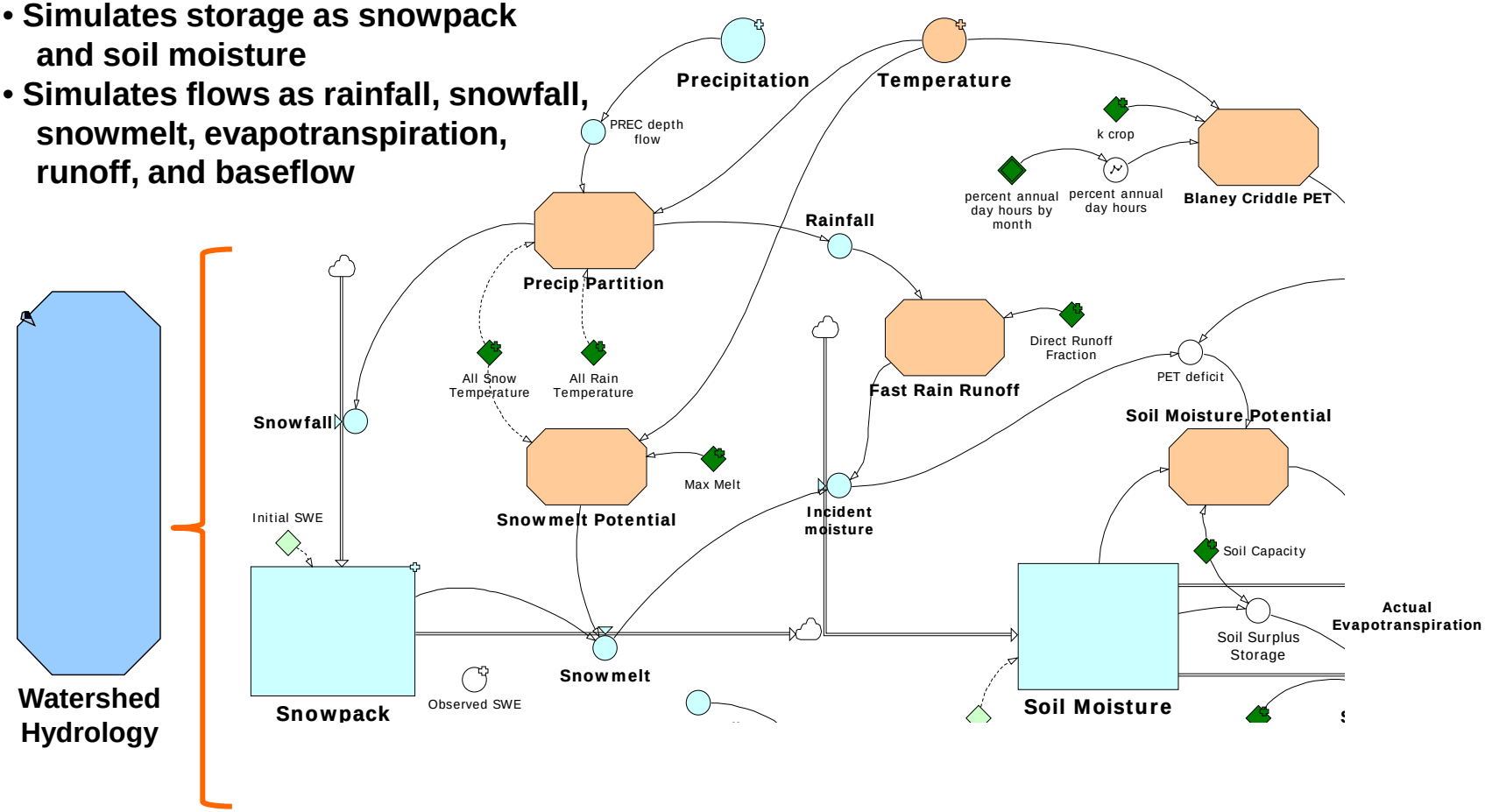
Modeling Concept



Surface water modeling

Watershed Model Object

- Simulates the natural contribution to streamflow in a watershed
- Simulates storage as snowpack and soil moisture
- Simulates flows as rainfall, snowfall, snowmelt, evapotranspiration, runoff, and baseflow

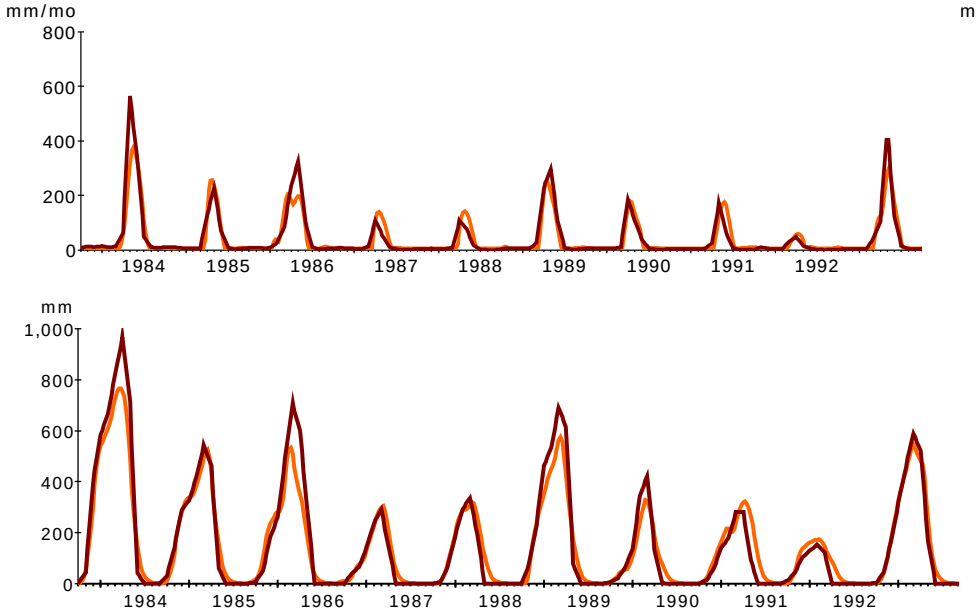


Surface water modeling (Cont)

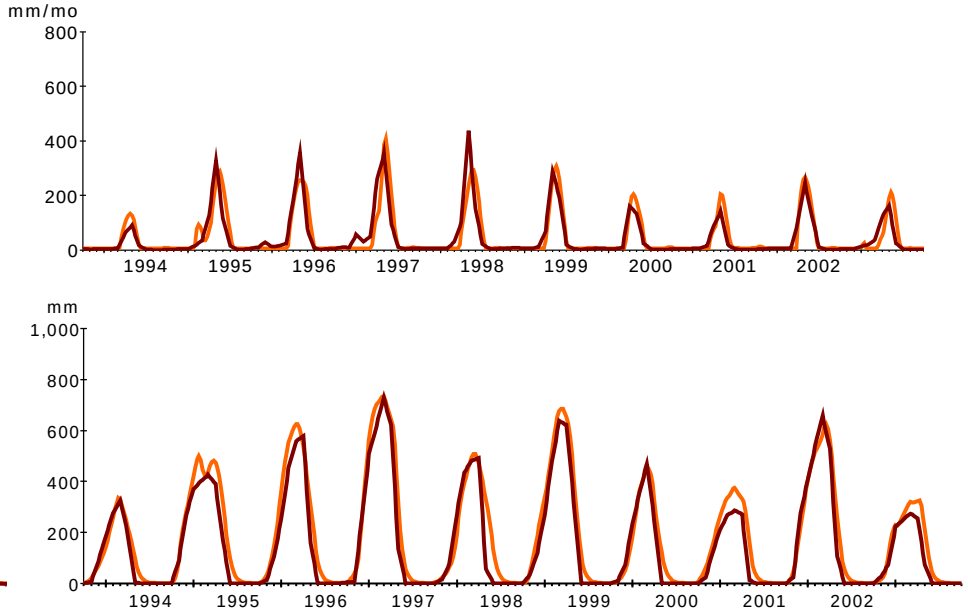
Watershed Model Object

- Validated in Upper Snake and Reynolds Creek watersheds
- 10-year calibration period, followed by 10-year validation period
- Reflects multiple watershed types
- Input is monthly precipitation and temperature
- Output is surface runoff to stream

Calibration period



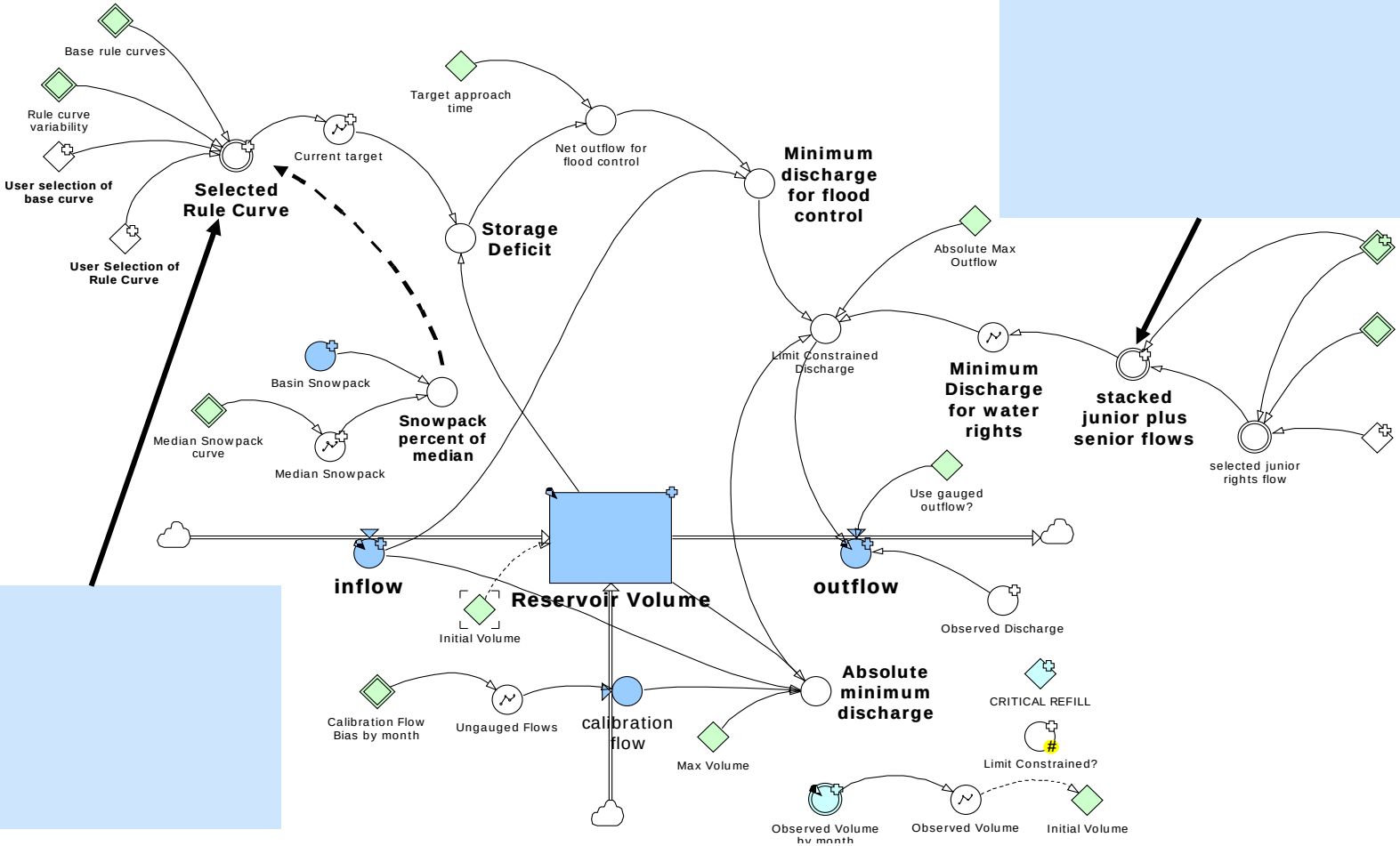
Validation Period



Reservoir modeling

Reservoir Model Object

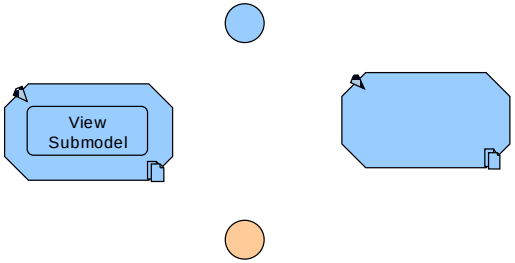
- Uses a system of rule curves to set target storage and/or target discharge
- Coupled with watershed object to show the effect of climate change on balancing flood control and agricultural demand



Scenario Test: Climate Variation

Coupled Watershed Object + Reservoir Object

- Shows the effect of climate change on balancing flood control and agricultural demand for a single year
- Introduces policy of an adaptive rule curve



Climate Controls

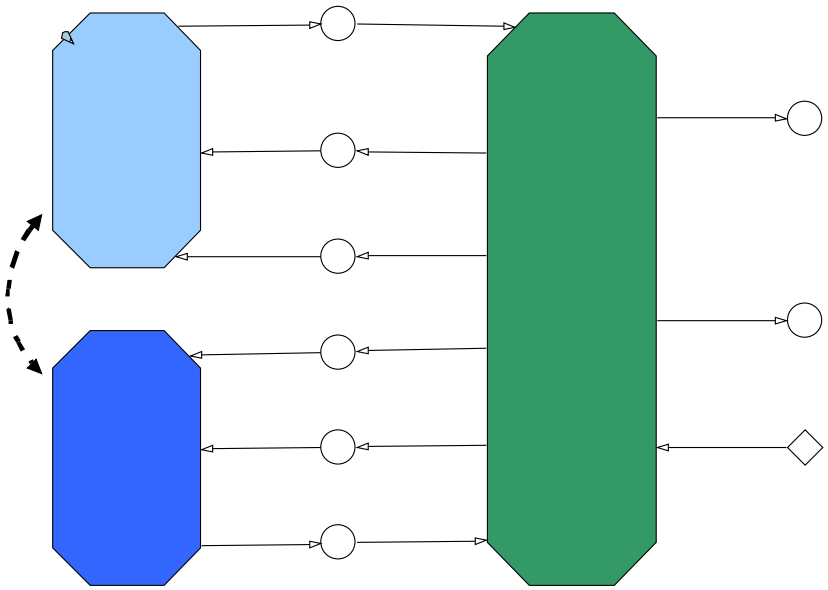
Storage: climate normal

Storage: warmer, drier

Warmer, drier, earlier refill target

Current tasks and future direction

- Refine the behavior of irrigated agriculture, aggregated by watershed
- Refine and validate the groundwater storage object
- Incorporate rules for dams operated primarily for power generation
- Explore the energy and water use of municipalities and industry
- Explore the limits and costs of hydropower for wind power “shaping services”



Takeaways

Just the right science, and scientists

At just the right complexity

For an immersive, collaborative environment

To engage stakeholders and decision-makers

In cross-sector energy and water system planning

Thanks to the audience for your attention

Collaboration partners:

Washington State University, University of Idaho,
Idaho State University, Utah State University,
Sandia National Laboratory

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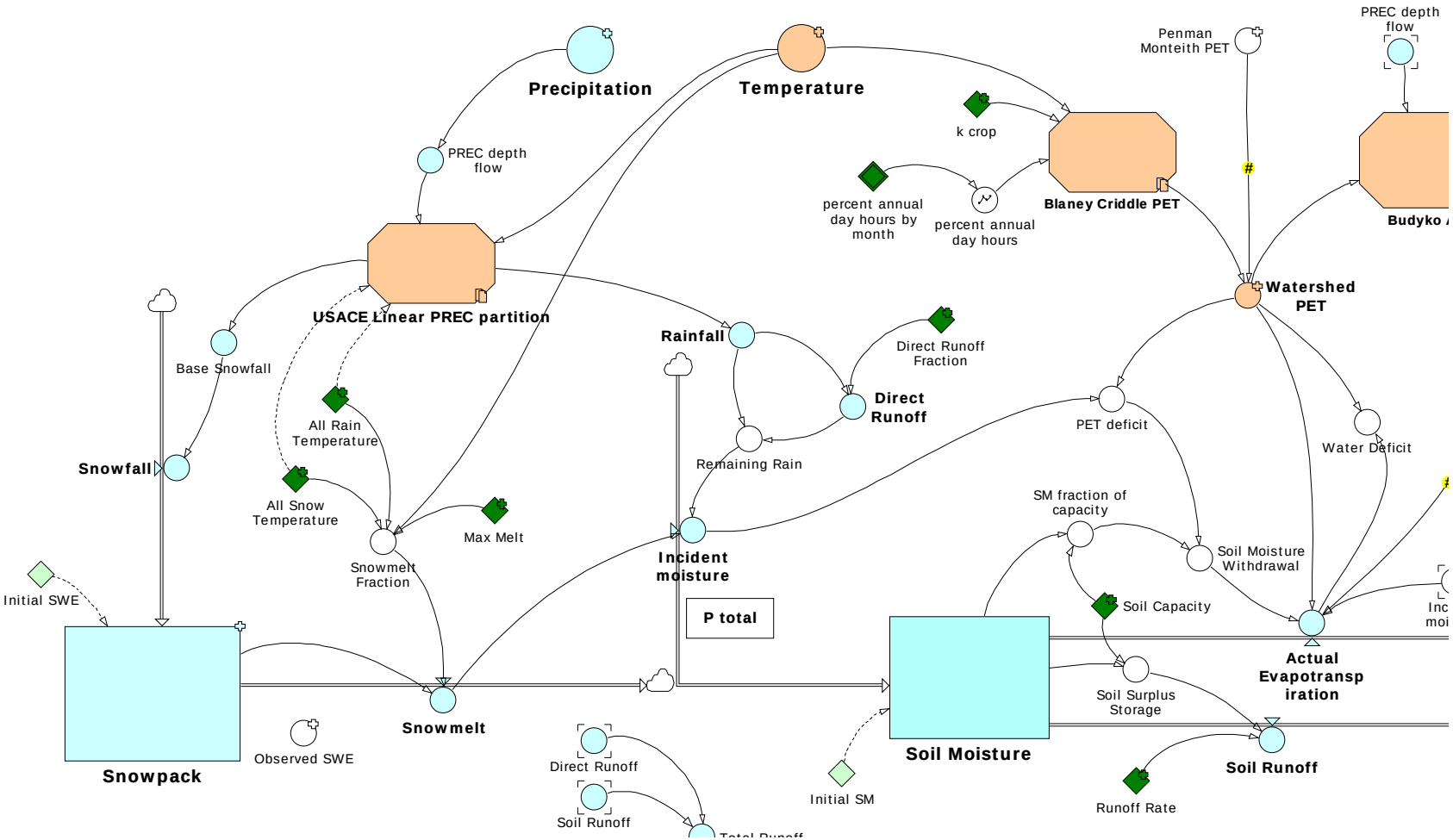
EXTRA SLIDES


Precipitation
Temperature
PREC depth flow
k crop
Penman Monteith PET
PREC depth flow
percent annual day hours by month
percent annual day hours
Blaney Criddle PET
Budyko
Watershed PET
USACE Linear PREC partition
Base Snowfall
Rainfall
Direct Runoff Fraction
Direct Runoff
All Rain Temperature
Remaining Rain
PET deficit
Water Deficit
Snowfall
All Snow Temperature
Max Melt
Snowmelt Fraction
Incident moisture
SM fraction of capacity
Soil Moisture Withdrawal
Initial SWE
P total
Soil Capacity
Actual Evapotranspiration
Soil Surplus Storage
Snowmelt
Observed SWE
Snowpack
Direct Runoff
Soil Runoff
Soil Moisture
Initial SM
Soil Runoff
Runoff Rate