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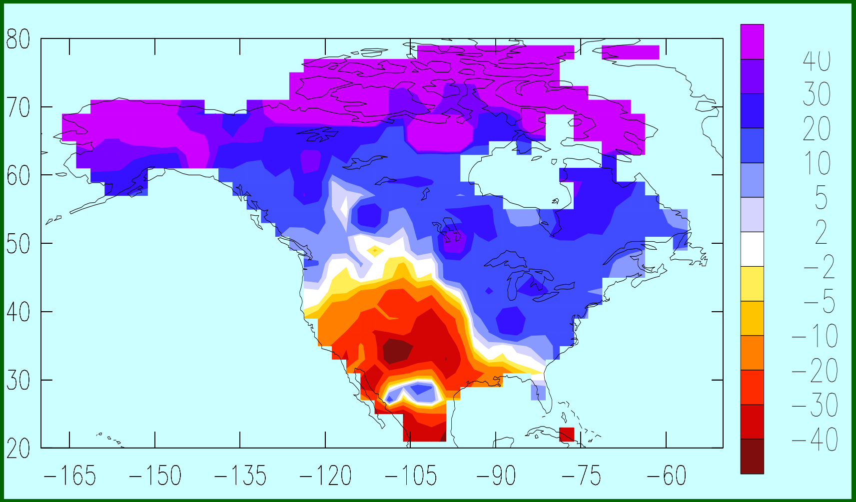
science for a changing world

Water planning and climate change: actionable intelligence yet?

Christopher Milly, USGS



U.S. Department of the Interior
U.S. Geological Survey

What is "Actionable Intelligence"?

- Information about water in a changing climate that provides the basis for an adaptation that reduces net adverse impacts.

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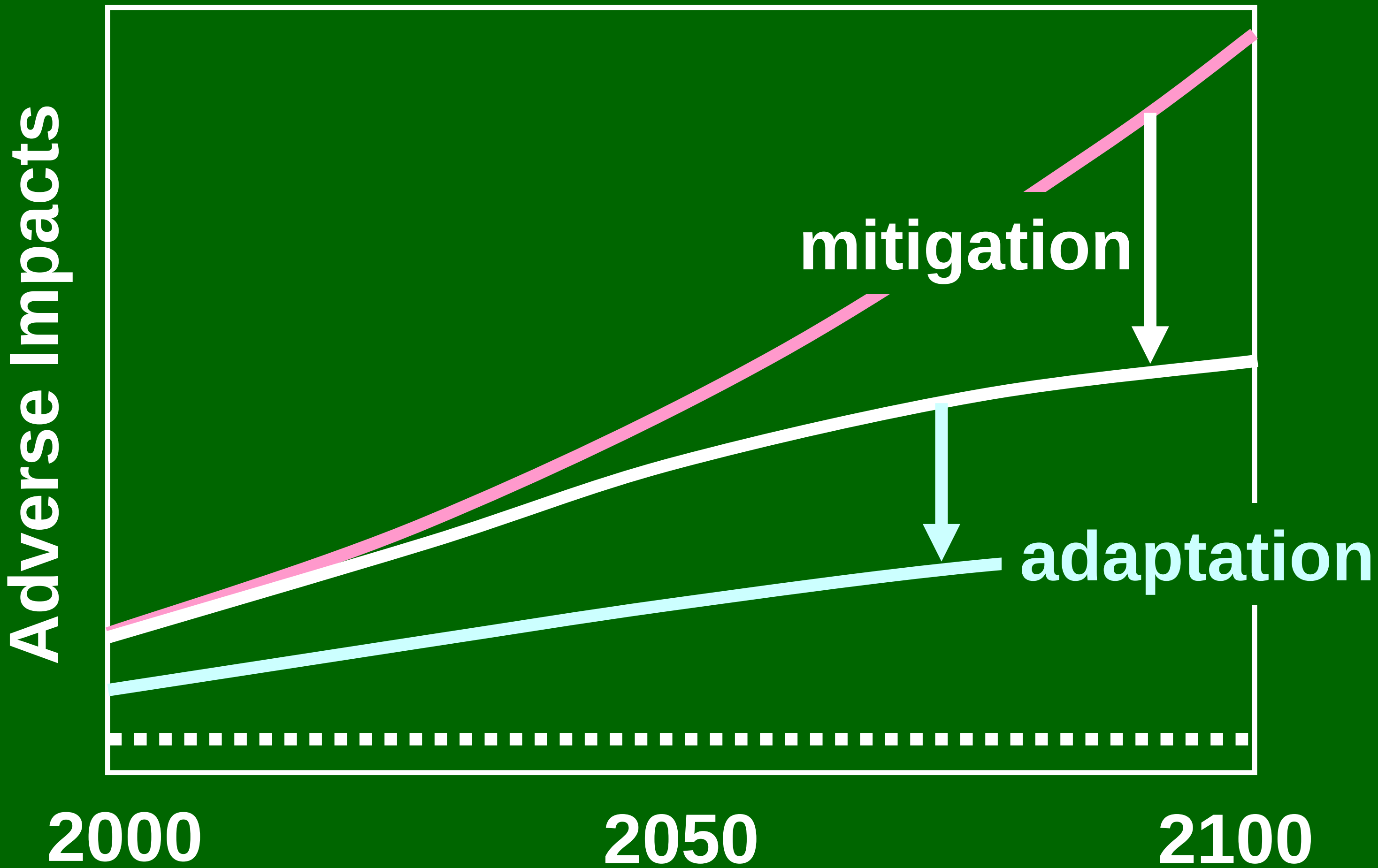
Impact, Mitigation, and Adaptation (Schematic)



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Stationarity vs. Adaptation

- Stationarity is a state of affairs where the future looks like the past.
- Under stationarity, historical stream flow observations can be used to evaluate performance of future water projects.
- The assumption of stationarity is the foundation of water planning (and planning in other important sectors).
- The assumption of stationarity implies no need for adaptation.

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CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change.

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global

Why Does Use of Stationarity Persist?

- Inertia: legal, professional, corporate
- Straightforward, standard methods
- Lack of a clear, simple alternative
- Legitimate distrust of model projections

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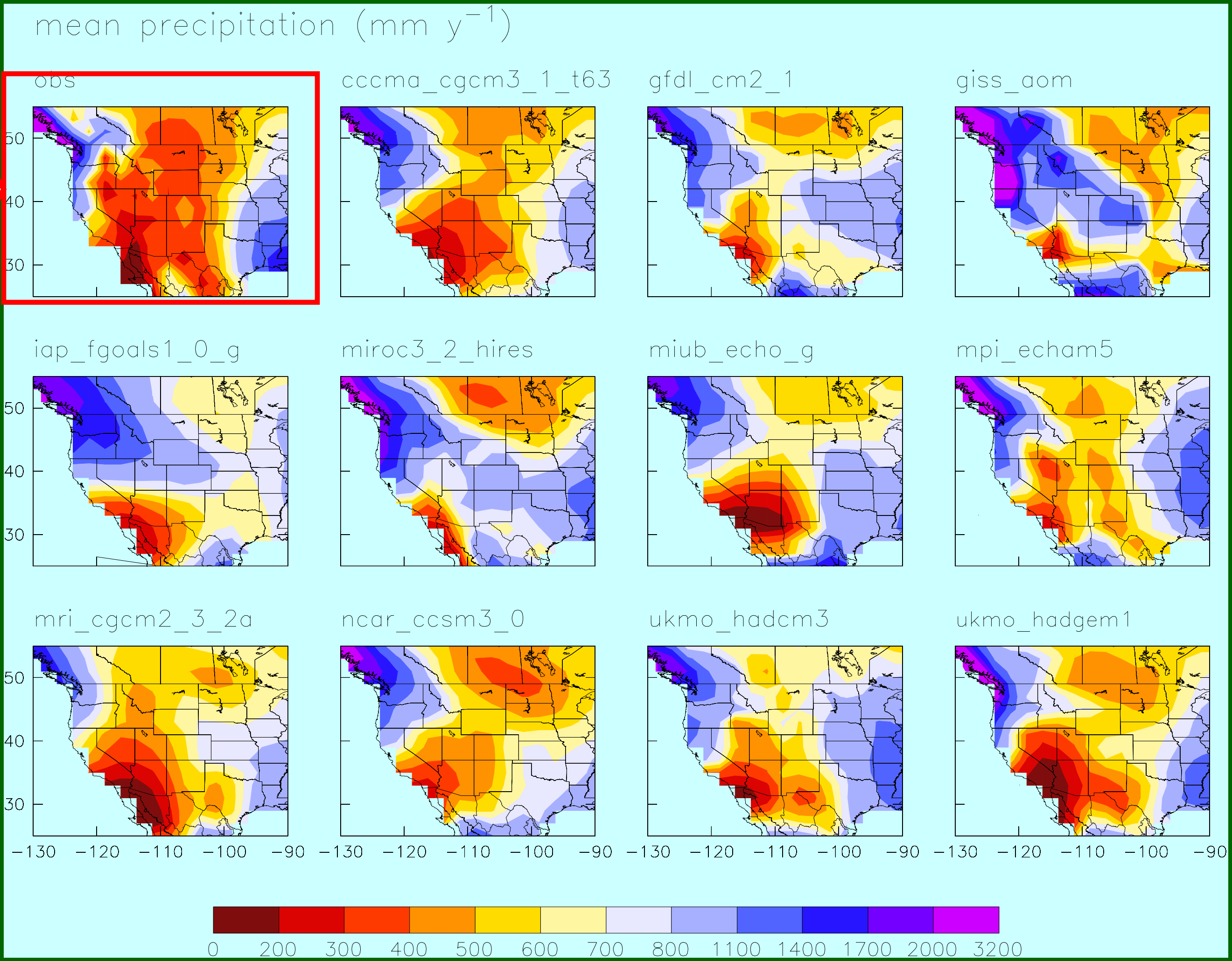
Observed and Modeled Precipitation



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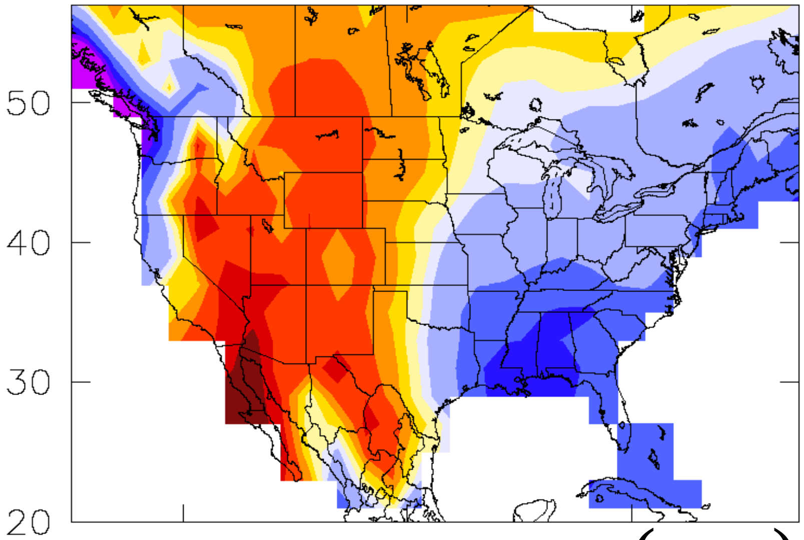
Observed Precipitation

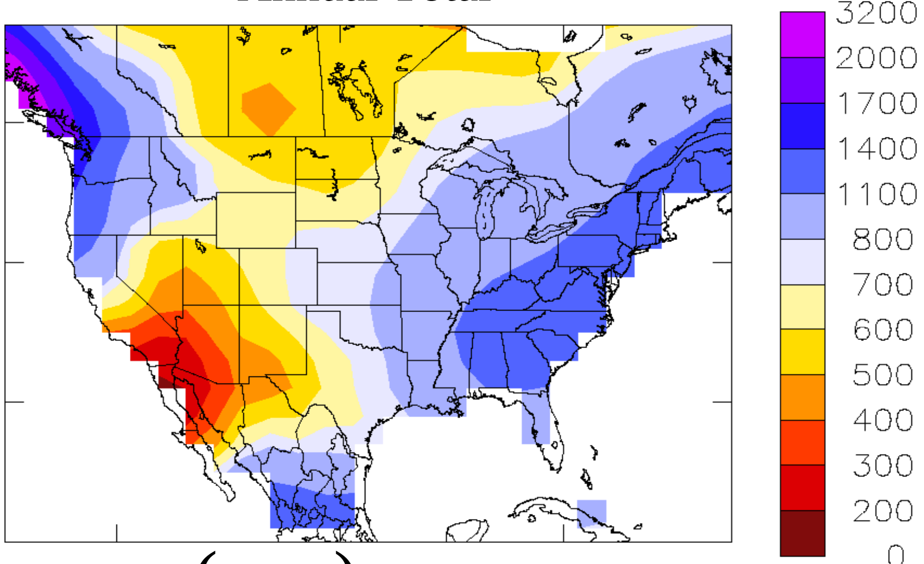
Annual Total



mean (mm)

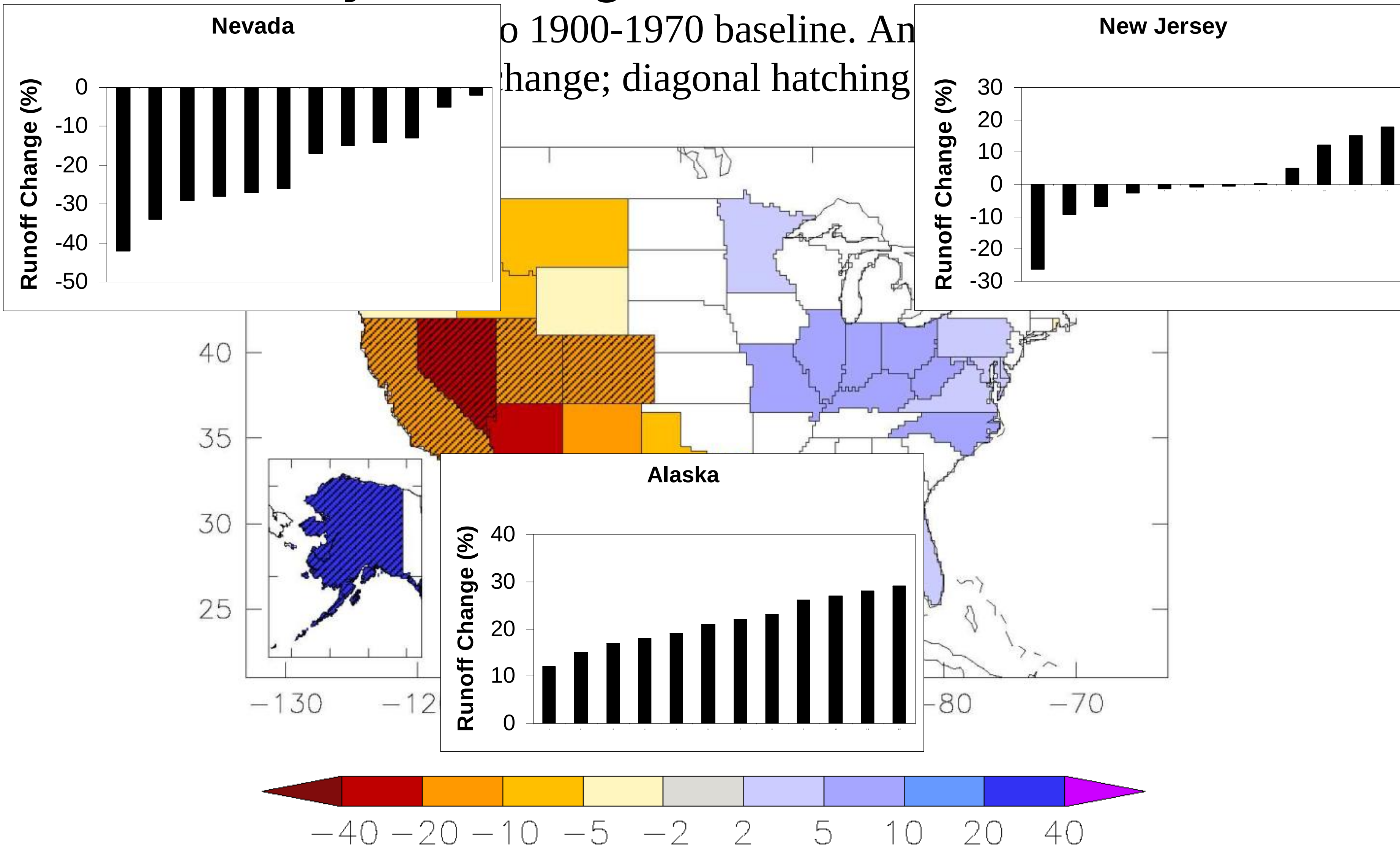
Modeled Precipitation

Annual Total



mean (mm)

Model-Projected Changes in Annual Runoff, 2041-2060



(After Milly, P.C.D., K.A. Dunne, A.V. Vecchia, Global pattern of trends in streamflow and water availability in a changing climate, *Nature*, **438**, 347-350, 2005.)

Potentially Actionable Intelligence

- Sea-level rise
- Snow-pack loss
- Global redistribution of runoff

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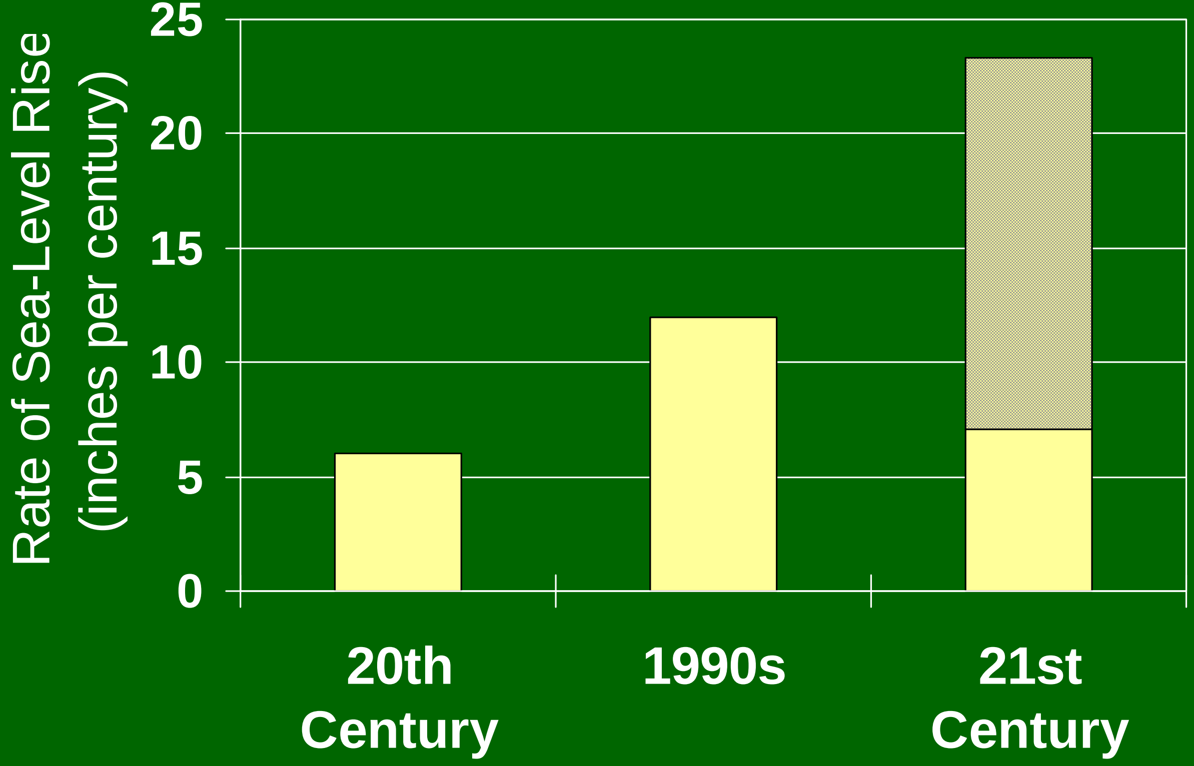
Model-Estimated Sea-Level Rise



(Data from IPCC WGI Summary for Policymakers)

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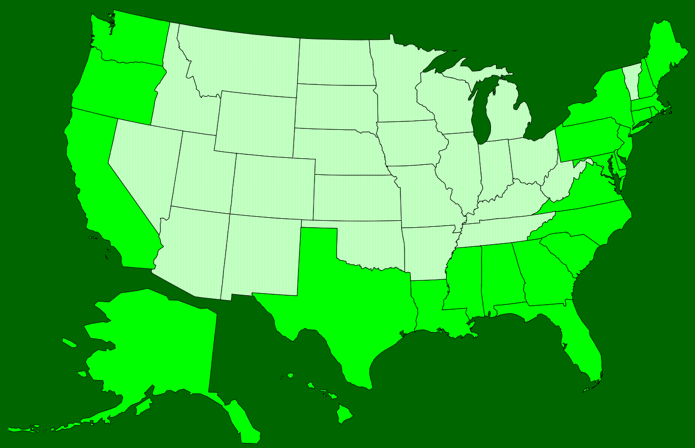
Sea-Level Rise and Water Supplies

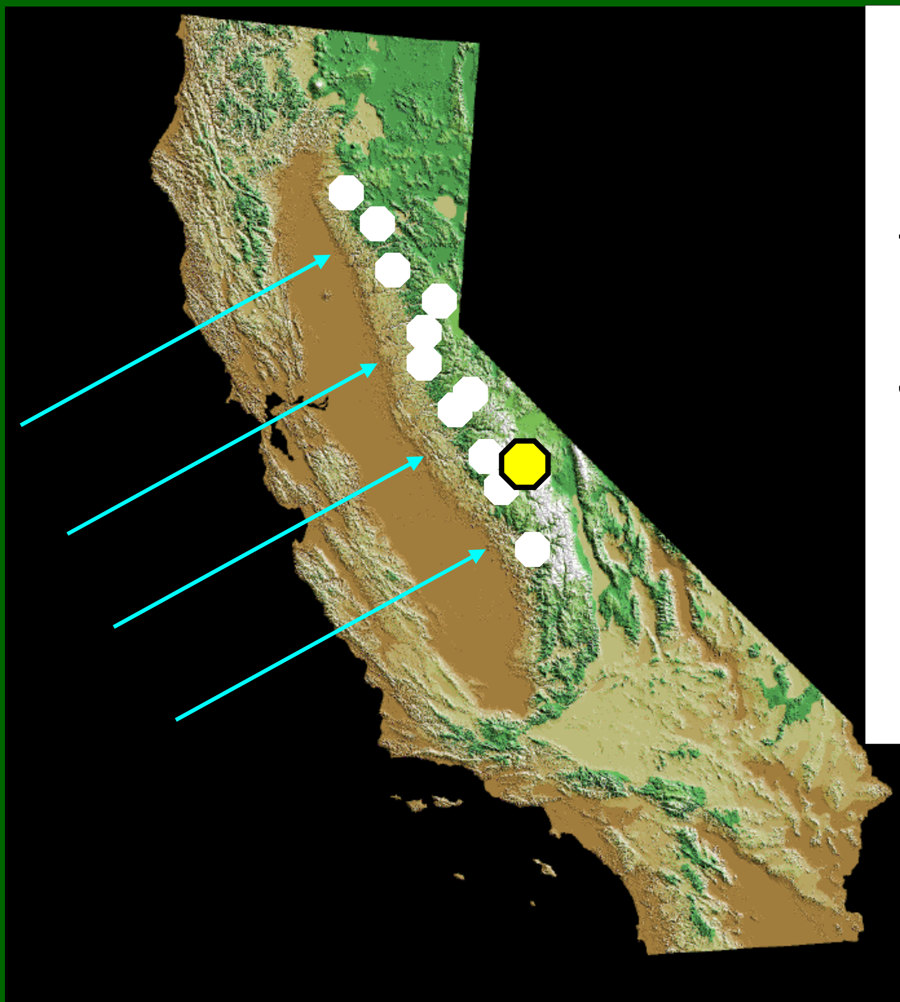
- **Saltwater contamination of coastal ground-water wells**
- **Salinity encroachment on municipal water intakes from rivers**

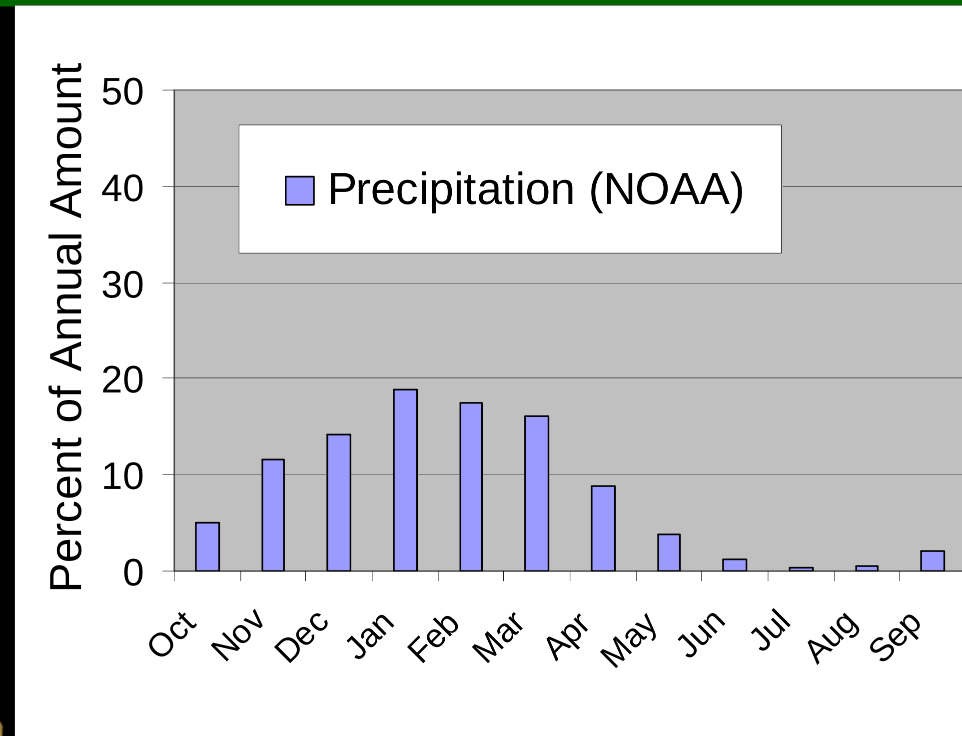


Coastal States

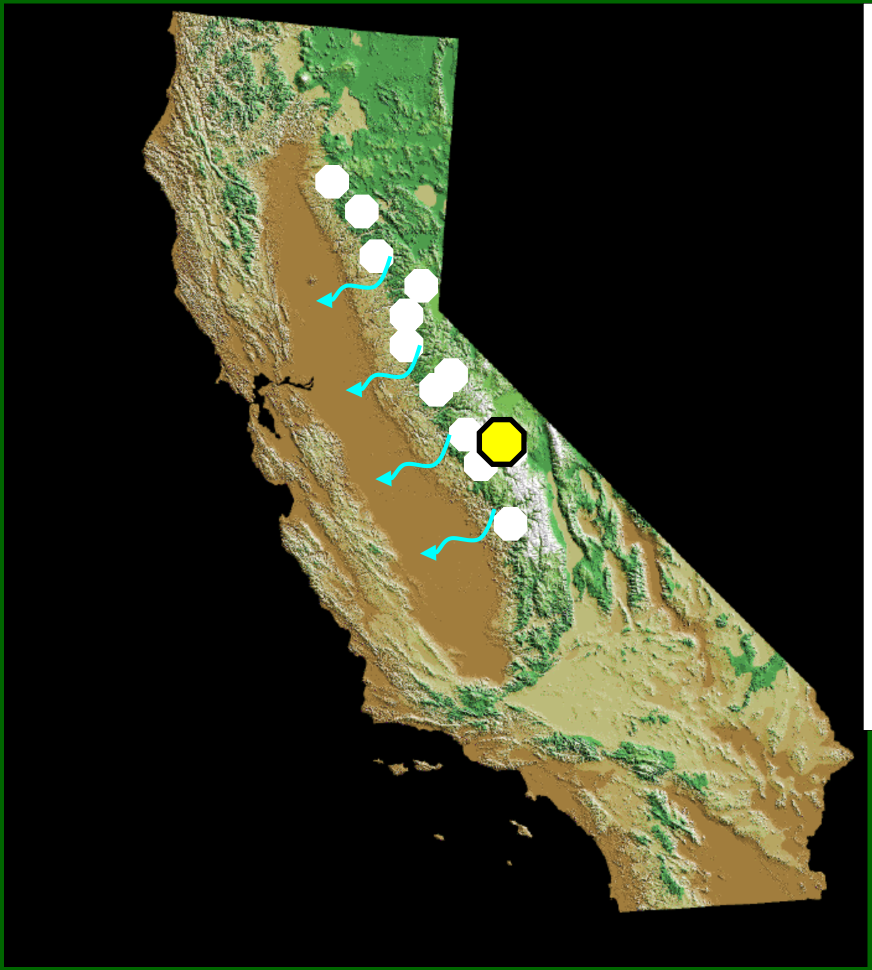
Snowpack Runoff

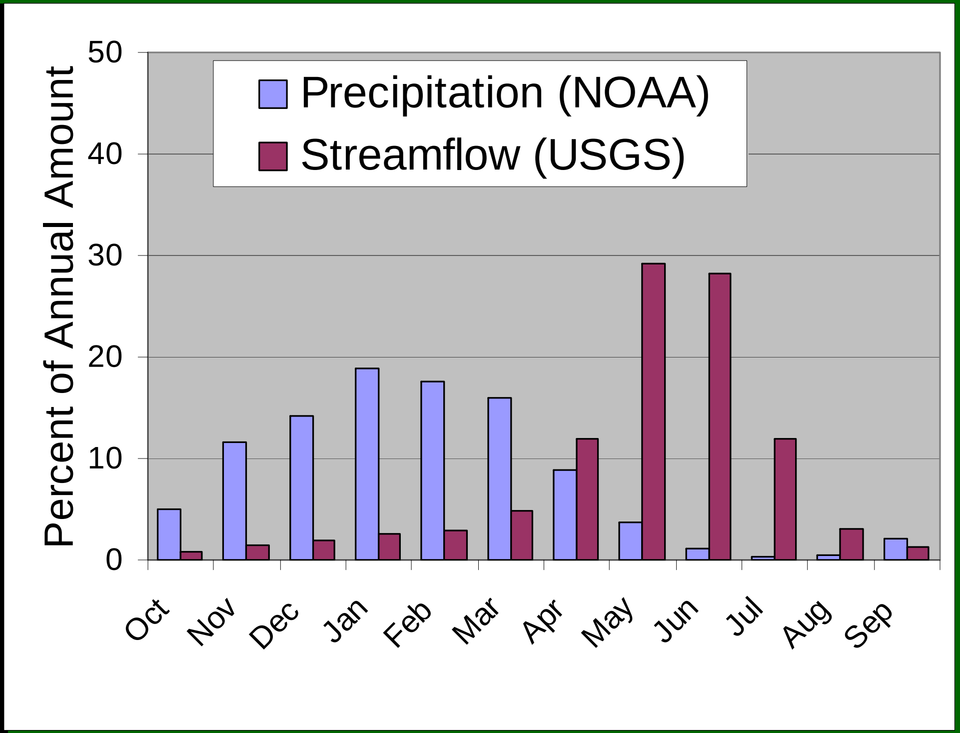
Snowpack Runoff: Winter





Snowpack Runoff: Spring





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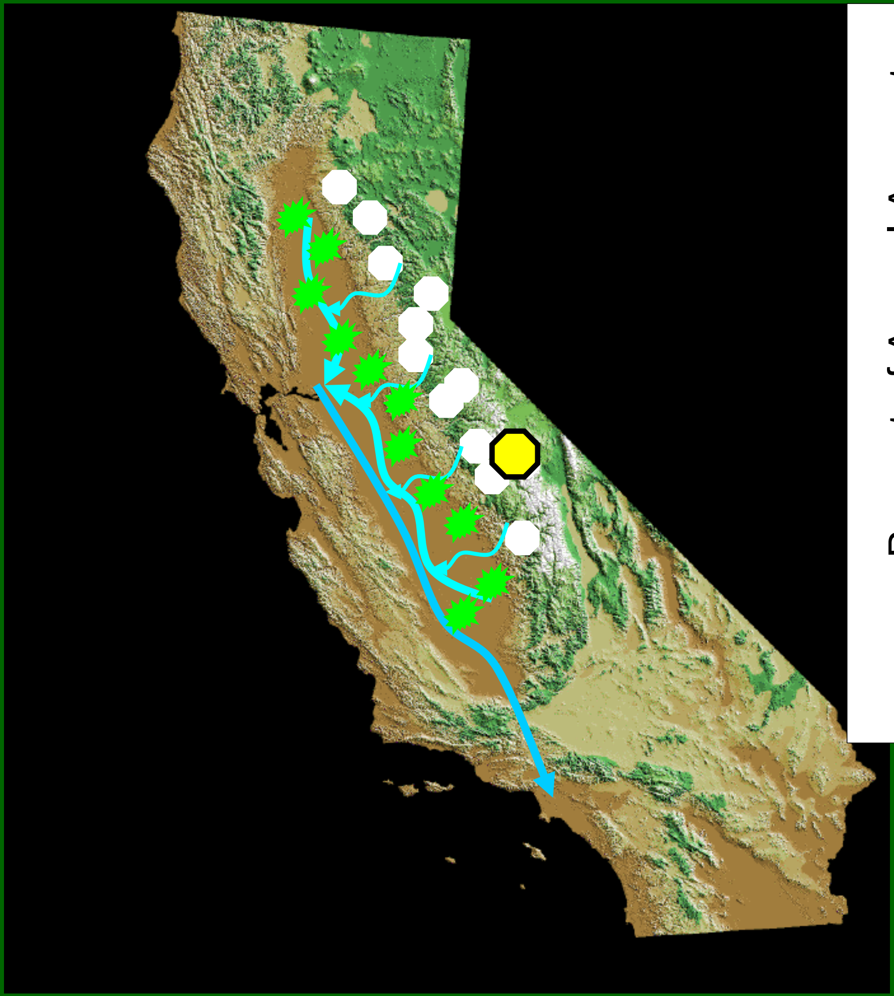
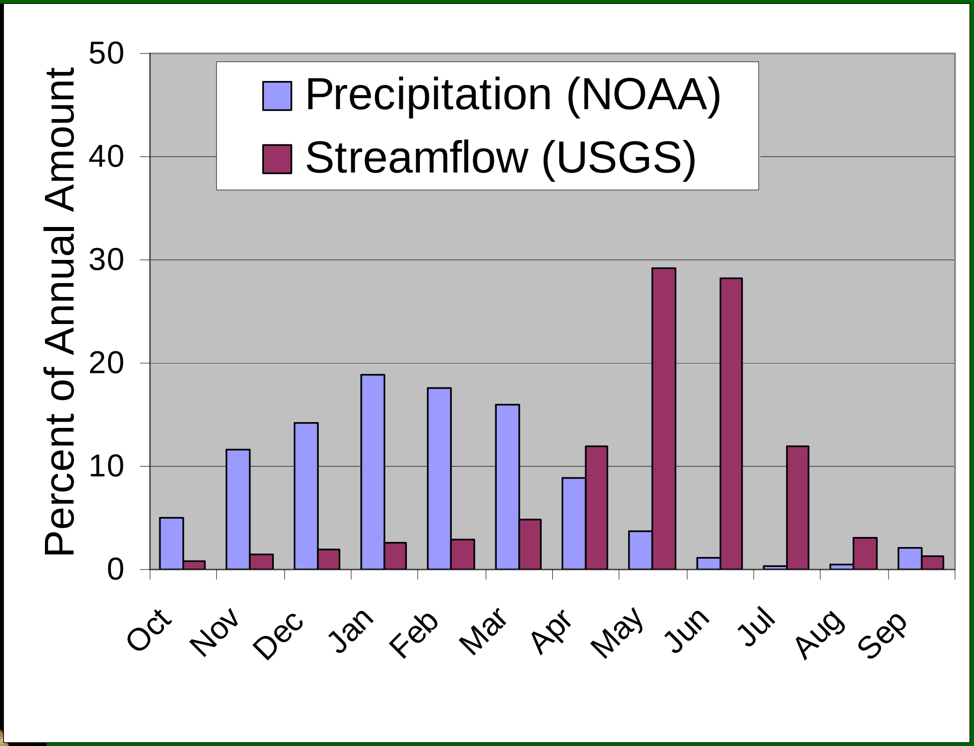
Snowpack Runoff: Spring-Summer





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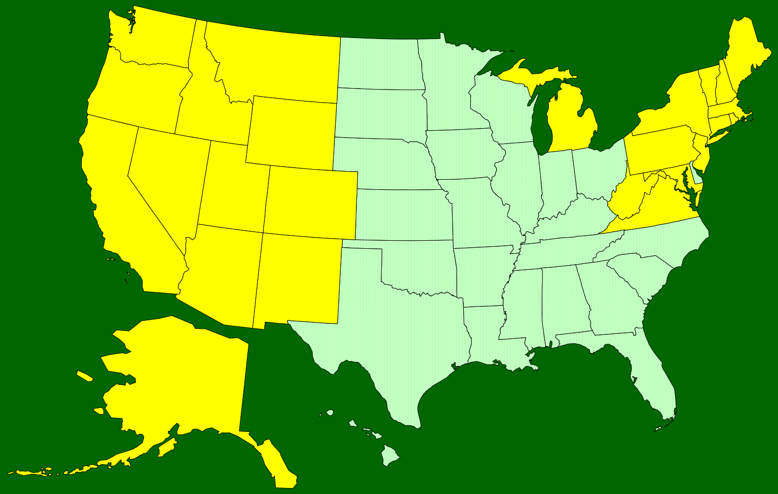
Snow-Pack Loss and Water

- Loss of natural winter-summer storage
- Loss of natural flood control system
- Loss of natural fire suppression



Snow-Pack States

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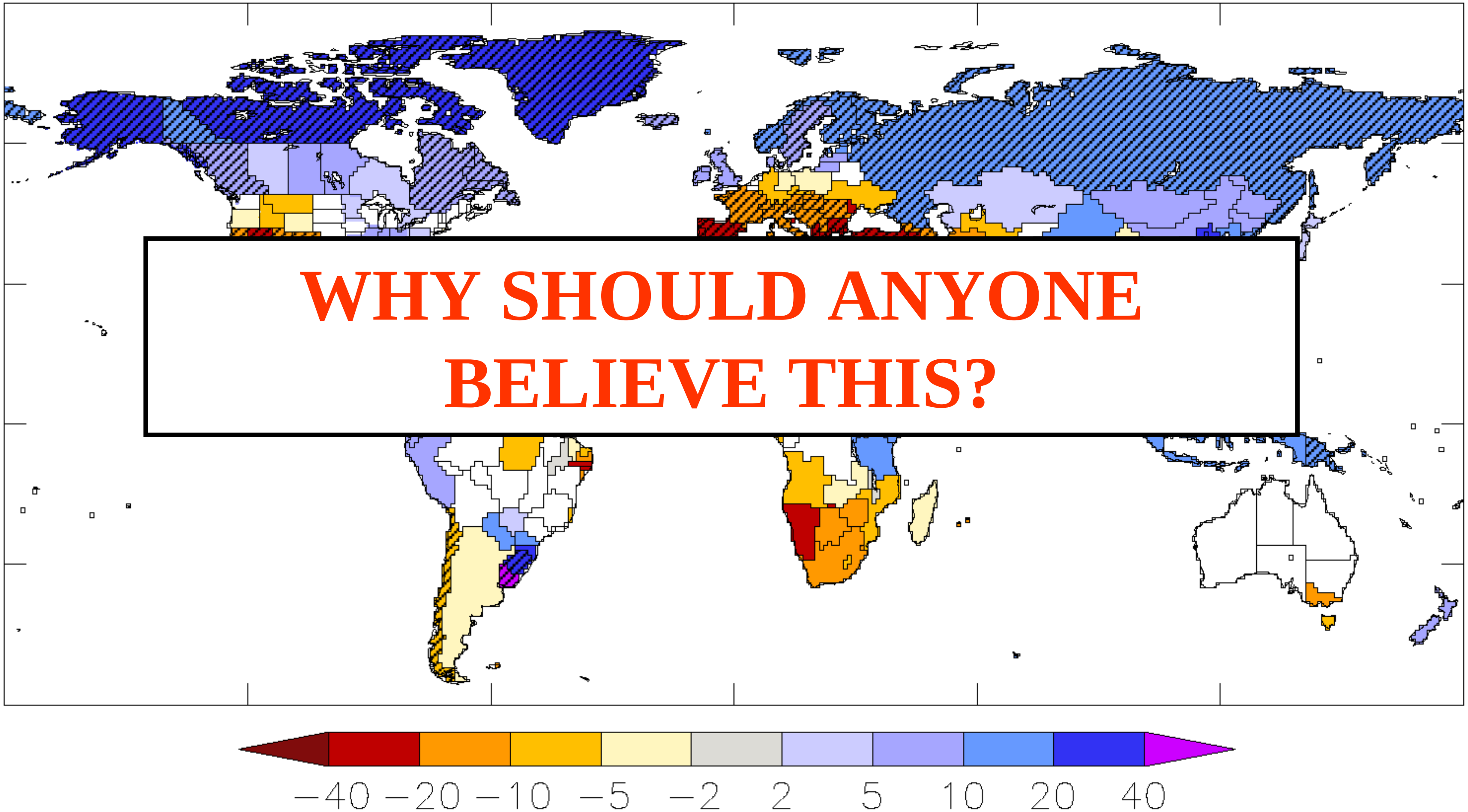
Model-Projected Changes in Annual Runoff, 2041-2060

Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement.



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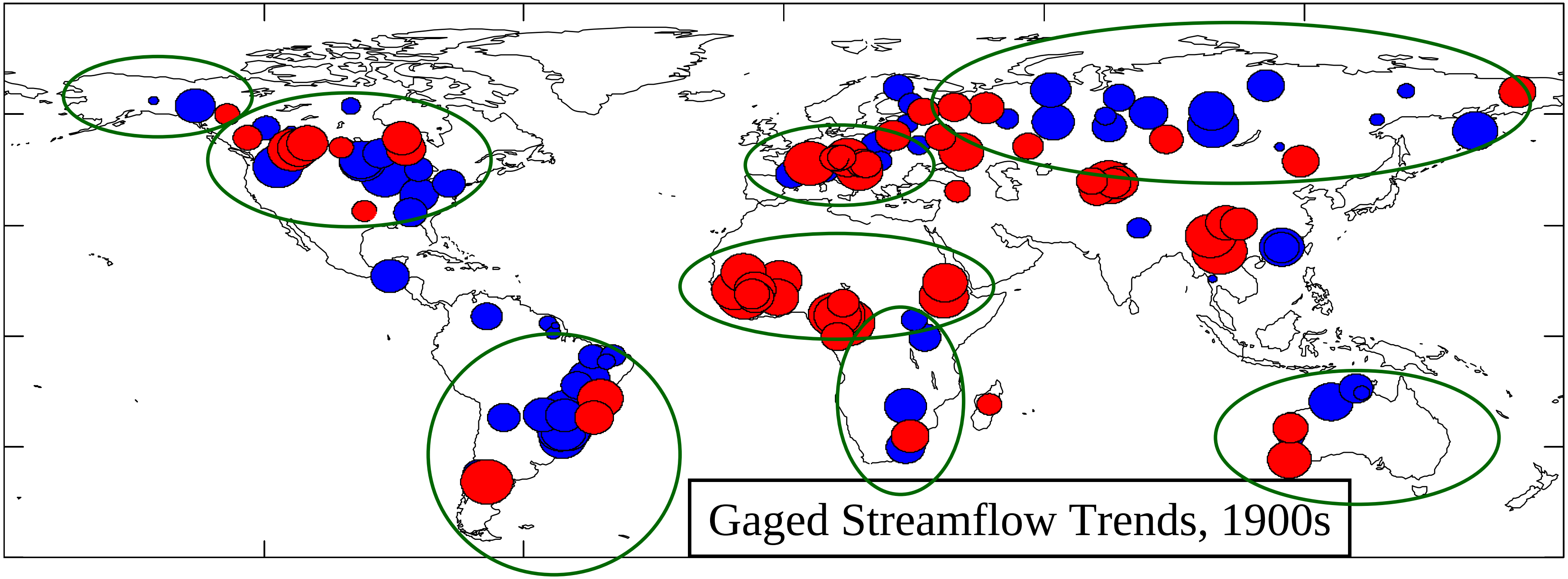

streamflow decreased

streamflow increased

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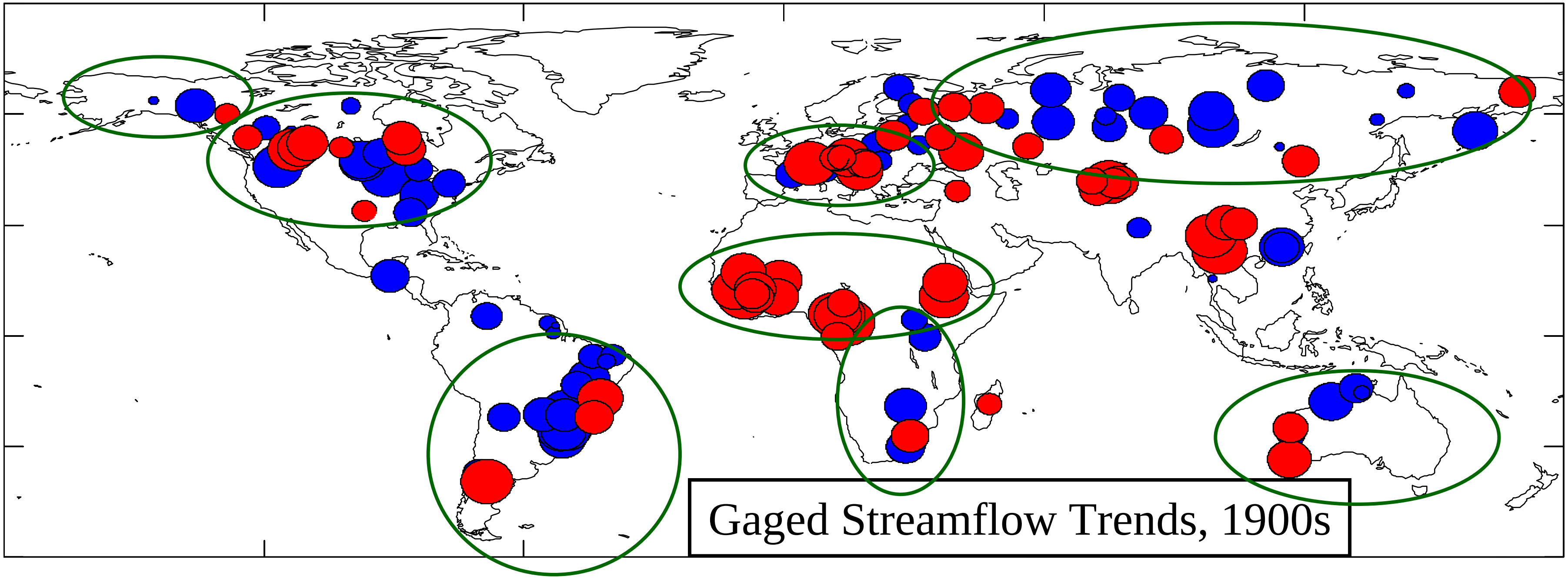
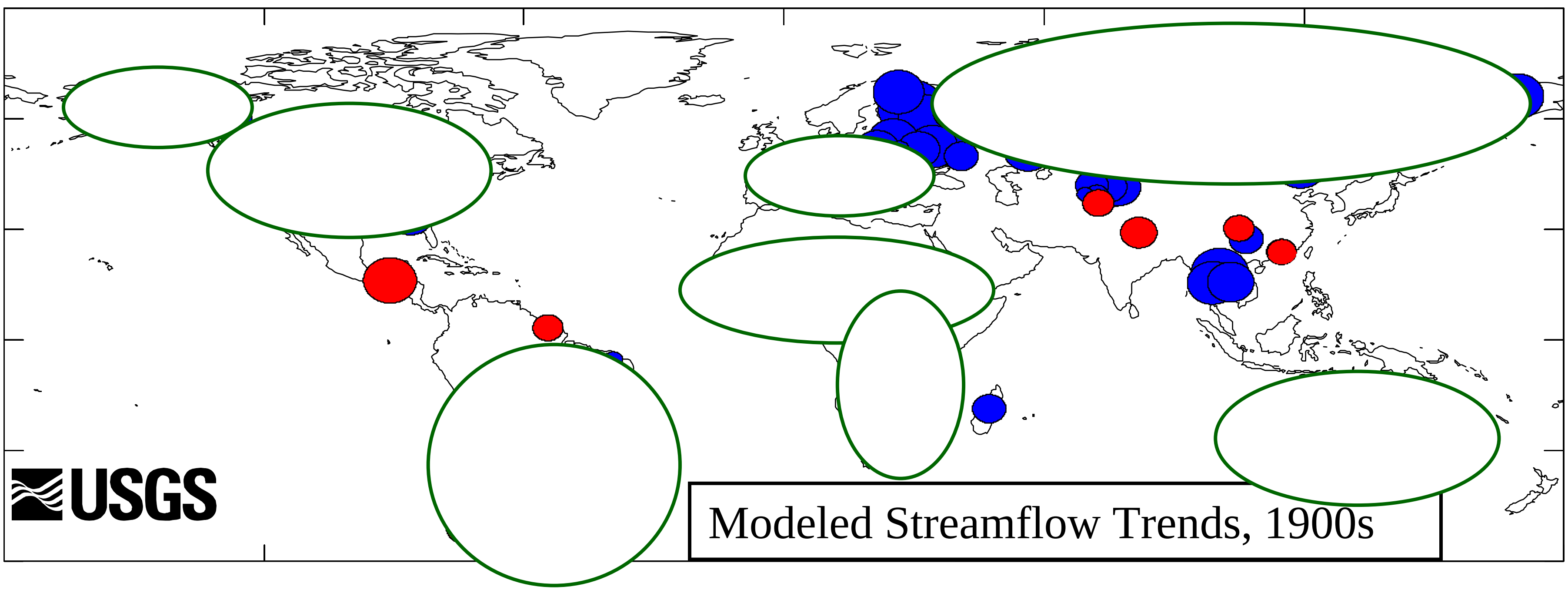

Gaged Streamflow Trends, 1900s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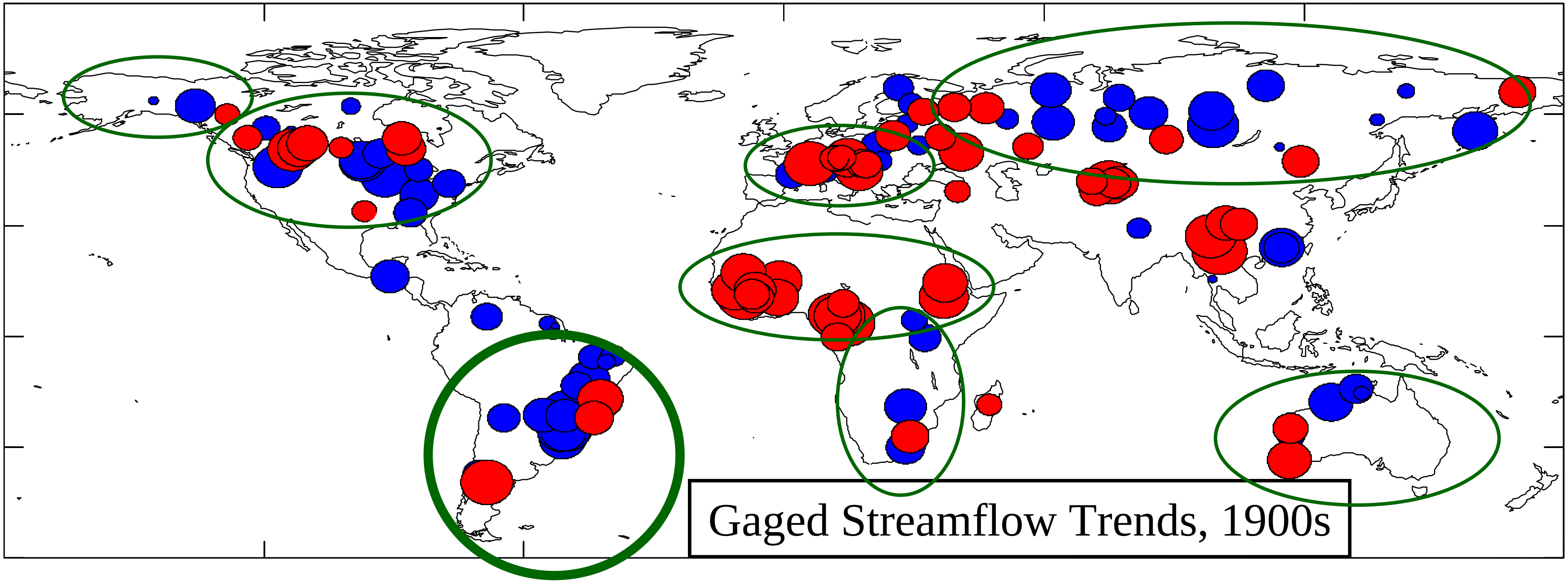
Modeled Streamflow Trends, 1900s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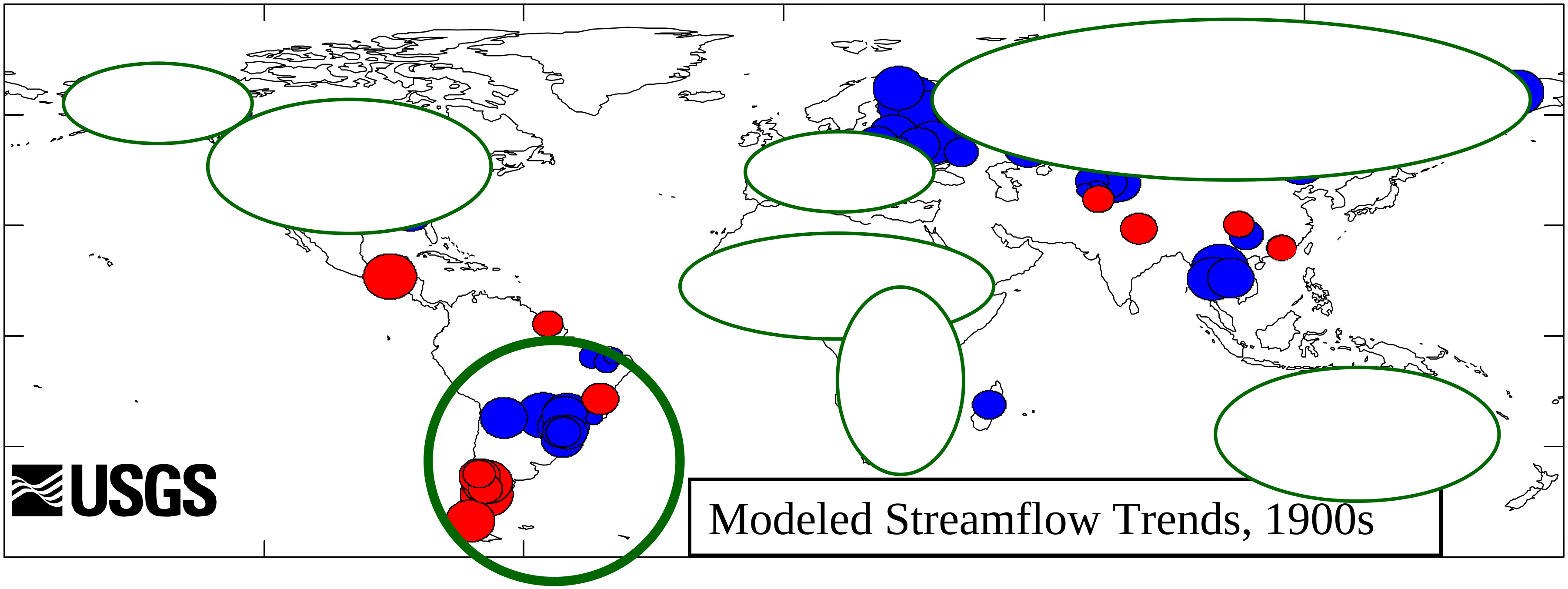
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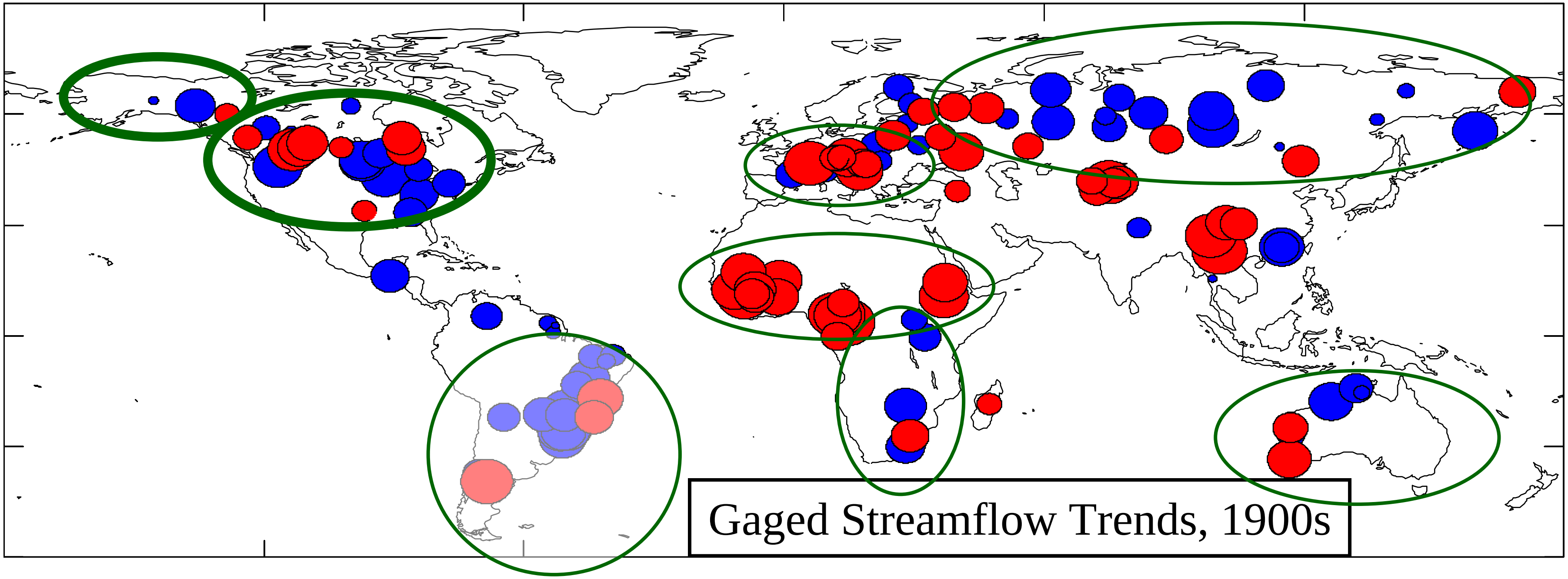
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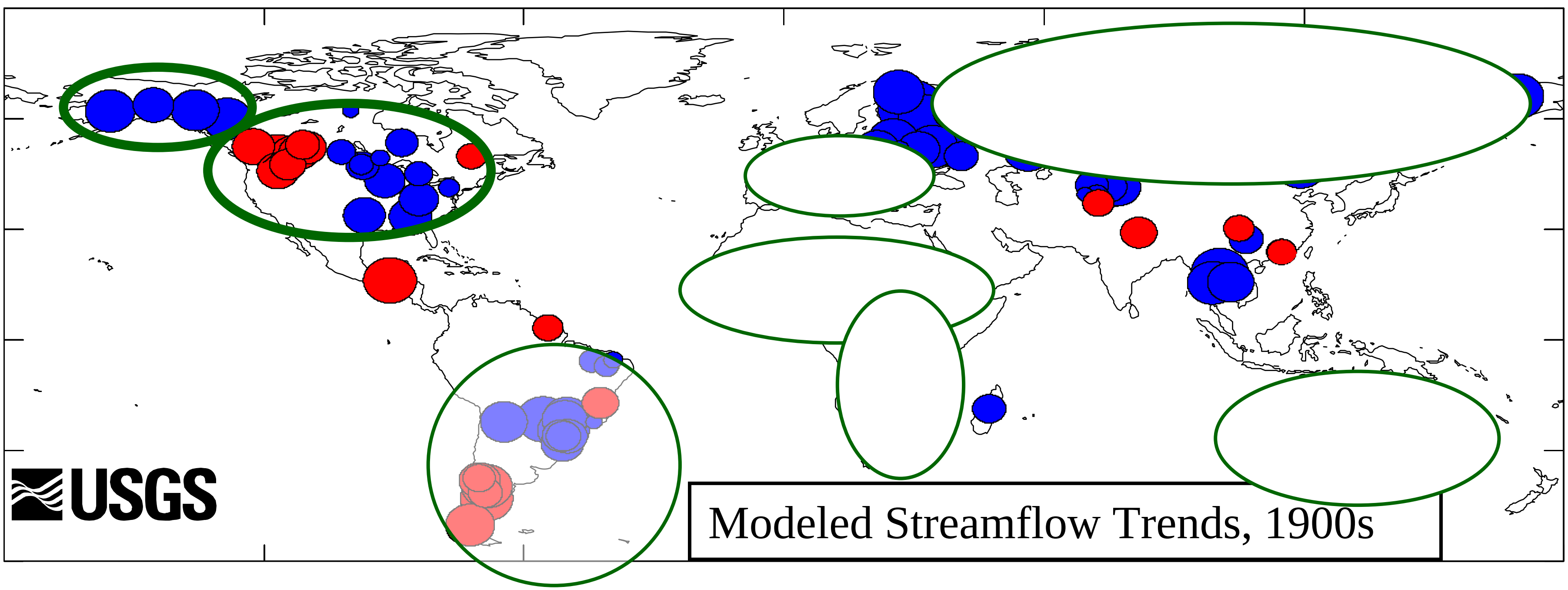
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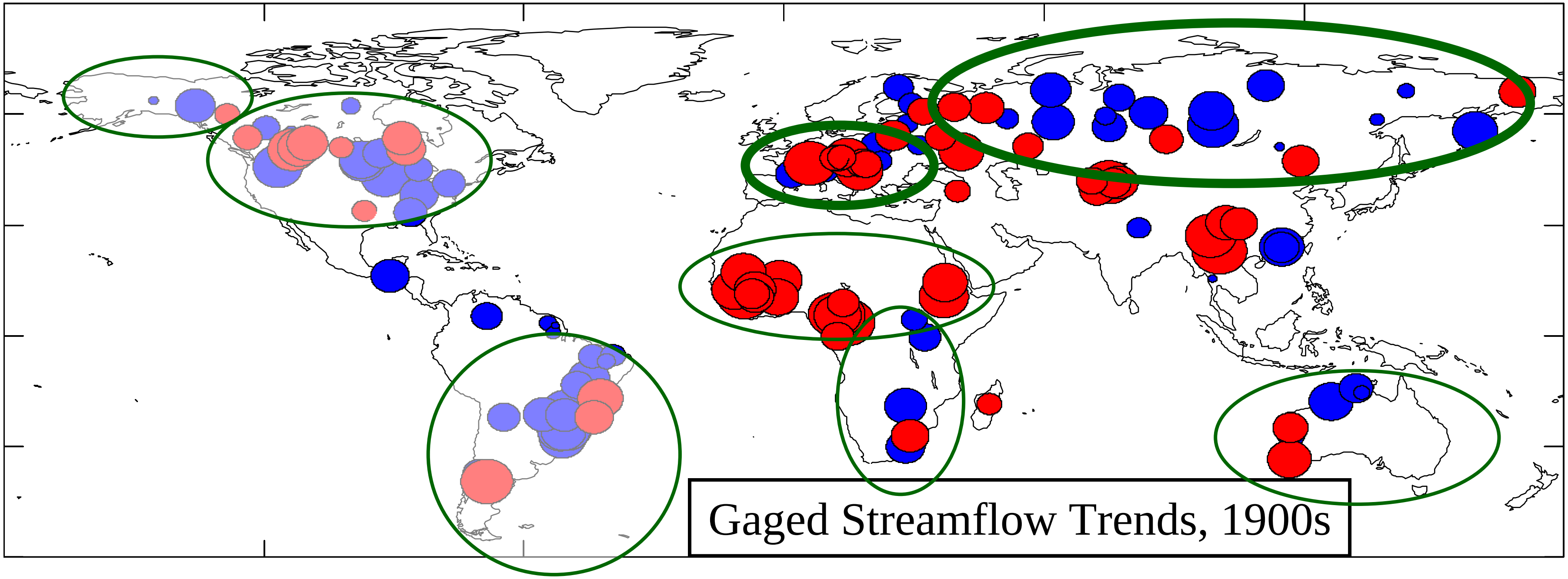
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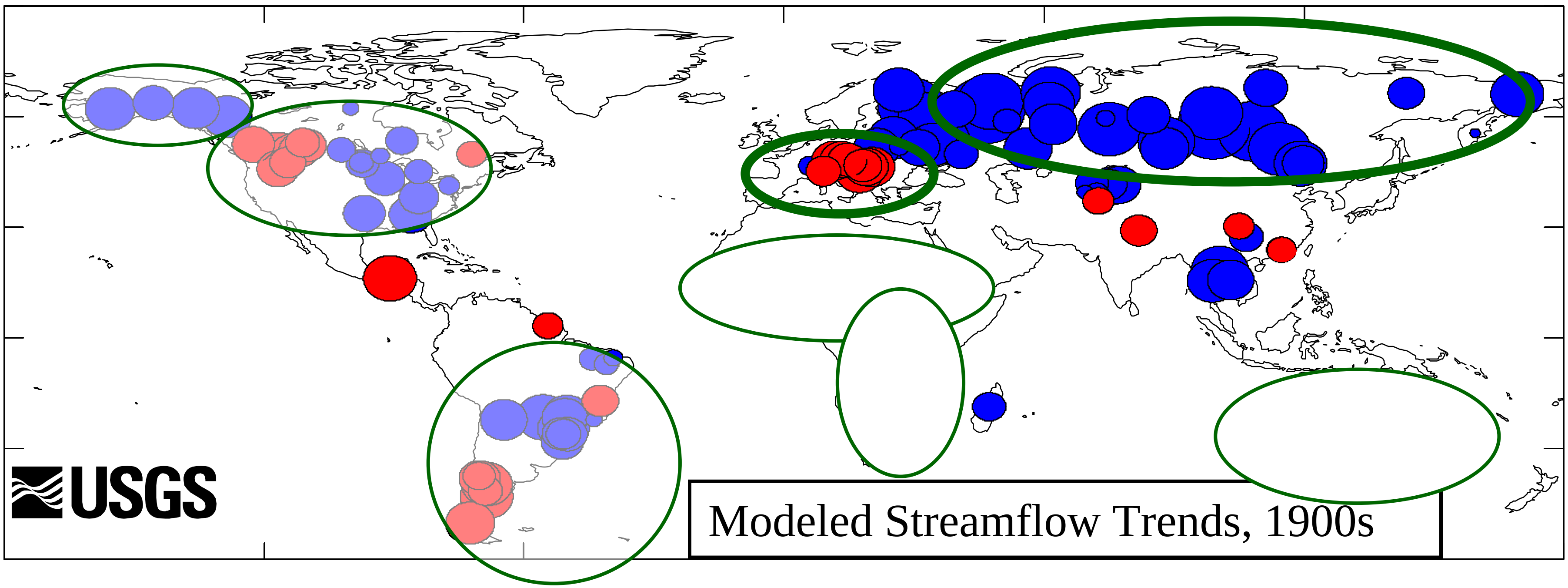
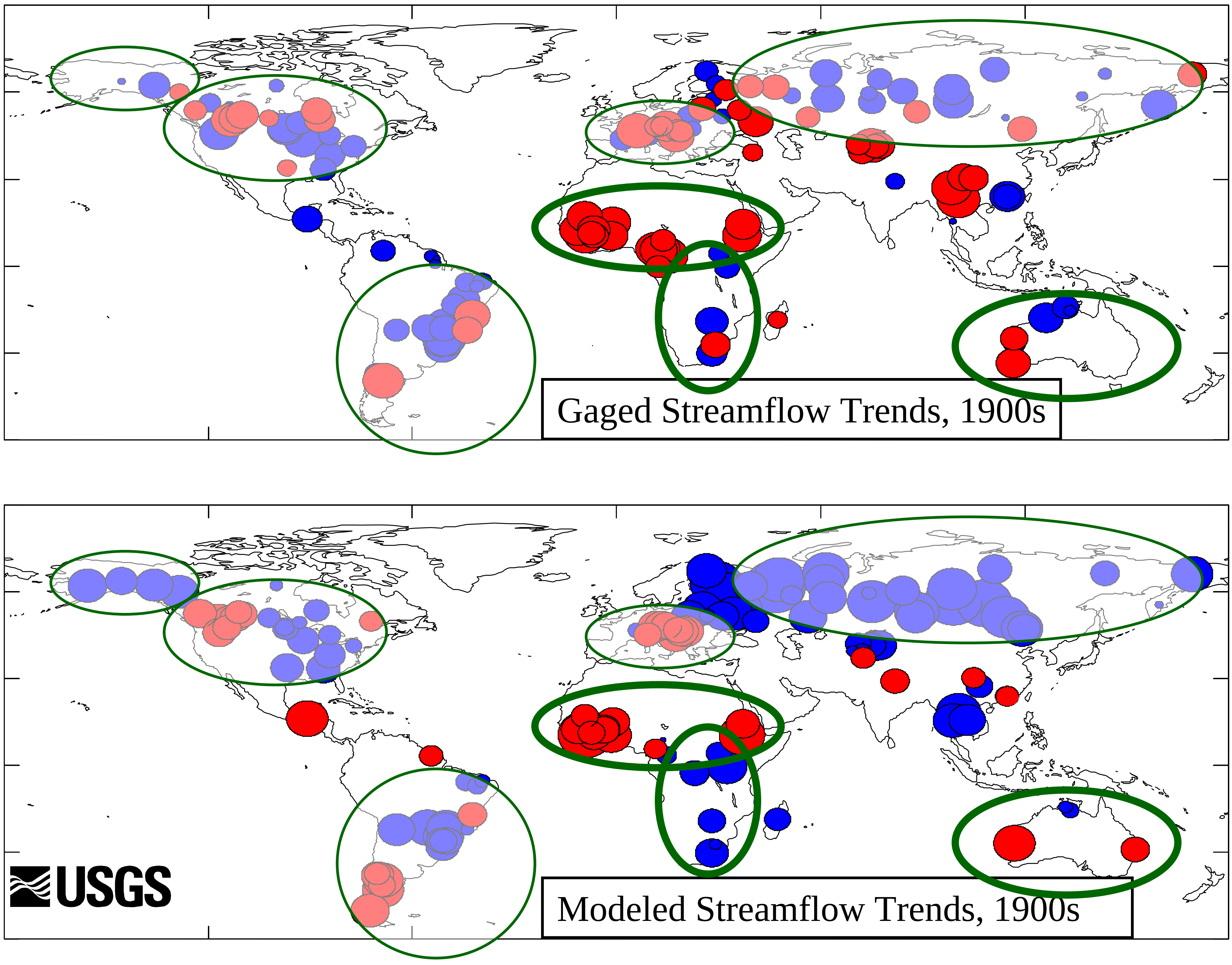
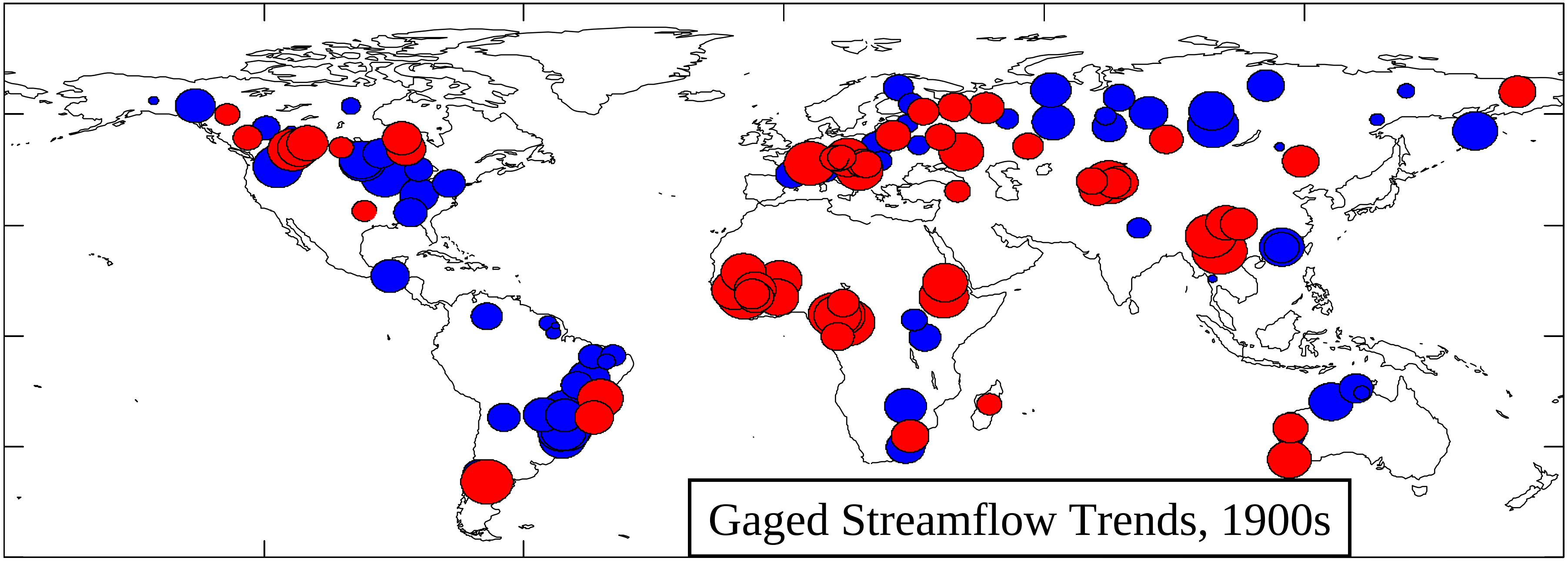

Modeled Streamflow Trends, 1900s
USGS


Gaged Streamflow Trends, 1900s
Modeled Streamflow Trends, 1900s
USGS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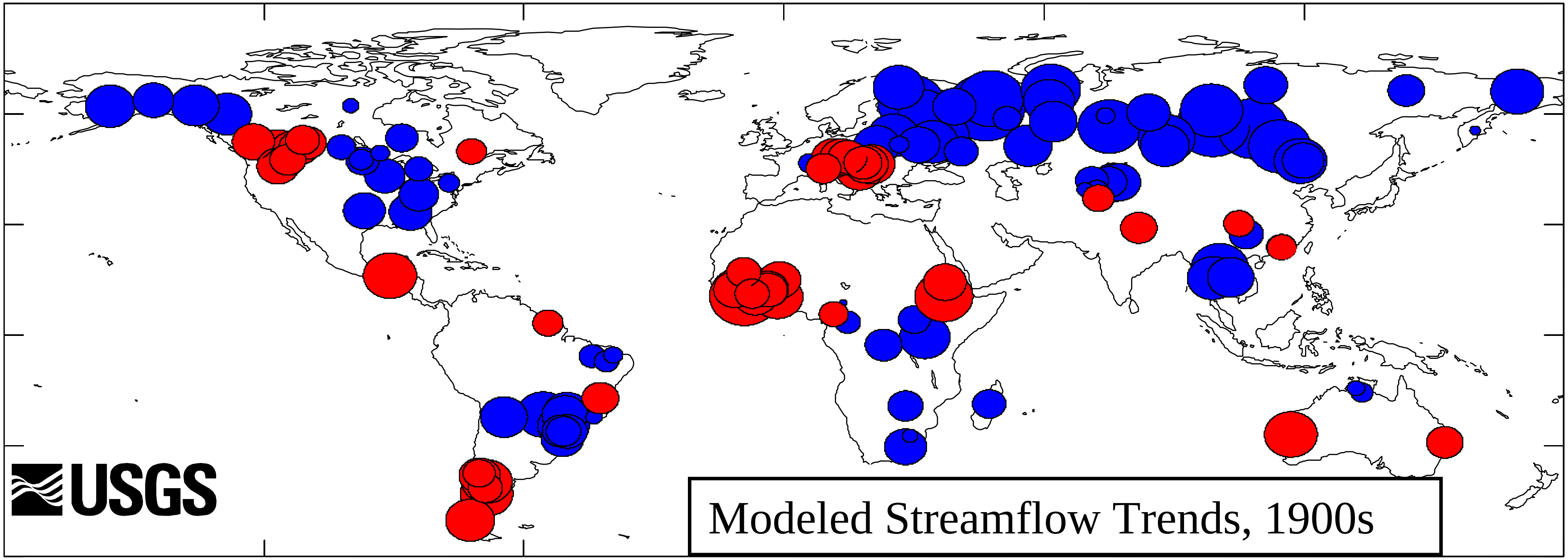
Modeled Streamflow Trends, 1900s

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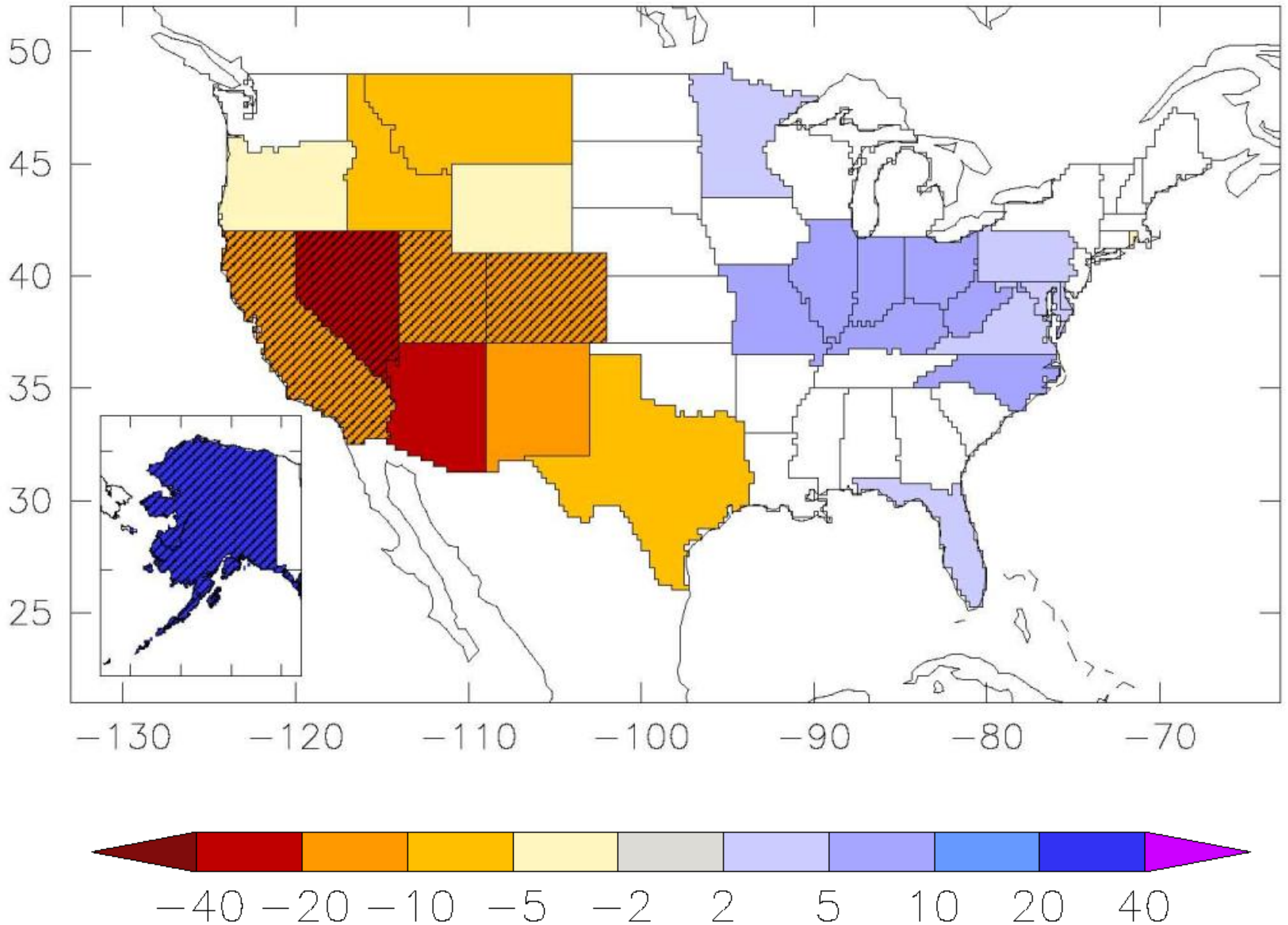

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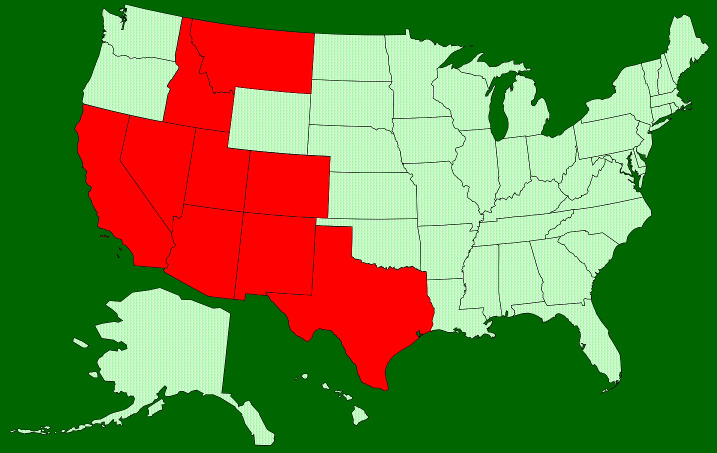
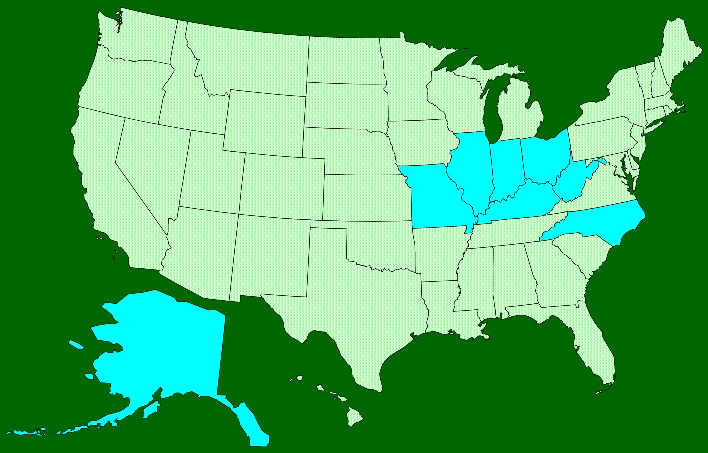
Redistribution of Water Resources

- Changing risk of unmet water demands
- Changing risk of floods (?)
- Changing risk of droughts



Drying States



Wetting States

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Final Thoughts

- A practical alternative to stationarity will need to use climate-model projections.
- Climate-model projections have errors.
- The perfect is the enemy of the good.
- Stationarity is a projection, too.
- Climate projections do not need to be perfect to be actionable; they only need to be better than stationarity.

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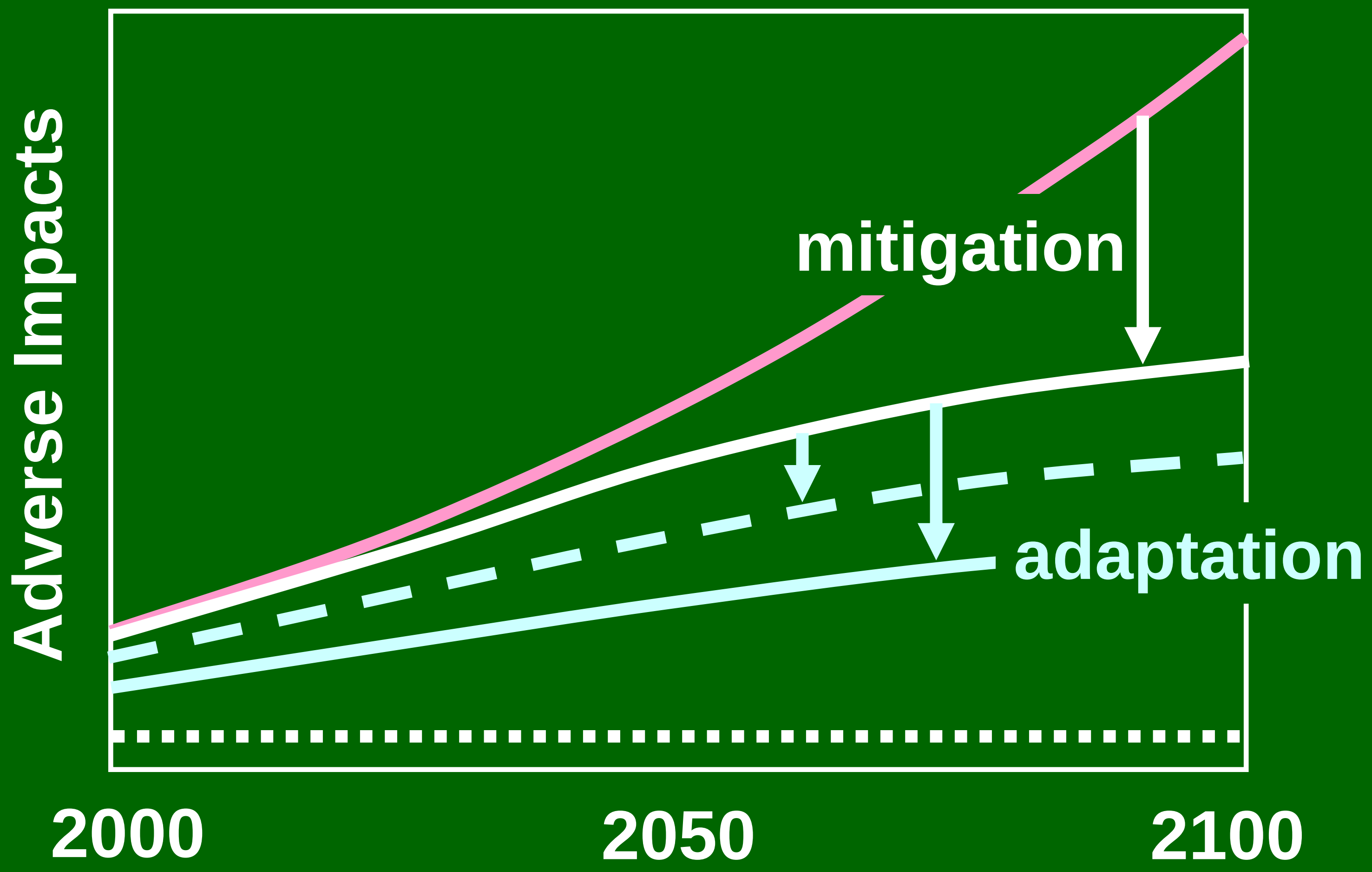
Impact, Mitigation, and Adaptation (Schematic)



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