The Need to Account for Water Resources Management in Climate Change Impact and Adaptation Studies

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Abstract

In 2020, renewables became the second-largest source of electricity generation in the United States after natural gas (US EIA, 2021). In recent years, wind energy generation has overtaken hydropower as the dominant source of renewable generation in the United States, but hydropower continues to offer advantages, in particular large-scale storage, that makes it particularly valuable as a complement to other weather-driven renewables. This storage, in the form of reservoirs, is rarely managed exclusively to optimize hydropower generation. Instead, reservoirs are operated for flood control, ecosystem services, irrigation, water supply, navigation, and recreation as well as hydropower. Managing these competing demands in a changing climate with existing infrastructure creates difficult challenges, because all these demands are themselves subject to change as is the electricity demand itself. Yet many climate change impact studies continue to treat rivers as entirely natural systems and water resources infrastructure is ignored or treated as an afterthought. In this presentation, we will discuss recent climate change impact studies in both the northwestern and southeastern United States in which we quantified the effects of regulation on discharge and other variables. We will make the case that to develop new strategies for mitigating and adapting to climate change, it is paramount to account for humans as active agents in the hydrologic cycle. The first study focuses on the Columbia River Basin in the Pacific Northwest, the main hydropower producing region in the United States, and examines the effect of accounting for regulation on changes in high and low flow extremes. The second study focuses on the southeastern United States and evaluates the effects of regulation on estimated changes in flow, stream temperature, and habitat suitability. US EIA, 2021: Monthly Energy Review, July 2021. www.eia.gov/mer [Last accessed on 8/3/2021].

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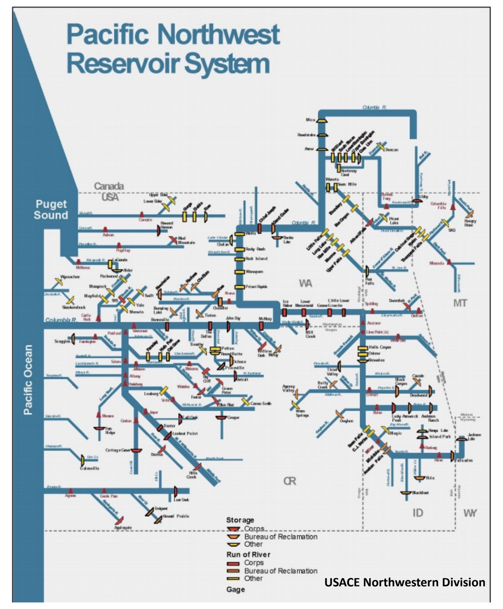
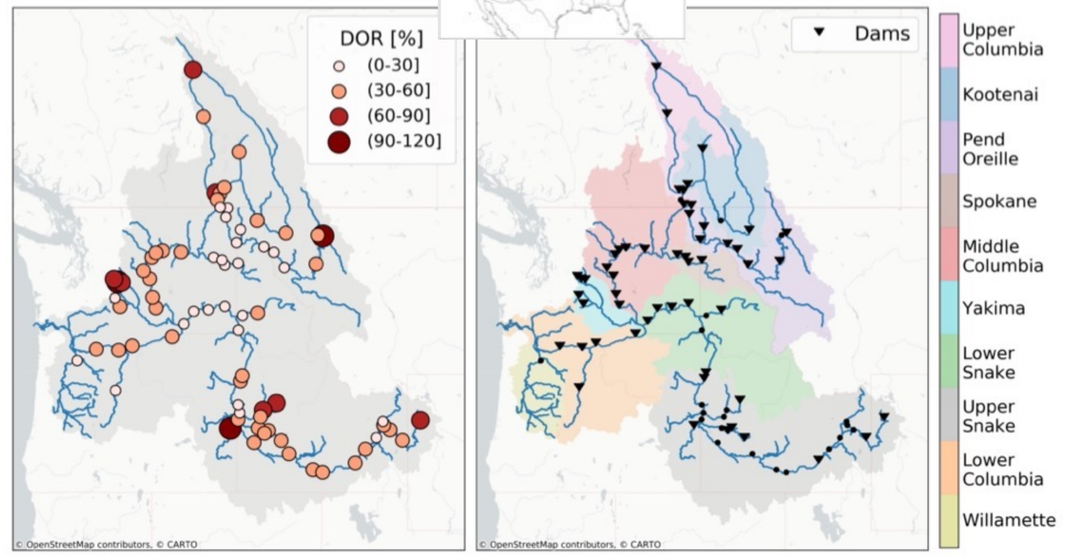
Streamflow: Columbia River Basin in the Pacific Northwest

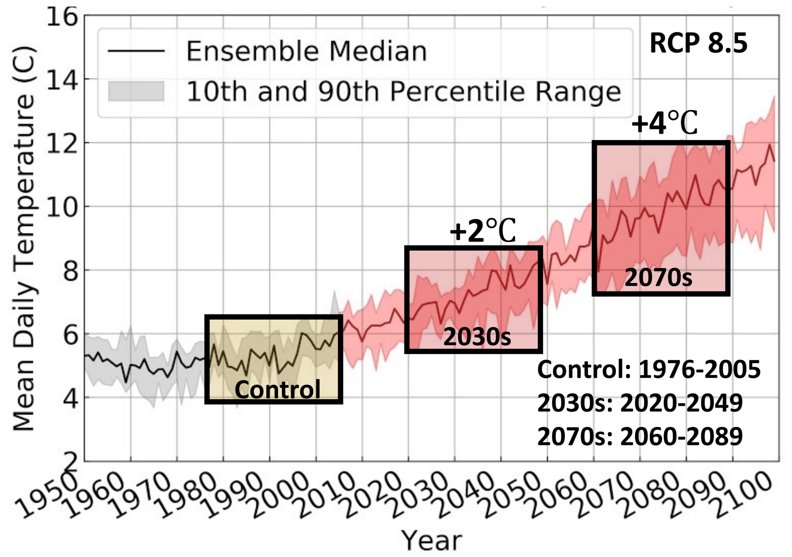
Degree of Upstream Regulation (DOR)

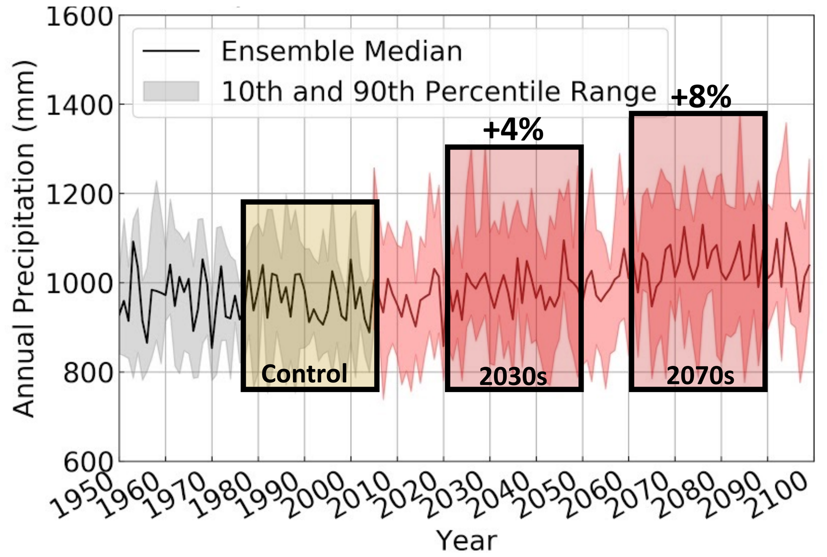
$$DOR = \frac{\sum \text{Upstream Storage Volume}}{\text{Average Annual Volume}} * 100\%$$



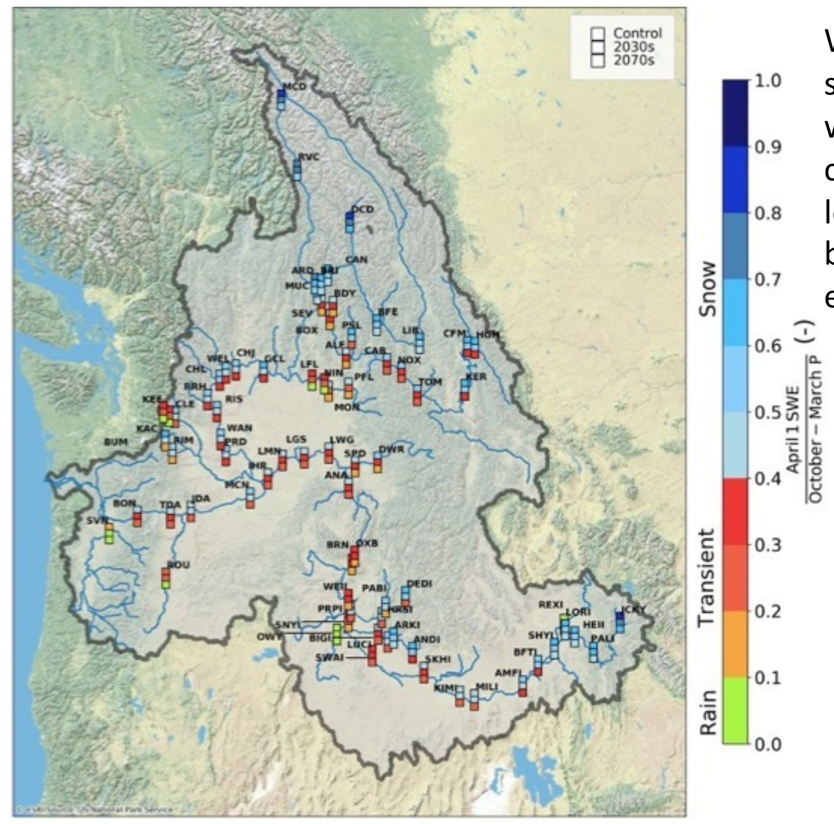


The Columbia river in the Pacific Northwest is a transboundary river that is heavily regulated for flood control, hydropower, fisheries, irrigation water supply, recreation, and navigation. The region's electricity supply is heavily dependent on hydropower.

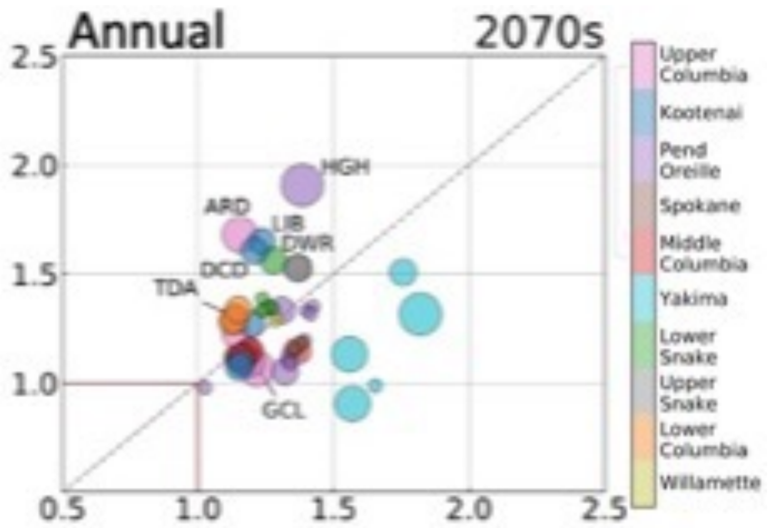


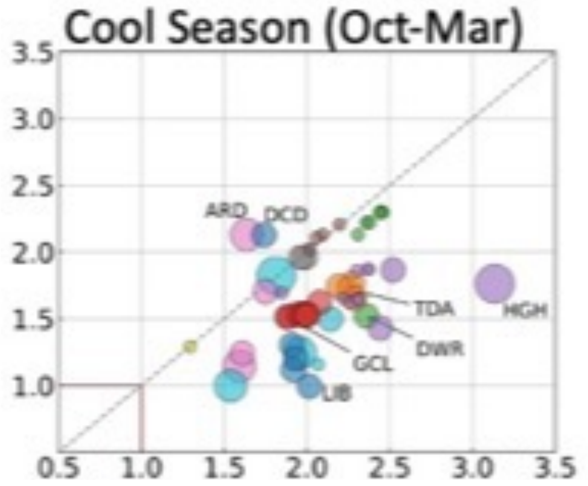


Projected changes in temperature and precipitation based on CMIP-5 simulations for RCP85 (above). Climate change is expected to significantly impact the hydrology of the Columbia River basin (Chegwidden et al., 2019; RMJOC-II, 2018; 2020) and hydrologic regimes are expected to shift from snow-dominant to transient and rain dominant (below left).

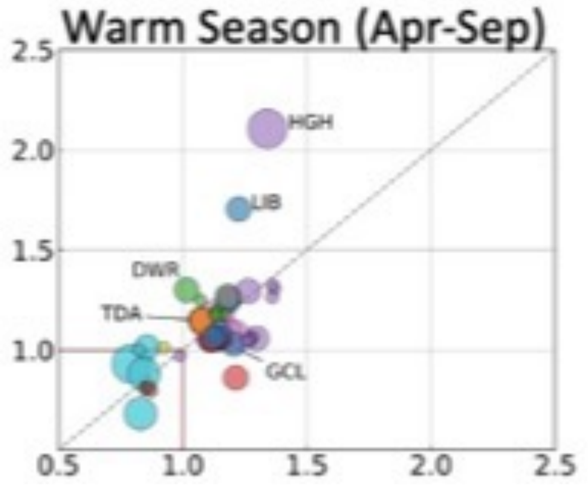


We compared modeled changes in annual and seasonal high flows (50-year return period) with and without regulation for the 2070s (below). Annual and cool season high flows are expected to increase at all locations in the regulated and unregulated scenarios, but regulation dampens increases in high flow extremes during the cool season (flood control).





Some of the amplification under regulation occurs because of changes in the hydrologic regime. For example, with more cool season precipitation falling as rain, less storage is available to meet spring flood targets.



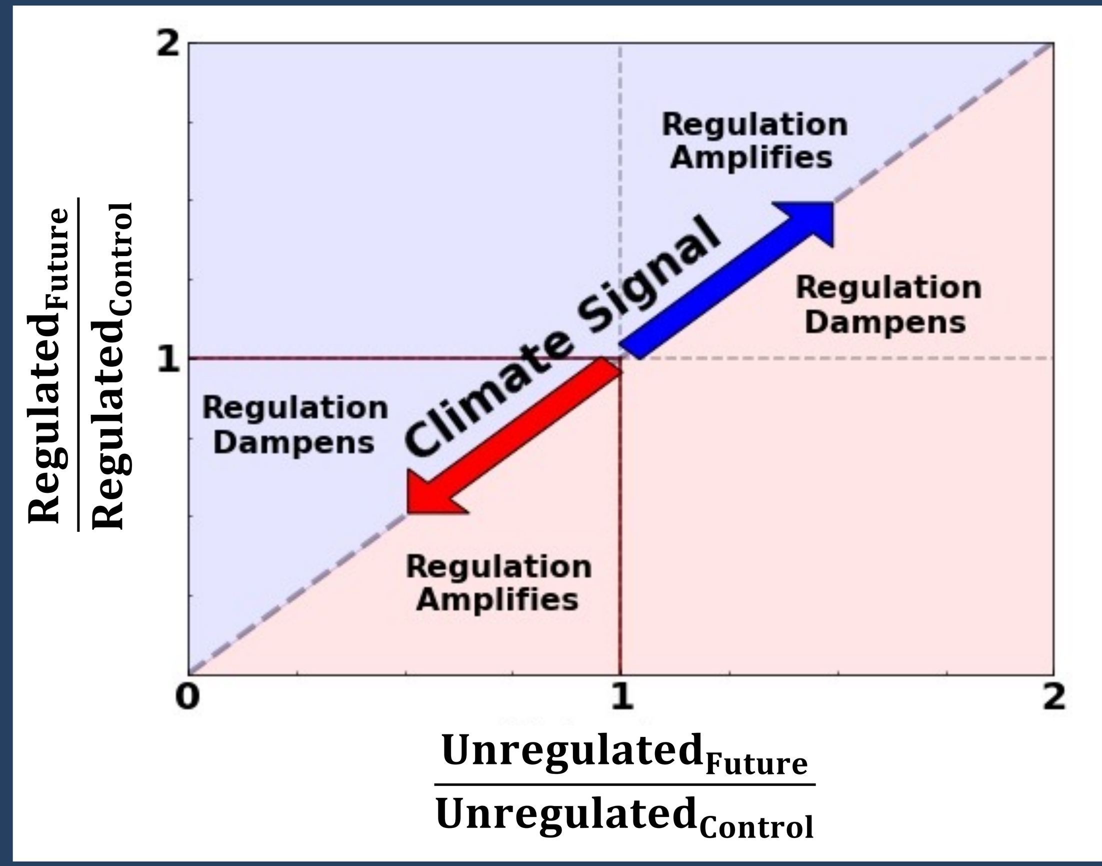
For more detail: Please see [H54E-05 Where and When Does Streamflow Regulation Significantly Affect Climate Change Outcomes in the Columbia River Basin?]

Motivation and overview

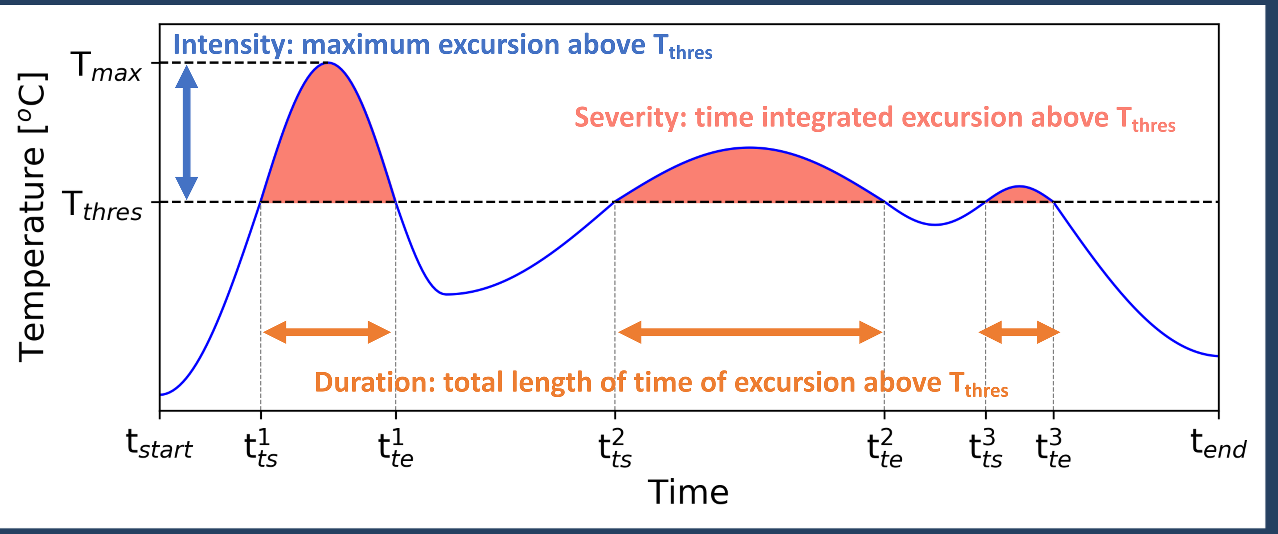
Many climate change impact studies treat rivers as entirely natural systems and water resources infrastructure is ignored or treated as an afterthought.

In this poster, we present two recent climate change impact studies in the northwestern and southeastern United States in which we quantified the effects of regulation on discharge and other variables such as stream temperature.

Evaluation methods



In the study to the left (Columbia) we examined changes in streamflow under climate changes. We looked at annual and seasonal volumes, high flows and low flows with and without regulating and evaluated how regulation amplifies or dampens changes associated with climate change. On this poster we only show results for high flows.



In the study to the right (southeastern United States), we examined changes in stream temperature under climate change and the role of regulation in changes in temperature extremes.

Finding

Not unexpectedly, regulation strongly modulates the response of climate change and can lead to both dampening and amplification of the climate signal (e.g., streamflow extremes in the Columbia). However, regulation in most cases cannot fully mitigate hydrologic changes due to climate change (e.g., stream temperature extremes in the southeastern US).

We need to start accounting for regulation in climate change studies.

References:

Chegwidden, O. S., B. Nijssen, D. E. Rupp, J. R. Arnold, M. P. Clark, J. J. Hamman, S. C. Kao, Y. Mao, N. Mizukami, P. W. Mote, M. Pan, E. Pytlak, and M. Xiao (2019), How Do Modeling Decisions Affect the Spread Among Hydrologic Climate Change Projections? Exploring a Large Ensemble of Simulations Across a Diversity of Hydroclimates, Earth's Future, 7(6), 623-637, doi:10.1029/2018ef001047.

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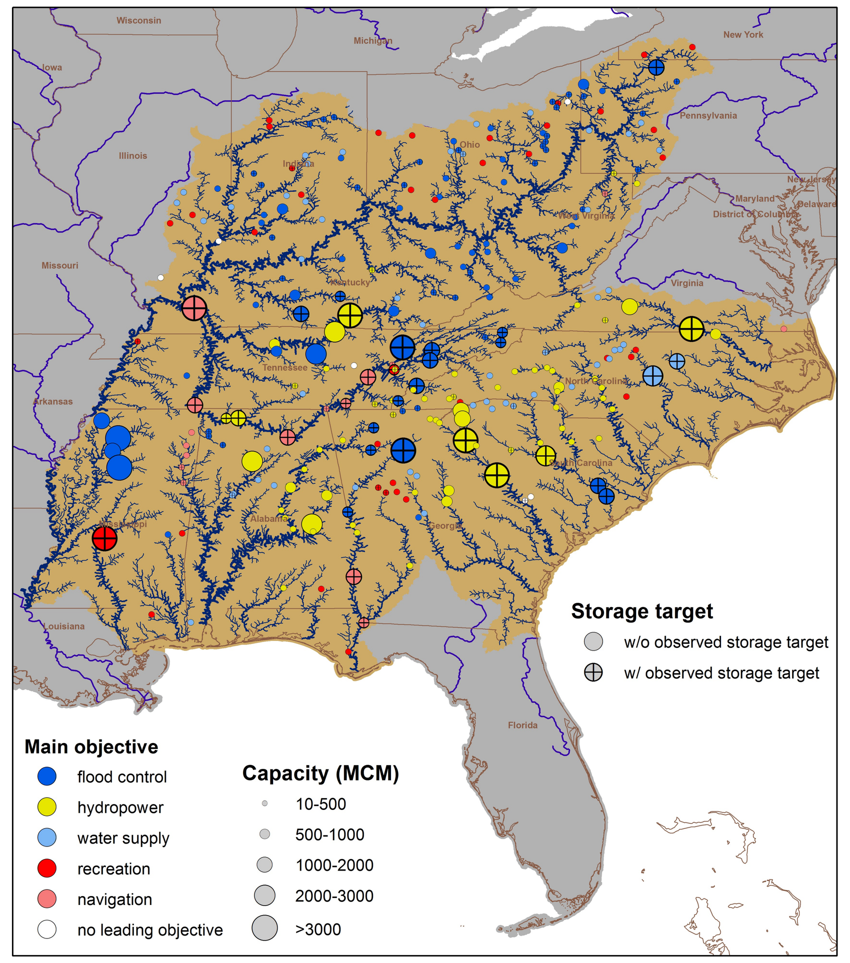
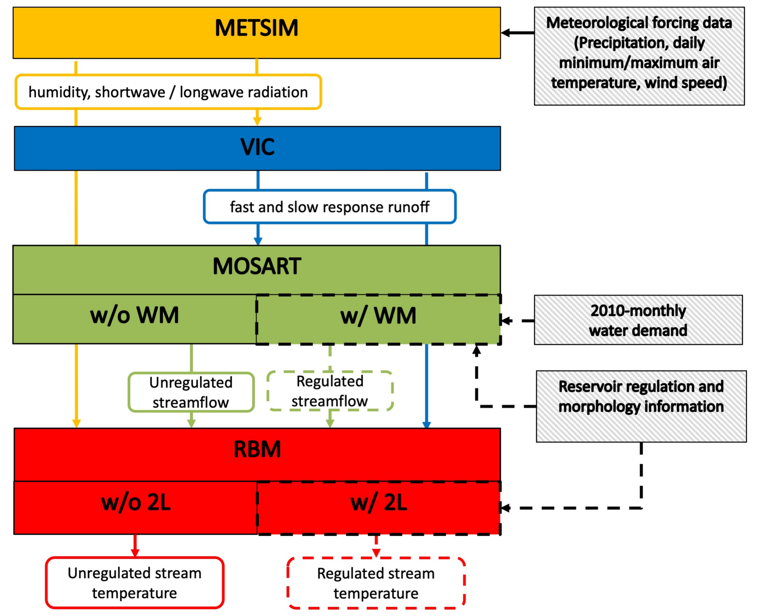
US EIA, 2021: Monthly Energy Review, July 2021. www.eia.gov/mer [Last accessed on 8/3/2021].

Stream Temperature: Southeastern United States



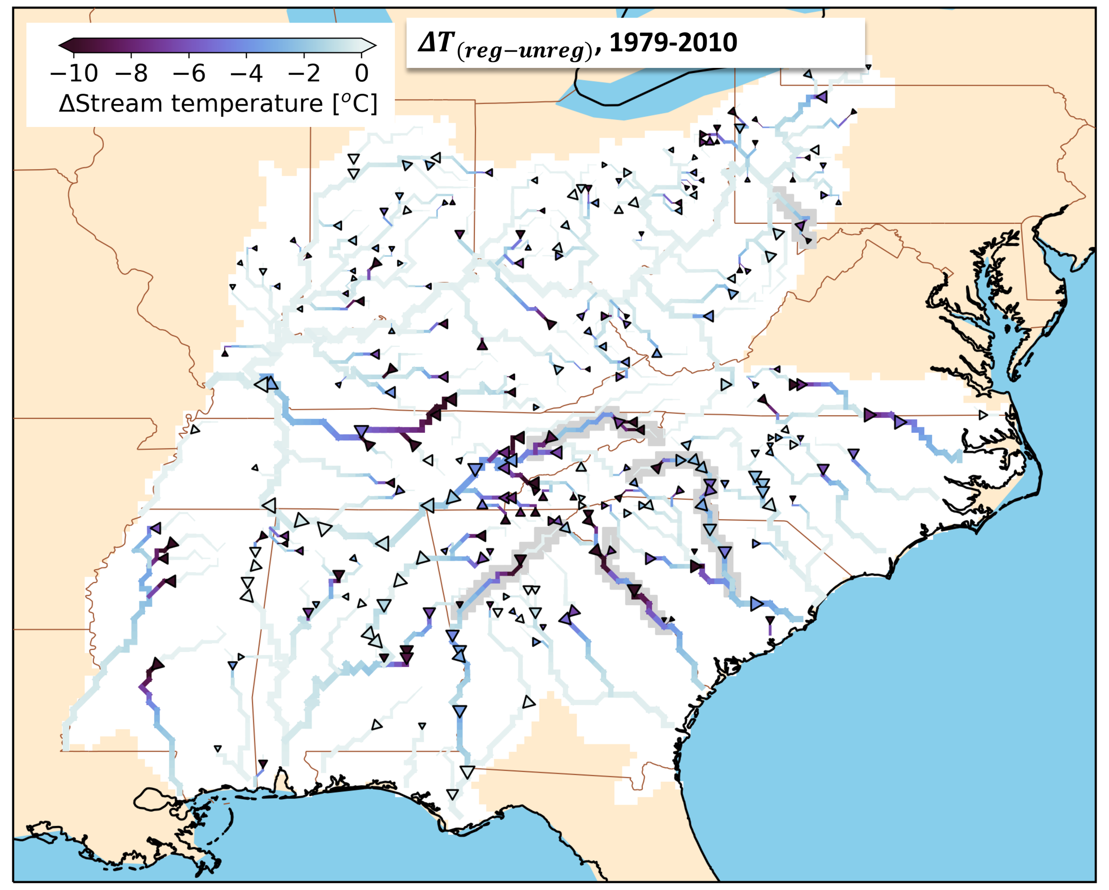
Our study area in the southeastern United States consisted of multiple river basins with 271 individual reservoirs (Cheng et al., 2020a).

We used a series of models (below) to examine the effects of climate change and regulation on stream temperature; explicitly accounting for reservoir stratification on downstream temperature (Niemeyer et al., 2019).

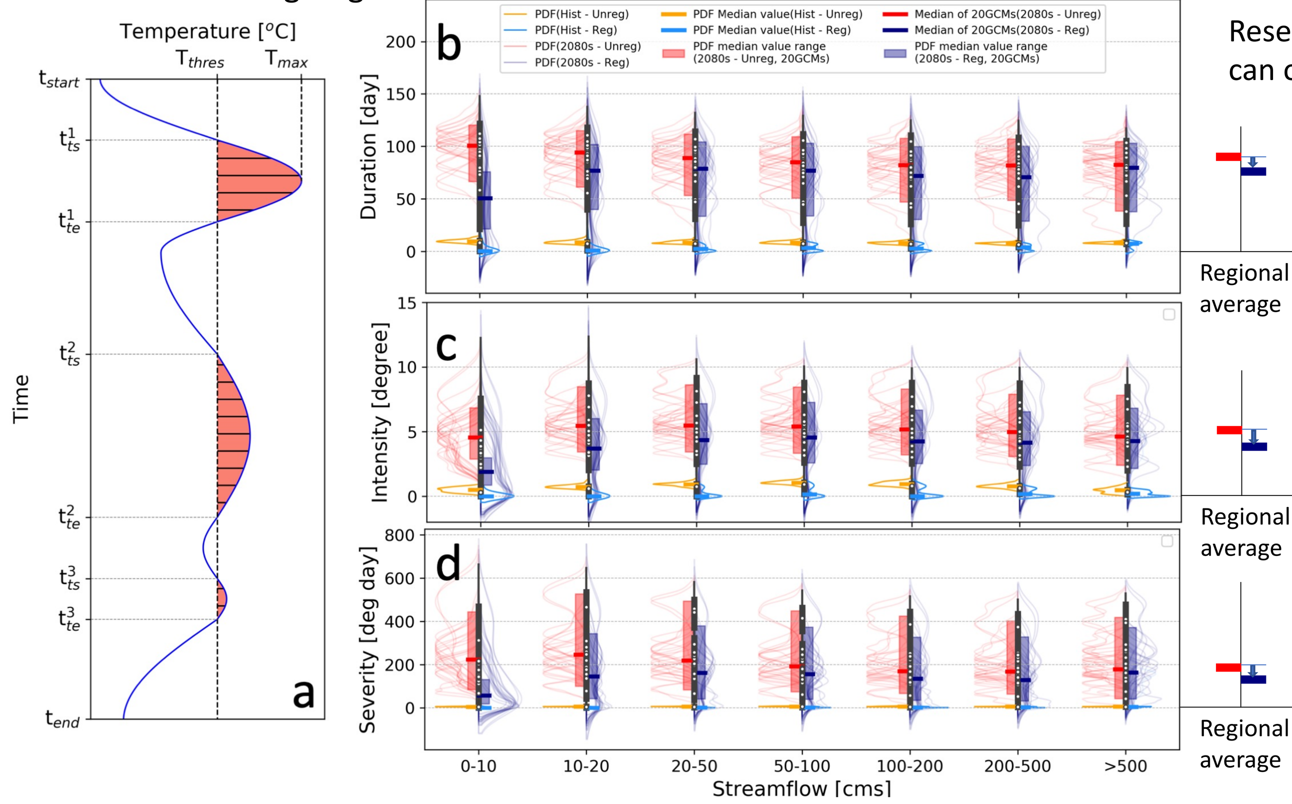


Reservoirs that stratify in summer result in lower downstream stream temperatures during the summer months. This effect dissipates further downstream but can be large immediately downstream of dams.

The figure to the right shows the effect of regulation on modeled warm season stream temperatures for the period 1979-2010.



We then evaluated extremes in stream temperature (duration, intensity, severity) during the summer under climate change (2080s versus historic) for those stream reaches that were affected by regulation. We grouped streams of similar size and calculated changes in extremes with and without regulation. Extremes increased significantly in both unregulated and regulated scenarios and regulation generally dampened only a small part of the climate change signal.



Reservoir regulation can only mitigate:

12.2% of Duration

19.7% of Intensity

26.2% of Severity