Evaluating the impact of inter-basin water transfer on Delaware Estuary salinity with the Energy Exascale Earth System Model

Matthew Cooper[1], Tian Zhou[1], Darren Engwirda[2], Ning Sun[1], Chang Liao[1], and Donghui Xu[1]

[1]Pacific Northwest National Laboratory
[2]Los Alamos National Laboratory

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Abstract

The Delaware River is a major freshwater supplier of New York City (NYC). Nearly half of NYC drinking water is supplied by inter-basin transfer of surface water stored in reservoirs within the upper reaches of the Delaware River. In its lower reaches, the Delaware River is a tidal estuary, and upstream freshwater discharge provides a critical control on estuary salinity. During the record 1950–1960's drought, NYC water withdrawals exacerbated low flows. Estuary salinity reached levels that threatened freshwater intakes and groundwater recharge, resulting in legal action and Supreme Court decrees. We revisit this classic case study in coupled human and natural systems using the Energy Exascale Earth System Model (E3SM). The E3SM water management sub-model is updated to include inter-basin water transfer and reservoir-specific operating rules. Model simulations are developed to investigate competition between NYC water demand and in-stream flow targets needed to maintain estuary salinity within regulatory guidelines under historic and future climate. To our knowledge, this is a first demonstration of an Earth System Model simulation with inter-basin water transfer, which, in this study area, provides water for nearly five million people living outside the Delaware River basin in New York City and New Jersey.

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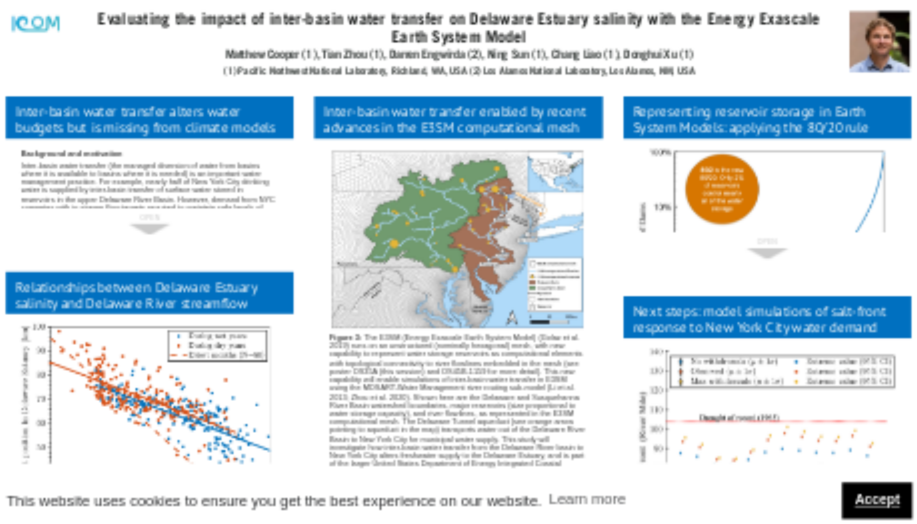

Matthew Cooper (1), Tian Zhou (1), Darren Engwirda (2), Ning Sun (1), Chang Liao (1), Donghui Xu (1)

(1) Pacific Northwest National Laboratory, Richland, WA, USA (2) Los Alamos National Laboratory, Los Alamos, NM, USA

PRESENTED AT:

INTER-BASIN WATER TRANSFER ALTERS WATER BUDGETS BUT IS MISSING FROM CLIMATE MODELS

Background and motivation

The managed transfer of water from basins where it is available to basins where it is needed is an important water management practice known as inter-basin water transfer. For example, nearly half of New York City drinking water is supplied by inter-basin transfer of surface water stored in reservoirs in the upper Delaware River Basin. However, these same reservoirs are managed to meet in-stream flow targets in the Delaware River required to maintain safe levels of salinity in the Delaware Estuary, which competes with demand from NYC (Figure 1 and Figure 3).

Consumptive water use in the Delaware River Basin is dominated by diversions for New York City drinking water

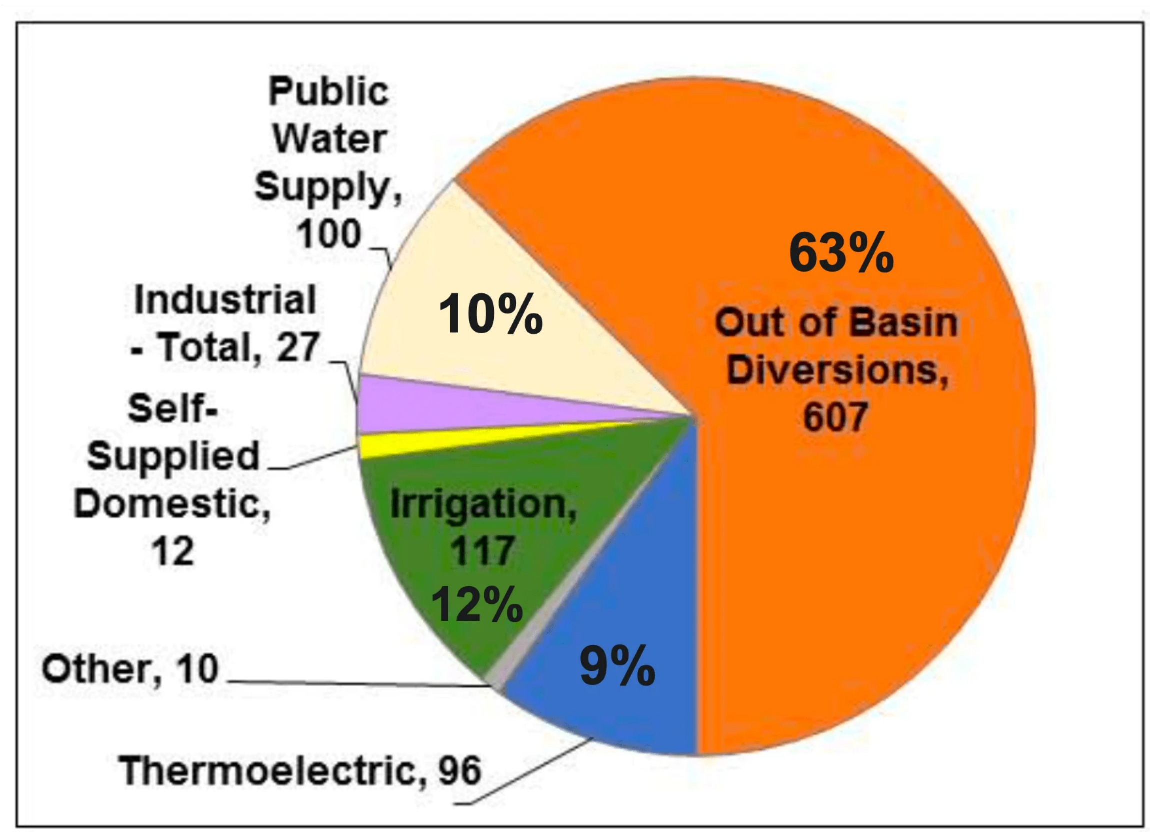

Figure 1: Consumptive water use budget in the Delaware River Basin. About 63% of consumptive water use is allocated to inter-basin (i.e., out-of-basin) diversions, the majority of which is for New York City drinking water, with other significant diversions to New Jersey. Yet, to our knowledge, these inter-basin diversions are not represented in climate model simulations. Units: million gallons per day. Data source: Delaware River Basin Commission.

Historical context

During the record 1950–1960's drought, NYC water withdrawals exacerbated low flows and estuary salinity reached levels that threatened freshwater intakes and groundwater recharge, resulting in legal action that reached the Supreme Court (Wolock et al. 1993). Similar comptetition exists among water users in regions worldwide, but these dynamics are rarely if ever represented in climate model simulations.

We revisit this classic case study in coupled human and natural systems, and demonstrate how inter-basin water transfer is enabled by the representation of water storage reservoirs in the United States Department of Energy's Energy Exascale Earth System Model (E3SM). Together with an initial analysis of historic observations, this new capability will support

E3SM model simulations of inter-basin water transfer in the mid-Atlantic region of the eastern United States.

RELATIONSHIPS BETWEEN DELAWARE ESTUARY SALINITY AND DELAWARE RIVER STREAMFLOW

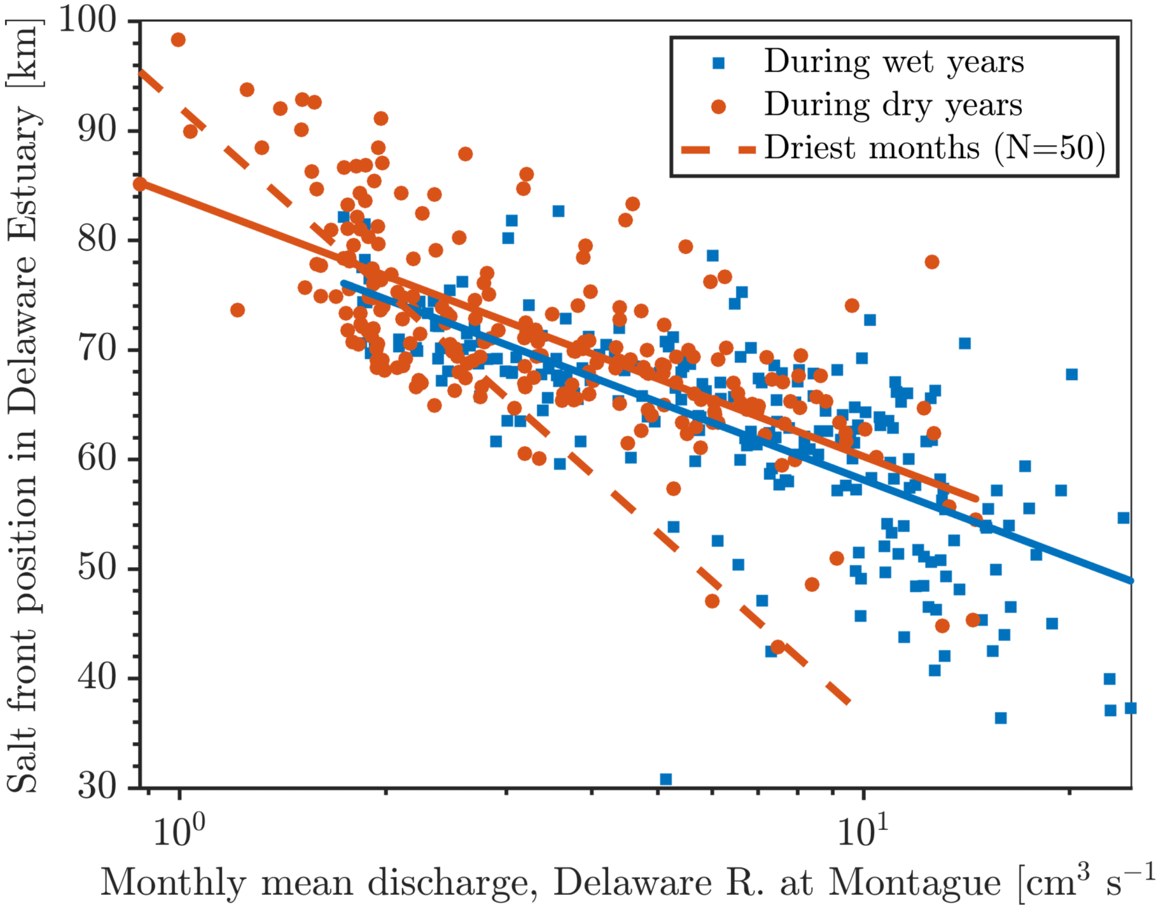

Figure 2: Statistical relationships between the salt front position in the Delaware Estuary (y-axis) and monthly average discharge in the Delaware River (x-axis) measured at Montague, New Jersey during the period 1963-2020. When streamflow is low, the salt-front postion moves further up-river, during both wet years (blue squares) and dry years (orange circles). However, the relationship is stronger in the driest months, as illustrated by a curve fit to the driest 50 months on record (dashed-line). The USGS discharge gage at Montague is located below the diversion to New York City. Discharge levels at Montague are regulated via release from upstream reservoirs and corresponding reduction in NYC water withdrawals to prevent the salt front in the Delaware Estuary from threatening freshwater intakes along the Delaware River downstream of Montague. The salt front is the 250 mg/L isochlor, reported as a 7-d average position in "river kilometers" upstream of an estuary datum, aggregated here to monthly-averages for comparison with monthly average streamflow. Water management is headed by a coalition of water resource managers known as the Delaware River Basin Commission (DRBC). Data source: DRBC (salt front position) and USGS (discharge).

For details on the E3SM computational mesh see poster OS35A (this session) and OS45B-1159.

INTER-BASIN WATER TRANSFER TO BE ENABLED BY ADVANCES IN THE E3SM COMPUTATIONAL MESH

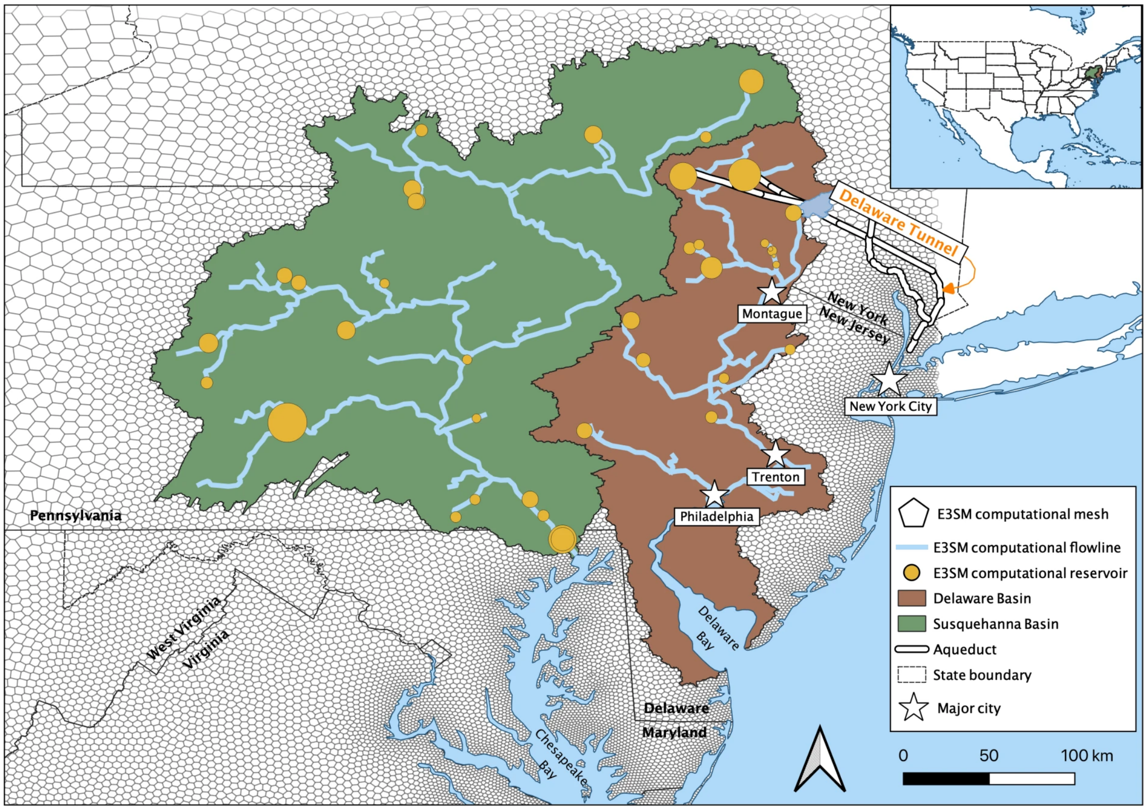

Figure 3: The E3SM (Energy Exascale Earth System Model) (Golaz et al. 2019) runs on an unstructured (nominally hexagonal) mesh, with new capability to represent water storage reservoirs as computational elements with topological connectivity to river flowlines embedded in the mesh (see poster OS35A (this session) and OS45B-1159 for more detail). This new capability will enable simulations of inter-basin water transfer in E3SM using the MOSART-Water Management river routing sub-model (Li et al. 2013; Zhou et al. 2020). Shown here are the Delaware and Susquehanna River Basin watershed boundaries, major reservoirs (size proportional to water storage capacity), and river flowlines, as represented in the E3SM computational mesh. The Delaware Tunnel aqueduct (see orange arrow pointing to aqueduct in the map) transports water out of the Delaware River Basin to New York City for municipal water supply. This study will investigate how inter-basin water transfer from the Delaware River basin to New York City alters freshwater supply to the Delaware Estuary, and is part of the larger United States Department of Energy Integrated Coastal Modeling (ICoM) project focused on the mid-Atlantic region of the eastern United States.

REPRESENTING RESERVOIR STORAGE IN EARTH SYSTEM MODELS: APPLYING THE 80/20 RULE

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1639518669/agu-fm2021/25-D3-B5-D1-C4-49-BF-AC-AD-D0-7F-30-41-40-83-42/Video/cooper_agu_2021_icom_narration_compressed_qw3xt9.mp4

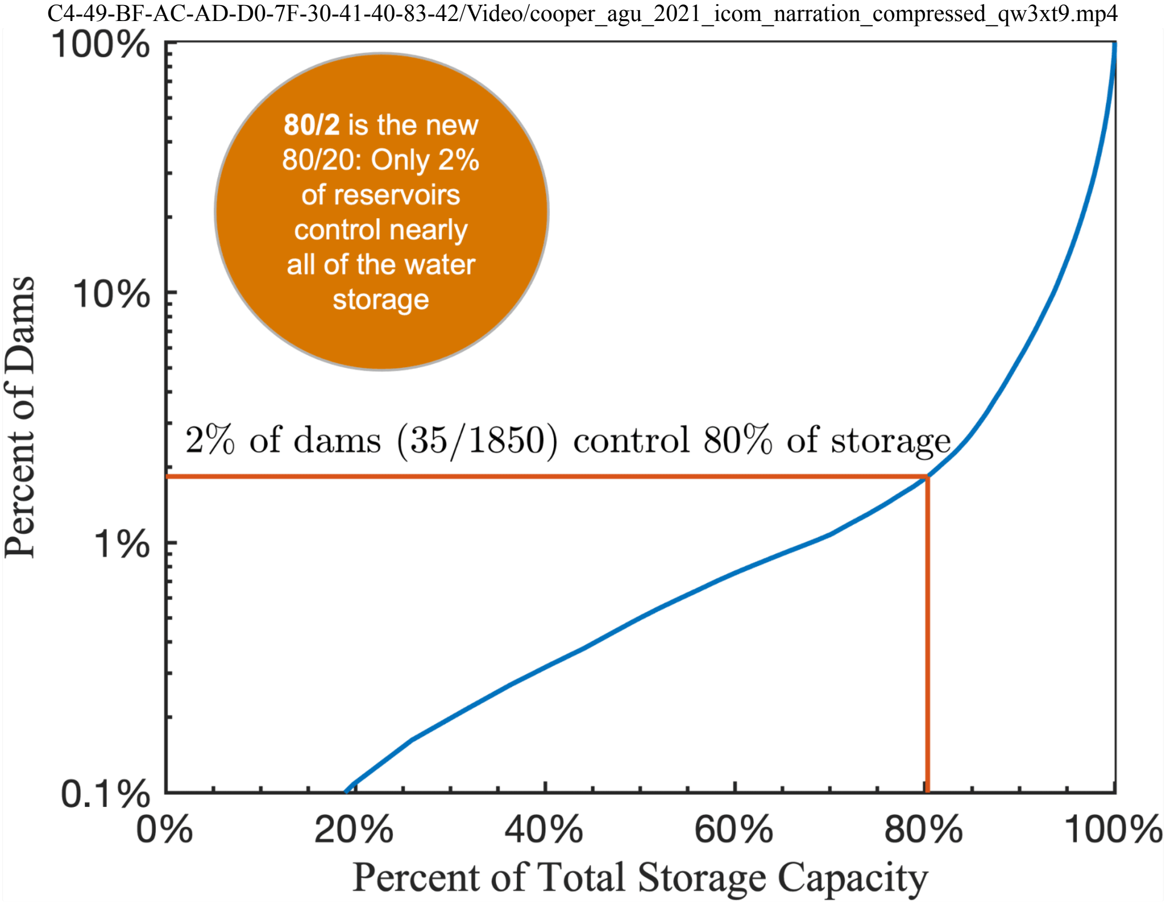

Figure 4: There are 1850 reservoirs in the Delaware and Susquehanna River basins, but just 35 of them (2%) control 80% of the total water storage capacity. This suggests that the effect of reservoir water storage on water budgets can be represented by a relatively small number of dams in this region, an important computational consideration for Earth System Models. These 35 reservoirs are embedded in the E3SM computational mesh, permitting simulations of water storage, release, and diversions along computational river flowlines (see orange circles proportional to reservoir storage capacity, Figure 3).

NEXT STEPS: MODEL SIMULATIONS OF SALT-FRONT RESPONSE TO NEW YORK CITY WATER DEMAND

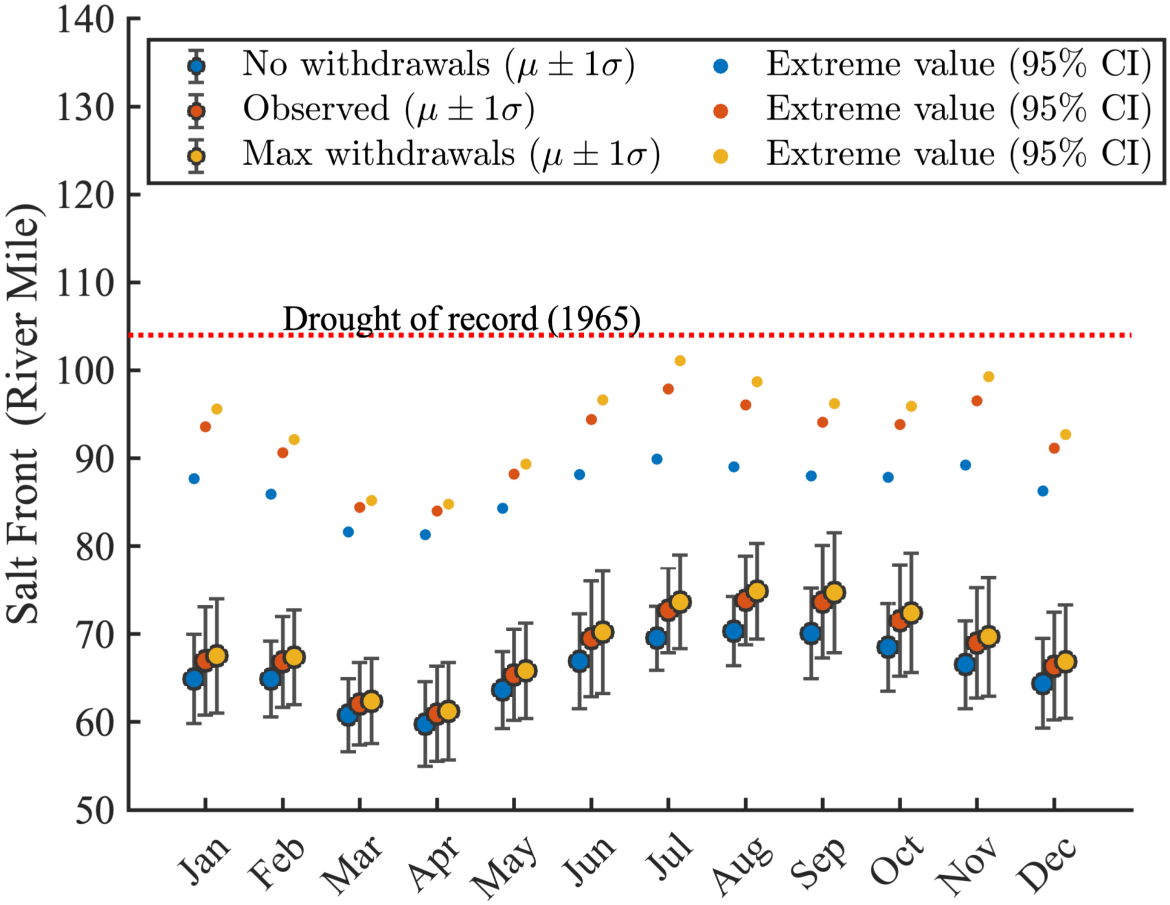

Figure 5: Mean monthly values of observed salt front position in the Delaware Estuary compared with two counterfactual scenarios: 1) no NYC water withdrawals, and 2) maximum allowed withdrawals. The counterfactuals were generated by 1) adding back reported values of NYC withdrawals to observed streamflow records, and 2) subtracting maximum allowed NYC withdrawals from observed streamflow records, and then predicting salt front position with the statistical relationship between observed river discharge and salt front position during 1964-2020 (Fig. 2). Each monthly box-and-whisker plot shows the mean monthly salt front position plus or minus one standard deviation, and an outlier representing the 95% prediction interval. The horizontal dashed line is an extreme salt front position recorded during the record 1965 drought, when the salt front moved up the estuary and threatened freshwater intakes for Philadelphia and surrounding municipalities. This preliminary analysis suggests NYC withdrawals may already approach maximum allowable values. In the next stage of this study, we will use the E3SM model to explore tradeoffs between New York City withdrawals and estuary salinity under current and future climate.

Conclusions

- Inter-basin water transfer is an important water management practice which, in this study area, provides water for nearly five million people living in New York City and New Jersey.
- Similar inter-basin arrangements exist in regions worldwide, yet these dynamics are rarely if ever represented in climate model simulations.
- The United States Department of Energy's Energy Exascale Earth Sytem Model (E3SM) was updated to include water storage reservoirs as computational elements linked to flowlines.
- An initial analysis determined that just 2% of reservoirs store ~80% of water in this region, and that water transfers from these reservoirs to NYC may already approach levels above which salinity in the Delaware

Estuary threatens freshwater intakes and groundwater recharge.

- Together, these findings will enable the representation of controlled release and diversion from reservoirs, and model simulations of inter-basin water transfer under future climate scenarios in the mid-Atlantic region of the United States.

Acknowledgements

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Please contact Matthew Cooper (matt.cooper@pnnl.gov) with questions.

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