Quantifying the Impact of Dams on Floods and Nutrient Flux in the Lamprey River Watershed

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Dams and Nutrients

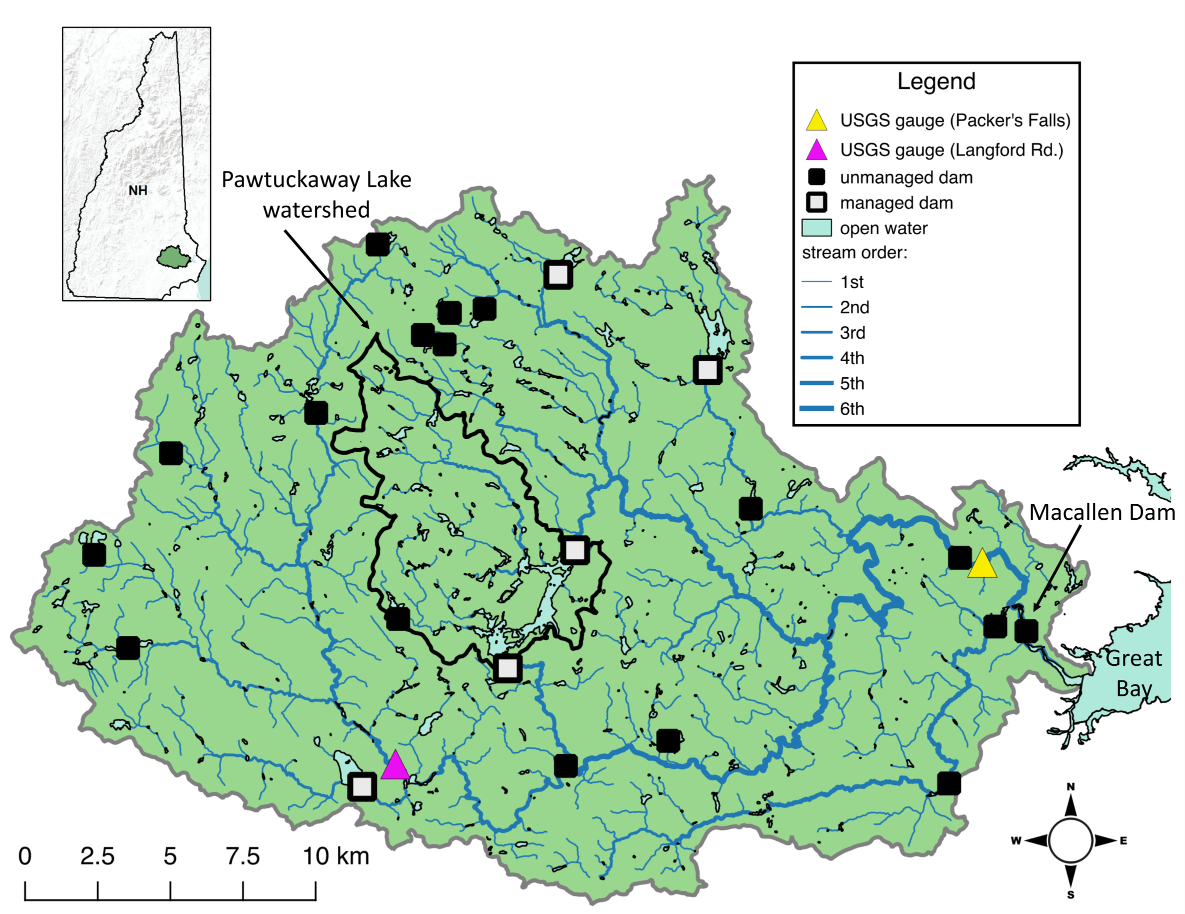
Attenuation of nitrogen by river networks is an important ecosystem service to mitigate eutrophication at vulnerable coastal estuaries downstream (Boyer et al. 2002). Dam reservoirs increase the residence time of water, effectively increasing the amount of nitrogen removed via denitrification as compared to a free-flowing river channel (Seitzenger et al. 2002). In addition, dams substantially change the flow regime of rivers, including reducing the magnitude of high-flow events downstream of an impoundment (Magilligan et al. 2005).

Drowns Dam, Nottingham, NH

Macallen Dam, Newmarket, NH

Lamprey River watershed

The Lamprey River watershed contains many active dams ranging in height from 1 to 10 m, some of which are being considered for removal. The Lamprey is also the largest contributor of nitrogen from non-point sources to the Great Bay Estuary, which is experiencing increased algae blooms and decreased eel grass habitat in part due to elevated levels of nitrogen (NHDES 2012). Flooding in the Lamprey River has been problematic and is expected to increase in the future due to changes in land use and climate (Wake 2013). Excessively low flow can stress aquatic organisms, leading to NHDES piloting instream flow regulation in the Lamprey (NHDES 2013). Making decisions about managing and removing dams in the Lamprey River watershed requires weighing tradeoffs between nutrient fluxes, flow duration and magnitude, water supply, recreation, and fish passage.



Map plotted in QGIS 2.14 with USGS National Hydrography river flow lines and NID and EPSCoR Dam Inventory.

Acknowledgements

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Field Measurements of Reservoir N Retention

Nitrogen retention was estimated at Pawtuckaway Lake from May 2018 to May 2019.

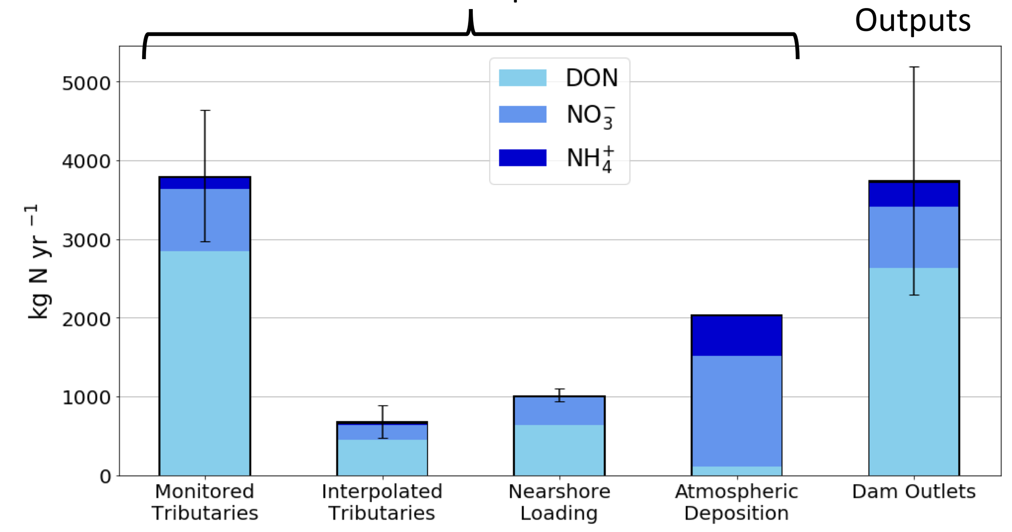
$$\text{Retention} = \frac{\text{Inputs} - \text{Outputs}}{\text{Inputs}}$$

Reservoir Inputs:

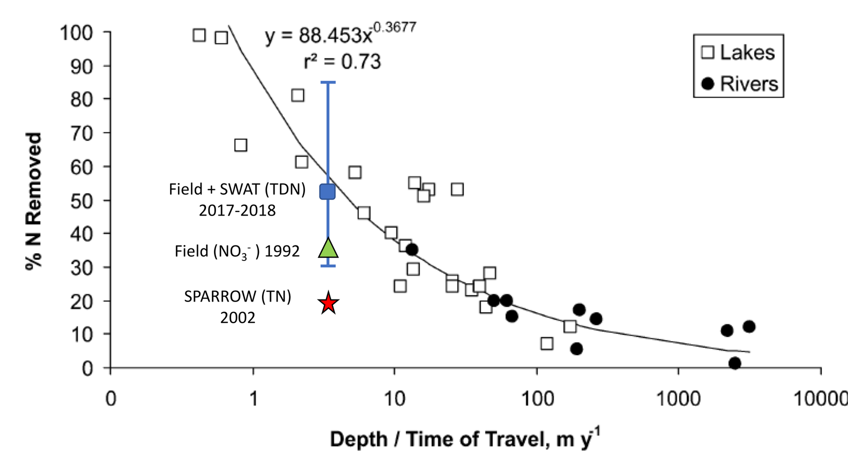
- Tributaries
- Nearshore Runoff
- Nearshore Groundwater Seepage
- Atmospheric Deposition
- Sediment Loading

Reservoir Outputs:

- Dam Outlets
- Groundwater Leaving



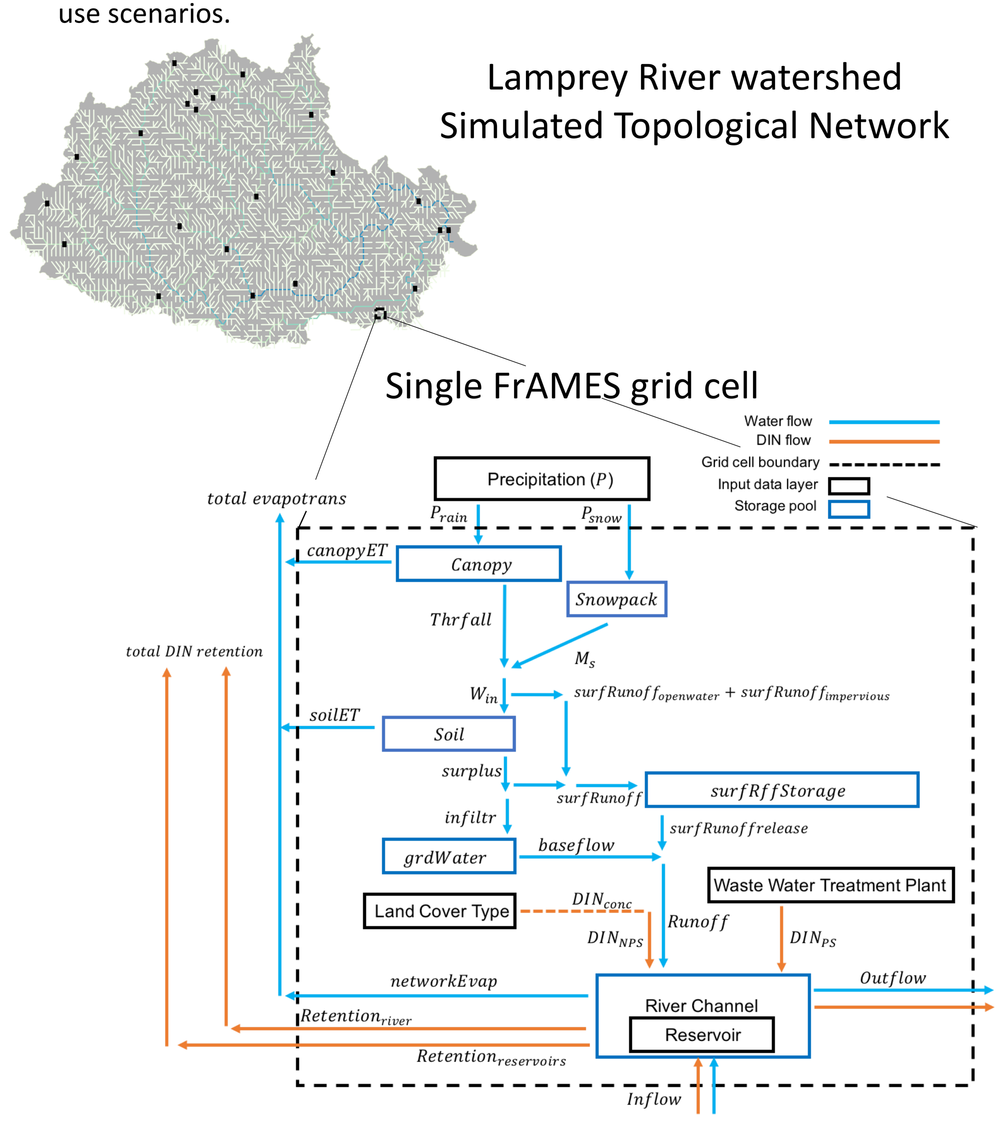
Nitrogen inputs and outputs estimated at Pawtuckaway Lake from 05-19-2017 to 05-18-2018.



Empirical relationship between fraction of nitrogen removed and the ratio of water depth to residence time from a meta-analysis of river and lake studies (Seitzenger et al. 2002). Blue square represents estimates of total dissolved nitrogen retention (TDM) of Pawtuckaway Lake from this study. Green triangle represents estimates of nitrate retention by a NH DES study of Pawtuckaway Lake (NHDES 1995). Red star represents estimates of total nitrogen (TN) retention from the SPARROW model developed for the northeastern United States. (Moore et al. 2011)

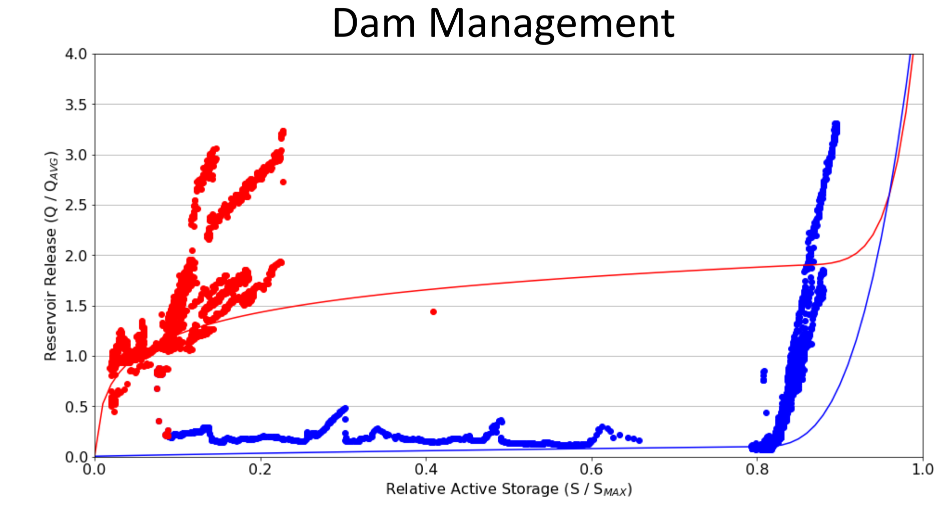
Modeling Methods: FrAMES

- The numerical hydrological and biogeochemical model FrAMES (Framework for Aquatic Modeling in the Earth System) was calibrated and validated for the Lamprey River watershed.
- FrAMES was calibrated using observed historical data.
- Model output (mean daily discharge and summer and winter dissolved inorganic nitrogen flux) was then compared under various dam management, climate, and land use scenarios.

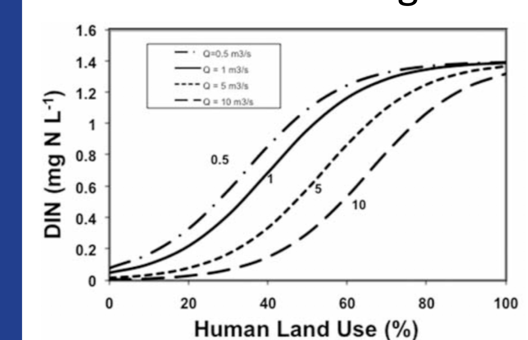


Modeling Assumptions

Dam Management

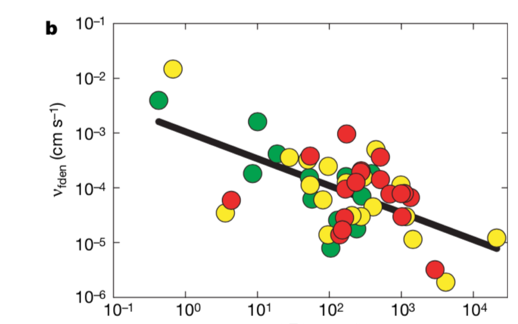


DIN Loading



Wollheim et al. 2008

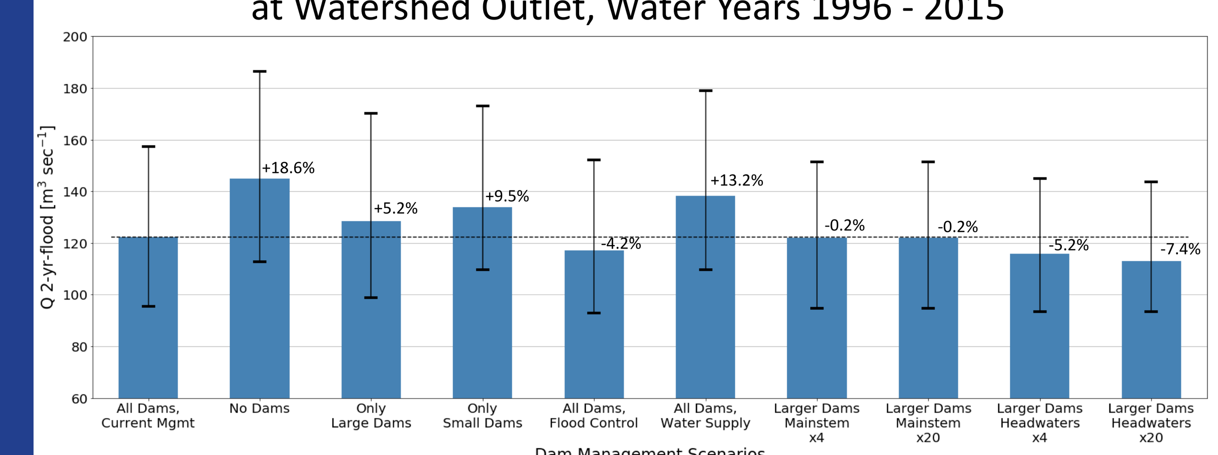
DIN Retention from River Network



Mulholland et al. 2008

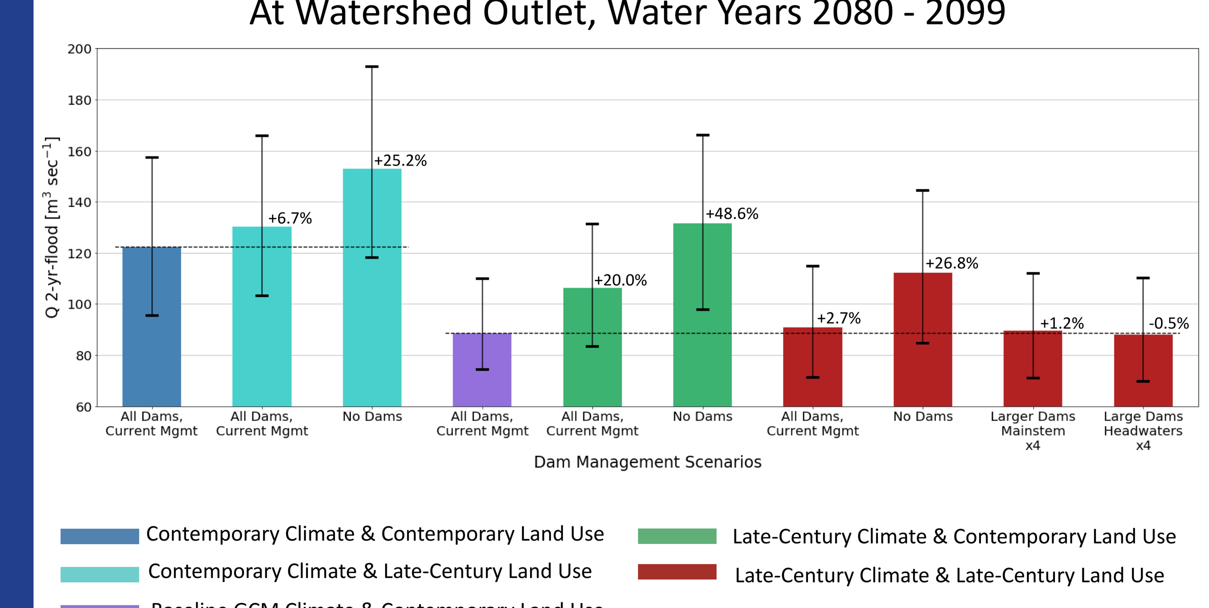
Modeling Results: Flood Magnitude

Two-Year Flood Magnitude Contemporary Scenarios at Watershed Outlet, Water Years 1996 - 2015



- A network of dams decreases the magnitude of the two-year flood event on average by 18%.
- Larger dams decrease floods more than smaller dams within the watershed.
- Different dam operations affect flood flow magnitudes.
- Increasing the size of reservoirs in the headwaters reduced flood flow magnitude, while increasing the size of reservoirs along the lower mainstem had little effect.

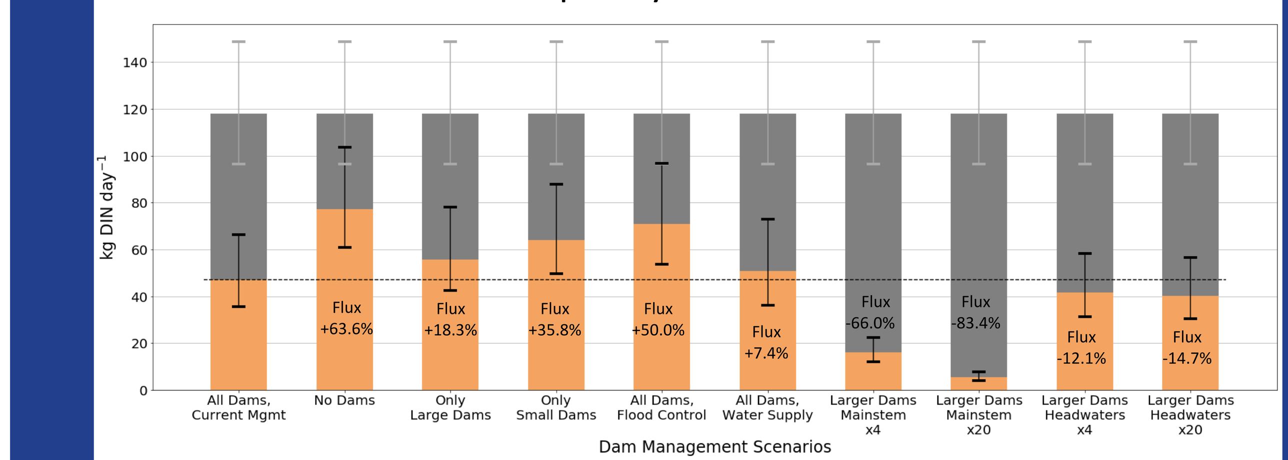
Two-Year Flood Magnitude Late-Century Scenarios At Watershed Outlet, Water Years 2080 - 2099



- Projected increases in impervious surfaces result in 6.7% larger floods
- Projected increases in precipitation intensity result in 20% larger floods.
- Dam removal could further exacerbate floods when combined with changes in land use and/or climate. Conversely, increases in reservoir storage could mitigate projected flood increases.

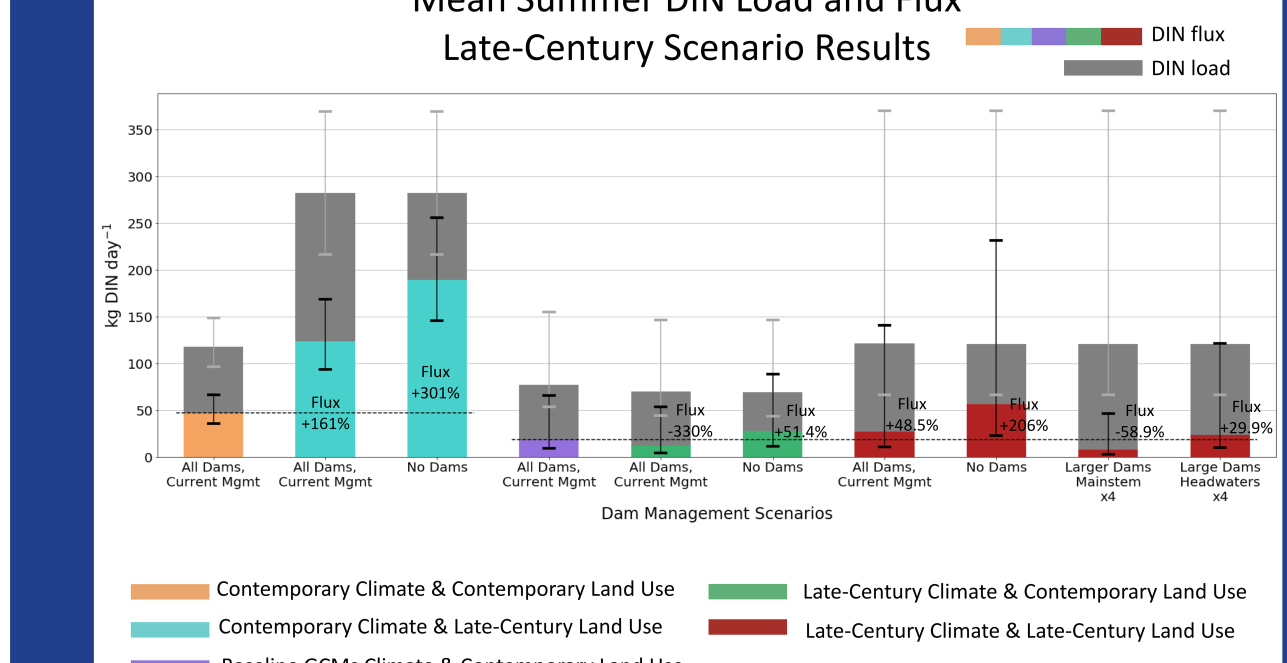
Modeling Results: Nutrient Retention

Mean Summer DIN Load and Flux Contemporary Scenario Results



- A network of dams increases in-stream dissolved inorganic nitrogen (DIN) retention within the watershed during both summer and winter seasons.
- Larger dams retain more DIN than smaller dams.
- Dam operations can significantly alter DIN retention within the watershed.
- Increasing the size of reservoirs along the lower mainstem retained the most DIN compared to all other scenarios.

Mean Summer DIN Load and Flux Late-Century Scenario Results



- With projected land use, DIN loaded to the river network will increase; thus the dam network will retain more DIN, but less efficiently.
- With projected climate, more DIN is retained by the dam network and the river network as a result of higher air temperatures.
- DIN retention by the dam network with the combination of future land and climate results in similar trends with contemporary scenarios; however, there is large model uncertainty.

Conclusions

- Model results will be used to construct relationships between the distribution and size of reservoirs, land use, and DIN retention within the Lamprey River watershed.

DIN Reservoir Retention