Dams and Hydrologic Regime in the Penobscot River: A reappraisal based on historical records and hydrologic modeling

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Introduction:

The Penobscot River Watershed has a long history of hydrologic alteration by humans. Dams, and the logging / mill industries that built them, have caused large changes to land use and surface water storage throughout the watershed. These modifications can influence runoff and routing processes, changing the timing and magnitude of downstream flows. The Penobscot also has a large variety of dam types (i.e. storage, run-of-river) built for different purposes (i.e. flood control, hydropower), by different stakeholders (i.e. timber industry, utilities), which we hypothesize will have different influences on downstream flow regime.

As part of the larger Future of Dams project, and in concert with our collaborators throughout the New England Sustainability Consortium, we focus our research on providing stakeholders with tools to facilitate better-informed decisions about dams. Towards this ultimate goal, the research we present here is targeted at quantifying changes to hydrologic regime in the context of varied dam management, so that stakeholders can better understand the interaction between dam management decisions and downstream surface water flows. We ask 1) how have dam management decisions altered hydrologic regime throughout the history of this watershed, 2) can changes in watershed characteristics be identified through comparison of simulated and measured discharge.

We present two approaches to quantifying interactions between dams (and dam-related activities such as logging) and downstream flow. The first uses a hydrologic model to identify when changes have occurred in a watershed. We use the Kingsbury Stream, a tributary of the Piscataquis River, as a case study for this approach because it has nearby discharge and precipitation measurements, and because its watershed characteristics are similar to those in the larger Penobscot Watershed. Our second approach uses USGS gauge data at other locations in the Penobscot to measure changes to flow regime relative to changes in upstream river or land use, such as dam construction or log drives. Together these analyses fill in gaps in our quantitative understanding of the Penobscot River, its changes throughout history, and the implications of potential dam management decisions for downstream surface water flows.

Study Area:

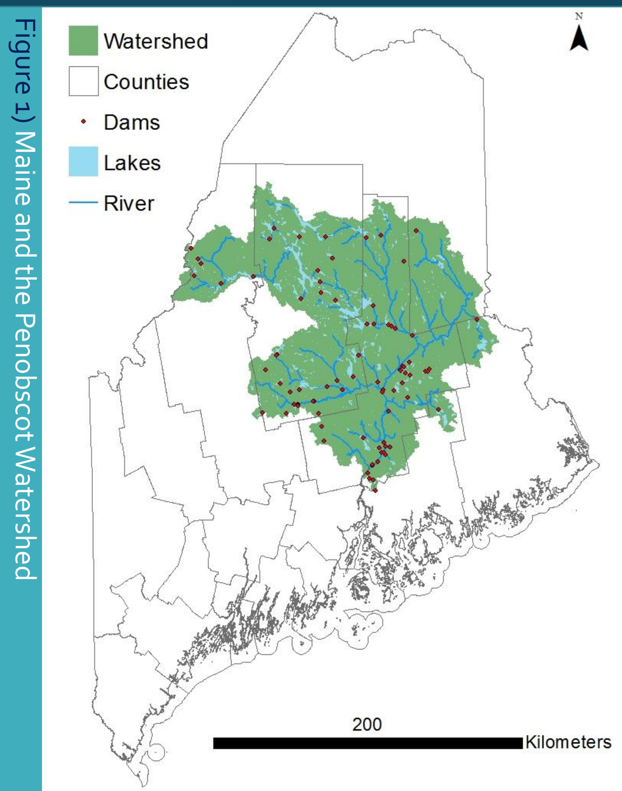
Penobscot River Watershed

- 22,300 km²
- 20 USGS river gauges
- ~120 dams (41 Run of River & 79 Storage)
  - 19 of which have hydrologically adjacent downstream gauges
  - 5 of which have records before & after dam construction

Kingsbury Stream Watershed

- Tributary to the Piscataquis in Abbot, ME
- 247 km²
- 1 gauge (At outlet in Abbot, ME)
- 1 dam (storage)

Figure 1) Maine and the Penobscot Watershed



Objectives & Applications:

Identify periods of change in watershed characteristics, caused by dams, landuse change, or climate.

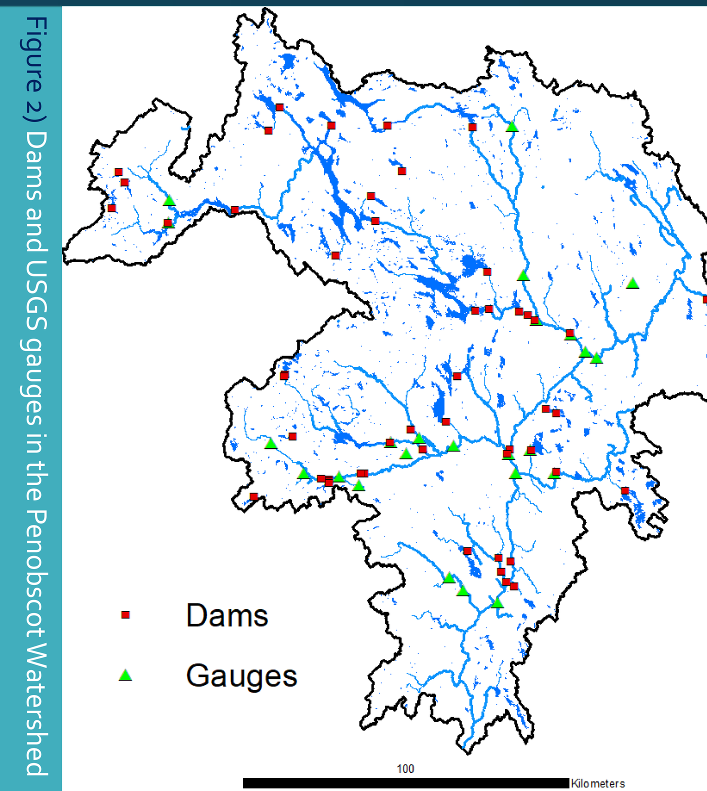
Quantify change to downstream flow regime related to known periods of change in watershed characteristics

Apply discharge information to other useful hydrologic metrics of interest to…

- power generation, via stream power
- channel habitat, via hydraulic geometry for channel width, depth, and velocity
  - Using relations developed by Dudley, 2004

Estimate flow regime for the Penobscot in an un-dammed scenario

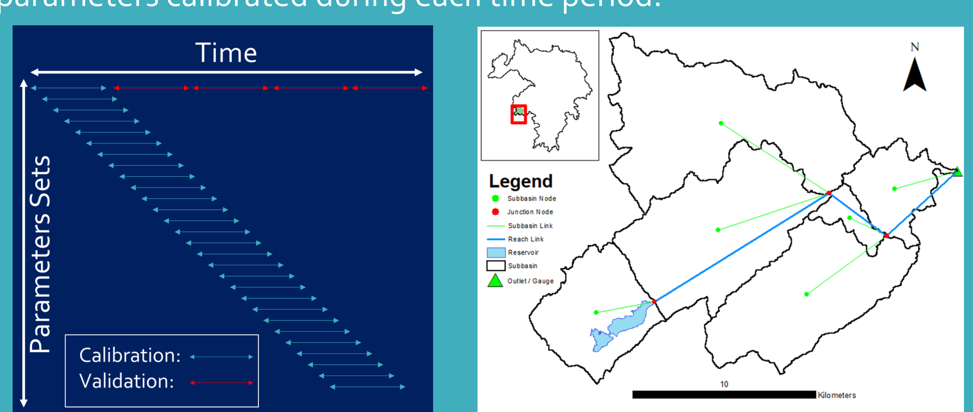
Figure 2) Dams and USGS gauges in the Penobscot Watershed



Approach 1, Hydrology → History: Identifying periods of change in the Kingsbury Stream based on hydrologic model performance.

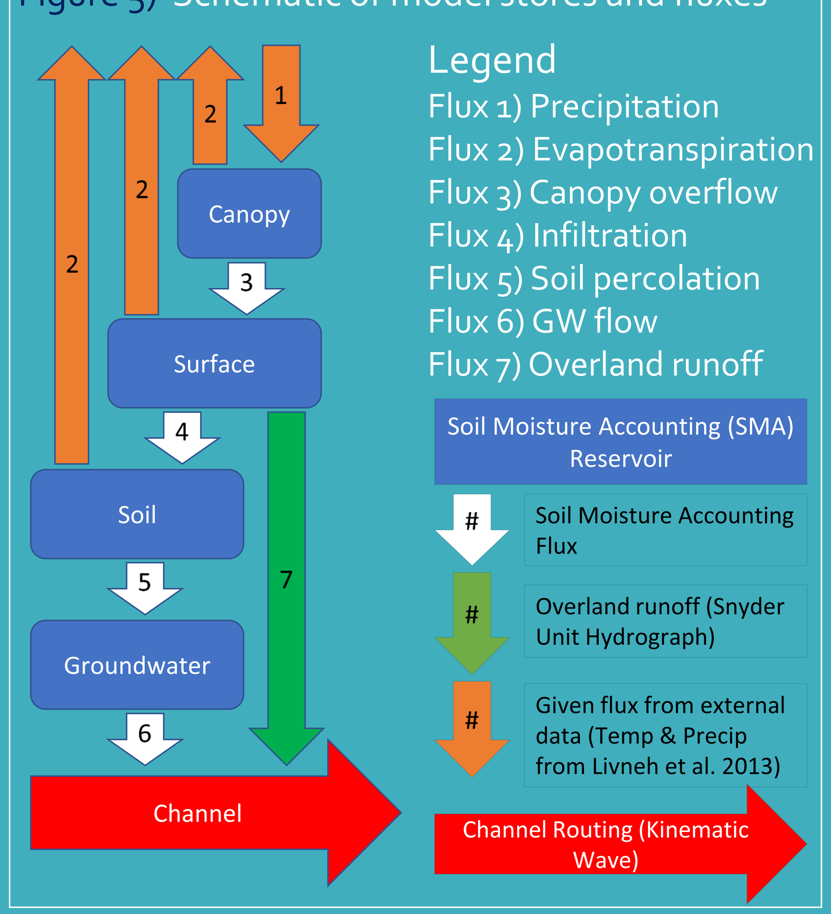
Methods:

- Simulate surface water discharge: Calculate landscape storage, runoff, and routing of water based on daily precipitation and evapotranspiration data, using a HEC-HMS hydrologic model.
- Calibrate model parameters: Adjust parameters so that simulated discharge more closely matches measured discharge, using automated Nelder-Mead search method in HEC-HMS.
- Evaluate performance over time: Measure the difference between measured and simulated time-series using the Nash-Sutcliffe Efficiency (NSE) index over a rolling-window of time periods, and with different parameters calibrated during each time period.



Figures 3-4) Conceptual diagram of rolling-window calibration approach, and map of Kingsbury Watershed with HEC-HMS basin model elements

Figure 5) Schematic of model stores and fluxes



Results:

Figures 6-8) Simulated and measured hydrographs of the Kingsbury Stream over the full available record, and years of relatively good and poor performance

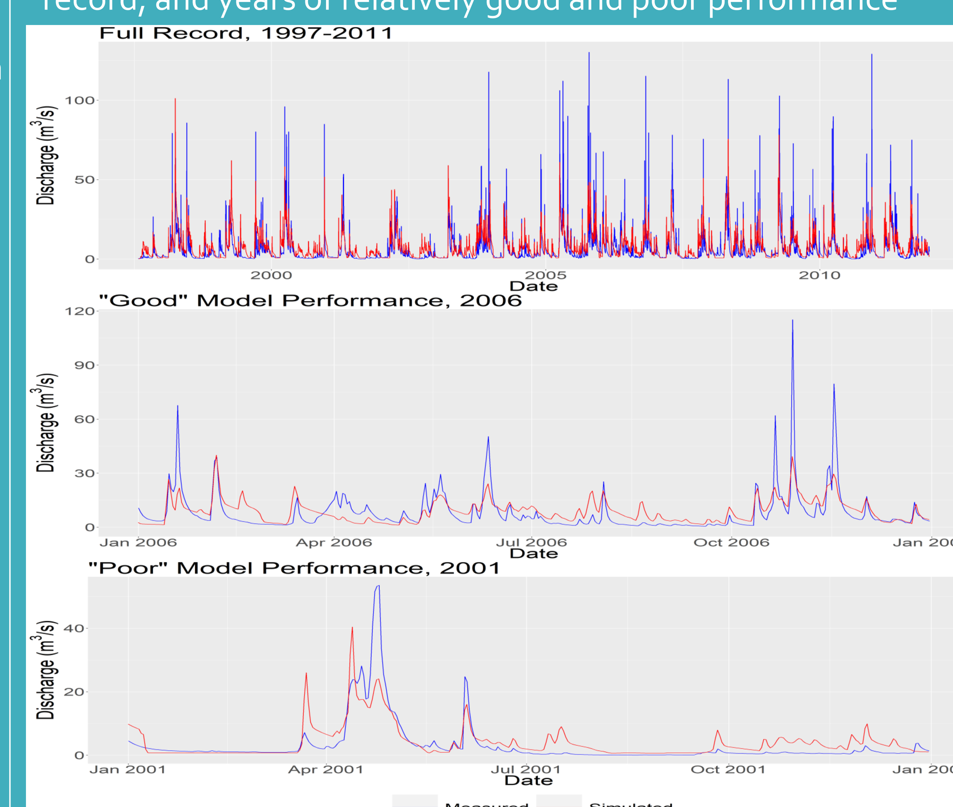
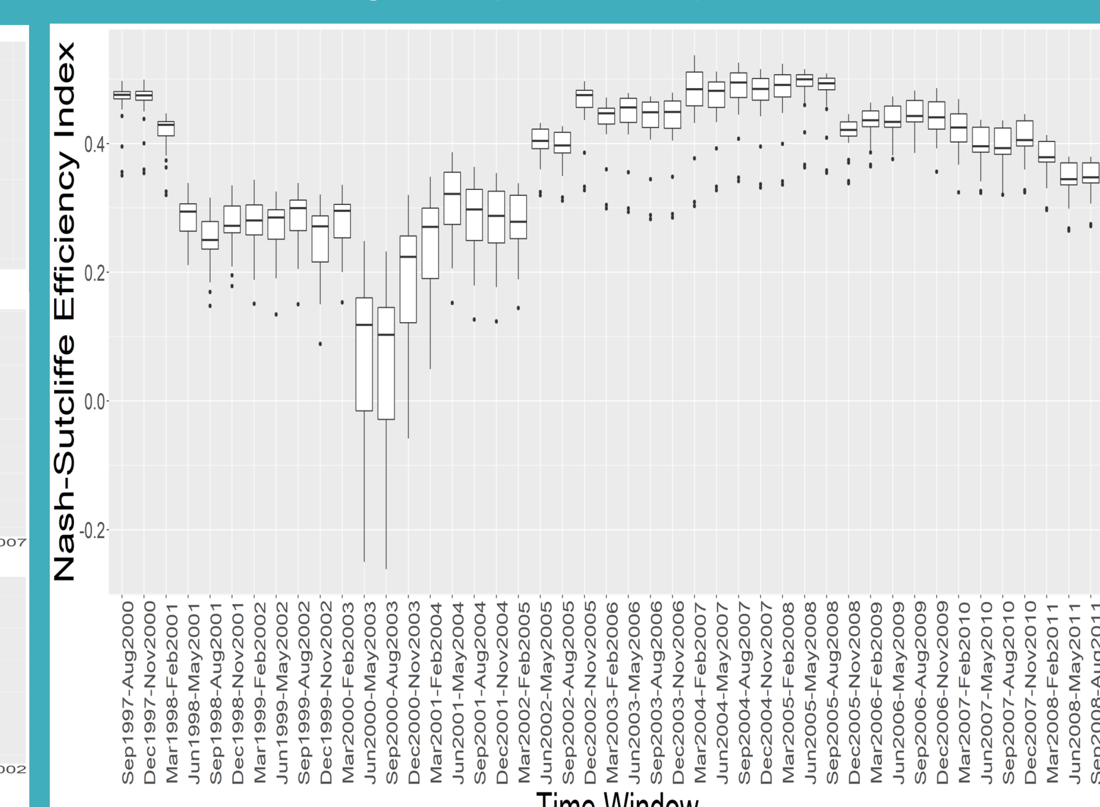
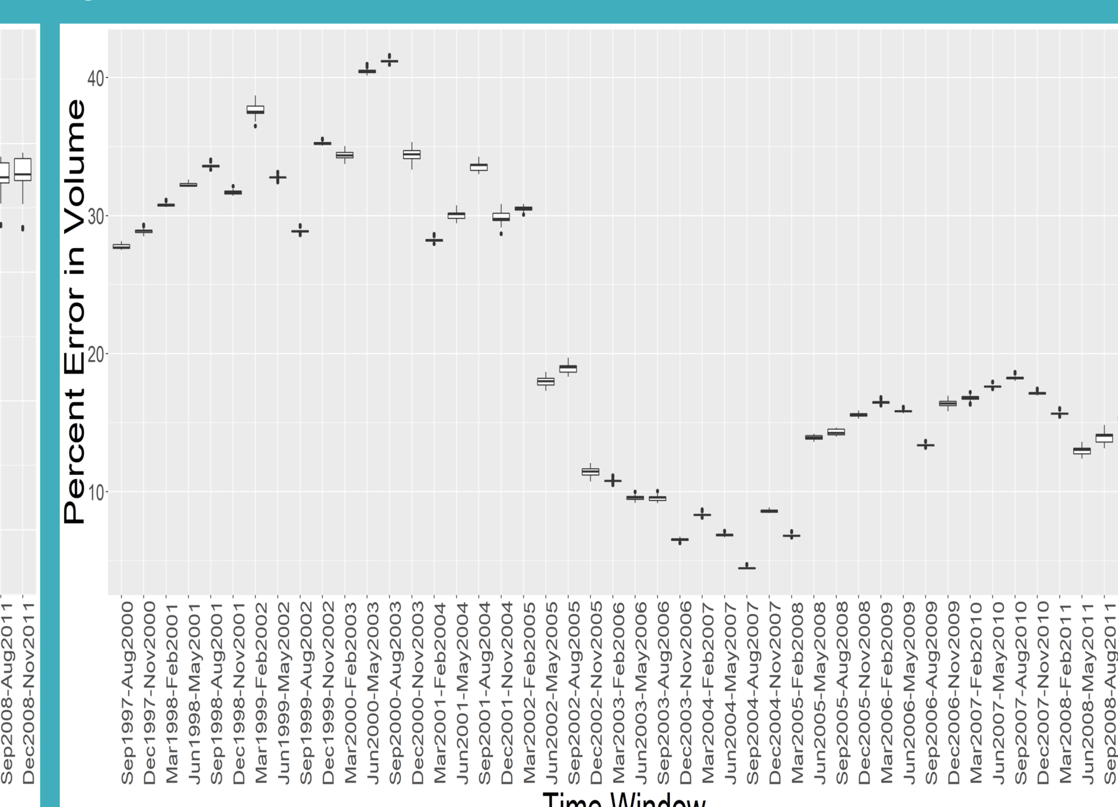


Figure 9-10) Model performance over rolling window. Each value in each boxplot is of a comparison between simulated and measured discharge (left: NSE, right: percent error in total runoff volume) resulting from simulations run with 46 different parameter sets for the Kingsbury Stream HEC-HMS model over a single time period. Each parameter set is calibrated during one time-window, and then validated over all other time-windows.





Approach 2, History → Hydrology: Quantifying changes to downstream flow patterns before and after changes to dam management.

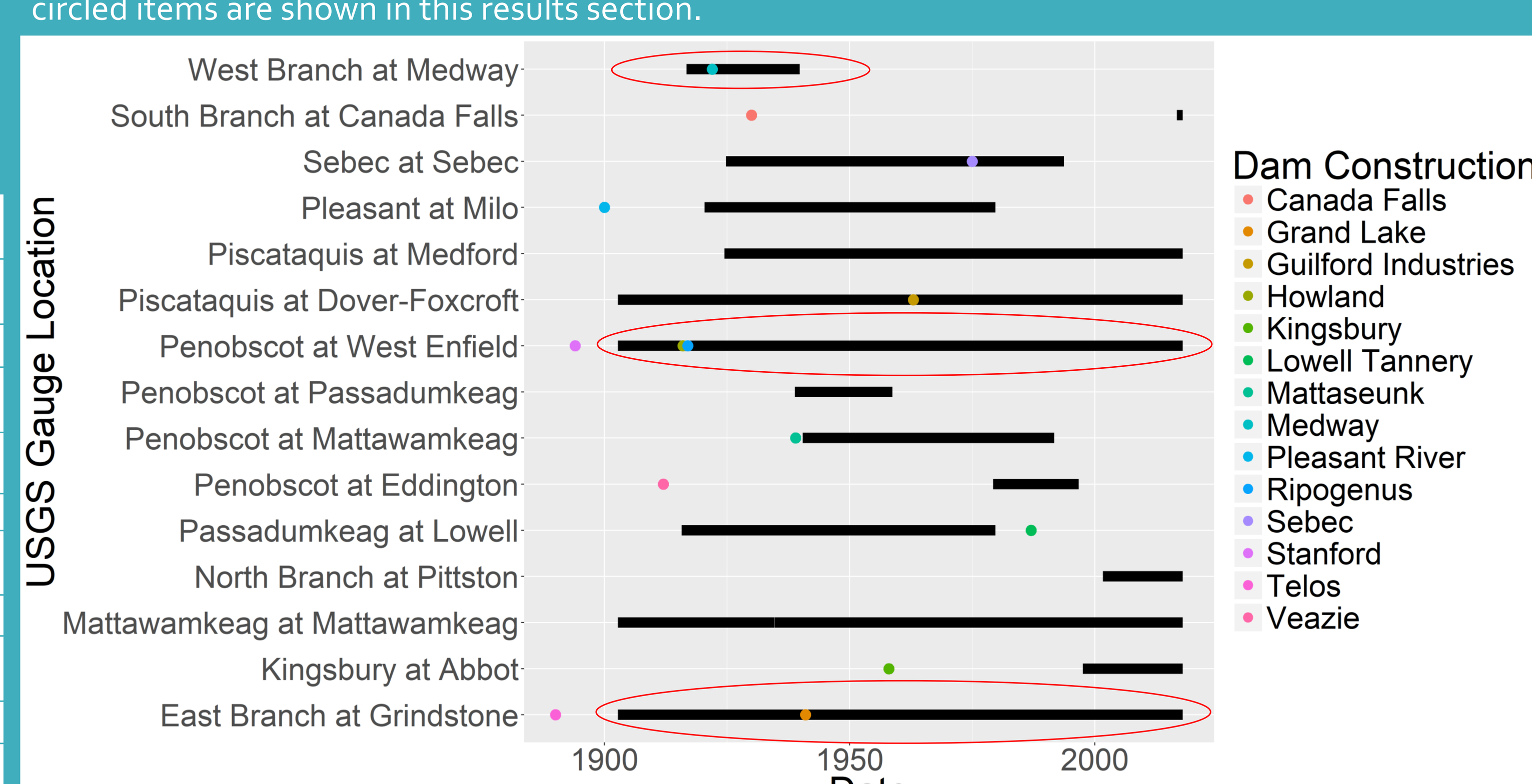
Methods:

- Compile discharge measurements from all USGS gauge data in the Penobscot Watershed
- Compile spatial and historical data relating to dams and their stakeholders
- Quantify the change in flow regime relative to known changes in watershed history
- Characterize flow regime using Flow Duration Curves (cumulative probability distributions)

Table 1) Sites with a dam nearby upstream from, and overlapping the record of, a USGS gauge.

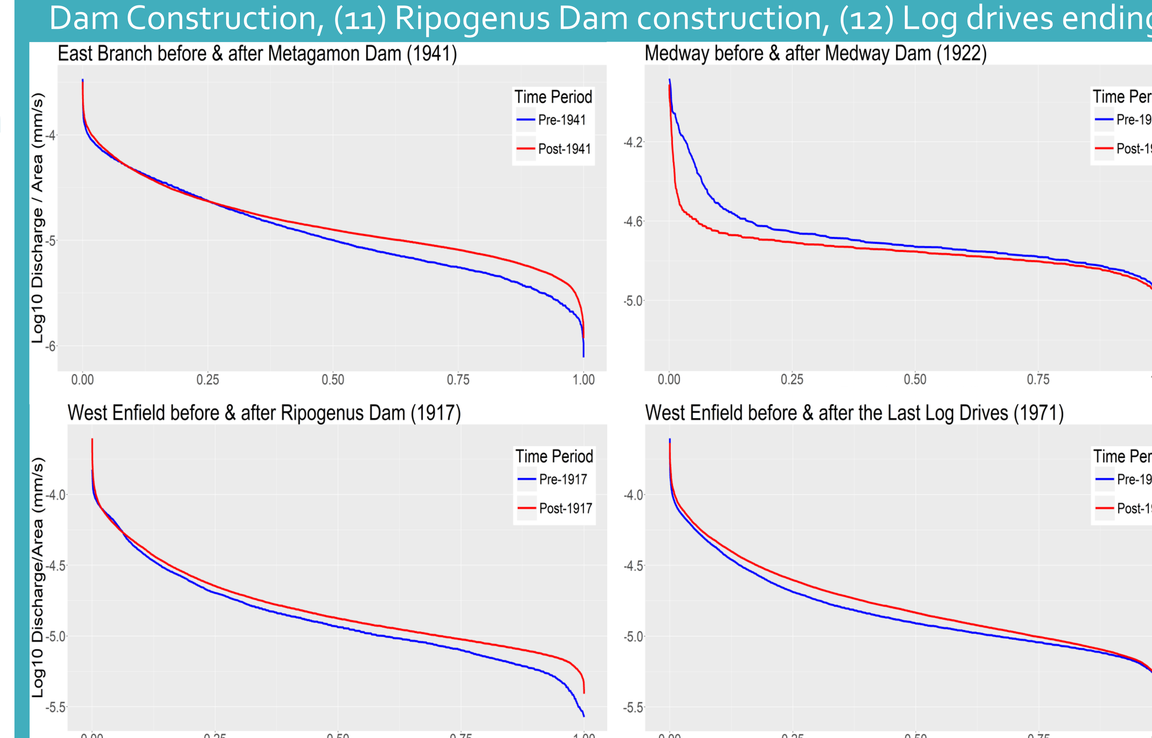
Dam Name	Gauge Site	Distance Downstream (km)	Added Contributing Area (km2)	Tributaries and other influences	Available Flow Record
Canada Falls	South Branch at Canada Falls	0.422	< 1	None	After
Dole Pond	North Branch at Pittston	25.306	466.957	Many tributaries	After
Mattaceunk	Penobscot R. at Mattawamkeag	0.696	2.404	None	After
Metagamon	East Branch at Grindstone	63.586	1,537.023	Many tributaries	Before & After
Sebec	Sebec R. at Sebec	0.257	0.096	None	Before & After
Medway	West Branch at Medway	0.476	29.275	One small tributary	Before & After
Pleasant River	Pleasant R. at Milo	3.835	9.589	None	After
Howland & West Enfield	Penobscot R. at West Enfield	1.858	1.906	Two large Run of River dams on two merging channels	B&A Howland, After W.E.
Veazie	Penobscot R. at Eddinton	0.987	< 1	Possible tidal signal at gauge	After
Guilford Insustries	Piscataquis R. at Dover-Foxcroft	6.296	87.869	Small system of lakes with three dams on them	Before & After

Figure 11) Timeline of gauge data and dam construction. Black bars show the available USGS discharge record at select sites, points show dam construction nearby upstream of those sites. The circled items are shown in this results section.

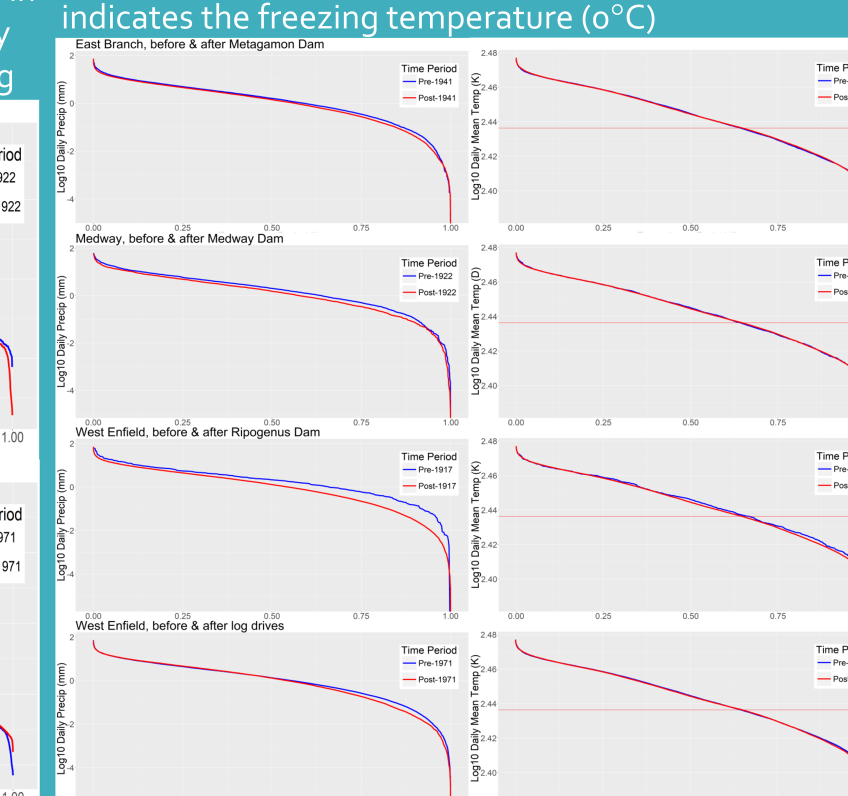


Results:

Figures 12-15) Flow Duration Curves (cumulative probability distributions) representing flow regime before and after historical changes in the Penobscot Watershed. (9) Metagamon Dam construction, (10) Medway Dam Construction, (11) Ripogenus Dam construction, (12) Log drives ending



Figures 16-23) Cumulative probability distribution of mean areal precipitation (left) and temperature (right) over the area draining to USGS gauges at the East Branch, Medway, and West Enfield. Red horizontal line indicates the freezing temperature (0°C)



Discussion & Future Work:

Approach 1

- Changes in model performance before and after the 2000-2003 interval may indicate change in runoff or storage within the Kingsbury Watershed.
- Consistently low model performance indicates large uncertainty in model parameters, processes, and inputs.
- Connecting variation in model performance with changes to a watershed requires this result be repeated for a known change, such as dam construction.

Approach 2

- Storage and Run-of-River dams show different changes in flow regime before / after their construction.
- The same changes are not seen in precipitation and temperature records.
- Uncertainty in discharge measurements needs to be taken into account to verify differences in flow regime.
- Observed differences in cumulative probability distributions can not be attributed to dams alone.

Future Work

- Further investigation into historical changes in the watershed is necessary to attribute these changes in flow regime to dams, land use or climate.
- Use model to identify changes elsewhere in Penobscot where the record is longer.
- Use model to estimate the flow regime of the Penobscot River in an un-dammed scenario.

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