POTENTIAL IMPACT OF CHANGING SEA LEVEL AND STREAMFLOW ON SALINITY OF THE UPPER DELAWARE BAY

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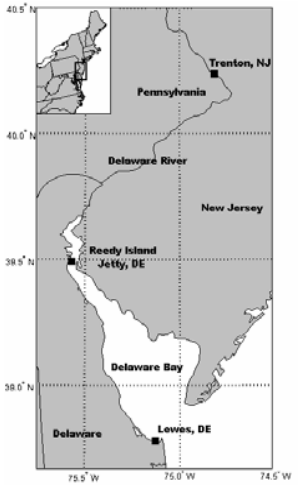
1. MOTIVATION

- Salinity is a variable of prime ecological, biogeochemical, and physical importance in the Delaware Estuary.
- Through altered streamflow and sea level, climate change is likely to affect the salinity of the Delaware Estuary.
- Only two studies have estimated the impact of climate change on salinity of the Delaware Estuary (Hull and Tortoriello, 1979; U.S. Army Corps of Engineers, 1997); both were model-based and considered sea level only.

OBJECTIVE: To make observation-based estimates of future climate-induced salinity change in the Delaware Estuary.

APPROACH: Determine the historical influence of streamflow and sea level on salinity and use the relationships found in combination with climate projections to estimate future salinity change.

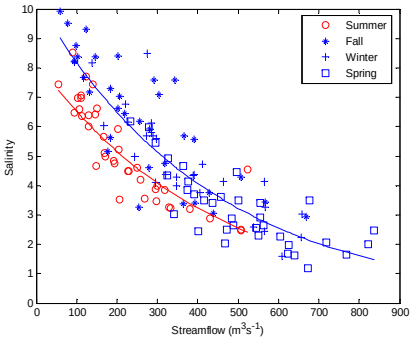
2. OBSERVATIONS



Location of observation sites.

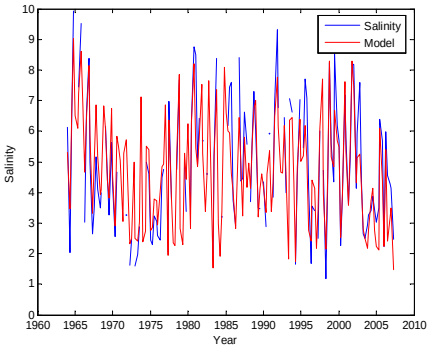
- Daily averaged surface salinity at Reedy Island (USGS), 1963-2007.
- Daily streamflow at Trenton (USGS).
- Monthly averaged sea level at Lewes (NOAA).
- Seasonal averages computed for all variables; done for salinity only if all months in season have at least 15 days of data.

3. STREAMFLOW-SALINITY RELATIONSHIPS



Salinity *S* vs. streamflow *Q* and corresponding least squares fits of the form $S = se^{-Q/q}$, where *s* and *q* are constants.

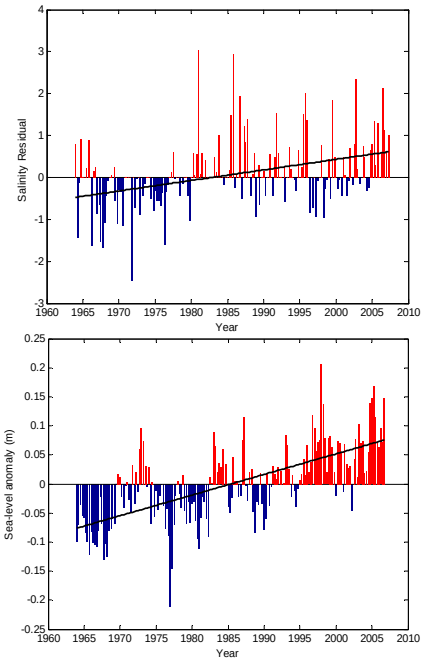
- The seasons do not have relationships that differ significantly (95% confidence) from each other except for summer, which has lower salinity for a given flow.
- Seasonality in sea level (highest in fall, lowest in winter) does not seem to influence seasonality in salinity.
- Anomalously low summer salinity may be due to weaker winds and greater heating, which would reduce vertical mixing and allow runoff to be confined to the surface more so than in other seasons.



Time series of observed (blue) and modeled (red) seasonal salinity.

- Model does a good job at simulating interannual variability in salinity, with $r^2 = 0.80$ and a root-mean-square error of 0.89.

4. RESIDUAL SALINITY AND SEA LEVEL



Salinity residual (observed minus modeled, top) and sea-level anomaly (bottom) as a function of time. Lines are least-squares linear fits.

- Salinity residual has a slope of 0.025 ± 0.011 yr^{-1} or an increase of 1.1 ± 0.5 over the 43.5-year record (95% confidence interval).
- Seasonal sea level anomaly has a long-term linear trend of 3.5 ± 0.6 mm yr^{-1}.
- From the linear trends in salinity residual and sea level anomaly, we compute a salinity change per unit sea-level rise ($\Delta S/\Delta H$) of 7.1 ± 3.4 m^{-1}.
- Estimates of $\Delta S/\Delta H$ at Reedy Island from numerical models vary from 1 to 3 m^{-1} (Hull and Tortoriello, 1979; U.S. Army Corps of Engineers, 1997); tidal variations suggest 2 m^{-1} (not shown).
- Our high estimate of $\Delta S/\Delta H$ compared to others may reflect bathymetric changes in the Bay: Walsh (2004) and Sommerfield and Walsh (2005) showed that the mean depth of Delaware Bay increased from 1945-1960 to 1980-1987 a rate of 8.1 ± 5.8 mm yr^{-1}, more than twice the rate of sea-level rise.
- If we adjust the rate of sea-level rise accordingly, our estimate of $\Delta S/\Delta H$ is 3.1 ± 2.6 m^{-1}, more in line with the estimates based on models and tidal data.

5. CLIMATE CHANGE IMPACTS ON SALINITY

- Sea level
  - Projected relative sea-level increase by 2100 is 1.1 ± 0.5 m, using the global projection of Rahmstorf (2007) and a local subsidence component of 0.1 m.
  - Combined with our $\Delta S/\Delta H$ estimate of 3.1 ± 2.6 m^{-1}, this yields a projected salinity increase of 3.3 ± 3.1 by 2100, substantial compared to the long-term mean salinity of 4.8 at Reedy Island Jetty.
- Streamflow
  - Runoff predictions for an approximate doubling of atmospheric CO_2 vary between -40% and +30% in the Mid-Atlantic region (Najjar et al., 2008).
  - Combined with the least-squares fits of Reedy Island salinity to Trenton streamflow, we estimate corresponding salinity changes of +1.6 and -0.9.

6. CONCLUSIONS

- After accounting for variation due to streamflow, salinity in the upper Delaware Bay increased by 1.1 ± 0.5 from 1963 to 2007.
- This is larger than expected from sea-level rise and relationships between sea level and salinity from numerical models and short-term observations.
- The discrepancy could be accounted for by long-term changes in the bathymetry of the Bay.
- Projected changes in salinity due to sea level are comparable in magnitude with those expected from climate-induced changes in streamflow.
- Further work is needed to better constrain the response of the Bay to sea-level rise. Attempts to synthesize historical salinity data throughout the Bay and reconcile it with numerical modeling studies that account for changing sea level, streamflow, and bathymetry would be beneficial.

REFERENCES

Hull, C. H. J., and R. C. Tortoriello (1979), Sea-level trend and salinity in the Delaware Estuary, Staff Report, Delaware River Basin Commission, West Trenton, N. J.

Najjar, R. G., L. Patterson and S. Graham. 2008. Climate simulations of major estuarine watersheds in the Mid-Atlantic region of the United States. *Climatic Change*, in press.

Rahmstorf, S. (2007), A semi-empirical approach to projecting future sea-level rise, *Science*, *315*, 368-370.

Sommerfield, C. K., and D. R. Walsh (2005), Historical changes in the morphology of the subtidal Delaware Estuary, paper presented at First Delaware Estuary Science Conference, Partnership for the Delaware Estuary.

U.S. Army Corps of Engineers (1997), Chapter 5: Hydrodynamic and salinity modeling, in *Delaware River Main Channel Deepening Project: Supplemental Environmental Impact Statement*, edited, pp. 5-1 to 5-62.

Walsh, D. R. (2004), *Anthropogenic influences on the morphology of the tidal Delaware River and Estuary: 1877-1987, Masters Thesis in Marine Studies*, 90 pp., University of Delaware, Newark, Delaware.

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