Saltwater intrusion events along the Tar-Pamlico River: Evaluating seasonality and increased risk during drought conditions

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ABSTRACT

Saltwater (SW) intrusion events along coastal plain rivers can occur with changes in the balance between freshwater & saltwater. Increased salinity in rivers can affect human & ecosystem health & impair infrastructure. There is growing evidence that sea level rise is influencing SW intrusion in SE coastal plain river systems. This research focuses on specific conductivity (SC-a salinity proxy) patterns & the influence of discharge on SC along the Tar-Pamlico River, NC. Upstream (riverine discharge) & downstream (estuarine salinity & hydrodynamics) influences on the temporal variability of SW intrusion events were investigated using long-term discharge & water quality data (1970s-present) & ongoing monitoring since 2022. Along the Tar-Pamlico River, SW intrusion events were documented along freshwater reaches up to 10 miles inland & these events were more common during drought & low-flow periods during July-December. Drought had the greatest influence on water quality along the lower tidal reaches of the river due to SW intrusion events. Low-flows during droughts are typically a pre-cursor to SW intrusion. During low-flow periods, interactions between riverine discharge, wind & tidal patterns can result in low hydraulic gradients & transport of brackish water inland. At the USGS Pamlico R. gage at Washington, NC, mean annual water levels have been rising over the past two decades, suggesting that sea level rise is increasing the risk of SW intrusion. Water conservation efforts during summer-fall low-flow periods may help reduce the intensity & duration of SW intrusion events.

INTRODUCTION

- In an era of sea level rise, an improved understanding of SW intrusion is needed for management & adaptation planning for coastal plain river & estuarine systems (**Fig. 1**).
- Freshwater salinization impacts include: reductions in agricultural & forest productivity, impairment to freshwater supplies & wetlands, alteration of aquatic habitat, soil sulfidation, nutrient release, & corrosion (Tully et al. 2019).
- Specific conductivity (SC) has been utilized to improve understanding of salinization of aquatic ecosystems (e.g. Herbert et al. 2015). SC is a measure of the dissolved ions in water that can conduct an electrical charge (@ 25 degrees-C), & a proxy for salinity.
- **Study Objective:** evaluate the influence of drought, flow conditions & sea level rise on SW intrusion along the Tar-Pamlico River.

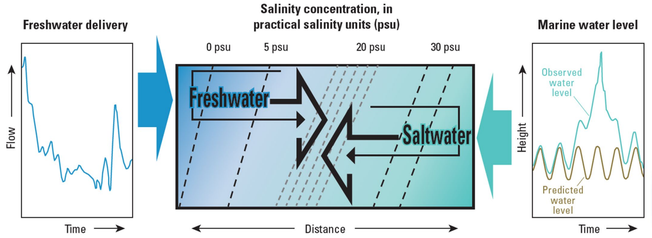

Figure 1. Salinity dynamics in coastal estuaries & tidal rivers are influenced by the balance of freshwater & saltwater fluxes (Conrads et al. 2018).

STUDY AREA & METHODS

- The Tar River originates in the Piedmont & flows through the Coastal Plain to Washington where it becomes the Pamlico River Estuary that drains to the Pamlico Sound (**Fig. 2**).
- SC monitoring (calibrated YSI meters) was conducted at 36 sites to evaluate monthly SC variability in the watershed (2022-present).
- Streamflow & water level data from USGS stations at Tarboro, Greenville, Grimesland, & Washington, NC and NOAA Beaufort tidal gage were used to evaluate flow-SC and sea level rise relationships. Long-term SC data (1974-2022) was acquired from NC DEQ for Grimesland (Tar), & Washington (Pamlico) stations & drought data from NOAA-National Centers for Environmental Information (NCEI).

RESULTS

Spatial Variability and Influence of Streamflow on SC/Salinity

- The lower reaches of the Tar River exhibited the highest variability in SC (**Fig. 2**).
- Drought influence on water quality (SC) was > in the riverine-estuarine transition zone (Greenville-Washington) due to SW intrusion during low-flows.
- During drought conditions in Fall 2022, SC data indicated SW intrusion occurred at site 10 (Pactolus) ~ 10 miles inland of the estuary (**Fig. 2c).**

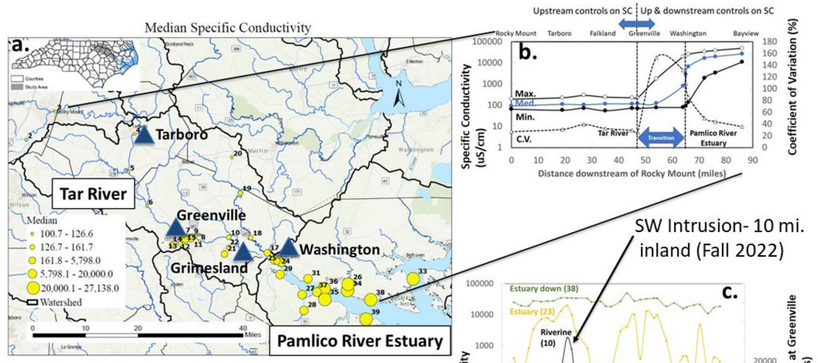

Figure 2a. Sampling sites from Rocky Mount (Tar River) to Bayview (Pamlico River Estuary) & median SC values. Triangles indicate USGS stream gage locations. **b**. 2022-24 SC data along the mainstem of the Tar River & N-side of the estuary. **c**. Variability of SC at select sites, indicating SW intrusion in Fall 2022 (site 10).

- During low-flows, reduced velocity (V) & hydraulic gradients, decreased dilution, & elevated SC in the estuary can increase the risk of SW intrusion (**Fig. 3**).
- When the Tar River is experiencing low-flows, lower river stages result in decreased hydraulic gradients between Greenville-Washington, increasing the likelihood of bi-directional flows.
- During these baseflow periods, wind & tides can enhance inland flows **(Fig. 3**).
- SW intrusion is more likely when V < 1 ft/s & stage difference (G-W) < 1 ft. (**Fig. 3b**).

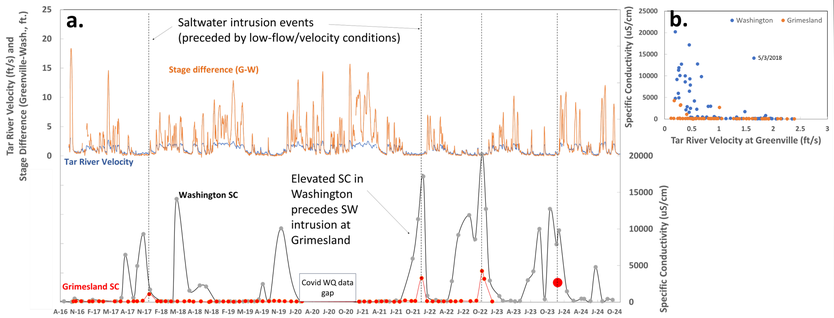

Figure 3a. Comparison of SC at Washington (Pamlico R. Estuary) & Grimesland (Tar R.~7 miles upstream) with Tar R. velocity & stage difference between Greenville-Washington. NC DEQ data was available through 2022. Max. salinity- 12.1 ppt. **b.** Relationship between Tar R. velocity at Greenville and SC downstream at Grimesland & Washington (outlier: 5/2018).

Drought, Low-Flows, and Saltwater Intrusion Events

- SW intrusion events observed at Grimesland (~ 7 miles upstream of the estuary), typically occurred during drought & low-flow conditions (**Fig. 4)** in summer-fall.

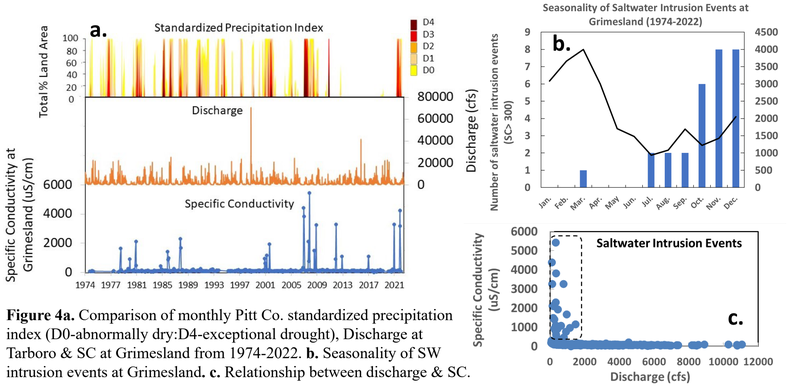

Figure 4a. Comparison of monthly Pitt Co. standardized precipitation index (D0-abnormally dry:D4-exceptional drought), Discharge at Tarboro & SC at Grimesland from 1974-2022. **b.** Seasonality of SW intrusion events at Grimesland**. c.** Relationship between discharge & SC.

Factors Indicating Future Increases in SC/Salinity along the Tar-Pamlico River

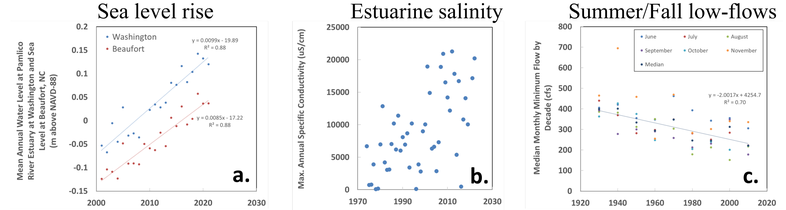

Figure 5a. Sea level rise at Beaufort, NC NOAA tidal gage and Washington, NC USGS water level station. **b.** Max. annual SC at NCDEQ Washington PR estuary site. **c**. Decadal low-flow trends for summer-fall months at USGS Tarboro station.

CONCLUSIONS

- SC/salinity along the Tar-Pamlico River was most variable in the riverine-estuarine transition zone. SW intrusion was documented 10 miles upstream of the estuary.
- Drought impacts in the Lower Tar region are projected to increase in the coming decades (Tran et al. 2024). Recent data suggest that sea level rise is causing rising estuary levels, increasing SC/salinity in the estuary, & low flows during summer/fall months along the Tar River are declining. These data suggest that future droughts may have a greater influence on water quality along the lower reaches of the Tar.
- These changes have implications for surface water & wastewater management for Greenville, as well as agricultural drainage, & aquatic/wetland habitat management.

ACKNOWLEDGMENTS & REFERENCES

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We are thankful for the support of WaterCorps students that assisted with monthly sampling and lab efforts and supporting staff members, Dr. John Hoben and Dr. Matt Siriani, and graduate student Sarah Radel for GIS support.

Funding Acknowledgement: NSF: Coastlines and People (CoPe): Moysey, S. et al. (2021-2026) Supporting Environmental Justice in Connected Coastal Communities through a Regional Approach to Collaborative Community Science.