Investigation of Hydrologic Variability of Freshwater Inflows to Estuarine Systems in Florida using GIS, Machine Learning and Geophysical Techniques

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Introduction

- **Background:** Freshwater inflows are crucial for maintaining the balance of salinity, nutrients, and habitat conditions in estuarine ecosystems (1,2). The estuarine system is sensitive to hydrologic variability, affected by precipitation, river discharge, runoff, and groundwater input (3,4).
- **Problem Statement:**

✓ Watershed impacted: The St. Marks River and Apalachee Bay watershed.
✓ Primary Challenges: Population growth, industrialization, and land use changes.
✓ Effects on Ecosystem: Altered freshwater inflows impacting watershed health, estuarine salinity and corresponding coastal habitats like oyster beds and seagrass meadows.

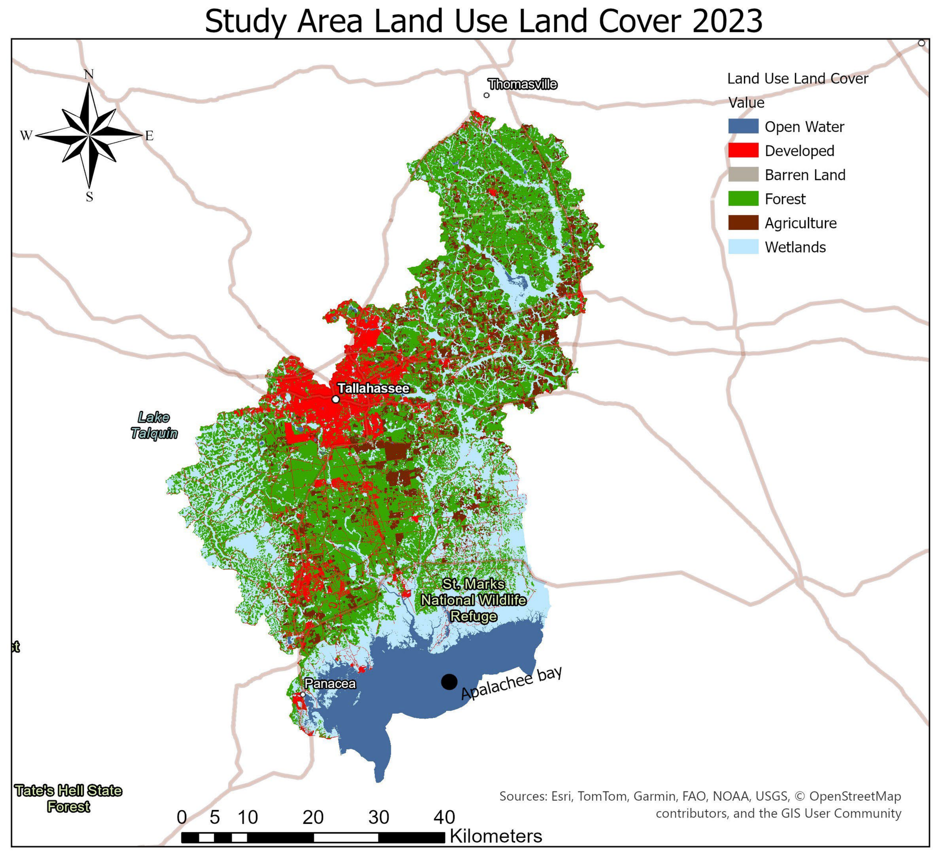
- **Research Focus:** This study investigates and models the hydrologic variability of freshwater inflows into estuarine systems using GIS, Long Short-Term Memory (LSTM) machine learning, and geophysical techniques, with an emphasis on predicting inflow patterns and impacts to support effective water resource management.
- **Specific Objectives:**

✓ Develop watershed hydrology model
✓ Analyze spatial and temporal inflow variability
✓ Predict inflow and rainfall-runoff with LSTM
✓ Map hydrologic features with GIS and geophysical techniques.

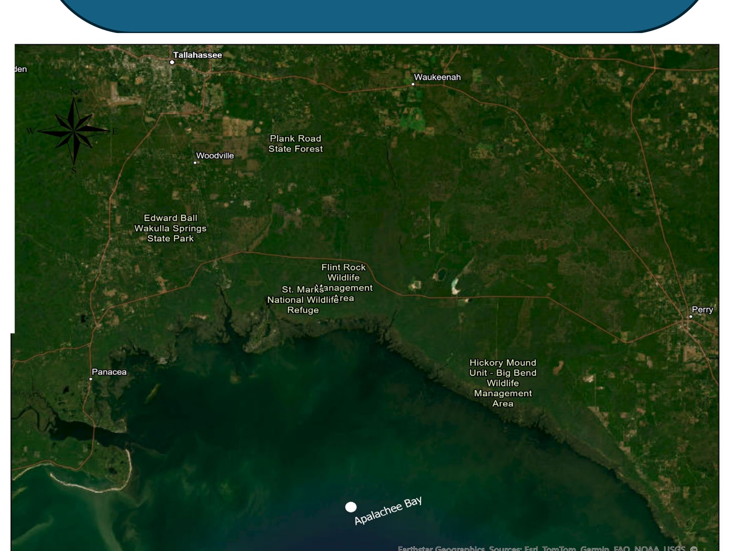
Study Area

- **Location**: North Florida and South Georgia
- **Size**: Approximately 1,168 square miles (about 3000km^2).
- Features: Known for unique geological formations and distinctive landforms.

Study Area Land Use Land Cover 2023



- **Ecological Significance:** Supports diverse estuarine habitats critical to local aquatic life and coastal ecosystems(4).



Methods

DATA COLLECTION

Hydrologic Data
* River discharge
* Salinity measurements
* Groundwater levels
* Stormwater Runoff

Meteorological Data
* Precipitation
* Air temperature
* Surface water temperature
* Wind pressure

Geospatial Data
* Watershed Boundary Dataset
* Land Use Land Cover (LULC)
* Digital Elevation Model (DEM)
* Water Withdrawals

CONCEPTUAL MODEL

MACHINE LEARNING

HYDROLOGIC MODELING (LSTM)

Methodology flow diagram

Data Collection → Data Engineering → Model Development → Model Training → Model Evaluation → Model Validation

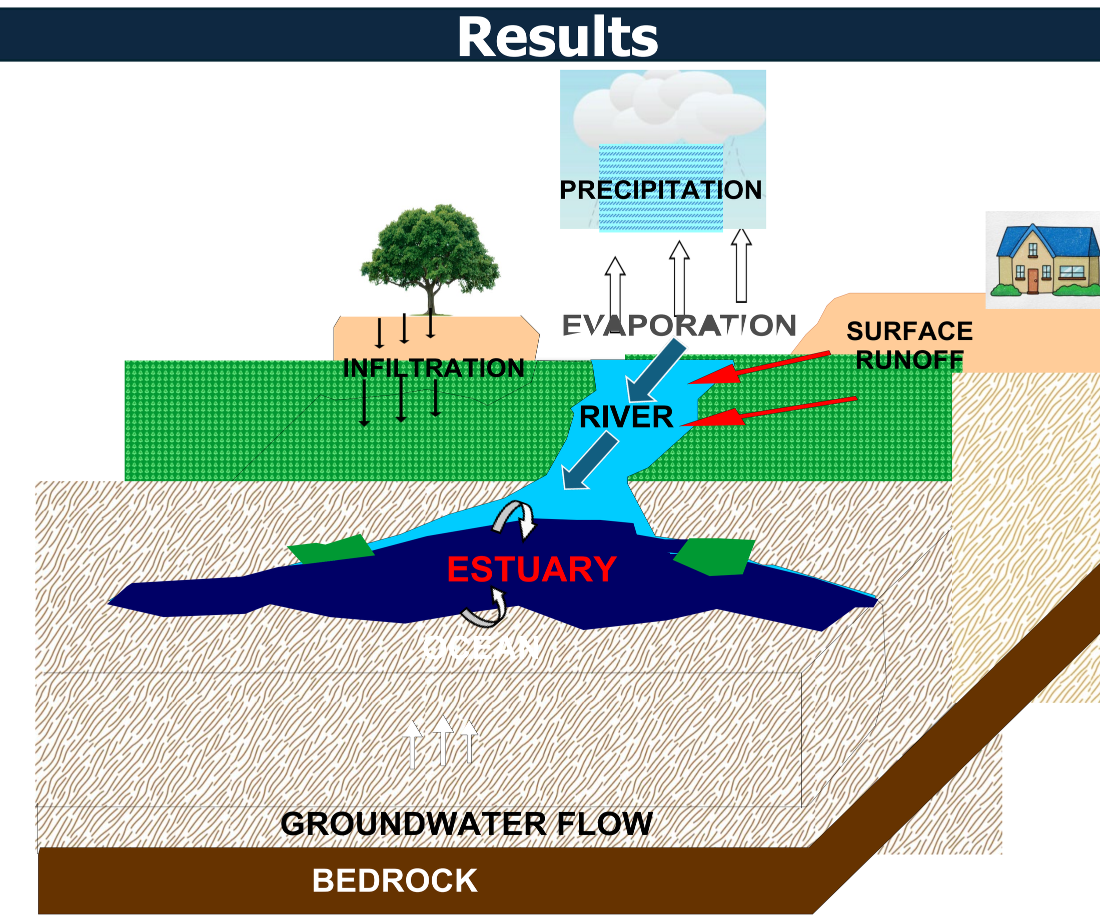
LSTM-Based Hydrologic Prediction Model

To model hydrologic variability, we used an LSTM network to predict freshwater inflows and associated parameters by capturing temporal dependencies in time-series data.

- Forget Gate: $f_t = \sigma (W_f [h_{t-1}, x_t] + b_f)$
- Input Gate: $i_t = \sigma (W_i \cdot [h_{t-1}, x_t] + b_i)$
- Output Gate: $o_t = \sigma (W_o \cdot [h_{t-1}, x_t] + b_o)$
- Cell State Update: $c_t = f_t \cdot c_{t-1} + i_t \cdot \tilde{c}_t$
- Hidden State Update: $h_t = o_t \cdot \tanh(c_t)$

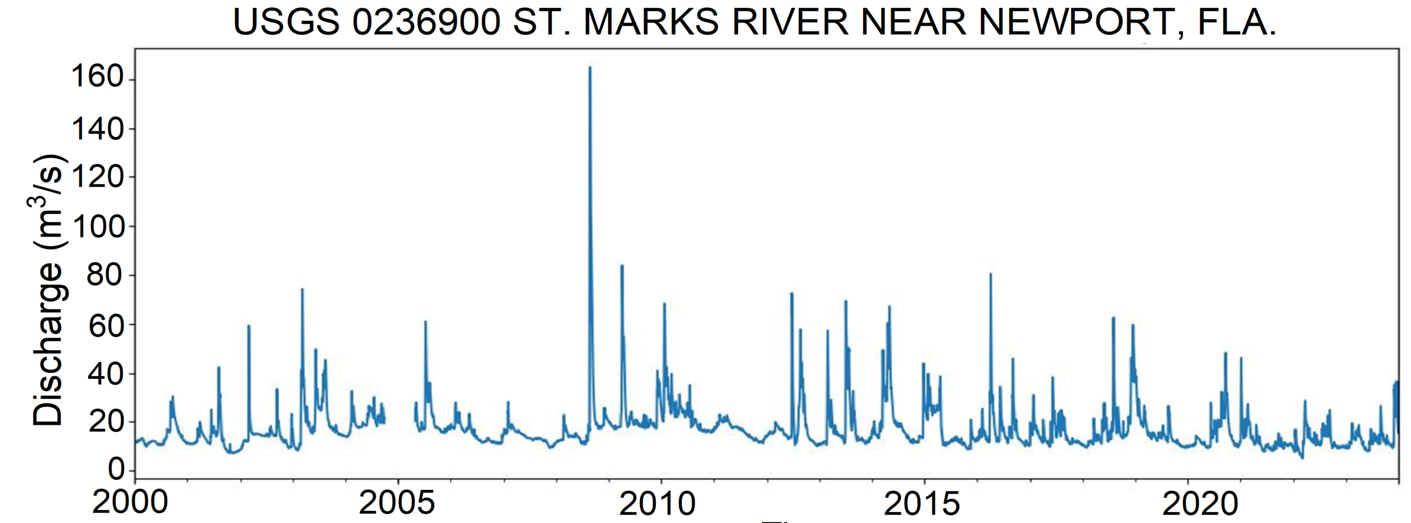
LSTM Machine Learning Modeling Process

Results

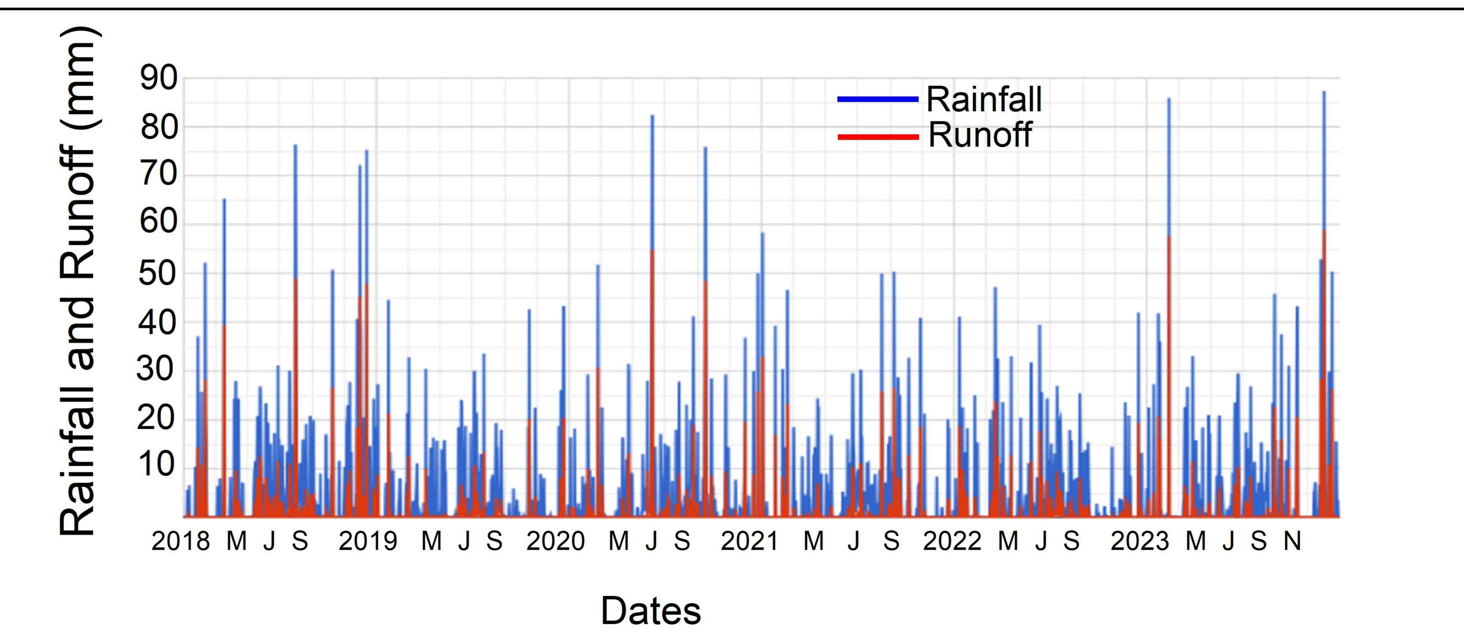


Conceptual watershed hydrology model

USGS 0236900 ST. MARKS RIVER NEAR NEWPORT, FLA.

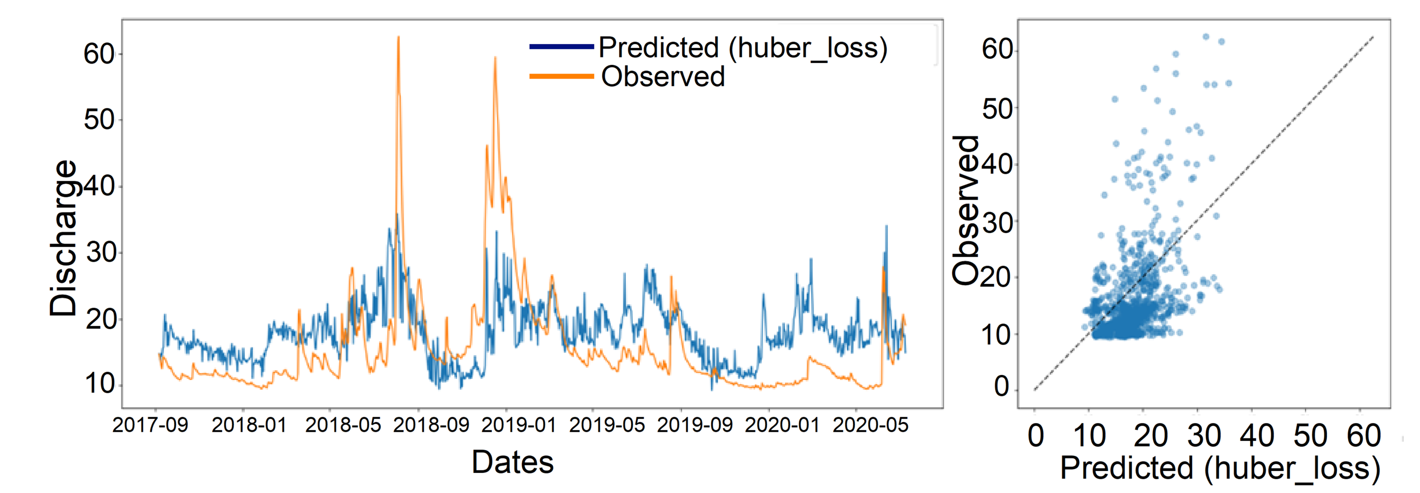


St. Marks River Daily Discharge (m^3/s) from 2000 to 2024



Mean daily rainfall and runoff time series for the whole St. Marks watershed from 2018 to 2024

Machine Learning Loss Function (Huber_Loss)



Huber loss function applied during training the model for St. Marks River Streamflow from 2017 to 2020

Conclusion

This project emphasizes the sensitive role of hydrologic variability in shaping estuarine systems and demonstrates the integration of GIS, hydrological, meteorological, machine learning models, and geophysical data to assess these relationships and impacts. The findings will provide a basis for informed water resource management and conservation strategies to promote balance in human and environmental needs.

Future Work

- Application of Geophysical method - Electrical Resistivity Imaging (ERI) in conductivity measurements to assess subsurface hydrology and salinity patterns.
- Inclusion of other watershed data for a robust data training.

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References

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