学 位 論 文 内 容 の 要 約/Dissertation Summary

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学 位 論 文 題 名/Title of Dissertation

A simple approach for estimating freshwater discharge from a tidal wetland stream to a brackish lake
(湿原を流域に有する感潮河川から汽水湖への簡便な流出量推定))

1. Research Background & Problem Statement

Background: Freshwater discharge from terrestrial sources is a primary driver of nutrient cycling and primary productivity in coastal ecosystems like Akkeshi Lake. The Bekambeushi River basin, a Ramsar site, is a critical source of these inputs.

Core Problem: As a subarctic wetland influenced by tides, the river exhibits complex stage-discharge relationships. Traditional rating curves fail due to backwater effects, and the lack of long-term data hampers hydrological modeling.

2. Hydrological Characteristics of the Tidal Zone, Bekambeushi River Basin

2.1 Topographic alignment via GNSS

A unified datum for all observation stations was established using Global Navigation Satellite System (GNSS) surveying, ensuring the spatial consistency of water level measurements.

2.2 Continuous monitoring of water level and temperature

High-resolution pressure sensors were deployed to record long-term, continuous variations in water level and temperature. This data captured the rhythmic oscillations of the tide and the hydrological response to individual weather events, providing the fundamental time-series data necessary for analyzing the river's hydraulic gradient.

2.3 Salinity intrusion monitoring

Through continuous monitoring of electrical conductivity (EC), the maximum extent of tidal salinity intrusion was determined. This confirmed that Station RB3 is a representative location for measuring freshwater discharge before significant mixing occurs.

2.4 Limitations of the stage-discharge (H-Q) curve

Observations confirmed that in tidal reaches, backwater effects cause a "hysteresis" phenomenon where a single water level does not correspond to a unique discharge value. This resulted in low accuracy for traditional H-Q curves at RB3, necessitating the index-velocity approach.

3. A Simple Approach for Estimating Freshwater Discharge

3.1 Methodology

Dual-ADCP Strategic Monitoring: The RiverSurveyor M9 was used for cross-sectional profiling, revealing an asymmetric channel with a deep thalweg on the right bank. Simultaneously, the SonTek-IQ Plus was deployed to monitor index velocity within a stable water layer.

The Index Velocity Method: By establishing a linear regression between the local "index velocity" (V_{index}) and the mean cross-sectional velocity (V_{mean}), the study enabled high-frequency continuous discharge estimation independent of tidal stage fluctuations.

3.2 Results

Analysis of M9 measurements during diverse hydrological conditions captured the spatial distribution of flow. The results highlighted how the asymmetric bathymetry influences flow velocity, with the highest velocities consistently aligned with the deep thalweg on the right bank.

A key finding was the quantification of the characteristic phase lag between peak water level and peak flow velocity. At the RB3 site, a 3–5 hours' time delay was observed, revealing the complex interaction between tidal wave propagation and riverine outflow. This result clarifies that peak discharge does not coincide with peak water level, a critical insight for understanding the momentum balance in the estuarine transition zone.

4. Discussion

4.1 Physical mechanism of the $d - P$ relationship

Correlation between Cumulative Precipitation and Daily Discharge: The study found that while instantaneous rainfall has a weak correlation with discharge, the 5-day cumulative precipitation shows a strong linear relationship ($R^2 > 0.8$) with daily total discharge.

Quantitative Characterization of Wetland Buffering: This strong correlation is attributed to the "sponge effect" of the extensive wetlands. The wetlands effectively smooth rainfall pulses, converting transient events into steady discharge over several days.

4.2 Model generalization and external validation

Validation in the Kushiro River (Wetland Environment): To prove the model's utility in data-scarce regions, the method was applied to the Kushiro River. Even with limited datasets, the model accurately predicted long-term discharge trends, confirming its transferability to other subarctic wetland basins.

Comparison with Non-Wetland Environments: Comparison with the Abashiri River (which lacks extensive wetlands) highlighted the unique role of wetland storage in maintaining discharge stability and smoothing hydrological responses.

4.3 Uncertainty and long-term applicability

The $d-P$ model is particularly robust for long-term (monthly/seasonal) assessments. While daily fluctuations may involve minor deviations due to specific tidal noise, the integrated multi-day approach provides highly reliable data for total freshwater budget management.

5. Conclusions

5.1 Key findings

The research established a monitoring framework based on the Index Velocity Method, overcoming the inherent inaccuracies of water-level-based methods in complex tidal environments. A simplified, high-precision $d-P$ empirical model was constructed, providing a practical path for discharge estimation in ungauged or data-scarce wetland basins.

5.2 General conclusions

Freshwater flux in the Bekambeushi River is governed by the interplay between tidal dynamics and wetland retention. The wetlands act as a critical hydraulic buffer that ensures the temporal continuity of freshwater supply to Akkeshi Lake.

5.3 Limitations

The $d-P$ model is more effective for long-term trend analysis than for capturing extreme instantaneous daily peaks.