A dual tracer study to describe the hydraulic heterogeneity of a small, natural wetland in the humid tropics of Costa Rica

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1. Introduction

Fig. 1. Banana plantations cover ~50k ha in Costa Rica; 82% have no runoff treatment (Astorga, 1998).

- Environmental pressures from growing populations and agricultural development in the tropics (Fig. 1) can be mitigated by ecosystem services provided by natural wetlands (Daniels, 2008; Junk, 2002).
- Assessment of wetland ecosystem services requires an improved understanding of wetland hydraulics, velocities, and flow pathways.

- Tracer studies (Fig. 2) are an effective way to study wetland hydraulic behavior (Harden et al., 2003), however detailed studies of flow in natural, tropical wetlands are scarce.
- Bromide (Br^-) is the most widely used tracer in wetland systems (Martinez, 2001).
- An alternative to conventional tracers is the gas sulfur hexafluoride (SF_6). SF_6 is detectable at minute concentrations, although, as a gas, it is not conservative.

Fig. 2. Movement of the tracer Rhodamine-WT along short-circuit flow paths in a wetland.

2. Research Objectives

<u>Small wetlands in the tropical landscape of Central America have a critical and multifaceted role in the environment</u> (water storage, flood control and water quality improvement). The case study presented here and in a related study (Kaplan et al., 2011) aims to quantify these functions. Specific objectives of this study were to:

1. Conduct a dual tracer study to characterize hydraulics and potential ecosystem services of a small tropical wetland
2. Assess the feasibility of using SF_6 as a tracer under humid tropical, slow flow conditions.

3. Study Location

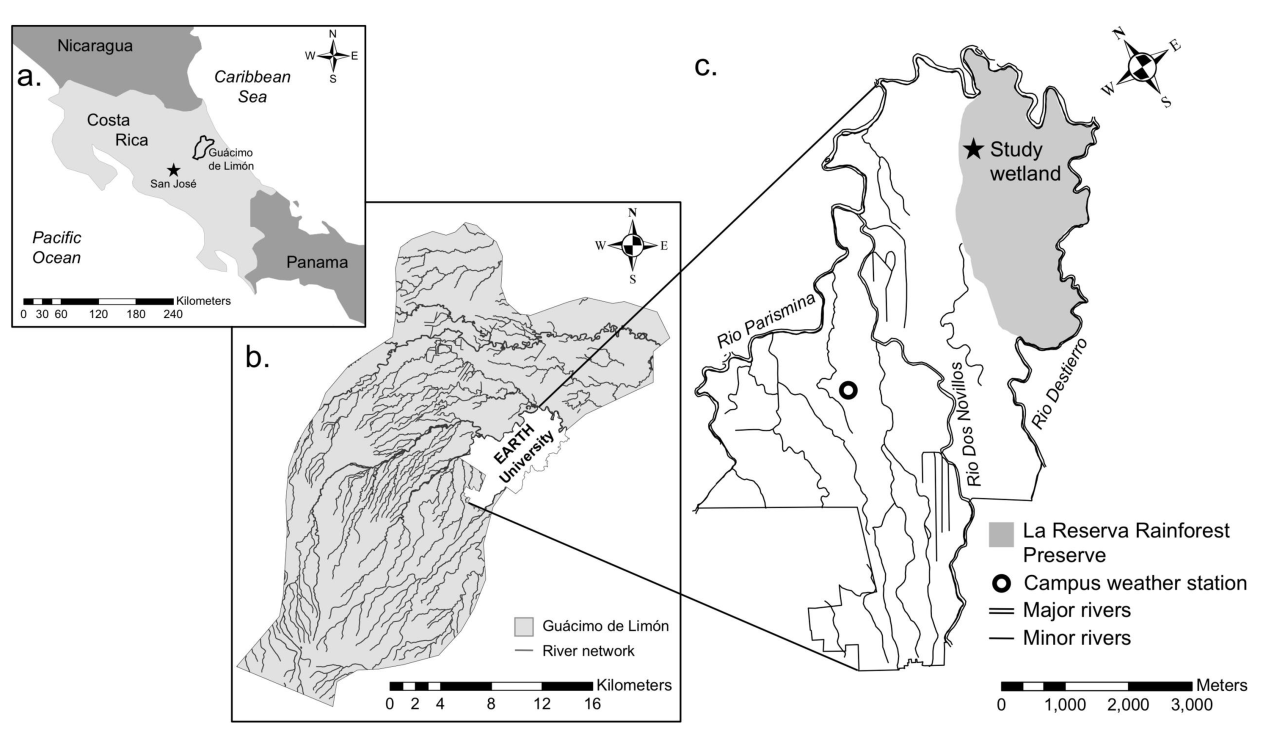


Fig. 3. The study was carried out at EARTH University, in Guácimo de Limón, Costa Rica (a-b). The ~1.5-ha study wetland was located in a sub-watershed of the "La Reserva" rainforest preserve (c); the larger watershed is dominated by banana production.

4. Materials and Methods

- Br^- and SF_6 tracers were injected at two sites as point sources, each as a single injection. Sampling points were distributed downgradient to capture flow paths and wetland water velocity (Fig. 4).
- Samples were manually collected from injection and monitoring sites and reference buckets (Fig. 5d) daily for three weeks using 40 mL septum vials.
- Samples were analyzed for SF_6 using a gas chromatograph with electron capture detection and for Br^- using high-pressure liquid chromatography.

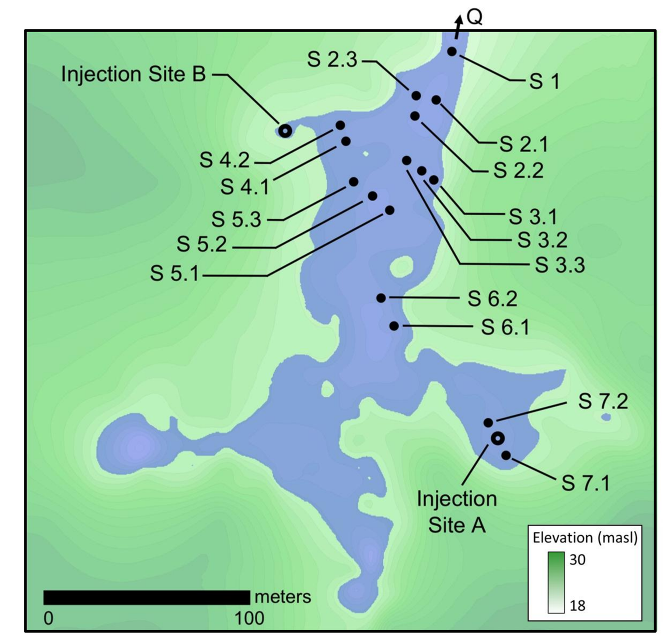
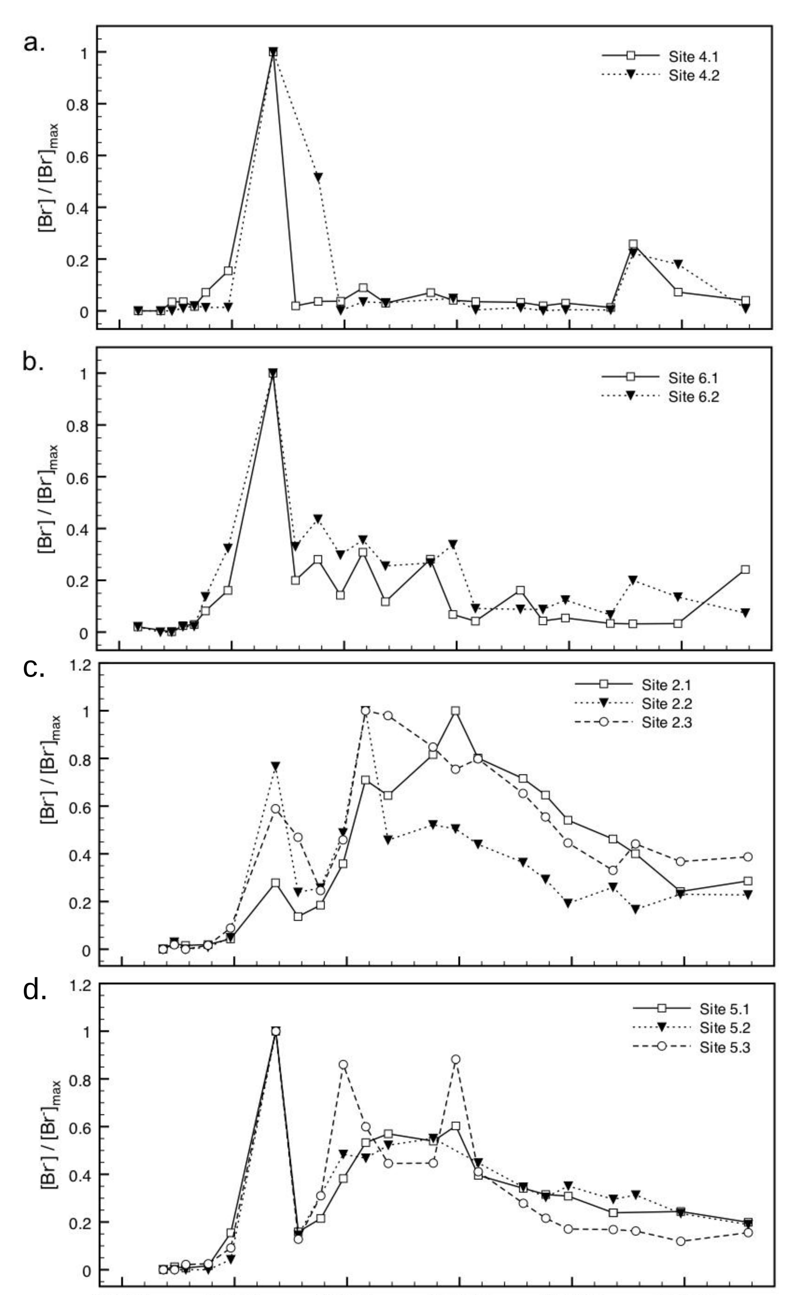


Fig. 4. Tracer injection and monitoring sites. The wetland has a single outlet downstream (Q) and no surface water inlet.

Fig. 5. Methods used in tracer preparation: (a) dissolving KBr into injection barrel filled with wetland water; (b) SF_6 canister connected via tygon tubing to a porous soaker hose in the bottom of the barrel; (c) dense stream of bubbles from SF_6 sparging; (d) reference bucket tented with plastic to prevent direct rainfall and minimize evaporation (left) and injection barrel covered with plastic to prevent SF_6 volatilization prior to tracer release (right).

5. Results - Bromide



- Comparing plots of tracer concentration over time (breakthrough curves; BTC) allowed us to describe water velocities, flowpaths, and dominant transport mechanisms.
- A single Br^- peak was observed at Sites 4 and 6 (Fig. 6a-b), indicating that only tracer from the injection point upstream of these stations was captured. Sharp peaks suggested advection-dominated transport.
- Two Br^- peaks at Sites 1, 2, and 5 (Fig. 6c-d) indicates the passage of tracer from both injection sites. The first peaks were sharp, indicating advection-dominated flow from Site A, while the second peaks were broader with long tails, suggesting more dispersion along slower (or more convoluted) flowpaths.

Fig. 6. BTCs for various sampling locations (see Fig. 4 for map).

6. Results – Sulfur Hexafluoride

- SF_6 was not detected, except early after the release at the injection sites (Fig. 7). The rapid loss of SF_6 from reference buckets, presumably by volatilization, explained this finding.
- SF_6 was a poor surface water tracer under the study's environmental conditions, although results may have been improved by increasing [SF_6].

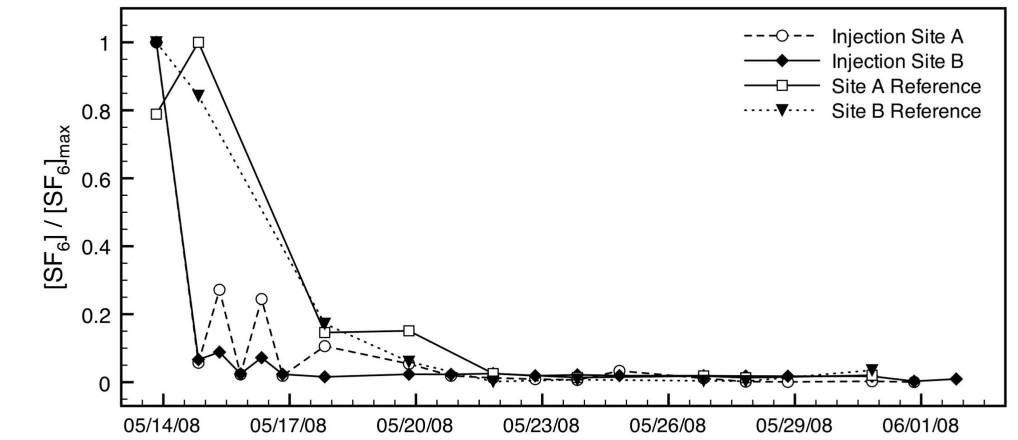


Fig. 7. SF_6 concentrations observed in reference buckets and at Injection Sites A and B.

7. Wetland Hydraulics and Ecosystem Services

- The timing of Br^- peaks were used to elucidate flowpaths through the wetland and estimate average water velocities (Fig. 8).
- BTCs suggested the presence of faster flow in the eastern branch, likely due to short sections of channelized flow, and several slower flowpaths in the western branch.
- Spatial heterogeneity in velocity and flowpath distribution likely supports a number of wetland functions by providing: (1) spatially variable flow regimes for habitat diversity; (2) differential sediment deposition zones; and (3) proximally located aerobic and anaerobic areas for enhanced biogeochemical cycling.

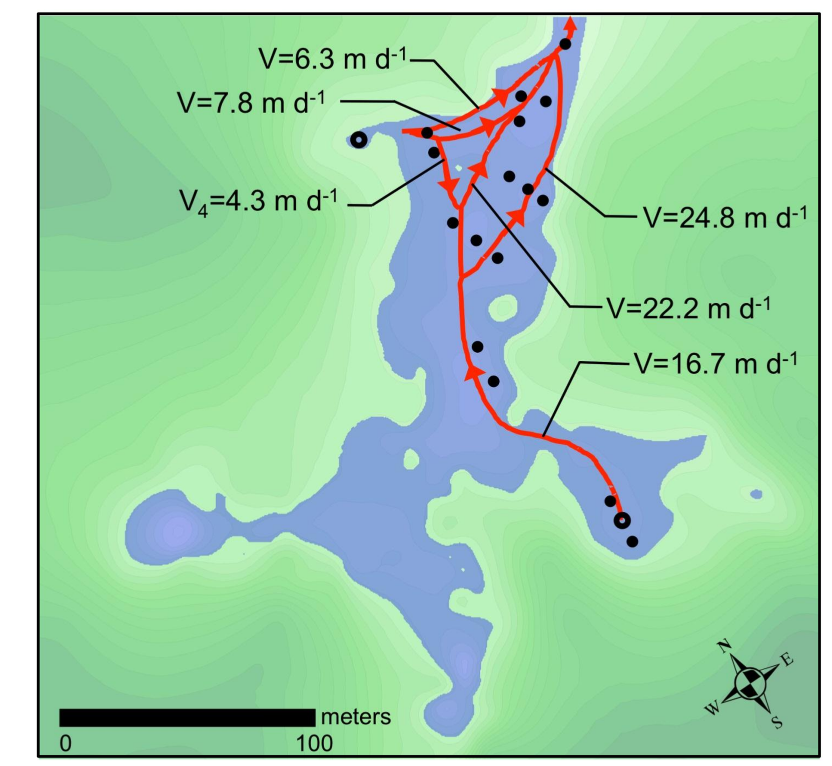


Fig. 8. Proposed flowpath distributions and average velocities along each path.

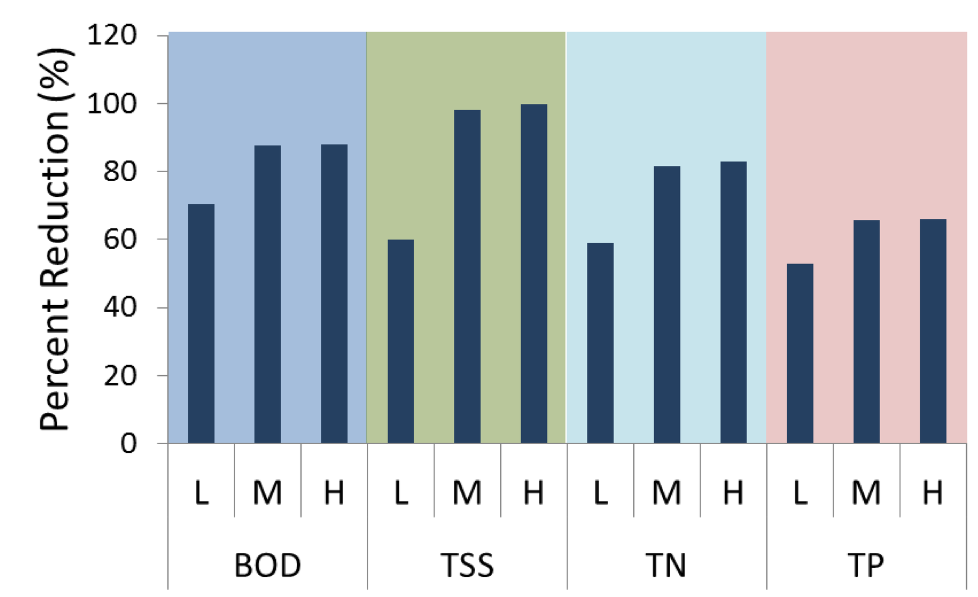


Fig. 9. Estimated wetland treatment over a range of low (L),medium (M), and high (H) influent concentrations.

- Wetland residence time (τ), calculated from velocity data, was 28-41 days.
- High potential treatment efficiencies for biological oxygen demand (BOD), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) were estimated based on τ using the k-C* Model (Kadlec and Knight, 1995) (Fig. 9), reinforcing the environmental services provided by this and other small tropical wetlands.

8. Acknowledgements and References

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