Investigating the Potential for Nitrate-N Removal in Rhode Island Transient Headwater Streams

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Introduction

Background

Excess nitrogen (N) has detrimental effects on ecosystems, particularly in coastal waters where nitrate inputs from septic systems and agricultural runoff can lead to algal blooms, hypoxic zones, and fish kills. However, certain areas on the landscape have the ability to remove nitrate before it reaches the coast. Studies (Peterson et al. 2001; Mulholland et al. 2008) have suggested that shallow, low-flowing headwater streams may promote denitrification, the microbial processing of nitrate-N to N gases. Since headwater streams comprise about 70 to 80% of watershed drainage systems, they may be a valuable N sink, a place where nitrogen is retained, processed or removed from the water.

Hypothesis

Transient headwater streams in forested areas in southern Rhode Island have high N removal potential because of their low flow rates, long retention times, and high surface-to-volume ratios, providing time for N processing and allowing for hyporheic interactions, i.e., groundwater and stream water mixing (Fig. 1). Additionally, nearby hydric soils are often anoxic and rich in organic matter, conditions necessary for denitrification.

Approach

We used GIS tools to identify transient headwater streams and conducted slug nitrate-N and bromide tests to determine flow rates and assess N removal.

Site Selection

We used the Digital Elevation Model data in the GIS ArcHydro program to identify vernal stream locations based on the topography of the Wood-Pawcatuck Watershed in southwestern RI. Four forested, vernal stream study sites were selected in Arcadia Management Area (termed ASE4 and ASO2), Crawley Preserve (CP1), and Fisherville Brook Wildlife Refuge (FB1) (Fig. 2).


Transient Stream Site ASO2

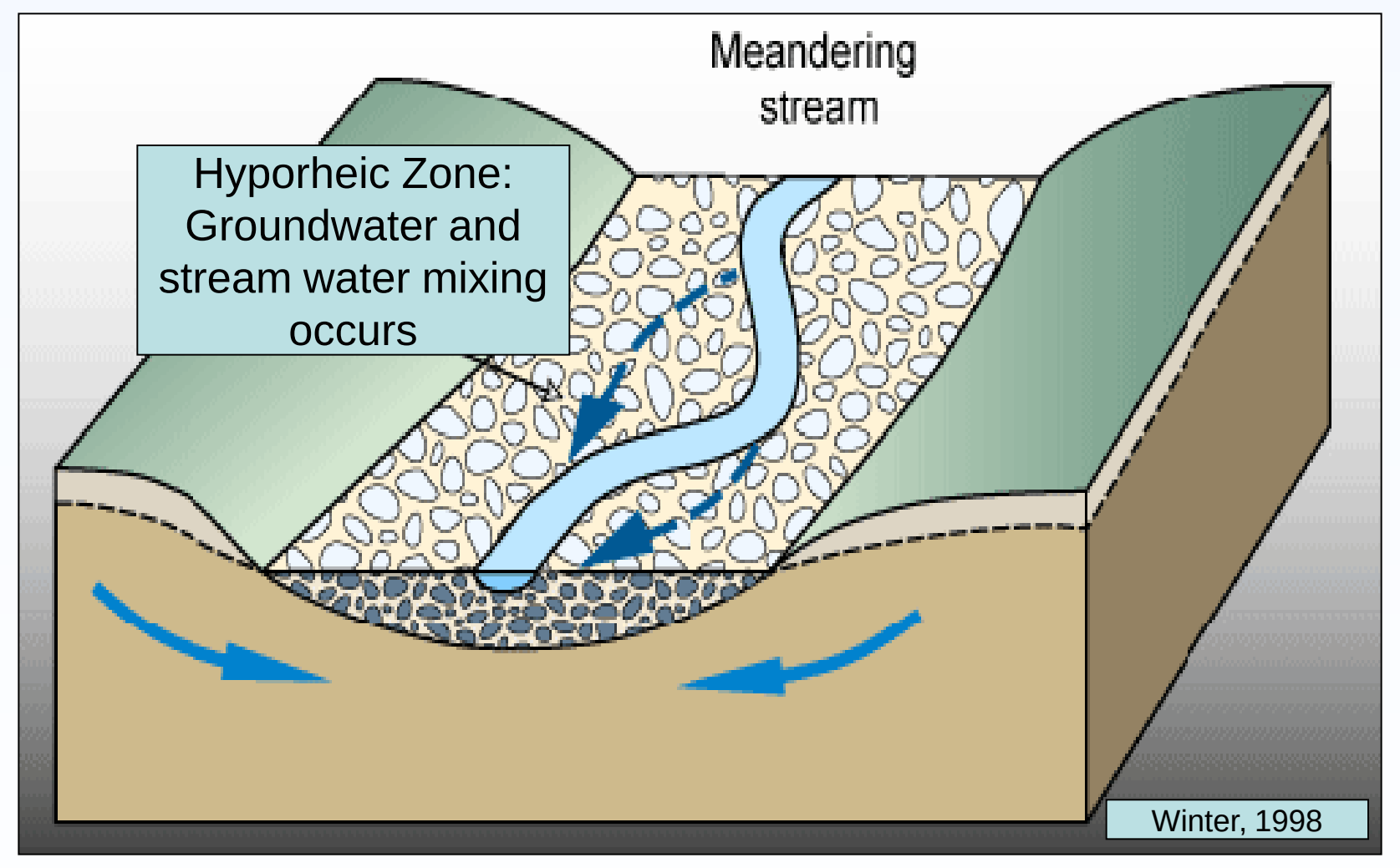

Figure 1: Diagram of hyporheic flow, arrows illustrate stream water interaction with the groundwater and streambed. Nitrate-N removal often occurs during hyporheic flow

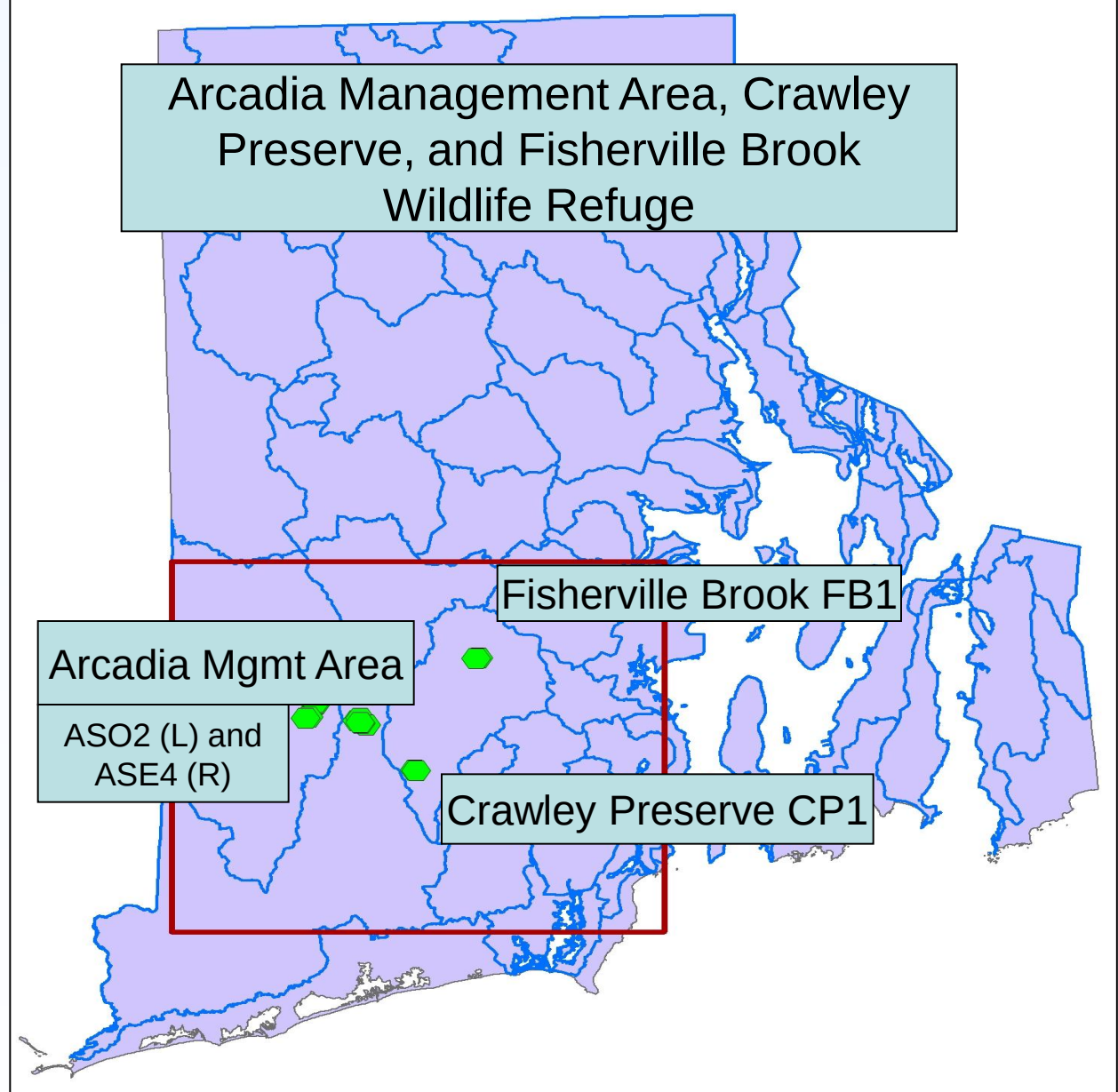

Figure 2: Stream sites were located in Southern Rhode Island

Methods

Flow rate measurement: Every 4-6 weeks from February to June 2010, we determined the flow rate of each stream using slug tests (Fig. 3).

- A conservative tracer bromide (Br) slug was introduced into the stream and samples were taken 30 m downstream every 1-2 minutes for 2 hours (Figs. 4 and 5)
- Water samples were filtered and run on an Astoria Pacific auto-analyzer to determine Br concentrations
- A flow rate was calculated in L/sec based on the initial Br concentration, the average Br concentration of downstream samples, and the time for the Br slug to pass downstream

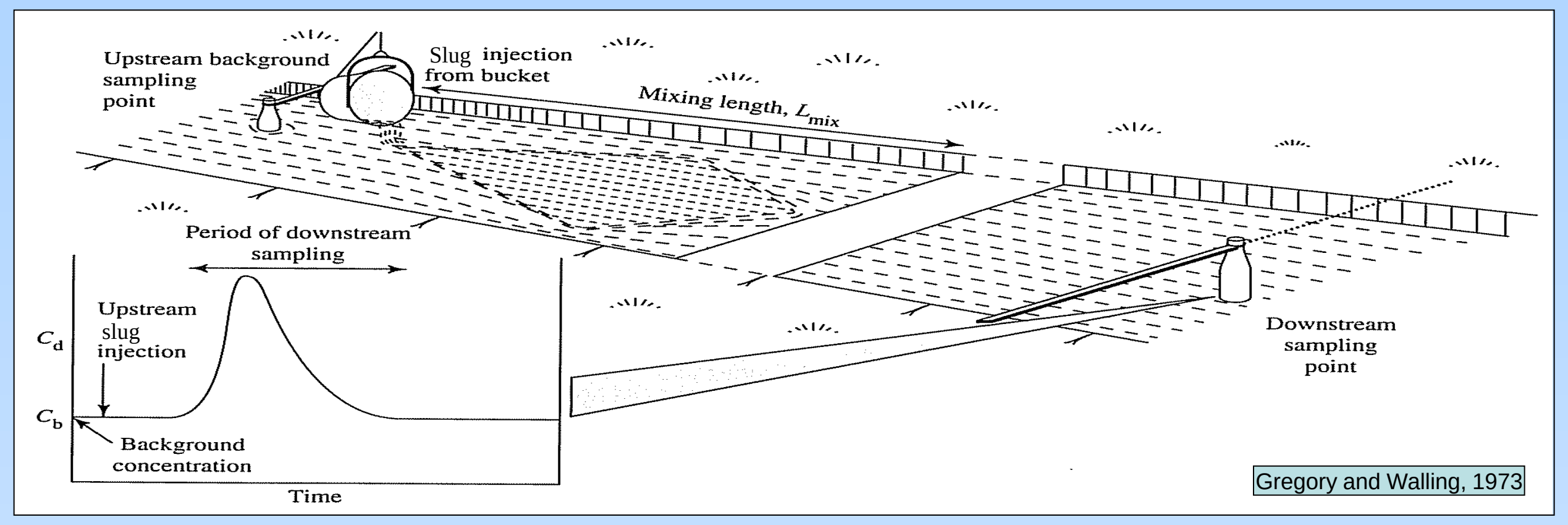

Figure 3: Diagram of a slug tracer test, slug is injected and sampled downstream. As slug passes sampling point, Br rises, peaks and falls (see graph)


Figure 4: A slug containing amendments was introduced and sampled 30 m downstream


Figure 5: We used 30 m reaches to conduct slug tests

Nitrogen removal assessment: We added Nitrate-N to our Br slug several times to compare its behavior to the conservative tracer.

- Sampling, filtering, and analysis occurred as described above
- Nitrate removal was determined by comparing N:Br ratios in the initial slug and downstream samples. An ending ratio of N:Br less than the initial ratio indicated N removal


Transient Stream Site ASO2

References

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Diagram Credits:

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Results

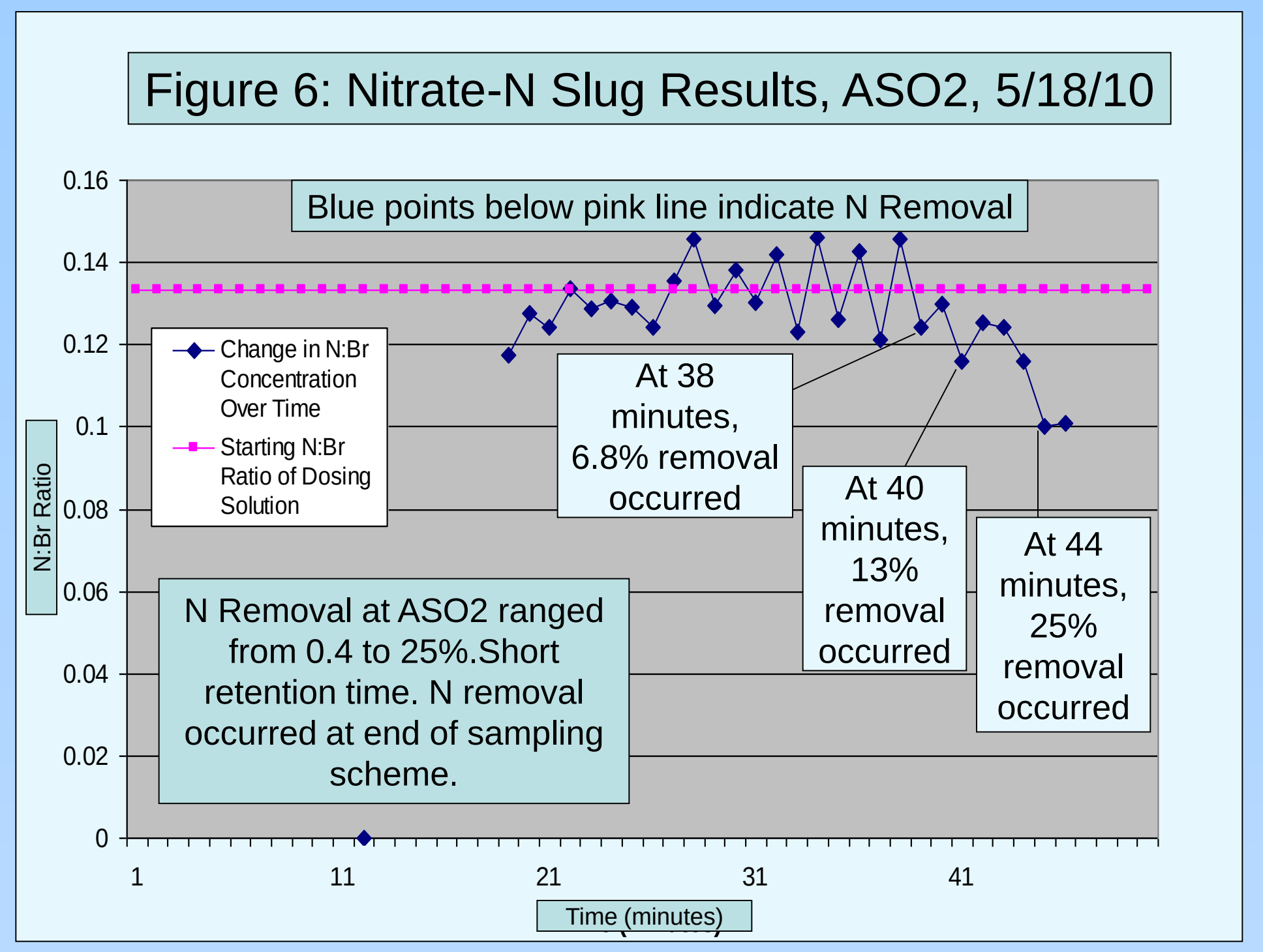
Figure 6: Nitrate-N Slug Results, ASO2, 5/18/10

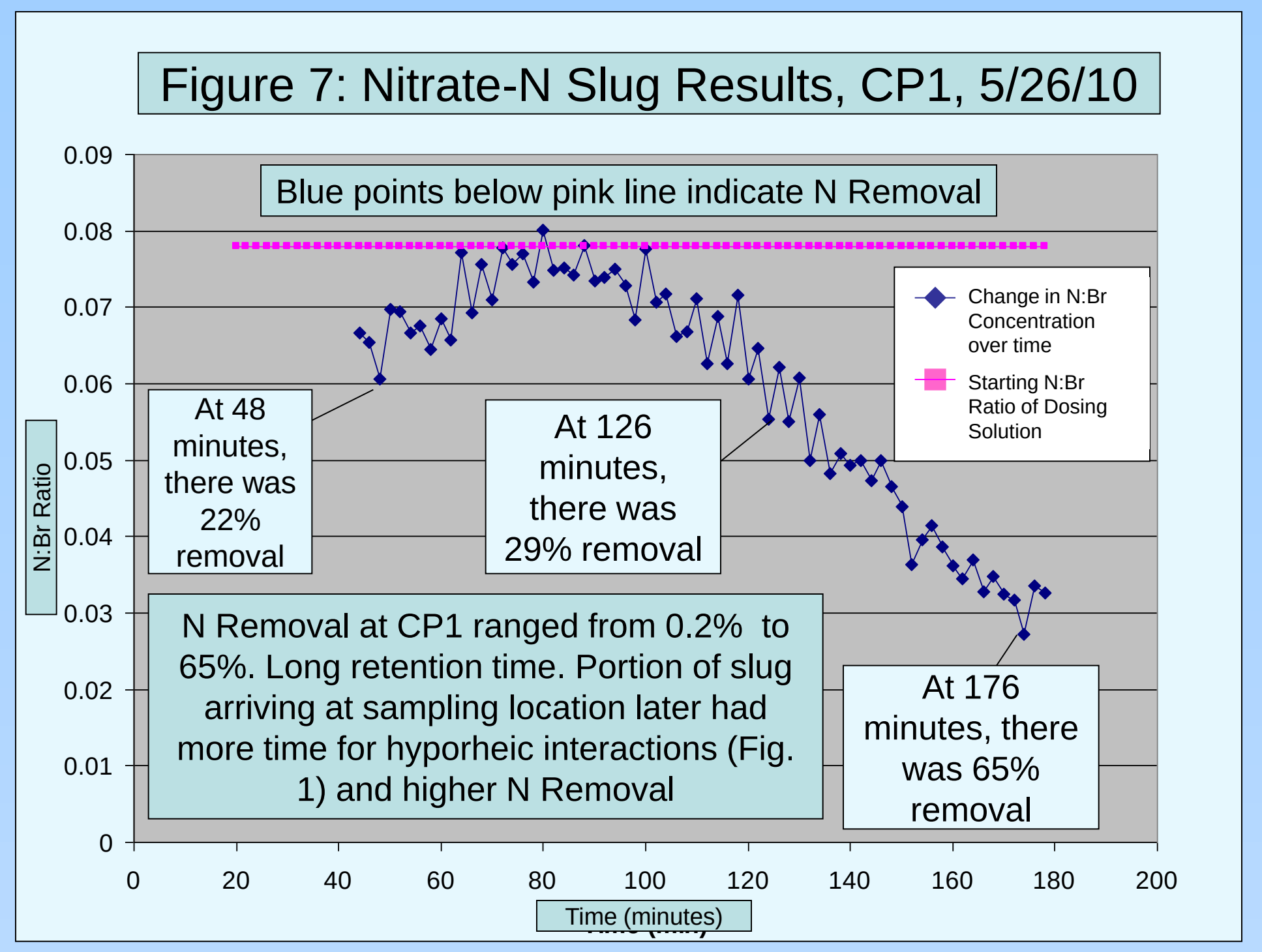
Figure 7: Nitrate-N Slug Results, CP1, 5/26/10

Figs. 6 and 7: N Slug Test Results: Less N removal with shorter retention time (6) and greater N Removal with longer retention time (7)

Fig. 6, ASO2: By 49 minutes, the plume passed the sampling point, indicating a short retention time. Most removal occurred at the end of the sampling scheme, after 40 minutes. Percent N Removal ranged from 0.4 to 25%.

Fig. 7, CP1: After 182 minutes, the plume passed the sampling point, indicating a long retention time. Most removal occurred at the end of the sampling scheme, after 120 minutes. Percent N Removal ranged from 0.2 to 65%. Percent removal was higher than ASO2 due to longer retention time.

Additional Comments: Flows at all sites were low, ranging from 0.66-4.5 L/sec. ASE4 also showed removal, ranging from 0.4 to 52% with a retention time of 35 min. FB1 showed no N Removal, possibly due to not sampling long enough to allow hyporheic interactions or to a gravelly stream bottom low in organic matter

Discussion

- **Three out of the four test slugs demonstrated substantial Nitrate-N removal**

  Transient headwater streams may be important in preventing excess inputs of N from reaching the coast.
- **At the sites that showed N removal--CP1, ASO2 and ASE4--removal occurred as the tail end of the slug passed the sampling point**

  As the later part of the Br-NO_3 plume gradually flows downstream, there has been more time for hyporheic interactions (Fig. 1), in which ground and surface water mix and interact with the substrate, causing longer retention times and more interaction with organic matter to allow denitrification to occur.
- **Longer retention times lead to more N removal**

  The longer N is retained, the greater the potential for N transformation becomes

Figure 8: A stream pool


Figure 9: In-stream sphagnum at site ASE4


Figure 10: Organic matter present at site ASO2

- **The streams with high N removal tended to have several locations where pooling occurred (Fig. 8)**

  Lateral scour pools, plunge pools, and impoundment pools were common at the sites. Pooling leads to longer retention time, which allows more time for N to be transformed.
- **Sphagnum was present in-stream and around the banks of the sites that showed N removal (Fig. 9)**

  In a study comparing the seasonal dynamics of N in two Sphagnum moss species, Berwyn Williams et al. suggested that sphagnum has high nitrate removal capacity (Williams et al, 1999).
- **Organic matter was present in sites that showed N removal (Fig. 10)**

  Fibrous root mats were present, a possible source of N uptake. Woody debris and leaf packs also provided sources of organic material within the streams. The streambeds contained gravel, sand, cobbles and boulders--permeable materials--but often had soils rich in organic matter underneath. Organic matter may serve as a source of carbon for denitrification (VanBreeman et al, 2002).
- **Based on their potential for N removal, more research should be conducted on identifying N processing in transient headwater streams.**

  Efforts should be made to include transient stream N sink functions in N models for watershed management.