Aquatic ecosystems and In-stream Processes
Outline

- Introduction
- Stream dimensions
- Stream biota
- RCC concept
- Abiotic and biotic processes
- Factors
- Examples
- Bernhardt Studies

Lotic – moving waters; streams
Lentic – still freshwaters
Introduction

• Previous studies have typically neglected the influence of in-stream processes for watershed exports of nutrients.

• Treated as "pipe" in watershed studies

• Measurement at any point in the stream reflects terrestrial controls
Early recognition

Hynes (1960) …

“…if the river is long enough and receives enough extra water from tributaries and surface runoff, it can “re-purify” itself”

Hynes (1970) …

“A lifeless river would have a very different chemical regime”

H. B. Noel Hynes
1917-2009
Canadian Ecologist - Considered “the father of running water ecology”
Streams are not pipes!

- Organization & character
- Living ecosystem!
- Can transform nutrients

Colorado Rocky Mountain stream
Key Instream processes

- Adsorption-desorption
- Deposition/burial
- Erosion/Dissolution
- Photodegradation
- Heterotrophic consumption/breakdown
- Autotrophic production/uptake
Drainage Network In the watershed

Fig. 1.30 — Stream ordering in a drainage network. "1" = first order stream; "2" = second order stream, etc.
Interagency Stream Restoration Working Group (15 federal agencies) (FISRWG).
Dimensions of the stream corridor. A four-dimensional framework serves as a good starting point for examining stream corridors..
Vertical dimension
Longitudinal dimension

Lateral dimension and exchange - flooding

e.g., Flood-pulse concept

The flood-pulse concept diagrammed in five stages of an annual hydrologic cycle. The left column describes nutrient movement, the right describes typical life history traits of fish.

Temporal dimension

- Daily
- Seasonal
- Long term (decades…..centuries)
- Natural versus Anthropogenic changes?
Stream Biota

A living ecosystem!

This biota can influence the cycling, consumption, and release of nutrients.

A diversity of aquatic species that include -

- Shredders
- Grazers
- Collectors

Process organic matter and nutrients at different levels
Biodiversity in the benthic biofilm!

Battin et al. 2016

Autotrophs

Heterotrophs
contrast micrographs and colorized scanning electron micrographs of a stream biofilm (750× magnification).

https://microbewiki.kenyon.edu/index.php/File:Stream_biofilm_microscope.gif
River Continuum Concept (RCC)

- Coined by **Robin Vannote**, former Director of the Stroud Water Research Center in Avondale, PA!

- Indicated that the stream network is a continuum

Organizing theory that predicts that **ecosystem structure and function changes in a systematic way from the headwaters to larger order streams**

Based on –

- Benthic invertebrates
- Organic matter input
- Photosynthesis (P) and Respiration (R)
PERSPECTIVES

The River Continuum Concept

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Allochthonous inputs
CPOM; shredders & collectors

P/R < 1

Allochthonous, autochthonous
FPOM; grazers & collectors

P/R > 1

Authchthonous
FPOM; collectors & predators

P/R < 1
Instream processing terms

Some key nutrient processing terms in stream networks -

- **Uptake length (Sw)** – distance travelled by solute in dissolved inorganic form before conversion/consumption

- **Turnover length – (Sb)** – distance travelled by solute in biota before being mineralized

- **Spiraling length = S = (Sw + Sb)**
Instream Processes

• **Abiotic** –
  • Sorption/desorption
  • Precipitation, dissolution, and leaching
  • Photo-oxidation
  • Erosion and burial

• **Biotic** –
  • Assimilation or uptake
  • Dissimilatory reduction (e.g., denitrification)

Both autotrophs (algae) and heterotrophs (bacteria, fungi) play a role.

These processes are reflected in spatial and temporal (daily, seasonal, annual) changes in solutes.
Factors affecting processes

- Stream discharge and velocity (residence time)
- Water exchange and groundwater flow paths
- Hyporheic zone and stream sediments
- Light / solar radiation
- Water temperature
- Nutrients – N, P, silica
- Organic matter inputs – coarse, fine, dissolved

These factors can be limiting at different times and to differing extents thus influencing instream processing
Flow rate and stream velocity affect instream processes

Big Elk Creek

baseflow

Stormflow/flooding
Light reaching the stream matters and varies seasonally

Spring (early April)

Summer (July)

Fair Hill first order stream
Examples

• Spring periphyton – “vernal algal bloom”

• Consumption of nitrate-N by algae – Roberts and Mulholland, 2007
Examples

- “vernal algal bloom”
- Diel DOC production by benthic algae – Kaplan and Bott 1982
Examples

• “vernal algal bloom” and NO3-N consumption – at Fair Hill second order stream!
Examples

Autumn leaf fall – results in nitrate decrease, depression, “crash”

- Input of fresh litter and labile DOC
- Stimulates heterotrophic microbial uptake (C limited microbes)
- C supply also stimulates denitrification

Kaushik and Hynes (1968); Goodale et al. (2009); Sebestyen et al. (2014) and many others.
Autumn nitrate depression in Fair Hill second order stream
Examples

BIOTIC CONTROL OF STREAM FLUXES: SPAWNING SALMON DRIVE NUTRIENT AND MATTER EXPORT

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Salmon move nutrients up the stream network!
Bernhardt et al. (2005) make the case that *in-stream processing may be one of the factors responsible for the recent decrease in nitrate exports observed for some of the NE watersheds.*
Temporal changes in NO3-N

TEMPORAL PATTERN of NITRATE N

Average concentrations of NO3-N

• 1965-74 – 0.40 +/- 0.18 mg/L
• 1993-2000 – 0.09 +/- 0.07 mg/L

Average annual export –

• 1965-74 = 3.61 kgN/ha/yr
• 1993-2000 = 0.85 kgN/ha/yr
Figure 2. Seasonal patterns of (a) nitrate (NO$_3^-$) concentration (micrograms of nitrogen as NO$_3^-$ [NO$_3$-N] per liter) and (b) NO$_3^-$ export (kilograms NO$_3$-N per month) compared between the first and last decades of the long-term record at the Hubbard Brook Experimental Forest.

DECLINE in NO$_3$-N exports in 1992-2001
Potential hypotheses to explain NO3-N decline –

- **Increased storage** in plant biomass and soil organic matter
- **Climate change** and its impact on forests
- **Forest disturbances** – soil frost, defoliation, tree disease, ice storms
  - Forest disturbances have not declined since the 70s. increasing tree disease – but that should increase exports.
- **In-stream processes**
Objective

The focus of this paper was to estimate how in-stream processing could account for nitrate decline.
How have HBEF streams changed –

• Bear brook – headwater stream, originated in a 13 ha watershed, bedrock bottom

• No algae earlier, but algal blooms observed in the 90s

• NO3 uptake in the 70s was low and not stimulated by labile C additions. Not so in the 90s when uptake rates increased due to C addition

• Net retention was determined to be 2.4 kg N per year through input-output budgets across a 200m length of the stream
Question 2

What changes in nitrogen retention mechanisms would explain the increased nitrate processing ability of HBEF streams?

Two possibilities –

• Increased immobilization of inorganic N and conversion to dissolved and particulate organic N.

• Facilitated by increased organic biomass in the streams as the watersheds age.
Question 2

- Increased debris accumulation in the streams, more complexity, increased residence time of water by the formation of debris dams.
Question 2

- Increased benthic storage of PON
- Increased autotrophic uptake following snowmelt – "vernal dam"
- Not able to determine if DON exports have increased since DON was not measured – major weakness of this study to not account for total N.
Question 2

• Measured denitrification rates were very high and could likely explain all of the discrepancy in inorganic N

• Accumulation of organic matter in streams and debris dams likely enhance the possibility of denitrification
Figure 5. A conceptual model of changes in stream nitrogen (N) cycling as the surrounding forest ages.

Transformations between forms of N are indicated by arrows: (1) uptake of ammonium (NH4+) through both abiotic sorption and biological assimilation; (2) mineralization of organic N to NH4+; (3) nitrification (the oxidation of NH4+ to NO3– by chemoautotrophic bacteria); (4) denitrification (the reduction of NO3 – to nitric oxide [NO], nitrous oxide [N2O], and N2 by denitrifying bacteria; (5) biotic assimilation of NO3–; (6) release of dissolved organic nitrogen (DON) into solution (through leaching of organic material and exudation or excretion of organic molecules); (7) sorption and biological assimilation of organic molecules.

In this model we assume that inputs of N to the stream remain constant. If this assumption were met, we would expect faster cycling of N between inorganic and organic forms in streams draining mature forests, due to increased density of debris dams and storage of organic matter. These changes in the channel would increase hydrologic storage and the presence of anoxic zones in the stream bed—conditions that favor storage of particulate N and denitrification of NO3–.
Conclusions

Key Conclusions –

• In-stream processes can influence stream water N signals. Important to understand instream processing and distinguish it from terrestrial processes.

• Need to include in-stream processes in watershed and ecosystem models

• Terrestrial and in-stream processes may not work in tandem and may differ in their influence (timing and magnitude) of nutrient processing. They might even have opposite trajectories with respect to nutrient cycling and retention.
Example

In-stream uptake dampens effects of major forest disturbance on watershed nitrogen export

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Increased algal uptake of NO3-N

Conversion to organic N and retention?

Denitrification?
Questions & Comments?