

THE INFLUENCE OF DISCHARGE ON TRACER DILUTION AND NITROGEN DYNAMICS IN A SMALL MOUNTAIN STREAM OF THE HUBBARD BROOK EXPERIMENTAL FOREST

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Abstract. Nitrogen emissions are now a major source of acidity in precipitation and have led to increased deposition of nitrogen over much of the United States. Nitrate and acidity in precipitation affect soil fertility and can lead to increased concentration of nitrogen in streams. For these reasons, scientists predict that nitrate will be a major factor controlling stream and soil chemistry. The extent to which processes in small streams affects downstream nitrate concentrations, however, is not fully understood. A study of in-stream nitrate dynamics was conducted downstream of the weir on Watershed 3 in the Hubbard Brook Experimental Forest (HBEF). This project focused on four questions regarding nitrate dynamics in a small mountain stream: 1) How does discharge affect dilution in nutrient additions? 2) How is discharge related to fine-scale spatial variation of nitrate concentration in a forest stream? 3) How does stream discharge affect rates of nitrate uptake and uptake lengths? 4) Do any specific physical structures (such as organic debris dams) influence changes in nitrate uptake? On five dates, nitrate was added to the stream to examine how dilution and uptake affected changes in nitrate concentration. Water samples were collected at approximately 2m intervals and were analyzed for nitrate concentration. Dilution was inversely related to discharge. A high amount of variability was found in the background concentrations of nitrate, and variability increased with decreasing discharge. Limited data indicated that uptake lengths for this stream tended to be long with low uptake rates, suggesting that added nitrate travels long distances. Areas with organic debris dams, which were expected to experience a higher nitrate uptake rate, did not have increased uptake rates. These results suggest that discharge and spatial variability of uptake rates are important considerations in whole-stream estimates of nutrient cycling.

INTRODUCTION

In recent years the impact of human actions, such as the burning of fossil fuels, on aspects of our environment including water quality has come under close scrutiny. Levels of nitrogen in the atmosphere, which has been directly linked to acid deposition, are elevated in industrialized regions of the world and continue to accelerate in developing regions (Galloway, 1995). Growing concern has been placed on the influence of nitrogen emissions on acid deposition. Commonly referred to as acid rain, acid deposition has been an increasing worry in forest ecosystems as elevations in nitrogen deposition have been observed (Aber et al., 1989). Possible effects of this chronic nitrogen deposition include elevated concentrations on nitrate in streams, which could lead to harmful algal blooms and affect the quality of drinking water. Nitrate levels in rain have also increased cation leaching from soils, leading to decreased soil fertility (Aber et al., 1989).

In order to be able to estimate the impact of increases in nitrate levels on ecosystems, which Aber et al. (1989) predict will be the most influential chemical species in streams and soil chemistry, it is necessary to understand the dynamics of nitrate flow within streams. By studying the dynamics of nitrate within a stream, we will increase our knowledge of nutrient cycling in streams and be able to better anticipate how streams will react to increases in nitrate concentrations.

Solute dynamics refers to the spatial and temporal patterns of solute transport and transfer (Stream Solute Workshop, 1990). Studies of solute dynamics provide two important types of information. They develop information on rates of transport and transformation of specific solutes necessary for the function of the stream ecosystem. These studies can also be used to quantify various hydrological properties of a stream, including transient storage (Webster and Ehrman 1996).

The dynamics of many stream solutes are determined primarily by biogeochemical and hydrologic interactions occurring in the whole watershed (Webb and Walling, 1992). Because of this, the processing of nutrients in a stream is sometimes overlooked when examining the nutrient dynamics of a watershed. However, many important in-stream processes also occur (Webster and Ehrman 1996). Recent studies have found that nutrient levels in streams are lower than groundwater inputs, suggesting that in-stream processes are important in regulating stream-water nutrient concentrations (Mulholland 1992). Mass balance studies have also shown that streams can retain nutrients on a short time-scale, which can lead to substantial nutrient load release during high-flow storm events (Meyer and Likens 1979).

This variance in retention times could cause streams to shift between being sources and sinks for nutrients (Mulholland 1992), including nitrate, at various points along the stream. Since, streams are heterogenous environments, rates of biogeochemical processes most likely vary from one location to another within a single stream (Steinhart et. al. 1999).

The dynamics of the solutes in a stream are tightly linked to the flow of the stream. Spiraling is a term often used to describe the movement of solutes both in the water at any point in conjunction with their downstream, longitudinal movement (Newbold 1992). Factors that modify the flow of the stream can also impact the dynamics of the solute in the water. Organic debris dams are accumulations of organic matter including logs, sticks, and leaves, which obstruct normal water flow in many small streams. Pools are often formed upstream of the dams. These pools and the dams themselves collect particulate organic matter acting as reservoirs for the organic matter and associated nutrients (Bilby 1979).

Solutes can span a whole range of chemical species, however one of the most biologically limiting is nitrate (Raven 1998). Loss of nitrate from running waters can be accounted for through assimilation of nitrate by algae and denitrification by bacteria in anaerobic conditions (Webster et. al. 1996). The controls and importance of stream channel nitrogen transformations, particularly denitrification, are not well understood (Steinhart et. al. 1999).

The Hubbard Brook Experimental Forest (HBEF) has been the site for a great deal of work on both organic debris dams (Bilby 1979, Bilby and Likens 1980, Bilby 1981) and nutrient cycling via whole stream manipulations (Meyer 1979, Richey et al., 1985). Bilby and Likens (1980) examined the effects of debris dams on particle export by removing all dams in Watershed 5. Bilby found that dam removal dramatically increased the export of fine and coarse particulate organic carbon (630% and 138%, respectively) thus illustrating the importance of the in-stream debris dams in the regulation of carbon export. A 6% increase was seen in dissolved matter export (Bilby 1979).

Richey et al. added urea, ammonium and nitrate to Bear Brook. They discovered that ammonium and urea were removed from the stream while nitrate was not. More recent work by Steinhart and others showed that denitrification may play an important role in nitrogen processing in streams at HBEF (Likens et al. 1999).

This study aimed to address the following questions: 1) How does discharge affect dilution in nutrient additions? 2) How is discharge related to fine-scale spatial variation of nitrate concentration in a forest stream? 3) How does stream discharge affect rates of nitrate uptake and uptake lengths? 4) Do physical attributes of a stream, such as organic debris dams, affect nitrate uptake at various rates of stream flow?

METHODS

Study Site

The study site consisted of a 65m stretch of stream immediately downstream of the weir of Watershed 3 in the Hubbard Brook Experimental Forest (HBEF), near West Thornton, New Hampshire. The HBEF is located in White Mountain National Forest. Watershed 3 (W3) encompasses 42.4 ha. The section of stream contained 4 large organic debris dams. The entire valley was clear-cut some 80 years ago, but no further harvesting has occurred in W3 since.

Nutrient Releases and Sample Analysis

Throughout the month of July and in the beginning of August, small-scale nutrient additions were performed at the study site. A solution containing NO₃-N (as NaNO₃) and NaCl (as a conservative tracer) was dripped into the stream via a peristaltic pump for each nutrient release. Target final streamwater concentrations for each added solute were 3000-7000 ug/L of Cl⁻ and 30-50 ug/L of NO₃-N, which would be approximately 3-5 times the summer ambient levels, providing sufficient magnification to look at uptake patterns without being too unfeasibly high. Discharge (Q) was calculated via the 90° weir located at the most upstream portion of the study site. For the weir on watershed 3, the following formula was used to convert the weir readout to discharge:

$$Q=(H)^{2.47} \cdot 71.4 \quad (1)$$

where H is given as a readout height by the weir. Discharge was measured before the release was performed in order to determine the drip concentration necessary to achieve the desired target concentration of both nutrient and conservative tracer. The conservative tracer served a twofold purpose: 1) to monitor the progress of the release and 2) to allow for the correction of apparent nitrate loss due to downstream dilution. NO₃⁻ loss is corrected for background by finding the concentrations of Cl⁻ and NO₃-N in the initial samples and subtracting that from the concentrations found in the release samples. Samples were then corrected for dilution by dividing the corrected NO₃-N concentration by the corrected Cl⁻ concentration.

The first question addressed in this section will be whether or not discharge had any effect on the dilution of the conservative tracer. For each release, the conductivity was taken at each sampling point. By knowing the conductivity of the most upstream sampling point and the conductivity of the monitoring point, the percent dilution of the release can be calculated in the following manner:

$$\text{Dilution\%} = \frac{\text{UpstreamCond.} - \text{Monitor Cond.}}{\text{Upstream Conductivity}} \quad (2)$$

Releases were performed at 5 different discharges (2.4, 1.0, 0.7, 0.56, and 0.3 L/s). Prior to the start of the drip, background stream water samples were collected from a well-mixed area designated as a sample site. In order to address questions regarding impact of organic debris dams on uptake rates and whether or not specific areas had higher uptake rates, the use of a high spatial resolution sampling method was incorporated. Sample sites occurred approximately every 2 meters over a 65.2m total stretch of stream. The areas immediately before and after every debris dam were sampled regardless of where they occurred in the sampling continuum.

A peristaltic pump released the solution at a constant rate (20 ml/min). A conductivity meter placed ~30 meters downstream of the pump monitored the progress of the release. Once plateau conductivity had been achieved (<0.5 uS change over 10 min.), water samples for NO₃-N and Cl⁻ were again taken at each designated sample site, as well as the wetted width of the site.

Water samples were taken back to the lab and frozen until analysis could be completed. Samples were analyzed for nitrate and chloride concentrations with a Dionex Ion Chromatograph (IC).

Data analysis was performed in Microsoft Excel. Uptake lengths were calculated by running a regression between the log of the corrected (for background and dilution) $\text{NO}_3\text{-N}$ concentrations and the downstream distance. The inverse of the slope of this regression was the uptake length.

RESULTS

A negative relationship between percent dilution and discharge was found upon calculating the percent dilutions from each release (Fig. 1). At low discharge the dilution of stream water solutes from the uppermost sample point to the last sample point of the reach was substantial, while at high discharge much less dilution occurred.

Interesting trends in chloride and nitrate background concentrations were found (Fig. 2 and 3). For instance, in Fig. 2 the 2.4 L/s discharge has the lowest standard deviation of 19.18 (among longitudinal points), while slower discharges, such as 0.56 L/s had a standard deviation of 270.14. Similar trends are seen for nitrate in Fig. 3 where the discharge of 2.3 had a standard deviation of 3.45 and the discharge of 0.56 had a standard deviation of 40.75. An interesting spatial trend was also found within the first 20 m of the stretch for both graphs. For each release, chloride and nitrate levels started around the same concentration and then tended to increase, which was not expected for background concentrations. For a few points within the same discharge release, peaks and dips in the concentrations of both species were seen, however, no overall pattern was observed.

The third set of questions dealt with how discharge influences uptake lengths and rates. For the releases performed during this experiment, very little uptake was seen. Although, as Figure 4 shows, nitrate did decrease in concentration downstream, most of this was due to dilution and not uptake. This is clear because the addition of the conservative tracer allowed for dilution corrections to be made to the $\text{NO}_3\text{-N}$. To give a better idea of what is expected during a release in which uptake can be calculated, Emily Bernhardt has allowed the use of data from W3 she collected in the summer of 1999, which is shown in Figure 5. By comparison, it is seen that at high rates of uptake, as was the case in this release, the slope of the corrected nitrate would be much different from the slope of the conservative tracer.

Fig 4 shows the corrected concentrations of nitrate and chloride for each sampling point at a distance downstream. The nitrate line parallels the tracer line. This indicates that uptake lengths for this stretch of stream are long and rates are low.

DISCUSSION

For most releases conducted under this study, little or no nitrate uptake was measured. These findings contrast with the unpublished data of Dr. Emily Bernhardt (Figure 5), which showed substantial uptake. There are two possible explanations for the discrepancy between the results of the two studies. The first is that the rates of uptake were higher on the earlier dates. The second is that an insufficient amount of nitrate was added during the second study to measure uptake. Given the large difference between the rates from the two dates, the second option is the most viable explanation.

Despite the fact that nitrate uptake rates were difficult to measure, some interesting questions can be raised from the background chloride and nitrate concentrations seen in Figs. 2 and 3. In both figures, concentrations of both species started at about the same levels on each date and consistently increased downstream. It is important to keep in mind that these releases occurred immediately after the weir on watershed 3. In the construction of a weir, a ponding basin catches the measured water. Here the water pools before it is released into its regular course. It is possible that denitrification is taking place in the ponding basin, causing the water released into the

normal catchment to contain decreased nitrate concentrations. The concentrations could be increasing downstream due to groundwater additions or release by algae.

Conclusions as to whether or not physical attributes of the stream correlated to differing uptake lengths/rates could also not be concluded. It is interesting, however, that a large organic debris dam occurs in the first 10 m of the stream. This was also the area associated with consistently lower background nitrate concentrations that increased as the stream moved to 15 m. This would be consistent with laboratory studies which showed that rates of denitrification at Bear Brook (of the HBEF) may remove as much as 25-110% of the nitrate output in stream water during the months of July thru October (Steinhart et al. 1998). Steinhart et al. also found that denitrification potential was noticeably higher in areas of organic debris dams, suggesting that dams may play an important role on nitrogen transformations in this stream. Similarly, Hedin (1990) found that organic debris dams were hotspots for metabolic activity and community respiration.

The background data for the concentrations of both chloride and nitrate imply that spatial variation and sampling frequency can reveal some differences in uptake lengths and rates for various parts of the stream. As a general pattern, background variation of both nitrate and chloride tended to decrease with increasing discharge. High background variation can cause problems in correcting for background concentrations, as was found in this study. For many samples (Fig. 4), the background concentration of nitrate was higher than the concentration in the release sample, resulting in negative values, which could not be used to calculate uptake lengths. Release data also showed that discharge increases, dilution of the conservative tracer decreases. This means that the role of groundwater in dilution decreases with increasing discharge.

In conclusion, this study provides an interesting perspective as to the limitations of nutrient addition studies. If sufficient $\text{NO}_3\text{-N}$ is added to measure the uptake, the nutrient concentrations may be altered such that rates of algal growth or denitrification are affected. This could possibly produce magnified results that do not accurately reflect what is occurring in the stream.

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LITERATURE CITED

- Aber, J. D., K. J. Nadelhoffer, P. Steudler, and J. M. Melillo. 1989. Nitrogen Saturation in Northern Forest Ecosystems. *Bioscience* **39**:378-86.
- Bernhardt, E. S. 1999. Nutrient Release Protocol – HBEF Spring 1999. Personal communication on 20 June 2000.
- Bilby, R. E. 1979. The function and distribution of organic debris dams in forest stream ecosystems. Ph.D. Thesis, Cornell University. 141 p.
- Bilby, R. E., and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* **61**:1107-1113.
- Bilby, R. E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate organic matter from a forested watershed. *Ecology* **62**:1234-1243.
- Galloway, J. N. 1995. Acid deposition: Perspectives in time and space. *Water, Air and Soil Pollution* **85**: 15-24.
- Hedin, L. O. 1990. Factors controlling sediment community respiration in woodland stream ecosystems. *Oikos* **57**:94-105.
- Hubbard Brook Experimental Forest Website. 2000. Online: (<http://www.hbrook.sr.unh.edu/data/stream/stream.htm>).

Johnes, P. J., and T. P. Burt. 1993. Nitrate in Surface Waters. Pages 269-317 in Burt, T.P., Heathwaite, A.L., Trudgill, S.T. editors. Nitrate: Processes, Patterns and Management. John Wiley & Sons, New York, New York, USA.

Likens, G. E., R. O. Hall, E. S. Bernhardt, and K. H. Macneale. 1999. Online:(http://www.hbrook.sr.unh.edu/current/projects/streams/stream_99.htm#hist)

Meyer, J. L. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. *Ecology* **60**:1255-1269.

Meyer, J. L., and G. E. Likens. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. *Ecology* **60**:1255-1269.

Mulholland, P. J. 1992. Regulation of nutrient concentrations in a temperate forest stream: Roles of upland, riparian, and in stream processes. *Limnology and Oceanography* **37** (7):1512-1526.

Newbold, J. D. 1992. Cycles and Spirals of Nutrients. Pages 379-408 in Calow, P.E., Petts, G.E. eds. *A Rivers Handbook*. Blackwell Scientific Publications, Oxford, Great Britain.

Raven, P. H, R. F. Evert, and S. E. Eichorn. 1998. *The Biology of Plants*, 6th Edition. W H Freeman & Co.

Richey, J. S., W. H. McDowell, and G. E. Likens. 1985. Nitrogen transformations in a small mountain stream. *Hydrobiologia* **124**:129-139.

Steinhart, G. S., G. E. Likens, and P. M. Groffman. In press (1999). Denitrification in stream sediments in five northeastern (USA) streams. XXVIII SIL Congress, Dublin, Ireland.

Stream Solute Workshop. 1990. Concepts and methods for assessing solute dynamics in stream ecosystems. *Journal of the North American Benthological Society* **9**:95-119.

Triska, F. J, J. R. Sedell, K. Cromack, S. V. Gregroy, and F. M. Mcorsion. 1984. Nitrogen budget for a small coniferous forest stream. *Ecological Monographs* **54**:119-140.

Webb, B. W., and D. E. Walling. 1992. Water quality. Chemical characteristics. Pages 73-100 in P. Calow and G. E. Petts, eds. *The Rivers Handbook*. Blackwell Scientific, Oxford, UK.

Webster, J. R., and T. P. Ehrman. 1996. Solute Dynamics. Pages 145-160 in F. R. Hauer and G. A. Lamberti, eds in *Methods in Stream Ecology*. Academic Press, San Diego, CA, USA.

APPENDIX

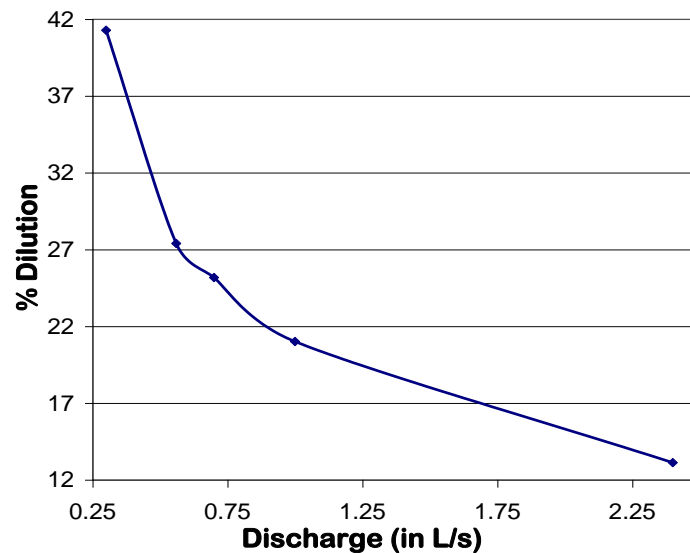


FIGURE 1. Percent Dilution of a Release as a Function of Discharge

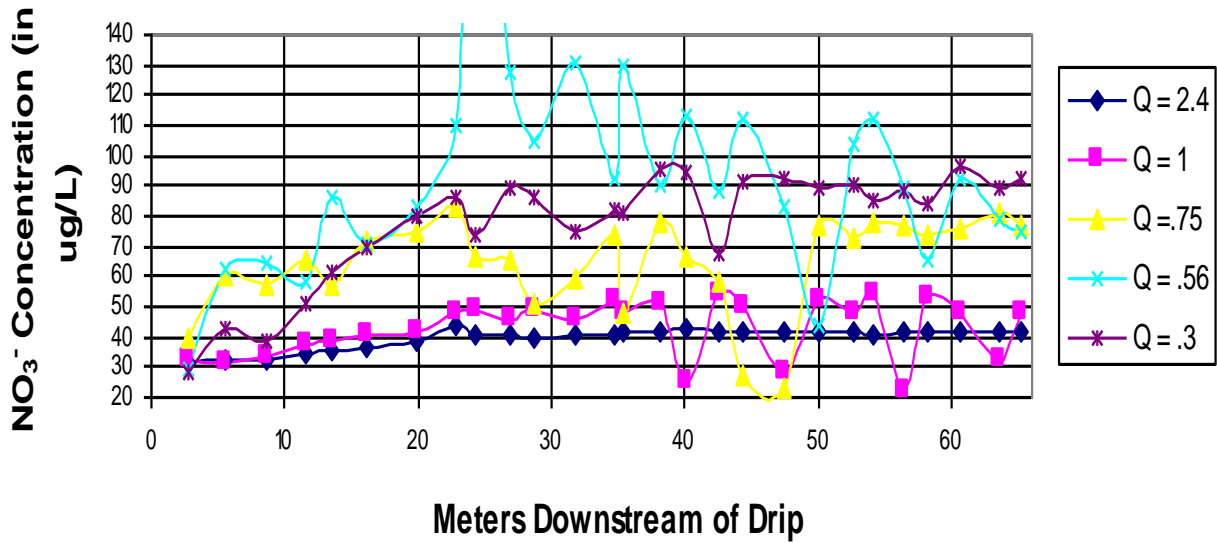


FIGURE 2. Background concentrations of chloride (a biologically conserved element), as collected at set sampling points along W3 at various stream discharges.

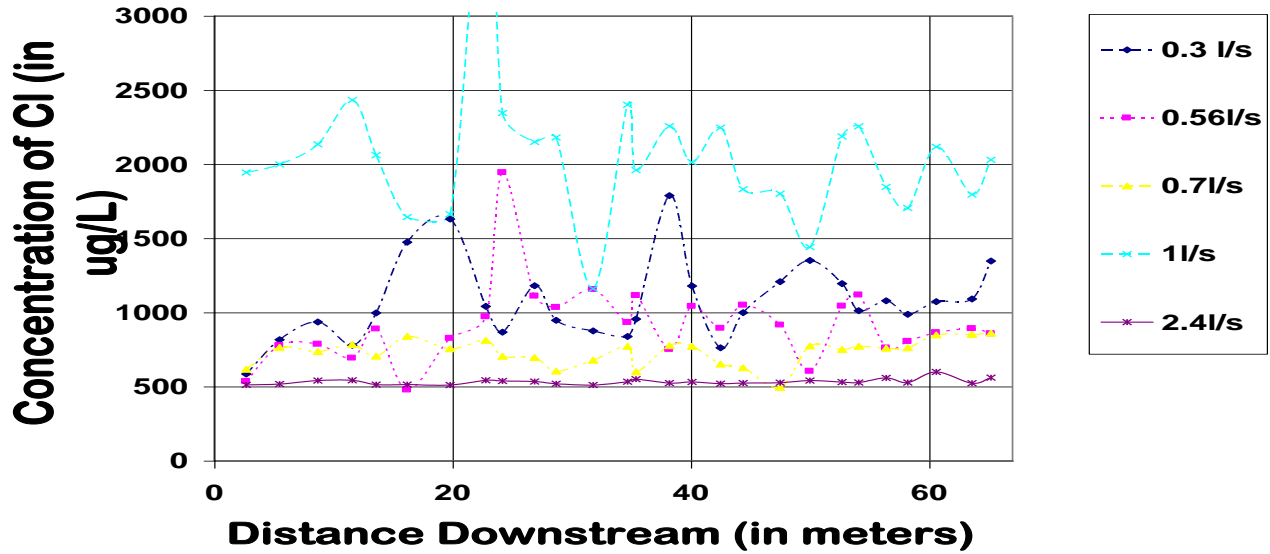


FIGURE 3. Background concentrations of nitrate as collected at set sampling points along W3 at various discharges

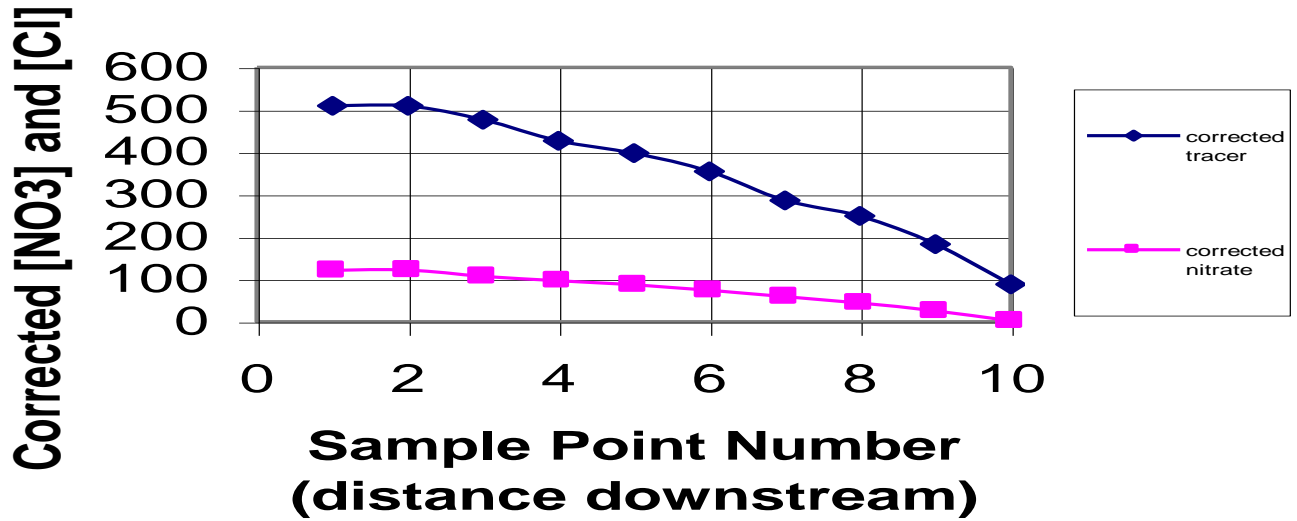


FIGURE 4. Corrected concentrations of nitrate and chloride for the .7 L/s release on W3. Data is plotted against the distance in meters.

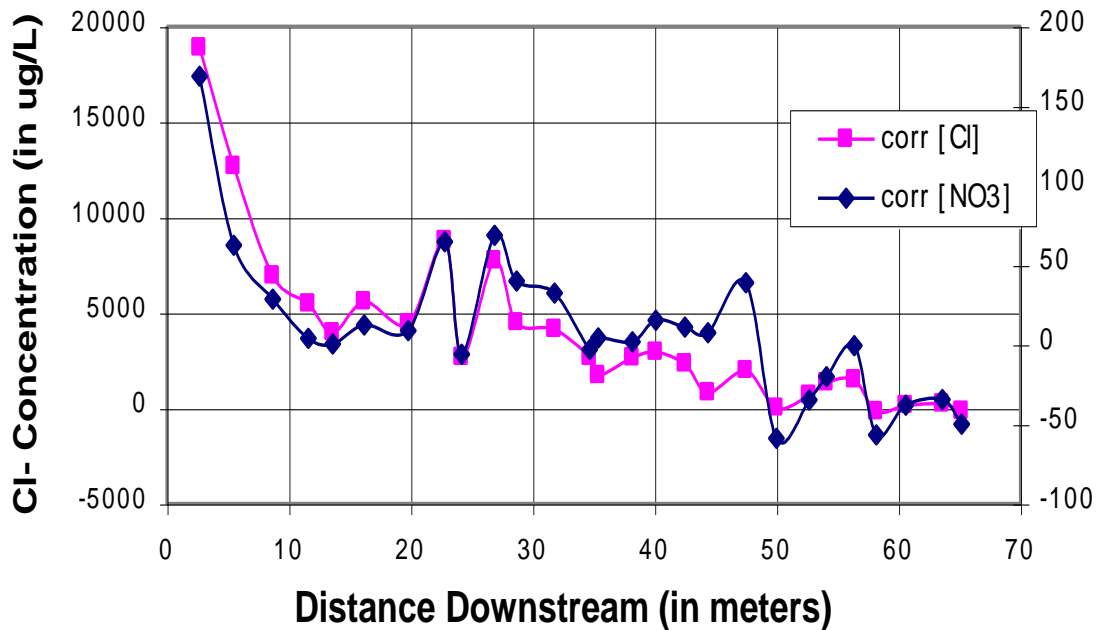


FIGURE 5. Data from a release performed by E. Bernhardt on W3. This is an example of what high nitrate uptake graphically looks like.