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Introduction

Research Program

Effect of Surface Coatings and Ionic Strength on Bacterial Removal Rates in Porous Media

Basic Information

Title:	Effect of Surface Coatings and Ionic Strength on Bacterial Removal Rates in Porous Media
Project Number:	2001NH501B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
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Research Category:	Not Applicable
Focus Category:	Groundwater, Waste Water, Water Quality
Descriptors:	Surface Coatings, Pollutants, Septic Tanks, Groundwater Quality,Bacteria
Principal Investigators:	Carl H Bolster

Publication

Project Title: Effect of Surface Coatings and Ionic Strength on Bacterial Removal Rates in Porous Media.

PI: Carl H Bolster, Dept. of Natural Resources, University of New Hampshire, Durham, NH 03824

Problem and Research Objectives:
The transport of pathogenic viruses and bacteria in the subsurface poses a potential threat to public health. Contamination of water supplies by fecal material is the most common source of waterborne pathogens. In the 1980's, the use of untreated ground water was responsible for 43% of waterborne disease outbreaks occurring in the U.S. In New England, greater than 96% of all drinking water supplies in violation of drinking water standards are contaminated with bacteria (USEPA 2000). Failing septic systems are considered by EPA to be one of the biggest problems today for New England water bodies and have been suggested as the source of bacterial contamination in surface waters of New Hampshire (Margolin and Jones 1991).

The prevention of microbial contamination of drinking water supplies and surface waters requires an understanding of the processes controlling microbial transport and removal within the subsurface. Among the most important factors shown to influence bacterial transport through porous media are ionic strength (e.g. Fontes 1991) and the presence of metal-oxyhydroxide coatings on sediment surfaces (e.g. Scholl, 1990 #62). In circumneutral pH waters, bacteria and quartz sand grains both exhibit a net negative charge leading to unfavorable conditions for bacterial attachment to sediment surfaces. Increasing ionic strength has been shown to increase this attachment by increasing van der Waals attractive forces. In addition to high ionic strength waters, the presence of metal-oxyhydroxide coatings has also been shown to result in greater attachment rates of bacteria to sediment surfaces owing to the charge reversal imparted by the oxyhydroxide coatings at circumnuetral pH.

While numerous studies have been conducted looking at the effects of ionic strength and surface coatings independently on bacterial deposition rates, no systematic study yet exists looking at the combined effects of ionic strength and surface coatings on bacterial attachment rates. To better understand bacterial attachment and transport in NH aquifers, research needs to be conducted on the combined effects of high ionic strength waters and metal-coated sands. This project examines the effects of ionic strength on bacterial attachment rates to iron-coated sands.

Methods:
To test the effects of ionic strength and surface coatings on bacterial retention rates, laboratory column experiments have been conducted using commercial-grade sediments coated with synthetic iron-oxyhydroxides. Homogeneous columns were constructed using Unimin™ quartz sand sieved into a discrete size fraction. The sand was coated with Fe-oxides by a method similar to that employed by Mills et al. (1994). Sterilized sand was slowly poured into 30-cm Kontes™ chromatography columns containing sterilized

buffer water. Columns were operated at a flow rate of ~1 m day^{-1}. Ionic strength was modified by addition of KCl to the buffer water. Ionic strength of the carrier fluid will range from 10^{-4} to 10^{-1} M.

A short pulse of ^{14}C-labeled bacteria was be passed through the columns at initial concentrations ranging from approximately 1×10^7 cells mL^{-1} to 2×10^7 cells mL^{-1}. These low concentrations help ensured that clean-bed conditions existed within the column. Organisms were grown on R2A medium (Difco) amended with ^{14}C-glucose (1 μCi mL^{-1} of growth medium) and allowed to reach stationary phase. Effluent samples were collected from duplicate columns and the effect of ionic strength on bacterial attachment rates was evaluated.

Sticking efficiency, a measure of the affinity of the bacteria to a sediment surface, was calculated from the method of Bolster (1998). This method allows for the calculation of the sticking efficiency from the fraction of influent bacteria (*fr*) recovered in the column effluent by the following equation:

$$\alpha = \frac{2d_c}{3(1-\theta)x}\frac{1}{\eta}\left[-\ln(fr)+\frac{\alpha_L \ln(fr)^2}{x}\right] \tag{1}$$

where x is the length of the column (L), θ is porosity, d_c is the diameter of the sand grains, η is the collector efficiency which is a measure of the physical mechanisms that bring a bacterial cell to the surface of a sand grain, and α is the sticking efficiency which is a measure of the affinity of the bacterial cells to the sediment surface. All variables were directly measured except for the he single collector efficiency, η, which was calculated from the model of Rajagopalan and Tien (1976).

Results

To date we have only collected and analyzed data from one set of column experiments. In numerous studies in the literature it has been observed that increasing ionic strength increases attachment of bacteria to clean quartz sand by increasing sticking efficiency. This enhanced attraction between two like-charged particles is a result of the compression of the double layer allowing attractive van der Waals forces to dominate. However, we observed opposite behavior of bacterial attachment to positively charged iron-coated sand. A clear log-linear decrease in sticking efficiency with increase in ionic strength was observed (figure 1). We plan on additional experiments to verify these findings.
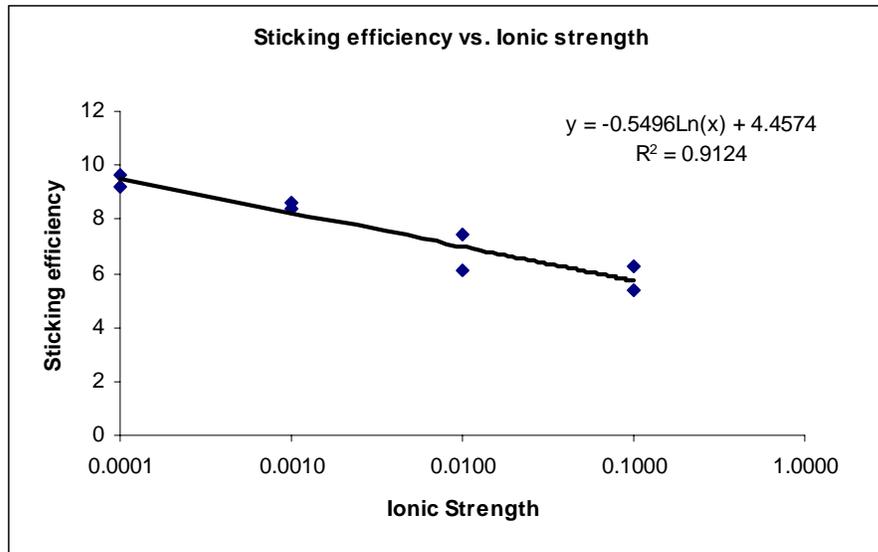
Figure 1. Effect of increasing ionic strength on sticking efficiency of an *e. coli* isolate to iron-coated Unimin sand grains.

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Students involved:

Two graduate students worked on this project during the past two summers.

Publications, Reports, and Presentations:
None to date.

Developing Phosphorus Management Guidelines for Agriculture in the Connecticut River Watershed

Basic Information

Title:	Developing Phosphorus Management Guidelines for Agriculture in the Connecticut River Watershed
Project Number:	2001NH541B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Nutrients, Water Quality, Non Point Pollution
Descriptors:	Soil Test , Phosphorus Saturation, Phosphorus Management, Phosphorus,Water Quality
Principal Investigators:	Elizabeth A Rochette, Tom Buob

Publication

1. Buob, T.E., and E.A. Rochette. Status of phosphorus in soils of Connecticut River Watershed in New Hampshire. Submitted to Communications in Soil Science and Plant Analysis.

Project Title: Developing Phosphorus Management Guidelines for Agriculture in the Connecticut River Watershed

PI's: Elizabeth A. Rochette, Dept. of Natural Resources, University of New Hampshire and Thomas E. Buob, University of New Hampshire Cooperative Extension

Problem and Research Objectives

A summary of soil test phosphorus levels in New Hampshire soil samples submitted to the UNH Analytical Services Lab during the past 3 years indicates that greater than 70% of soils from participating growers are in the high or greater range (greater than 50 mg P kg^{-1}, Mehlich III extraction) (Buob, unpublished data). It appears that P in New Hampshire's agricultural soils could pose a greater risk to the environment than originally thought. Furthermore, it is important that high P soils be identified, as there should be little or no yield response (increase) to added P in these agricultural soils. There is currently a need to determine at what level of soil test P, and on which soil types, the risk of nonpoint source pollution from P in runoff, erosion, and leaching is greatest.

Several states are adapting an assessment tool, the Phosphorus Site Index, for determination of P contamination risks from agriculture. This approach considers environmental features controlling the fate of phosphorus at any location: site characteristics and transport factors such as soil texture, erosion, runoff potential and proximity to water bodies; chemical features such as the form of phosphorus and its association with soil components, and release of P into solution; and site management factors such as fertilizer types and application rates that influence soil P content (soil test P) (Lemunyon and Gilbert, 1993; NRCS, 1994). In 2002, New Hampshire will begin determining P Site Indices for agricultural areas. As in other states, this tool will be useful for community planners, soil surveyors, cooperative extension specialists, crop consultants, and growers.

Soil test phosphorus values must be included in the New Hampshire P Site Index, and it will be necessary to determine an appropriate test for "environmentally mobile" soil phosphorus. The most appropriate approach will be convenient, cost-effective, and accurate for New Hampshire soils. New Hampshire agricultural soils are dominantly Entisols, Inceptisols, and Spodosols. Spodosols can have relatively high P sorption capacities due to relatively high iron and aluminum sesquioxide contents (Simard et al., 1994). Due to the influence of soil pedologic characteristics on the relationship between soil test P and P sorption characteristics (Beauchemin and Simard, 1999), and the variety of soil test approaches proposed for use in environmental assessments of P in soils, this study was undertaken to determine the most appropriate soil test approach for P Site Indices in New Hampshire.

The objectives of this study were to:
1) Chemically and physically characterize representative agricultural soils from the Connecticut River Watershed (CRW) in New Hampshire to allow comparison of soil

types within the state and New England, and estimate the behavior of P in untested soils with known characteristics.

2) Determine the relationships between soil test methods used in New Hampshire and Vermont (Mehlich 3, and Modified Morgan), using the CRW/New Hampshire soils.
3) Determine the relationship between water-extractable P and soil test P for the CRW/NH soils. This relationship will provide information to help predict sites that may be "susceptible" to phosphorus due to a high or very high levels of P in the soil test results.
4) Produce P sorption and desorption curves for a subset of the soils. The curves (i.e., the equations describing them) will be used to help group soil types based on their native abilities to hold or release phosphorus.

Methodology

Soil Collection

Soils were chosen to represent both agriculturally productive soils in the Connecticut River Watershed and the broad diversity of soils farmed in the state of New Hampshire. Once identified, soil samples were collected by horizon (A, B, and C horizons) with the assistance of a state NRCS soil scientist (Joe Homer), to confirm that the field sites were mapped correctly and that the soil series being collected were within the soil series description criteria. Although horizons were collected to a depth of 20 in (50 cm) the data described will be that of the A horizons. The depth of the A horizons ranged from 5 in (13 cm) to 12 in (30.5 cm) and the crop was either corn or hay. Each horizon was described and recorded in the field as it was collected. Approximately 1 gallon of soil from each horizon was collected. Soils were then air dried and sieved (2 mm) prior to chemical characterization.

Soil Characterization

Characterization data included textural analysis, organic matter content, deionized water pH, SMP buffer pH, Modified Morgan (MM) Al, Fe and P, and Mehlich III (M3) Al, Fe, and P. The MM and $CaCl_2$ pH determinations for the soils used in this study were provided by Drs. W. E. Jokela and F. Magdoff at the University of Vermont. The MM results were generated at the University of Vermont (UVM) Soils Laboratory with UVM standard methods of analysis. The textural analysis was performed using the hydrometer method (Bouyoucus, 1962). Organic matter content was determined using loss on ignition (LOI) at 360 degrees C, which is the standard method used by the UNH Analytical Services Lab. Deionized water pH and SMP buffer pH were determined using standard methods (Sims and Eckert, 1995) with a water to soil ratio of 1:1 (v:v). M3 analyses were also performed using standard methods (Sims, 1995) and samples were analyzed using a Vista AX/CCD Simultaneous ICP-AES (Varian).

Dilute Salt-Extractable Phosphorus

Water extractable (0.01 M $CaCl_2$) P was determined with the procedure described by Self-Davis et al. (2000). After one hour on a reciprocating shaker, samples were centrifuged for 10 min at 4000 rpm and filtered through a Whatman No. 42 filter paper. Samples were then analyzed by ICP-AES for total dissolved P.

Sorption Isotherm Determination

Sorption isotherms were obtained using the method developed by Graetz and Nair (2000). A substitution of 0.01 M KCl was made for the 0.01 M $CaCl_2$ background electrolyte to avoid precipitation of Ca in the neutral soils. From these data, Langmuir and Freundlich constants were determined, and sorption maxima (Langmuir b values) were calculated. Phosphorus sorption indexes (PSI) were also determined, using the method described by Sims (2000). All samples were shaken for the appropriate time and then filtered using 0.45um syringe filters. All samples were then analyzed using ICP-AES.

Principal Findings and Significance

Soil characteristics are given in Table 1 for the A horizons of soils collected for this study.

Soil Test Method Comparison and Phosphorus Saturation Indices

The relationship between Mehlich III extractions and Modified Morgan extractions was determined by comparing phosphorus saturation index values, with both methods. Phosphorus saturation indices were calculated with extractable phosphorus, iron, and aluminum obtained with M3 and MM extractions, as $P_{extr}/(Al + Fe)_{extr}$ (mmol kg^{-1} for P, Fe, and Al). In general, the relationship between M3 and MM saturation indices was not linear (regression information: M3 P = 0.06*ln(MM P) + 0.24, $r^2 = 0.91$). The overall relationship reflects the positive relationship between M3 and MM extractable P, best described as a non-linear relationship (regression information: M3 P = 4.31*ln(MM P) + 11.8, $r^2 = 0.74$), and that of M3 and MM extractable (Al + Fe), a weak linear relationship (regression information: M3 (Al + Fe) = 6.75*(MM (Al + Fe)) + 42.2, $r^2 = 0.42$). The latter relationship is influenced by a poor relationship between M3 and MM extractable iron (linear $r^2 = 0.004$). Mehlich III extraction was initially designed to extract metals, and has been adopted for nutrient extraction as well. The weak relationships between M3 and MM extractable metals suggests that either the M3 extraction (utilizing EDTA and fluoride) accesses metals and possibly P in primary and phyllosilicate minerals, as well as those in sesquioxides and metal phosphates. Alternatively, the MM extraction may not efficiently extract sesquioxide metals or metal phosphates. Extractable (Al + Fe) increased in the order Entisols < Inceptisols < Spodosols for both extractions (Table 2).

Water-Extractable Metals

Mehlich III P saturation index appears to be useful for predicting water/calcium chloride-extractable P. The water/calcium chloride-extractable P and the M3 P saturation index are closely related (linear $r^2 = 0.90$ with Pittstown and Dartmouth-1 excluded). Slightly stronger is the relationship between M3 P and water/calcium chloride-extractable P (linear $r^2 = 0.92$ with Pittstown and Dartmouth-1 excluded). MM extraction provides slightly lower r^2 values in some cases (Table 3). The M3-extractable P concentration of the New Hampshire agricultural soils was found to be lower than (ranging from 72 to 582 mg kg^{-1}) that of the Vermont soils (ranging from 500 to 1600 mg kg^{-1}) described by Magdoff et al. (1999).

The Pittstown series soils and samples from a clay-rich profile of the Dartmouth series (Dartmouth-1), were outliers on regression curves and were therefore excluded from the regressions. Both soils are Aquic Dytrochrepts (Homer, 1999; Aquic Dystrudepts by Soil Taxonomy, 1999), and both have high pHs relative to other soils (pH > 7). The clay-rich Dartmouth samples were relatively high in extractable P compared to other soils. The Pittstown soils were relatively low in extractable Al, while relatively high in extractable Fe compared to other samples.

Soils were grouped by soil order to compare means and standard deviations of water/calcium chloride-extractable P, M3 P saturation values, and MM P saturation values. As expected, the largest standard deviations were observed for Entisols, for all three of the parameters with one exception (Table 4). Spodosols had the lowest concentrations and standard deviations for all three parameters.

Sorption Isotherms

Batch phosphorus sorption isotherms were generated by treating soils with 0 to 12 mg L^{-1} P in the form of phosphate. The sorption isotherms represent phosphate-P sorption by the soil, rather than total P sorption. The isotherm data were fitted with the Langmuir model by plotting C* versus (C*/(x/m)*), where C* is the equilibrium concentration of P in the treated soil solution minus the equilibrium concentration of P in the "blank" solution (mmol P L^{-1}), and (x/m)* is the concentration of added P sorbed by the soil (mmol P kg^{-1} soil). Freundlich isotherms were generated by plotting log_{10} C* versus log_{10} (x/m)*. Sorption isotherms for most soils fit the Freundlich model slightly better than they fit the Langmuir model (Table 5). Spodosols had the highest Langmuir b (sorption maxima) of the three soil orders, while Entisols had the lowest. Spodosols also had the highest Freundlich K_f, and the lowest Freundlich linearity (1/n). Entisols had the lowest Freundlich K_f and highest linearity. Inceptisols were intermediate with respect to sorption parameters. Langmuir sorption maxima values were linearly related to Freundlich K_f values ($r^2 = 0.94$). Sorption analyses did not include Colton, Adams, and Fryeburg samples as these samples were not available when sorption experiments were performed.

Performing sorption experiments on soils is time consuming, and not likely to be a time and cost-effective approach for determining environmentally-mobile P for most laboratories. For this reason, phosphorus sorption indices (PSI) were determined by the method of Sims (2000). PSI is calculated as the mass of P sorbed ($mg\ kg^{-1}$) divided by the $\log_{10}$ of the mass of P sorbed. Strong linear relationships were observed for the New Hampshire soils when PSI was compared with Langmuir sorption maxima (b) values ($r^2 = 0.96$) and Freundlich K_f values ($r^2 = 0.95$). A strong relationship between sorption maxima and PSI was also observed by Simard et al. (1994) for Quebec soils. Because there is a close relationship between traditional sorption parameters and PSI, it appears that it would be possible to characterize phosphate sorption for New Hampshire soils using the one-step PSI approach in lieu of determining sorption isotherms.

Conclusions

A suitable approach for testing New Hampshire soils for environmentally-mobile P appears to include a combination of Mehlich III extractions for soil test P, PSI measurements to determine sorption capacities, and water/calcium chloride extractions to estimate P concentrations released to soil solutions. Rather than a single soil test P value as is typical in Phosphorus Site Indices, all three of the parameters could be considered as P quantity, P capacity, and immediate P release terms, respectively.

The Spodosols examined had both the highest sorption affinity for P, and currently the lowest extractable P (including water/calcium chloride-extractable P). If agricultural management of P does not change on these soils, assuming that the soils obtained for this study are representative of all agricultural Spodosols in New Hampshire, P associated with Spodosols may pose minimal threat to the environment. If, however, additional P is added to these soils in the future, they could pose a threat to the environment where erosion is an issue, because these soils can retain relatively high quantities of P that could be carried to surface water on soil particles. Seasonally-saturated Spodosols were not sampled in this study, and may not fit the pattern observed. Entisols and Inceptisols were variable with respect to sorption capacities and extractable P. The relatively lower sorption capacities of Entisols and Inceptisols, coupled with their higher P contents (especially for samples of the Hadley and Windsor soils) suggest that P runoff and leaching are potential considerations for these soil orders.

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Table 1. Characteristics of Ap horizons of New Hampshire soils.

Soil Series	Soil Order	pH[1] (CaCl$_2$)	pH water[2] (UNH)	pH SMP	% Clay	% Sand	% OM
Hadley	Entisol	5.7	6.27	6.79	13	34	5.0
Quonset	Entisol	5.8	5.96	6.93	10	63	4.5
Suncook	Entisol	5.8	5.78	7.20	9	72	1.4
Sunday	Entisol	5.2	5.8	6.96	8	74	1.8
Windsor	Entisol	6.4	6.95	7.04	5	74	5.4
Agawam	Inceptisol	6.2	6.42	6.96	11	12	1.4
Bernardston	Inceptisol	5.9	6.17	6.80	10	51	9.7
Dartmouth-1	Inceptisol	7.4	7.72	7.41	23	35	9.1
Dartmouth-2	Inceptisol	5.8	6.34	6.90	11	20	3.7
Hitchcock Ap1	Inceptisol	5.3	5.43	6.58	13	33	5.5
Hitchcock Ap2	Inceptisol	6.7	5.90	6.79	13	34	4.3
Occum	Inceptisol	5.3	5.95	6.96	14	32	2.7
Ondawa	Inceptisol	5.5	6.21	6.90	7	65	3.2
Pittstown	Inceptisol	6.3	7.09	7.22	9	54	7.6
Adams	Spodosol	6.0	6.31	6.58	10	69	9.0
Colton	Spodosol	5.9	6.49	6.88	8	79	4.9
Groveton	Spodosol	6.1	6.76	6.67	10	61	6.0
Marlow	Spodosol	5.2	5.35	6.37	15	39	6.9
Monadnock	Spodosol	6.1	6.65	6.75	15	64	9.4
Tunbridge	Spodosol	4.8	5.21	5.98	12	52	10

[1] 1:2 soil:solution, 0.01M CaCl$_2$ (UVM).
[2] 1:1 soil:deionized water.

Table 2. Extractable P and (Al + Fe) concentrations by soil order.

Soil Order	Mean M3 P (Std. Dev.) (mmol kg^{-1})	Mean MM P (Std. Dev.) (mmol kg^{-1})	Mean M3 (Al + Fe) (Std. Dev.) (mmol kg^{-1})	Mean MM (Al + Fe) (Std. Dev.) (mmol kg^{-1})
Entisols	8.38 (8.04)	0.77 (0.74)	48 (12)	1.4 (0.9)
Inceptisols	8.72 (4.34)	0.54 (0.44)	59 (13)	1.8 (1.1)
Spodosols	4.80 (2.21)	0.24 (0.14)	67 (6)	3.0 (0.7)

Table 3. Linear regression results for water-extractable P, Modified Morgan extractable P, and P saturation indices based on Modified Morgan extractions. Pittstown and Dartmouth-1 samples were excluded from regressions.

Regression	Linear r^2
MM P vs MM P sat[1]	0.90
Water/CaCl$_2$-extractable P vs MM P sat[1]	0.74
Water/CaCl$_2$-extractable P vs MM P	0.90

[1]MM P sat calculated as Modified Morgan extractable P/(Al+Fe)

Table 4. Average and standard deviations of water/calcium chloride-extractable P, Mehlich III and Modified Morgan P saturation values.

Soil Order	No. Obs.	Water/CaCl$_2$ Extr-P (mmol kg^{-1}) Mean (Std Dev)	Mehlich III P sat. P/(Al+Fe) Mean[2] (Std Dev)	Modified Morgan P sat. P/(Al+Fe) Mean[2] (Std Dev)
Entisols	5	0.27 (0.31)	0.16 (0.14)	1.01 (1.05)
Inceptisols[1]	9	0.17 (0.14)	0.18 (0.10)	0.96 (1.32)
Spodosols	6	0.12 (0.08)	0.09 (0.05)	0.12 (0.09)

[1]Pittstown and Dartmouth-1 series soils included. Modified Morgan P saturation mean and standard deviations without Dartmouth-1 and Pittstown soils are 0.25 (0.18).
[2]mmol kg^{-1} P, Al and Fe

Table 5. Langmuir and Freundlich sorption parameters by soil order.

Soil Order	Entisols	Inceptisols	Spodosols	All Soils
No. Obs.	5	9	4	18
Langmuir b Mean (Std Dev)	3.67 (1.77)	5.70 (1.92)	8.32 (1.14)	5.72 (2.35)
Langmuir Mean r^2	0.91	0.91	0.94	0.91
Freundlich 1/n Mean (Std Dev)	0.586 (0.125)	0.557 (0.070)	0.521 (0.125)	0.557 (0.096)
Freundlich K$_f$ Mean (Std Dev)	0.781 (0.253)	0.900 (0.293)	1.389 (0.196)	0.975 (0.341)
Freundlich Mean r^2	0.98	0.99	0.98	0.99

<u>Students involved</u>

This project had funding for only student labor. One undergraduate student and an hourly graduate student were involved in textural analyses of the soils.

<u>Publications, Reports, and Presentations</u>

Publication:
Buob, T.E. and E.A. Rochette. Status of phosphorus in soils of the Connecticut River Watershed in New Hampshire. *Submitted to Communications in Soil Science and Plant Analysis.*

Presentations:

Buob, T.E. NRCS State Nutrient Management Committee, Durham, NH. April 2001

Buob, T.E. American Society of Agronomy Poster Session, Charlotte, NC. Oct 2001

Buob, T.E. Merrimack County NRCS Nutrient Management Program, Concord, NH. Nov 2001

Buob, T.E. New Hampshire Nutrient Management Planning, Durham, NH Jan 2002

Buob, T.E. Sullivan/Cheshire County NRCS Nutrient Management Planning, Charlestown, NH. Feb 2002

Buob, T.E. UNH Cooperative Extension Inservice Training, Kingman Farm, Madbury, NH March 2002

Buob, T.E. UNH Cooperative Extension State Meeting, Poster Session, Concord NH. June 2002

Effects of Biosolids on Groundwater Quality

Basic Information

Title:	Effects of Biosolids on Groundwater Quality
Project Number:	2001NH581B
Start Date:	3/1/2001
End Date:	2/28/2002
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Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Nitrate Contamination, Groundwater, Water Quality
Descriptors:	water quality monitoring, waste disposal, sludge, pollutants, nitrogen, heavy metals,groundwater quality
Principal Investigators:	William H. McDowell

Publication

Final Report to DES and NH State Legislature, June 1998 – November 2001 Monitoring Demonstration at a Top-Soil Manufacturing Site in New Hampshire

William H. McDowell & Tamara J. Chestnut
University of New Hampshire
March 15, 2002

Executive Summary

A gravel pit reclamation and top-soil manufacturing site in Hooksett, NH was studied to determine if current management practices pose a threat to groundwater quality. The site has had repeated applications of biosolids on an annual basis since 1989 with top-soil removal approximately every five years. Each year materials were typically stockpiled on-site up to 9 months prior to application. The site was instrumented with groundwater monitoring wells within the biosolids application area, in an adjacent control field, and both up- and downgradient from the biosolids treatment area. Hydrologic and chemical characteristics of the groundwater were monitored on a bi-weekly basis during the growing season (April – November) and monthly during the winter for several years (1998-2001).

Our results show that unacceptably high levels of nitrate were found in some wells within the biosolids application area, but not in others. Elevated nitrate levels in groundwater tended to be found directly beneath, and immediately downgradient from, the stockpiling areas. Low-nitrate groundwater was found under other portions of the reclamation site. These two observations suggest that repeated application of residuals does not by itself cause significant increases in groundwater nitrate levels, but that stockpiling of residuals prior to application does cause significant groundwater contamination. Further research would be necessary to verify this conclusion. With the data we have collected, we can state unequivocally that DES regulations at the time of this study were not sufficiently protective of groundwater quality to prevent nitrate contamination. We also examined concentrations of metals in groundwater at this site. We found that they were well below NHDES and EPA allowable limits at all times, and in all areas. We can thus state with equal assurance that DES regulations were sufficiently protective to prevent groundwater contamination with trace metals at this demonstration site.

Our results from this site also show that groundwater in control and upgradient areas often has surprisingly high nitrate levels. Although these values were not above NHDES or EPA allowable limits, the data do suggest that some off site contamination may be entering our site or may be present in the surrounding groundwater. This makes it more difficult to determine the effects of biosolids applications at our site, and will make regulation of other reclamation sites more difficult if our findings are typical.

Problem Statement

Beneficial re-use of residuals, such as biosolids and short paper fiber, has become an increasingly important topic in both environmental policy and science over the past decade. These materials, which are a natural by-product of waste management, are becoming a significant disposal problem. Reclamation activities, such as those at abandoned gravel pits, provide a way for these secondary products to be recycled back into the environment. However, the same attributes that make this material valuable as an organic material also may cause deleterious effects to groundwater without proper management and monitoring. Excessively high nitrogen content in biosolids may lead to nitrate concentrations in groundwater that exceed EPA allowable limits and lead to harmful environmental and human health effects.

The State of New Hampshire along with the entire New England region have been actively trying to enact policies dealing with the use of residuals specifically for reclamation activities. However, environmental policy and effective management practices are extremely difficult to develop without the aid of comprehensive scientific studies that examine the impacts of these activities on the ecosystem.

Previous Research

Gravel and sand mining reclamation and restoration have become a major environmental concern for protecting water quality, preventing erosion, and re-establishing vegetation. The use of municipal biosolids and papermill sludge has become a cost effective alternative to performing these restoration activities and disposing of waste products. As with any land application of biosolids, the environmental impacts of this activity must be monitored to ensure ecological and public safety. The use of biosolids in reclamation activity provides a necessary catalyst for rehabilitating severely disturbed lands that would be very slow to recover without intervention. These disturbed areas require both the addition of nutrient fertilizer and the development of topsoil in order to support plant growth. This is an important distinction between reclamation and the application of biosolids to natural or agricultural lands. Therefore, the positive and negative impacts of land spreading biosolids for reclaiming mined lands is of particular interest to policy makers and land managers.

Several studies have examined the effects of utilizing municipal biosolids (semi-solid, solid and composted), paper mill sludge, and a combination of the two materials on re-vegetating gravel and sand mining operations following soil removal operations. Catricala et al. (1996) performed a microcosm study to examine the effects of using a combination of paper mill sludge and wood ash mixed with sand to reclaim an abandoned gravel pit in Maine. Chemical constituents responded to the sludge application to varying degrees. Chloride, SO_4^{2-} and Na mobilized quickly in the first year, whereas NO_3^- and Ca leached late in each growing season (October – November) as plant uptake and microbial immobilization slowed and N mineralization and nitrification increased. Organic matter decomposition caused the elution of dissolved organic carbon, copper, magnesium and potassium. Based on the results of this study, they suggest that a paper mill sludge with a

C:N ratio of 30:1 is optimal for minimizing water quality hazards and providing adequate plant re-growth.

Another study of reclaimed sand and gravel mines was performed in Virginia (Daniels et al. 1998) where anaerobically digested municipal biosolids mixed with sawdust (C:N ratio > 25) was applied. Corn was planted following biosolids application and increased yields were observed in treated plots. Nitrate leached from plots treated with biosolids once corn was harvested in the fall and declined slowly until spring of the following year. Plots where biosolids were mixed with sawdust had significantly lower NO_3-N leaching. Groundwater was unaffected by biosolids application in terms of NO_3-N contamination at this site. As with the study by Catricala et al. (1996), Daniels et al. (1998) found that increasing the C:N ratio of the biosolids to greater than 25 did not appear to have any impact on crop yields but did significantly reduce the amount of NO_3-N leaching from the plots.

Composted municipal biosolids were used in the New Jersey pinelands in order to reclaim sites where sand mining and other soil removal operations were performed. Jacobsen (1998) examined a composted biosolids application site at the Lakehurst Naval Air Engineering Station in New Jersey for groundwater quality and vegetation growth effects. Groundwater chemistry was monitored for 2 years following composted biosolids application. Concentrations of various chemical contaminants including nitrate, copper, zinc, lead, ammonia, calcium, sulfate, magnesium, sodium, chloride, potassium and dissolved organic carbon were found to increase above ambient levels for the first year following application and subsequently decreased to ambient levels by the end of the second year.

Project Purpose
The purpose of this project was to document any effects of reclamation utilizing residuals regulated by Env-Ws 800 on groundwater quality. Specifically, the project assesses the impact of residual application on nitrogen concentrations (nitrate, ammonium, and dissolved organic N) in groundwater at a reclamation site in New Hampshire. The site uses biosolids and/or short paper fiber (SPF) to reclaim (revegetate) a former gravel pit and manufacture topsoil. The primary goal of the project was to demonstrate whether current management and application practices are sufficient to protect groundwater from contamination with NO_3-N and other forms of dissolved nitrogen, and possibly to identify ways to improve best management practices (BMPs). A secondary goal of the project was to assess levels of trace metals and trace organic compounds in groundwater at the reclamation site.

Project Description
The site was evaluated over a multi-year period for nitrate, ammonium, dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in groundwater. At the site, a treatment plot was established that utilized residual materials including a manufactured topsoil (biosolids and SPF) and biosolids only.

Both the treatment plot and the control area were identified, and lysimeters and groundwater wells were installed in both areas. Wells were also installed to monitor groundwater quality beneath the treatment plot, and at locations presumed to be hydrologically up- and down-gradient of the treatment plot. Original stainless steel wells were insufficient for hydrologic and chemical characterization and were replaced in 1999 with 2" diameter PVC wells with 2' of slotted well screen. An additional six PVC wells were installed in May 2000 to supplement chemical and hydrologic data.

Site Description
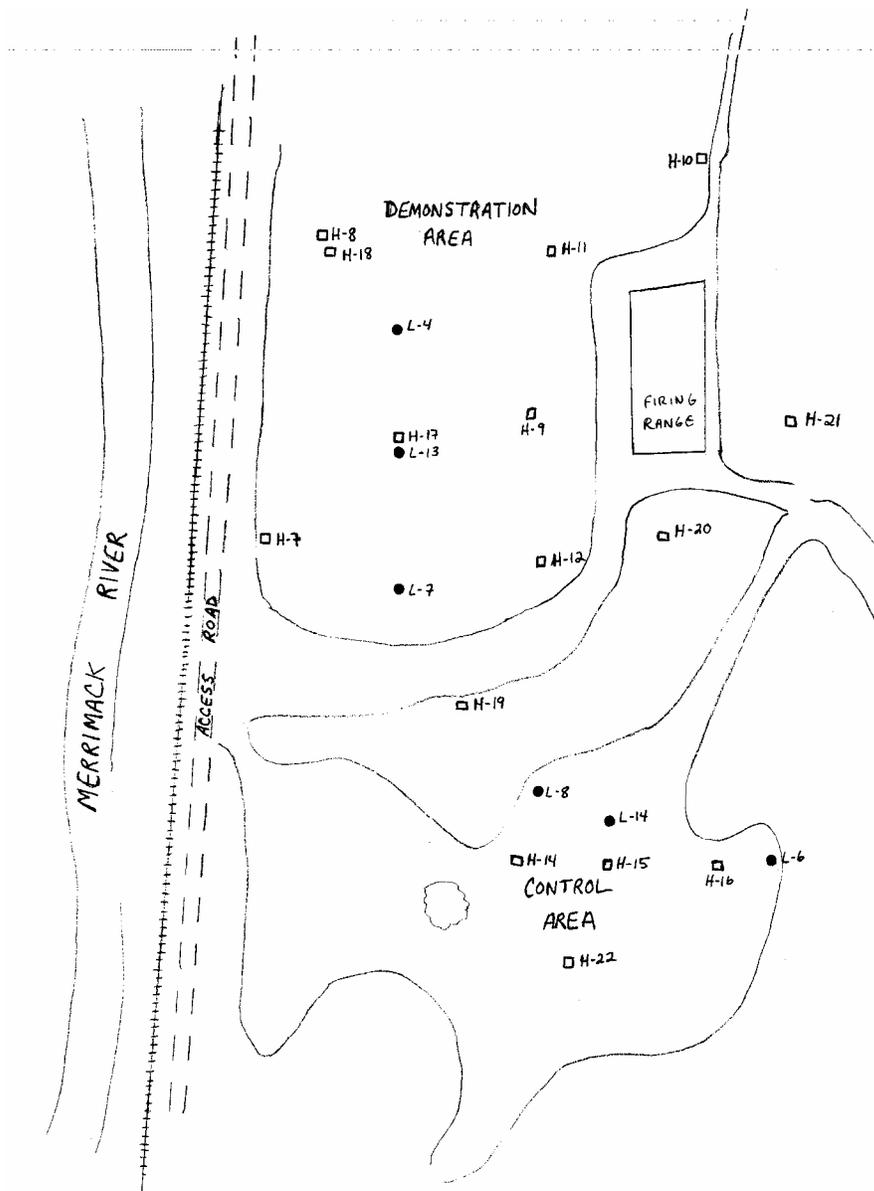
Figure 1: Map of Martin's Ferry in Hooksett, NH. Open squares indicate groundwater wells and solid circles indicate soil lysimeters. Scale = 1" ≈ 200 ft.

The site is Martin's Ferry located in Hooksett, NH and consists of a 5-acre topsoil manufacturing operation, which has had reclamation activity with biosolids for the past ten years and an adjacent control field of approximately the same size with no history of biosolids activity. The site is currently permitted under Env-Ws 800 as a site appropriate for biosolids utilization. This site is being monitored primarily to examine the impact of long-term biosolids applications on groundwater. At the site, biosolids only have been applied approximately annually since 1989 with removal of the organic topsoil approximately every five years. An application of a biosolids and SPF mixture was applied in October of 1999 with a C:N ratio of 27:1 (Table 1). Approximately 1,000 cubic yards of topsoil was removed in 1996, returning soils to their native condition of excessively drained Windsor loamy sand.

Table 1: Residuals application rates from 1996 to 2000 at the Martin's Ferry Site.

Year	Residuals	Biosolids (yds^3)	Total Nitrogen (#/acre)
1996	Biosolids only	166	512
1997	Biosolids only	337	1040
1998	Biosolids only	460	826
1999	Biosolids & SPF	353	1600
2000	None	0	0
2001	None	0	0

Hydrologic Characterization

Hydrologic characterization was done from 1999 to 2001 at Martin's Ferry in Hooksett to determine the flow path of groundwater through the plot. An additional objective was to determine if water from the Merrimack River was flowing through the subsurface and into our treatment plot, which would distort our assessment of the effects of residual applications on groundwater quality. Nine 2" diameter PVC wells were installed and surveyed over a several-month period. By April 2000, all nine wells were set to a depth sufficient to reach the water table. Six additional 2" diameter PVC wells were installed in May 2000 to aid in hydrologic studies and to characterize upgradient conditions. Our data show that the water table at Martin's Ferry is sloping steeply from the hillslope toward the river, and the path of groundwater is nearly perpendicular to the river. Our data also show that it is highly unlikely that the Merrimack River infiltrates into groundwater at this site (Figure 2).
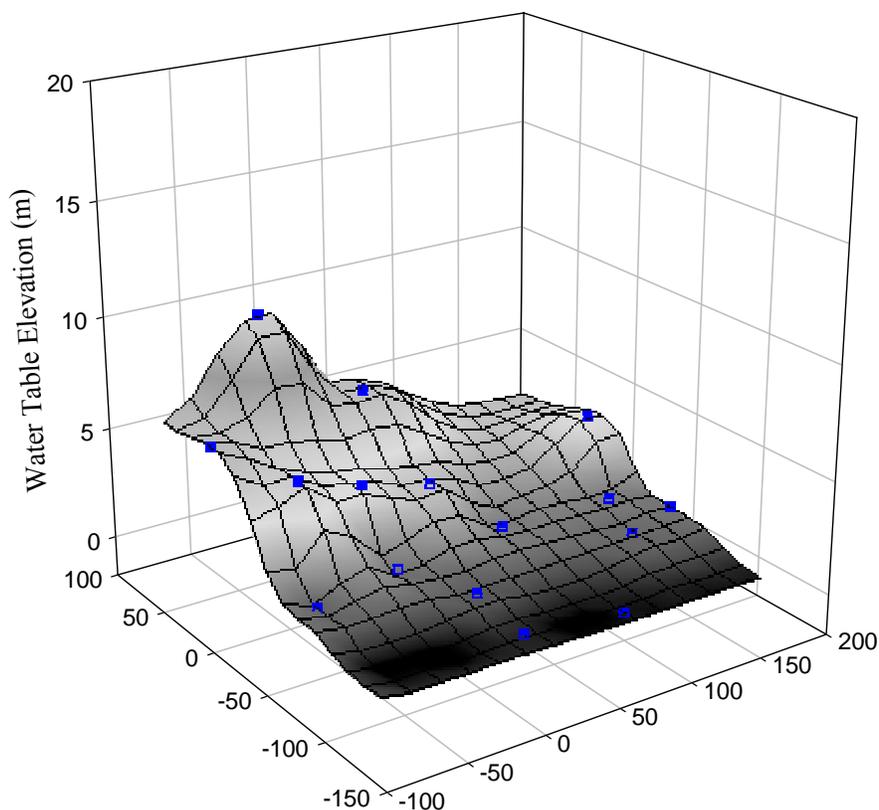
Figure 2: Hydrologic flownet for Martin's Ferry in Hooksett.

Sample Collection

Samples of soil solution and groundwater were collected every two weeks during the growing season (August 1 - November 1) and were continued on a monthly basis through the winter (December - April). Groundwater wells were evacuated with a Teflon bailer until three volumes of water within the well had been exchanged prior to sample collection, where feasible. If recharge rates were slow, less than three volumes were withdrawn. Samples from lysimeters and groundwater wells were placed in clean HCl-washed polyethylene bottles (HDPE) and remained on ice in coolers until delivery to UNH for chemical analysis. Samples were filtered with a 0.7 µm GF/F ashed filter and frozen until analysis. Samples for trace metals analysis were filtered with a 0.45 µm Metricel® membrane filter and treated with 3% nitric acid for refrigerated storage until analysis.

Chemical Analysis

Samples were analyzed for NO_3^-, NH_4^+, DON, and DOC at the analytical laboratory (Ecosystems Analysis Laboratory) of Professor William H. McDowell, University of New Hampshire. Nitrate and NH_4^+ are analyzed using flow injection analysis colorimetry (Lachat) with cadmium reduction for NO_3^- and the phenol hypochlorite method with sodium nitroprusside enhancement for NH_4^+. Total dissolved nitrogen (TDN) is measured using high temperature catalytic oxidation (Shimadzu TOC 5000) with chemiluminescent nitrogen detection (Antek 720, Merriam et al. 1996); DON is then calculated as the difference between TDN and (NO_3^- + NH_4^+). Dissolved organic carbon

is measured using a total carbon analyzer (Shimadzu TOC 5000). Trace metals are analyzed using an inductively coupled plasma emission spectrometer (ICP) at the Analytical Services Laboratory at the University of New Hampshire.

Results

Prior to 1998, and before involvement of the current research team, only NO_3-N was
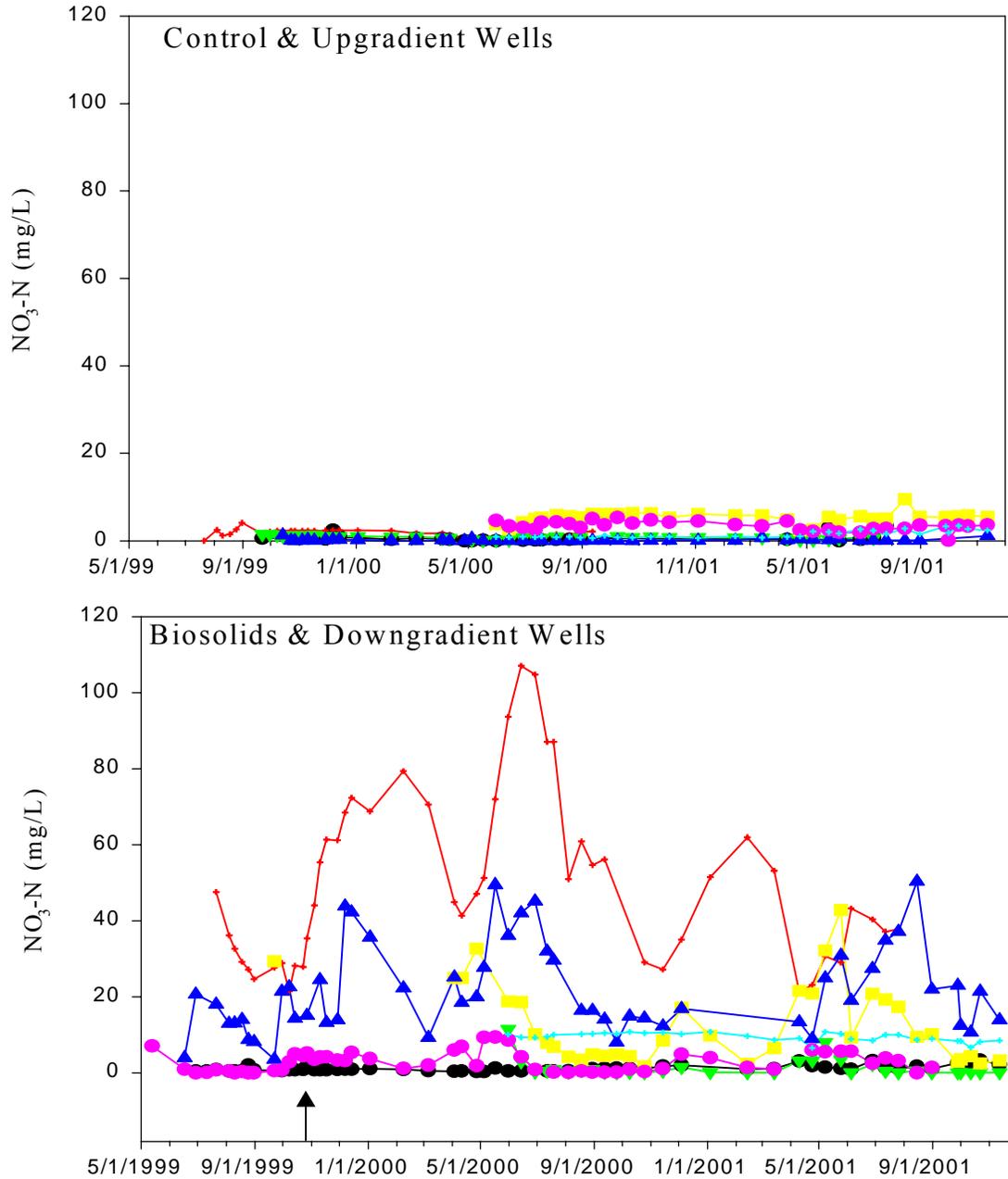
Figure 3: NO_3-N concentrations for groundwater using PVC wells (May 1999 – January 2001). (a) Control and upgradient wells; H-10 dark blue, H-14 black, H-15 red, H-16, green, H-20 purple, H-21 light blue, H-22 yellow; (b) Biosolids wells; H-7 dark blue, H-8 & H-18 yellow, H-9 purple, H-11 black, H-12 red, H-17 green, H-19 light blue.

analyzed at this site. Starting in June 1998, we extended this data set to include NH_4-N, DON and DOC in groundwater and some soil solution. Data reported here only include data collected by this research team using PVC wells, and thus span from May 1999 to January 2001, and focus on groundwater only. For more information on soil solution and data from stainless steel wells installed prior to 1999 refer to Appendix A.

Chemical Characterization

Groundwater concentrations of NO_3-N for this site are significantly higher in the biosolids application area than the control area (Figure 3). Overall, we see that the biosolids treatment wells seem to track each other over time with increases in concentration in the late summer and fall. We observed a major increase in NO_3-N concentrations in the fall of 1999 following the last biosolids application. This increase subsequently declines over time until the summer of 2000 where another large increase in concentration is observed. Concentrations peaked again in the late summer of 2001, but overall concentrations seem to be declining (Figure 3). However, there are significant differences between the different wells within the biosolids treatment area. Concentrations in the control and upgradient wells also show some spatial variability but do not appear to exhibit seasonal patterns. Overall concentrations of NO_3-N in control and upgradient wells do not exceed EPA allowable limits of 10 mg/L and are considerably lower than those of the biosolids treatment area.

 Spatial Variability

There is considerable spatial variability in NO_3-N concentrations in the groundwater at this site. Spatial heterogeneity in soils and or vegetation can lead to minor variability in groundwater NO_3-N, but at this site there is no evidence that these factors play any role in driving the observed patterns. Similarly, preferential groundwater flowpaths may lead to modest increases in NO_3-N concentrations in certain areas, but data from the well installation boring logs show that soils are extremely homogenous and preferential flowpaths are unlikely.

Spatial variability in NO_3-N concentration is associated with patterns of past stockpiling (Figure 4). This suggests that stockpiling at the site may have led to N saturation of the soils in isolated areas. The highest levels of NO_3-N in groundwater are located either in these areas of past stockpiling or immediately downgradient from them (Figure 4). We also find areas outside the biosolids treatment area both upgradient and in the control area (H-20 and H-22) that contain elevated levels of NO_3-N; however, concentrations in these wells did not exceed the EPA allowable limit of 10 mg/L. This suggests that there may be a secondary source of contaminated groundwater entering the site from the surrounding area, and contributing to the elevated groundwater levels found on-site. However, this secondary source is not sufficient to explain the exceedingly high NO_3-N levels in some wells.
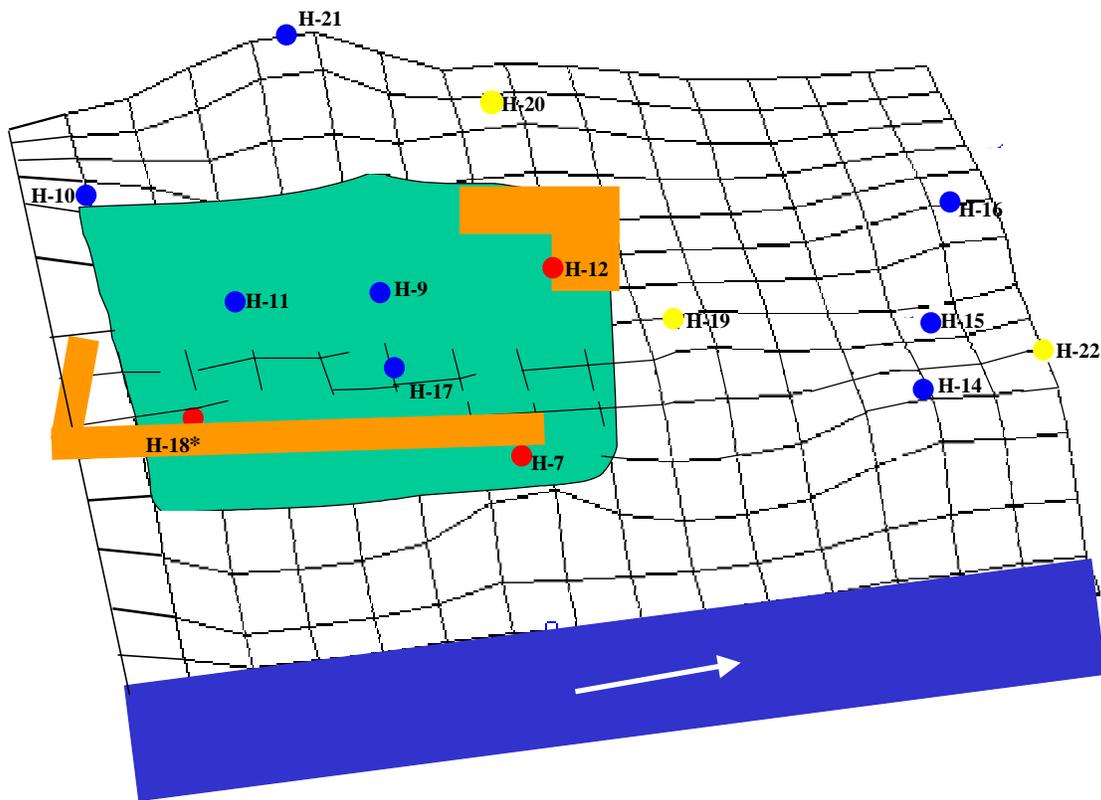
Figure 4: Topographic map with color-coded wells for Hooksett site. Scale: 1cm = 20m. Green shaded area = biosolids and SPF treatment area, orange shaded areas = stockpile locations, blue shaded area = Merrimack River. Red = wells > 10 mg/L, Yellow = 3 mg/L < wells < 10 mg/L, Blue = wells < 3 mg/L. Average well concentrations generated over the following time period: H-9 (5/99 – 11/01); H-7 and H-11 (6/99 – 11/01); H-10, H-12 and H-15 (7/99 – 11/01); H-14 and H-16 (9/99 – 11/01); H-17, H-19, H-20 and H-21 (5/00 – 11/01); H-18* includes data from H-8 (9/99 – 5/00) and H-18 (5/00 – 11/01).

Not all biosolids wells had high NO_3-N levels; in fact, some wells were lower in NO_3-N concentration than control wells. This spatial variability also supports the conclusion that stockpiling, rather than the actual biosolids application, may be driving the high levels of NO_3-N seen in groundwater at this site. Based on information from the site manager we have determined that the wells with elevated NO_3-N concentrations were in locations where stockpiling was heaviest during the past ten years of activity at this site (Figure 5).
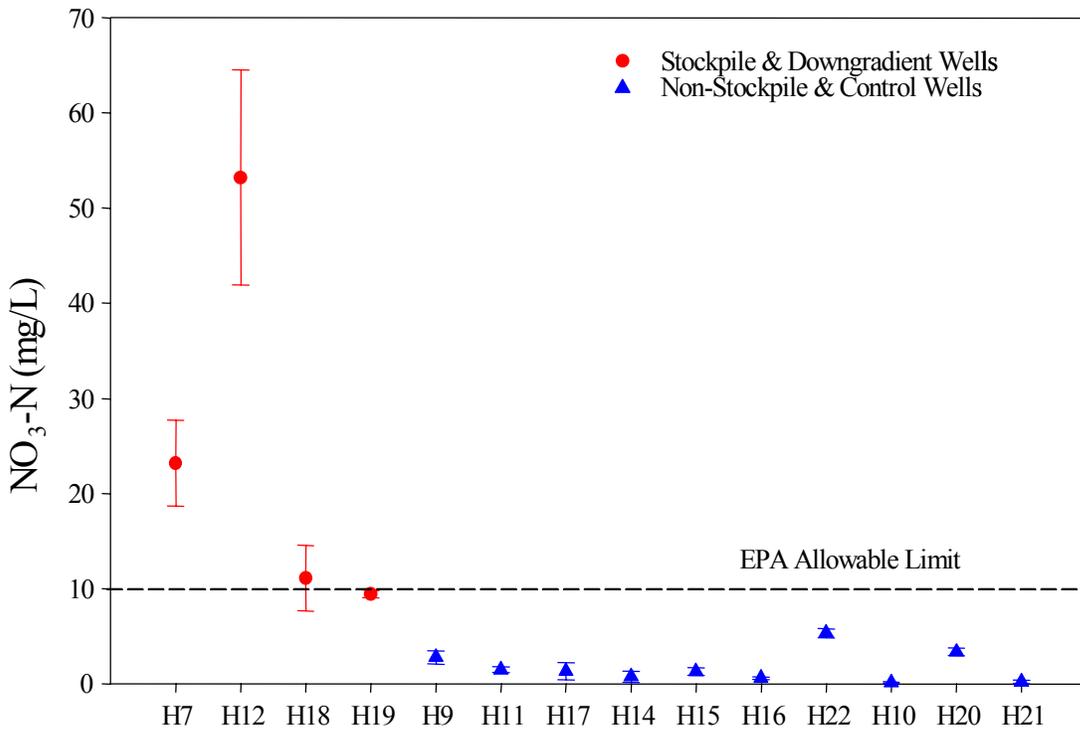
Figure 5: Mean NO_3-N concentration (mg/L) for individual wells grouped according to stockpile impact. Biosolids wells are H7, H9, H11, H12, H17, H-18; control wells are H14, H15, H16, H22; downgradient well is H19, and upgradient wells are H10, H20, H21.

Chemical Relationships

Relationships among various chemical constituents at this site are consistent with biosolids as a source of the elevated nitrate concentrations that we have observed.

Average values for temperature, conductivity, pH and dissolved oxygen are reported for each individual well (Table 2). Temperature was consistent between wells and was highest in the shallowest wells. Temporal variability for each well was quite low, however spatially variability within the treatment and control areas was quite high particularly for conductivity. This variability was consistent with that found for other chemical constituents, specifically NO_3-N. Dissolved oxygen concentrations were consistently high, suggesting an aerobic environment in both biosolids and control areas.

Table 2: Mean values for temperature, conductivity, pH and dissolved oxygen for individual wells by category (95% confidence interval reported in parentheses).

	Temp (°C)	Cond (µmhos/cm)	pH	DO (mg/L)
Control				
H-14	8.2 (± 0.8)	52.5 (± 11.6)	6.32 (± 0.48)	8.9 (± 2.5)
H-15	9.2 (± 1.1)	214.5 (± 36.6)	6.17 (± 0.16)	4.0 (± 1.2)
H-16	8.5 (± 1.0)	119.2 (± 26.2)	5.85 (± 0.16)	7.2 (± 1.5)
H-22	9.1 (± 1.0)	250.7 (± 38.8)	6.28 (± 0.18)	6.1 (± 0.9)
Upgradient				
H-10	9.0 (± 1.0)	32.9 (± 1.5)	5.44 (± 0.20)	10.0 (± 0.8)
H-20	8.6 (± 1.2)	71.6 (± 6.6)	4.78 (± 0.26)	9.3 (± 1.1)
H-21	9.8 (± 2.2)	40.1 (± 2.4)	4.91 (± 0.31)	7.3 (± 1.3)
Biosolids				
H-9	8.9 (± 1.2)	112.9 (± 32.7)	5.35 (± 0.28)	6.2 (± 0.6)
H-11	9.1 (± 1.0)	52.5 (± 4.3)	5.38 (± 0.19)	9.0 (± 0.8)
H-17	8.9 (± 0.6)	100.2 (± 28.6)	5.74 (± 0.23)	6.8 (± 1.0)
H-7	8.8 (± 1.1)	310.7 (± 70.2)	5.36 (± 0.17)	8.7 (± 0.8)
H-12	8.4 (± 1.3)	526.9 (± 101.1)	4.67 (± 0.15)	7.2 (± 1.5)
H-18	8.8 (± 0.8)	230.0 (± 78.4)	5.50 (± 0.21)	8.3 (± 1.0)
Downgradient				
H-19	8.4 (± 0.3)	170.6 (± 3.4)	5.53 (± 0.19)	6.6 (± 0.6)

There was a statistically significant relationship between conductivity and NO_3-N in groundwater samples collected at this site (Figure 6a). A similar relationship was found between pH and NO_3-N, which is expected since nitrification, a by-product of organic matter decomposition, is an acidifying reaction (Figure 6b). The acid produced by nitrification both decreases pH and increases conductivity, as H^+ ions are highly conductive.

Other constituents (NH_4-N, DOC and DON) at this site between May 1999 and November 2001 exhibit some differences between treatment and control groups for groundwater. Ammonium-N concentrations showed no significant differences between control and treatment wells and were near analytical detection limits for most samples (Figure 7). DON concentrations were significantly different between treatment wells (biosolids and downgradient) and control wells (control and upgradient); however, overall concentrations of DON in groundwater were not particularly high (Figure 7). We also found a positive linear relationship between DON and NO_3-N for groundwater wells ($r^2 = 0.503$, $p<0.01$). This suggests that the elevated levels of NO_3-N found in groundwater at this site are related to increased organic matter content in the treatment area due to the application of biosolids. However, the relatively low overall concentrations of DON in

groundwater indicate that DON production associated with biosolids application is of relatively minor environmental concern.
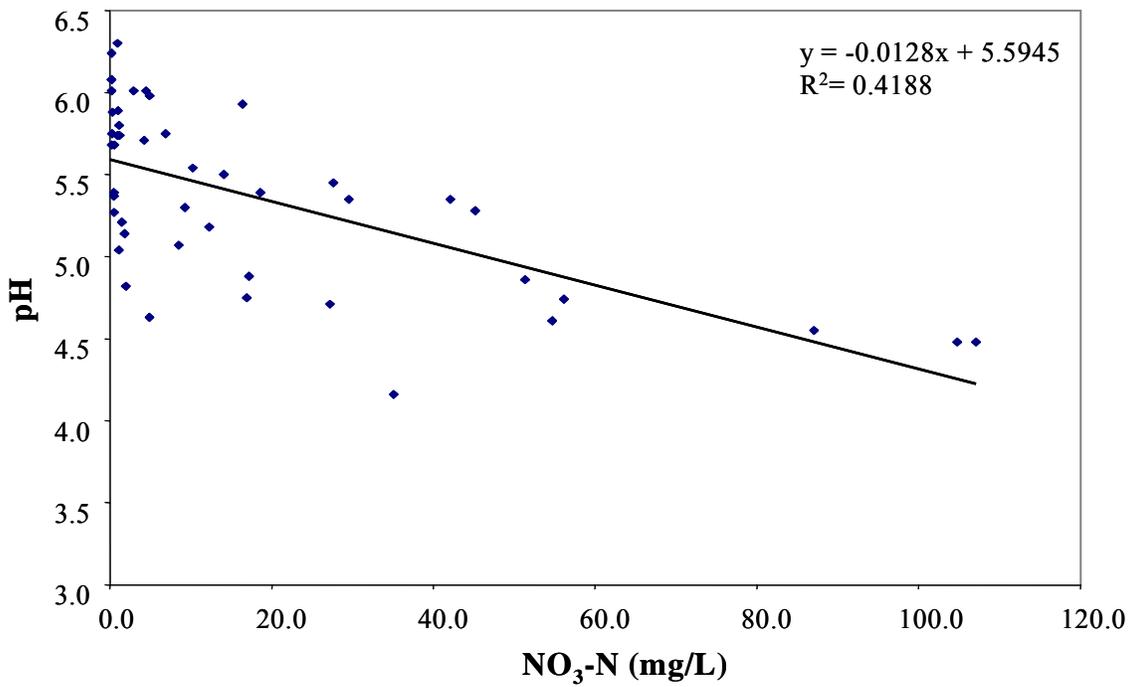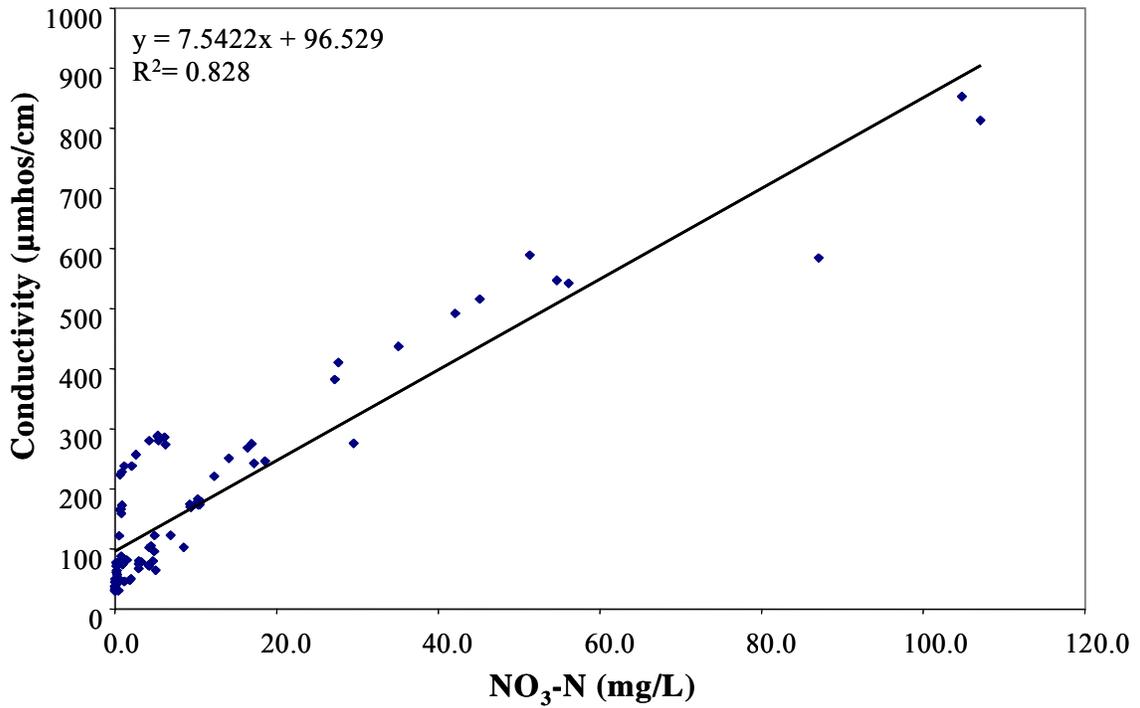
Figure 6: (a) Conductivity versus NO$_3$-N (mg/L), (b) pH versus NO$_3$-N.
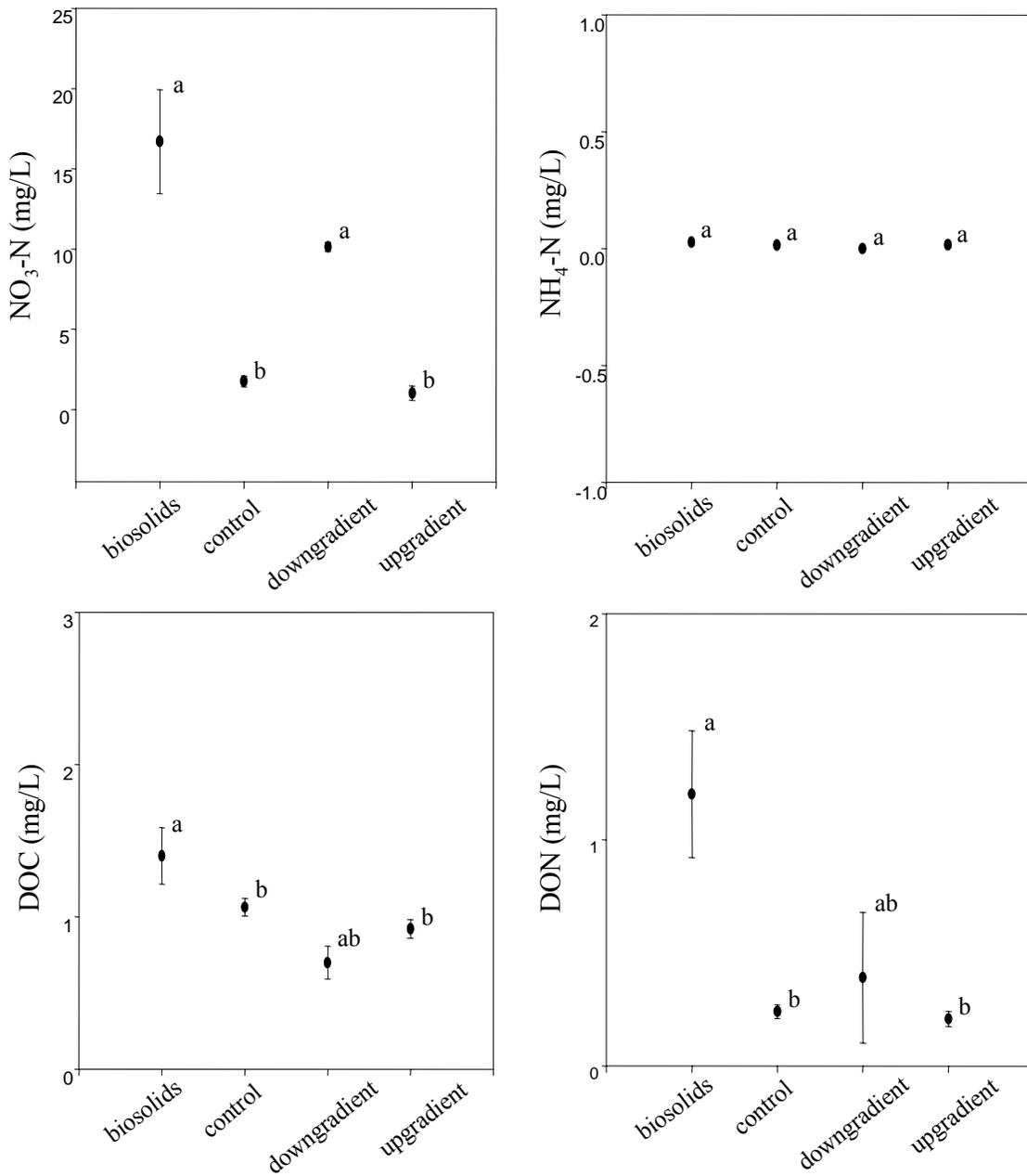
Figure 7: Means for NO$_3$-N, NH$_4$-N, DOC and DON in groundwater with 95% confidence intervals shown as bars. Statistical differences between means are noted with lowercase letters ($p<0.05$), and were determined using One-way Analysis of Variance with 4 levels and Tukey's pairwise comparison.
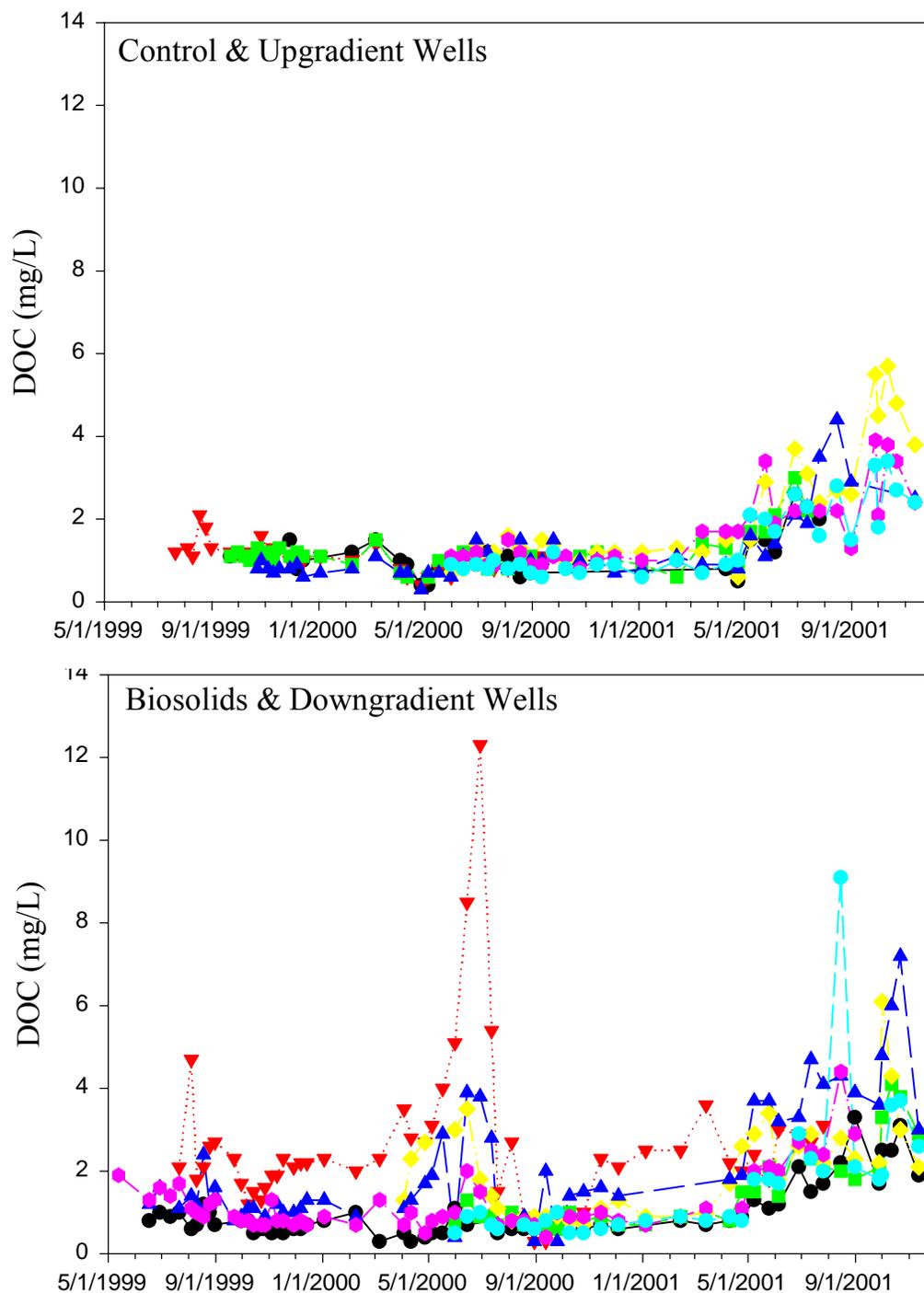
Figure 8: DOC concentrations for groundwater using PVC wells (May 1999 – January 2001). (a) Control and upgradient wells; H-10 dark blue, H-14 black, H-15 red, H-16 green, H-20 purple, H-21 light blue, H-22 yellow; (b) Biosolids & Downgradient wells; H-7 dark blue, H-8 & H-18 yellow, H-9 purple, H-11 black, H-12 red, H-17 green, H-19 light blue.

Similar to NO_3-N, DOC concentrations showed an increase in late summer 2000 in the groundwater wells, suggesting an association with biosolids application. DOC concentrations seemed to increase slightly in autumn 2001. However, overall concentrations of DOC in groundwater were quite low at this site (Figure 8). DOC concentrations in leachate following residuals application at Deadwater Pit in Maine (Catricala et al. 1996) were on average 10 times higher than those reported here. DOC concentrations were significantly higher for the biosolids treatment wells compared to the control and upgradient wells (Figure 7). However, these increases in DOC concentrations in groundwater in the biosolids plot compared to the control and upgradient wells were relatively small (35%) compared to the greater than 900% increase observed for NO_3-N in groundwater.

There was a significant relationship between DOC and NO_3-N for groundwater wells (r^2 = 0.514, p< 0.01) suggesting that the application and stockpiling of organic biosolids material at the site was the common driving factor for increases in both DOC and NO_3-N. Although increases in DOC and NO_3-N in groundwater appear to be caused by the application of biosolids, the relatively small increase in DOC compared to NO_3-N suggests that there is a shortage of available carbon for microbial metabolism. Therefore, the microbial community where biosolids have been applied, particularly in stockpile areas, is utilizing the process of nitrification to generate energy for microbial metabolism. The process of nitrification provides the microbial community with the energy it requires through the conversion of NH_4-N to NO_3-N. This subsequently creates an excess of NO_3-N in the system that is leached to the groundwater. As mentioned earlier, pH and conductivity values provide further support the hypothesis that nitrification of mineralized organic nitrogen from stockpile areas is causing the excessively high NO_3-N values in certain groundwater wells.

Metals, Pesticides, Volatile and Semi-volatile Organics
Analysis of metals was conducted at UNH for samples collected prior to the biosolids application in October 1999 through the end of the project in November 2001. Samples for dissolved metals indicate that concentrations of arsenic, cadmium, chromium, copper, nickel, lead, selenium and zinc are all well below the NHDES and EPA safe drinking water limits for groundwater (Figure 9; for graphs of all metals analyzed see Appendix B).

Concentrations for these metals were not significantly different between biosolids and control wells. Upgradient wells showed a significantly lower concentration than other wells for cadmium, nickel and selenium. The downgradient well was also significantly lower in nickel than the biosolids and control wells (Figure 10).
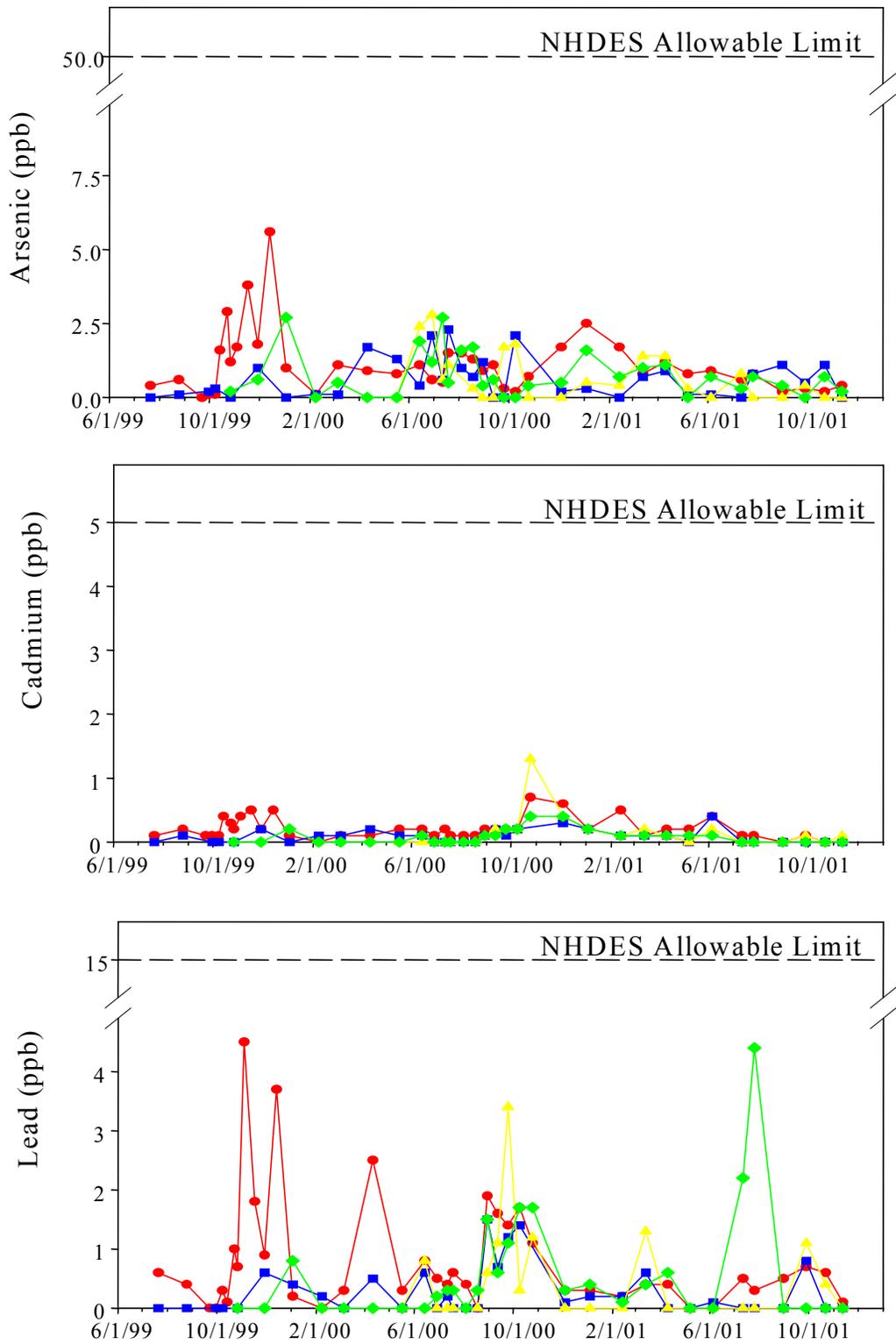
Figure 9: Concentrations for arsenic, cadmium, and lead using PVC wells (7/99 – 11/01). Red circles are biosolids wells; blue squares are control wells; yellow triangles are upgradient wells; and green diamonds are downgradient wells.

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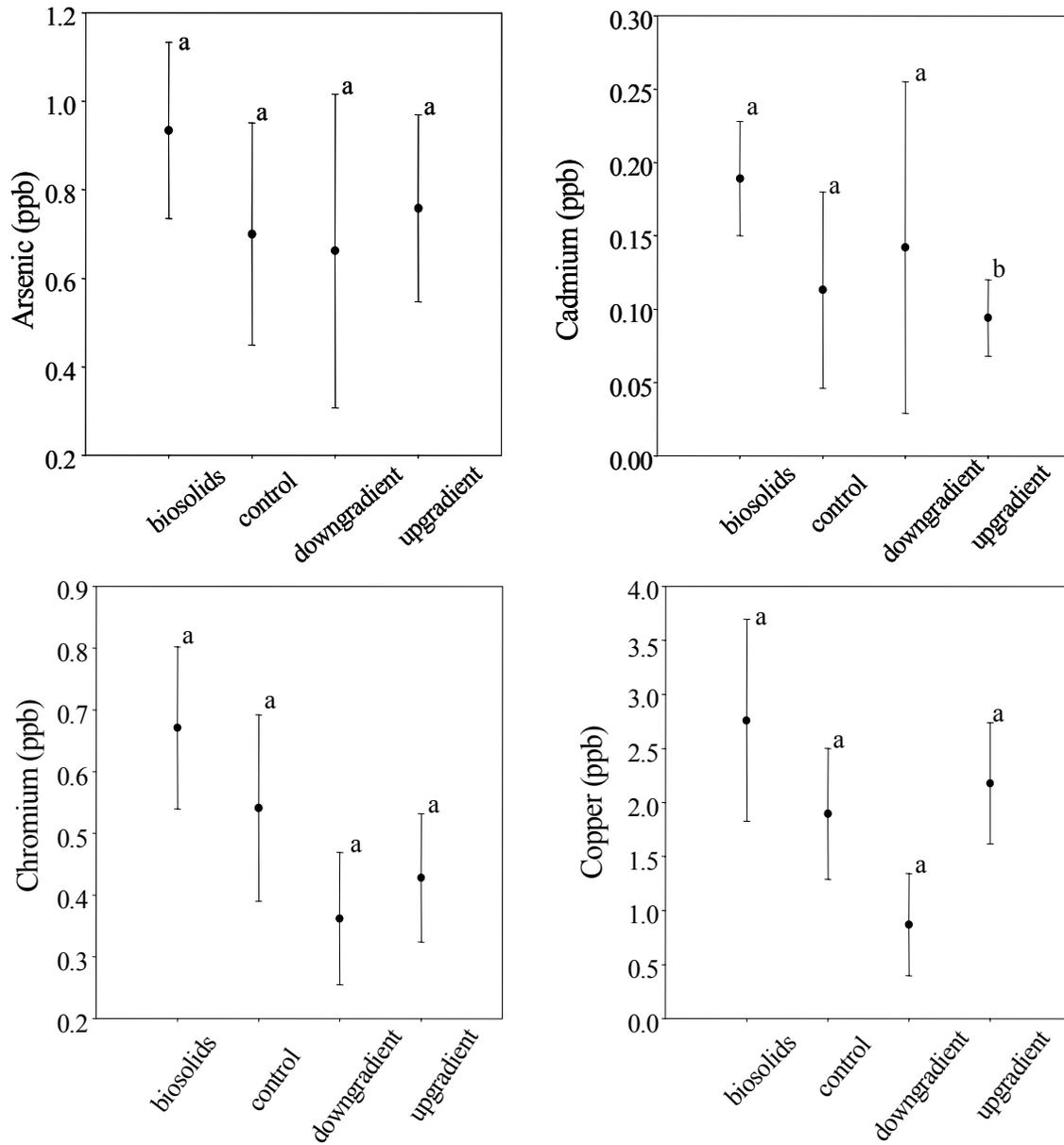
Figure 10a: Means for arsenic, cadmium, chromium, and copper in groundwater with 95% confidence intervals shown as bars. Statistical differences between means are noted with lowercase letters ($p<0.05$), and were determined using One-way Analysis of Variance with 4 levels and Tukey's pairwise comparison.
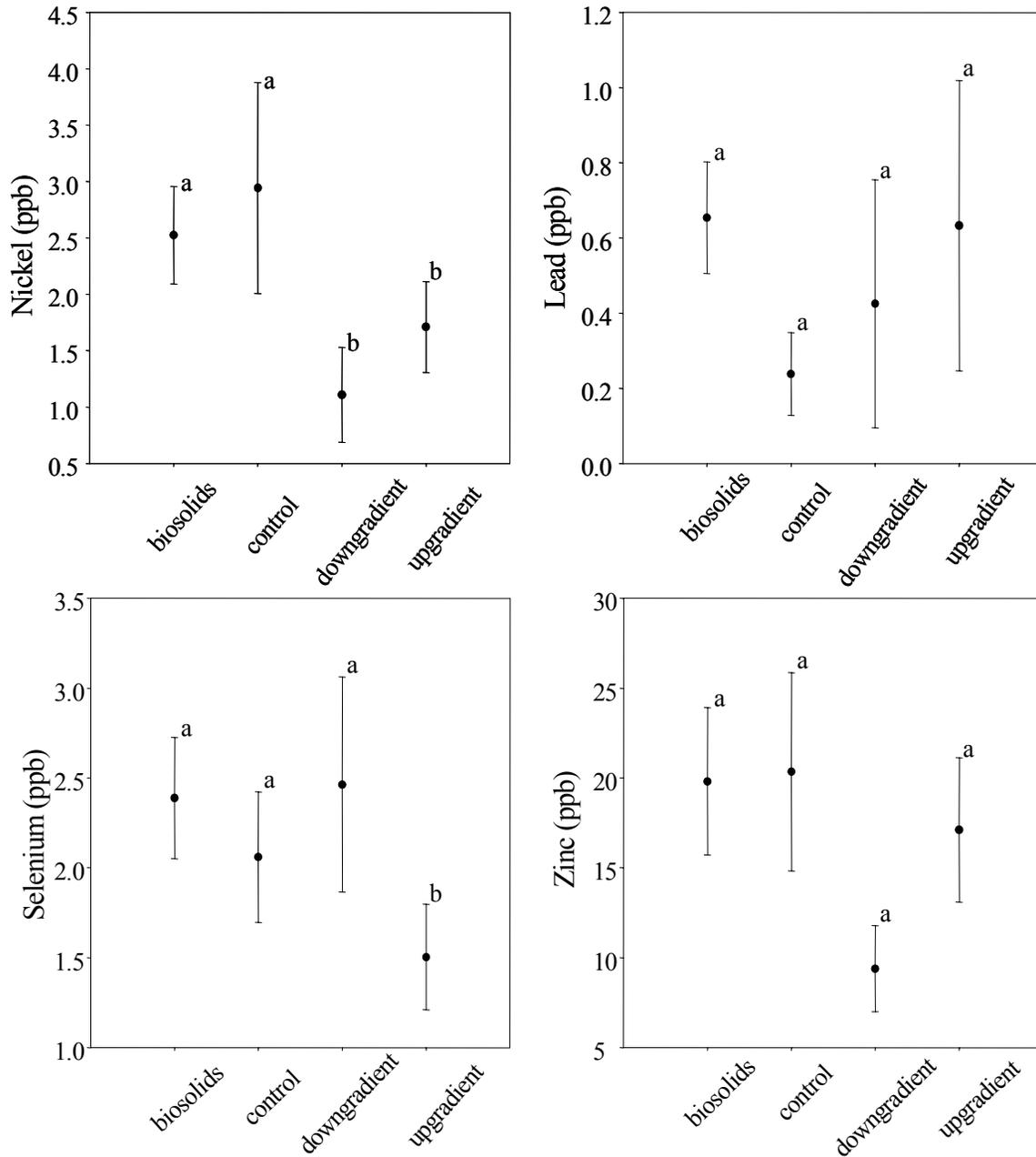
Figure 10b: Means for nickel, lead, selenium and zinc in groundwater with 95% confidence intervals shown as bars. Statistical differences between means are noted with lowercase letters (p<0.05), and were determined using One-way Analysis of Variance with 4 levels and Tukey's pairwise comparison.

The Massachusetts Water Resources Authority (MWRA) also analyzed a small number of samples for a wide variety of compounds before and after biosolids application. Results for metals are for total rather than dissolved metals, which includes sediments within the water sample. Groundwater samples at this site are quite variable with regard to the amount of particulates collected in the sample container and therefore do not accurately

represent the environmentally significant dissolved fraction in groundwater at the site. Their results show that some of the highest concentrations of metals were observed in control or up-gradient wells, where according to hydrologic characterization, as well as NO_3-N data, there has been no impact of biosolids application. There were no pesticides detected in any of the treatment or control wells. The only semi-volatile organic compound detected was bis(2ethylexyl) phthalate or DEHP, which is a typical laboratory and field contaminant. Based on the total amount of DEHP present in the biosolids and SPF which has been applied at the site, loading rates do not exceed the NH DES standard for contaminated soils of 39 mg/kg. This standard is designed to ensure that groundwater concentrations of DEHP do not exceed safe drinking water standards of 6 ug/L in groundwater. As with the metals, DEHP was detected in both control and up-gradient wells in addition to treatment wells (see Appendix B for more information).

Conclusions
The monitoring demonstration at this biosolids application site in Hooksett, NH has produced several key findings. First, there are significant increases in average NO_3-N concentrations in groundwater when wells beneath biosolids treatment areas are compared to control and upgradient wells at the site. However, the concentrations of NO_3-N in groundwater both within and downgradient from the biosolids treatment area show high spatial variability. This suggests that NO_3-N contamination has not resulted from the relatively uniform biosolids applications, but rather has resulted from non-uniform stockpiling at the site. Based on the management history of the site and the location of areas of high NO_3-N concentrations in groundwater we are convinced that this stockpiling activity is the most likely cause of deleterious impacts on groundwater.

We have also found moderately increased levels of NO_3-N in groundwater upgradient from the biosolids treatment area and in the control field suggesting that there may be a secondary source of contaminated water entering the site from the surrounding area. Although this secondary source contributes to the high levels observed beneath some of the biosolids application area, it is not a major contributor and can not explain the very high NO_3-N concentrations observed at several of the wells located in or adjacent to the treatment area.

We believe that gravel pit management practices can lead to nitrogen saturation of soils (Aber et al. 1989), a condition in which soil microbes and plants can no longer utilize available N in a predictable or effective way, resulting in contamination of groundwater with nitrogen. This was most likely the case at the Hooksett site where past stockpiling and application activity may have led to an inability of the soil to utilize the available N provided by the biomix application in October of 1999. Although available nitrogen appears to be high, the available carbon at the site appears to be quite low. This lack of available carbon as an energy source for microbial processing has led to increased levels of nitrification causing an increase in NO_3-N production and a subsequent leaching of NO_3-N to the groundwater.

The stated purpose of this project was to examine the impacts of current management practices associated with biosolids and SPF reclamation activity on groundwater quality. We can say unequivocally that the management practices employed at this site are not adequate to protect water quality, but we cannot identify with certainty which aspect of site management was most responsible for the groundwater contamination. The timing, magnitude, and frequency of biosolids applications, as well as on-site stockpiling, could all have contributed to the elevated levels of nitrate in groundwater. Based on the data we have collected, we believe that stockpiling is the most likely cause of the elevated NO_3-N concentrations. Stockpiling is the only cause of elevated NO_3-N that would show strong spatial variability. If the magnitude (application rate) or frequency of biosolids application were responsible for the elevated NO_3-N levels, we would expect high and relatively uniform concentrations of NO_3-N in the treatment area and in downgradient wells. Likewise, if the timing of the last application were primarily responsible for the elevated concentrations, we would expect a large pulse of NO_3 in the spring following a fall application, and significant declines in subsequent months. Instead, we observed greatest concentrations over a year after the last application. Therefore, we believe that past stockpiling activities is the most reasonable explanation for the increases in groundwater NO_3-N observed at this site.

Concentrations for other nitrogenous compounds and dissolved organic carbon were consistently low for both biosolids and control wells. Similarly, dissolved metals concentrations were consistently low and well below the NHDES and EPA safe drinking water standards for groundwater. Based on the data collected, NO_3-N is the only considerable risk to groundwater quality at this site.

Further work with a strong experimental design (including groundwater data before biosolids application and replicated sites) would be necessary to document the impacts of one-time applications of biosolids to reclaim gravel pits. Our data show that repeated stockpiling at a gravel pit carries significant risks of groundwater contamination, but they should not be used to condemn all gravel pit reclamation with biosolids.

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Appendix A – Martin's Ferry, Hooksett – Soil Solution Chemistry & Previous Data

Tension lysimeters were installed at depths of 50-60 cm for collecting soil solution. Vacuum (tension) on lysimeters was checked prior to sample collection to ensure that samplers were still drawing soil solution. Lysimeter samples were evacuated into a vacuum flask. After sample collection, a vacuum was applied (0.5 to 1.0 bars of tension) to each lysimeter and the lysimeter tubes were clamped until the next collection. Soil solution sampling was discontinued in the fall of 1999 due to technical difficulties and a lack of need for more information. Levels of NO_3-N in soil solution were extraordinarily high in the biosolids plot at Hooksett in 1997, but have decreased in recent years. Concentrations were as much as three orders of magnitude greater than the control area (Figure A1).
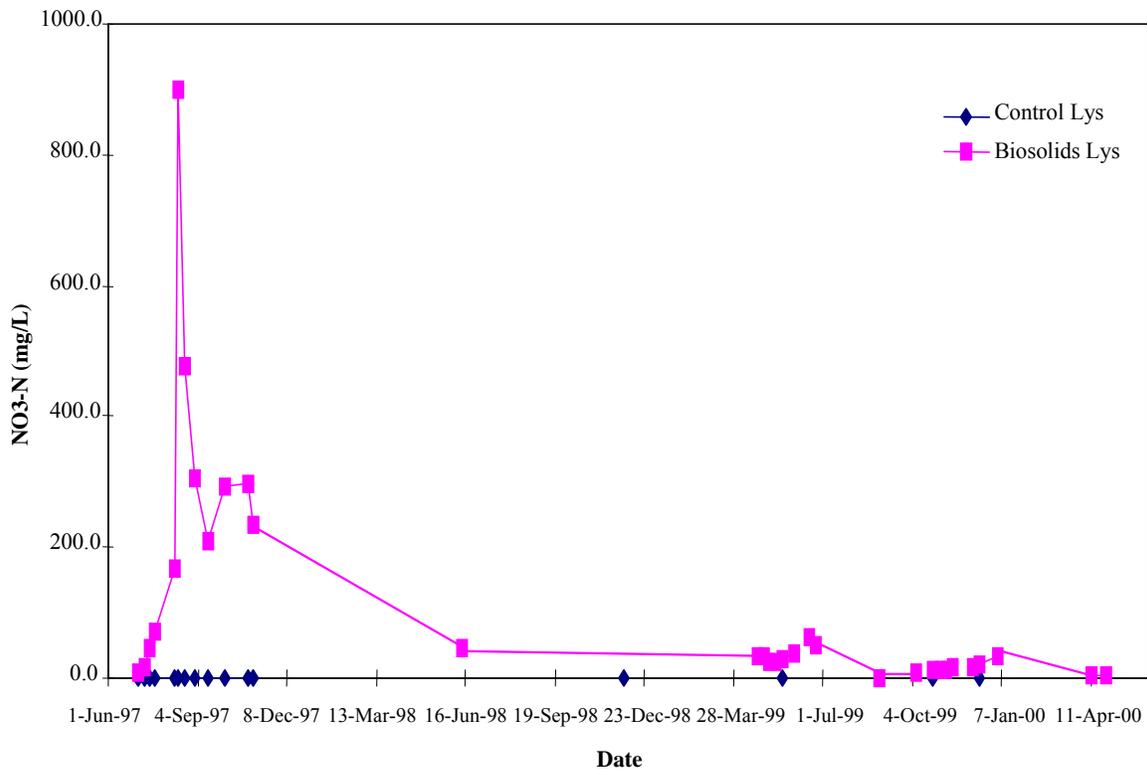
Figure A1: NO_3-N concentrations for the entire study period (1997-2000) for Martin's Ferry, Hooksett. NO_3-N in soil solution from both Biosolids and Control plots.

Due to various complications in the field including lysimeter damage by animals, dry conditions and sandy soils, we were unable to collect soil solution samples for the summer and fall in 1998 at this site (except for June 26, 1998). Even following repair of lysimeters, sample collection was limited. Statistical analysis of soil solution data was not appropriate, given these problems in sampling frequency and number.

Data for average groundwater concentrations using stainless steel wells beginning in June 1998 suggests similar patterns to that seen in subsequent PVC wells. Although the spatial coverage of the stainless steel wells was poor, we still find that the wells closest or immediately downgradient from the stockpiling areas showed periodic increases in NO_3-N (Figure A2).
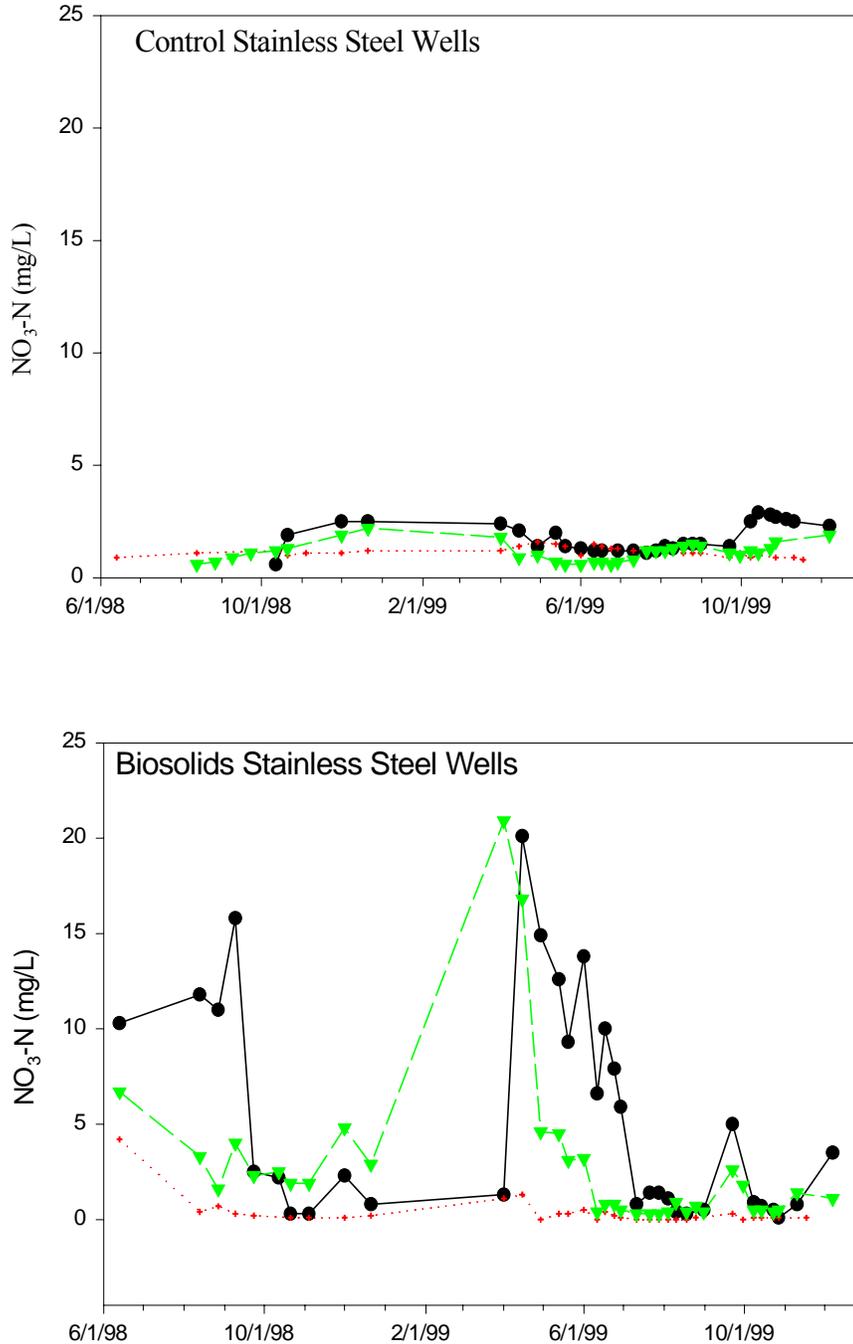
Figure A2: Groundwater NO_3-N concentrations for stainless steel wells from June 1998 to December 1999. (a) Control wells; (b) Treatment wells. Lines represent individual wells (3 control wells, 3 treatment wells).

Appendix B – Martin's Ferry, Hooksett – Metals and MWRA Data

Metals Data

Metals data collected and analyzed by UNH found no elevated levels for any constituents above the NH DES or EPA allowable limits for safe drinking water. The remainder of the timeline graphs for metals in groundwater wells is shown below.
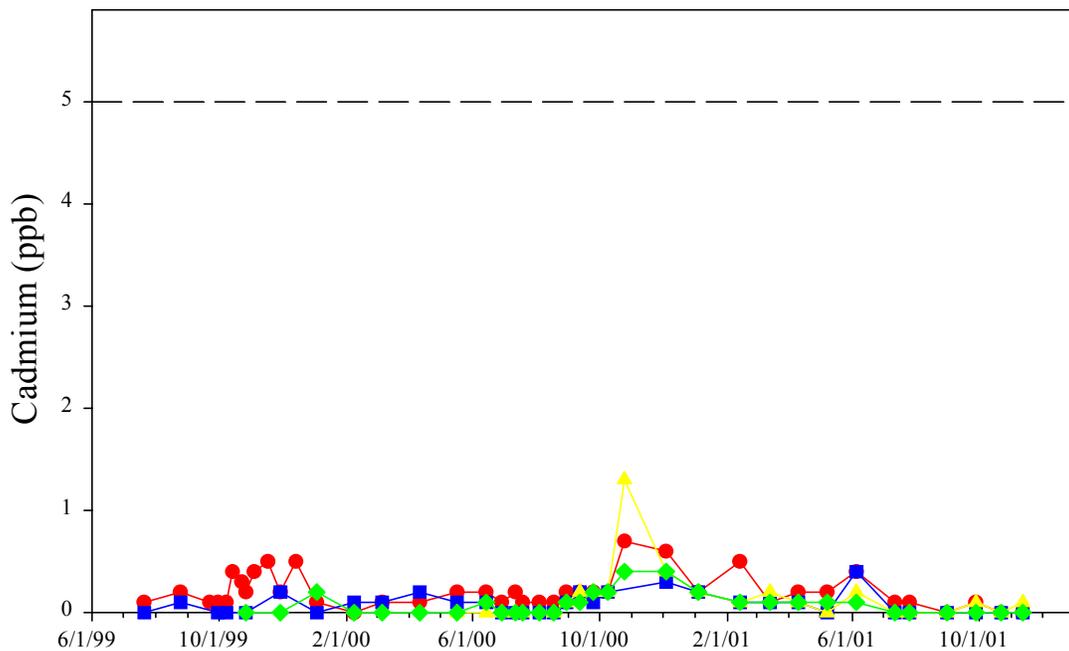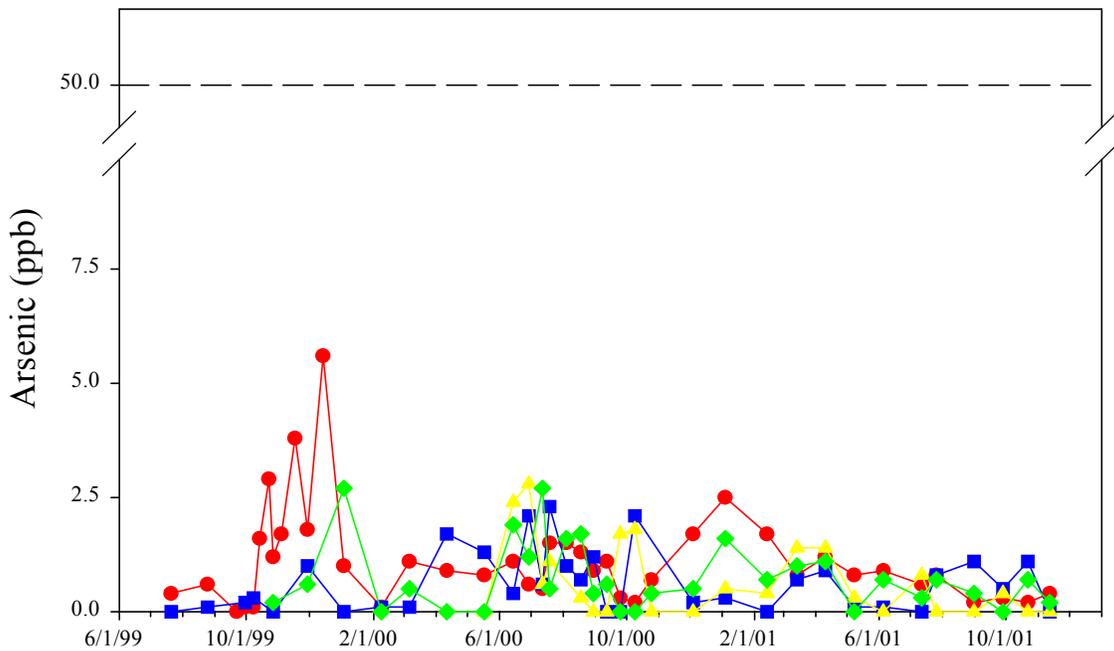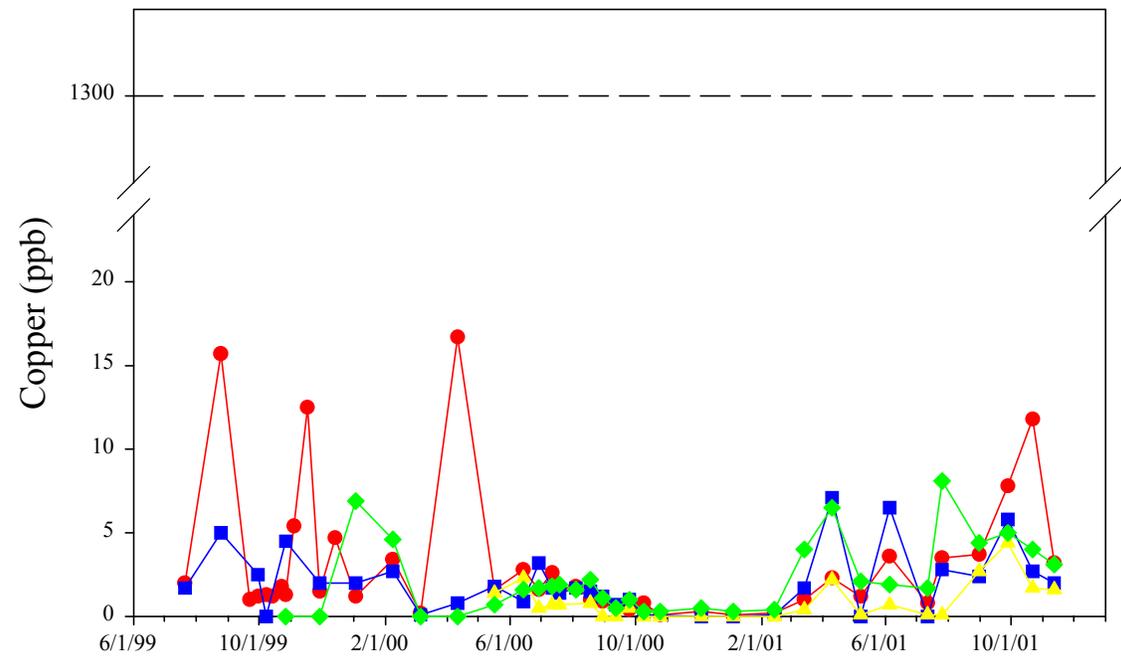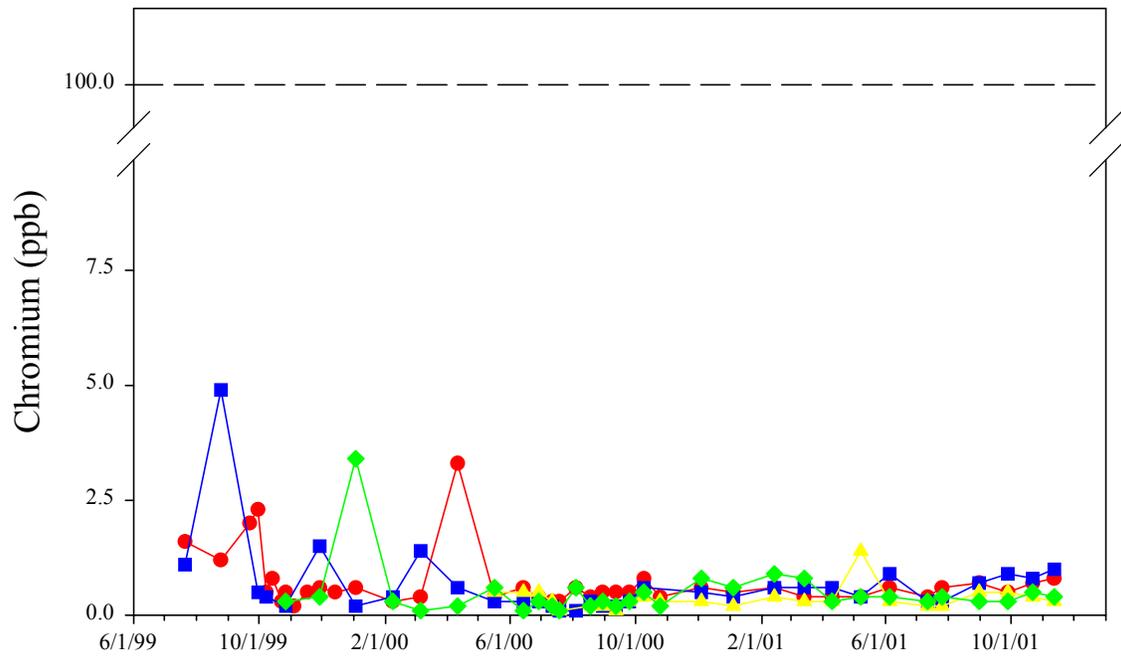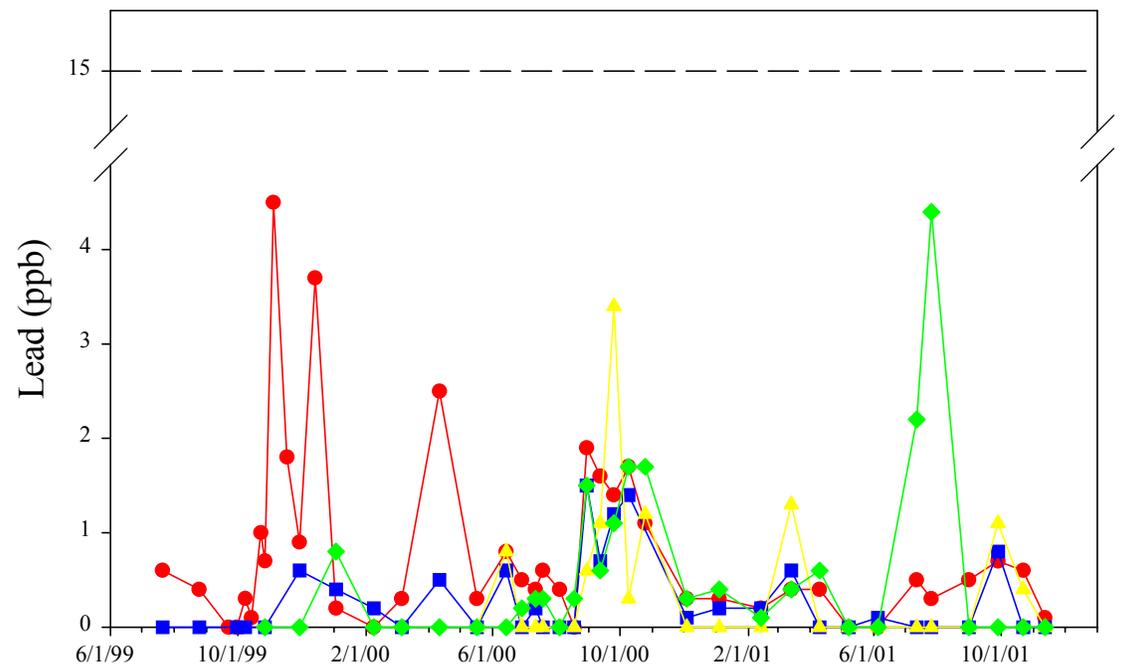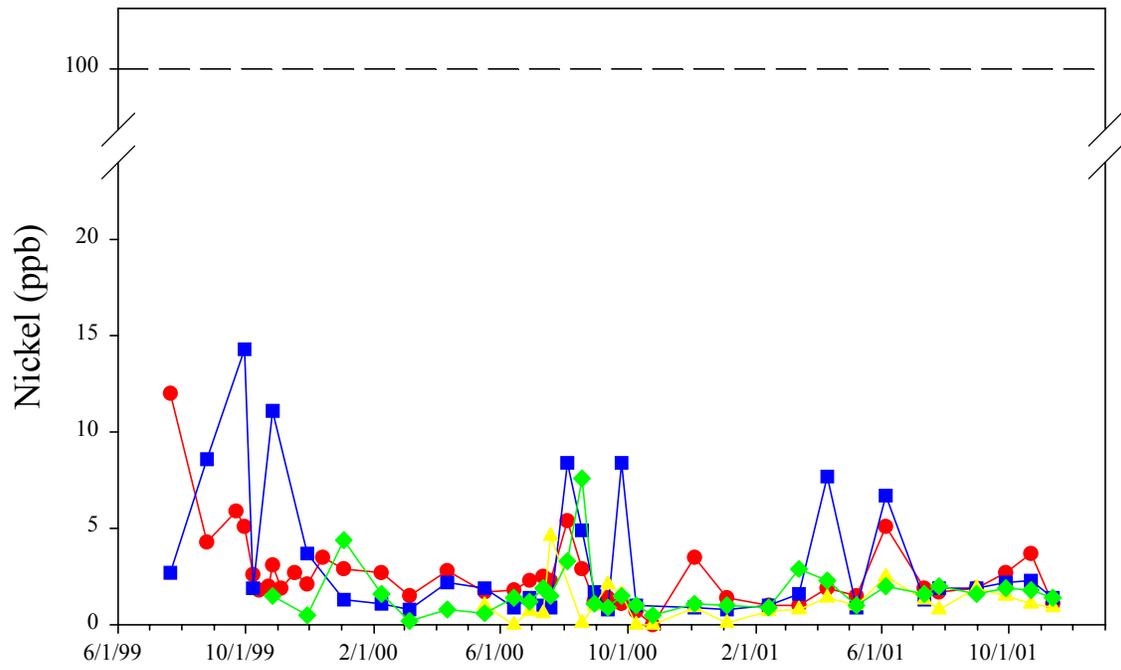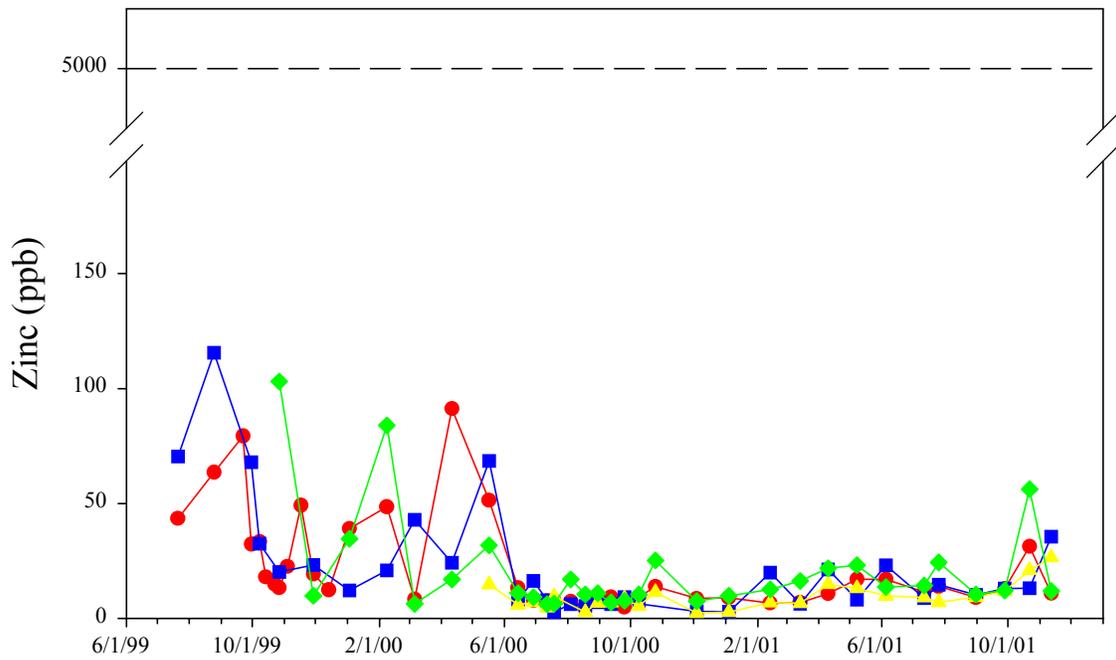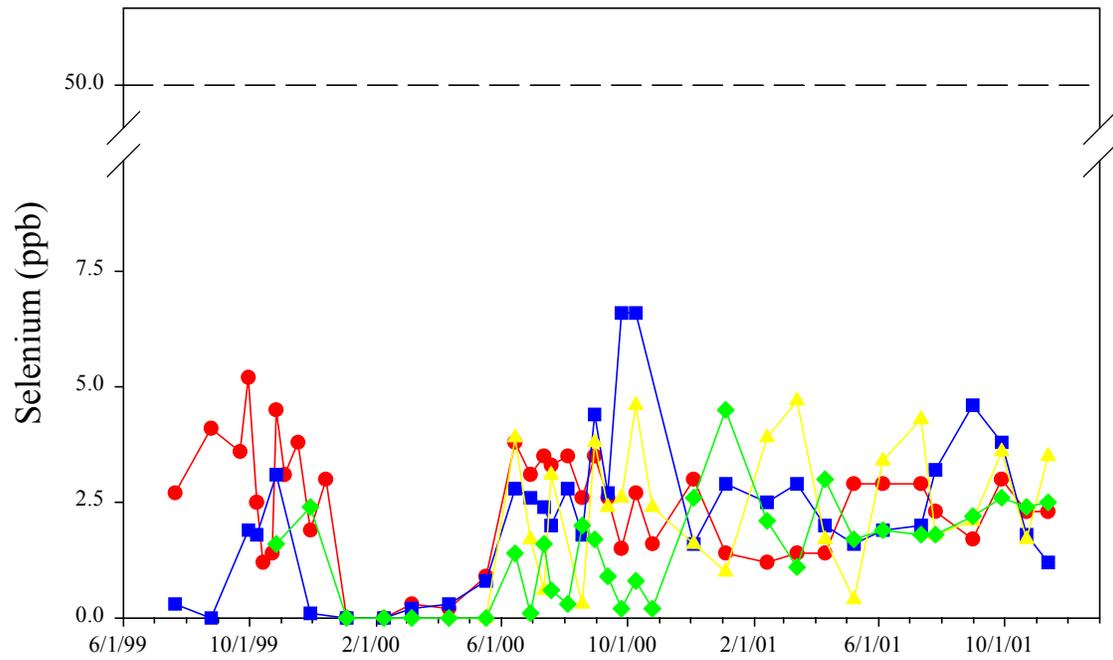
Figure B1: Concentrations of trace metals over time (July 1999 through November 2001). Red circles are biosolids wells; blue squares are control wells; yellow triangles are upgradient wells; and green diamonds are downgradient wells.

MWRA Data

Prior to the biomix application in October of 1999, one week after application and approximately one month after application, additional water samples were collected by UNH for analysis of PCBs, total metals, volatile organic compounds and semi-volatile organic compounds by the Massachusetts Water Resources Authority (MWRA). Samples were collected with a Teflon bailer cleaned with nitric acid and methanol and placed into clean sample bottles provided by MWRA. Samples were kept refrigerated and delivered to MWRA within 48 hours of collection. UNH also submitted to MWRA two equipment blanks and a field duplicate as part of QA/QC procedures. No analyses of PCBs, total metals, or VOC's were conducted by UNH with NEBRA funding.

Data on total metals, PCB's, semi-volatile and volatile organic compounds were at or below detection limits for most constituents analyzed. A complete list of all constituents analyzed is included in Table B1. Detection limits for MWRA were quite high for some compounds, particularly metals because samples were not filtered prior to analysis. Data for metals represent total concentrations, rather than the soluble fraction. Interpretation of the metals data is difficult because EPA and NH standards, as well as other research studies, use dissolved metals rather than the total metals reported by MWRA.

Concentrations of many total metals and DEHP (bis(2ethylexyl) phthalate) were actually higher prior to application of the biosolids and SPF mixture than after application, and levels were sometimes elevated within control wells (H-14 and H-15). In fact, some of the highest levels recorded were found in control wells (Table B2). Concentrations of all constituents analyzed were very low in the Merrimack River both upstream and downstream of the application area. The only organic found with some frequency was DEHP, which MWRA characterizes as a common laboratory contaminant (Steve Rhode, pers. comm.). The loading rates of DEHP for the site over the last five years do not exceed the NH DES standard for DEHP of 39 mg/kg, which is designed to protect groundwater concentrations from exceeding the standard of 6 ug/L. Given these results, we do not believe there is any evidence in this data set showing negative effects of residuals on trace organic contaminants or metals. Pesticides were not detected in either treatment or control wells. Additional analysis of dissolved metals will be conducted with separate funding by a UNH Ph.D. candidate during 2000-2001.

Table B1: Complete list of all constituents analyzed by MWRA. All constituents were below detection limits for all samples and for all dates except for those data reported in Table B2. Detection limits are in µg/L unless otherwise noted.

Constituent Analyzed	MWRA Detection Limit
1,1,1-TRICHLOROETHANE	<5.00
1,1,2,2-TETRACHLOROETHANE	<5.00
1,1,2-TRICHLOROETHANE	<5.00
1,1-DICHLOROETHANE	<5.00
1,1-DICHLOROETHENE	<5.00
1,2,4-TRICHLOROBENZENE	<10.0 - 13.3
1,2-DICHLOROBENZENE	<5.00 - 12.8
1,2-DICHLOROETHANE	<5.00
1,2-DICHLOROPROPANE	<5.00
1,2-DIPHENYLHYDRAZINE (AS AZOBENZENE)	<10.0 - 13.3
1,3-DICHLOROBENZENE	<5.00 - 13.3
1,4-DICHLOROBENZENE	<5.00 - 13.3
2,2'-OXYBIS(1-CHLOROPROPANE)	<10.0 - 13.3
2,4,5-TRICHLOROPHENOL	<10.0 - 13.3
2,4,6-TRICHLOROPHENOL	<10.0 - 13.3
2,4-DICHLOROPHENOL	<10.0 - 13.3
2,4-DIMETHYLPHENOL	<10.0 - 13.3
2,4-DINITROPHENOL	<20.0 - 26.6
2,4-DINITROTOLUENE	<10.0 - 13.3
2,6-DINITROTOLUENE	<10.0 - 13.3
2-BUTANONE	<5.00
2-CHLOROETHYL VINYL ETHER	<5.00
2-CHLORONAPHTHALENE	<10.0 - 13.3
2-CHLOROPHENOL	<10.0 - 13.3
2-HEXANONE	<5.00
2-METHYLNAPHTHALENE	<10.0 - 13.3
2-METHYLPHENOL	<10.0 - 13.3
2-NITROANILINE	<10.0 - 13.3
2-NITROPHENOL	<10.0 - 13.3
3,3'-DICHLOROBENZIDINE	<20.0 - 26.6
3-NITROANILINE	<10.0 - 13.3
4,4'-DDD	<20.0 - 26.7 ng/L
4,4'-DDE	<20.0 - 26.7 ng/L
4,4'-DDT	<20.0 - 26.7 ng/L
4-BROMOPHENYL PHENYL ETHER	<10.0 - 13.3
4-CHLORO-3-METHYLPHENOL	<10.0 - 13.3
4-CHLOROANILINE	<10.0 - 13.3
4-CHLOROPHENYL PHENYL ETHER	<10.0 - 13.3

4-METHYL-2-PENTANONE	<5.00
4-METHYLPHENOL (INCLUDES 3-METHYLPHENOL)	<10.0 - 13.3
4-NITROANILINE	<10.0 - 13.3
4-NITROPHENOL	<20.0 - 26.6
ACENAPHTHENE	<10.0 - 13.3
ACENAPHTHYLENE	<10.0 - 13.3
ACETONE	<5.00
ACROLEIN	<5.00
ACRYLONITRILE	<5.00
ALDRIN	<20.0 - 26.7 ng/L
ALPHA-BHC	<20.0 - 26.7 ng/L
ALPHA-CHLORDANE	<20.0 - 26.7 ng/L
ANILINE	<10.0 - 13.3
ANTHRACENE	<10.0 - 13.3
AROCLOR-1016	<505 – 667 ng/L
AROCLOR-1221	<1010 – 1230 ng/L
AROCLOR-1232	<505 – 667 ng/L
AROCLOR-1242	<505 – 667 ng/L
AROCLOR-1248	<505 – 667 ng/L
AROCLOR-1254	<505 – 667 ng/L
AROCLOR-1260	<505 – 667 ng/L
ARSENIC	<45 – 450
BENZENE	<5.00
BENZIDINE	<50.0 - 65.0
BENZO(A)ANTHRACENE	<10.0 - 13.3
BENZO(A)PYRENE	<10.0 - 13.3
BENZO(B)FLUORANTHENE	<10.0 - 13.3
BENZO(GHI)PERYLENE	<10.0 - 13.3
BENZO(K)FLUORANTHENE	<10.0 - 13.3
BENZOIC ACID	<20.0 - 26.6
BENZYL ALCOHOL	<10.0 - 13.3
BETA-BHC	<20.0 - 26.7 ng/L
BIS(2-CHLOROETHOXY)METHANE	<10.0 - 13.3
BIS(2-CHLOROETHYL)ETHER	<10.0 - 13.3
BIS(2-ETHYLHEXYL)PHTHALATE	<10.0 - 13.3
BROMODICHLOROMETHANE	<5.00
BROMOFORM	<5.00
BROMOMETHANE	<5.00
BUTYL BENZYL PHTHALATE	<10.0 - 13.3
CADMIUM	<2.0 - 20.0
CARBON DISULFIDE	<5.00
CARBON TETRACHLORIDE	<5.00
CHLORDANE (TECHNICAL)	<505 – 667 ng/L

CHLOROBENZENE	<5.00
CHLOROETHANE	<5.00
CHLOROFORM	<5.00
CHLOROMETHANE	<5.00
CHROMIUM	<4.0 - 40.0
CHRYSENE	<10.0 - 13.3
CIS-1,2-DICHLOROETHENE	<5.00
CIS-1,3-DICHLOROPROPENE	<5.00
COPPER	<10.0 – 100
DELTA-BHC	<20.0 - 26.7 ng/L
DIBENZO(A,H)ANTHRACENE	<10.0 - 13.3
DIBENZOFURAN	<10.0 - 13.3
DIBROMOCHLOROMETHANE	<5.00
DIELDRIN	<20.0 - 26.7 ng/L
DIETHYL PHTHALATE	<10.0 - 13.3
DIMETHYL PHTHALATE	<10.0 - 13.3
DI-N-BUTYLPHTHALATE	<10.0 - 13.3
DI-N-OCTYLPHTHALATE	<10.0 - 13.3
ENDOSULFAN I	<20.0 - 26.7 ng/L
ENDOSULFAN II	<20.0 - 26.7 ng/L
ENDOSULFAN SULFATE	<20.0 - 26.7 ng/L
ENDRIN	<20.0 - 26.7 ng/L
ENDRIN ALDEHYDE	<20.0 - 26.7 ng/L
ENDRIN KETONE	<20.0 - 26.7 ng/L
ETHYLBENZENE	<5.00
FLUORANTHENE	<10.0 - 13.3
FLUORENE	<10.0 - 13.3
GAMMA-BHC (LINDANE)	<20.0 - 26.7 ng/L
GAMMA-CHLORDANE	<20.0 - 26.7 ng/L
HEPTACHLOR	<20.0 - 26.7 ng/L
HEPTACHLOR EPOXIDE	<20.0 - 26.7 ng/L
HEXACHLOROBENZENE	<10.0 - 13.3
HEXACHLOROBENZNE	<20.0 - 26.7 ng/L
HEXACHLOROBUTADIENE	<10.0 - 13.3
HEXACHLOROCYCLOPENTADIENE	<50.0 - 66.5
HEXACHLOROETHANE	<10.0 - 13.3
INDENO(1,2,3-CD)PYRENE	<10.0 - 13.3
ISOPHORONE	<10.0 - 13.3
LEAD	<15.0 – 150
M,P-XYLENE	<5.00
MERCURY	<0.01 - 0.05
METHOXYCHLOR	<22.7 – 232
METHYLENE CHLORIDE	<5.00
MOLYBDENUM	<5.0 - 50.0

NAPHTHALENE	<10.0 - 13.3
NICKEL	<3.0 - 30.0
NITROBENZENE	<10.0 - 13.3
N-NITROSODIMETHYLAMINE	<10.0 - 13.3
N-NITROSODI-N-PROPYLAMINE	<10.0 - 13.3
N-NITROSODIPHENYLAMINE	<10.0 - 13.3
O-XYLENE	<5.00
PENTACHLOROPHENOL	<30.0 - 39.9
PHENANTHRENE	<1.00 - 1.30
PHENOL	<20.0 - 26.6
PYRENE	<10.0 - 13.3
SELENIUM	<50.0 – 500
STYRENE	<5.00
TETRACHLOROETHENE	<5.00
TOLUENE	<5.00
TOXAPHENE	<505 – 667 ng/L
TRANS-1,2-DICHLOROETHENE	<5.00
TRANS-1,3-DICHLOROPROPENE	<5.00
TRICHLOROETHENE	<5.00
TRICHLOROFLUOROMETHANE	<5.00
VINYL ACETATE	<5.00
VINYL CHLORIDE	<5.00
ZINC	<6.0 - 60.0

Table B2: MWRA data for constituents above detection limits. Total metals are
unfiltered. All data are in μg/L unless otherwise noted. DEHP represents bis(2ethylexyl)
phthalate. Rivu and Rivd represent upstream and downstream samples on the Merrimack

River, respectively. C = control wells, X = experimental wells, U = up-gradient wells. A mixture of biosolids and short paper fiber was applied to the experimental wells on October 25, 1999.

Well#	Type	Date	Acetone	Cr	Cu	Pb	Hg	Ni	Zn	DEHP
H-10	U	10/19/99	<5	61	<100	<150	0.041	46	254	29.4
H-10	U	10/27/99	<5	8	16	<15	0.038	9	43	12.5
H-10	U	12/15/99	<5	<4	14	15	0.038	5	30	22.2
H-11	X	10/19/99	<5	102	108	158	0.042	69	303	<13.3
H-11	X	10/27/99	<5	173	229	299	0.041	161	630	7.0
H-11	X	12/15/99	<5	<40	<100	259	0.016	41	194	27.6
H-12	X	10/19/99	<5	64	<100	<150	0.137	52	208	8.5
H-12	X	10/27/99	<5	59	<100	<150	0.039	54	177	17.9
H-12	X	12/15/99	<5	<40	<100	<150	0.041	38	153	40.8
H-14	C	10/19/99	<5	139	<100	319	0.127	132	449	<11.2
H-14	C	10/27/99	<5	87	<100	<150	0.049	72	255	<10.8
H-14	C	12/15/99	<5	<40	<100	<150	0.011	<30	88	<11.2
H-15	C	10/19/99	<5	<40	<100	<150	0.049	38	102	<11.1
H-15	C	10/27/99	<5	75	<100	<150	0.050	110	215	<10.3
H-15	C	12/15/99	<5	45	<100	153	0.034	35	101	31.1
H-7	X	10/19/99	<5	<40	<100	<150	0.038	<30	<60	7.6
H-7	X	10/27/99	15	11.6	<10	<15	0.037	8	35	57.4
H-7	X	12/15/99	<5	20	22	<15	0.084	13	68	42
H-9	X	10/19/99	<5	350	372	461	0.314	317	1250	16.5
H-9	X	10/27/99	<5	47	<100	<150	0.051	70	148	9.7
H-9	X	12/15/99	<5	35	43	64	0.051	31	127	31.1
RivU		10/19/99	<5	<4	<10	<30	<0.05	<3	7	<10.2
RivU		10/27/99	<5	<4	<10	<15	<0.01	3	<6	<10.9
RivU		12/15/99	<5	<4	<10	<15	<0.01	<3	7	<10.2
RivD		10/19/99	<5	<4	<10	<15	<0.05	<3	9	<10.0
RivD		10/27/99	<5	<4	<10	<15	<0.01	<3	<6	<10.1
RivD		12/15/99	<5	<4	<10	<15	<0.01	<3	9	<10.4

	Acetone mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Hg mg/kg	Ni mg/kg	Zn mg/kg	DEHP mg/kg
Biosolids & SPF Composite	2.46	5.92	96.7	<6.5	0.285	2.47	164	<11.9

Appendix C – Hooksett Individual Well Data for NO3-N

We present in this Appendix the nitrate concentrations over the length of this experiment for the individual wells (biosolids, control, upgradient, and downgradient).

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Control Well #22

Downgradient Well #19
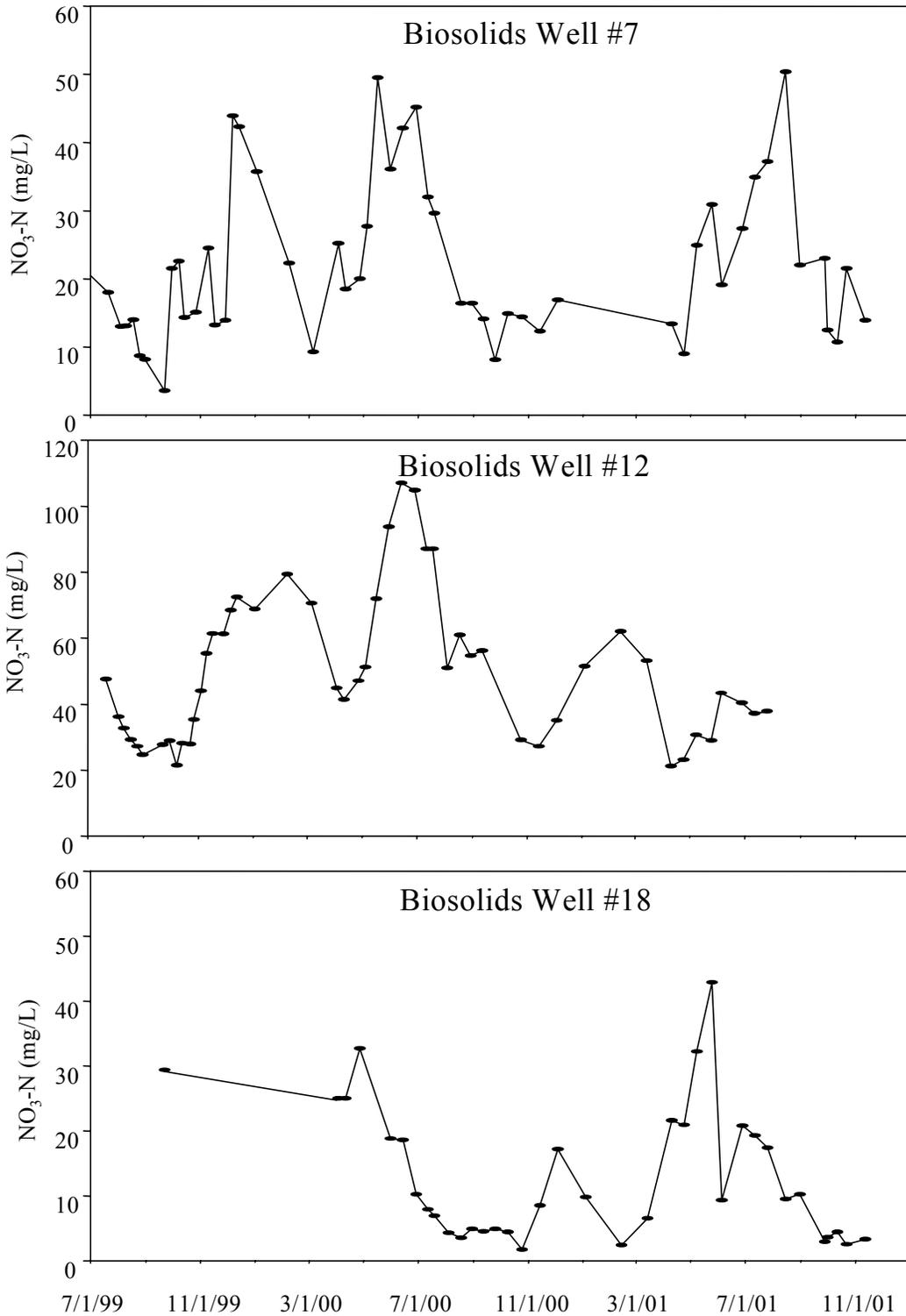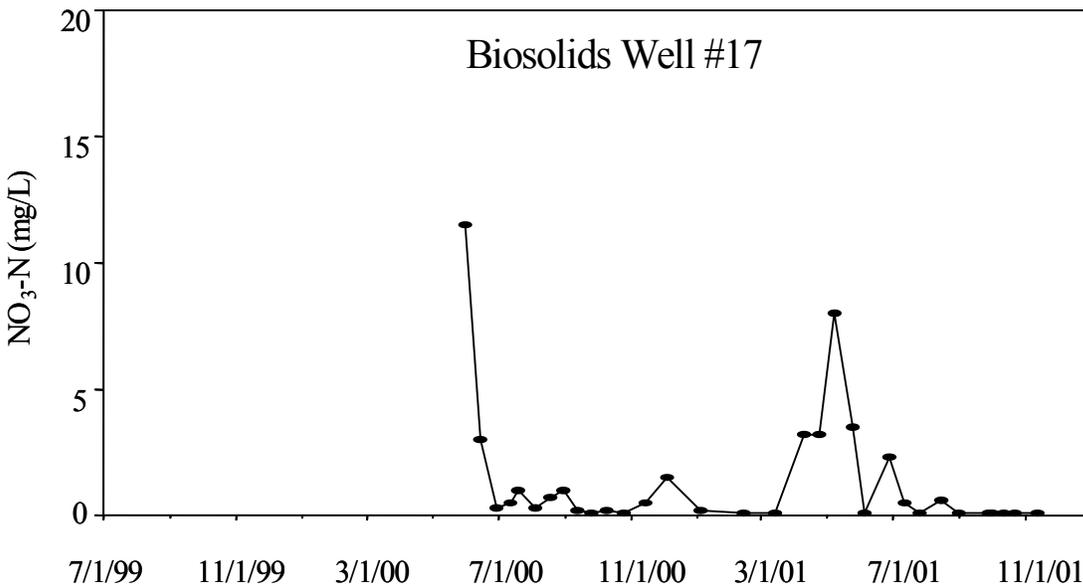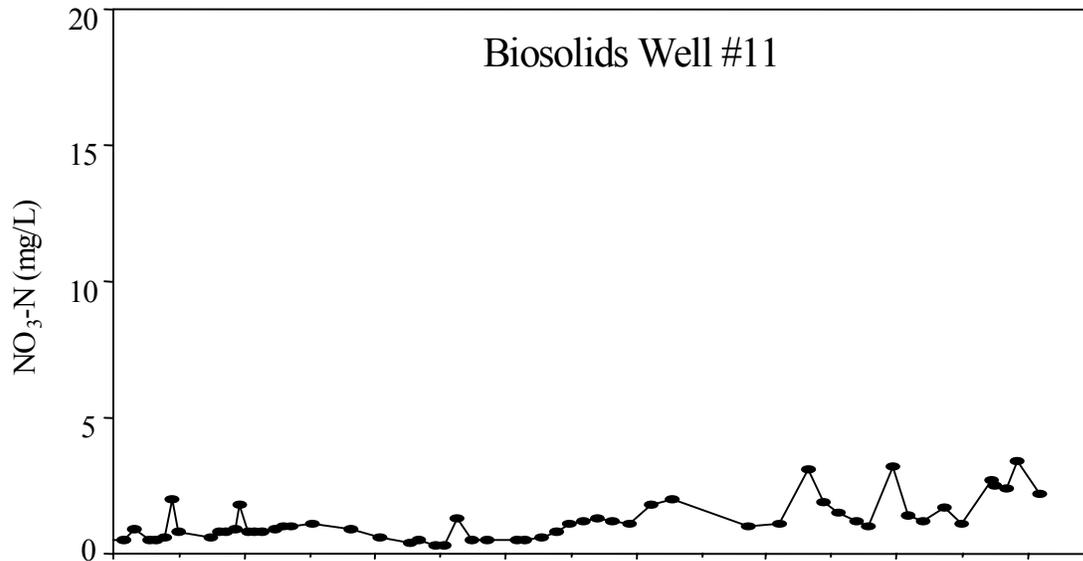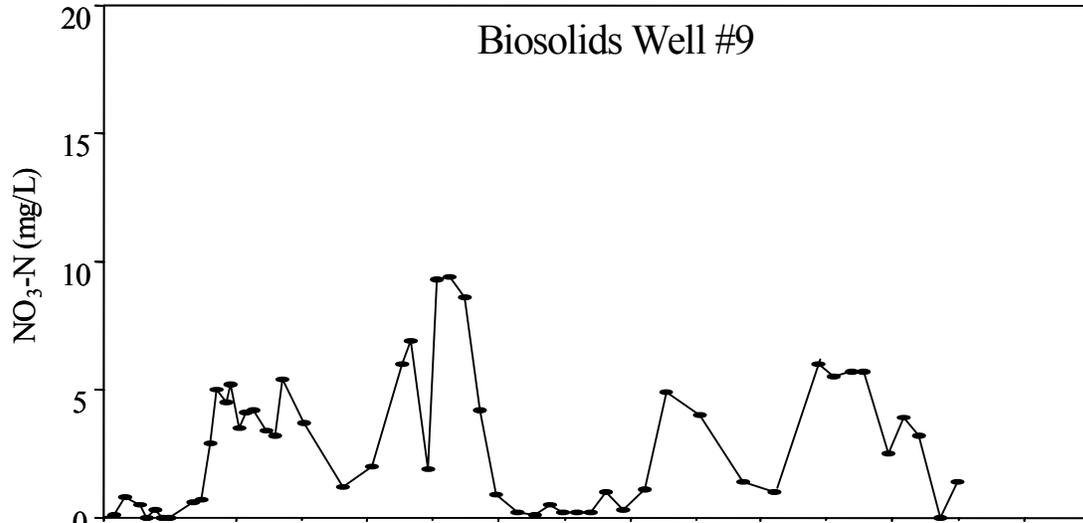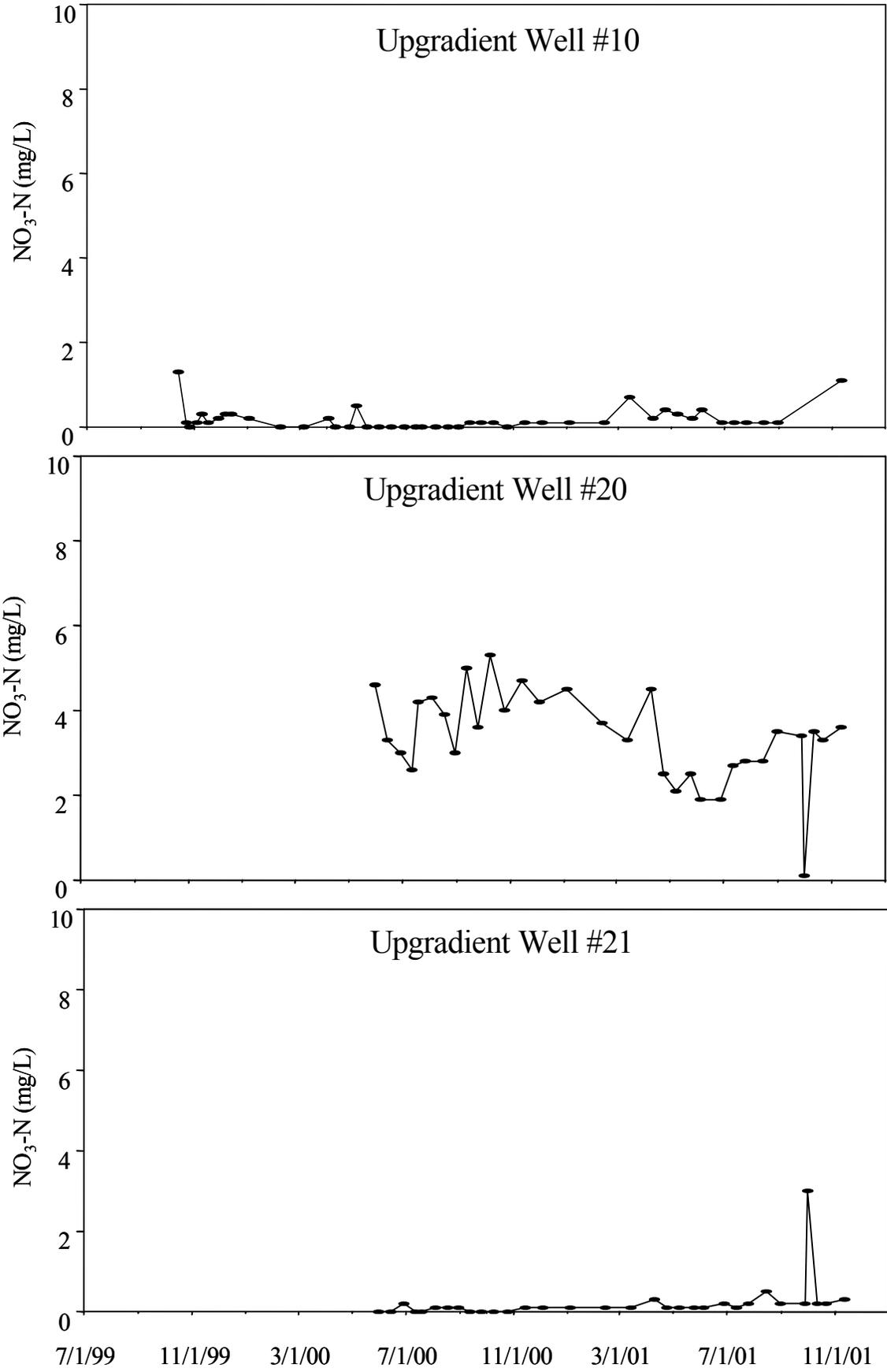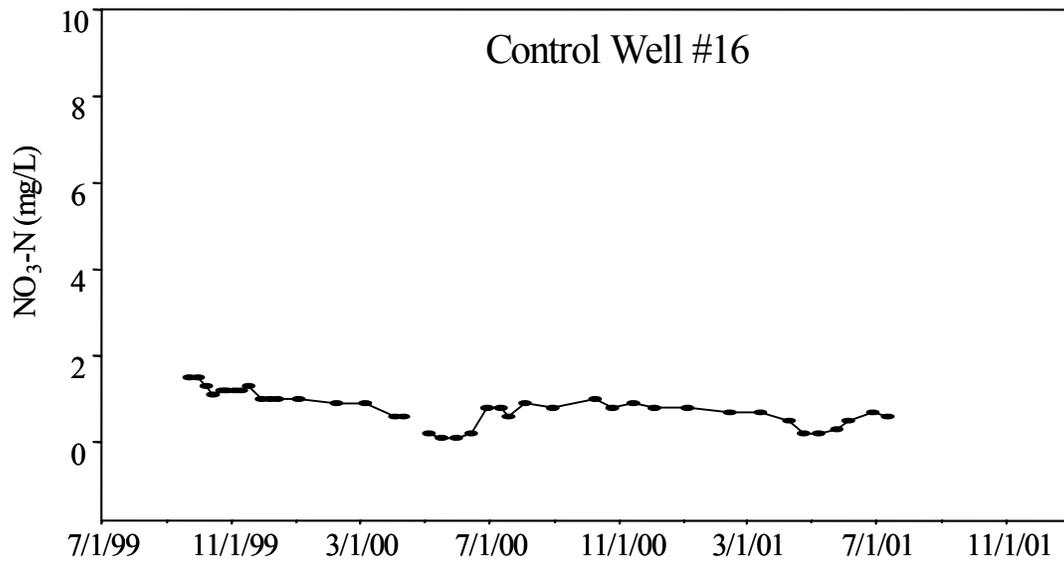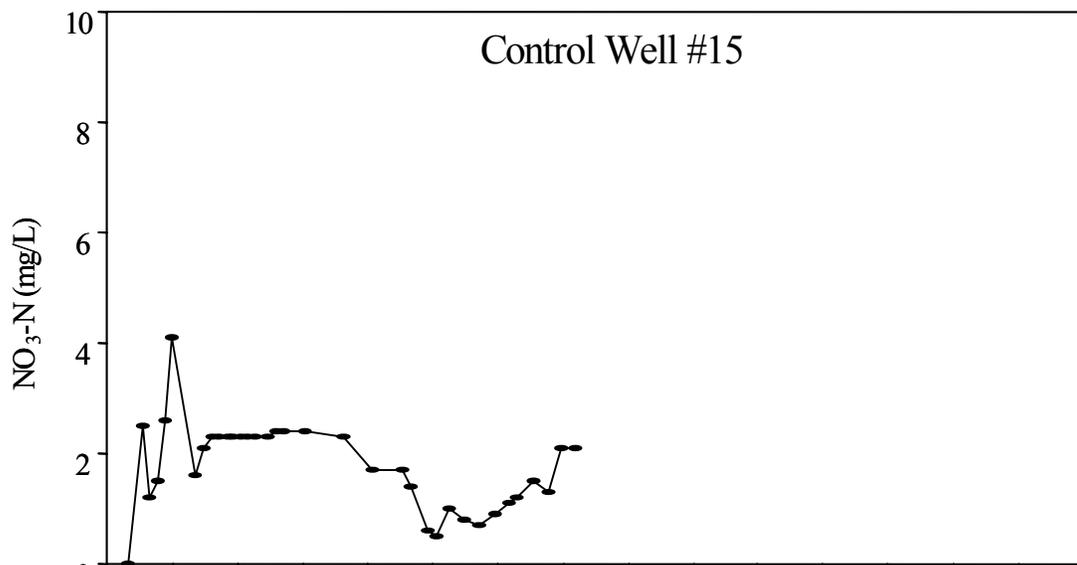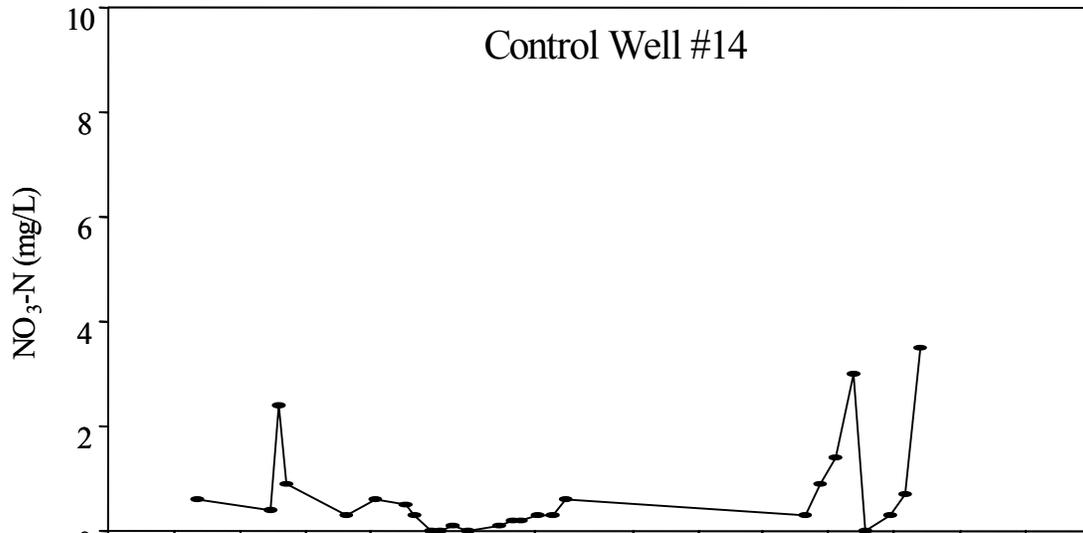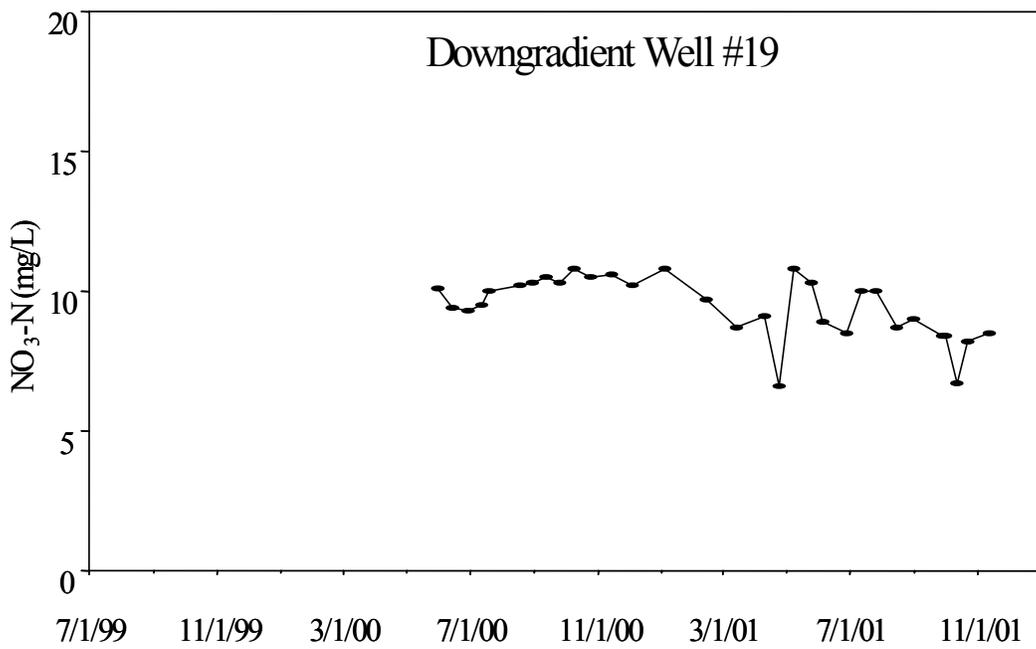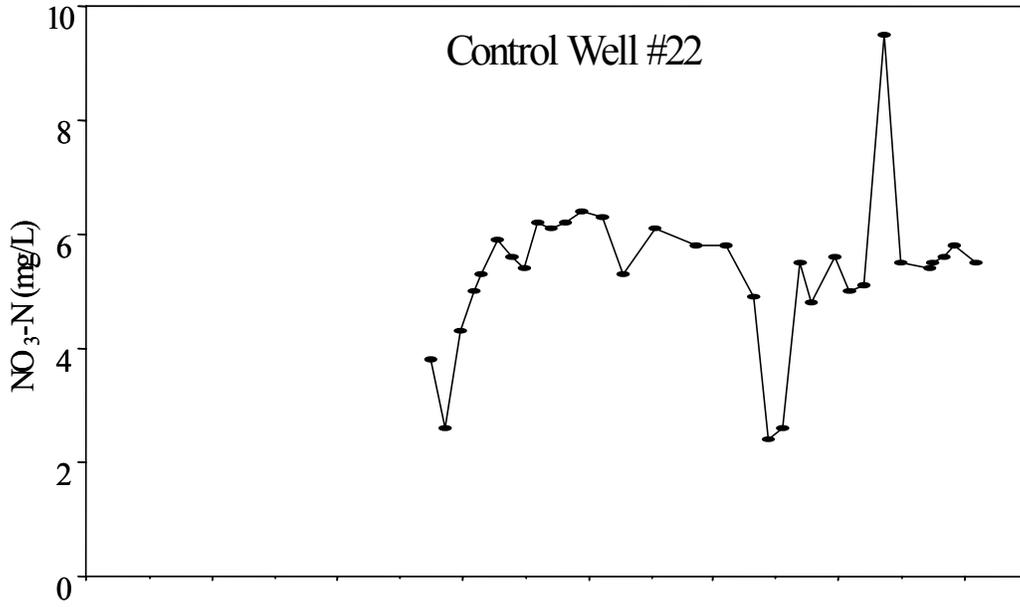
Effects of Land Use on Water Quality in a Changing Landscape

Basic Information

Title:	Effects of Land Use on Water Quality in a Changing Landscape
Project Number:	2001NH761B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Water Quality, Non Point Pollution, Nutrients
Descriptors:	lake, stream, water quality, nutrients, land use
Principal Investigators:	Jeffrey A. Schloss, William H. McDowell

Publication

1. Schloss, J.A. 2002. GIS Watershed Mapping: Developing and implementing a watershed natural resouces inventory, in R. France ed., Handbook of Water Sensitive Design and Planning, Boca Raton, FL, Lewis Publishers, 557-576.

Problem and Research Objectives:
State: New Hampshire
Project Number: NH761
Title: Effects of Land Use on Water Quality in a Changing Landscape
Project Type: Research Project
Focus Category: Water Quality, Non Point Pollution, Nutrients
Keywords: lake, stream, water quality, nutrients, land use
Start Date: 03/01/2001
End Date: 02/28/2002
Congressional District: 1
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Objectives:
1- The continued collection and analysis of long-term water quality data in selected watersheds.
2- The dissemination of the results of the analysis to cooperating agencies, water managers, educators and the public on a local, statewide and regional basis.
3- To offer undergraduate and graduate students the opportunity to gain hands-on experience in water quality sampling, laboratory analysis, data management and interpretation.
4- To further document the changing water quality in the College Brook Watershed in the face of land use changes and management efforts.
5- To document the effectiveness of constructed BMPs in the Chocorua Lake Watershed
6- To determine the next steps for further analysis of long-term data sets.

Methodology
Ongoing sampling of College Brook has been done on a monthly basis and during storm events. Parameters measured include: dissolved oxygen, pH, temperature, specific conductivity, total suspended solids, total dissolved nitrogen, ammonium, nitrate, phosphate, sulfate, chloride, silica, dissolved organic carbon, and base cations (Ca, Mg, Na, and K).
Lake and stream monitoring through the LLMP generally involved a minimum of monthly sampling from spring runoff through lake stratification, and weekly to bi-weekly sampling from stratification until fall overturn. Water clarity, chlorophyll a, acid neutralizing capacity, color, dissolved oxygen and nutrients (total N, total P and nitrate) was the default suite of parameters measured for lakes while nutrients, turbidity, color and flow were the parameters of choice for the lake tributary work. On occasion, student field teams traveled to join the volunteer monitors to perform quality assurance checks and do more in-depth analysis and lake profiling.
Land cover changes to study subwatersheds was documented on our established GIS data base and new management practices or conservation efforts were also documented. Particular emphasis was placed on the Squam Lakes Watershed this year.
This project was coordinated from the University of New Hampshire, which supplied the office and laboratory space (analytical and computer). The Center for Freshwater Biology Analytical Water Quality Laboratory has a Quality Assurance Project Plan for surface water analysis on file with the US Environmental Protection Agency Region 1 Office (EPA New England). Besides nutrient analysis (Total Phosphorus, Total Nitrogen, Nitrate), other water quality measurements

included chlorophyll a, dissolved oxygen, dissolved CO_2, acid neutralizing capacity, specific conductivity, pH, ORP, turbidity, water clarity, iron and E.coli. The Water Quality Analysis Laboratory of the NH WRRC uses automated flow injection analysis, ion chromatography, and high temperature combustion techniques for water quality analysis. They are also leaders in developing new analytical methods (e.g. Merriam et al. 1996; Yano et al. 1998).

UNH Cooperative Extension and the Natural Resource Department provided vehicles for travel for PI's, students and interns at a cost (mileage) basis. A dedicated GIS PC NT workstation was provided for use including Arc/Info and ArcView Software, ArcView Extensions: Spatial Analyst, 3D Analyst, Image Analysis and ArcPress. This was used in addition to other data input PC stations, laser printers and a large format (36" wide) ink jet plotter that was made available for the project.

The project utilized an extensive GIS database for the study subwatersheds created through previous WRRC funding to the PI. Updated and additional GIS data including a new land cover dataset for 2000 was made available through the UNH Complex Systems Research Center which manages the NH GRANIT statewide GIS data depository. The extensive data directory contains statewide GIS data layers (usually at 1:24,000 scale) including hydrology, geology, soils, National Wetlands Inventory, land-use, land cover, and digital elevation models. Also available are Landsat Thematic Mapper, SPOT Panchromatic and digital orthophoto imagery.

Principal Findings and Significance

Ongoing collection of ambient water quality data across the state continues. We added new sites for our statewide lake study. We saw an 8% increase in monitoring samples collected statewide with an over 25% increase in samples collected specifically in the Lakes region of NH: In all, we saw the addition of 3 new lakes, and the expansion of programs on 9 other lakes with the addition of 11 new or reactivated sampling sites (Table 1). We provided training for 29 new volunteer monitors!

Lake	Association/Sponsors	Town(s)
New Programs Initiated:		
Big Dan Hole Pond	Dan Hole Pond Watershed Assn.	Tuftonboro, Ossipee
Little Dan Hole Pond	Dan Hole Pond Watershed Assn.	Ossipee
Whitton Pond	Whitton Pond Cottage Assn.	Albany, Madison
Existing Programs Expanded (new monitoring sites):		
Bow Lake	Bow Lake Campowners Assn.	Strafford, Northwood
Crystal Lake	Eaton Conservation Commision	Eaton
Crystal Lake	Crystal Lake Association	Enfield
Great East Lake	Great East Lake Association	Wakefield
Goose Pond	Goose Pond Association	Canaan, Hanover
Lake Kanasatka	Lake Kanasatka Watershed Assn.	Moultonboro
Naticook Lake	Naticook Lake Assn. and Town of Merrimack	Merrimack
Newfound Lake	Newfound Lake Region Assn.	Alexandria, Bristol, Bridgewater, Hebron
Lake Winnipesaukee, Moultonboro Bay	LWA* and Tuftonboro Assn	Tuftonboro, Moultonboro
Lake Winnipesaukee, Meredith Bay	LWA and Meredith Rotary Club	Meredith
Lake Winnipesaukee, Wolfeboro Bay	LWA and Town of Wolfeboro	Wolfeboro

* LWA= Lake Winnipesaukee Association

The Lake Chocorua BMP Evaluation Study disclosed that a significant reduction in the phosphous loading was due to the road drainage mitigation techniques. The combination of the use of plunge pools, diversions to settling areas and a large collecting swale reduced loadings during storm events by 82-94%. The P concentration range from the runoff was also reduced

significantly (pre-range of 34 to 281ppb post range of 13 to 23 ppb). Further monitoring will be done to capture spring runoff and additional storm events in the upcoming year.

Analysis of the Squam Lake Watershed nutrient budget disclosed that subwatersheds with construction activity or active agriculture were the largest contributor of phosphorous on an aerial basis. Further study will be done on analysis of the effect of riparian buffer extent and updated nutrient export coefficients will be calculated in the upcoming year.

<u>Number of students involved or funded (#, undergrad, Masters, and PhD)</u>

Beckie Damm -- Marine and Freshwater Biology (Senior)   Fall/Spring Employ
Renee Gannon -- Marine and Freshwater Biology (Sophomore)   Fall/Spring Employ
Todd Brackett -- Environmental Conservation (Junior)   Summer/Fall and Spring Employ
Kirsten Pulkkinen -- Environmental Conservation (Junior)   Fall/Spring Employ
Rider Foley -- Environmental Conservation (Senior)   Summer/Fall and Spring Employ
Melissa McCartney -- Forestry (Sophomore)   Summer/Fall and Spring Employ
Gregg Decelles -- Marine and Freshwater Ecology (Junior)   Fall/Spring Employ
Darla Black -- Liberal Arts   Fall and Spring Employ
Shane Brandt- - Zoology (Grad student, PhD)
Juliette Nowak -- Zoology (Grad Student, MS)

In addition: water quality and GIS data were used in:
WARM 604- Watershed Hydrology -9 students
Zoology/Botany 719/819- Field Limnology- 12 students
Biology/Zoology 896- Multidisciplinary Lake Management- 9 students

Any publications, reports, presentations, from this work.

Publications:
Schloss, Jeffrey A. 2002. GIS Watershed Mapping: Developing and implementing a watershed natural resources inventory. In Handbook of Water Sensitive Design and Planning. R. France editor. Lewis Publishers, Boca Raton. FL. Chpt II.12 pages 557-576.

Presentations by Jeff Schloss covering all or parts of study:

New England Assoc. of Environmental Biologists	New England Water Resources Protection	March 2001 Warwick, CT	Presented:" In-situ chlorophyll fluorescence: The Good, the Bad and the Algae"
North American Lake Management Society (NALMS)	Enhancing State Lake Management Programs	April 2001 Chicago, Illinois	Presented **invited session**: "Lake Monitoring and NPS Partnerships Deliver: The Lake Chocorua Project."
Ohio Lake Management Society	Annual Meeting	February 2002	Presented **keynote address** "Watershed Stewardship Through Volunteer Water Quality Monitoring"

Information Transfer Program

Student Support

Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	9	0	0	0	9
Masters	5	0	0	0	5
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	16	0	0	0	16

Table header: Student Support

Notable Awards and Achievements

Publications from Prior Projects

None