Report for 2003ME18B: Nitrate Mobility in Shallow Groundwater Near Biosolids Stockpiles

- Dissertations:
  - Nadeau, James (2004, expected). MS Dissertation, Department of Civil and Environmental Engineering, University of Maine, Orono, Maine.
- Conference Proceedings:
  - Peckenham, J.M., J. Nadeau, and A. Amirbahman (2003). Biosolids Leachate Experiment, New England Water Environment Association, Bedford, NH, November 13, 2003.
  - Peckenham, J.M. and J. Nadeau (2003). Biosolids Field Stacking Experiment, Maine Waste Waste Control Association, Casco, ME, September 18, 2003.
  - Peckenham, J.M., J. Nadeau, and A. Amirbahman (2004). Nitrogen Loss From The Controlled Field Stacking of Biosolids, Maine Water Conference, Augusta, ME, April 22, 2004.
  - Peckenham, J.M., J. Nadeau, A. Amirbahman, W. Brutsaert, and J. Wilson (2004). Leachate From Biosolid Stockpiles: Nutrients and Metal Mobility, Amer. Geophys. Union Mtg., Montreal, PQ, May 21, 2004.

Report Follows

Title: Nitrate Mobility in Shallow Groundwater Near Biosolids Stockpiles.

Problem and Research Objectives

The loss of nitrate from biosolid (*i.e.* sludge) stockpiles is of great concern in Maine because groundwater is the common source of drinking water in rural areas. The use of farmland for landspreading organic wastes is a needed option for biosolids management. Biosolids are sludges that have been processed to be used as soil amendments. The quantification of leachate characteristics from biosolids stockpiles for typical soils is needed. For the past 3 years, over 90 per cent of the sewage sludge generated in Maine has been utilized as a soil amendment, after either being composted or lime-stabilized (biosolids). Sewage sludge is the by-product of making clean water, so it is generated year-round. However, since this product is only needed as a fertilizer during narrow windows in the crop cycle, it has to be stored. The most cost-effective and convenient method of storage is to stack the sludge in the field. Sludge may be stacked for up to 8 months before use.

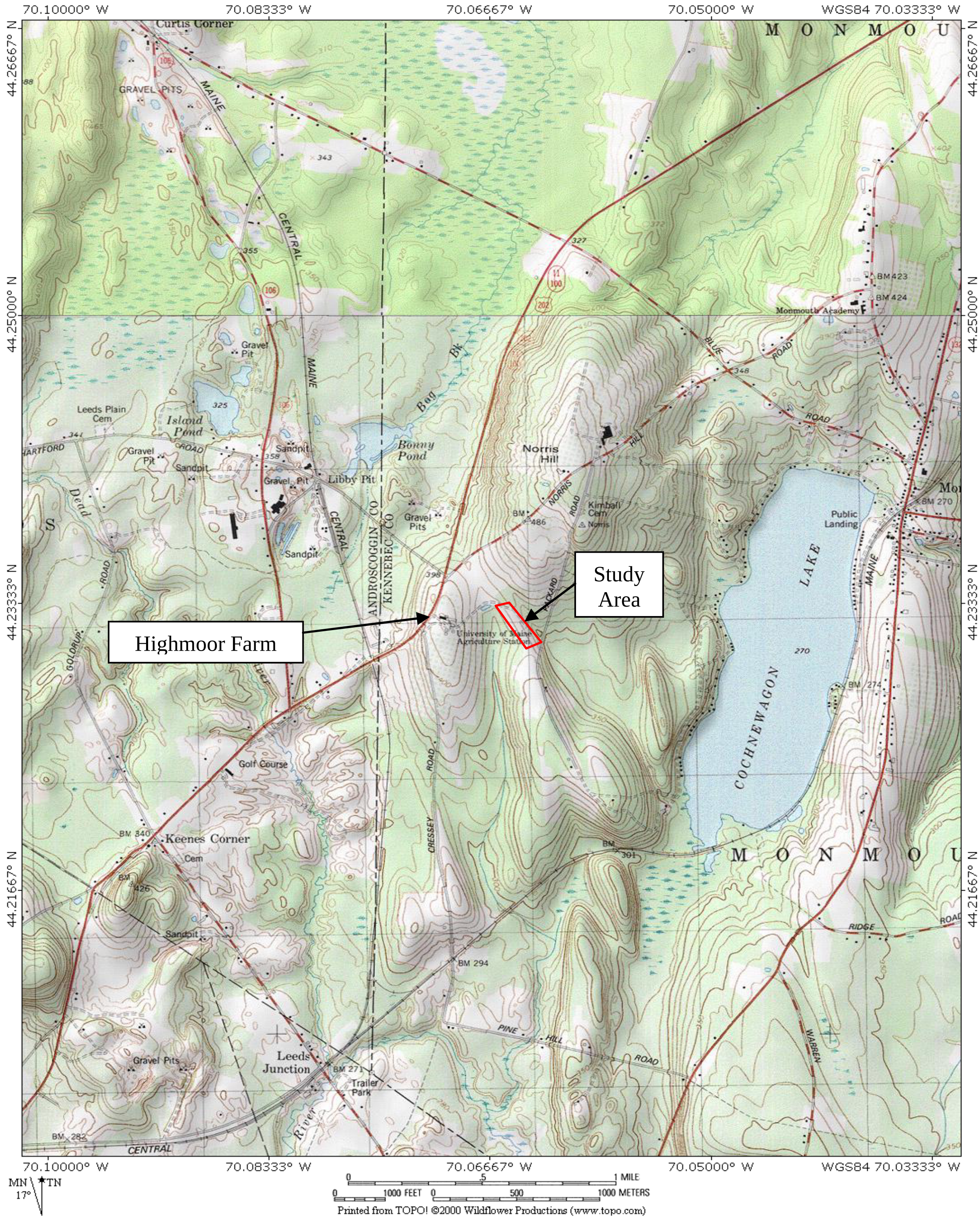
While field stacking is a standard agricultural practice, the Maine Department of Environmental Protection (MDEP) is concerned about the impacts to groundwater that the practice creates. In particular, the MDEP is concerned that nitrate-N leached from a pile may have significant adverse impacts on groundwater. The primary contaminant of concern for the study is nitrate-nitrogen (nitrate-N) and other forms of nitrogen that may change to nitrate in the environment. Nitrate-N and nitrite-N are a concern for groundwater contamination and are regulated under the federal Safe Drinking Water Act.

The objective of this study was to determine the potential for nitrogen species to move from stockpiled biosolids into the shallow groundwater. This study complements another co-located experiment using lined cells to measure the volume of leachate and runoff moving through and over stockpiles of class-B biosolids. This study is providing an independent measure of the concentration of nitrogen in these runoff pathways. Data from this study will be used as a basis for evaluating stockpiling rules under Maine Chapter 419 of the solid waste rules. Users of the resulting data are the Maine Department of Environmental Protection (MDEP) and biosolids-application stakeholders. The data will be used to evaluate current MDEP methods to model the attenuation of nitrate-N and other nitrogen forms in effluent from stockpiles in the vadose zone and ground water. The MDEP intends to model nitrate-N contamination of groundwater around stockpiles. The amount of nitrogen moving out of a representative stockpile is a critical parameter for the modeling. The data need to be representative of realistic leachate and runoff from biosolids stockpiles for actual regional soils.

Methodology

We measured nitrate-N and other forms of nitrogen moving out of biosolids stockpiles under field conditions at the Highmoor Farm in Monmouth, Maine (Figure 1). The design of the biosolids stockpile experiment is described here in summary detail to clarify how the groundwater study is integrated into an existing biosolids leachate characterization experiment funded by the Maine Department of Environmental Protection.

Figure 1. Location of Highmoor Farm in Monmouth and Leeds, Maine. Study area is outlined in red.



Existing Study. The existing biosolids stockpile study consists of three experimental plots: (1) a grass plot with pan lysimeters, (2) a rectangular lined cell (wide), and (3) a rectangular lined cell (narrow) (Figure 2). The stockpile above the pan lysimeter plot is laid directly on the ground with no barrier (4 meters x 10 meters). The lined cells are designed to capture runoff and leachate from two different pile geometries: linear (2.5 meters x 32 meters) and rectangular (5 meters x 25 meters). The surface runoff was collected via gutters along the bottom edge of the pile and above an impermeable membrane (flexible pvc liner). The pile was covered with a layer of sand over the liner and contained an under-drain to collect leachate.

Flow volumes for leachate and runoff from the lined cells were gauged along with rainfall amounts. Initial and final nutrient content and were analyzed for each iteration. Nitrogen species and total dissolved organic carbon (TOC) were determined in the underlying soil. Soil and leachate data were collected to calculate a mass balance profile of nutrients over the duration of the stockpiling. The piles were in place for 8-10 months depending on weather conditions. This time period corresponded to present allowable stockpiling duration limits.

Soil Water. An array of 17 pan lysimeters were located to capture water in the vadose zone directly below the stockpile. These were placed at three levels approximately 0.25m, 0.50m and 1.00m below the soil surface. Effluent samples were extracted from the lysimeters to determine the movement of nitrates through soil in an unrestricted condition (no liner) from stockpiles.

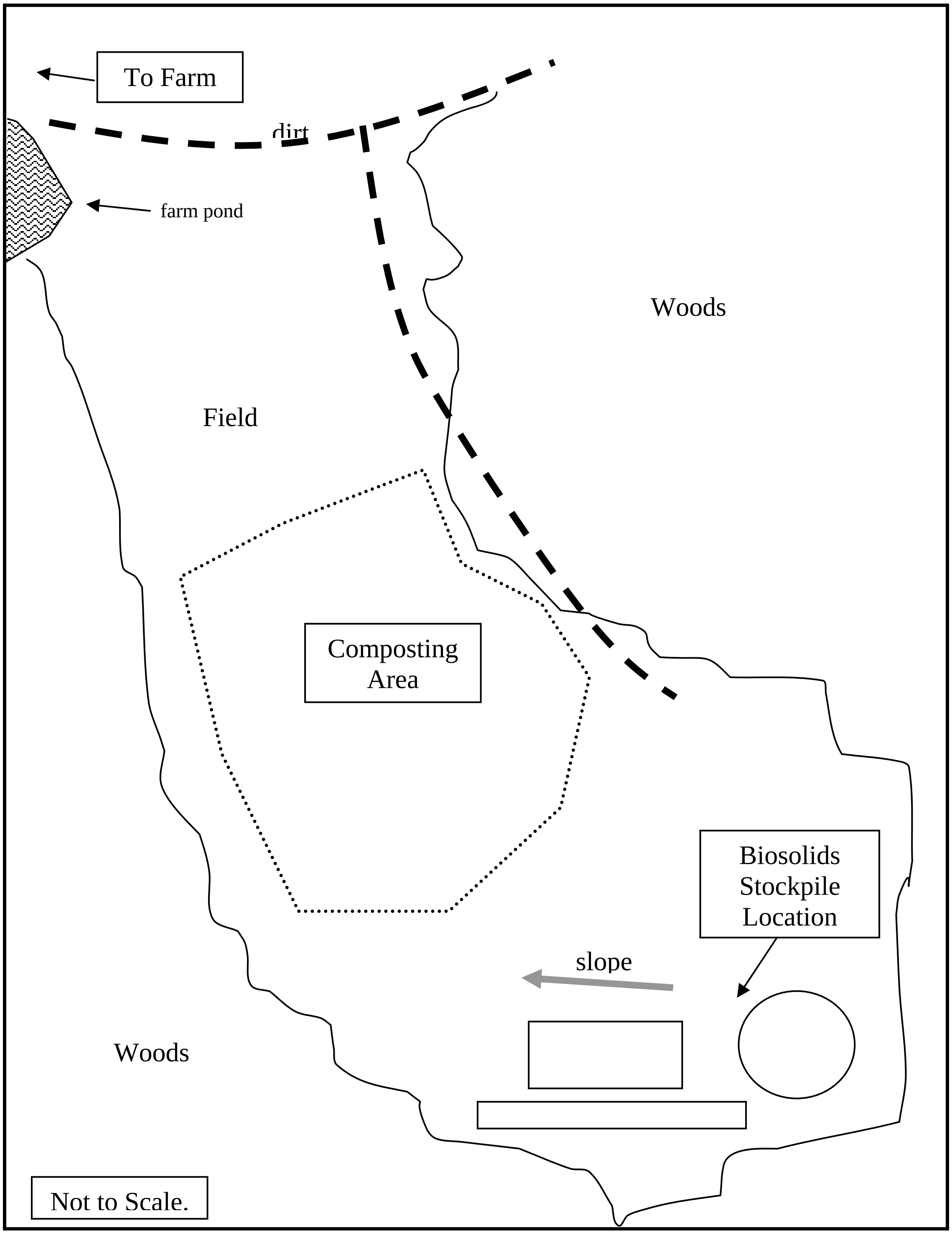
A composite water sample of soil solution (leachate) collected in the lysimeter plot was made for each vertical sampling level by event. The samples were composited to counteract the variability caused by installation and disruption of the soil column. The samples were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, and total dissolved organic carbon.

Shallow Groundwater. Seven groundwater piezometers were installed vertically using truck-mounted push technology. Field conditions limited the vertical penetration to a range of 1.5 to 2.5 meters below grade. The piezometer array was completed near the lysimeter plot (three points), the lined piles (two points), 25 meters down-gradient of the lined piles (one point) and 200 meters cross-gradient as a background reference (one point).

Piezometers were constructed from 5-foot lengths (1.52 m) of 0.010-foot slotted 1-inch I.D. (0.305 cm slots, 2.54 cm diameter) pvc pipe. Solid pvc pipe was used above the screen to above grade. The screen was packed with filter sand, sealed with several inches of bentonite powder and then native fill to the surface. After completion, only one point had measureable water (the reference point, W6). Sufficient shallow groundwater was not collectable until after several significant rainfall events in the fall. The pan lysimeters were sampled monthly from July through October and the piezoemeters were sampled three times before the weather became too cold and the ground froze.

Water levels in the piezometers were measured during site visits with a water level indicator. Groundwater samples were collected by purging the wells of multiple well

Figure 2. Schematic layout of the experimental site (not to scale).



volumes of standing water, or to dryness. Purge water was collected as a precaution because of low water volumes. Upon recovery, groundwater samples were collected into glass and polyethylene jars as appropriate for the analytical method. Groundwater samples were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, pH, and total dissolved organic carbon. Initial testing indicated that nitrate and nitrate were the anayltes of greatest concentration and later testing was limited to those two nitrogen species.

Sample Analysis were performed at the University of Maine according to Standard Methods and SW-846 Methods, as appropriate.

Principal Findings

Soils and Groundwater
The soil sampling probe was able to be pushed to a maximum depth of 2.74 meters. Advancement of the probe was stopped either by refusal on rock (bedrock or boulder) or excessive soil penetration resistance (dense soil). A total of 10 soil probes locations were sited and piezometers were installed in seven of these locations (Figure 3). Soils were logged in only the push-points where peizometers were installed.

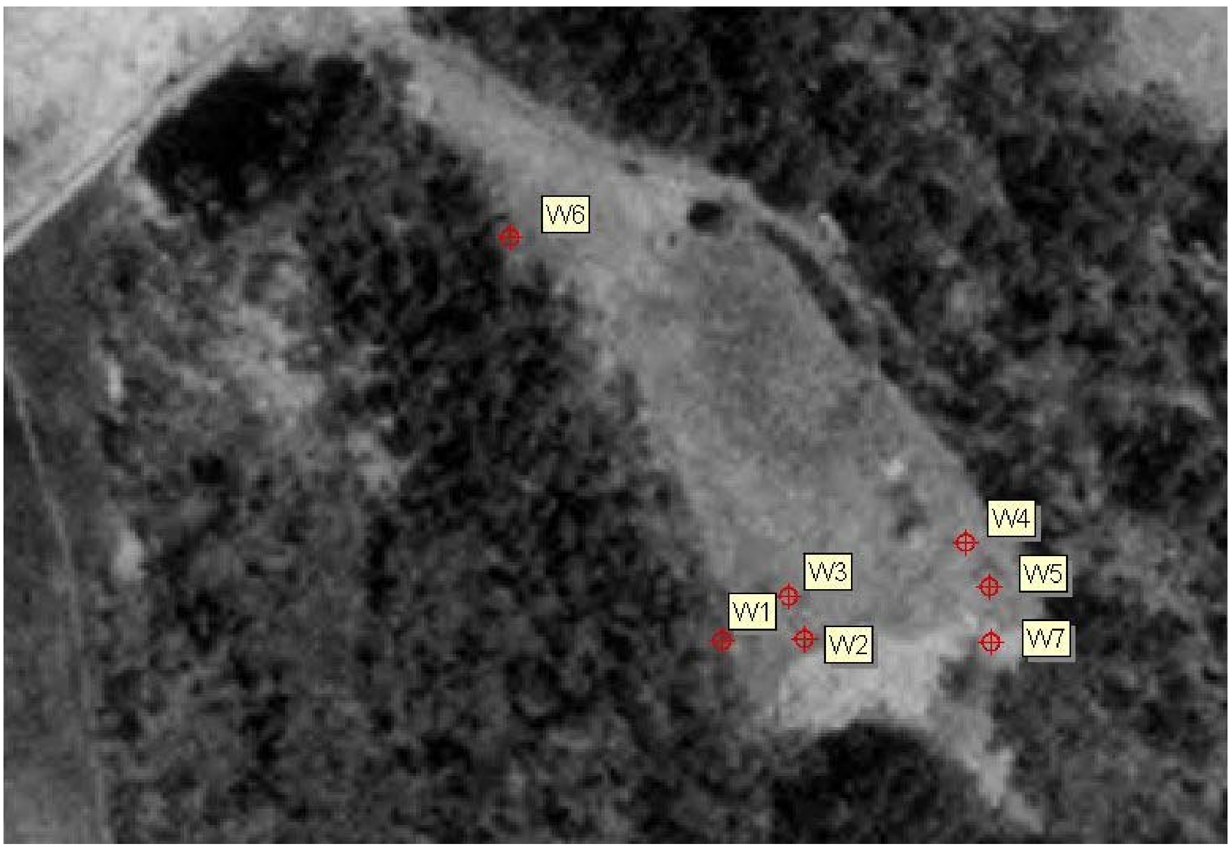
Table 1. Piezometer Construction Details.

Boring Number	Piezometer Number	Location	Total Depth (meters)	Screen Interval (meters)	Riser Length (meters)	Water Level at Completion (m bgs)
B-1	W1	46± m downslope of biosolids test cells	3.1	3.1-1.5	1.5	dry
B-3	W2	2± m east of lower end of long pile	2.7	2.7-1.2	1.5	dry
B-4	W3	Adjacent to wide pile level spreader	2.4	2.4-0.91	1.5	dry
B-5	W4	1.5± m north of lysimeter plot (uphill)	2.6	2.6-1.1	1.5	dry
B-7	W5	1.5± m north of lysimeter plot,15± feet east of W4	1.9	1.9-0.45	1.5	dry
B-8	W6	northwest corner of field in wet spot	3.6	3.6-2.1	3.1	0.3
B-10	W7	8± m east of lysimeters at top of rise	1.9	1.9-0.45	1.5	dry

The soils observed were consistent across the study area. The surface to approximately 10 centimeters was comprised of sod and dark brown organic soil. This organic layer graded into a layer 25± centimeters thick of dark-brown, friable sandy loam. This loam graded into a layer 90± centimeters thick of olive-brown, dense silty to sandy loam with up to 10 per cent pebbles to cobbles. Below this layer, the soil consisted of a layer 120± centimeters thick of moist olive-brown to gray, very-dense silty-sand with up to 10 per cent pebbles to cobbles. No evidence of mottling was observed in any soil samples. Boulders up to 80 centimeters in diameter were observed in excavations in the study area. This soil is interpreted to be glacial till derived (dense silt with pebbles to cobbles).

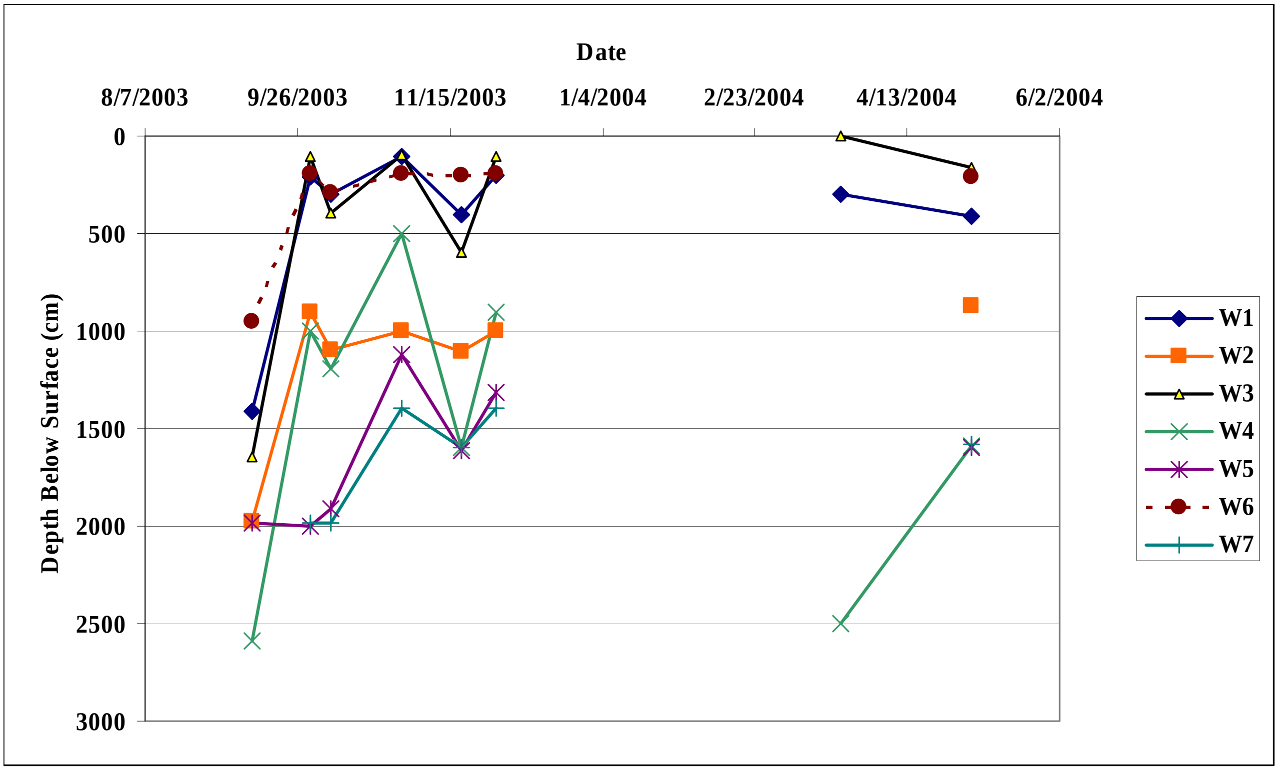
Groundwater was detected at completion in only one soil probe point (B-8) where piezometer W6 was installed. Piezometer completion details are summarized in Table 1. The piezometers were gauged for water levels in September, October, November, December, and April. The water in the piezeometers was frozen from December 2003 into April 2004. Relative water level trends are presented in Figure 4. It is clear from the data collected that these piezometers are saturated with groundwater seasonally.

Figure 3. Locations of piezometers at Highmoor Farm. The field is approximately 90 m. wide.



In general, the soils became saturated in the early fall as a consequence of increased rainfall. According to National Weather Service data for Auburn, Maine, rainfall was below normal for all of August 2003 until mid-September 2003 when precipitation events became more frequent. October 2003 was significantly above-normal for rainfall. During this period of time the piezometers exhibited evidence of soil saturation. The water in the piezometers froze by early December 2003 and the ice persisted through March 2004 and into April 2004 for some piezometers.

Figure 4. Temporal trends in relative water levels in the piezometers.



Shallow Groundwater Chemistry

Sufficient groundwater was present in a majority of the piezometers for sampling on September 30, October 8, and November 30, 2003. Samples collected in September and October were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, pH, and total dissolved organic carbon. Some samples were of insufficient volume for all analytes, so nitrogen species was given a priority. The samples collected in November were analyzed for nitrite-N, nitrate-N, and total dissolved nitrogen only.

Nitrogen species were detected in all samples. Results are summarized in Table 2. Nitrate-N was the dominant species, accounting for over 90 per cent of the total nitrogen. Detected concentrations ranged from 0.2 to 91 mg/L, significantly above drinking water limits. Nitrite-N was also detected in concentrations ranging from <0.002 to 7 mg/L. Ammonia-N was detected in only three piezometers in concentrations ranging from 0.1 to 9 mg/L.

The occurrence of nitrogen species in the shallow groundwater exhibited a strong spatial relationship to the biosolids stockpiles (lysimeter plot on bare ground or the leachate discharge zone for the lined cells). The greatest concentrations were found in piezometer W2, followed by W3, W4, and W5. The more distant points, W1 and W6, had the lowest concentrations. The relative concentrations of the nitrogen species varied by sample location in an irregular manner (Figure 5). There are insufficient data to explain these differences.

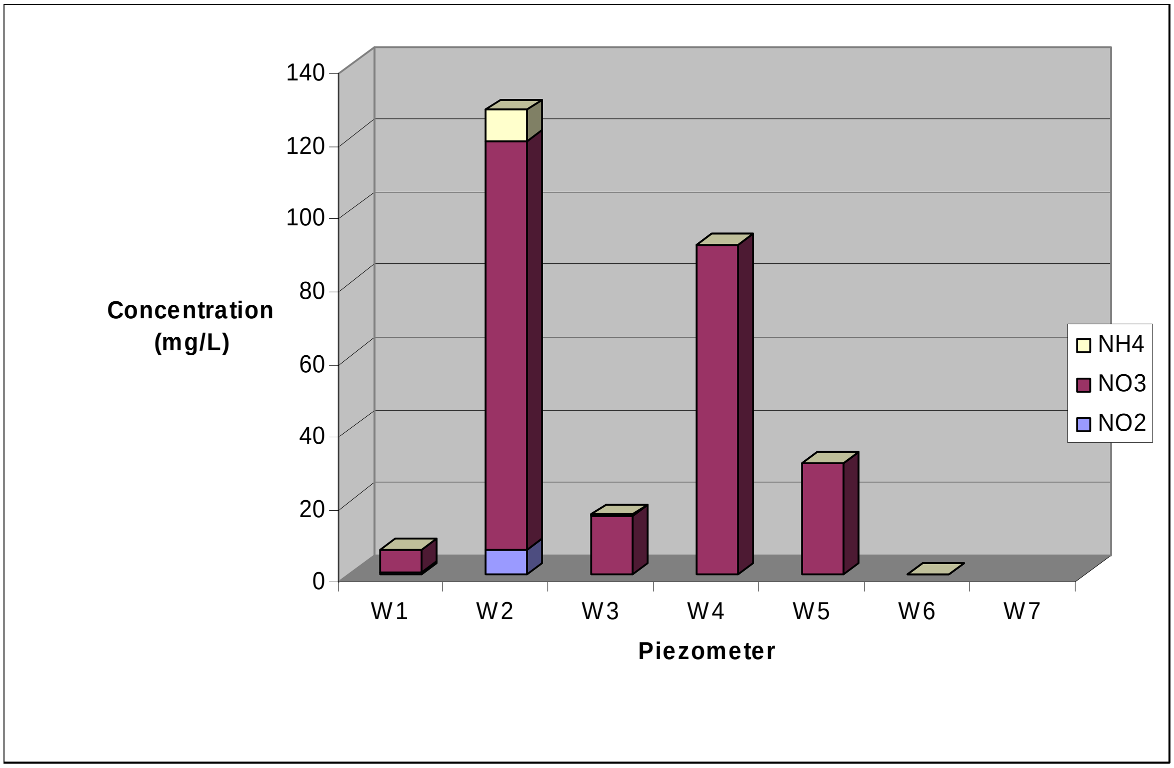
Table 2. Analytical results for the piezometers.

NO2-N	Station	9/30/2003	10/8/2003	11/30/2003	T-N	Station	9/30/2003	10/8/2003	11/30/2003
mg/L	1	0.795	0.135	0.010	mg/L	1	8.016	5.056	
	2	6.992	4.518	1.866		2	126.2	101	
	3	0.152	0.139	0.019		3	17.04	16.69	
	4	0.019		0.007		4	88.88		
	5	0.021		0.485		5			
	6	<0.009	<0.009	0.006		6	0.235	1.088	
	7			0.018		7			
NO3-N	Station	9/30/2003	10/8/2003	11/30/2003	TOC	Station	9/30/2003	10/8/2003	
mg/L	1	6.018	4.929	0.381	mg/L	1	4.58	3.98	
	2	112.1	85.98	46.14		2	9.94	7.53	
	3	16.02	16.75	24.36		3	5.12	4.00	
	4	90.74		20.61		4	4.61	2.83	
	5	30.66		18.82		5		3.76	
	6	0.224	1.082	0.336		6	1.32	1.33	
	7			7.83		7		10.77	
NH4-N	Station	9/30/2003	10/8/2003	11/30/2003					
mg/L	1	0.173	0.075						
	2	8.616	5.224						
	3	0.269	0.236						
	4	<0.05							
	5	<0.05							
	6	<0.05	<0.05						
	7								

Lysimeters. This summary includes results from the biosolids stockpile study (Peckenham, 2004). The results for the lysimeter plot must be interpreted carefully. This is because the soils had to be disturbed to install the pans. The natural soil structures were unavoidably changed. The results from the lysimeter samples exhibited two important characteristics: 1) leachate composition varied markedly within a given depth range, and 2) nitrogen species concentrations were significantly attenuated below two feet. The samples from the lysimeters were also very dark brown in the shallow samples and almost clear in the deep samples. However, some deep samples were colored, reflecting differential flow paths from the surface. Ammonium dominated the other nitrogen species. The concentrations detected exhibited marked variability at each sampling depth. This is interpreted to reflect preferred flow paths through the soil.

Overall the concentrations of TKN increased from one to two feet and then declined markedly from two to three feet (Figure 6). The differences in TKN by depth were statistically significant (ANOVA, $p<0.001$). These results imply that overall, nitrogen species are strongly attenuated through the soil column, and particularly between two and three feet. It is apparent that the leachate presents an elevated oxygen demand on the

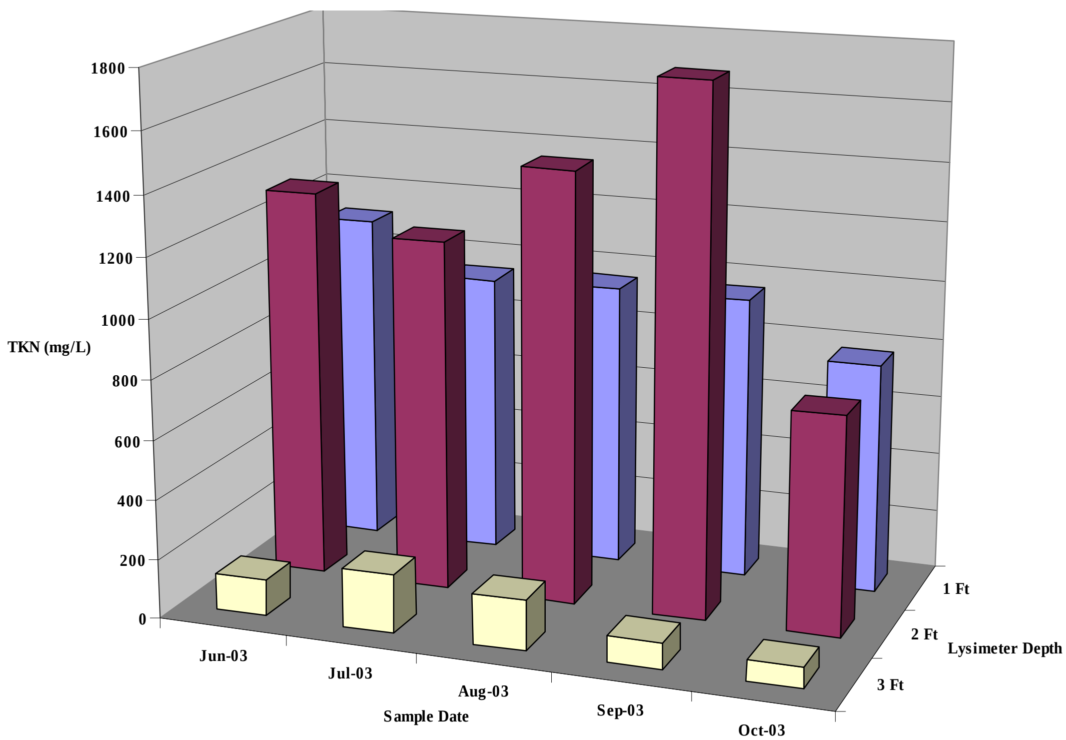
Figure 5. Nitrogen species concentrations in the piezometers. Point W2 is near the discharge from the long pile and point W4 is near the lysimeter stockpile.



At the one-foot depth ammonium-N accounts for 87% of the TKN, but this specie only is 78% of TKN at two-feet and 71% at three-feet. Although nitrate-N and nitrite-N increase with depth of sample, they are not sufficient volumetrically to compensate for the relative decrease of ammonium-N. This means that there is a relative increase in the proportion of organic nitrogen with depth.

Time-series trends for sampling depths exhibited different trends. The one-foot depth, although having high ammonium-N concentrations had slightly decreasing concentrations between June and October. At the two-foot depth, ammonium-N increased consistently from June to September, and then decreased by over 50% in October. At the three-foot depth, ammonium-N concentrations were only 10% of the values at two-feet. The concentrations increased from June to August then decreased from September to October. These results are intriguing because the input is nearly a constant concentration but the soil processes cause marked variations in nitrogen species concentrations.

Figure 6. Variations in total kjeldahl nitrogen in lysimeter samples.



Summary

The data collected to data suggest that nitrogen species are converted from ammonium-N to nitrate-N while moving through the soil under unsaturated to saturated conditions. The overall concentration of nitrogen species appear to be attenuated approximately by one order of magnitude for each vertical meter. Horizontal decreases must be occurring but can not be quantified with available data. Although leachate concentrations of nitrogen are high as a point load, attenuation through the soil column provides some protection to groundwater quality in shallow groundwater. Additional work is needed to assess deep groundwater.

Reference:

Peckenham, J. M. (2004). Maine Biosolids Stockpiling Study Project Report, Report to the Maine Depart. Env. Prot., 39 p.

Students Supported:

James Nadeau, M.S. Civil and Environmental Engineering, basis of Master's research project.

Jennifer Wilson, Ph.D., Ecology and Environmental Science, supporting thesis research for 2 semester (no longer a student at the University).

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