EFFECTS OF BIOSOLIDS APPLICATION ON GROUND WATER NITRATE-N LEVELS IN SAND AND GRAVEL MINE RECLAMATION IN VIRGINIA[1]

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Abstract. Sand and gravel mine reclamation in eastern Virginia is hampered by low mine soil water holding capacity and fertility levels. Application of biosolids at higher than agronomic rates has been recommended for these areas, but agency concerns over the potential for NO_3-N leaching to shallow ground water persist. In the fall of 1998 and the spring of 1999, a mixture of two different biosolids was applied to a 20-ha reclaimed site in the Virginia Coastal Plain at various rates ranging from 1.5 to 5x the agronomic N rate for corn (*Zea mays*). By the end of the 2000 growing season, the majority of the biosolids treated areas supported at least 90% vegetative cover, and most of the area supported 100% ground cover, with average standing biomass > 5 Mg/ha. Nitrate-N levels remained low in all wells within the treated areas over the winter/spring/summer of 1998/1999, indicating that a mixed application of two biosolids materials to the majority of the site had little effect on ground water with regard to NO_3-N. Of 13 monitoring wells under and downgradient of the application areas, only three showed any significant treatment effects, and all levels dropped to < 2 mg/L by the spring of 2001. Nitrate-N levels in several wells directly adjacent to an area receiving a 3x agronomic rate application of lime-stabilized biosolids slowly began to increase in the fall of 1999, peaked at 50 mg/L in late winter/early spring of 2000, and then dropped below drinking water standard levels (10 mg/L) by May, 2000. Neither the surface water within the site nor two external downgradient wells adjacent to the Mattaponi River showed any elevation in NO_3-N levels through the late winter of 2001. Significant background levels of NO_3-N appeared to be entering the site via ground water flow from an adjacent agricultural field. Overall, these data support earlier findings that while application of biosolids at higher than agronomic rates will lead to an ephemeral (first winter) leaching loss of NO_3-N, that the impact to ground water is highly localized, small in magnitude, and relatively short lived.

Additional Key Words: Water quality, nitrogen leaching, sewage sludge.

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Introduction

Municipal wastewater treatment biosolids are commonly applied to surface mined lands as soil amendments to enhance organic matter, nutrient pools, water holding capacity, and overall long-term soil productivity (Haering et al., 2000). Applications of biosolids in conventional farm management scenarios are typically governed by the "agronomic rate" that supplies only the amount of N needed by the subsequently grown crop. Higher than agronomic rates (ranging from 50 to > 200 Mg/ha) of biosolids are commonly applied in mined land reclamation scenarios (Sopper, 1993) under the assumption that NO_3-N losses to ground-water will have minimal long term negative effects from one-time application. The USEPA 503 biosolids rules (USEPA, 1995) and resultant state regulations recognized the need for higher than agronomic rate biosolids applications to mined lands. The underlying assumptions were (1) that biosolids would only be applied once at the higher rate and (2) that NO_3-N leaching losses would be expected, but would not seriously degrade ground-water quality with a one-time application. Detailed research studies in Pennsylvania (Carello, 1990; Sopper and Seaker, 1990) and Virginia (Daniels and Haering, 1994) concluded that application of higher than agronomic rates of various biosolids products to coal mined lands had little, if any, short- or long-term effects on ground water NO_3-N levels under application areas or at permitted surface water discharge points. Significant NO_3-N leaching following heavy biosolids applications to forest lands on gravelly coarse-textured soils in the Pacific Northwest has been reported by Riekirk (1978, 1981), but the observed effects were ephemeral, largely limited to the first two winters after application.

In 1995, the State of Virginia Dept. of Mines, Minerals, and Energy developed guidelines for the application of biosolids to coal mined lands (VDMME, 1995) with Virginia Tech's assistance. These guidelines capped loading rates at 75 Mg/ha (dry) for biosolids cake and at 115 Mg/ha when the C:N ratio of the applied product was 25:1 or greater. However, the application of higher than agronomic rates of biosolids to very gravelly and coarse-textured mine soils with shallow ground water regimes within the Chesapeake Bay watershed raised significant regulatory concerns with regard to long-term effects on nutrient loadings to ground water.

In response to the regulatory concerns expressed above, we implemented an experimental program at Shirley Plantation in Charles City County, Virginia (Daniels et al., 2001). At Shirley, we evaluated a range of biosolids loading rates (1x to 7x) agronomic rate of 14 Mg/ha with and without added sawdust (to adjust the applied C:N ratio to approximately 20:1) on a reclaimed gravel mined soil and an undisturbed prime farmland soil for three growing seasons. The two experimental blocks were cropped to corn (*Zea mays*) in 1996, and winter wheat (*Triticum aestivum*) and soybeans (*Glycine max*) in 1997. Root zone leachates were collected from zero-tension lysimeters under adjacent micro-plots. Effects of biosolids loading rate on crop yields were not as pronounced as expected due to relatively wet weather. Leachate NO_3-N over the winter of 96/97 increased incrementally (from < 20 to > 100 mg L^{-1}) with loading rate (1x to 7x) and then declined sharply in March and April of 1997, finally approaching control level concentrations through the winter of 1997/1998 and beyond. Addition of sawdust significantly decreased NO_3-N leachate levels at all biosolids loading rates except the 5x biosolids + sawdust treatment which exhibited a first winter spike in excess of 100 mg L^{-1}. Four shallow wells surrounding the 10-ha experimental plot area indicated no net effects of the experimental block on NO_3-N levels in shallow (< 2 m) ground water. Overall, these data clearly indicated that higher than agronomic loading rates of biosolids lead to enhanced NO_3-N leaching potentials over the first winter following application. However, we concluded that this "one-time event" supported the original USEPA presumption that while some net leaching under elevated loading rates is to be expected, it is a short-term effect.

When the results of the Shirley Plantation experimental program were presented to Virginia regulators, they were generally accepted, but concerns were still raised by the Department of Conservation and Recreation (DCR) Nutrient Management Program. In particular, DCR expressed concerns that (1) our zero-tension lysimeter data could not be readily extrapolated to estimate actual field-scale ground water effects, and (2) that our shallow ground water monitoring locations at Shirley were insufficient. An additional complication came from the fact that the mine soils studied at Shirley were highly productive due to the return of up to 1 m of loamy native soil materials, and were managed in row-crop production rather than the mixed grass/legume species more typical of sand and gravel mining operations in Virginia. Therefore, this research program was conducted to specifically determine the water quality effects of operational-scale higher than agronomic rate land application of biosolids to sand and gravel mines in Virginia. Additionally, this study was conducted on a site reclaimed with minimal soil cover and conventional grass/legume revegetation species.

Methods and Materials

This research project was carried out on a minimally reclaimed sand and gravel mining site in eastern King William County, Virginia (N37^{o} 50.1' W77^{o} 7.6'), immediately adjacent to the Mattaponi River. From this site, Aylett Sand & Gravel Inc. mined approximately 5 m of the Late Pleistocene sand and gravel unit (Tabb Formation) that overlies thick compact fine-grained sediments of the upper Tertiary Chesapeake Group (Mixon et al., 1989). Little if any native soil materials were salvaged, and the mixed overburden spoils were replaced back over the intact and compact Chesapeake Group sediments. The 20-ha site (Fig. 1), is comprised primarily of gently rolling regraded uplands which slope down to a series of central inter-fingered open water ponds. Several wetter seeps and perched wetlands (presumably above compacted zones) do occur within the reclaimed uplands. Final grading was completed in 1997 and several revegetation efforts utilizing conventional fertilization and seeding practices failed to produce more than 10 to 25% living vegetative cover across the majority of the site. The area immediately to the west of the mine has been managed in intensive row-crop production for over 100 years, while the areas north and south are wooded. The vast majority of the mine soils were gravelly to very gravelly sands and sandy loams, strongly acidic and highly variable in extractable nutrients (Table 1). We assumed that revegetation success here was being directly limited by soil acidity and lack of water holding capacity, with fertility posing a secondary limitation.

Based upon our previous work discussed earlier, we designed a soil amendment strategy for this site utilizing a mixture of two different biosolids products to (1) supply adequate organic matter amendment, (2) limit excessive NO_3-N leaching potentials and (3) simultaneously provide adequate lime to buffer soil pH above 6.0 for long periods of time. The two materials utilized were Blue Plains lime-stabilized biosolids from Washington D.C. and Zimpro^{tm} processed biosolids from the Passaic Valley Sewerage Commissioners (PVSC) plant in Newark, New Jersey (Table 2). The Blue Plains material was approximately 28% calcium carbonate equivalent (CCE) when applied and is relatively high in total and plant-available N and P. The PVSC material is heat/pressure treated, and as a result is higher in solids and C:N ratio than Blue Plains. Both products easily meet USEPA 503 Class B standards for land application (USEPA, 1995). Previous unpublished work by our group has shown that the PVSC materials have much lower N-mineralization potentials than Blue Plains, which presumably would limit NO_3 leaching potentials when mixed with the Blue Plains product at higher than normal agronomic loading rates.

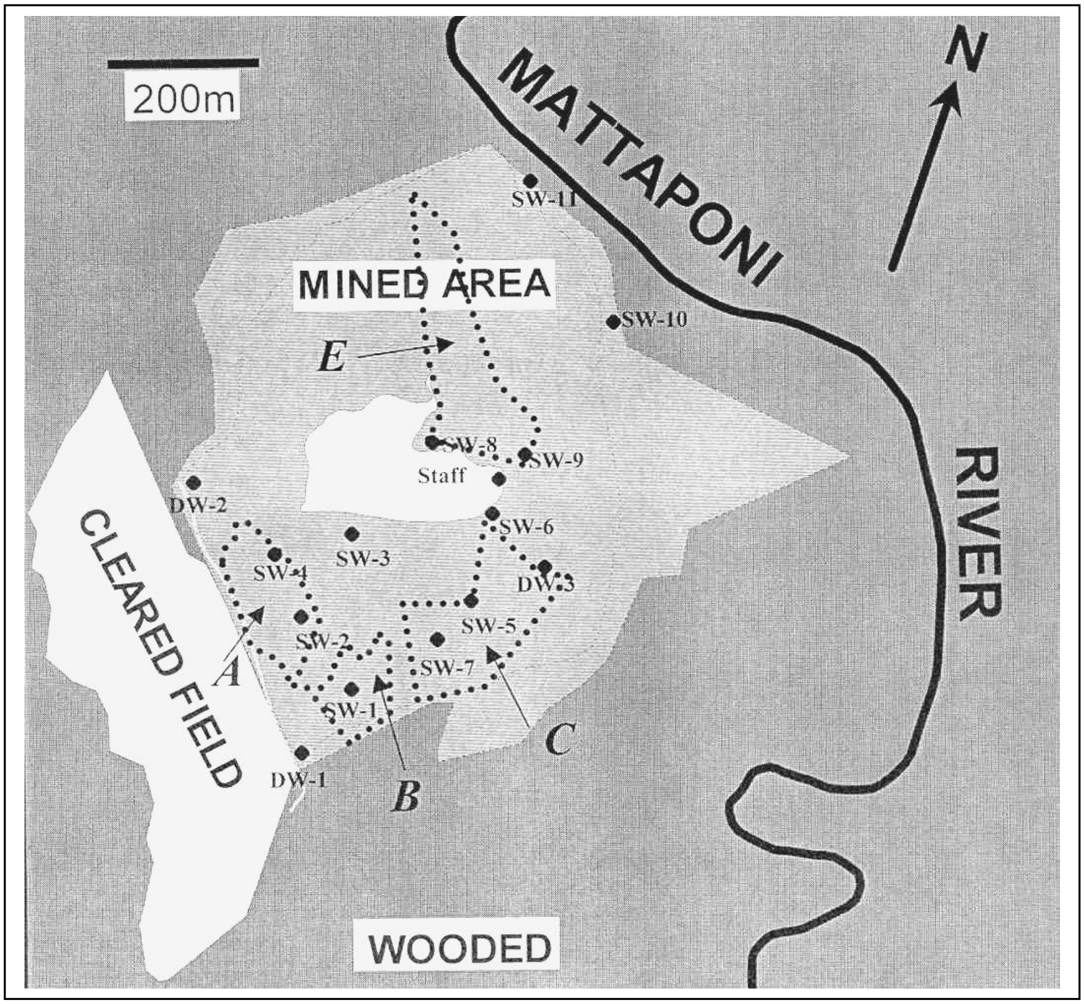

Figure 1: General map of Aylett Sand & Gravel land application site showing monitoring well locations and treatment cells. Cells A, B, and C received higher than agronomic rates of Blue Plains biosolids in the spring of 1999. The rest of the mined area received a mixture of Blue Plains and PVSC biosolids in the fall of 1998.

Table 1. Soil chemical properties from samples taken at Aylett Sand and Gravel prior to biosolids application on March 3, 1999, and standing biomass and soil chemical properties in the fall of 1999 and 2000.

		Biomass	NO_3-Soil	pH	P	K	Ca	Mg	Zn	Mn	Cu
Area	# obs.	Mg/ha	mg/kg		------------mg/kg Dilute Acid Extractable-----------						
	Sampled 3/3/99										
A	n=2			5.1	63	16	229	66	0.59	4.45	0.13
C	n=2			4.9	6.0	57	247	54	1.57	7.45	0.18
Adjac. Control	n=2			6.4	27	37	553	41	2.92	4.86	0.99
	Sampled 10/5/99										
A	n=5	2.55	82	7.23	93	33	2180	95	5.04	18.04	1.41
B	n=5	4.91	66	6.60	71	20	1522	78	2.25	4.61	1.00
C	n=5	5.92	122	6.35	59	51	2741	73	4.83	10.49	1.13
E	n=5	3.04	141	7.30	136	31	2894	85	13.76	15.62	1.91
	Sampled 10/10/00										
A	n=5	5.98	ND	6.48	80	29	1133	78	1.89	6.19	0.79
B	n=5	4.75	ND	7.48	85	34	2134	100	3.36	8.11	1.36
C	n=5	6.97	ND	5.53	65	61	1056	65	2.22	5.94	0.86
E	n=5	5.99	ND	7.00	191	25	2538	83	26.91	13.89	1.78

For areas A, B, & C, Blue Plains biosolids were applied in the spring 1999; Area E Blue Plains and PVSC biosolids were applied in the fall 1998.

Table 2. Blue Plains Biosolids and PVSC (Zimpro) analysis report summaries for materials applied at the Aylett Sand and gravel site in fall 1998 and spring 1999.

	Section A	Section B	Section C	PVSC
	--------------------------------------%		--------------------------------	
Solids	24.2	24.5	26.6	54.2
Nitrogen (TKN)	4.2	4.1	4.1	1.5
Ammonia-Nitrogen	0.4	0.2	0.4	ND
Organic Nitrogen	3.8	3.9	3.7	1.5
Total Organic Carbon	35.2	34.4	35.1	22.4
C/N ratio	8.5	8.5	8.6	14.5

A detailed water quality monitoring network was installed at the site over the summer of 1998, and was monitored monthly for water level, NO_3-N, NH_4-N, pH and electrical conductance (EC) through January, 2001. Sampling locations included a number of wells within (SW 1-10; DW 3) the treated area, just outside (DW 1 and 2) of the mined area, and two locations (SW 10 and 11) beyond the mining permit dike next to the Mattaponi River. We also collected surface water grab samples from the staff gauge and discharge pipe near (SW 10) from the mining pit ponds as indicated in Fig. 1. This central pond was surrounded and recharged by biosolids treated lands. At all shallow well (e.g. SW-1) locations, our nested wells were installed at two depths. One well was installed as a 1.0 m piezometer (open in lower 25 cm) to sample the pore waters from the upper portion of the water table in the coarse-textured gravelly sand mining spoil, while a deeper well was screened from approximately -0.5 m to a depth of approximately 2.5 m, through to the dense blue-gray silty material that underlies the mined profile. Our presumption was that the seasonal winter water table would more than likely "perch" over the denser undisturbed subsurface and this monitoring design would allow us to capture any shallow NO_3-N plume that deeper fully open wells might dilute. Several deeper well clusters (DW 1 etc.) were also installed where the deeper open screened well was extended to a depth of approximately 4 m. All wells were constructed of commercial PVC pipe and well screen, sand filter packed, and bentonite sealed at the surface. Monthly samples were collected following well purging and analyzed in the field for pH and EC. Sample splits were chilled and then immediately shipped to and analyzed in our labs in Blacksburg for NO_3- and NH_4-N. Water quality sampling locations are shown in Fig. 1.

Between October 1998 and May 1999, essentially all areas within the road boundary shown in Fig. 1 were treated with biosolids, with the exception of 5-m buffers adjacent to open water or ditches, and a small well-vegetated area in the NW corner of the mine. First, in the fall of 1998, a mixture of Zimpro^{tm} processed PVSC biosolids and Blue Plains lime stabilized biosolids was applied to the majority of the site (except Areas A, B and C in Fig. 1) at an average loading rate of 78 Mg of PVSC and 34 Mg of Blue Plains per ha. This application was based upon detailed mined land mapping for suitability and the concept that the presumably higher C:N ratio of the PVSC materials would offset potential NO_3-N leaching. We estimated that this mixture would supply 1.5 x the agronomic rate of plant available N for corn. The fall 1998 treated areas were seeded to cereal rye (*Secale cereale*) tall fescue (*Festuca arundinaceae*), birdsfoot trefoil (*Lotus Corniculatus*), and Korean lespedeza (*Lespedeza stipulaceae*) in November, 1998. The following April (1999), treatment cells A and B (West of wells SW 1, 2, and 4) were treated with a 3x agronomic rate (x = 15 Mg/ha for corn) of Blue Plains biosolids while treatment cell C (East and adjacent to wells SW 5, 6, and 7, and DW 3) received a 5x agronomic rate of the Blue Plains material. These areas were immediately seeded to German millet (*Setaria italica*) and the same mixture of perennial grasses and legumes used in the fall 1998 seeding. All biosolids were chisel-plowed within 48 h, disked, and then broadcast seeded. Thus, while the majority of the site received an overall application of biosolids, the two areas which presumably presented the highest NO_3-N leaching risk were the three cells treated in the spring of 1999.

Standing biomass was estimated at five random 1 m^2 quadrats within each treatment cell (A, B, C) and a combined Blue Plains/PVSC area (E) in October of 1999 and 2000. Soil samples were taken from 0-15 cm beneath each sampling quadrat and analyzed for pH, and dilute double acid extractable P, K, Ca, Mg, Zn, Mn, Fe, Al, Cu and B by the Virginia Tech Extension Soil Testing Laboratory (Donohue and Heckendorn, 1994). Extractable NO_3-N was also run on the fall 1999 sample set. Similar analyses were run on a set of pre-application soils from areas A and C and the adjacent agricultural field sampled in March, 1999.

Results and Discussion

The combined 1998 and 1999 growing seasons were some of the driest on record in Virginia. This certainly affected vegetation establishment and vigor in the fall of 1998 and subsequently over the 1999 growing season. Regardless, by the end of the 2000 growing season, the majority of the biosolids treated areas supported at least 90% vegetative cover, and most of the area supported 100% ground cover. This cover was a mixture of intended (seeded) and invasive weedy species, however. Standing biomass ranged from 2.5 to 5.9 Mg/ha in the fall of 1999, and from 5.8 to 6.9 Mg/ha in the fall of 2000 (Table 1). The use of lime-stabilized biosolids was effective at raising soil pH to acceptable levels and produced expected increases in extractable nutrients and organic matter. Previous work by our group (Haering et al., 2000) indicates that these soil-building benefits will be long lived.

A hydrologic evaluation of the ground water data sets was performed for all months, and the estimated late summer ground water gradients are presented in Fig. 2. Seasonal water levels in upland wells generally fluctuated from less than -1.0 m during the late winter and early spring to -2.0 to -3.0 m in late summer/early fall. In general, ground water appears to flow from higher potentiometric levels under the agricultural field to the west of the site and under areas A and B, eventually recharging the pond in the center of the site. Groundwater from the southwest corner of the site (near DW-1) appears to flow under areas B and C and then toward the Mattaponi River. Both DW-1 and DW-2 are clearly upgradient from biosolids treated areas (Fig. 2). The ground water flow regime was also evaluated for early spring (March, 1999) conditions, and the overall estimated flow regime was quite similar to that shown in Fig. 1. The surface water in the central pond shown in Figs. 1 and 2 is interconnected with smaller ponded areas that become continuous and discharge via a drop inlet at high water conditions in late spring. Thus, analysis of surface waters sampled at both the staff gauge and outlet pipe sampling locations presumably reflected whether or not the land application of biosolids to the uplands significantly affected ground waters recharging the ponds along with any run off additions.

Ammonium-N levels in ground and surface waters sampled through the late winter of 2001 showed no treatment effects, and EC levels generally mirrored changes in NO_3-N concentrations, so the balance of our discussion will focus upon observed NO_3-N variations over time. In general, ground-water NO_3-N levels before treatment (summer/fall 1998) were low (< 1 mg/L). However, significant levels were detected at locations DW 1 and 2, presumably derived from the adjacent rowcrop land upgradient from these wells (Fig. 2). In general, NO_3-N varied between 5 and 10 mg/L throughout the duration of the study at location DW-2 (see Fig. 3), indicating significant background NO_3-N moving into and under the site from the adjacent agricultural lands. Similar, but lower, NO_3-N concentrations were observed at DW-1 throughout the study. Nitrate-N levels remained low (< 2 mg/L) in all wells within and downgradient of the treated areas over the winter/spring/summer of 1998/1999, indicating that the mixed application of PVSC/Blue Plains materials to the majority of the site had little effect on ground water with regard to NO_3-N. A relatively minor increase (to less than 10 mg/L) was noted at well location SW 8 over the winter of 1999/2000 (Fig. 4), which appears to have been related to local grading disturbance of the surface soil by the mining company in the summer of 1999. Nitrate-N levels in two wells (SW 1 and 3) directly adjacent and downgradient to areas receiving the 3X application of Blue Plains biosolids slowly began to increase in the fall of 1999, peaked around 40 to 50 mg/L in late winter/early spring of 2000 (Fig. 5), dropped under drinking water standard levels (10 mg/L) by May 2000, and subsequently remained < 2 mg/L through the winter of 2001.

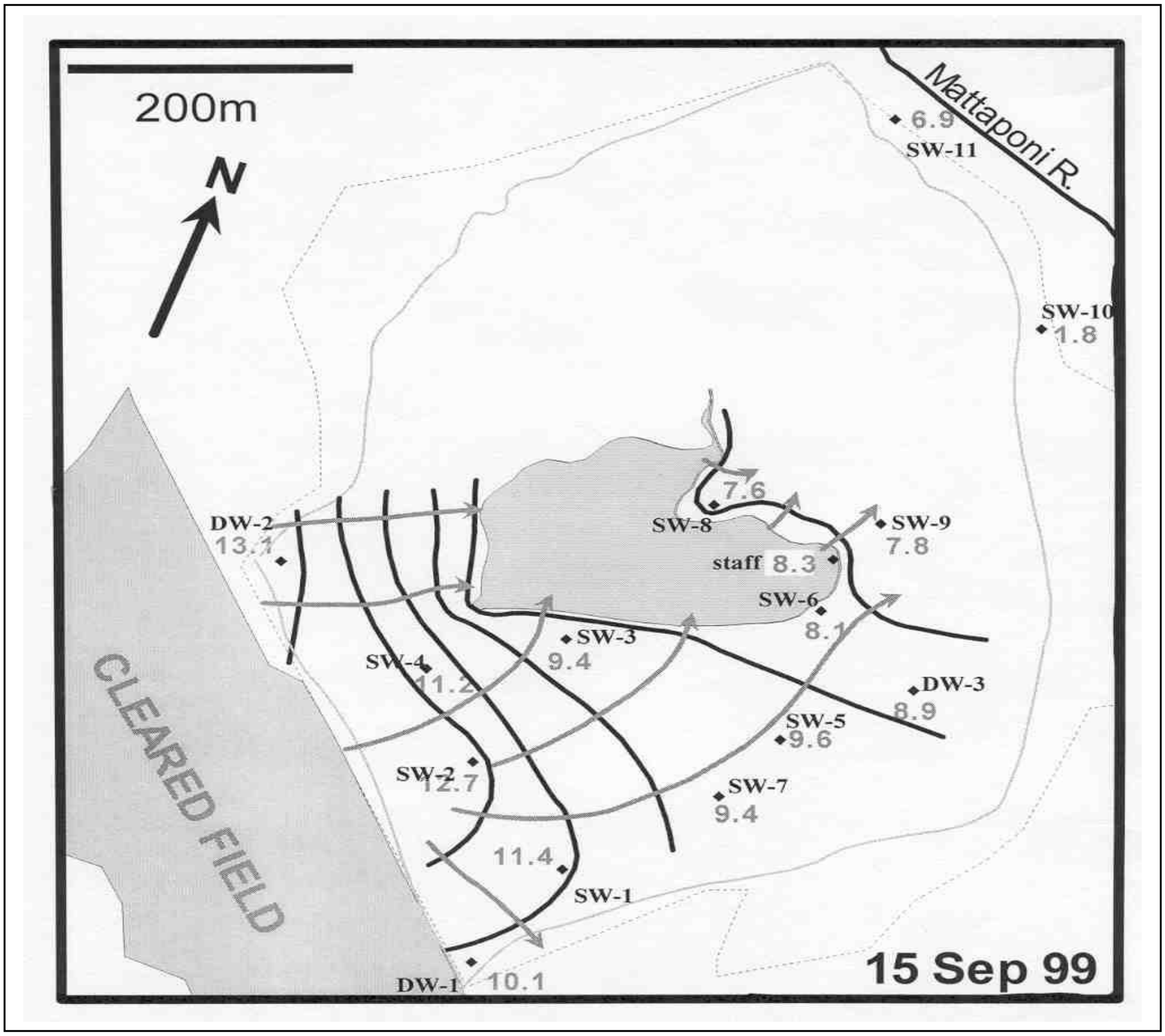

Figure 2: Ground water gradient map for site in September 1999. Ground water generally flowed from west to east, under biosolids treated areas, into the central pond, and towards the Mattaponi River.

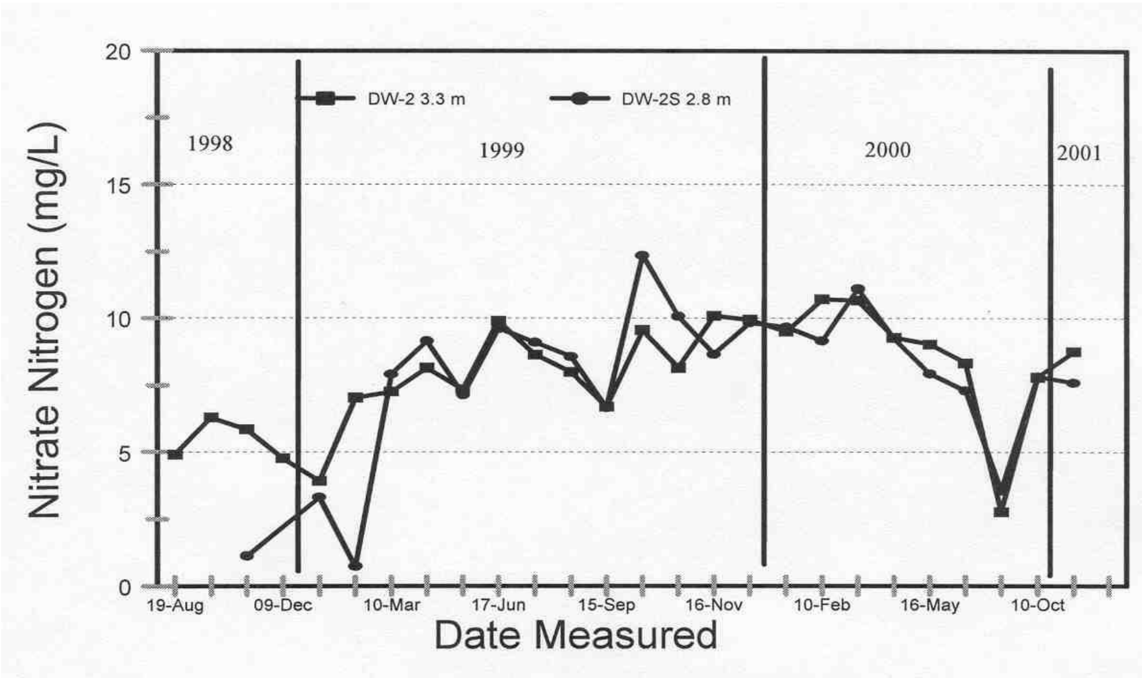

Figure 3. Nitrate-N concentrations at deep well 2. This well was located upgradient from all areas receiving biosolids. Elevated NO_3-N is presumably due to adjacent agriculture.

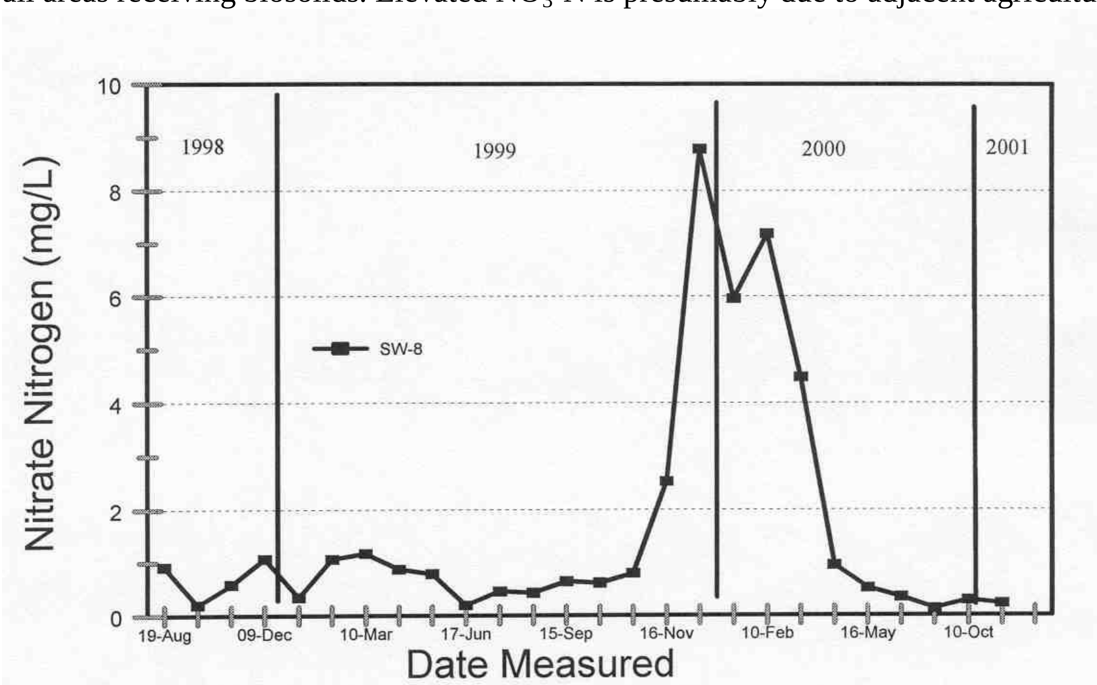

Figure 4: Nitrate-N levels in ground water at monitoring location SW-8. Biosolids were applied to the uplands around this well in the fall of 1998, but no effects were seen over the winter of 1999 as expected. However, the surface mine soil immediately above the well were disturbed by grading in mid-summer 1999, presumably leading to the limited NO_3-N release seen the following winter.

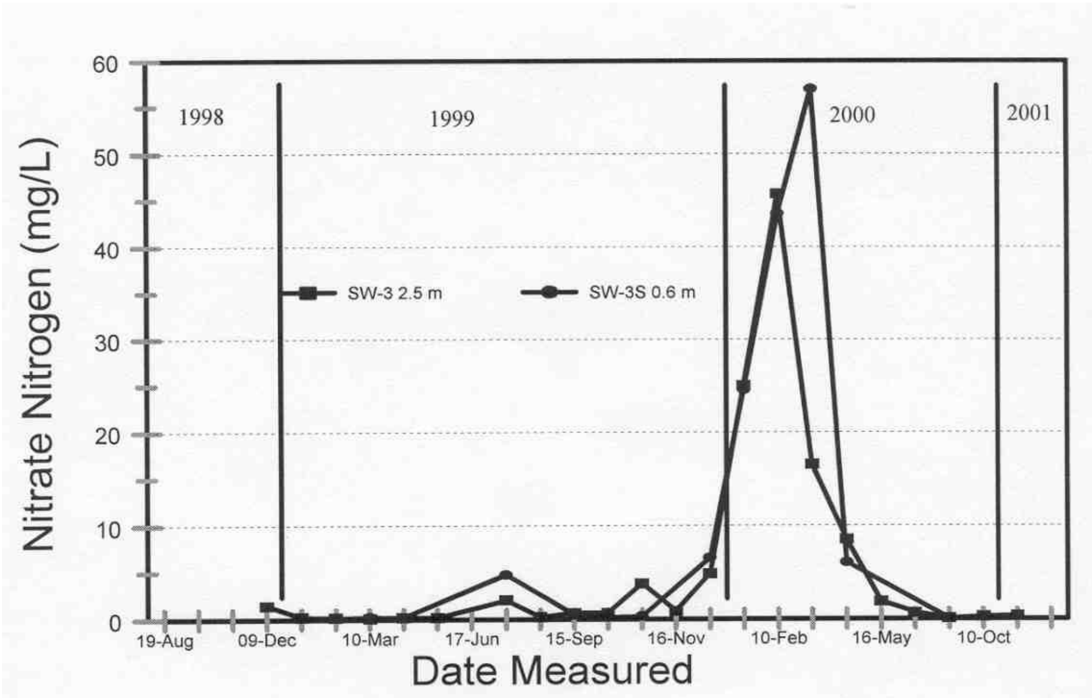

Figure 5: Nitrate-N levels in ground water at monitoring well nest SW-3. Lime stabilized biosolids were applied at higher than agronomic rate (3x) in April, 1999. Nitrate-N levels in the shallow well (0.6 m) were only slightly more concentrated than in the open well, which sampled ground water from 1.0 to 2.5 m, indicating that the N leachate plume was relatively well mixed. These were the maximum NO_3-N levels detected in thirteen wells, and only three wells showed any elevation of NO_3-N during the three-year study period.

It is important to point out that none of the wells adjacent to (SW 5, 6) or actually within (SW 7) the 5x treated zone indicated significant movement of NO_3-N, and several wells (SW 2 and 4) directly adjacent to the 3x cell also showed no effect. Similarly, neither the surface water within the site, the pond discharge, nor the external wells adjacent to the Mattaponi River showed any elevation in NO_3-N levels over this period of time. The lack of any NO_3-N response in the pond waters indicates that either the total NO_3-N mass loading to the pond via local ground-water discharge is quite low, or that denitrification mechanisms around the pond/mine soil border are quite effective. The reasons why certain wells appeared to intercept the first winter after application NO_3-N leaching event while others did not is not clear. Overall, of the 11 well clusters installed within the treated mining area boundary, only three showed significant NO_3-N elevations, even though the vast majority of them were either directly under or downgradient from biosolids treated areas. It is possible that those wells showing higher NO_3-N levels may have intercepted much coarser textured zones of the mining backfill that connected directly to the surface treated zones. We also know that the surface soil in and around the 5X loading rate cell (C) had an overall wetter soil moisture regime, which may have enhanced denitrification losses there relative to the 3X loading rate cell. Overall, it does appear that NO_3-N leaching potentials across a site such as this are quite diverse spatially, varying with local differences in soil wetness/redox, texture and permeability, biomass N uptake, and other unknown factors.

Overall, this apparently localized and seasonal NO_3-N leaching behavior (first winter flush followed by return to lower levels) is very similar to that observed in our shallow root zone lysimeters at Shirley Plantation (Daniels et al., 2001) in a precursor experiment, but the NO_3-N levels observed in the several affected wells at this location (Aylett) were considerably lower (50 to 90%) in peak concentrations. These data do not appear to indicate any significant difference in NO_3-N losses between the 3x and 5x applications, although the limited number of affected wells obviously complicates this differential conclusion.

Summary and Conclusions

Overall, these data support our earlier findings that while application of biosolids at higher than agronomic rates will lead to an ephemeral (first winter) leaching loss of NO_3-N, that the impact to ground water is highly localized, small in magnitude, and relatively short lived. It also appears that the fall, 1998, application of the PVSC/Blue Plains treatment had little effect on ground water NO_3-N levels. Both treatments significantly improved revegetation success at the site compared to previous conventional strategies. It is also important to point out that due to the extremely poor 1999 growing season, vegetation biomass yield and associated N-uptake were strongly curtailed, which more than likely led to more NO_3-N being available for leaching at the close of the 1999 growing season that would be the case in a normal year. We believe that the soil/site conditions encountered at Aylett of a very gravelly/sandy and thin mine soil lying over a semi-confining dense silty layer generated worse case leaching conditions which were further multiplied by the poor vegetative response associated with the drought of 1999. Continued monitoring of water quality at this site through the winter of 2001 indicated no long-term water quality degradation from this land application practice and no surface water effects at any point in time.

In our opinion, the use of appropriate rates of stabilized municipal biosolids is one of the best and most economic treatments available to us today for the long-term revegetation of surface mined lands. A sequence of Virginia Tech studies since the early 1980's (Haering et al., 2000) and the overall scientific literature base (Sopper, 1993) clearly support the use of higher than agronomic rates of biosolids with typical mined land loading rates averaging between 50 and 125 Mg/ha (dry). The positive effects of this treatment on rebuilding soils, promoting rapid revegetation, and maintaining long-term soil productivity are very real and obvious to both scientists and reclamation practitioners. However, it is likely that use of higher than agronomic rates will lead to a predictable but small, short-term loss of NO_3-N to ground water. In fairness, it is also important to point out that conventional application of fertilizer-N to these very sandy soils would more than likely lead to a one-time loss of NO_3-N to ground-water, without the long-term soil building benefits of the biosolids. The long-term ground water monitoring data for this site also appear to indicate that the background addition of NO_3-N from offsite agricultural sources is significantly greater over time than any short-term effects from reclamation related biosolids utilization.

Acknowledgments

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