An ASABE Meeting Presentation

Paper Number: 06-4048

Water Quality of Deep Row Biosolids Incorporation on a Tree Farm

Carrie U. Buswell, Graduate Student
Biological Resources Engineering,
University of Maryland
College Park, Md 20742-2315

Gary K. Felton, Assoc. Prof.
Biological Resources Engineering,
University of Maryland
College Park, Md 20742-2315
gfelton@umd.edu

Jonathan S. Kays, Senior Agent
Cooperative Extension,
University of Maryland
Keedysville, Md 21756-1104

Eric J. Flamino
ERCO, Inc
Glen Burnie, Md 21061

Written for presentation at the
2006 ASABE Annual International Meeting
Sponsored by ASABE
Oregon Convention Center
Portland, Oregon
9 - 12 July 2006

Abstract ***Deep row biosolids application to grow hybrid poplar trees on sand and gravel mine spoils is a unique and innovative beneficial-use technique that solves many of the conventional problems. The technique has been developed on 49.4 ha (122 ac) site in the Washington, D.C. metro area since 1983 by a private company, ERCO, Inc. Research has been carried out since 2001, and has been combined with long-term monitoring data to develop a better understanding of water quality impacts, operational methods, clonal selection, hybrid poplar growth and nutrition, and the factors affecting economics and profitability. For all wells in the aquifer and aquiclude below the site, nitrate water concentrations were most commonly at or less than detection limits. In the sub-soil immediately beneath the biosolids, there was an overall trend of an increased ammonium concentration with time. The ammonium concentration decreased with depth below the biosolids which suggests that attenuation is occurring as it travels deeper through the soil profile. Given the large acreage of mine spoils in the metro area, deep row application has the potential to utilize significant amounts of biosolids produced in the region.***

Keywords Biosolids, deep row application, incorporation, hybrid poplar trees, nitrate, ammonium, water quality.

INTRODUCTION

The Washington, D.C. and Baltimore, MD metro area produces approximately 1.07 dry Mg (1.2 million wet tons) of biosolids (MDA 2002; DC-WASA 2002). Utilization of biosolids has relied heavily on agricultural land application outside of Maryland (56%), as well as some instate application (9%). The remainder is utilized as follows: hauled out of Maryland (14%); storage (9%); composed (7%); incinerated (3%); and landfill (2%). Stricter nutrient management laws, the loss of agricultural land to development, odor problems, and political concerns of county and state governments requires that sewage treatment authorities find new and innovative methods to beneficially utilize biosolids. Finding methods that can be utilized in Maryland is becoming increasingly important as concerns of surrounding states become prominent.

Deep row incorporation of biosolids on sand and gravel reclamation sites is a unique alternative land application method that solves many of the problems associated with surface application techniques. We have placed biosolids at application rates of 383.3 to 659.1 Mg/ha (171 to 294 dry tons/ac) into deep rows that were 76.2 cm (30 in) deep and 106.7 cm (42 in) wide and spaced approximately 2.4 m (8 ft) on center. The trenches were filled with 45.7 cm (18 in) of biosolids and the remaining 20.3-30.5 cm (8-12 in) of deep rows was filled with overburden, which eliminated odor problems and maintained biosolids in a fairly stable, anaerobic environment.

Developed by ERCO, Inc., deep row incorporation with trees has been commercially used since 1983 on only one site in the world with no adverse water quality impacts – a 49.4 ha (122 ac) gravel spoil in southern Maryland that is within 40 km (25 mi) of many large municipal wastewater treatment plants. Approximately 4 ha (10 ac) were treated each year starting in 1984. The site was then planted with fast-growing, nutrient-demanding hybrid poplar trees, the roots of which provided a natural recycling system that can utilize up to 336-504 kg N/ha (300-450 lbs N/ ac) per year over a six-year or longer period. Harvesting was performed at about 7 years on most sections.

The success of this technique appears to be dependant upon: 1) the presence of clay that impedes vertical leaching while tree roots utilize the nutrients; and/or 2) maintenance of biosolids in an anaerobic condition, minimizing nitrate generation and promoting denitrification.

The objective of the project reported here was to determine the effects of tree density and biosolid application rate on water quality around deep rows on a gravel mine spoil.

METHODOLOGY

SITE DESCRIPTION

The site consists of a plateau with steep banks that fall away to a stream incision. All steep banks are covered with permanent forest cover. The plateau has an upper area (two sections) near the entrance on a 0-2% slope. The remaining seven sections have an elevation drop of between 1.5 and 3 m (5-10 ft), followed by a level section (0-2% slope) to the edge of the area. Prior to any biosolid application, the reclamation site was representative of thousands of acres of sand and gravel mines in the Metro Washington, D.C. area. The research site is an existing reclamation site that has utilized deep row biosolid application with forest trees for 15 years. The entire site has been applied once with biosolids using deep row application. The edges of the plateau are bermed and runoff is routed to one of four detention ponds. The streams on the east and north sides of the site are protected by an additional three detention ponds.

Additionally, the surface water flow on the site is significantly reduced due to the introduction of tree crops.

Geology

There are conventional soils on the steep side slopes that were not disturbed by sand and gravel mining, but there are no soils, as we normally think of them, on the plateau surface. In 1983, the spoil consisted of a clay layer with occasional remnants of sand and gravel and some filled-in gullies. The clay layer was 5.0 to 21.3 m (70 ft) or more thick. Description of geology at the ERCO site was derived from Wilson and Fleck (1990) and, to a lesser extent, Tompkins (1983). Below the surface is the lower Miocene Calvert Formation. The Calvert is a light to medium, olive gray to olive green, micaceous, clayey silt. The thickness of the Calvert in the Waldorf area is about 90 to 100 ft. The formation represents deposition in a marine shelf environment.

At one time there were as many as eight monitoring wells placed around the perimeter of the site. Well placement was a condition of various permits. Wells encountered water at approximately 75 ft. below the surface of the site. This puts the water at the base of the Calvert formation.

Production Treatments

The deep-row technique, developed in 1983, involved the application of biosolids, averaging about 20% solids, that were lightly amended with lime to control odor (but not lime-stabilized), at a rate of 383.3 Mg/ha (171 dry tons/ac.). The pH of the biosolids ranged from 7.0-8.0. Approximately 4.05 ha (10 ac) sections were treated each year beginning in 1984. Hence, only 8-16% of the site is exposed to rainfall and subject to runoff. The deep row dimensions were 762 mm (30 in) deep and 1067 mm (42 in) wide, spaced on or about 2.44 m (8 ft) centers. The deep-rows were filled with 457 mm (18 in) of biosolids for the 383.3 Mg/ha (171 dry tons/ac) rate and 559 mm (22 in) for the 659.1 Mg/ha (294 dry tons/ac) rate. The remaining 200-300 mm was filled with overburden. After each section was filled, the site was leveled using a low-ground pressure bulldozer and disked, in preparation for planting. The application rate used at the tree farm is similar to experimental trenching site applications made from 1974 through 1980 on well-drained, silt loam soils of the Manor and Glenelg soil series (Sikora, et al., 1982). In 1988, the permit allowed for addition of a special demonstration plot with biosolids applied at 659.1 Mg/ha (294 dry tons/ac).

Experimental Treatments

The 3.1-acre study site is located on the existing ERCO property and has previously received one biosolids application. A replicated treatment design was used to determine the effect of three tree densities 0, 717, and 1,063 trees/ha (0, 290, and 430 trees/ac) and three deep row biosolid application rates on water quality and tree production. Unlike past application rates, which were based solely on biosolids weight, the experimental rates will be expressed in kilograms of nitrogen per hectare (11921, 23843, 35764 kg N/ha).

The width of the deep rows was maintained at 1.06 m (42 in) and the depth was adjusted (Table 1) to accommodate the required amount of biosolids and allow for 250-300 mm of cover on top of the biosolids. The distance between deep rows was approximately 2.44 m (8 ft.). The maximum depth of the deep rows is limited by the depth to which the poplar tree roots can reliably grow. If deep row depth exceeds 2.13-2.44 m (7-8 ft), which is likely too deep to be sure that roots can reach the material, some of the same nutrient loss problems discovered by Sikora et al. (1982) could occur.

Table 1. Treatment rates, depth of biosolids in the deep row, total deep row depth, and approximate biosolids application rate.

Application Rate (kg N/ha) *[lbs N/ac]*	Depth of Biosolids (mm) *[in.]*	Total Depth of Deep Row (mm) *[in.]*	Biosolids Rate (Mg/ha) *[dry tons/ac]*
11,921 *[4,000]*	320 *[12.5]*	610 *[24]*	384 *[172]*
23,843 *[8,000]*	640 *[25]*	940 *[37]*	768 *[345]*
35,764 *[12,000]*	95 *[37.5]*	1240 *[49]*	1153 *[517]*

In spring 2002, plots were established at the ERCO site. The site was partitioned into three blocks based on a north-south gradient. Each block contained each biosolids application rate/tree density combination. There were 30 treatments: 3 densities (0,717, 1063 trees/ha), 3 application rates (11921, 23843, 35764 kg N/ha), 3 replicates, and 3 control treatments (no biosolids, no trees). The result was an incomplete split block experimental design. Figure 1 provides a layout of the relative locations of the three blocks and the treatments within each block as they were installed at ERCO. The total area depicted is 1.25 ha (3.1 ac).

Within each treatment the outer two rows of trees around the perimeter were buffered to isolate treatments. The sample collection areas within each treatment consisted of the innermost 16 trees, to reduce possible edge effects. The central area of four rows by four columns of trees contained all soil water sample collection equipment. The three control treatments (no trees, no biosolids) were 10.7 m X 10.7 m with instrumentation in the central portion of the plots.

Biosolids application rates were randomly assigned within each block. Tree plantings were not randomized due to logistical considerations associated with the equipment and labor used.

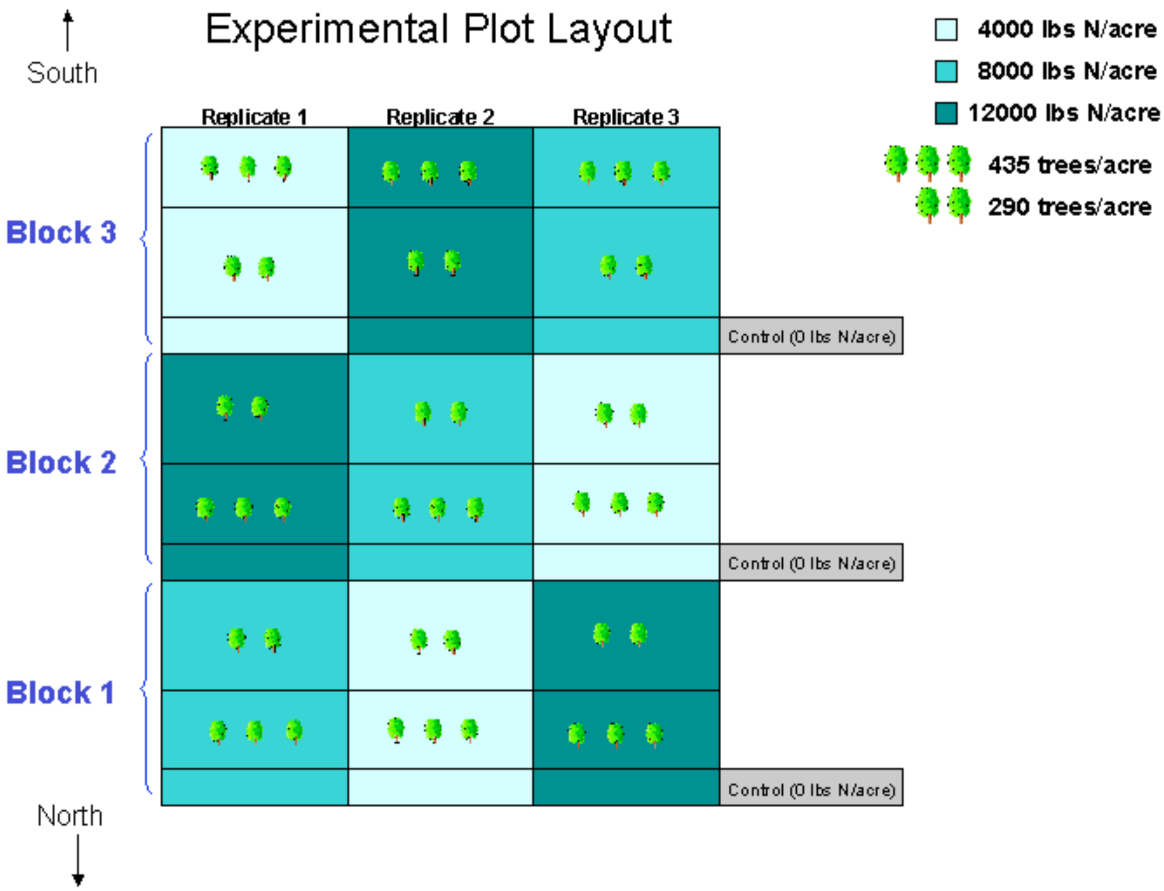

Figure 1. **Schematic layout of treatments.**

WELLS.

Overall water quality in the ground water has been assessed by regular measurement from previously installed groundwater monitoring wells already resident in the top of the Nanjemoy formation, which is the first water supply aquifer beneath the site (Wilson and Fleck, 1990).

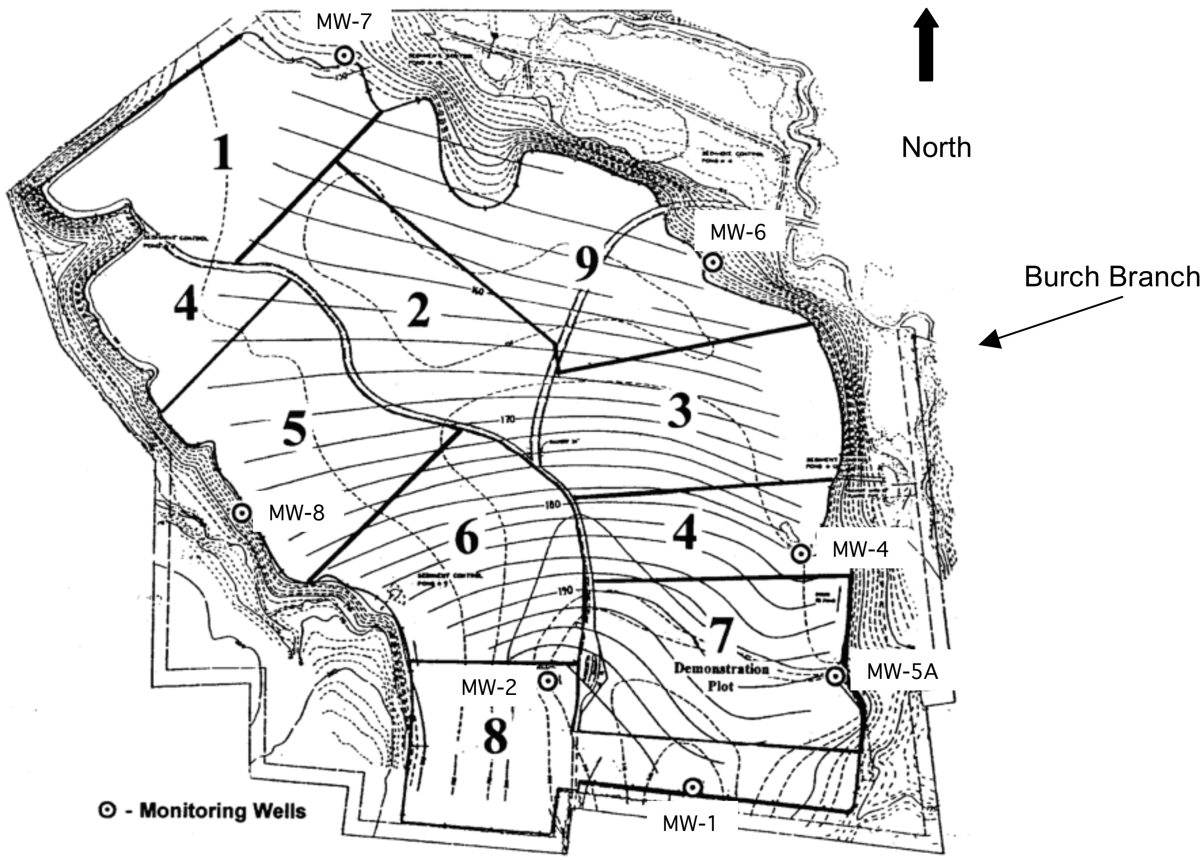

Figure 2. **ERCO study site topography with treatment sections, monitoring wells, and estimated ground water potential lines**

Figure 2 illustrates ground water contours using data from all the wells located at the ERCO Tree Farm. The solid lines represent ground water potential contours and the dashed lines represent topographic contours. There are seven functioning ground water monitoring wells (fig. 2) installed at the Tree Farm site that range in depth from 7.6 m to 39 m (25 ft. to 127 ft.). In Figure 2, the groundwater potential decreases from Section 8 toward Section 9. Overall, these contours show a general hydraulic gradient toward Burch Branch, which flows past the Tree Farm site to the north and east. An unnamed tributary to Burch Branch flows along the western boundary of the ERCO Tree Farm. Based on the ground water contours and the presence of perennial streams on three sides of the Tree Farm, water quality in the aquifer and aquaclude below the site can be reasonably well estimated by reviewing the historical analytical data from the monitoring wells.

The first well, installed in November 1982, is designated MW #2, and is situated within 31 m of the ERCO trailer. The well is cased to 9.4 m, followed by 3 m of screen.

Additional monitoring wells have been installed in conjunction with permit amendments/modifications, especially those related to the inclusion of additional acreage. Well descriptions are as follows.

Well No.	Date Installed	Depth of: Casing	Screen
1	7/26/88	70'	70'-80'
2	11/15/82	31’	31’-41’
4	7/14/88	25'	25'-35'
5 (removed)	7/26/88	10'	10'-20'
5A	3/28/89	28'	28'-38'
6	10/8/90	107'	107'-127'
7	10/8/90	77'	77'-97'
8	10/8/90	80'	80'-95'

Well 5A is a replacement well for the abandoned and removed Well 5.

Monitoring Well #1, installed in July 1988, generally represents background or up gradient conditions not expected to be substantially affected by the application of biosolids. Well #2 was the first well installed (November 9, 1982) and served as the sole monitoring well until Wells #1, #4, and #5A were installed.

Wells #4 and #5 were installed in July 1988 as down gradient monitoring points at locations and depths dictated by MDE. Well #5 was dry and never produced a sample. Consequently, in March 1989, MDE directed ERCO to remove Well#5 and replace it with Well #5A. Three additional wells (#6, #7, and #8) were mandated by Permit Number S-90-16-809-ABE. Although these three wells were expected to represent one additional up gradient and two down gradient wells, they in fact are down gradient of the earlier work areas and thus could be expected to reflect any changes in water quality across the entire site.

The Prince George's County Health Department and the State of Maryland sampled and analyzed Wells #1 - #5A for the period November 1982 to May 1989 (monthly for Well # 2 from February 1983 to June 1985, then quarterly; other wells generally quarterly after installation). Since May 1989, Gascoyne Laboratories, Inc. has sampled and analyzed water from all wells.

WATER QUALITY INSTRUMENTATION AND MEASUREMENT.

Each treatment (application rate X tree density combination) within each block contained several types of sampling instrumentation to evaluate hydrology and/or nutrient transport: 1) in each of the 30 treatments, one zero-tension lysimeter positioned 304.8 mm (12 in) directly below a deep row; and 2) in each of the 30 treatments, suction lysimeters nested under and around the deep row.

Pan lysimeters were installed from July 2002 through March 2003, just after the deep row was filled with biosolids. Water collected from zero-tension lysimeters (a.k.a, pan lysimeters) may be macropore flow (Figure 2). Where macropores are minimal or non-existent, as may be the case in this drastically disturbed soil profile, the flow represents gravity-drained water. This flow is estimated to account for anywhere between 10 to 85% of the percolating water. Because the water percolates relatively rapidly, and does not have prolonged contact with the soil matrix, there is less time for nutrient uptake from the surrounding soil matrix. Hence, concentrations from the pan lysimeters provide an estimate of the lower limit of nutrient loss.

Each plot also contains two sets of suction lysimeters installed under and around the biosolids rows (Figure 3). Suction lysimeters were installed after the deep row was filled with biosolids, after the area was leveled and disked, but before planting. Where water flows a great distance vertically to the water table, nutrients leaving a source generally create plumes that migrate downward. Therefore, one set of suction lysimeters were installed 150 mm, 300 mm, and 610 mm (6, 12, and 24 in.) directly below a biosolids row to monitor long-term migration of any plume in the vertical direction.

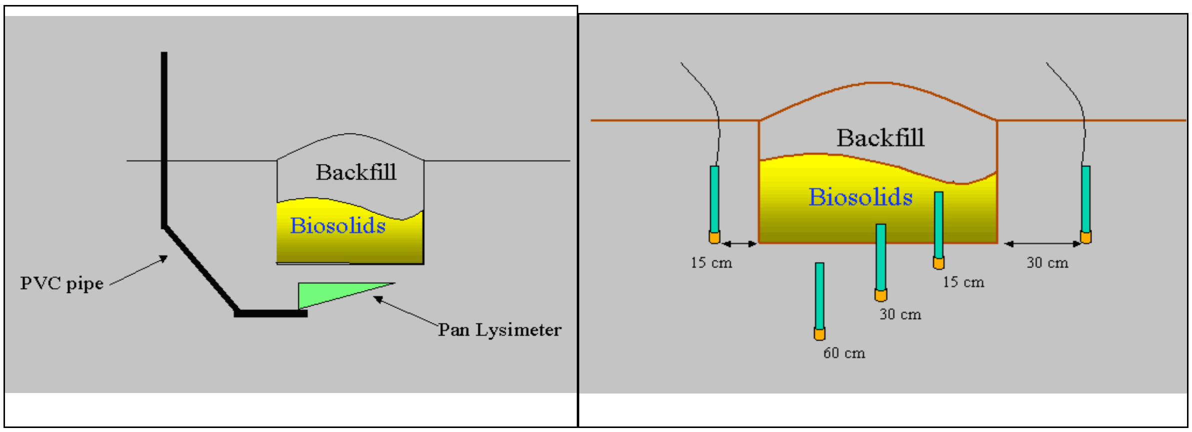

Figure 3. **Pan lysimeter installation (left) and suction lysimeter installation (right).**

The second suction lysimeter nest is located beside the row in the soil level with the bottom of the deep row. Because this site has a thick clay subsoil layer overlain with gravel and mixed clay loam backfill, lateral flow on top of the horizon interfaces (sometimes referred to as locally perched water) is a possibility. Suction lysimeters were installed 150 mm and 300 mm from the side of a row to monitor lateral movement. Suction lysimeters collect soil water that may contains nutrient levels elevated above that of free flowing sub-surface water. Hence, concentrations provide an estimate of the upper limit of nutrient loss.

SAMPLING FREQUENCY & PARAMETERS MEASURED

Water quality sampling began in April, 2003. Water samples from pan and suction lysimeters were collected on a monthly basis for the first year. For the following years, samples were collected every other month. These routine collections amounted to 4860 sampling attempts. Due to dry weather conditions and other climatic factors, however, there were instances in which water is not present. All subsurface water samples have been sampled for pH, nitrate, nitrite, total nitrogen, orthophosphate, total phosphorus, sulfate, and chloride.

LABORATORY ANALYSIS OF SOIL WATER, BIOSOLIDS AND SOIL SAMPLES

Soil Water Samples

Pan and suction lysimeter samples were transported to the laboratory after collection. Samples were analyzed for pH on a Fisher Scientific accumet Basic AB15 pH meter. An aliquot of sample was vacuum filtered through a 0.45*um* pore size nylon membrane filter (Whatman part no. 7404-004) and frozen until analyzed. Original, unfiltered aliquots were frozen and placed in storage. Filtered samples were analyzed for total nitrogen, ammonium, nitrite, and nitrate. With the exception of some nitrate and nitrate analyses noted below, all analyses were performed by the Appalachian Laboratory at the University of Maryland Center for Environmental Studies in Frostburg, MD. Analytical methods/protocols used included the following.

Total nitrogen: Standard Methods, Method 4500-N B. In-Line UV/Persulfate Digestion and Oxidation with Flow Injection Analysis (APHA, 1998)

Ammonium nitrogen: Lachet QuickChem Method 10-107-06-3-D, Revision Date August 26, 2003 (Sodium salicylate –based method).

Nitrite/nitrate:

Methods for Chemical Analysis of Water and Wastes (MCAWW) Method 353.2 Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry (using a Lachet Quick Chem 8000 Flow Injection Analyser) (EPA, 1993). Both nitrite and nitrite+nitrate are determined; nitrate is then mathematically calculated as the difference.

OR

Bran and Luebbe Method 696E-82W (nitrite) and 696F-82W (nitrite+nitrate). These methods are based on Methods 4500-NO_2 B. and 4500-NO_3 H, respectively, from Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Nitrate is mathematically calculated as the difference between Nitrite+nitrate and nitrite.

Note: The Braun and Luebbe method was used for samples collected prior to March 2004, which were analyzed at the University of Maryland's Water Quality Laboratory in the Biological Resources Engineering Department in College Park, MD. Samples collected during and after March 2004 were analyzed using MCAWW Method 353.2 by the Appalachian Laboratory at the University of Maryland Center for Environmental Studies in Frostburg, MD.

Biosolids Samples

Biosolids samples collected on a monthly basis during set up of the experimental plot were delivered to the University of Maryland's Maryland Cooperative Extension Laboratory in College Park, MD. Analytical methods/protocols used included the following.

Ammonium nitrogen: A representative fresh (not dried) aliquot is distilled using MgO (Association of Official Analytical Chemists {AOAC} Section #2.057.

For all remaining analyses, a sample aliquot is dried at 80°C and ground in a Wiley Mill to pass through a 20 Mesh sieve.

Organic nitrogen: Leco CHN combustion determination (Campbell, C.R. 1992. In Plant analysis reference procedures for the southern region of the U.S. Southern Cooperative Research Ser. Bulletin 368. USDA, Washington, D.C. pp. 21-23).

Total nitrogen: The sum of ammonium and organic nitrogen.

Magnesium, phosphorus, potassium and calcium: Perchloric/Nitric acid digestion followed by Technicon AutoAnalyzer determination (Walsh, L.M., 1971).

Manganese, zinc, and copper: Perchloric/Nitric acid digestion followed by Atomic Absorption determination (Gorsuch, 1970).

Sulfur: Leco S132 combustion determination (Leco Application Bulletin 203-601-073).

Soil Core Samples

Hydraulic conductivity was determined on soil cores collected concurrent with the pan lysimeter installations. Analyses were performed in-house at the University of Maryland Biological Resources Engineering Soil Water Laboratory using an adaptation of the constant head protocol delineated in Methods of Soil Analysis (Knute, A. 1986). The protocol is based on Darcy's Law, in which:

$$q = Q/A = -k(\Delta h/\Delta l) \quad (1)$$

where:

q = hydraulic flux,

Q = volumetric flow rate = volume of water flowing through core sample (V) for a given time (t) = V/t

A = cross sectional area of the core sample (cylinder),

k = hydraulic conductivity [L/t],

Δh = The hydraulic head difference imposed across a sample of length "l" {i.e., difference in height between the bottom of the Mariotte air tube (i.e., bottom of copper tubing) and bottom of brass soil core cylinder}

Δl = length of the core sample (distance through which the water flows), and

t = time.

For these experiments, $\Delta h/\Delta l$ was approximately 10.

Briefly, a soil core sample was placed in a Tempe Cell and saturated with water from the bottom up. The Tempe Cell set up was modified to replace the ceramic disk that is normally placed in the bottom of the cell underneath the soil core with a thin, porous hydrophobic polypropylene material made by Porex Corporation. The resistance of the material is orders of magnitude less than the soil samples and hence is neglected in the hydraulic conductivity calculation.

A Mariotte reservoir is filled with water and is used to deliver water to the sample at a constant outlet pressure through Tygon tubing extending from the bottom of the Mariotte reservoir to the upper opening of the Tempe Cell. A known pressure head is consequently established with the Mariotte air tube positioned at a known height above the core sample that sits in the Tempe Cell. The spigot at the bottom of the Mariotte reservoir is opened. A stream of water from the Mariotte reservoir flows to the Tempe Cell and through the soil core sample. The volume of water flowing through the core sample for a known amount of time is used to determine the hydraulic conductivity based on the equation provided above.

DATA ANALYSIS

Data were statistically analyzed using analysis of variance (ANOVA) techniques (Kuehl, 2000) to evaluate trends in hydraulic conductivity with depth and location, water quality over time, and whether differences exist in water quality between biosolids application rates and tree densities. SAS 9.1. © 2002-2003 (SAS Institute, Inc., Cary, North Carolina) was used to perform these analyses. Details of the protocols used for each type of data are provided in the results and discussion section of this thesis.

TREE PLANTING METHOD

The operational technique for planting hybrid poplar cuttings outside the 1.25 ha (3.1 ac) research area uses a low ground surface pressure bulldozer with a subsoiling bar to create a single cut approximately 30 cm (1 ft) deep. Subsoiling, in which a strip of compacted soil is broken up prior to planting, was implemented to break up the extremely dense overburden so that the newly planted cuttings were easier to plant, could quickly form roots, and could access the soil moisture and nutrients in the biosolids. The bulldozer then created another planting row 3.1 m (10 ft) from the existing row by lining a boom up on the existing row, resulting in subsoil rows 3 m on center. Subsoil rows were then cut 90 degrees to the first set of rows, resulting in a 3 m by 3 m grid. When completed, the cuttings were easily hand planted where the rows intersect, creating a 3.1 m (10 ft.) square grid.

The research site was planted in June 2003 using hand-planting with a dibble bar, not the operational technique, because the bulldozer weight had the potential to collapse the pan lysimeters. Both areas were planted on the same day. Vegetation management on the research area was implemented by applying pre-emergent herbicides such as Goal® and Pendulum®. The two distinct, but adjacent tree crops that were planted using the subsoiling method provided the opportunity to determine the effect of planting technique on the mortality and growth of the planted cuttings.

The total height and basal diameter (5 mm above the growth from the cutting) was measured for each cutting after the first and second growing seasons (2003 & 2004) in the research plot and for a subset of trees in adjacent plots.

FOLIAR LEAF COLLECTION AND ANALYSIS

The collection of foliar leaf samples of hybrid poplar trees is an accepted method to assess the uptake of available nutrients by the trees and the impact of various treatments on tree growth (Hansen, E.A 1994; Hansen, E.A. and D.N. Tolsted 1985). Changes in foliar leaf concentrations for N and P have been correlated with changes in growth of hybrid poplar (Zabek, 1995). The literature on hybrid poplar foliar nutrition (Zabek, 2001) can be summarized as follows:

- Maximum growth of hybrid poplar under fertilized conditions occurs at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth occurs at 2.5 - 3.5% foliar nitrogen and 0.25 - 0.40% foliar phosphorous.

- Foliar N:P ratios of above or below 9.5 seem to coincide with differences in tree growth response to N and P applications. The ratio of N:P may prove to be an effective diagnostic tool.

- Foliar nutrient levels of N and P at or above the levels for fast growth, combined with a N:P ratio around 9.5 should be expressed in measures of increased growth (height, diameter, and biomass) over treatments with lower optimum levels.

To establish a baseline for the foliar nutrient uptake and enable trends to be identified in the future, foliar nutrient samples were collected during the second growing season (August, 2004) using an accepted protocol (VanHam 2003). Plant tissue samples were analyzed by a commercial laboratory.

RESULTS AND DISCUSSION

EARLY MONITORING RESULTS.

A water sample, intended to be representative of ground water conditions prior to biosolids application, was obtained by the Prince George's County Department of Health for the MDE (then Department of Health and Mental Hygiene) on November 9, 1982. Analysis of this sample yielded the following results:

pH	7.8 units	alkalinity (total)	98 mg/l	hardness	65 mg/l
nitrate	1.5 mg/l	chloride	30 mg/l	fluoride	2.45 mg/l
color	60 units	turbidity	24 units	total residue	364 mg/l
cadmium	0.005 mg/l	lead	0.01 mg/l	mercury	<0.0005 mg/l
copper	<0.01 mg/l	iron	1.3 mg/l	manganese	<0.01 mg/l
sodium	80 mg/l	zinc	0.05 mg/l		

Groundwater monitoring data from 1983 through 1994 indicate little evident change in overall groundwater quality due to biosolids application. A detailed review of the chloride, nitrate nitrogen, cadmium, lead and fecal coliform results was performed. Chlorides are anionic compounds that are not well retained in soils and are commonly found in biosolids. They are easily leached from the soil and are often utilized as an indicator of pollution potential in groundwater. Nitrate nitrogen is an anionic compound that may be introduced from high levels of fertilizer application and, at excessive levels in water supplies, has been demonstrated to cause health problems in cattle and infant humans. The presence of nitrates in ground waters is often an indication of fertilizer nitrogen application in excess of plant needs.

Because both chlorides and nitrates easily move from the soil into groundwater and both could be attributed to biosolids applications at the site, a review of the ERCO Tree Farm analytical data from ground water samples was conducted to determine if either or both compounds were moving from the deep rows. Generally, equal increases in ground water concentrations of the two compounds would suggest that the biosolids were the source. Increased concentrations of chloride but not nitrates would suggest that leaching of water from the biosolids was occurring, but that other mechanisms were preventing either nitrate production or excess nitrate movement from the deep row. Finally, no increase in the concentration of either compound would suggest that nothing was migrating from the deep rows.

For the period between 1983 and 1994, chloride and nitrate concentrations from groundwater samples obtained at the Tree Farm were quite low. While the reported values for chloride generally were above detection limits, concentrations were usually reported at one to two orders of magnitude below the drinking water limit of 250 mg Cl/L. No trend of increase in chloride concentration in the well samples was seen after biosolids application.

For all wells, nitrate water concentrations were most commonly at or less than detection limits (0.2 mg/L when the State was conducting analyses, 0.1 mg/L when Gascoyne conducted the analyses). Occasionally, nitrate concentrations were reported at higher levels than detection limits but never did the level approach the drinking water standard of 10 mg/L. Twice Well # 2 exhibited nitrate concentrations above the detection limits: On November 10, 1982 (the day after the well was drilled and before any biosolids were applied to the site), the nitrate level was reported at 1.5 mg/L; and on May 24, 1989, the level was reported at 1.9 mg/L.

On this latter sampling date, several of samples from the other wells also were reported to contain nitrate concentrations above the detection limits. Well # 1, the site's up gradient well, was reported to contain a nitrate concentration of 1 mg/L. This well was screened at 21.3 m to 24.3 m (70 to 80 ft.) deep, which corresponds to the top of the Nanjemoy formation (Wilson and Fleck, 1990). The increased nitrate levels in the up-gradient Well #1 suggest classic lateral inflow occurred, which would be consistent with an aquifer formation (the Nanjemoy) beneath an aquitard (the Calvert). Well # 4 produced a nitrate concentration at 1.3 mg/L and Well # 5A produced a nitrate concentration of 1.6 mg/L. Wells 2, 4, and 5A were each screened in 3.1 m (10 ft.) intervals and range in depth to the top of the screen from 7.6 m to 9.4 m (25 ft. - 31 ft.). All are in a silty clay sand layer that is surrounded by layers described as "white clay" and "green clay" (Pepperman, 1995). Hence, because the events were singular in time and the wells appeared to intercept isolated layers, it would suggest that lateral inflow was documented.

Cadmium and lead are two elements commonly found in biosolids that are not known to be required for plant growth. Research has demonstrated that these elements contained in biosolids are generally quite immobile and not expected to move from the zone of incorporation. Nevertheless, due to the health hazards associated with these elements, concentrations in the waters draining the ERCO Tree Farm were reviewed. Cadmium and lead concentrations in the monitoring wells over the 1983-1994 period were generally at or near the detection limits for the respective laboratories (Cd, 0.001 mg/L, Pb, 0.01 mg/L for the State; Cd, 0.0005 mg/L, Pb 0.005 mg/L for Gascoyne). The drinking water standards and/or the health effect level used by the USEPA in development of the risk assessment for 40 CFR 503 is 0.01 mg/L for cadmium and 0.05 mg/L for lead. The highest concentration of lead in any well (0.04 mg/L) occurred in Well # 2 on October 16, 1984.

The one exception was Well # 4, which is generally down gradient of Section 7 (the demonstration plot), and consistently exhibited cadmium concentrations just above the detection limits over the period May 1989 to November 1993. The range of cadmium concentration in Well # 4 over this time was 0.0009 mg/L to 0.0027 mg/L -- still almost an order of magnitude below the drinking water standard. Cadmium levels in samples from other wells infrequently exceeded the lower end of this range. The highest concentration of cadmium in any sample from any well on the site was 0.041 mg/L in Well #7. This sample was obtained on November 28, 1990, approximately one month after the well was constructed.

Finally, fecal coliforms counts were reviewed. Biosolids are known to contain substantial populations of these organisms; therefore, changes in populations across the site on the same sampling date may indicate movement of biosolids into the water. Fecal coliform analyses were conducted by both the State and Gascoyne Laboratories during the period 1983-1994. Although the State (through Prince George's County) obtained samples for field fecal coliform analysis, the results were not commonly reported in Most Probable Number or other units directly comparable to the Gascoyne data. The State testing did report the results of both presumptive and confirmed tests on 10 mL samples. In most of the State's tests, positive indications of coliforms occurred in all five samples in each of the two tests, although positive indication of fecal coliforms were seldom reported in the confirmed tests and only rarely at a value > 1 in the presumptive tests. Since Gascoyne has been conducting the analyses using dedicated bailers, the majority of the samples have been either at the laboratory's detection limit of 2 MPN or reported not detected (ND).

Infrequent exceptions have occurred. Samples obtained on November 11, 1991, and November 22, 1993, from Monitoring Well #1, which is generally up gradient of the sludge application areas, were reported to contain 5 and 7 MPN, respectively. Well #2 and Well # 6 also produced fecal coliform values of 5 MPN on November 11, 1991. No other wells had fecal coliform counts above the detection limit on that sampling date.

A sample from Well # 6 was reported to have 4 MPN fecal coliforms on November 28, 1990. A sample from Well # 2 obtained on the same date was determined to contain 2,200 MPN. It appears that there is an increased likelihood of incidence in fecal coliform detection in ground water samples obtained at the site during November when field conditions are typically very muddy which may contribute to sample contamination.

A similar condition occurs in samples obtained in August, but with less frequency. For example, samples obtained August 6, 1991, from Wells # 6 and # 7 were reported to contain 8 and 33 MPN, respectively. A sample obtained from Well # 2 on August 9, 1990, was reported to contain 17 MPN and a sample obtained on August 3, 1992, from Well # 8 was reported to contain 8 MPN. Only one other sample was reported to contain fecal coliforms above the detection limits. A sample obtained from Well # 4 on May 24, 1989 was reported to contain 23 MPN.

An evaluation of the fecal coliform observations indicates that they pose no environmental impact from the biosolids activities at the ERCO site. A total of 103 samples were analyzed for fecal coliform over the sampling period March 1991 to May 1998. Only four samples (or less than 4%) indicated fecal coliform densities over 10 MPN. The four samples came from four different wells. Further, all observations above detection limits indicate no trend to the data, therefore the incidences of positive fecal coliform concentrations may be due to sample contamination.

MORE RECENT WELL MONITORING RESULTS.

The following discussions provide an overview of the results of more recent groundwater monitoring from the past 14 years for the following parameters: pH, chlorides, nitrates, ammonia, and total solids.

pH:

This parameter is a measurement of the relative acidity or basicity of the groundwater. This parameter is usually measured in the field during well sampling events. Increases or decreases in the water pH may infer that the biosolids application is causing water quality impacts – for example, because lime-stabilized biosolids have been exclusively applied to the site for some years, movement of biosolids-borne pollutants from the deep rows to groundwater resources might be suggested by an increase in the pH (due to the lime).

The historical pH values are completely unremarkable, save for the period of time that the pH was elevated immediately following the installation of Well 5-A, which was performed in 1989. Up to December 1991, the pH ranged between 7.0 and 10.0 and remained near 7.0 after a period of approximately 24 months. This provides an indication of how long it can take for impacts of disturbance (well installation) to subside. From 1991 through the present, the pH has remained between 6.5 and 8.0. From Figure 4, it is clear that pH levels remain fairly constant, with each different well having a slightly different average pH.

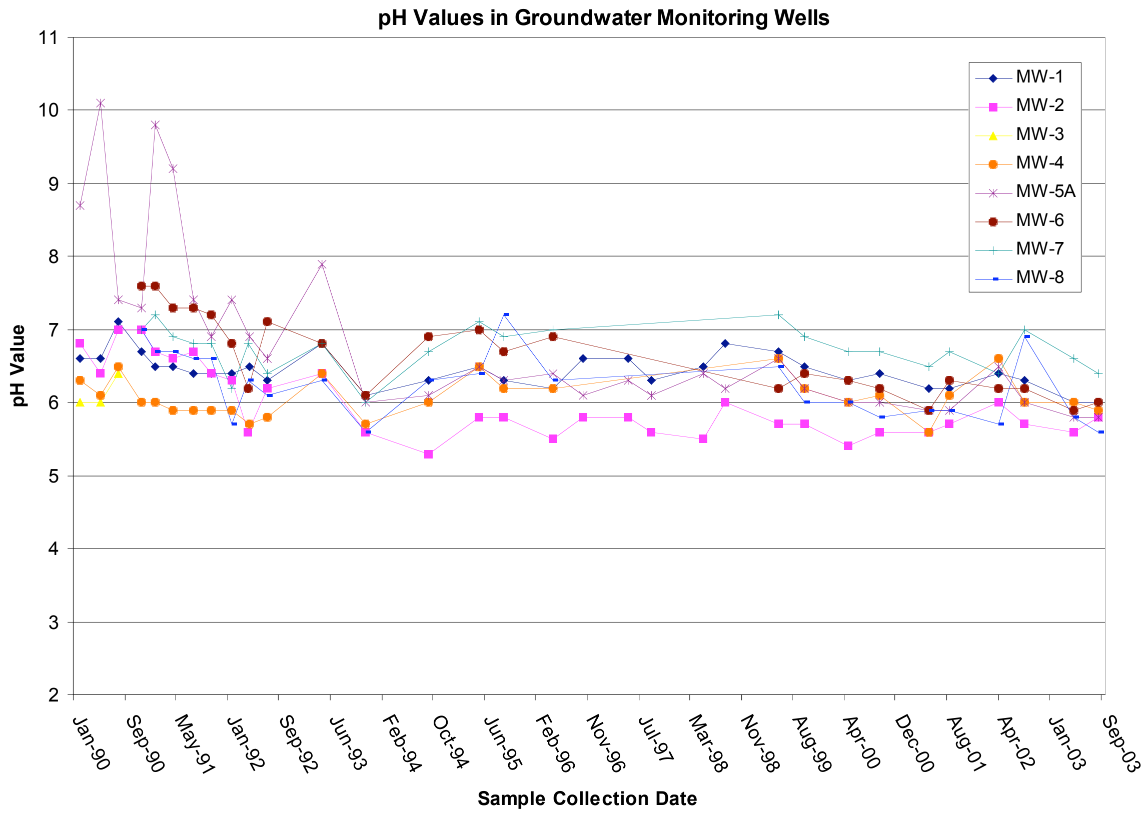

Figure 4. **pH values for each of the eight monitoring wells.**

Chloride:

Chloride in groundwater is not typically associated with human health or environmental concerns. It is listed in EPA's Secondary Drinking Water Regulations with a limit of 250 mg/L to address potential cosmetic or aesthetic effects. Measurement of chloride is a useful tool insofar as chlorides are usually found within biosolids in substantial concentrations *and*, as anionic (negatively charged) compounds; they would be expected to move through the soil matrix at a rate similar other water-soluble compounds, including nitrates (another anion).

The data for chlorides over time is presented in Figure 5. From these graphs, it can be seen that a number of wells are exhibiting an increase in measured chloride concentrations over the past two years (including Monitoring Well #1, the up gradient well measuring background water quality). Prior to this general rise, the chloride concentration in Wells #2 and #6 rose higher relative to the other wells, and Well#8 exhibited a relatively high spike in concentration. Well #2 chloride concentrations peaked in late 1994 and have generally been declining since then (in fact, the concentration of chloride for MW#2 on the last sampling date represented on Figure 5 is lower than the concentration of chloride for the same date in up gradient Well MW#1). The chloride concentrations in MW#6 peaked in late 2001 and have been trending downward since.

Changes such as seen in Wells 2, 6 and 8 can be attributed to changes in the influent water constituents or can also be an indicator that the well has suffered a failure. If these changes are a function of the biosolids application, we would expect to observe similar increases in nitrates in the same wells over the same periods.

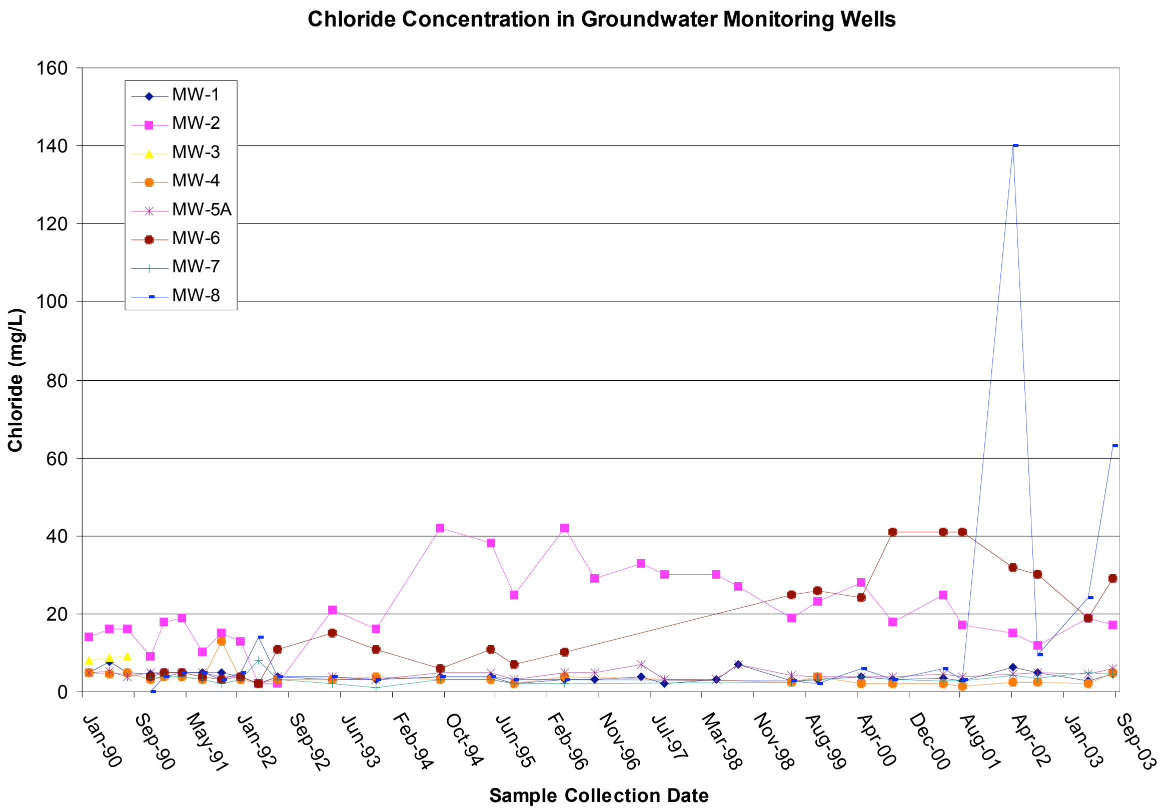

Figure 5. **Chloride (mg/L) values for each of the eight monitoring wells**

Nitrate:

Nitrate in potable water supplies is a concern. High concentrations in drinking water can impact human health as well as cause impacts to farm animals. The federal drinking water standard for this pollutant is 10 mg/L. As indicated above, nitrates are anionic compounds that would tend to move through the soil matrix with water. For these reasons, this is the pollutant most at issue with the ERCO deep row technique.

Figure 6 presents the historical nitrate concentration data from the ERCO monitoring wells and places those data in context to the 10 mg/L drinking water standard. As can be seen, no sample even approaches the 10 mg/L limit and in fact, only one sample even exceeds a concentration that is one-tenth of the standard. These data indicate that there is no nitrate migration to groundwater supplies as a consequence of the biosolids related activities at the ERCO site.

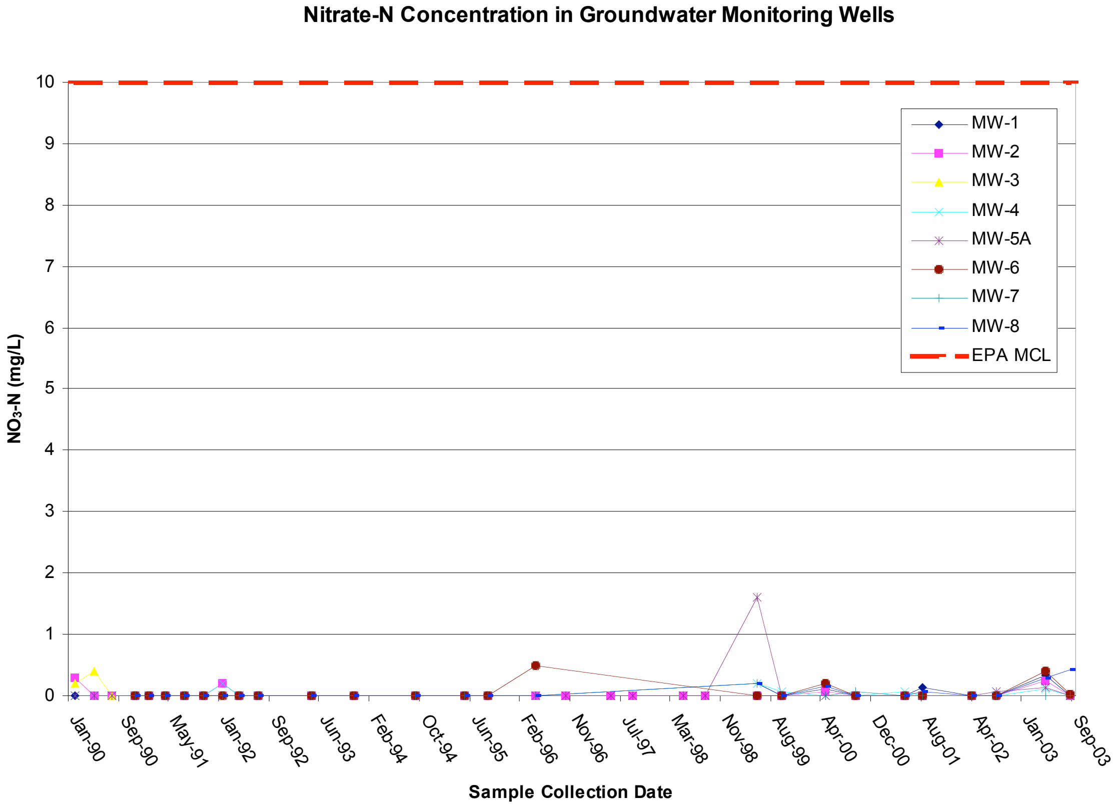

Figure 6. **Nitrate values (mg/L NO_3-N) for each of the eight monitoring wells**

More importantly, it calls into question the prospective source(s) of chlorides in MWs 2, 6, and 8. If the presumption that the two compounds would move from the biosolids to monitoring points at about the same rate is correct, then the data suggests that these chlorides are not sourced in the biosolids. Conversely, if the chlorides were in fact of biosolids origin, then this implies that there is a mechanism in the deep rows for limiting the production of nitrates and/or denitrification (conversion of nitrates to nitrogen gas).

Ammonia:

Figures 7 and 8 represent the ammonia data for the ERCO site monitoring wells. As with many of the water quality parameters evaluated for the ERCO site, there is no drinking water standard for ammonia. Therefore, referring to a “critical” level has no meaning. However, ammonia is a nutrient of concern to the Chesapeake Bay. Therefore, most wastewater treatment plants in the region have ammonia limits in their discharge permits. The Blue Plains effluent limit for ammonia is 6.5 mg/L. Figure 7 places the historical ammonia concentration in the monitoring wells at the ERCO site into context by using the Blue Plains limit as a benchmark.

Figure 8 places the ammonia concentration in all wells over the period in context with background levels. As can be quite well seen on Figure 8, in May 2002, Well 2 had an ammonia concentration spike of 85 mg/L. The subsequent reading was 1.4 mg/L. This is unusual and one-time events suggest that the well may have direct surface linkage or the integrity of Well 2 may be questionable.

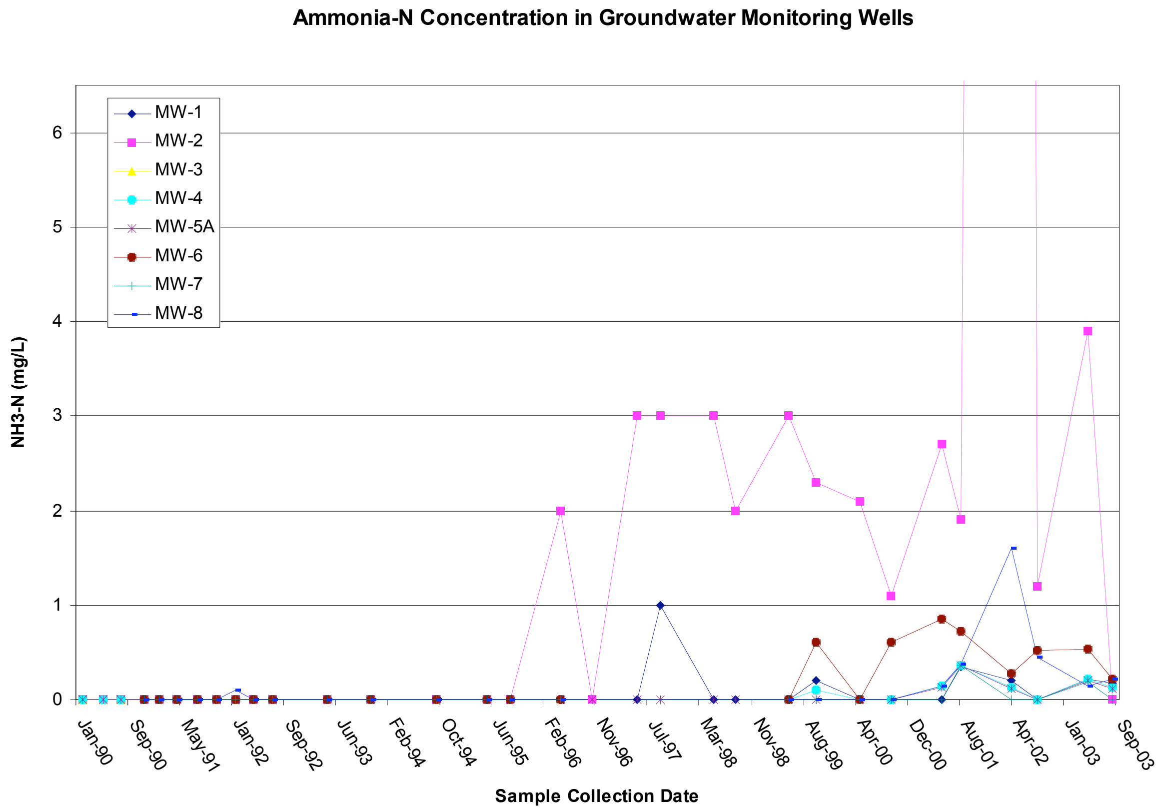

Figure 7. **Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells with scale truncated at the Blue Plains effluent limit of 6.5 mg/L.**

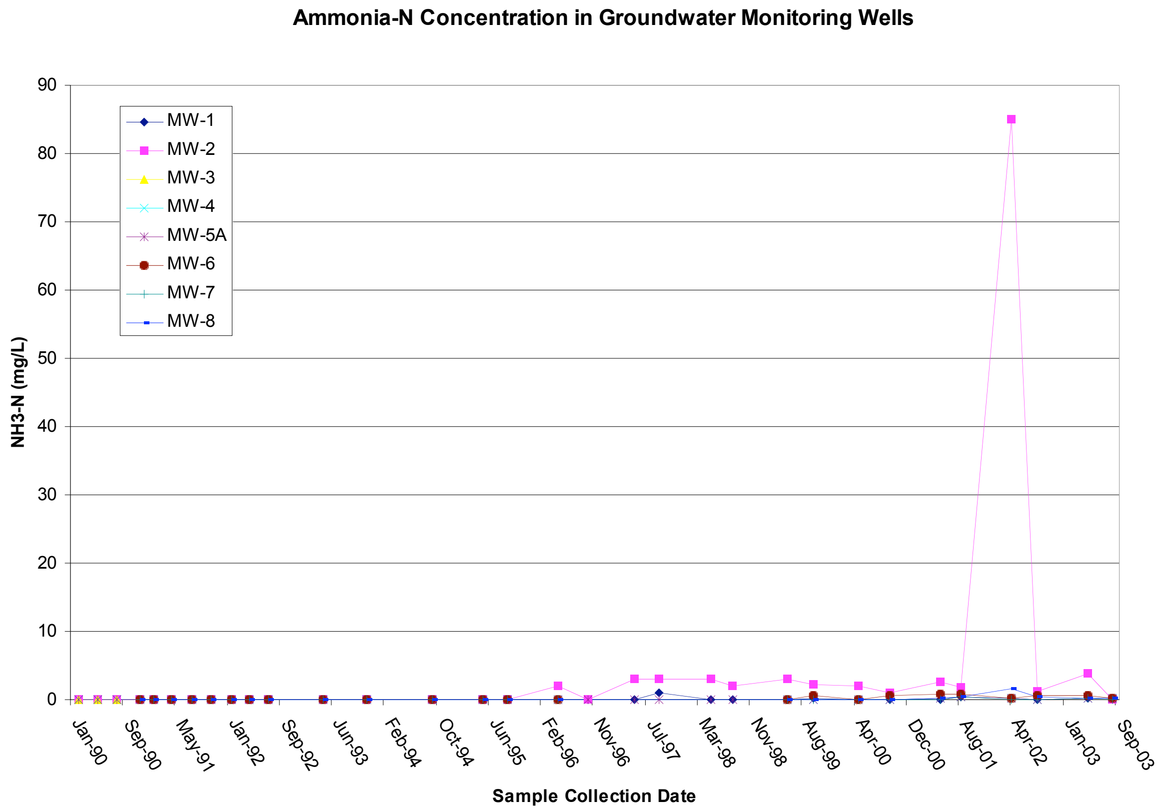

Figure 8. **Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells (in full scale).**

Ammonia in groundwater also usually indicates an elevation in nitrates as ammonia tends to be quickly converted to nitrate in this environment. So this spike in Well #2 is also curious insofar as the water sampled on this date did not exhibit elevated nitrate levels (reported as a nondetect). In any case, it is clear that the levels of ammonia in the deeper wells are un-remarkable, always remaining between non-detect and less than 1.0 mg/L.

Total solids:

Total solids data are presented in Figure 9. Well 2 consistently exceeds the average values in all other wells. The average total solids in all other wells is 206 mg/L while Well 2 average's 823 mg/L. Total solids should not be elevated in a well that is sampling water that runs through a porous media. The porous media should filter all but the dissolved solids from the water. This well is in the Calvert formation and is finished at a depth of 41 feet, with screening ranging from 31 feet to 41 feet.

Unique to this well is that it is finished in marl. All other wells at the ERCO site are finished in some form of clay and no marl is reported in any of the various drilling and core sample logs. Marl or *bog lime* is a deposit of crumbling earthy material principally composed of clay with magnesium and calcium carbonate. This calcareous clay is formed when a marine deposit is overlain with an organic layer, such as peat. The result is a friable formation. This is the last place one would want to finish a well because the flow of water can be locally channeled and would be suspect as unrepresentative of actual porous media flow. Furthermore, the well sampling technician from Gascoyne has indicated that this well fills as rapidly as it can be bailed. This suggests that water moves in an almost unobstructed manner in this local anomaly.

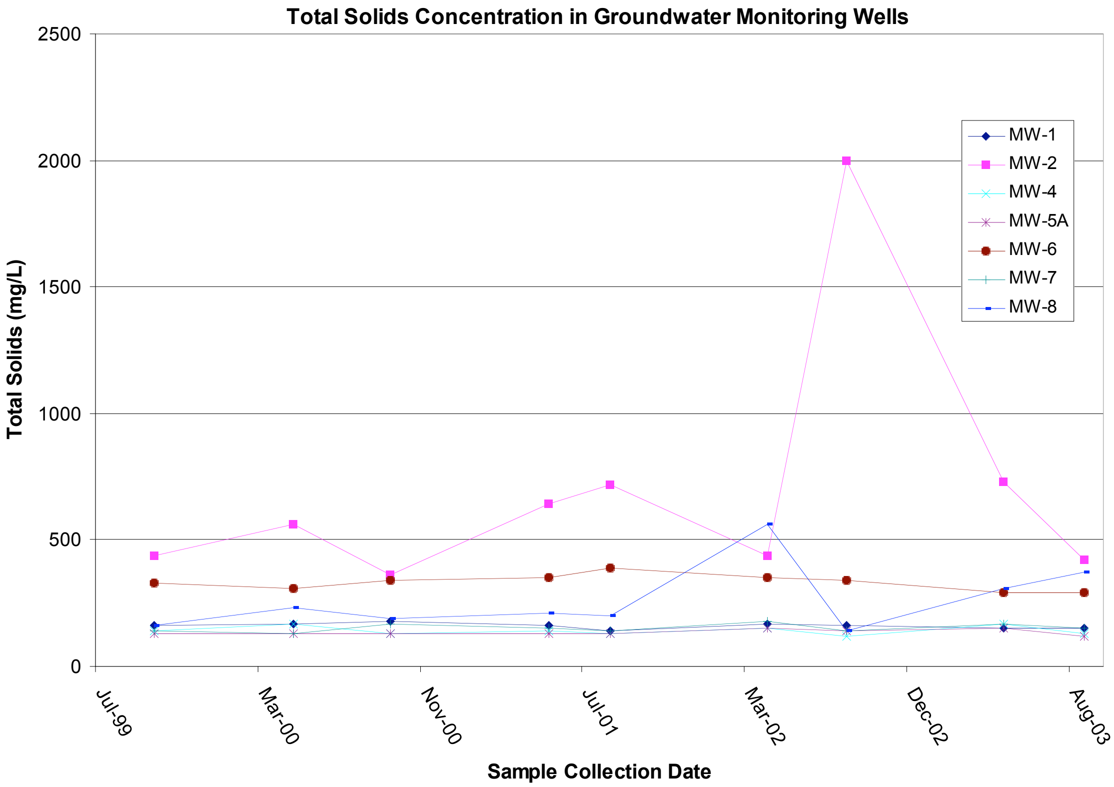

Figure 9. **Total solids (mg/L) for each of the eight monitoring wells.**

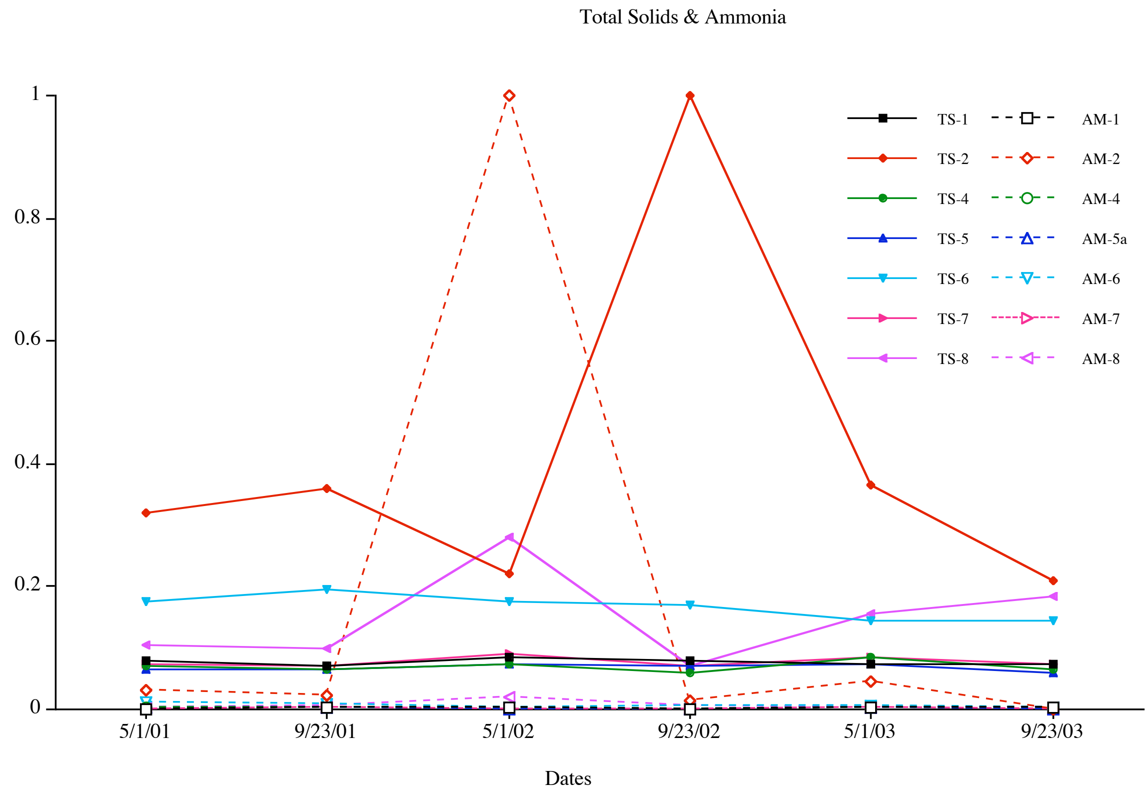

Figure 10. **Normalized total solids and normalized ammonia for each of the eight monitoring wells.**

In Figure 10, the maximum value for the period was used to normalize each series. All values of total solids were divided by the largest value, 2000 mg/L. The same was done for ammonia values. This results in unitless values that range from 0 to 1.0 and allows comparisons of total solids and ammonia on the same graph.

Most of the wells track along in relatively straight lines. However, again, Well 2 is very different. The normalized ammonia value peaks during the May 2002 sampling and the normalized total solids is slightly depressed during that sampling. During the following sampling, the relative total solids value peaks while the relative ammonia drops to a very low level. This suggests that solids and ammonia are moving at different rates, but that they are both spurred on by a single event. The period October 2001 through October 2002 was the wettest year on record at BWI airport. This could possibly be the driving force that caused the ammonia and total solids to spike so dramatically in Well #2.

Monitoring well data indicate that nitrate and chloride are not entering the water bearing formations that are 7 to 21 m below the site. Over time, the total nitrogen content of the entrenched biosolids dropped by more than half to 1.21%. Soil samples surrounding the trench had nitrogen levels of 0.02-0.04%, which indicates that nitrate is not invading the surrounding soil.

For all wells, nitrate water concentrations were most commonly at or less than detection limits. In the most recent sampling and analysis event, the nitrate concentration in all wells at the Tree Farm was determined to be below detection limits. Occasionally, nitrate concentrations were reported at higher levels than detection limits but never did the level reported approach the drinking water standard of 10 mg/L.

HYDRAULIC CONDUCTIVITY

Results show a wide range in saturated hydraulic conductivity from 1.40×10^{-7} to 1.84×10^{-2} cm/sec, reflecting varied soil composition, some with high clay content and others dominated by sand and gravel. This range is consistent with visual observations during equipment installations at the site. Visual observations indicated higher sand and gravel contents in Block 1, with successive transition over to higher silt and clay content through Blocks 2 and 3. Also noted, however, during equipment installations was the fact that some subplots with sandy soil at the surface had clay layers or pockets further in the soil profile. Similarly, the higher clay content surface in Block 3 would sometimes contain sandier layers and pockets at different depths. Thus, the soil composition was reflective of the extensive disturbance and mixing of overburden that would occur during excavation operations at a gravel mine and subsequent re-grading of the site.

A fresh sample of biosolids was also subjected to the hydraulic conductivity analysis. The hydraulic conductivity measured was 2.55×10^{-6} cm/sec, reflecting properties similar to silty and clay soils. If the soil surrounding the biosolids row has a higher conductivity value than the bisolids, water entering the subsoil system will likely travel around the biosolids row. Conversely, if the soil has a lower conductivity value, water will choose the path of least resistance and percolate through the bisolids row. It is also important to note that within the bisolids row the hydraulic conductivity value will change over time as biosolids dewater and decompose. Based on observations of decomposed biosolids at the tree farm as well as the actual water flow in and around old biosolids rows, the conductivity increases as the bisolids age.

To better quantify these visual observations, the hydraulic conductivity data were evaluated and subjected to statistical analyses to determine if: 1) significant differences occurred between the three blocks at the experimental site and 2) significant differences existed at different depths in the soil profile. Although soil cores were collected at three different depths within each subplot, because those depths varied with biosolids application rate and variances in the topography of the site, the range of depths over which soil cores were collected were separated into four different levels. This allowed for a more consistent comparison across the experimental area based on the standard datum of depth from the surface. The four depth levels consisted of: 30-60cm; 61-94cm; 95-129cm; and 130-168cm. The shallower depths were typically associated with the lowest and middle application rates; the highest depths were almost exclusively associated with the highest application rate. The middle depths included samples associated with all application rates.

The two factors under consideration were block (i.e., areas of the experimental plot with differing topographic features and soil composition) and depth. This constitutes a factorial treatment design with three levels of the block factor and four levels of the depth factor. PROC Mixed was used to perform a factorial analysis of variance. Results showed statistically significant differences between blocks ($Pr<0.0001$), but not between depths or block*depth interactions. Least Squares Means evaluation showed all three blocks to be significantly different from one another ($Pr <0.0031$ for Blocks 1 and 2; $Pr<0.0001$ for Blocks 1 and 3; $Pr<0.0038$ for Blocks 2 and 3). These results are reflected in plots of the data as shown in Figures 11-13.

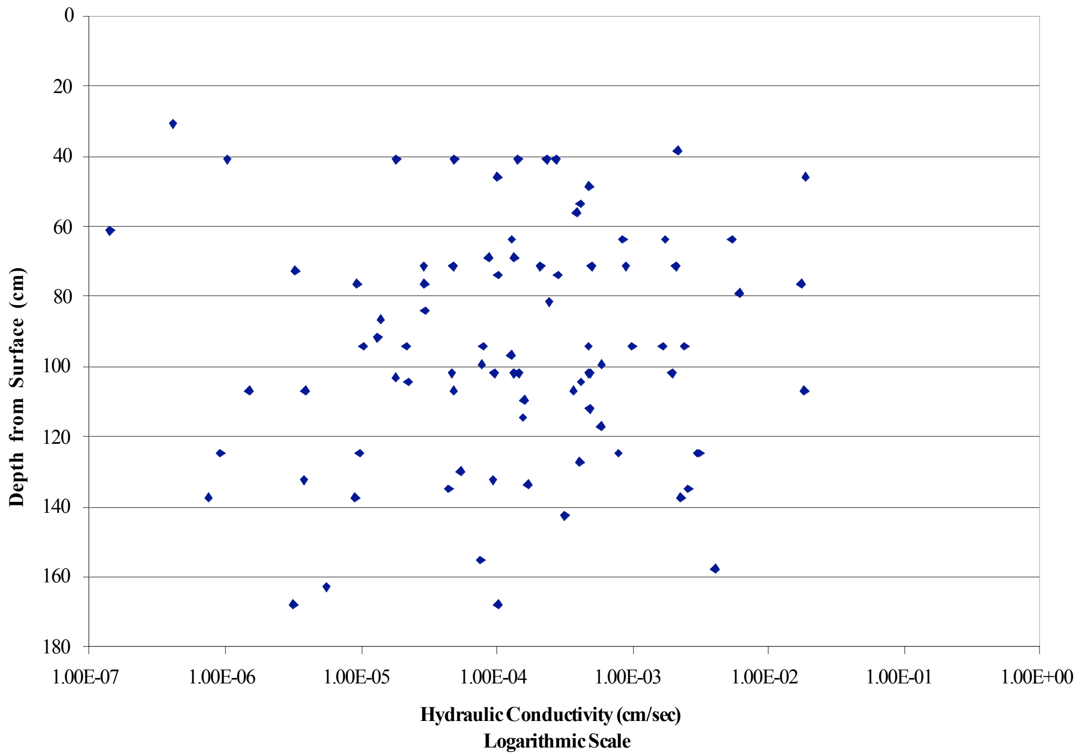

Figure 11. Hydraulic conductivity by depth (no significant differences between depths).

As can be seen from Figure 11, as depth increases, hydraulic conductivity neither increases nor decreases in a consistent trend. Higher and lower values exist at both shallow and deep locations within the soil profile. This demonstrates the varying nature of the soil composition within the profile. The subsurface stratigraphy of this region indicates that underneath the gravel and sand formations (Upland Deposits and Calvert Formation) there exists the silty clays and clayey sands of the Nanjemoy Formation followed by a confining unit of clays known as the Marlboro Clay (Wilson and Fleck, 1990). It was originally assumed that the mining operations would have removed most of the gravel and sand formations, leaving the silty clays and clays exposed at the experimental site, such that with increasing depth, a higher proportion of clays would be encountered in the soil profile.

Mining operations, however, will only remove what is economically feasible, and it is obvious from the visual inspection and soil core analyses that pockets of sand and gravel remain at the mined site, particularly in the north end of the experimental site (Block 1). The range of depths examined in this experiment encompassed the upper two meters of the soil profile (i.e., was limited to the soil profile in proximity to the biosolids rows). The relatively shallow profile considered likely did not cross over different geographic formations within each subplot considered. Furthermore, with all of the soil disturbance inherent to the mining operations, and the fact that this experimental site had previously been subjected to bisolids application, significant alteration of the profile had already occurred. Were there originally a trend of increasing clay content with depth reflecting different stratigraphic regions in the upper two meters of the profile, they may have been mixed enough to render them indistinguishable.

Figures 12 and 13 show hydraulic conductivity by block. Figure 12 emphasizes the marked differences between blocks, the most notable difference belonging to Block1, with the highest overall values. Block 1 is located on the north end of the experimental plot, is approximately 10-15 feet lower in elevation than Block 3, and is characterized by high sand and gravel content. Figure 13 shows the same data, but with a log transformed scale to make the lower end of the scale more visible.

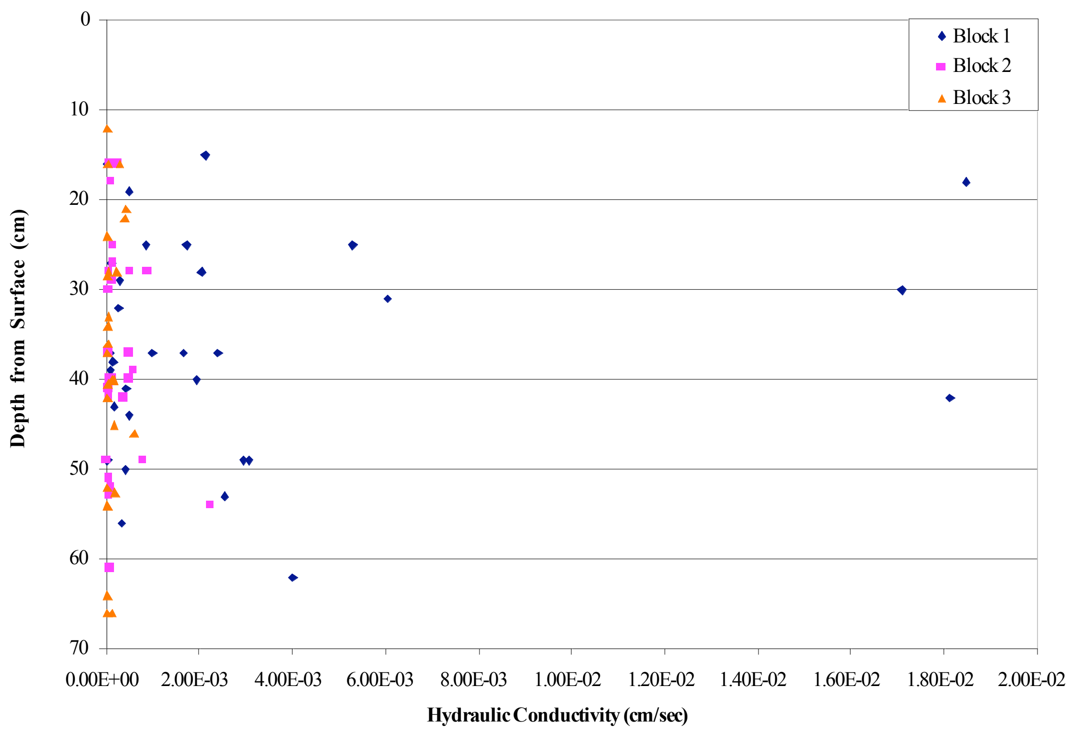

Figure 12. **Hydraulic conductivity by block.**

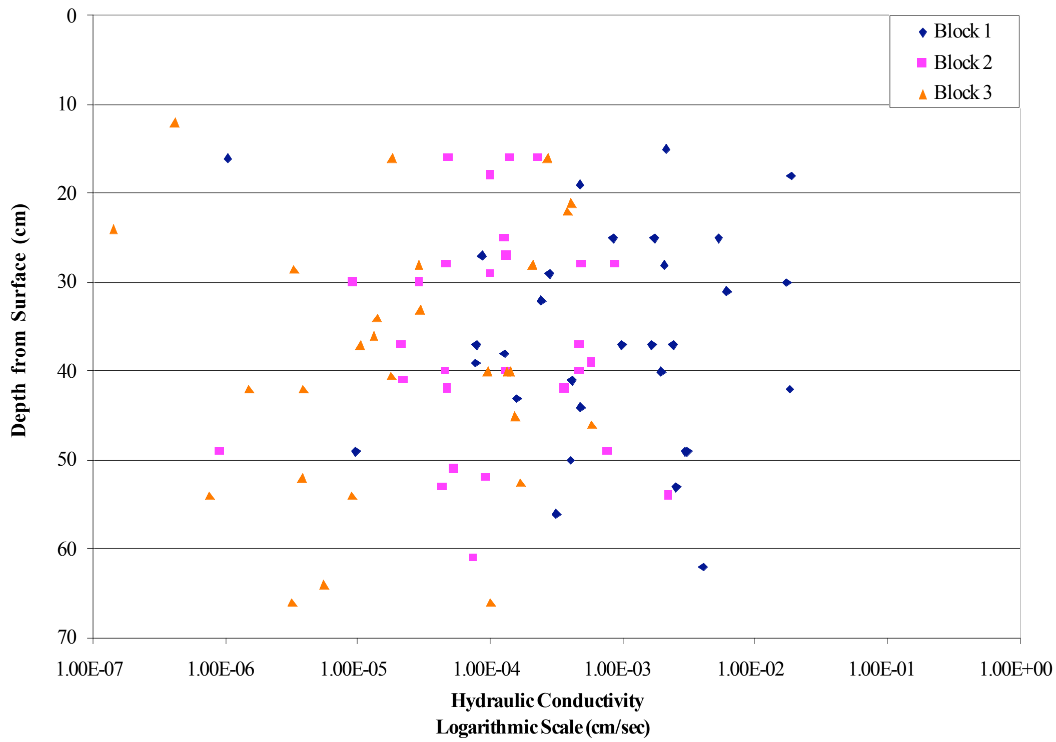

Figure 13. Hydraulic conductivity by block (logarithmic scale).

Though not a specific goal during the design of the experiment, the vast range of soil conditions encountered has expanded the scope to examine nutrient fate and transport in a much wider variety of soil types. Consequently, results will provide information about whether or not this reclamation technique is environmentally feasible not only in high clay content soils, but in sandier soils as well.

NITROGEN IN SOIL NEAR BIOSOLIDS

Samples were collected on a monthly basis during application to the experimental site to monitor the concentrations of macro and micronutrients. Prior to beginning applications in mid-March 2002, four biosolids samples were collected from routine deliveries at the ERCO site to determine nitrogen content. The four samples together produced an average value of 1.16% total N on a wet weight basis. During the design stage of the research project, several biosolids samples were collected upon drop off at the tree farm and showed, on a wet weight basis, an organic nitrogen concentration of 1.16% (11,600 mg/kg), total phosphorus content of 0.38% (3800 mg/kg), pH of 11-12, and percent solids content of 20-25%. Mean nitrogen content was 4.12 % on a dry weight basis. Ammonium (NH4-N) was 0.27%. By simple calculation, inorganic nitrogen constitutes 7% of the total nitrogen.

The product, ammonium, is soluble in water and easily infiltrates the soil profile, though movement is often limited by the cation's attraction to negatively charged particles in the soil (Haynes, 1986). In fact, more than half of the pan and suction lysimeter samples contained ammonium concentrations in exceess of 1000 mg/L. There was no significant differences between any application rates, tree densities, or time. Experiments conducted by Brutsaert, et al. (2004) on nitrate leaching from biosolids stockpiles showed that leachate samples collected over an eight month time frame in pan lysimeters installed in the soil profile one and two feet under the stockpile contained 800-1500 mg/L total Kjeldahl nitrogen (most of which was in the form of ammonium). Three feet below the stockpile, a marked decrease in total Kjeldahl nitrogen was noted, with values typically below 100 mg/L. Leachate collected directly from the stockpile contained 2,800 – 4000 mg/L ammonium, demonstrating that some attenuation or conversion of ammonium had occurred.

Based on the fact that ammonium is held in the soil by the reversible process of cation exchange, in which ammonium is adsorbed to negatively-charged soil sites, as well as the non-exchangeable process of fixation within clay lattices (Haynes, 1986), it may have been expected that ammonium would be more selectively absorbed by those subplots with higher silt and clay concentrations. Haynes (1986) and others have noted that, barring other factors, leaching losses of ammonium are usually only problematic in soils with a low cation exchange capacity (CEC), as is often evidenced in sandy soils. Block 3 contained the highest amount of clay in the soils, followed by block 2. Block 1 contained the sandiest of the subplots. Based on this observation, block 1 should allow the highest amount of ammonium to flow through the soil profile to the pans, followed by block 2, with block 3 hindering flow the most. However, the results indicated that no single block stood out as having predominantly higher ammonium concentrations across the treatments.

There was an overall trend of an increase in ammonium concentration with time, but the trend was not consistent and was generalized, because the trend did not differentiate between suction lysimeter positions (i.e., the "application rate by tree density by position by quarter" interaction was not significantly different). Comparison of application rates did show the controls to have significantly less ammonium than other application rates.

The most notable trend from both observational and statistical analysis was that ammonium concentration decreased with depth below the biosolids which suggests that more ammonium is reaching the first of the vertical suction lysimeters, with attenuation as it travels deeper through the soil profile. The decrease with depth could be due to cation exchange reactions in the soil that hold the ammonium and delay movement with soil water, microbial interactions (i.e., immobilization) or, though less likely, conversion of ammonium to nitrate with subsequent immediate denitrification.

Figure 14 presents the nitrate-N results from both the pan lysimeter samples and the suction lysimeter samples by application rate for all treatments, with the 10 mg/L drinking water level highlighted.

- Of the 521 pan and 1820 suction lysimeter results taken from 11/03 to 4/05, only 5 results (0.2%) exceeded the drinking water MCL of 10 mg/L.

- Some individual results with statistically significant differences were found, but there were no discernable trends between application rates (including controls), tree densities, and/or time.

- Statistically significant differences in such low levels of nitrate do not translate to significant differences from an agricultural, engineering, or water quality perspective.

Regardless of the soil composition, it appears nitrates are not being produced or leached into the water table, even before the tree roots are in place. The conditions in the deep rows are not conducive to the production of nitrate. The biosolids lack oxygen due to encapsulation by soil. Because of encapsulation, ammonia volatilization is impeded. The moist or near-saturation conditions create an anaerobic environment which impedes nitrification. Additionally, high salt content strongly inhibits nitrifying bacteria. The depressed temperatures, ranging from approx. 13-18°C (55-65°F) also inhibit bacterial activity.

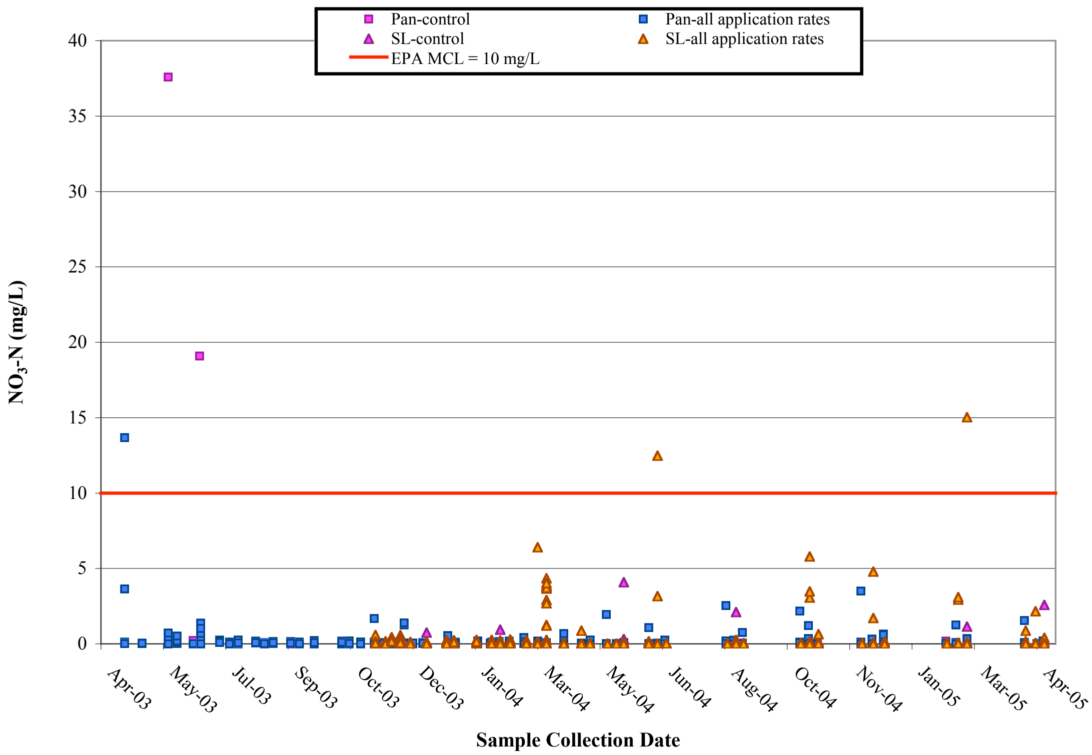

Figure 14. **Nitrate levels from pan and suction lysimeters (April 2003-April 2005).**

Foliar Nutrient Status of Hybrid Poplar Trees

It was not expected that any of the treatments would cause any significant differences in growth or foliar nutrient uptake during the first two years. It is not until the trees have established their root systems and the crowns and roots of the trees start to compete with each other for nutrients that treatment effects are expected to occur.

Values for percent foliar nitrogen in the research area ranged from 2.72 – 3.13 and values for percent foliar phosphorous range from 0.25 – 0.31, both well within the range of values typical of fast growth on fertilized plantations. The N:P ratios ranged from 10.1 to 10.9, above the value of 9.5 in the literature that corresponds withrapid growth.

Field observations indicate these trees (in growth year two) are just in the process of accessing the available nutrients in the biosolids.

Tree Planting Method

After one year, the mortality of cuttings on the plots with subsoiling was much lower (1.7%) compared to the cuttings planted without subsoiling (14.2%). Height growth of the cuttings planted without subsoiling was also much higher (0.524 m) than the cuttings planted without subsoiling (0.339 m). It was assumed that the better growing conditions created by subsoiling were in part the cause of these differences in mortality and height growth. The long-term impacts of planting without subsoiling are that trees will take longer to establish themselves and that rotation length may need to be extended to accrue similar amounts of biomass compared to trees planting with subsoiling. The first year results indicate that subsoiling is an essential part of site preparation for planting and is critical to good survival and rapid site colonization by hybrid poplar.

CONCLUSIONS

The following conclusions can be drawn from the research highlighted:

- The well data indicate that the aquifer and aquiclude below the site are not impacted by the biosolids application. For all wells, nitrate water concentrations were most commonly at or less than detection limits. Occasionally, nitrate concentrations were reported at higher levels than detection limits but never did the level approach the drinking water standard of 10 mg/L.
- There was an overall trend of an increase in ammonium concentration with time, but the trend was not consistent. Comparison of application rates did show the controls to have significantly less ammonium than other application rates.
- Ammonium concentration decreased with depth below the biosolids which suggests that more ammonium is reaching the first of the vertical suction lysimeters, with attenuation as it travels deeper through the soil profile.
- • Of the 2341 pan and suction lysimeter nitrate results, only 5 results (0.2%) exceeded the drinking water MCL of 10 mg/L. During these first two years, no discernable trends between application rates, tree densities, and/or time were found.
- Taken as a whole, the water quality work suggests strongly that the deep row biosolids application rates used in this study are not releasing nitrate to the environment in the first 24 months following application.
- The use of subsoiling prior to planting to reduce soil compaction is essential for early growth and survival.
- Based on foliar nitrogen and phosphorous levels, the trees responded similarly to fertilized plantations.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the commitment and financial support of Steve Gerwin with the Washington Suburban Sanitary Commission throughout this project, as well as the ideas and support of Chris Peot with the Washington, D.C. Water and Sewer Authority. The installation of the equipment, data collection, and analysis on this project would not have been possible without the hard work of the graduate students, Carrie Buswell and Tommy Griffith. The expert machine operation of Scott Flamino has been critical to making things work. The University of Maryland authors on this project have the greatest respect and admiration for the years of commitment and hard work by Eric Flamino, who without his effort and support this technology would not have advanced.

References

APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.

Brutsaert, W., J.M. Peckenham, and Hunter. 2004. Report for 2003ME18B: Nitrate mobility in shallow groundwater near biosolids stockpiles. http://water.usgs.gov/wrri/02-03grants_new/prog-compl-reports/2003ME18B.pdf

Campbell, C.R. 1992. Plant analysis reference procedures for the southern region of the U.S. Southern Cooperative Research Services Bulletin 368. USDA, Washington, D.C.

DC-WASA, 2002. Biosolid utilization statistics. Washington, D.C. Water and Sewer Authority. Washington, D.C.

EPA, 1993. Methods for Chemical Analysis of Waters and Wastes. EPA 600/4-79-020.

Gorsuch, T.T. 1970. The Destruction of Organic Matter. Pergamon Press, New York, New York.

Hansen, E.A. 1994. A guide for determining when to fertilize hybrid poplar plantations. Res. Pap. NC-319. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station.

Hansen, E.A. and D.N. Tolsted. 1985. Nitrogen sources and fertilization rates affect growth of hybrid poplar. In: Proc. Fifth Central Hardwood Forest Conf., J.O.Dawson and K.A. Majerus (eds). Dept. Forestry, University of Illinois, Urbana-Champaign, IL.

Haynes, R.J. 1986. Mineral Nitrogen in the Plant-Soil System. Academic Press, Inc. Orlando. Florida.

Knute, A., ed. 1986. Methods of Soil Analysis Part 1: Physical and Mineralogical Methods, 2nd edition. Number 9 (Part 1) in the Series Agronomy, American Society of Agronomy, Inc., Soil Science Society of America, Inc. (publishers), Madison, Wisconsin. Chapter 28: Hydraulic Conductivity-Diffusivity: Laboratory Methods. Constant Head Method. (pg 687).

Kuehl, R.O. 2000. Design of Experiments: Statistical Principles of Research Design and Analysis, 2nd edition. Brooks/Cole Publishing Cmpany, Pacific Grove, California.MDE. 2002. Sewage sludge utilization in Maryland,@ Maryland Department of Environment, Design and Certification Division, Baltimore, MD.

Pepperman, R.E. 1995. Report on the ERCO, Inc. Tree Farm Biosolids Benifical Reuse System. Environmental Group Services, Inc., Baltimore, Md. pp74.

Sikora, L.J., W.D. Burge and J.E. Jones. 1982. Monitoring of a municipal sludge entrenchment site. J. Environ. Qual. 11(2): 321-326.

Tompkins, M.D. 1983. Prince Georges County Ground-Water Information: Well Records, Chemical-Quality Data, Pumpage, Appropriation Data, Observation Well Records, and Well Logs. Maryland Geological Survey Water Resources Basic Data Report No. 13.pp160.

Van Ham, M.D. 2003. Personal communication.

Walsh, L.M., ed. 1971. Instrumental Methods for Analysis of Soils and Plant Tissues. Soil Science Society of America, Madison, Wisconsin.

Wilson, J.M. and W.B. Fleck. 1990. Geology and Hydrologic Assessment of Coastal Plain Aquifers in the Waldorf Area, Charles County, Maryland. Maryland Geological Survey, Report of Investigation No. 53. Baltimore, MD.pp138.

Zabek, L.M. 1995. Optimum Fertilization of Hybrid Poplar Plantations in Coastal British Columbia. M.Sc. thesis. University of British Columbia, Vancouver BC.

Zabek, L.M. 2001. Nutrition and Fertilization Response: A Case Study Using Hybrid Poplar. Ph.D. Dissertation. University of British Columbia, Vancouver BC.