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Determination of Optimum Tree Density, Biosolid Application Rate, Water Quality Impacts and Tree Growth Effects Using the Deep Row Biosolids Incorporation Method

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EXECUTIVE SUMMARY

Deep row incorporation of biosolids on reclamation sites is a unique alternative land application method that solves many of the problems associated with surface application techniques. It presently involves the placement of biosolids at application rates of 171 to 294 dry tons per acre into trenches that are immediately covered with overburden, eliminating odor problems and maintaining biosolids in a fairly stable, anaerobic environment. The site is then planted with hybrid poplar trees, the roots of which provide a natural recycling system that utilizes nutrients over a six-year period.

A three-year research and Extension education project was implemented to investigate the effect of application rate on water quality resulting from deep row biosolid applications. The objectives are to determine the effect of biosolid application rates on water quality around deep rows on a gravel mine spoil, determine the contribution and nutrient removal made by trees, and educate state and local environmental professionals about the use of deep-row biosolid applications to develop sustainable forest crops and simultaneously rehabilitate disturbed soils. Long-term records from well and surface water analyses were evaluated to determine water quality and supply implications. Hydraulic conductivity data from the soil profile and biosolids, and nutrient data from soil water samples were collected to examine the fate and transport of nitrogen (N) and phosphorus (P) from the biosolids trench.

Water Quality Impacts

Well and surface water data from the past 20 years were examined to decipher water quality and supply impacts. More recent data collected between 1990 and 2004 focused on the following parameters: fecal coliforms, chloride, nitrate, ammonia, and total solids. Data from approximately 250 samples encompassing eight monitoring wells conclusively demonstrated that nitrate is not entering the water supply from the biosolids operation. The pH did not vary much over the 14-year time frame. Chloride concentration did vary between some wells, with both Well #2 and Well #6 exhibiting higher levels than the others, though all values from all wells were well below drinking water standards. Ammonia and total solids concentrations were low for all wells with the exception of Well #2. Overall, Well #2 produced slightly higher values throughout the 14-year time span, with an individual spike in concentration for each analyte on separate sampling dates. Elevated total solids in a groundwater monitoring well is indicative of a direct hydraulic connection to the surface, which may be caused by a compromised well structure. Based on this and other observations, monitoring Well #2 was identified as possibly in need of repair or replacement.

Biosolids utilized in this experiment averaged 1.15% nitrogen (wet weight basis) and 71.8% moisture. Preliminary hydraulic conductivity results over the 3.1-acre experimental site show a range of 1.4×10^{-7} to 1.8×10^{-2} cm/s and an average value of 1.19×10^{-3} cm/s. From April 2003 through December 2004, soil water from 425 pan lysimeter samples and 1465 suction lysimeter samples were analyzed. Nitrate and orthophosphate results are presented in this report. Total nitrogen, total phosphorus, ammonia, chloride, sulfate, and pH results are still being compiled.

Nitrate concentrations were extremely low, with 98.7% of results (all but 25 samples) at or below 1.0 mg NO_3-N/L and a majority non-detected. Of the 1890 samples, 0.2% (i.e., 4 samples) exceeded the drinking water standard of 10 mg NO_3-N/L for nitrate. Orthophosphate concentrations ranged from 0.5 to 2.5 mg/L, with an average concentration of 0.096 mg/L. Only orthophosphate from the pan lysimeters appears to be related to biosolids application rate, with several spikes occurring only at the heaviest loading rate. The cause of the spikes may, in part, be due to the exceedingly high precipitation received during the course of the experiment. Taken as a whole, this work strongly suggests that the deep row biosolids application at the assigned rates is not releasing nitrate to the environment in the first 25-30 months following application.

Responses of hybrid poplar to deep row application.

Survival and initial growth were significantly impacted by the planting technique used. Specifically, the use of subsoiling (the standard technique practiced at the ERCO tree farm) prior to planting hybrid poplar cuttings significantly reduced mortality and increased one year height growth compared to planting with a dibble bar. Mortality was only 1.7% with subsoiling compared to 14.2 % when using a dibble bar. One-year seedling growth was 52.4 cm. with subsoiling compared to 33.9 cm. without subsoiling. Subsoiling appears to be essential because, unlike the dibble-bar technique, it fractures and loosens the compacted soil so tree roots can rapidly establish and water can readily penetrate the soil surface.

Nitrogen (N) levels in foliar leaf samples from two-year old seedlings were between 2.72%-3.13%, foliar phosphorus (P) levels were between 0.25% and 0.31%, and N:P ratios were between 10.1-10.9. These nutrient contents were well within the ranges found on fertilized hybrid poplar plantations elsewhere, indicating even young seedlings were accessing the nutrients and/or water in the biosolids. No growth or foliar nutrient differences were found, or expected, between application rates or planting densities at this early stage of stand establishment.

Elsewhere on the tree farm site, experiments were performed to determine the effect of vegetation management and phosphorous amendments on four year old and newly planted hybrid poplar seedlings. After year one of the two-year study, results were mixed. In four-year old trees, all treatments (surface vegetation management, phosphorous amendments, and combined vegetation management and phosphorous amendments) increased height growth, but only vegetation management combined with phosphorous amendments increased diameter. None of the treatments impacted biomass production after one year. Foliar nitrogen levels were between 3.6% and 4.0%, foliar P levels were between 0.31% and 0.42%, and N:P ratios were between 9.5 and 12.1. Trees with phosphorous amendments only had a significantly higher N:P ratio (12.1). These are representative of maximum levels found in fertilized plantations and indicate the trees are utilizing the biosolids.

Experiments to determine vegetation and phosphorous amendment effects on growth of newly planted seedlings were inconclusive due to heavy deer browsing. Foliar nutrient levels were again at high levels characteristic of fertilized plantations (%N between 2.9 and 3.5, %P between 0.28 and 0.31, and N:P ratios between 9.5 and 12.4). No significant differences were observed, however, between treatments.

Data collection continued on a long-term evaluation of 10 different hybrid poplar clones. Five-year results confirm the ongoing trend in superior performance, survival, and height growth of the OP367 clone. Although many species exhibited good survival, height growth was a distinguishing characteristic. Average height values of the OP367 and the four closest clones were as follows: OP367 (933 cm); DN17 (833 cm); 15-1029 (743 cm); DN34 (708 cm); and NM6 (701 cm). Based on survival, growth, and other factors such as disease resistance, OP367 was chosen as the operational clone used at the ERCO Tree Farm site.

In summary, OP367 hybrid poplar clones are well suited to these sites and are utilizing nutrients at levels typical of those used by hybrid poplars grown on surface applied or subsurface injection fertilizer plantations. The impacts of vegetation and phosphorous amendments should be better understood after another growing season. Subsoiling prior to planting is essential for early growth and survival and deer are a major factor in early plantation establishment.

Economic Analysis and Potential Utilization

A hypothetical business analysis of a deep row operation based on reasonable assumptions and values found that an application rate of 4,000 lbs/N/acre resulted in only $4,075 profit (income – expenses) per year. However, if the application rate was increased to 8,000 or 12,000 lbs/N/acre then the profit increased to $208,325 and $412,575 per year, respectively, despite the fact that equipment and personnel needs increased.

The profitability of the enterprise can be improved by: 1) reducing taxes by utilizing a woodland assessment; 2) decreasing water quality monitoring costs; 3) reducing costs for permits and assessment; 4) producing larger trees that can be sold for pulp; and 5) reducing the opportunity cost of the land. Additionally, this deep row technology has the capability to reduce external costs to society caused by pollution and other factors.

As of 1998, 12,788 acres of permitted mine spoils existed in the Metro area and 72% of those parcels were larger than 50 acres. Assuming only 50% of the sites larger than 50 acres are available for deep row application, the three application rates in this research study (4000, 8000, & 12000 lbs/N per acre) could utilize 62%, 125%, and 187% of the annual biosolids produced in the Metro area, respectively. In parcels over 100 acres in size, the utilization rate for the three treatments would be 38%, 77% and 116%, respectively. These initial estimates show great promise for application of this technique, and suggest the need for a more current assessment of applicable acreage.

Educational Programs

Annual October field days at the ERCO site have resulted in a better understanding of deep row application by university, industry and regulatory professionals, as well as better networking that has increased program support and garnered additional funding. Each of these sessions was attended by 35-50 professionals and informed citizens from industry, state agencies, universities, and others. Participants were not only from Maryland but from Virginia, Pennsylvania, and West Virginia.

INTRODUCTION

Since the advent of civilization, with increasing populations living in fixed locations, disposal and treatment of household waste has been a necessity of life. Domestic wastewater systems evolved from more rudimentary flushing systems that discharged raw waste directly into waterways to the more sophisticated wastewater treatment plants in use today. In current systems, raw sewage enters the facility; is treated through physical, chemical, and biological processes to meet regulatory requirements; and exits in two forms: 1) as effluent and 2) as sewage sludge (a.k.a., biosolids). Liquid effluent is effectively integrated back to the environment via discharge into waterways, or in some cases by underground injection. Biosolids, however, poses a greater integration challenge that, in many cases, proves costly. It is therefore of societal interest to develop safe, effective, and economical means of biosolids disposal, or better yet, recycling.

Current United States regulations for disposal are delineated in The Standards for Use of Disposal of Sewage Sludge (Title 40 of the Code of Regulations {CFR} Part 503). In addition to incineration, landfilling, and composting, these Environmental Protection Agency (EPA) regulations allow for land application of biosolids, and strongly encourage implementation of this technique for beneficial uses. Most beneficial uses consist of land application to agricultural fields and other nutrient-deficient lands to enhance growth of vegetation. In such cases, application must follow the protocols in 40 CFR part 503 to ensure that excess nutrients are not transported to surface water or leached to ground water.

Biosolids utilization in forest lands, particularly in silviculture operations, has gained increased popularity in the United States. Surface spraying, spreading and subsurface mixing in the soil are the primary distribution techniques, typically with applications required each year or multiple times a year to successfully meet the nutrient needs of the trees and production goals of the operation. Because it is not a food crop, concerns related to the potential uptake and ingestion of biosolids contaminants do not exist. Not only do the biosolids provide a nutrient source for the trees, they also build up the topsoil, reduce erosion and increase above and under ground ecosystem diversity.

An alternative land application regimen, referred to as deep row application, has been in use on private property owned and managed by the Environmental Reclamation Company, Inc. (ERCO, Inc.) since the early 1980s. This technique was established on an exhausted surface sand and gravel mine that, prior to reclamation as a tree farm, consisted of sand and gravel remnants underlain by a clay layer. As such, it was devoid of organic matter and subject to erosion. In concert with regulatory requirements to reclaim abandoned mine sites, ERCO devised a reclamation plan to grow hybrid poplar trees over deep rows that had been filled with biosolids. The biosolids would serve as a long-term nutrient source for the fast-growing, nutrient-demanding poplars. The poplars, in turn, would provide erosion control, wildlife habitat, and potentially become a marketable product.

BACKGROUND

Biosolids production for 2002 for the Washington, D.C. & Baltimore, MD metro area, which includes the counties of Baltimore, Howard, Montgomery, Prince George's, Charles, and Anne Arundel, was 827,514 wet tons (MDA, 2002; WASA, 2002). These biosolids were utilized as follows on a percentage basis: applied on agricultural land outside of Maryland (56%); applied on agricultural land in Maryland (9%); hauled out of Maryland but utilization unknown; composted (7%); storage (9%); incinerated (3%); and landfilled (2%). It is clear from these statistics that Maryland relies heavily on agricultural land application in adjoining states (Virginia and Pennsylvania) to utilize the majority of biosolids produced in-state.

The passage of the Clean Water Act in 1972 resulted in elevated pressure on municipalities to find methods other than dumping to utilize biosolids from treatment plants. Presently, biosolids are surface-applied on farmland, marketed for compost, and incinerated; however, the most cost-effective methods of biosolids management are either by application to agricultural land or burial in landfills. Agricultural land application makes up a significant portion of the biosolids utilized in the Metro area, but the passage of the Water Quality Improvement Act (WQIA) of 1998 in Maryland may reduce farmland application due to phosphorous-based application requirements. Agricultural land application of municipal biosolids can boost soil productivity for field crops and improve soil characteristics. However, regular broadcast applications necessary to provide crop nutrient requirements can cause logistical, safety, and economic problems due to transportation cost, poor weather, frozen soils, restricted availability of labor, and other problems. Resentment by rural landowners and offensive odors in urbanizing areas has resulted in many local application restrictions. Difficulty in permitting and developing new landfills and possible future restrictions on out of state hauling may result in restriction and/or increased cost of landfill disposal of biosolids. The developing drawbacks of landfill and agricultural land application points to the need for alternative utilization technologies for biosolids that are both cost-effective and environmentally sound (Sikora and Calacicco 1980; Kays et al., 1997).

PREVIOUS WORK

The land application of biosolids on native forests, reclamation sites, and plantations through regular broadcast applications has been used in other parts of the country, with significant growth responses documented (Cole et al., 1986; Heilman et al., 1995; Sopper, 1993; Aschmann, 1988; Purkable, 1988). Deep-row biosolid applications for forest product production has the potential to solve many of the problems associated with agricultural land application and other land disposal methods and enhance the multi-state Chesapeake Bay cleanup effort.

Deep Incorporation Research

Documented records regarding the utilization of sewage as fertilizer dates back to the 1500s in Germany, where sewage was used on croplands. Under the Federal Water Pollution Control Acts of 1972, land application of biosolids was recognized as a protocol for disposal, provided the disposal was managed in accordance with the applicable regulations. In conjunction with this recognition, experts from the EPA, United States Department of Agriculture (USDA), and National Land Grant Universities pooled their resources to form a Coordinating Committee on Environmental Quality that developed a subcommittee on Recycling Efforts of Sludges on Land. This subcommittee evaluated research that had been conducted on the pros and cons of biosolids application to provide guidance on the most appropriate protocols for use. This increased interest, along with the ongoing buildup of biosolids at wastewater treatment plants, sparked a series of research projects that evaluated the impacts of biosolids application to land (Lue-Hing, et al., 1992).

Burying biosolids in deep-rows covered by a soil overburden was researched in the 1970's (Sikora and Colacicco, 1980; Taylor et al., 1978). In the early 1970's, the Washington Suburban Sanitary Commission purchased hundreds of acres of land in the counties surrounding Washington, D.C. for the purpose of burying biosolids in trenches at rates approximately equal to and greater than 171 dry tons per acre. Long term monitoring of the sites has found elevated nitrates in groundwater at some areas (Sikora et al., 1982). While the production of annual corn crops on treated areas was researched (Sikora et al., 1980), no forest crops or other deep-rooted perennial crops were intentionally established to utilize the large reservoir of nutrients.

Two studies are of particular interest. Sikora, with USDA-ARS at Beltsville, Md., reported on trench studies in both sandy soils and heavier soils. Sikora's tests placed lime-stabilized biosolids in trenches 610 mm (24 in.) wide by 500-1300 mm (20-50 in.) deep on 1270 mm (50 in.) centers, covered with 0.15-0.30 m of subsoil. Water samples were collected from drainage tile lines, a catchment pond, and monitoring wells within and around the trenched plot. Sikora's various experiments grew corn and grass in field studies and Taylor et al. (1978) grew corn in 160 day simulated deep-row experiments in a greenhouse setting.

In the Beltsville studies (Sikora et al., 1982), five years after the application on Manor and Glenelg silt loam soils, no increases in N and Cl were detected in ground water, although elevated levels were found in the soil water just beneath the trenches. However, in similar studies on a sandy soil (Sikora et al., 1979a), ground water pollution was recorded. Specifically, these studies showed a peak in chloride levels 18 months after entrenchment and a peak in nitrate concentration a year after the chloride peak (i.e., 30 months after entrenchment). Nitrate concentrations were below the EPA MCL of 10 mg/L nitrate-N in wells above and below the trench plot. Though a high nitrate concentration of 60 mg/L occurred during November 1974 in one well within the trench plot, most concentrations (>85%) were below 10 mg/L. Tile drains exhibited a high nitrate-N concentration of 32 mg/L. Other observations of note were that metals did not migrate and pathogens were significantly reduced.

Metal movement through soil is generally considered minimal except in instances when the pH is below 5.5 (Chaney et al., 1977), which is not a problem on most sites due to liming requirements. The general conclusion concerning ground water pollution by biosolids at other deep-row sites is ground water immediately beneath the sites has the potential to experience increases in N and Cl and these levels decrease with time.

The researchers (Sikora et al., 1979b, 1980) noted some interesting characteristics of the biosolids in the trenches. Observations included an analysis of the original sludge sample and then the progression of the sludge starting at 22 months after entrenchment. First, the biosolids dewatered from the top down, or, in other words, the tops of the trenches were dry, whereas the bottoms of the trenches remained wet. After 22 months of entrenchment, the top portion of the sludge (2-8 inches from the top of the trench) had dried out and was densely penetrated with roots. The middle and bottom portions of the trench did not dewater until 49 months after entrenchment. After this four-year period, the entire trench contents appeared to have stabilized. Similar to Walker's observations (1974), dewatering occurred from the top down. This observation led to the conclusion that mineralization and subsequent transformations began in the uppermost portion of the biosolids shortly after entrenchment but that denitrification was taking place concurrently as the leachate from the upper portion of the biosolids moved into the wetter, lower portions of the entrenched biosolids. Sikora et. al. (1980) reported on the trenching of digested biosolids. Certain physical observations of the biosolids-filled trenches are meaningful. The first sampling of these trenches occurred almost two years after biosolids placement. At that time the top portion of the trench was densely rooted and "peat-like" and the middle portion was only sparsely rooted, wet in appearance, and odorous. After four years, the top and middle portions were brown and odorless. The Sikora team concluded that trenched biosolids become "stabilized" with respect to further decomposition after about four years.

Nitrogen Fate

<u>The Nitrogen Cycle</u>

In order to understand the implications of sewage sludge disposal techniques and associated scientific studies, the nitrogen cycle must be understood. Nitrogen is one of the most important nutrients for plant growth. Only certain water-soluble inorganic forms, however, including ammonium (NH_4^+) and nitrate (NO_3^-), can be absorbed by higher plants. In biosolids, the ratio of organic to inorganic forms of nitrogen is determined by the treatment process. Liquid anaerobically digested sludge may contain a majority of nitrogen in the form of ammonium, with lesser amounts as organic nitrogen and negligible amounts of nitrate. In undigested lime-stabilized biosolids, however, the majority of nitrogen present is in the form of organic nitrogen (Shepherd, 1996; Gshwind and Pietz, 1992). Several biochemical processes must therefore occur before plants benefit from this nutrient source. Mineralization is an enzymatic process in which organic nitrogen is decomposed to inorganic forms. The first step is ammonification, in which microbes break down organic nitrogen and produce the ammonium cation (NH_4^+). This process occurs in either anaerobic or aerobic conditions and is performed by a broad group of heterotrophic organisms.

Nitrification consists of two main sequential steps that include: 1) the oxidation of ammonium to nitrite (NO_2^-) by the autotrophic *Nitrosonomas* bacteria; and immediately thereafter 2) oxidation of nitrite by *Nitrobacter* bacteria to produce nitrate. The swift transition from nitrite to nitrate prevents accumulation of nitrite. Both of the nitrifying organisms responsible for this reaction sequence are aerobes, requiring the presence of oxygen to perform these conversions. In addition, they favor soils with no more than 60% of pore volume filled with water, need a carbon source (i.e., bicarbonates and carbon dioxide), and optimally perform at temperatures between 20-30°C (Brady and Weil, 2002).

Nitrate is an anion that is not readily adsorbed to soil particles, is water soluble and therefore highly mobile. Of the forms of nitrogen described above, it presents the highest risk of leaching through the soil profile to the groundwater table. Additionally, nitrate warrants the most concern from a human health and environmental pollution perspective. Most acutely in infants and ruminant animals, ingested nitrate is reduced to nitrite, which decreases the oxygen-carrying ability of red blood cells and produces a condition known as methemoglobinemia (Brady and Weil, 2002). Consequently nitrate is a regulated pollutant in drinking water with a Maximum Contaminant Level (MCL) of 10 mg/L for NO_3-N (EPA, 1994).

Initially, biosolids contain extremely low levels of nitrate, 0.019% or 0.4 lbs/ton biosolids (Pepperman, 1995). Nitrate evolves slowly from biosolids when anaerobic conditions prevail and lime stabilized biosolids have a significantly lower nitrate production rate than do digested biosolids (Taylor et al., 1978).

Nitrate also can have a pronounced impact on aquatic systems. An influx of nitrate promotes algal blooms that, upon dying, are decomposed by oxygen-demanding bacteria. Exponential growth and decay results in exponential demand and depletion of oxygen. Hypoxic conditions result that are toxic to many forms of aquatic life. Proliferation of this cycle can expand these inhospitable zones on a yearly basis, rendering once productive waters lifeless.

The converse of mineralization is immobilization, in which ammonium or nitrate is complexed into an organic form via biotic or abiotic means. Both processes occur simultaneously, as microbe populations grow and die, and rates are dependent upon the composition of the soil. Some forms of nitrogen, particularly organic nitrogen and ammonium, can also be adsorbed on active sites of the soil, limiting movement through the soil profile.

Denitrification refers to those processes in which nitrate ions are converted to gaseous forms of nitrogen {e.g., nitric oxide gas (NO_2+), nitrous oxide gas (N_2O^+), and nitrogen gas (N_2)}. The majority of bacteria performing this function are facultative anaerobes that can be either heterotrophs (i.e., obtain their energy and carbon from oxidation of organic compounds) or autotrophs (i.e., obtain their energy and carbon from carbon dioxide or carbonates). Required environmental conditions include: low soil air content (<10%), temperatures between 2-50°C (with an optimum range of 25-35°C), and an appropriate energy source (Brady and Weil, 2002).

Patrick and Gotoh (1974) studied the impact of O_2 levels in nitrogen loss from saturated soils and indicated that anaerobic conditions greatly inhibited biological oxidation of NH_4^+ to NO_3^-. In their study, nitrate that was formed then migrated to an anaerobic layer where denitrification occurred. Again, under very saturated conditions, Lindau et al. (1988) demonstrated that nitrogen applied as N-urea and N – KNO_3 was denitrified. Between 44% and 77% of applied N was denitrified and between 28% and 40% of the applied and denitrified N became trapped in the soil.

Land Application of Biosolids

Land application of biosolids to improve soil conditions, enhance crop production, and reclaim mined land has been extensively studied. Biosolids are either applied 1) on the surface, 2) by disking or plowing into the soil to a prescribed depth (usually no more than 15 cm) or 3) via injection underneath the surface. Nitrogen requirements of the crop and background soil concentration dictate application rates, with seasonal or yearly applications often being performed. Site and crop specific management are the key to optimizing growth while preventing nitrogen loss from the system (Ritter, 2001; USEPA, 1994b; Outwater, 1994; Granato and Pietz, 1992).

Numerous examples of nitrate leaching under biosolids-amended agricultural land have been reported in the literature (Ritter, 2001; Shepherd, 1996; Clapp, et al., 1994; Sopper, 1993). In these studies, the timing and rate of application, type of biosolids used, nutrient demands of the crop, and soil conditions influenced the loss of nutrients. Often, a majority of the leaching could have been prevented through more careful management.

Conversely, other studies have been performed that demonstrate the ability to minimize nitrate leaching. Studies as varied as those performed by Mitchell, et al. (2000) in a small stand of Scots pine in Scotland to larger scale reclamation operations (Van Ham, et al., 2000; Sopper 1993; Lue-Hing, 1992) and agricultural operations (Shepherd, 1996) show that with appropriate biosolids type, application rates, and conditions, nitrogen from the biosolids can be preserved and recycled in the upper layers of the soil profile. The reclamation project presented by Sylvis Environmental in British Columbia (Van Ham, et al., 2000) transformed nutrient depleted gravel mines into self-sustaining tracts of vegetation that increased the environmental quality of the site. The vegetation not only enhanced the aesthetic and ecological value of the site, but actually reduced nitrogen and phosphorus movement that previously migrated to a nearby aquifer. When properly used, biosolids are an environmentally safe and effective nutrient source that greatly improves soil condition, optimizes crop production, and enhances the soil and land ecosystem into which it is introduced.

<u>Leaching potential.</u>

Monitoring of nitrogen and chlorides in biosolids and soils below trenches was conducted in an effort to determine potential for leaching (Sikora et al., 1980). Chloride, a water-soluble anion commonly found in biosolids, does not interact chemically with most soils and provides an indication of water flow and maximum leaching potential through the biosolids and soil profile. The data from these analyses demonstrated two distinct trends. First, the levels of ammonium, nitrate and chlorides all generally diminished from the first sampling period (665 days) to the last (1,508 days).

The second observation made from these data is an apparent enrichment of both ammonium and chloride with depth on the same sampling date. For example, for almost every sampling event, the dry weight concentration of ammonium was greater in the lower portion of the trenches than in the middle portion. The concentration of ammonium in the middle portion was generally greater than in the top portion.

This distribution did not hold for nitrate. For each sampling date, nitrate nitrogen concentration in the lowermost portion of the trench was less than or about equivalent to the concentrations in the upper two sections of the trench. Given relatively high levels of ammonium, the precursor to nitrate formation in these samples, it would be expected that the nitrate concentration in the samples would show similar trends as ammonium and chloride unless some mechanism for nitrate removal was acting.

Leaching is the first mechanism that comes to mind to explain this anomaly. However, the enrichment of the lowermost portion of the trench with chlorides suggests that leaching was not occurring rapidly enough to account for low nitrate concentrations. Two other explanations are plausible. The first is that conditions in the lower section of the trench were not conductive to nitrate formation, so conversion of ammonium was quite slow (this would account for the accumulation of ammonium in the lowermost portion). The production of nitrate via mineralization of ammonium requires an aerobic environment, which only existed in the top of the trench at the beginning of the experiment. Subsequent dewatering of the trench fostered conditions for additional mineralization to occur deeper in the trench. A second mechanism may be denitrification. Conditions that are not favorable for nitrification are required for denitrification. It is probable that both mechanisms were at work (Pepperman, 1995).

Denitrification.

Also important to note is that once produced, nitrate will either 1) be taken up by plants or microorganisms or 2) leach further down the trench with the water flow and/or 3) undergo denitrification. The fact that nitrate concentrations do not correspond to the timing patterns exhibited by the equally water-soluble chloride indicates that 1) nitrate production via mineralization was delayed for months after biosolids entrenchment and 2) once produced, though some nitrate may have leached the bottom of the trench, the waterlogged, anaerobic conditions were optimal for denitrification. This theory is supported by the fact that concentrations in the bottom of the trench did not reach the levels in the upper portions. Additionally, concentrations in the soil below the trenches, though elevated for a time to a maximum of 54 mg/kg, decreased to low levels (2-6 mg/kg) by the end of the experiment.

Sikora et al. (1982) found that NO_3–N levels in biosolids did not change between 20 months and 45 months except in the top 20 cm. The inorganic N content in water beneath the biosolids increased and then decreased with time. Denitrification in the soil profile was demonstrated. Walker (1974) indicated that entrenchment promoted slow nitrification and favored denitrification. Again, nitrogen was found beneath the biosolids but not in ground water wells.

The comparison of chloride and nitrate concentrations in water samples from below the biosolids was utilized to assess the potential for leaching and, in this study, also to determine if denitrification occurred. The ratio of nitrates to chlorides decreased with depth below the trench, indicating that there existed some mechanism for reduction in nitrates (since both nitrates and chlorides are expected to move through the soil at generally the same rate). Since there were no plant roots at the depths evaluated and microbial immobilization was discounted, it appeared that denitrification was occurring (Sikora et al., 1979b).

Taylor and his fellow researchers (Taylor et al., 1978) indicated that the relatively low oxygen and high methane content of the soil atmosphere adjacent to the biosolids would be an ideal environment for denitrification. It was suggested that, from the levels of nitrate found within the biosolids, after 160 days some nitrification had occurred. They concluded, however, that the extremely low levels of nitrate within the soil surrounding the biosolids indicated that, if such a transformation were occurring, very little nitrate was moving from the biosolids. They further concluded that it was likely that any nitrate which did move from the biosolids would have been subjected to denitrification.

Literature suggests that mineralization is depressed by both temperature and anoxic conditions. These same conditions favor denitrification, so nitrate is generated only slowly and it is likely that any nitrate that is not quickly captured by the roots of the trees is denitrified.

Experiments provided evidence, however, that recharge would likely dilute the nutrients. Consequently, the specific characteristics of an individual site would need to be evaluated to determine if groundwater contamination posed too much risk for this technique. It is important to note, however, that these experiments did not attempt to utilize a deep rooted crop or plant a specific crop density that could reach and utilize the nutrient reservoir supplied by the biosolids.

Hybrid Poplar Trees and Their Use With Pollution Management

The genus *Populus* includes those trees commonly referred to as poplars and aspen. They are part of the botanical family *Salicaceae*, which also includes willow trees. Hybrid poplars are crosses of two different species that are often developed to enhance desirable traits, such as hardiness, nutrient uptake, or salinity tolerance. Clones are a group of genetically identical plants that result from vegetative production of a single tree.

Hybrid poplars are well known for their high water uptake and transpiration rates and have been used for the containment and remediation of nutrients, explosives such as TNT, trichloroethylene, and a variety of other organics (Pivetz, 2001; Newman, et al., 1999; Burken and Schnoor, 1998). Specific studies evaluating groundwater capture and hydrologic flow have recorded water use between 1.2 and 25 gallons/day/tree (Ferro, et al., 2001). Other studies in which root growth was directed to an aquifer 25 feet below the surface estimated even higher uptake rates between 8-50 gallons/tree/day dependent upon the month and age of the tree. (Quinn, et al., 2001). Such high water use supports the potential to provide a large degree of leachate containment, though results vary according to the specific site characteristics, density of trees planted, and climatic conditions.

Licht (1990) evaluated the effectiveness of poplar tree buffer strips to control nonpoint source pollution, particularly nitrogen. He concluded that hybrid poplars 1) naturally form extensive rooting systems that can be further enhanced using deep planting techniques; 2) significantly reduce nitrate concentrations in the soil profile as well as in near-surface groundwater from 90 mg/L levels to 2 mg/L (well below the drinking water MCL of 10 mg/L), and 3) are capable of surviving in both waterlogged and drought conditions.

In summary, characteristics that favor use of hybrid poplar trees in nutrient recycling and land reclamation activities include:

- They are nutrient demanding, with an uptake rate of 200-360 lbs of nitrogen per acre per year (National Agroforestry Center, 2000)
- They are phreatophytes, will extend roots to the capillary fringe, and can survive periods with their roots in the saturated zone
- The fibrous nature of the roots enable penetration of both highly permeable and less permeable soils.
- Impressive growth rates produce large amounts of biomass that act as a significant carbon sink.
- They are hardy, with high survival rates and can withstand high planting densities.

Root Distribution.

Taylor et al. (1978) attributed the restriction of root penetration to the expected environment within the entrenched biosolids – encapsulating biosolids in trenches created an environment similar to an anaerobic digester. Not only would such an environment be inhospitable to plant roots, it would also suggest very low levels of oxygen and thus, not support the obligate aerobes which are required to mineralize the organic matter to ammonium and nitrate (Pepperman, 1995). Taylor et al's hypothesis was supported by Gouin (1994, personal communication) who suggested that mineralization rate of biosolids in deep rows would be slowed due to the low soil temperatures (at depth), relatively high moisture content of the biosolids, and lack of oxygen. Thus, the anaerobic conditions and lower temperatures in the deep-rowed biosolids a) maintains N in organic forms that were not easily leached and b) inhibit root growth (Taylor et al., 1978).

Evidence that the hybrid poplar is absorbing nitrogen can be obtained from foliar nitrogen measurements (ERCO, 2000). Hybrid poplars are capable of utilizing nitrogen at rates similar to corn but, unlike corn, this nitrogen is extracted by a deep perennial root system. During the years when the trees were actively growing, foliar N levels were in excess of 3.5

percent. After 6-9 years, however, foliar N levels dropped below 3.5 percent, indicating that either 1) the trees were utilizing N faster than the mineralization rate of the biosolids or 2) the N content in the biosolids had been exhausted.

Pepperman (1995) performed a detailed nitrogen balance for the ERCO site. Some highlights of the computations are: denitrification was 40% of biosolids N, volatilization was negligible, mineralization was 6% of organic N, and the total requirement to meet immobilization, tree, and understory requirements was 605 kg/ha (540 lb/ac) dry weight. The requisite application rate to meet these needs was 506.6 Mg biosolids /ha (226.7 tons /ac) dry weight.

Nitrogen Utilization by Hybrid Poplars

The application rate of biosolids for most mine spoils is based on a nitrogen budget that considers the nutrient uptake of the trees, as well as rate of N mineralization, denitrification and other factors. Hybrid poplar trees are capable of uptaking 200-360 lbs. of N per acre per year (National Agroforestry Center, 2000). Different application rates must be tested to determine the effects on tree growth and water quality. Preliminary tests have indicated that the standard rate of 171 dry tons per acre (11,970 lbs. N per acre until 1997) may be inadequate to meet the nitrogen demands of the trees for the six-year rotation (Pepperman, 1995). This calculation was performed when biosolids contained 3.5 percent total nitrogen. Since 1997, lime-stabilized biosolids have been used which contain approximately 1.15 percent total nitrogen. Therefore, to apply nitrogen at the same rate using presently available biosolids would require approximately 400 dry tons per acre. To provide higher amounts of nitrogen would require higher application rates. It is critical that permitted applications not be based on tons per acre, but on pounds of N per acre to supply the needs of the trees. The actual application rate can and should be adjusted, depending on the N content of the biosolids. Additionally, foliar N samples indicate that the crop is N-deficient during the last two years. Therefore, this shortfall should also be incorporated into the production system.

The use of lower tree densities to produce a larger diameter and more marketable crop is another factor that may impact root distribution. The one concern of using lower tree densities is the increased time it will take for roots to colonize the area around the trenches and utilize the nutrients. This may allow time for movement of leachate (and any accompanying nutrients) away from the trenches. The anaerobic environment, however, should minimize mineralization and the consequent production of water-soluble forms of nitrogen. Prior studies indicate that denitrification in the wet anaerobic deep row environment may result the loss of 15-40 percent of the original nitrogen as it is converted to nitrogen gas.

The distance between nutrient source and crop roots was considerably greater in previous experiments (Sikora et al., 1980; Taylor et al., 1978) because a) the trenches were deeper and b) the grass crop utilized had a much shallower root system. Additionally, because grass spends more time in a dormant state, these experiments had a shorter annual period of nutrient uptake. The result was a greater potential for nutrient escape to the ground water system. None of the previous trenching studies have used deep-rooted plant material to minimize leaching of nitrogen. The use of fast-growing, nitrogen-demanding hybrid poplars at high densities on the ERCO site provided deep root penetration around the deep-rows.

Phosphorus

Hybrid poplars require adequate phosphorus to produce roots that can encase the deep rows and uptake nitrogen. Foliar leaf samples collected in September of 1999 demonstrated low average percent phosphorus levels of 0.18 (range 0.120-0.248). Optimum phosphorus foliar concentration is 0.33 percent (Van Ham, 1999; Zabeck, 2001). To correct for this phosphorus deficiency, the following protocol has been recommended for the ERCO site. Each tree requires 1/2 lb. of 8-24-8 fertilizer split into two 1/4 lb. portions. A planting pole is used to insert two holes 6-8 inches from each side of the tree at rooting depth. The fertilizer is then placed in the hole.

Incorporation of biosolids below ground eliminates the potential for transport through erosion. Incorporation also reduces nitrogen volatilization to essentially zero. Phosphorus will not move easily in subsurface flow because it readily adsorbs onto soil particles. In summary, phosphorus transport from trenches is not at all likely.

Field Site Description

ERCO History

In 1983, ERCO Inc. developed the deep row application technique in response to the need to utilize large volumes of biosolids from the Washington, D.C. area and reclaim sand and gravel mine spoils. The company received a permit from the Maryland Department of Environment (MDE) for application of biosolids to grow nutrient-demanding hybrid poplar trees. Harvesting was performed at about 7 years on most sections when foliar leaf samples were below 3.5 percent nitrogen and total nitrogen mineralization reached 70 percent.

The overburden soils were treated to obtain a pH of 6.2. Approximately 10 acres were treated each year starting in 1984. The deep row technique initially involved the application of biosolids at a rate of 171 dry tons per acre and, for a special demonstration plot, at a rate of 294 dry tons per acre. The biosolids were placed in trenches that were 30 inches deep and 42 inches wide, spaced approximately 8 feet on center. The trenches were filled with 18 inches of biosolids. The remaining 8-12 inches of trench were filled with overburden. Fast-growing, nitrogen-demanding, hybrid poplar cuttings were planted at a dense spacing of 3,000-4,000 trees per acre to utilize the nitrogen over a planned 6-year rotation. Competing vegetation was controlled by mowing (no herbicides were used). After six or more years, a 10-acre section was harvested and subsequently cross-trenched for another biosolid application.

Site Location

The ERCO Beneficial Reuse Tree Farm site is a privately-owned 49.4 (122 ac.) gravel spoil in Prince George's County (fig. 1) within 40 km (25 miles) of many large municipal wastewater treatment plants. The site is approximately three miles north of Waldorf, MD.

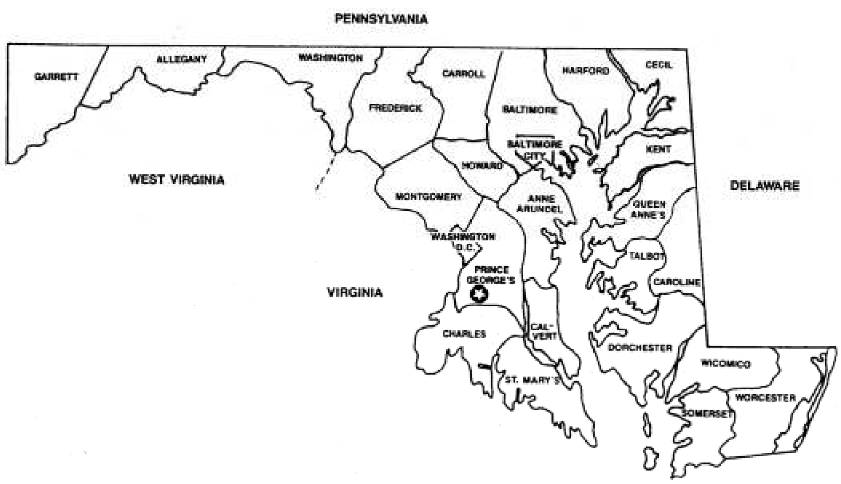

Figure 1. ERCO study site marked with star is located in Prince George's County, MD within the Washington, D.C. metro area.

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 bermed area.

The research site is an existing reclamation site that has utilized deep row biosolid application with forest trees for 15 years. 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 entire site has been applied once with biosolids using deep row application. At any one time, only one or two sections (4.05 ha each) are cleared and replanted. Hence, only 8-16% of the site is subject to significant surface runoff generation. Approximately 25% of the site (13 ha) is in permanent cover, consisting of either forested steep slope or detention ponds and buffers.

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 five to 70 feet (or more) thick. Description of geology at the ERCO site was derived from Wilson and Fleck (1990) and, to a lesser extent, Tompkins (1983). The following describes the deeper deposit first and concludes with the surface deposit that was removed in the mining operations.

The lower formation is the Marlboro Clay, a confining unit of dense, reddish silty clay between 15 and 30 feet in thickness. The lower Eocene Nanjemoy Formation overlies the Marlboro Clay, and predominantly consists of beds of dark green, fine to medium, glauconite-bearing sands in the upper part of the formation. The thickness of the Nanjemoy at Waldorf ranges from about 90 to 125 ft.

Overlying the Nanjemoy 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 is the basal unit of the Chesapeake Group and it represents deposition in a marine shelf environment.

The Calvert is overlain by the Pliocene Upland Deposits. The Upland Deposits consist of orange-tan, silty, fine to very course sands and gravels, and yellowish to orange, silty clays. The Upland Deposits range from 20 to 50 ft thick and crop out throughout the Waldorf area. These materials are what was removed in the sand and gravel mining process. Hence, the ERCO site has very slight remnants of the Pliocene Upland Deposits over the Calvert clayey silt, over the Nanjemoy.

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 and the top of the Nanjemoy formation. The clayey silts and fine clayey sands of the Nanjemoy are the sandier of the two formations. The Calvert formation, above the Nanjemoy formation, is less permeable, with estimated vertical conductivities that are two to three orders of magnitude lower than the Nanjemoy formation (Wilson and Fleck, 1990). Hence, water that rose in observation wells to within 15 feet of the ground surface derived from the Nanjemoy and the rise in water elevation was the result of the confining action of the overlying Calvert formation.

Potential for Application

Sand and gravel spoils similar to the ERCO site (complete with clayey subsurface geology) are found in a reasonably wide North-South band along much of the Mid-Atlantic region, close to large metropolitan centers, and provide excellent candidates for reclamation using deep-row biosolid applications. The ERCO site resides on geology with a deep clay layer. There is the potential to apply this technique to thousands of acres of sand and gravel spoils with similar geology in the Baltimore-Washington, D.C. metropolitan area, and to other areas throughout the country with similar conditions. In Prince Georges, Charles, Anne Arundel, and Baltimore counties, there are 12,788 acres of sand and gravel mining sites. Obviously, not all sites are applicable for tree farming utilizing biosolids. If sites smaller than 50 acres are removed from consideration, there are still 9,246 acres available. If we assume that half of these sites are not appropriate for one reason or another, then 4,623 acres have the potential to be converted to beneficial re-use tree farms. At a conservative rate of 171 dry tons of biosolids per acre, the 4,623 acres could utilize approximately 43% of the regions annual biosolids production (assuming a six year rotation).

This technique provides for the utilization of large volumes of biosolids per unit area to produce forest products at a site near treatment plants in urban areas. Compared to conventional land application, it requires much less land and, because no crop exists at the time of application, this technique can be used at a steady rate over the entire year. Development of this technique could contribute to a multi-state effort to reduce nutrient loading of the Chesapeake Bay. The current cost of deep-row applications, however, is higher than tipping fees at out-of-state landfills. It will therefore require political cooperation of states involved in the Chesapeake Bay watershed to discourage landfill dumping and encourage alternative methods such as deep-row application.

OBJECTIVES

This report is divided into different parts that address each of the four objectives in the original proposal. The four objectives are:

1) determine the effect of tree density and biosolid application rate on water quality around deep rows on a gravel mine spoil;

2) determine the effect of tree density and biosolid application rate on the above ground growth, production, and survival of hybrid poplars with deep row biosolid applications;

3) determine the economic feasibility of deep row application with forest trees at different planting densities and application rates, as well as the value of its environmental benefits. Feasibility relative to other biosolid disposal methods (or other reclamation activities) will be assessed; and

4) educate state and local environmental professionals about the use of deep-row biosolid applications to develop sustainable forest crops and simultaneously rehabilitate disturbed soils.

POTENTIAL BIOSOLIDS UTILIZATION

Materials and Methods

A simple analysis was completed in 1998 to determine the number of acres of gravel spoils in the southern Maryland area that may have the potential for deep row application of biosolids. The Maryland Department of Natural Resources Water Management Administration provided a list of mining permits for Prince George’s, Charles, Anne Arundel and Baltimore

Counties that included the acreage of each permitted sites and the ADC map location. Information was requested for above-listed counties because they are more likely to have geological characteristics similar to that of the ERCO site and would be viable candidates for deep row application. Attempts to locate the gravel mine sites on current ADC maps that could be coordinated with geologic maps failed because ADC map coordinates have changed with revised editions, resulting in different locations for the same coordinate. Older ADC maps are not readily available. Current developments in GIS technology should foster the production of databases and maps that will provide easy access to mine locations and their development status.

The mine permit data were analyzed to estimate the number of tracts and acreage in parcels that were either over 50 acres or over 100 acres. This categorization is based on the assumption that 50 acres would be the minimum operationally feasible size, with 100 acres being more realistic. It is likely that within this group of identified parcels, a number of the mine sites have since been developed for housing or industrial uses. Recognizing, however, that other mine permits have been issued since 1998, additional available acreage has likely been produced in the past seven years. This highlights the need to update the collation of mine permit data to get a more accurate assessment of applicable land.

Results and Discussion

Sand and gravel permits issued prior to 1998 indicate there are a total of 12,788 acres in the four counties of interest (Table 1). Parcels over 50 acres in size accounted for 9,246 acres (72% of the total) and parcels over 100 acres accounted for 5,698 acres (45% of the total). The largest number of acres and parcels were found in Prince George’s County. Sites over 50 acres in size were found on only 78 parcels, and sites over 100 acres in size were found on only 31 parcels. The relatively small number of sites over 50 and 100 acres in size makes a future assessment for underlying geology, development status and other factors that would influence availability for deep row application a reasonable endeavor.

Table 1. Number of Acres and Parcels of Gravel Spoils by County

Measure	Prince Georges Co.	Charles Co.	Anne Arundel Co.	Baltimore Co.	Total
No. Acres	5,887	3,132	2,693	1,076	12,788
Average Size	53	38	44	215	350
Acres in tracts over 50 acres (No. parcels)	4,367 (33)	1,881 (20)	1,959 (22)	1,039 (3)	9,246 (72 % of total acreage)
Acres in Tracts over 100 acres (No. parcels)	2,762 (13)	1,102 (9)	795 (6)	1,039 (3)	5,698 (45 % of total acreage)
Source: MDE, 1998					

In order to estimate the mass of biosolids that could be utilized in the Baltimore/Washington D.C. metro area, a rough analysis was completed using conservative assumptions of acres available and the three application rates (4,000, 8,000, and 12,000 lbs N/acre) used in the research study at ERCO.

Table 2 uses acreage figures for parcels over 100 acres in size only. Since the status of many of these parcels is unknown, it was assumed that only half of the acreage (2849 acres) would be available and meet the criteria for deep row application. Based on a 7-year rotation, 407 acres would be available for treatment each year, utilizing 319, 638, and 957 thousand wet tons per year, respectively, for each of the application rates in the study. The most current figures indicate 827,514 wets tons of biosolids were produced in the Baltimore/Washington, D.C. metro area in 2002. Consequently, at the lowest application rate, which is representative of what is currently applied operationally under permit at the ERCO site, 38% of the annual biosolids output could be utilized. At the higher application rates of 8,000 and 12,000 lbs. N/acre, 77% and 116% of the annual biosolids output could be applied each year, respectively.

Table 2. Potential utilization of biosolids on parcel over 100 acres in size.

Application rate in research study (lb N/ acre)	Actual wet tons per acre using biosolids with 1.6%N	Acres available in parcels over 100 acres in size	Assume only 50% of acres available	Number acres that could be treated on 7-year rotation	Wet tons biosolids that could be utilized per year * (1000's)	Wet tons biosolids produced per year in Metro area (1000's)	% of annual biosolids utilized by deep row application
4,000	784	5698	2849	407	319	828	38%
8,000	1567	5698	2849	407	638	828	77%
12,000	2351	5698	2849	407	957	828	116%
* 827,514 Wet tons produced per year from MDE and DCWASA, 2002							

Table 3 uses acreage figures for parcels over 50 acres in size only. Since the status of many of these parcels is also unknown, it was assumed that only half of the acreage (4623 acres) would be available and meet the criteria for deep row application. Based on a 7-year rotation, this would mean 660 acres would be available for treatment each year, utilizing 517, 1034, and 1552 thousand wet tons per year for each of the application rates in the study. Using the annual biosolids production figure of 827,514 wet tons for the Baltimore/Washington, D.C. metro area, the lowest application rate would utilize 62% of the annual biosolids output. At the higher application rates of 8,000 and 12,000 lbs. N/acre, 125% and 187% of the annual biosolids output could be applied each year, respectively.

Table 3. Potential Utilization of Biosolids on Parcels over 50 Acres in Size

Application rate in research study (lb N/ acre)	Actual wet tons per acre using biosolids with 1.6%N	Acres available in parcels over 50 acres in size	Assume only 50% of acres available	Number acres that could be treated on 7-year rotation	Wet tons biosolids that could be utilized per year * (1000's)	Wet tons biosolids produced per year in Metro area (1000's)	% of annual biosolids utilized by deep row application
4,000	784	9246	4623	660	517	828	62%
8,000	1567	9246	4623	660	1034	828	125%
12,000	2351	9246	4623	660	1552	828	187%
* 827,514 Wet tons of biosolids produced per year from MDE and DCWASA, 2002							

Conclusions

This simple analysis assumes the parcels in question are available and would meet the soil and geology criteria for deep row application. Other gravel mines of considerable size have been permitted since 1998, which means additional acres are likely available. This study needs to be updated using current GIS technology to make a more accurate assessment. Regardless, the potential utilization of biosolids available by deep row applications provides great optimism and justification for continued research.

WATER QUALITY

The following two sub-objectives better define the overall objective:

1) Determine the effect of soil characteristics and biosolid application rates on water quality around deep rows on a gravel mine spoil; and

2) Determine the contribution made by hybrid poplar trees to nutrient removal.

Methods and Materials

Experimental Design

This section describes the standard tree farm production implemented since the 1980's, followed by the design of the University of Maryland experiments performed at the site.

Production treatments.

The deep-row technique, developed in 1983, involved the application of biosolids, averaging about 20 percent 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. In 1988, the permit allowed for addition of a special demonstration plot with biosolids applied at 659.1 Mg/ha (294 dry tons/acre). Approximately 4.05 ha (10 acre) sections were treated each year beginning in 1984. 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/acre) rate and 559 mm (22 in.) for the 659.1 Mg/ha (294 dry tons/acre) 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. Application rate used at the farm are 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).

Experimental Treatments.

The 3.1-acre study site is located on the existing ERCO property and has previously received one biosolids application, as described above (Production Treatments). A replicated treatment design was used to determine the effect of three tree densities (0, 290, and 430 trees per acre) and three deep row biosolid application rates (4,000, 8,000 and 12,000 lbs. N per acre) on water quality and tree production. Unlike past application rates, which were based solely on biosolids weight, the experimental rates will be expressed in pounds of nitrogen per acre per year. The application rate of biosolids in units of dry tons per acre required to meet these nitrogen targets will depend on the N content of the biosolids used, which past results have shown to vary between 1% and 3.5%.

Prior to beginning applications in mid-March 2002, a biosolids sample was collected from a routine delivery at the ERCO site to determine nitrogen content and the corresponding application rates necessary to meet the research requirements. Results showed a total nitrogen content of 1.14%. Three other samples subsequently collected confirmed this general value, and all four samples together produced an average value of 1.16% total N.

The lower nitrogen content necessitated application rates of approximately three times more biosolids than used in the production operation in order to supply the design nitrogen application rates. The experimental application rates of 4,000, 8,000, and 12, 000 lbs/N per acre bracket the production level of 4,300 lbs/N per acre, and are designed to discern the most appropriate application rate that results in higher crop production while protecting water quality. To accommodate the increased load from these required application rates and the lower nitrogen content, between-row-spacing was reduced from eight feet to approximately 6 feet. The width of the deep rows will be maintained at 42 inches and the depth will be adjusted (as shown in Table 4) to accommodate the required amount of biosolids and allow for 10-12” of cover on top of the biosolids. The maximum depth of the deep rows is limited by the depth to which the poplar tree roots can reliably grow. If trench depth exceeds seven or eight feet, which is likely too deep to be sure that roots can reach the material, some of the same problems discovered by Sikora et al. (1982) could occur.

Table 4. Treatment rates, depth of biosolids in the trench, total trench depth, and approximate biosolids application rate.

Application Rate (lbs N/A)	Inches of Biosolids	Total Depth of Deep Row in Inches (12" overburden)	Dry Tons / Acre
4,000	12.5	24	172
8,000	25.0	37	345
12,000	37.5	49	517

Plot layout.

Beginning in spring 2002, plots were established at the ERCO site. The site was partitioned into three blocks based on a north-south gradient of changing soil composition and slope. Each block contains each biosolids application rate/tree density combination. The project funded by WSSC required 18 plots (2 tree densities)(3 biosolids rates)(3 replications). Funds from the McIntyre Stennis grant provided for an additional 12 plots that consisted of: three biosolids rates with no trees replicated three times (9 plots) plus control plots with no biosolids and no trees, replicated three times (3 plots). The result is an incomplete split block experimental design.

Each plot that received biosolids is 72 feet wide (11-12 rows of biosolids). Figure 2 represents a single plot (72'X70') with the locations of biosolids trenches and trees illustrated. Plots that were planted with 435 trees/acre are 70 feet long to accommodate 10 foot x 10 foot tree spacing (8 rows x 8 columns of trees). Plots that are planted with 290 trees/acre are 105 feet long to accommodate 10 foot x 15 foot tree spacing (again 8 rows x 8 columns of trees). The no-tree biosolids plots are 35 feet wide. Figure 3 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 133,540 square feet or 3.11 acres.

Within each plot the outer two rows of trees around the perimeter were designated as buffers to isolate treatments and provide access routes, thereby reducing disturbance of soil and vegetation in the plots. The sample collection areas within each plot consist of the innermost 16 trees, to reduce possible edge effects. The central area of four rows by four columns of trees contains all soil water sample collection equipment. The three control plots (no trees, no biosolids) are 35 feet x 35 feet with instrumentation in the central portion of the plots.

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

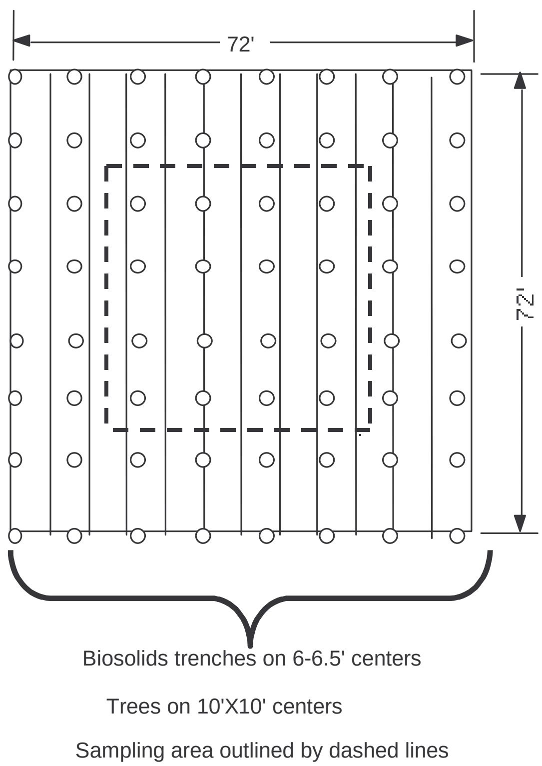

Figure 2**.** Schematic layout of one plot with biosolids and trees.

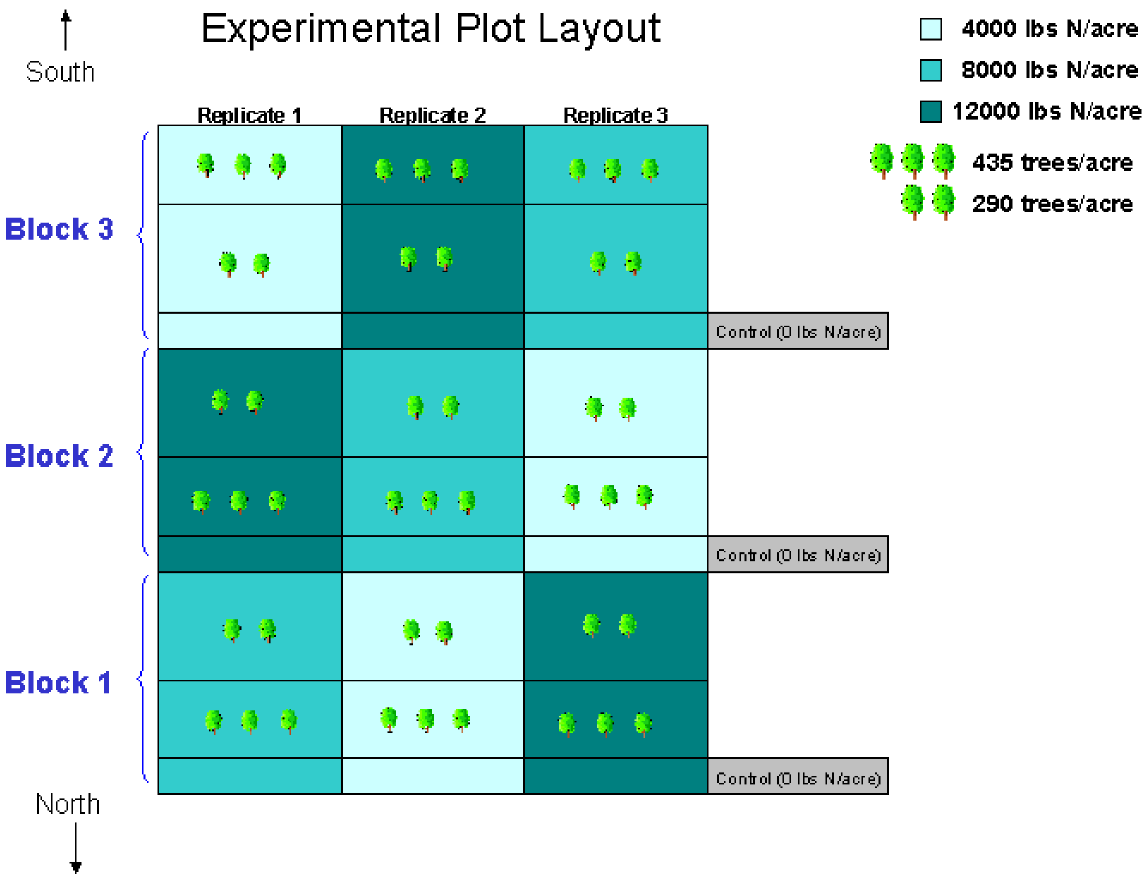

Figure 3. Schematic layout of all three blocks showing total area.

Water quality instrumentation and measurement.

Each treatment (application rate x tree density combination) within each block contains several types of sampling instrumentation to evaluate hydrology and/or nutrient transport: 1) two shallow stand-pipe wells were installed in the 8000 lbs N/acre x 435 trees/acre plot, with one well positioned through the deep row and the other well in the surrounding soil/gravel spoils profile; 2) in each of the 30 plots, one zero-tension lysimeter positioned 12 inches directly under a deep row; and 3) in each of the 30 plots, suction lysimeters located under and around the deep row.

Each set of two shallow standpipe wells were installed with one in the deep row and one 25 cm to the side of the row in the spoil. Both were screened for a one-foot section at the bottom of the trench and sealed with bentonite. Water level is being measured by University of Maryland staff using well tapes. The difference in the storm-based rise and fall in these two wells will provide an indication of within-trench flow. Long-term water levels in the trench will provide insight to the hypothesis that the biosolids are in anaerobic conditions for the entire six to seven year rotation.

Each plot has one zero-tension lysimeter installed 25cm below the bottom of the trench. Water collected from zero-tension lysimeters (a.k.a, pan lysimeters) is predominantly macropore flow. Where macropores are minimal or non-existent, as may be the case in this area, the flow represents gravity-drained water. This flow is estimated to account for anywhere between 10 to 85 percent of the percolating water. Because the water percolates relatively rapidly, and does not have prolonged contact with the soil matrix, it is reasoned that 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. A schematic depicting the pan lysimeter is provided in Figure 4 below.

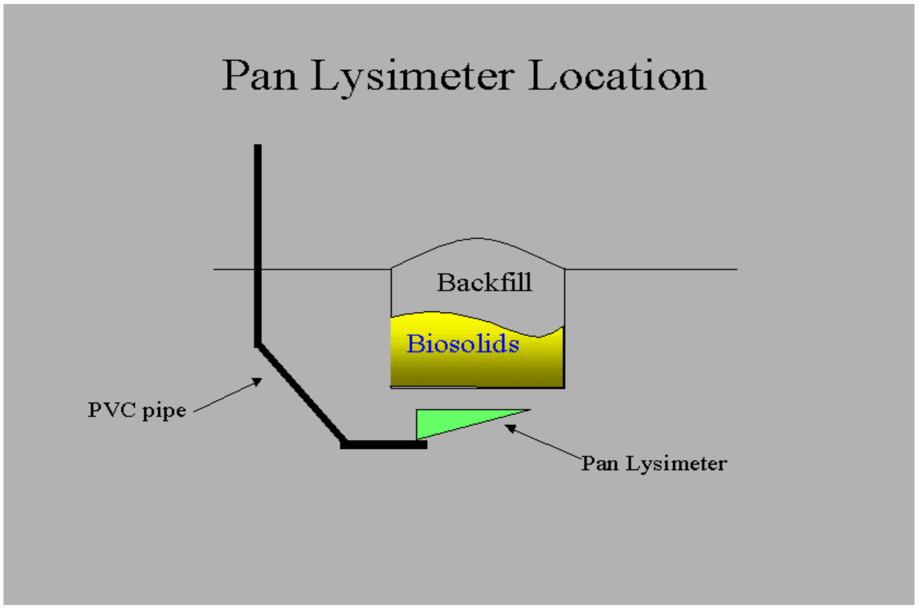

Figure 4. Pan Lysimeter Installation Schematic

Each plot also contains two sets of suction lysimeters installed under and around the biosolids rows. 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 15cm, 30cm, and 60cm (6, 12, and 24 inches) directly below a biosolids row to monitor long-term migration of any plume in the vertical direction.

The second suction lysimeter nest is located on either side of the row in the soil level with the bottom of the trench. 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. Two suction lysimeters were therefore installed 25cm and 50 cm from the side of a row to monitor lateral movement. A schematic of the position of all five suction lysimeters in relation to a biosolids row is presented in Figure 5. 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.

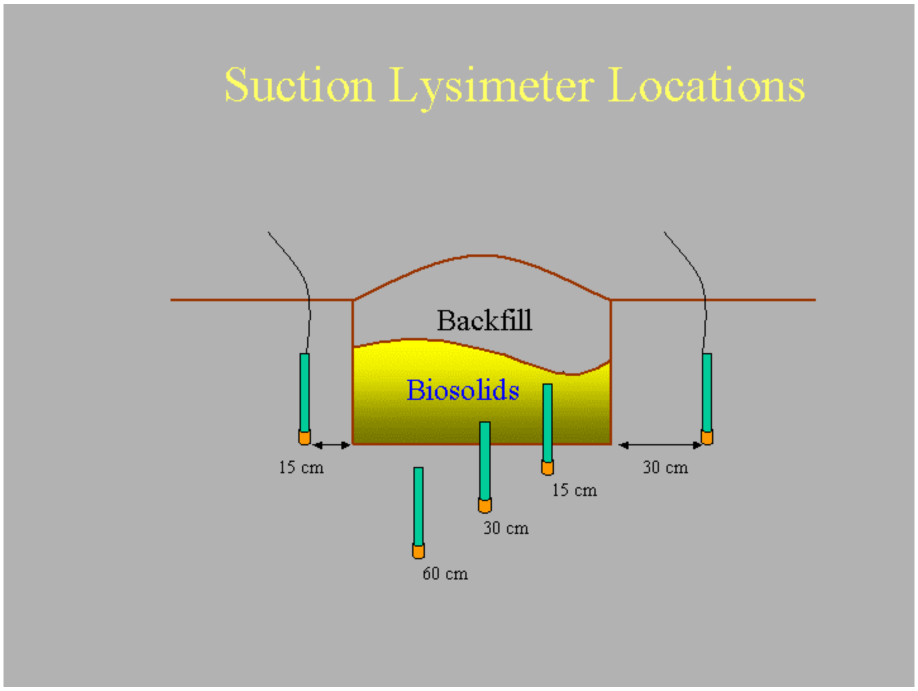

Figure 5. Suction Lysimeter Installation Schematic

Pan lysimeters were installed just after the deep row was filled with biosolids. Suction lysimeters were installed after the trench was filled with biosolids but before planting. Pan lysimeters were installed from July 2002 through March 2003. Suction lysimeters were installed after the area was leveled and disked. Water quality sampling began in April, 2003.

The term "ground water" will be used to denote water in the zone of saturation (Bear, 1972). More specifically, this is water in the geologic formations that are completely saturated (Freeze and Cherry, 1979). 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).

Sampling frequency.

Water samples from pan and suction lysimeters were collected on a monthly basis for the first year. For the following years, samples will be collected every other month. These routine collections amount to 4860 sampling attempts. Due to dry weather conditions and other climatic factors, however, there may be instances in which water is not present or cannot be extracted using the sampling equipment.

Parameters.

All subsurface water samples have been sampled for pH, nitrate, nitrite, total nitrogen, sulfate, and chloride. At the ERCO site, subsurface water flow is greatly restricted by the clay. This restricted flow provides any aqueous phosphorus with ample opportunity to adsorb onto charged sites, which are plentiful in the clay subsoil. For this reason, ortho-phosphate and total phosphorus will be analyzed for the first six to twelve months, but analysis will be discontinued if phosphorus is not detected in these samples.

Results and Discussion

Wells

Description and installation

There are seven functioning ground water monitoring wells installed at the Tree Farm site. These wells are identified in Figure 6. The first well, installed in November 1982, is designated MW #2, and is situated within 100 feet of the ERCO trailer. The well is cased to 31 feet, followed by ten feet 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 - Permit	Depth of: Casing	Screen
1	7/26/88 - S-88-16-809-ABE	70'	70'-80'
2	11/15/82	31’	31’-41’
4	7/14/88 - S-88-16-809-ABE	25'	25'-35'
5 (removed)	7/26/88 - S-88-16-809-ABE	10'	10'-20'
5A	3/28/89 - S-88-16-809-ABE	28'	28'-38'
6	10/8/90 - S-90-16-809-ABE	107'	107'-127'
7	10/8/90 - S-90-16-809-ABE	77'	77'-97'
8	10/8/90 - S-90-16-809-ABE	80'	80'-95'

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

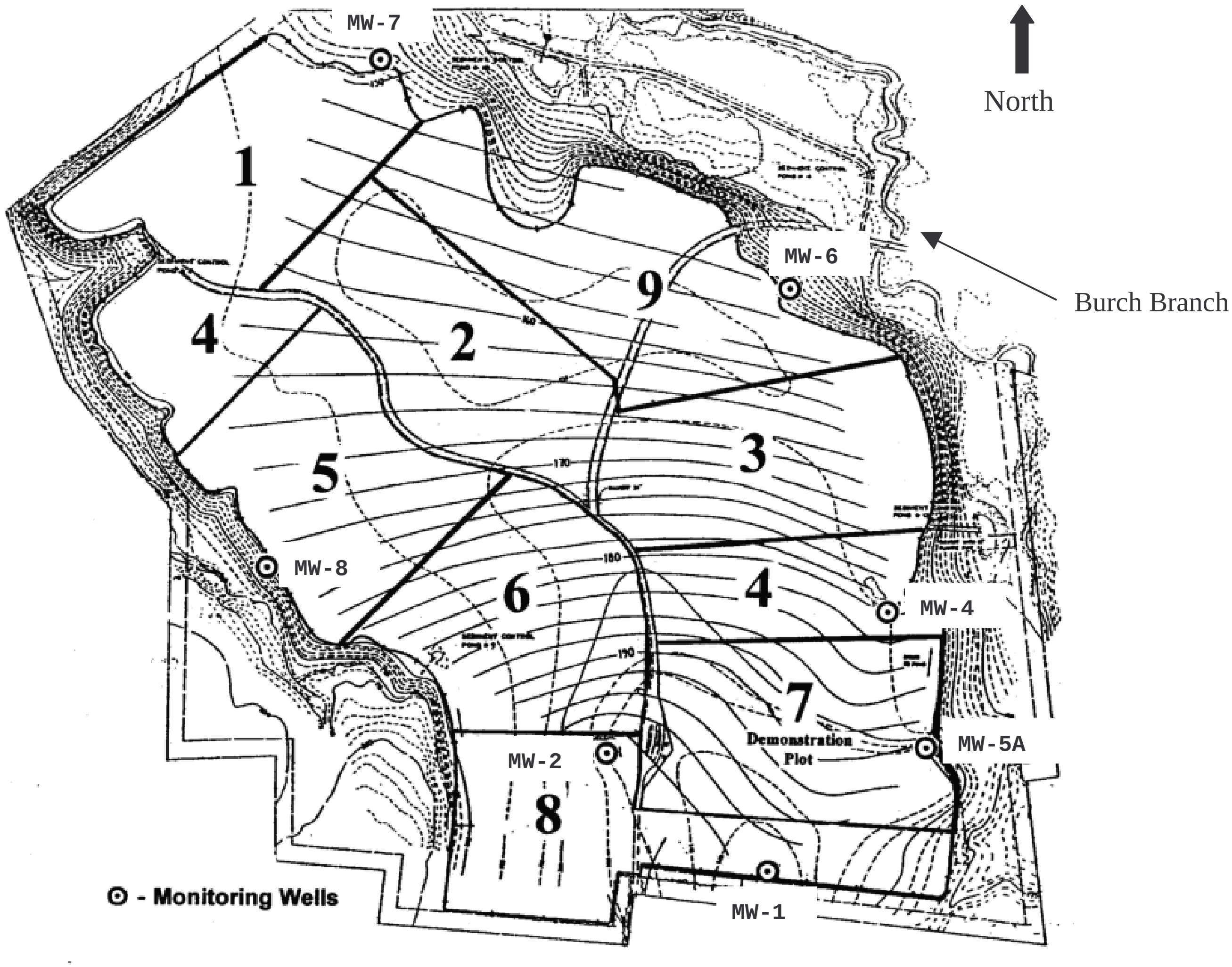

Figure 6. ERCO study site topography with treatment sections, monitoring wells, and estimated ground water potential lines.

Figure 6 provides estimated 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. In Figure 6, 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 related to biosolids management operations can be reasonably well estimated by reviewing the historical analytical data from both the wells and the surface waters draining the site.

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.

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 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 7, it is clear that pH levels remain fairly constant, with each different well having a slightly different average pH.

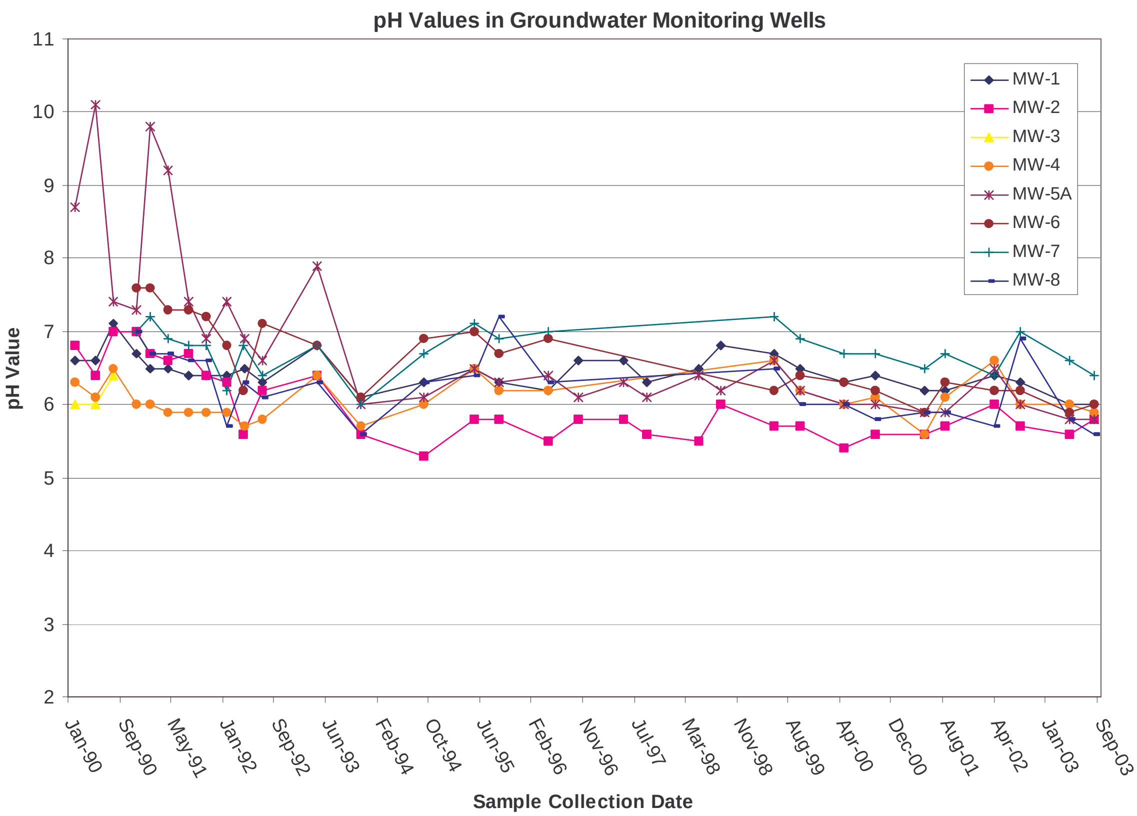

Figure 7. pH values for each of the eight monitoring wells.

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 8. 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 8 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.

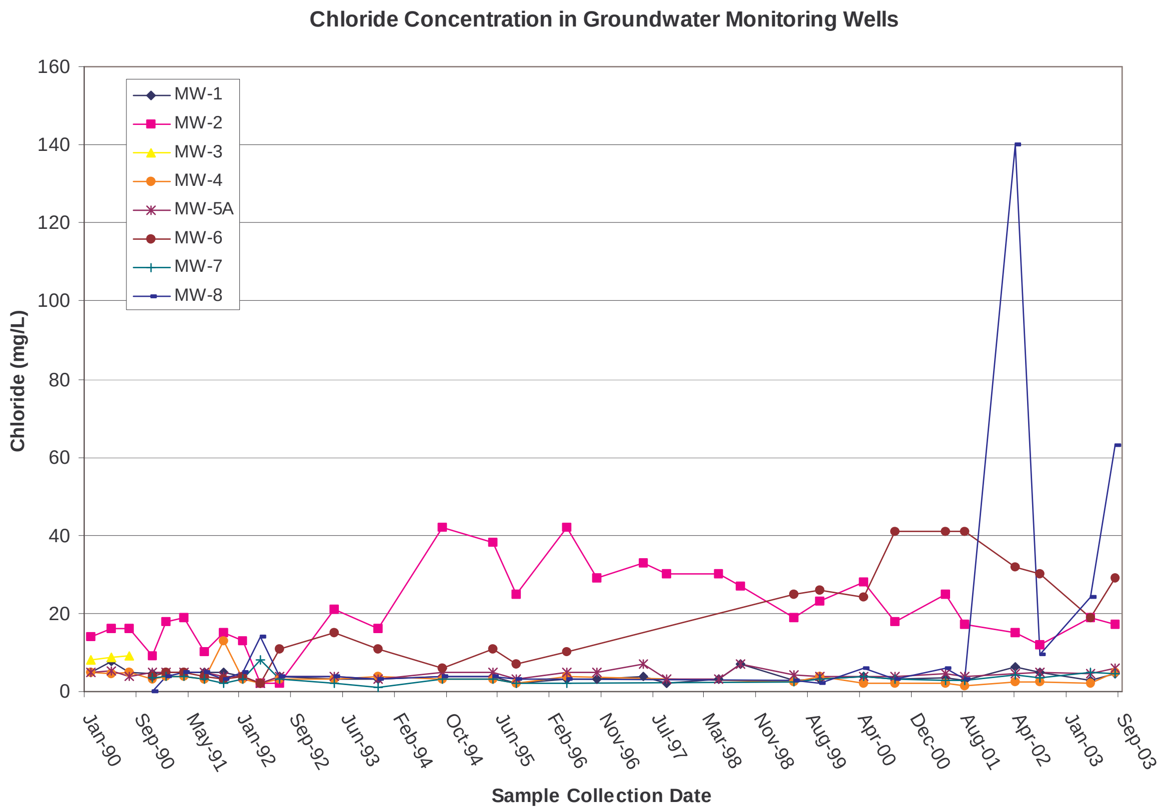

Figure 8. Chloride (mg/L) values for each of the eight monitoring wells

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 9 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.

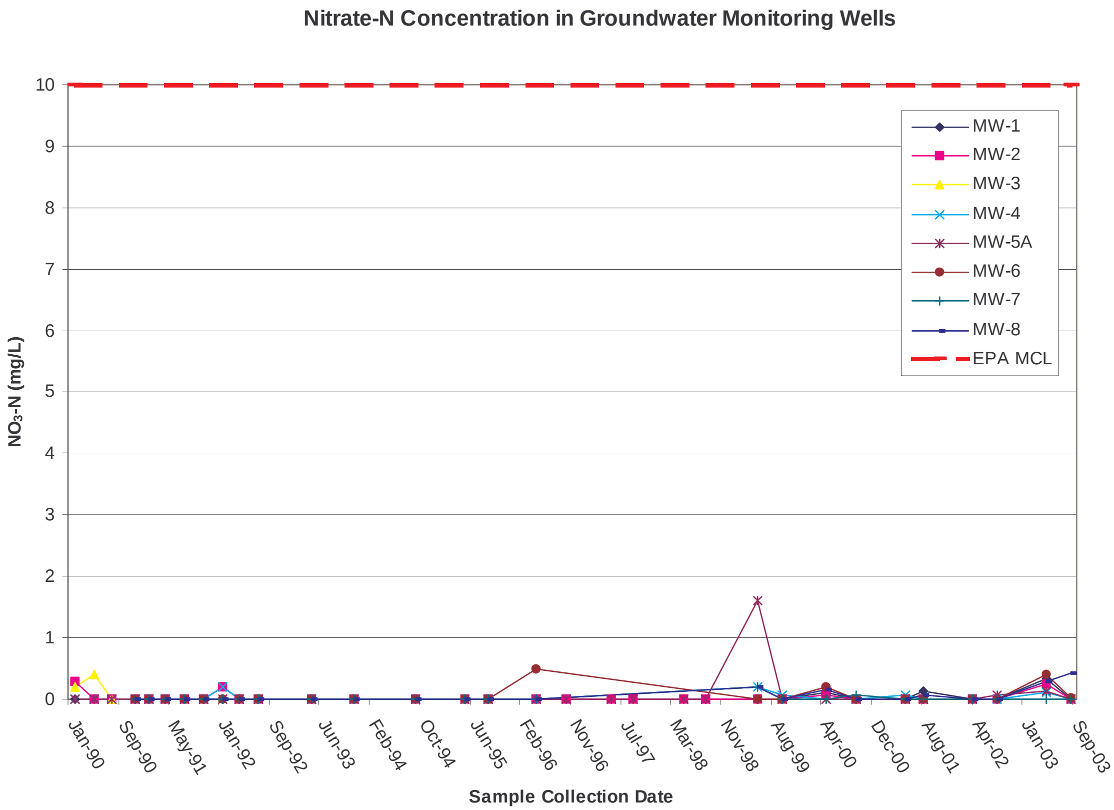

Figure 9. Nitrate values (mg/L NO_3-N) for each of the eight monitoring wells

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 10 and 11 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 10 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 11 places the ammonia concentration in all wells over the period in context with background levels. As can be quite well seen on Figure 11, 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.

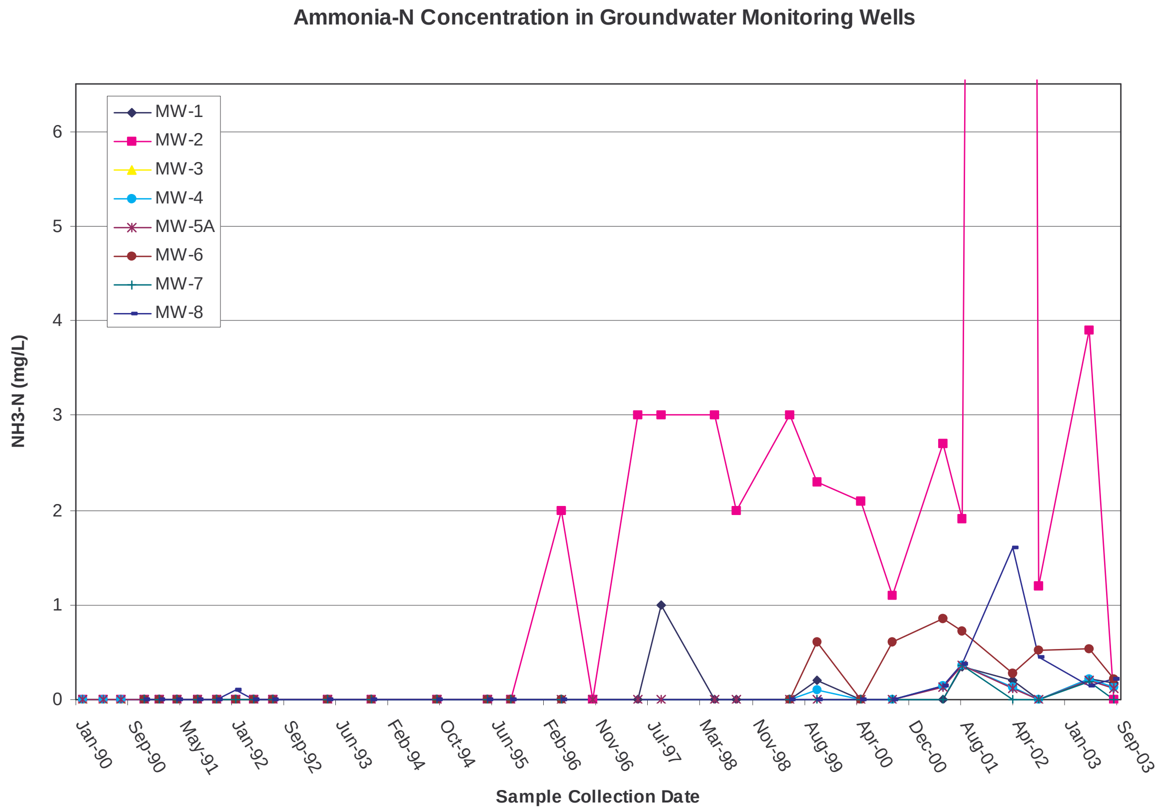

Figure 10. Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells with scale truncated at the Blue Plains effluent limit of 6.5 mg/L.

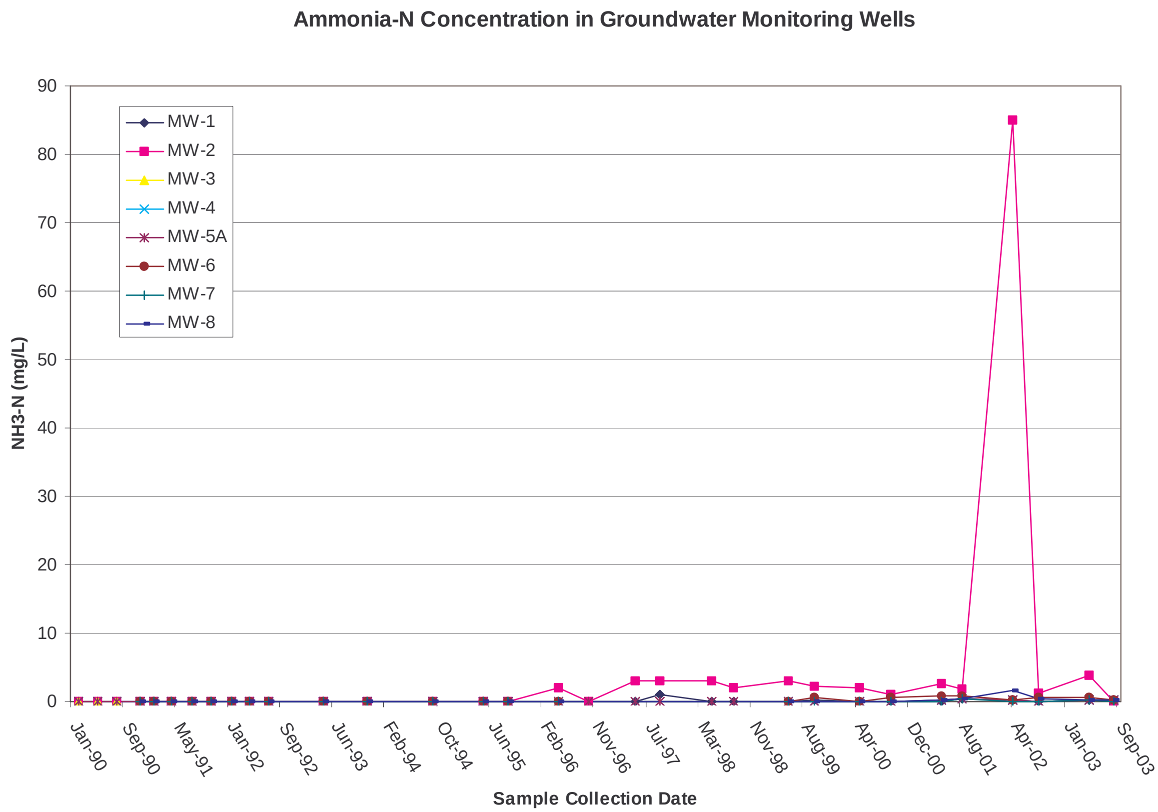

Figure 11**.** Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells (in full scale).

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 12. 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.