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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 $1.4\text{x}10^{-7}$ to $1.8\text{x}10^{-2}$ cm/s and an average value of $1.19\text{x}10^{-3}$ 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

The Nitrogen Cycle

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.

Leaching potential.

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

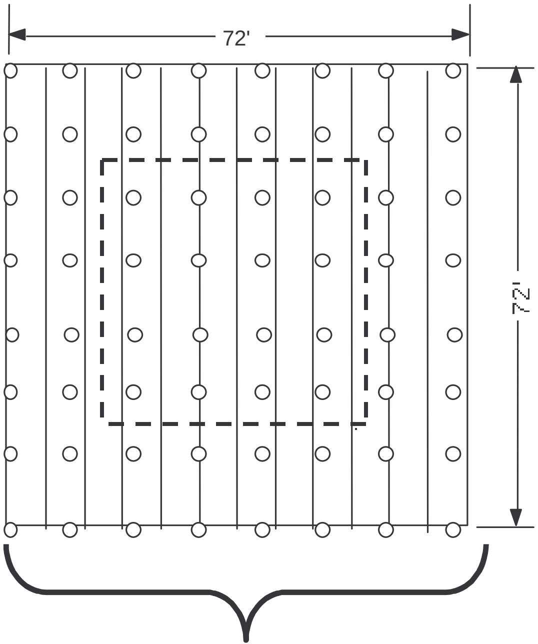
Plot layout.

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.



Biosolids trenches on 6-6.5' centers

Trees on 10'X10' centers

Sampling area outlined by dashed lines

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

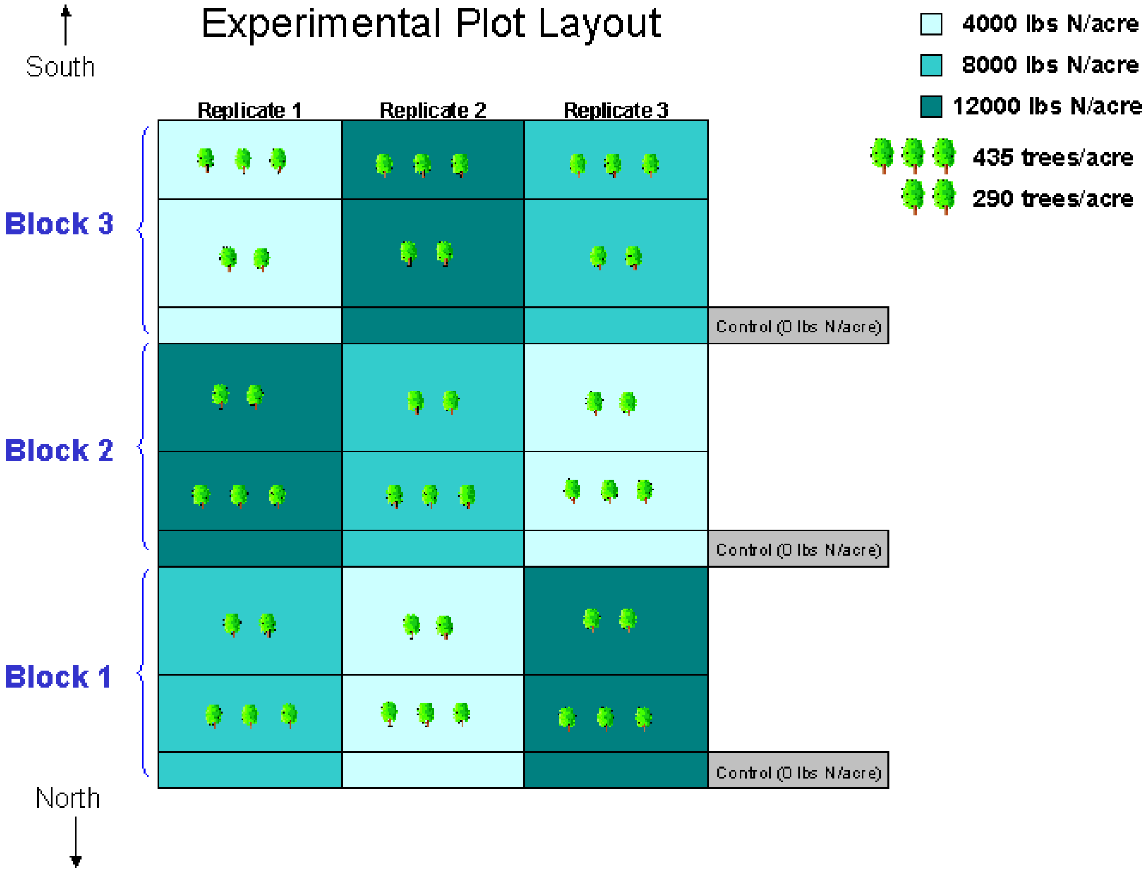


Figure 3. Schematic layout of all three blocks showing total area.

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.

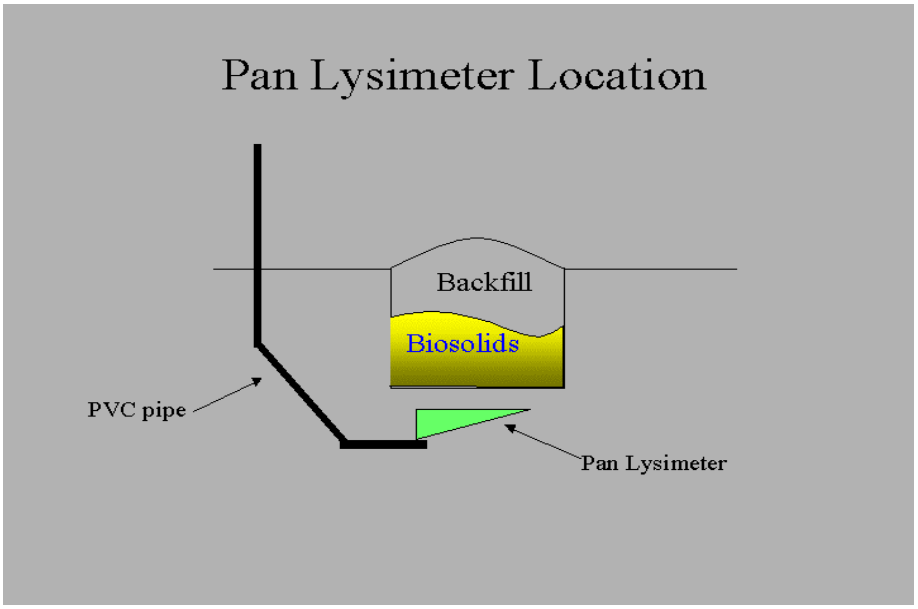


Figure 4. Pan Lysimeter Installation Schematic

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.

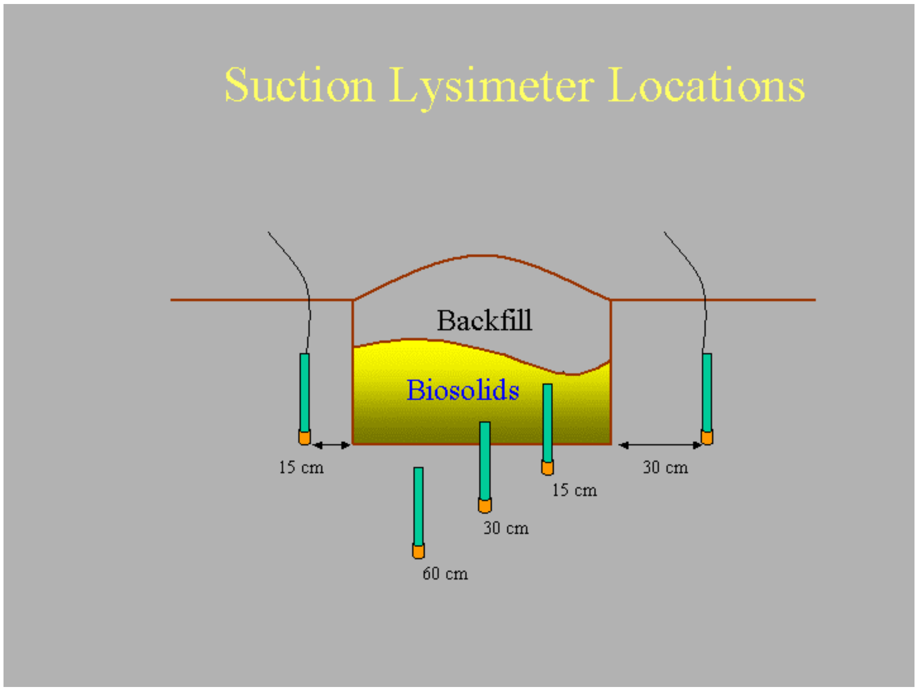


Figure 5. Suction Lysimeter Installation Schematic

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.

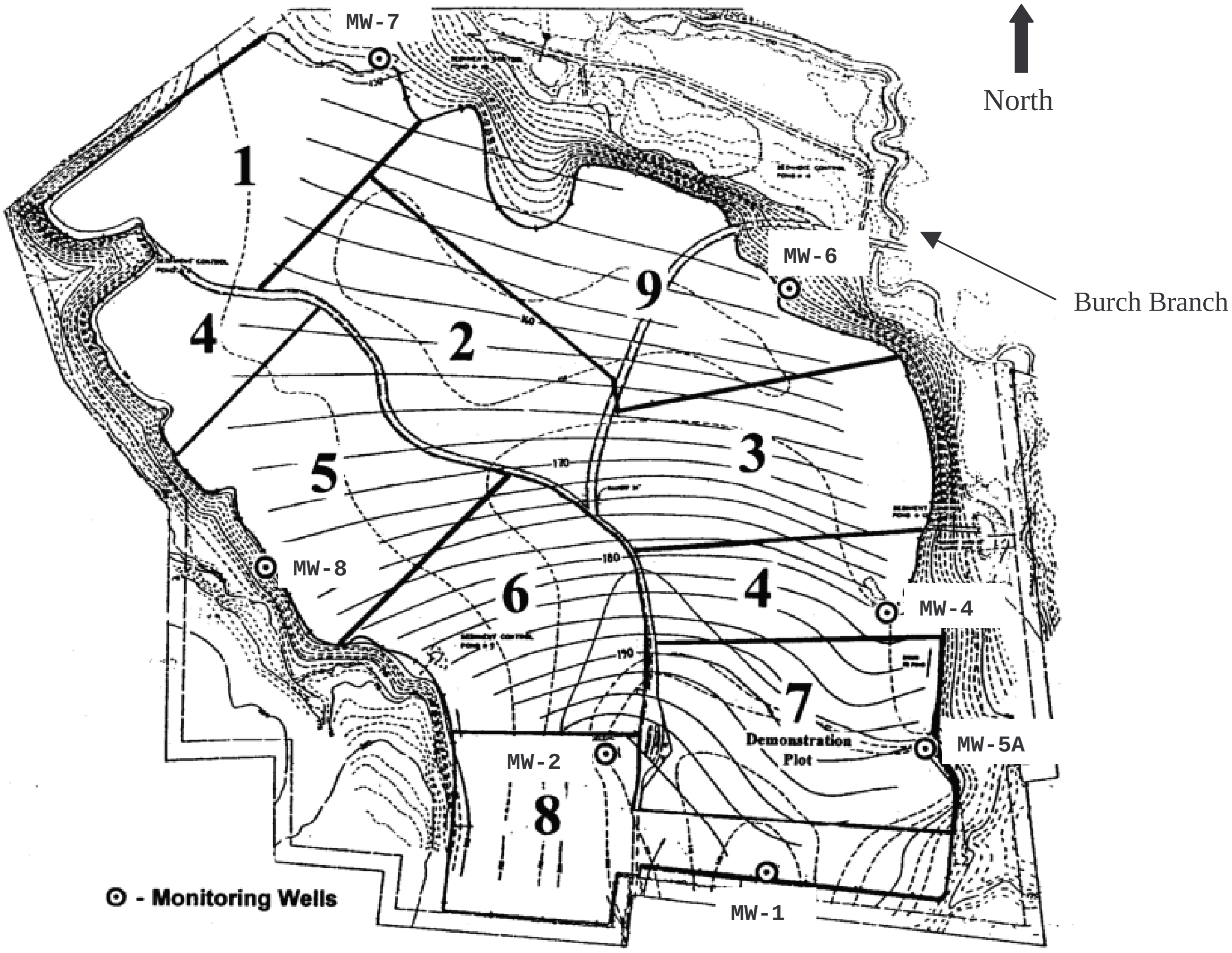


Figure 6. ERCO study site topography with treatment sections, monitoring wells, and estimated ground water potential lines.

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.

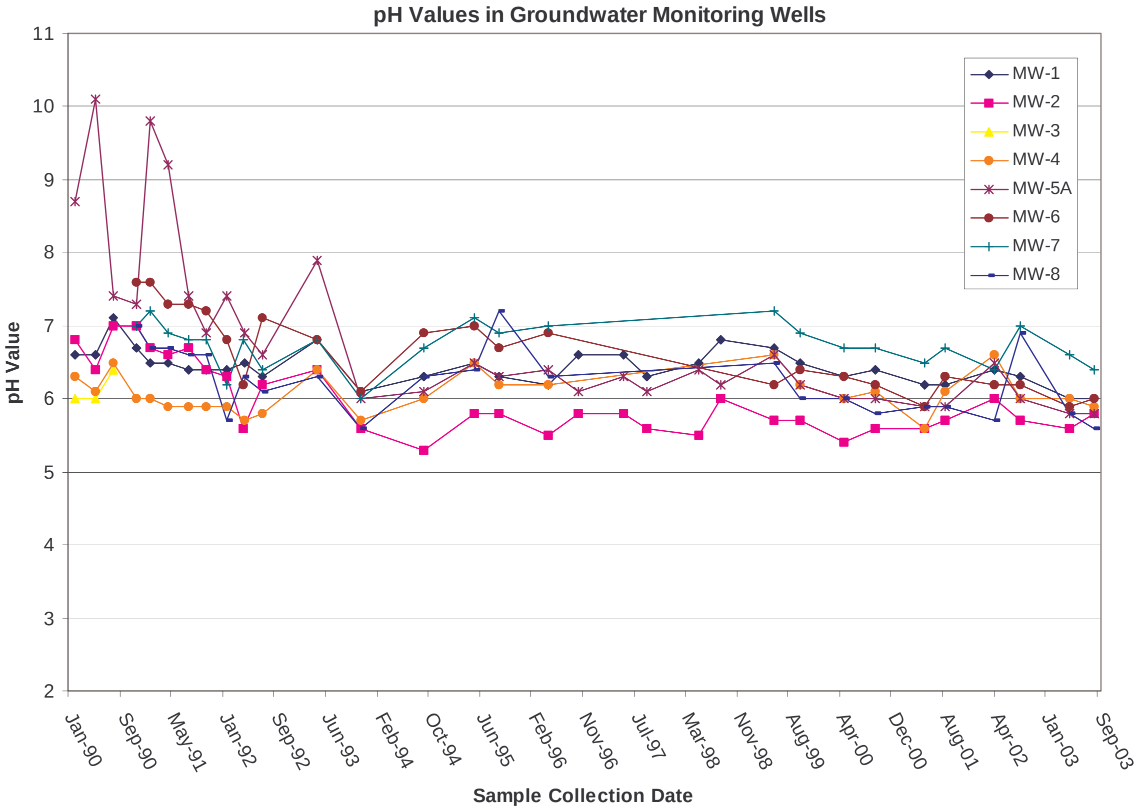


Figure 7. pH values for each of the eight monitoring wells.

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.

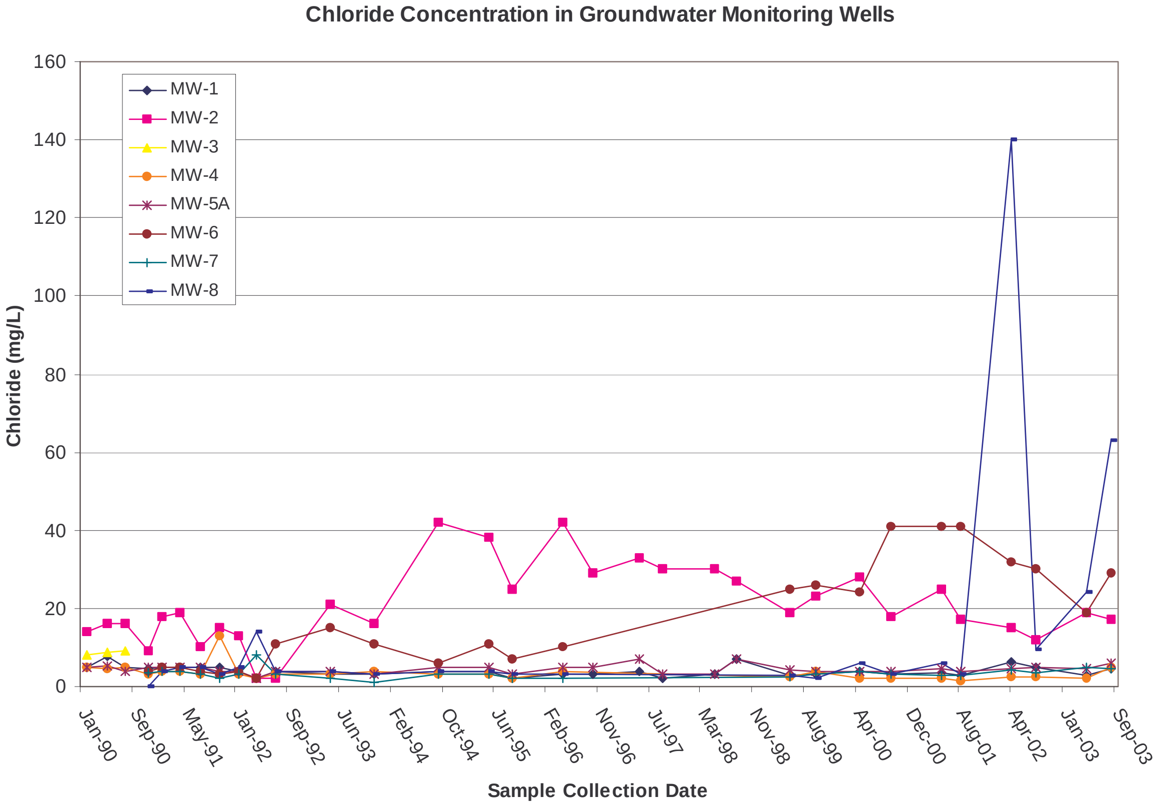


Figure 8. Chloride (mg/L) values for each of the eight monitoring wells

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.

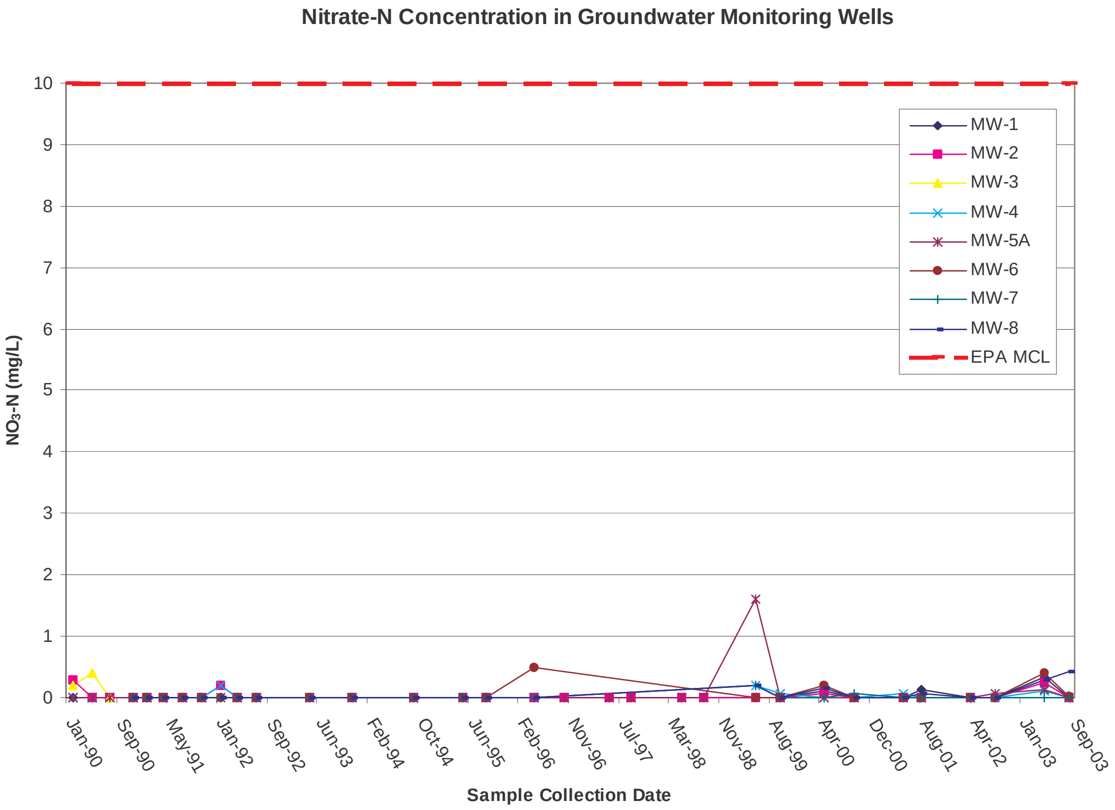


Figure 9. Nitrate values (mg/L NO_3-N) for each of the eight monitoring wells

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.

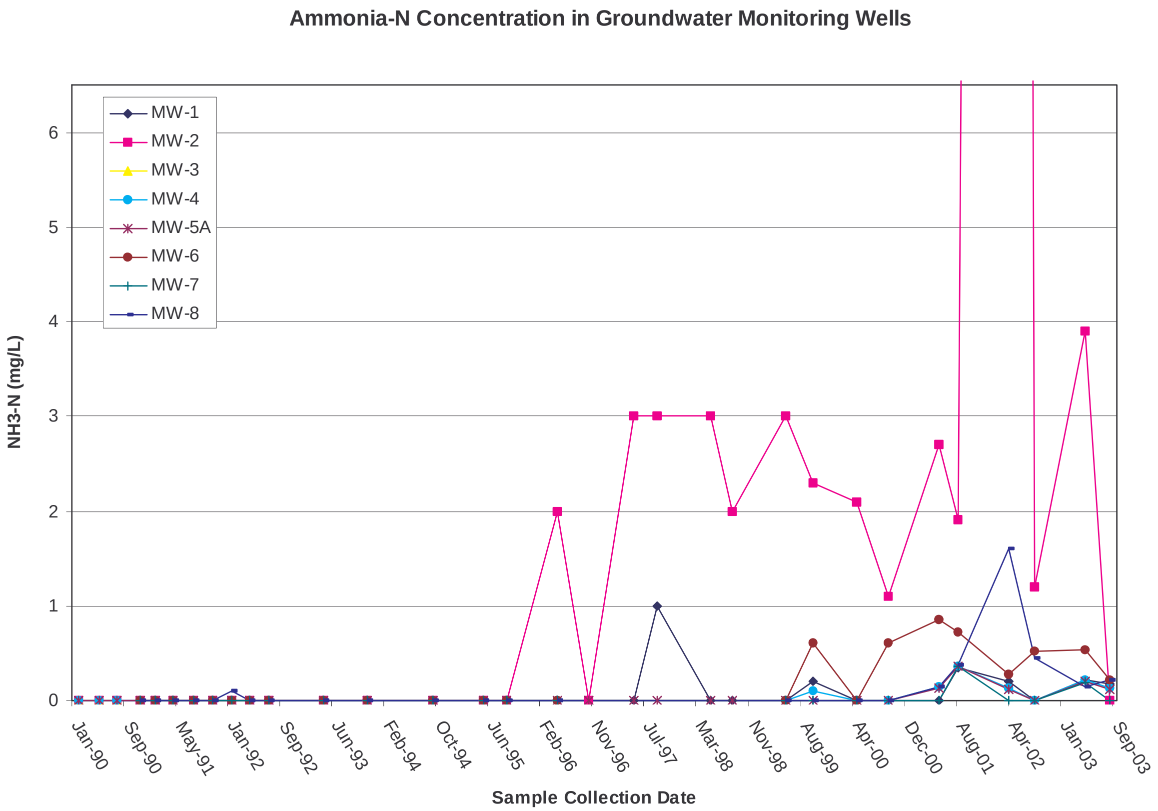


Figure 10. Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells with scale truncated at the Blue Plains effluent limit of 6.5 mg/L.

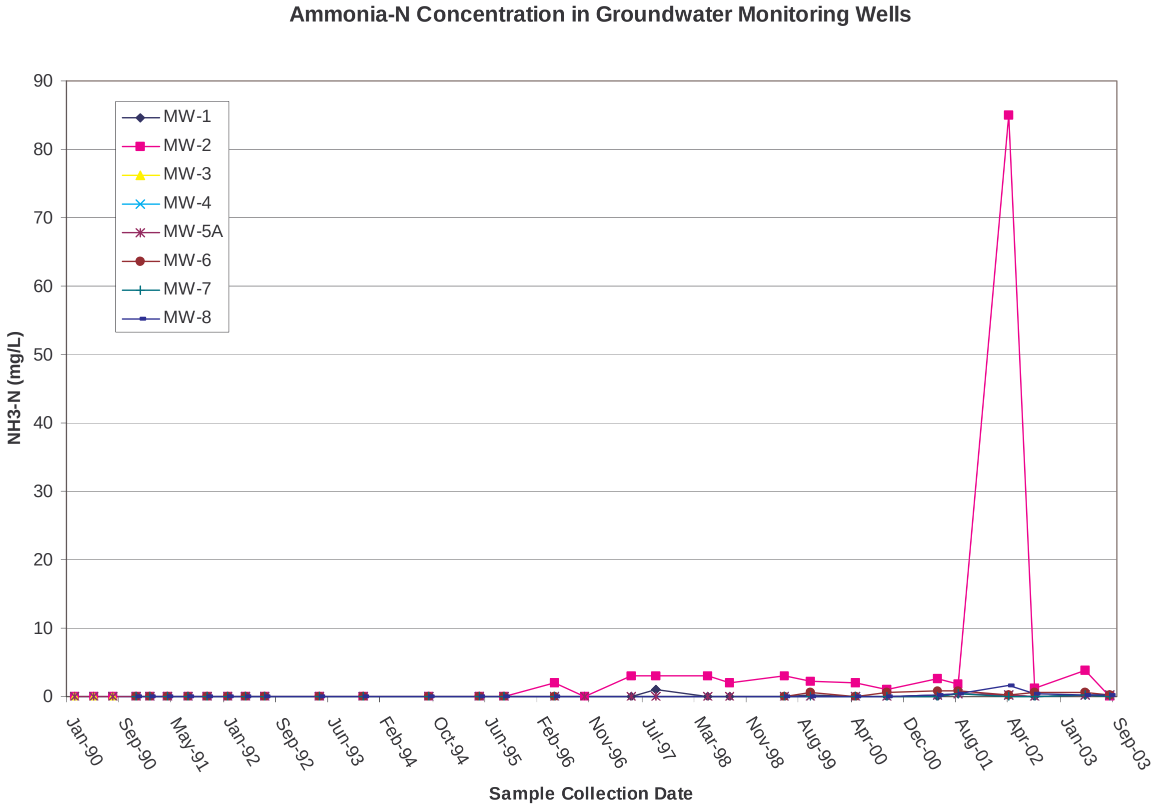


Figure 11**.** Ammonia values (mg/L NH_4-NH_3-N) for each of the eight monitoring wells (in full scale).

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.

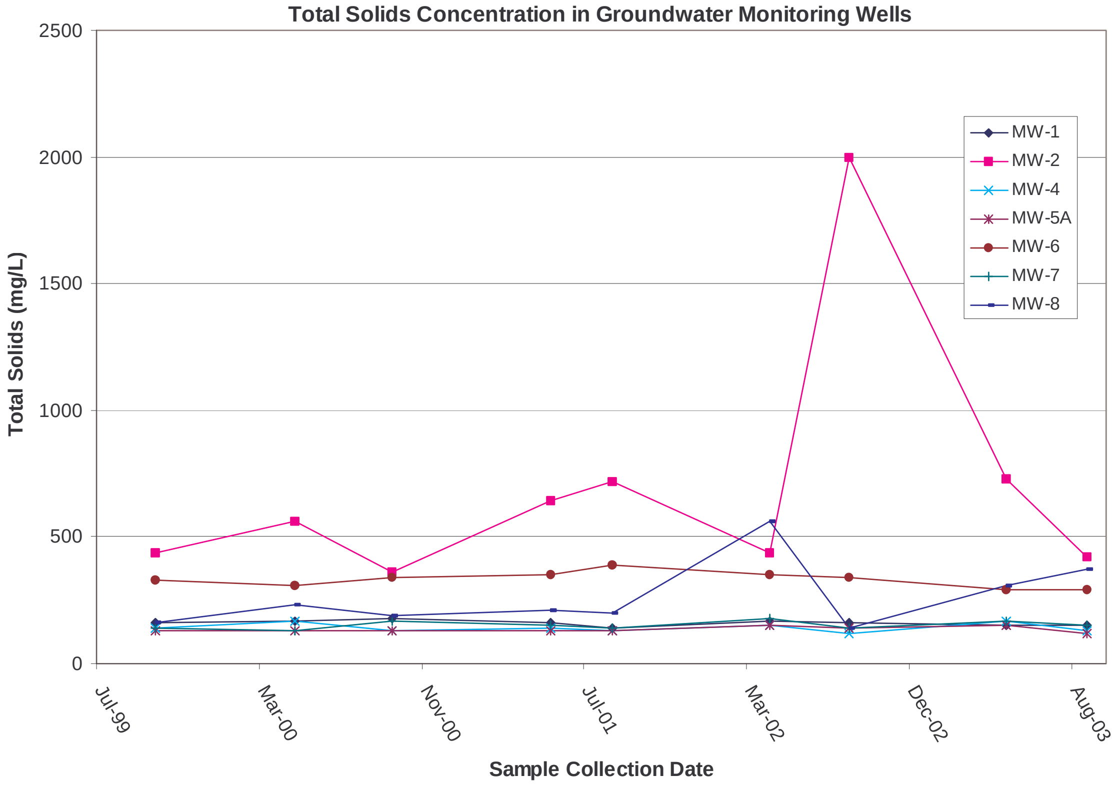


Figure 12.	Total solids (mg/L) for each of the eight monitoring wells.

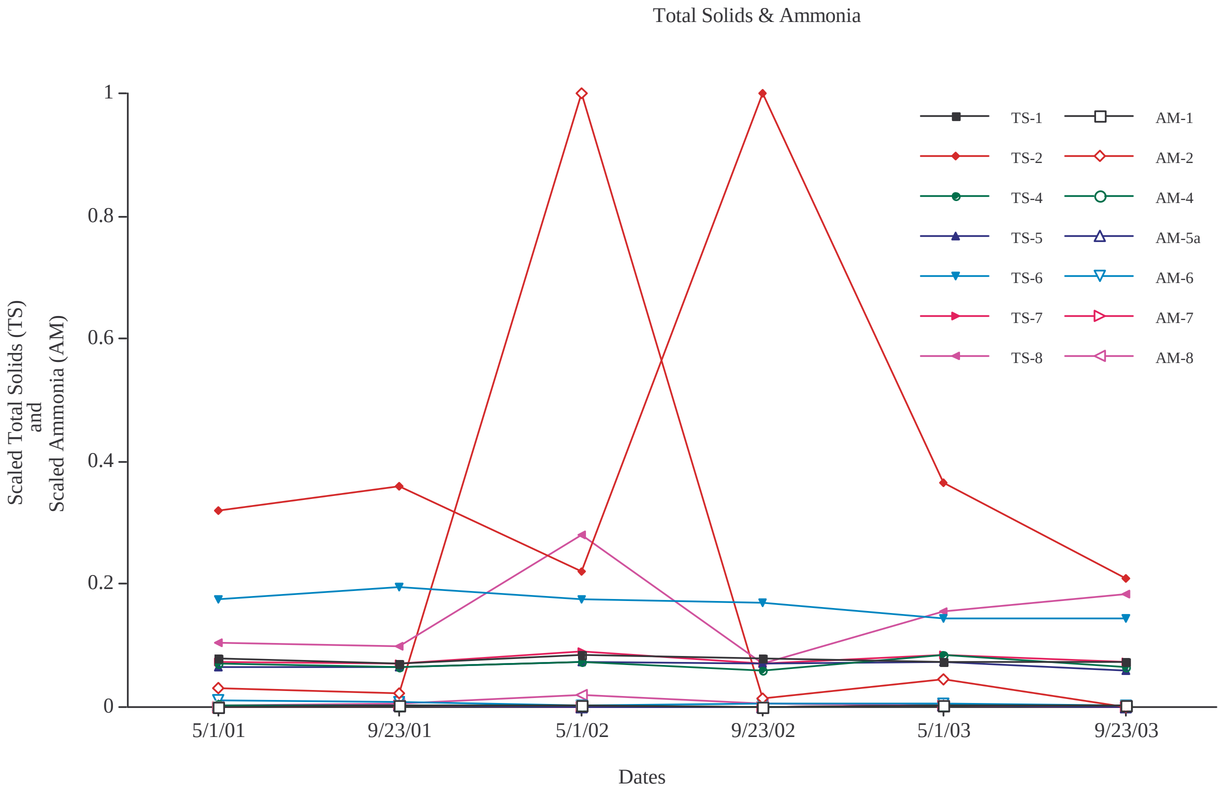


Figure 13. Normalized total solids and normalized ammonia for each of the eight monitoring wells.

In Figure 13, the maximum value for the period was used to normalize each series. All values of total solids were divided by the largest value, 2000 mg/L. The same was done for ammonia values. This results in unitless values that range from 0 to 1.0 and allows comparisons of total solids and ammonia on the same graph.

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

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

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

Surface water:

Surface water analyses have also been conducted. Burch Branch and its unnamed tributary upstream of the site along with a spot downstream of the site on Burch Branch were routinely sampled by Prince George's County and samples were submitted to the Maryland Department of Health and Mental Hygiene laboratory for analysis for the period from December 1982 to July 1988 (monthly for the period February 1983 to March 1985, less frequently thereafter). At the direction of the MDE, sampling and analyses of surface waters was discontinued after 1988.

Nitrate analyses of the surface waters potentially affected by the Tree Farm site were conducted by the State. In no instance did the analyses of surface waters yield nitrate concentrations in excess of the drinking water standard (10 mg/L). The nitrate concentrations at the two sampling locations upstream of the Tree Farm routinely fell within the 0.5 mg/L to 1.5 mg/L range. The concentration of nitrates in Burch Branch downstream of the Tree Farm was similarly low.

On two occasions (June 2 and July 5, 1983) nitrate concentrations in the unnamed tributary upstream of the Tree Farm were reported as high as 7.7 mg/L and 6.5 mg/L (respectively). No concurrent increase in nitrates in Burch Branch downstream was noted. On May 21, 1986, the Burch Branch downstream water sample was reported as having a nitrate concentration of 6.3 mg/L.

In all cases surface water samples yielded concentrations of cadmium and lead at or just above the detection limits. The highest concentration of cadmium of all surface water samples was reported for Burch Branch downstream of the site (sampled obtained February 24, 1983; concentration 0.015 mg Cd/l). The sample which yielded this result was obtained one month after sludge was first brought to the site.

As anticipated, because the surface waters drain rural agricultural lands (including some on which livestock are kept), wildlife habitat and lands impacted by residential development (including septic systems), samples obtained from Burch Branch and the unnamed tributary were more frequently determined to have elevated levels of fecal coliforms than were groundwater samples. The results of fecal coliform analyses on the surface waters are highly variable. Results ranged from a low of 3.6 MPN (Burch Branch upstream and downstream, February 24, 1983 and February 17, 1987, respectively) to 15,000 MPN on Burch Branch downstream (samples of May 21, 1986 and May 17, 1988). Elevated levels of fecal coliform were observed in other surface water samples collected in May: 1986, 430 MPN tributary upstream and Burch Branch upstream; 1987, 9300 MPN Burch Branch upstream and 430 MPN Burch Branch downstream; and 1988, 930 MPN tributary upstream and 430 MPN Burch Branch upstream. The elevation of fecal coliform densities in the spring in both up and down-gradient sampling locations infers that these densities may be a function of the increase in runoff from the local agricultural land use expected through the late Winter and early Spring months.

Biosolids description

In addition to well monitoring, biosolids were sampled at deposition and after tree harvest. Total nitrogen content of the biosolids (dry weight basis) at the time of the first application averaged 3.32 percent and ranged from 3.16-3.63 percent. When the sites were harvested and prepared for reapplication of biosolids at 6 to 9 years after the initial application, total N of the biosolids was 1.21 percent, which suggests that much of the biosolids had mineralized and/or denitrified.

In the past two decades, biosolids have become more benign, due mostly to the EPA point source reduction efforts. The metal content of biosolids has dramatically dropped. Some average values, as reported by the W.S.S.C. Operations Bureau are tabulated below.

Table 5. Components in biosolids from W.S.S.C., soil, and regulatory limits for Exceptional Quality Class A biosolids.

	Biosolids	**Units**	**Soil**	**Exceptional Quality Class A**
Cadmium	<4.86	mg/kg	<0.5	39
Chromium	38.4	mg/kg		1200
Cobalt	53.1	mg/kg		
Lead	61.4	mg/kg	10	300
Vanadium	<49.4	mg/kg		
Aluminum	44,100	mg/kg		
Copper	202	mg/kg	20	1500
Iron	11,000	mg/kg	730	
Zinc	370	mg/kg	11.2	2800
Chloride	10,600	mg/L		
Sulfate	1,820	mg/L		
Ammonia	1,840	mg/kg		
Total Nitrogen	32,300	mg/kg		
Nitrate	87	mg/kg		
Total Phosphorus	17,200	mg/kg		

The above table suggests that the biosolids coming from modern wastewater treatment plants are much lower in regulated metals than even the most rigorous classification (Class A, Exceptional Quality; USEPA, 1994a). Additionally, the lime stabilization elevates the pH such that any metals will be immobilized. Therefore, the major concern with this material is the appropriate utilization of the nutrients.

More recently, on-site samples indicated that total nitrogen was approximately 11,500 mg/kg (1.15%) wet weight and total phosphorus (as elemental P) was approximately 3,755 mg/kg (0.38%) wet weight. Moisture content on delivery ranges from 70 to 80%.

Biosolids were collected as trucks arrived to deliver biosolids for the experimental trenches. Biosolids results from samples collected in 2002 and 2003 are presented in Table 6, below. Results show levels throughout the 11 months of sample collection. Of particular note are the mean nitrogen content of 1.15% (wet weight basis) and moisture content of 71.76%. Standard deviations indicate that the product is very consistent.

Table 6. Biosolids analysis results

Date of Collection	N (%)	NH4-N (%)	P2O5 (%)	K2O (%)	Ca (%)	Mg (%)	S (%)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Moisture (%)
3/7/2002	1.09	0.06	0.80	0.09	3.12	0.06	0.05	29.30	89.00	52.60	74.70
3/18/2002	1.17	0.12	0.69	0.09	2.81	0.05	0.18	30.40	78.70	49.00	74.90
3/15/2002	1.15	0.06	0.80	0.07	2.70	0.05	0.17	29.60	77.00	55.80	77.20
3/13/2002	0.96	0.03	0.75	0.07	3.19	0.07	0.18	44.20	91.10	69.30	65.50
6/25/2002	1.23	0.08	0.82	0.08	3.35	0.06	0.20	64.10	97.50	58.60	69.60
6/26/2002	1.07	0.05	0.75	0.07	2.59	0.05	0.16	56.40	78.70	50.10	74.70
6/28/2002	1.54	0.09	1.02	0.09	2.80	0.06	0.24	71.60	143.30	77.50	67.40
7/26/2002	1.11	0.05	0.77	0.08	2.24	0.05	0.21	38.50	92.90	58.30	74.00
7/29/2002	1.16	0.06	0.78	0.07	2.45	0.05	0.21	28.80	107.60	62.10	73.60
7/30/2002	1.19	0.06	0.76	0.06	2.31	0.05	0.20	39.80	134.90	55.70	73.50
8/23/2002	1.18	0.04	0.82	0.09	2.19	0.06	0.31	48.90	131.40	79.00	71.10
8/27/2002	1.21	0.05	0.74	0.12	3.70	0.07	0.34	42.20	138.50	80.00	68.20
8/28/2002	1.44	0.09	1.07	0.10	3.30	0.06	0.30	74.50	192.00	76.40	68.70
9/27/2002	1.10	0.06	0.85	0.09	2.79	0.07	0.23	79.40	96.40	56.00	73.10
9/30/2002	1.05	0.08	0.83	0.11	2.84	0.08	0.21	72.90	89.40	63.60	74.20
9/30/2002	1.17	0.08	0.91	0.14	4.63	0.10	0.31	81.20	171.50	86.30	63.30
10/25/2002	1.10	0.05	0.91	0.13	2.66	0.07	0.18	70.10	170.50	59.40	75.80
10/28/2002	1.32	0.08	1.04	0.13	4.90	0.08	0.22	71.20	129.90	71.20	68.80
10/28/2002	1.36	0.11	1.08	0.14	6.49	0.08	0.24	77.20	187.30	72.80	66.30
11/27/2002	1.19	0.07	0.89	0.11	2.98	0.07	0.17	60.90	100.80	57.60	72.30
11/27/2002	1.26	0.07	0.87	0.13	4.87	0.91	0.18	64.10	153.50	51.70	68.10
11/27/2002	1.17	0.05	0.78	0.12	2.34	0.06	0.15	46.00	80.60	49.30	74.60
12/23/2002	0.92	0.04	0.66	0.11	2.24	0.05	0.12	39.25	70.69	40.36	77.70
12/23/2002	0.99	0.04	0.70	0.11	2.59	0.06	0.13	43.29	79.33	48.67	76.60
12/23/2002	1.14	0.06	0.87	0.13	6.27	0.08	0.18	48.76	87.46	47.82	68.54
1/20/2003	1.22	0.06	0.97	0.15	6.09	0.09	0.20	46.62	91.60	49.57	67.17
1/21/2003	1.11	0.07	0.83	0.18	3.57	0.06	0.16	42.44	85.67	46.66	73.64
1/24/2003	1.02	0.05	0.90	0.23	3.75	0.08	0.18	45.00	93.05	52.74	72.39
2/25/2003	1.23	0.05	0.87	0.20	3.68	0.08	0.16	40.44	99.51	61.92	68.41
3/10/2003	1.11	0.06	0.82	0.15	3.74	0.07	0.15	35.13	94.76	54.32	70.48
3/4/2003	1.08	0.05	0.77	0.13	3.61	0.07	0.13	30.88	99.44	54.11	71.67
3/25/2003	1.10	0.07	0.81	0.13	5.01	0.08	0.16	41.93	95.47	54.96	71.67
3/25/2003	1.18	0.06	0.92	0.21	5.78	0.11	0.18	55.56	107.53	63.92	70.13
3/26/2003	1.07	0.35	0.93	0.11	2.14	0.06	0.13	41.58	229.51	56.22	76.77
4/25/2003	1.19	0.07	0.83	0.10	2.12	0.06	0.13	32.98	88.39	51.90	72.97
4/30/2003	1.09	0.09	0.64	0.07	2.26	0.05	0.13	25.32	75.18	44.58	73.62
4/30/2003	1.06	0.08	0.74	0.07	2.41	0.05	0.13	28.61	78.49	45.41	73.75
Average	1.15	0.07	0.84	0.12	3.42	0.09	0.19	49.16	111.04	58.53	71.76
Std. Dev	0.12	0.05	0.11	0.04	1.24	0.14	0.06	16.47	37.88	11.03	3.50

Hydraulic Conductivity

Results are presented in Table 7. below.

Table 7. Hydraulic conductivity measurements by block

Block 1		**Block 2**		**Block 3**	
Sample ID	**Hydraulic Conductivity (cm/sec)**	**Sample ID**	**Hydraulic Conductivity (cm/sec)**	**Sample ID**	**Hydraulic Conductivity (cm/sec)**
1A-shallow	5.27E-03	2A-shallow	4.66E-04	3A-shallow	4.05E-07
1A-middle	1.64E-03	2A-middle	7.73E-04	3A-middle	1.40E-07
1A-deep	3.05E-03	2A-deep	7.47E-05	3A-deep	1.30E-05
1B-shallow	1.71E-03				
1B-middle	7.78E-05	2B-middle	4.73E-04		
1B-deep	9.53E-06	2B-deep	9.17E-05	3B-deep	1.02E-05
1C-shallow	8.33E-04	2C-shallow	2.88E-05	3C-shallow	2.68E-04
1C-middle	1.67E-03	2C-middle	3.60E-04	3C-middle	2.84E-05
1C-deep	2.92E-03	2C-deep	2.23E-03	3C-deep	9.44E-05
1D-shallow	1.85E-02	2D-shallow	1.01E-04	3D-shallow	1.48E-06
1D-middle	1.71E-02	2D-middle	2.18E-05	3D-middle	8.91E-06
1D-deep	1.81E-02	2D-deep	4.36E-05	3D-deep	3.13E-06
1E-shallow	4.71E-04	2E-shallow	1.27E-04	3E-shallow	3.81E-06
1E-middle	6.03E-03	2E-middle	2.12E-05	3E-middle	7.44E-07
1E-deep	1.57E-04	2E-deep	9.05E-07	3E-deep	9.99E-05
1F-shallow	2.11E-03	2F-shallow	1.32E-04	3F-shallow	1.41E-04
1F-middle	8.56E-05	2F-middle	5.77E-04	3F-middle	3.74E-06
1F-deep	7.64E-05	2F-deep	5.30E-05	3F-deep	5.48E-06
1G-shallow	2.77E-04	2G-shallow	4.77E-05	3G-shallow	3.24E-06
1G-middle	4.10E-04	2G-middle	4.67E-05	3G-middle	1.77E-05
1G-deep	2.52E-03	2G-deep	4.59E-05	3G-deep	1.67E-04
1H-shallow	2.40E-04	2H-shallow	9.93E-05	3H-shallow	3.80E-04
1H-middle	4.75E-04	2H-middle	9.16E-06	3H-middle	1.38E-05
1H-deep	3.10E-04	2H-deep	4.74E-05	3H-deep	5.76E-04
1I-shallow	1.26E-04	2I-shallow	1.40E-04	3I-shallow	4.04E-04
1I-middle	4.00E-04	2I-middle	8.74E-04	3I-middle	2.91E-05
1I-deep	3.99E-03	2I-deep	4.67E-04	3I-deep	1.52E-04
4C-shallow	1.02E-06	4B-shallow	2.28E-04	4A-shallow	1.79E-05
4C-middle	2.03E-03	4B-middle	4.89E-04	4A-middle	2.07E-04
4C-deep	1.92E-03	4B-deep	1.31E-04	4A-deep	1.32E-04

The average value over the entire site is 1.19 X 10^{-3} cm/s. These are tentative results pending a more entailed review of the results. The highest saturated hydraulic conductivity occurred in Block 1, which has lowest landscape elevation by approximately 10 – 15 feet and has highest remnants of sand and gravel. Soils typically do not have as high a range of hydraulic conductivities as has been found at this site. Here, there is a wide range of saturated hydraulic conductivity, from 1 x 10^{-7} up to 1 x 10^{-2} cm/s. Any particular soil would normally range over one order of magnitude, but at this site we find five orders of magnitude, which is indicative of some of the influence of drastic disturbances (typical of sand and gravel mining) on soil properties.

Figure 14 represents the variance of saturated hydraulic conductivity with depth. The original hypothesis was that saturated hydraulic conductivity will decrease with depth. This figure suggests that there is no significant difference in average saturated hydraulic conductivity with depth. However, the likely reason for this is because the variance is so high (CV = 2.7 for the deep soils, 3.1 for the shallow soils). An Analysis of Variance (ANOVA) will soon be completed which may show that saturated hydraulic conductivity does decrease with depth but that the spatial variance across the site may mask that fact.

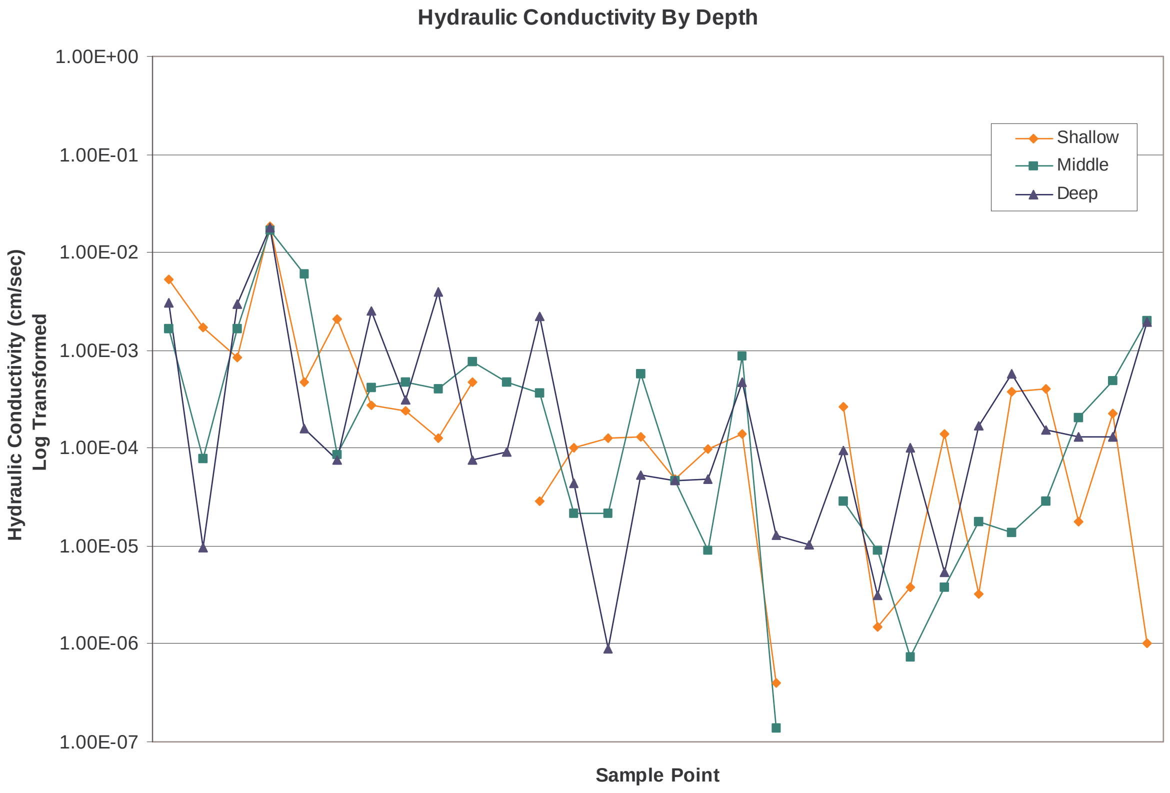


Figure 14. Saturated hydraulic conductivity as it varies with depth from the thirty pan lysimeter installations at three depths in each excavation.

Figure 15 represents the variance of saturated hydraulic conductivity with block and the blocks are related to landscape location. Block 1 is lowest in the landscape, at the bottom of a gentle slope. Block 3 is highest and has less slope. Additionally, block 1 had more remnants of sand and gravel than did blocks 2 and 3. The average saturated hydraulic conductivity for block 3 was 9.9 x 10^{-5} cm/s, the average saturated hydraulic conductivity for block 2 was 2.8 x 10^{-4} cm/s, and the average saturated hydraulic conductivity for block 1 was 3.1 x 10^{-3} cm/s. There are clear differences (an order of magnitude difference between each block) and there are also lower variances (CV = 1.48 for block 3 up to 1.71 for block 1). Hence, there is clear variation by landscape position. An ANOVA will be run to further investigate two-way interactions (depth by location) in saturated hydraulic conductivity.

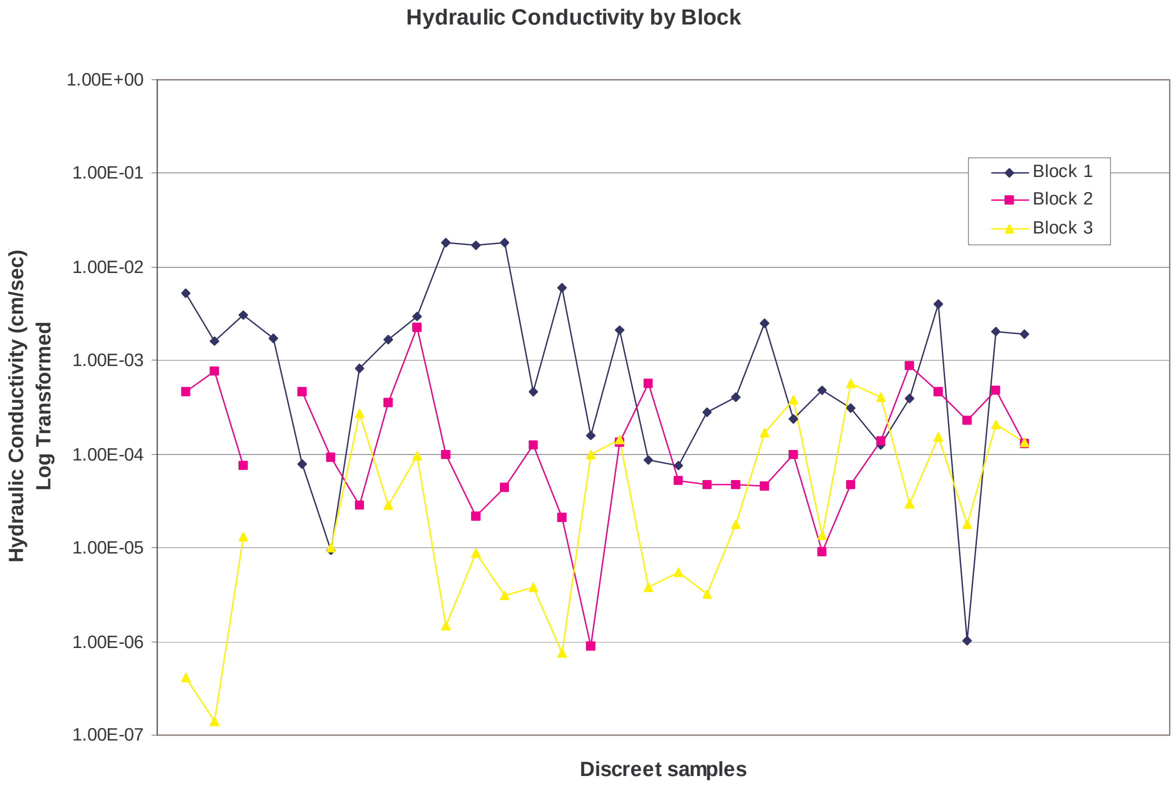


Figure 15. Saturated hydraulic conductivity as it varies with landscape location (represented by block) from the thirty pan lysimeter installations at three depths in each excavation.

Soil Water Samples

Soil water sample collection activities commenced in April 2003 for the pan lysimeter samples and November 2003 for the suction lysimeter samples. The experimental plot was split into three replicates (refer back to Figure 4), each of which was sampled in a given week within the same month. For the first year of the study (i.e., through June 2004) samples were collected on a monthly basis. After June 2004, samples were collected every other month. A summary of sampling dates and number of samples collected is provided in Tables 8 and 9 below.

Table 9 Pan lysimeter samples only: collection summary

Sampling Date	Number of samples collected
4/23/2003	10
5/7/2003	8
5/28/2003	9
6/4/2003	8
6/17/2003	9
6/23/2003	9
7/8/2003	11
7/16/2003	9
7/23/2003	10
8/6/2003	8
8/13/2003	11
8/20/2003	11
9/3/2003	8
9/10/2003	10
9/22/2003	11
10/14/2003	10
10/20/2003	11
10/29/2003	10

Table 8 Pan and suction lysimeter sample collection summary

Pan Lysimeter Samples		Suction Lysimeter Samples	
Sampling Date	Number of samples collected	Sampling Date	Number of samples collected
11/9/2003	9	11/10/2003	43
11/16/2003	8	11/18/2003	44
11/24/2003	11	11/23/2003	44
12/3/2003	10	11/30/2003	46
12/10/2003	9	12/8/2003	44
12/18/2003	9	12/21/2003	47
1/7/2004	10	1/6/2004	45
1/13/2004	8	1/12/2004	42
1/31/2004	4	1/30/2004	31
2/10/2004	8	2/11/2004	47
2/17/2004	9	2/18/2004	46
2/25/2004	7	2/26/2004	45
3/8/2004	9	3/10/2004	46
3/19/2004	8	3/19/2004	47
3/26/2004	7	3/26/2004	45
4/9/2004	10	4/9/2004	45
4/23/2004	9	4/23/2004	45
4/30/2004	6	4/30/2004	43
5/13/2004	9	5/14/2004	48
5/21/2004	9	5/21/2004	44
5/27/2004	10	5/27/2004	45
6/16/2004	10	6/16/2004	50
6/23/2004	11	6/23/2004	47
6/29/2004	12	6/30/2004	47
8/17/2004	11	8/18/2004	50
8/23/2004	11	8/25/2004	49
8/30/2004	11	8/31/2004	44
10/15/2004	10	10/16/2004	49
10/22/2004	11	10/23/2004	47
10/29/2004	11	10/30/2004	44
12/3/2004	11	12/4/2004	49
12/12/2004	5	12/13/2004	47
12/21/2004	11	12/22/2004	44

Each pan lysimeter was fitted with a dedicated line of polyethylene tubing running down the inside of the PVC pipe that was connected to the pan lysimeter. Samples were drawn out of the polyethylene tubing into a 1-L filtration flask by applying suction on the arm of the flask with a vacuum hand pump. Water was withdrawn until the pan emptied or the estimated volume of the pan (i.e., 10 L) was collected, whichever occurred first. In some instances, volumes greater than 10 L could be collected, due to the fact that water recharged more quickly than a sample could be removed. For each 1-L of volume collected, 100-mL was sub-sampled using a graduated cylinder and placed in a 1-L high density polyethylene container to produce a composite sample representative of the contents of the pan. Samples were stored on ice and delivered to the laboratory.

Each suction lysimeter apparatus contains a dedicated pressure-vacuum access tube and discharge access tube. Approximately three to four days prior to the collection date, 60-70 centibars of suction was applied to the vacuum access tube with a hand pump while keeping the discharge access tube closed. The vacuum tube was then closed to maintain suction and draw sample from the soil matrix through the porous ceramic cup of the suction lysimeter. Sample was then recovered from the suction lysimeter by opening both lines, applying pressure to the pressure-vacuum tube, and collecting the sample that ejected from the discharge access tube. Samples were stored on ice in a cooler and delivered to the laboratory.

Results have been obtained for pH, orthophosphate, nitrite, and nitrate. Samples are currently in process for the remaining parameters: total nitrogen, total phosphorus, and ammonia. Ammonia was not a component of the grant proposal but, to provide more information on the nitrogen conversions taking place, it was incorporated into the study. Results for pH show the majority of samples within a range of 6.4 – 7.6, though some of the suction lysimeter samples positioned 6 inches directly under the biosolids row had higher pH levels of 9 or 10 (a response to the lime in the biosolids). Overall, concentrations for nitrite and nitrate were very low. Of the

425 pan lysimeter results and 1,465 suction lysimeter results, only three pan samples and one suction lysimeter sample, or 0.2 % of the nitrate results exceeded the drinking water maximum contaminant level of 10 mg/L. Furthermore, only 15 pan and 10 suction lysimeter nitrate results were above 1 mg/L (one tenth of the MCL). Orthophosphate results ranged from 0-2.5 mg/L in the pan samples and 0-4.6 mg/L in the suction lysimeter samples. Nitrate and orthophosphate results are presented in Figures 16 through 19 below.

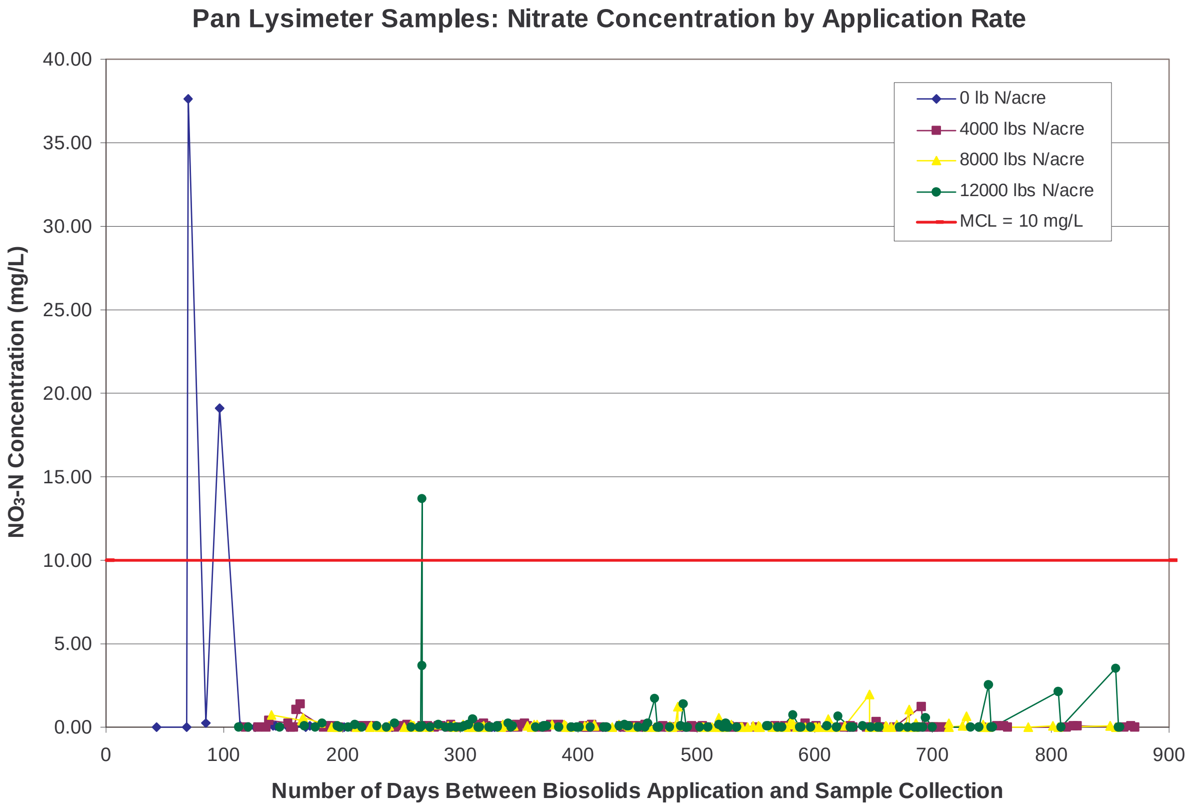


Figure 16. Nitrate Results for Pan Lysimeters by Application Rate

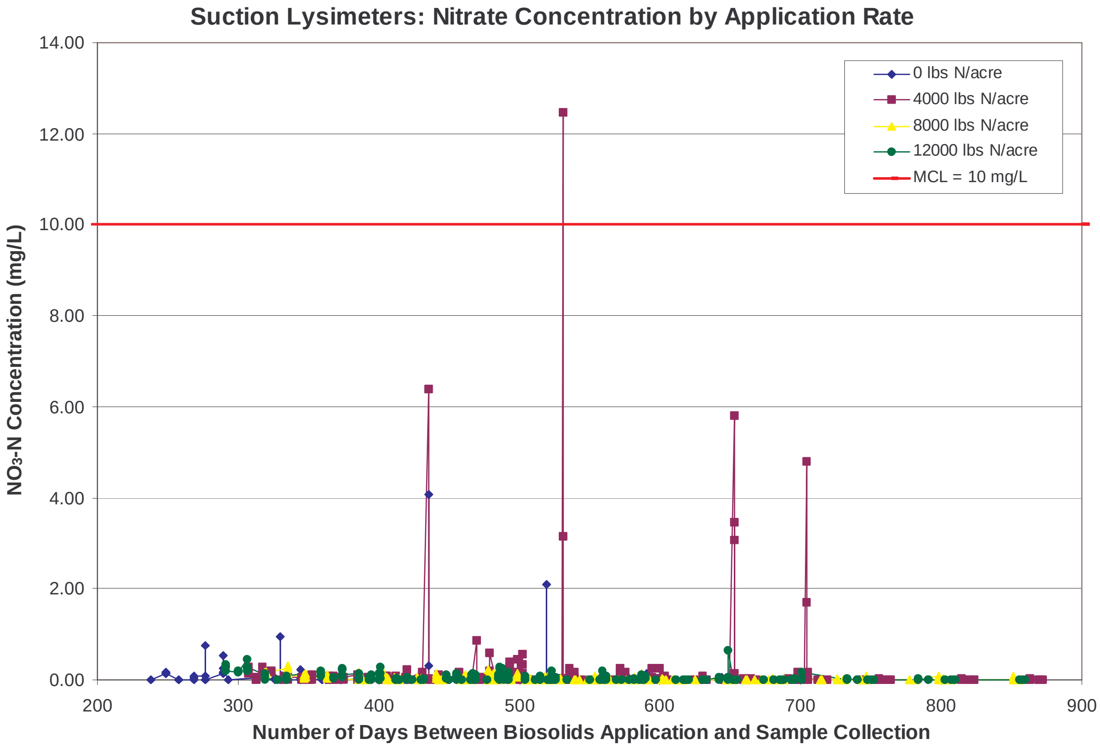


Figure 17. Nitrate Concentration for Suction Lysimeters by Application Rate

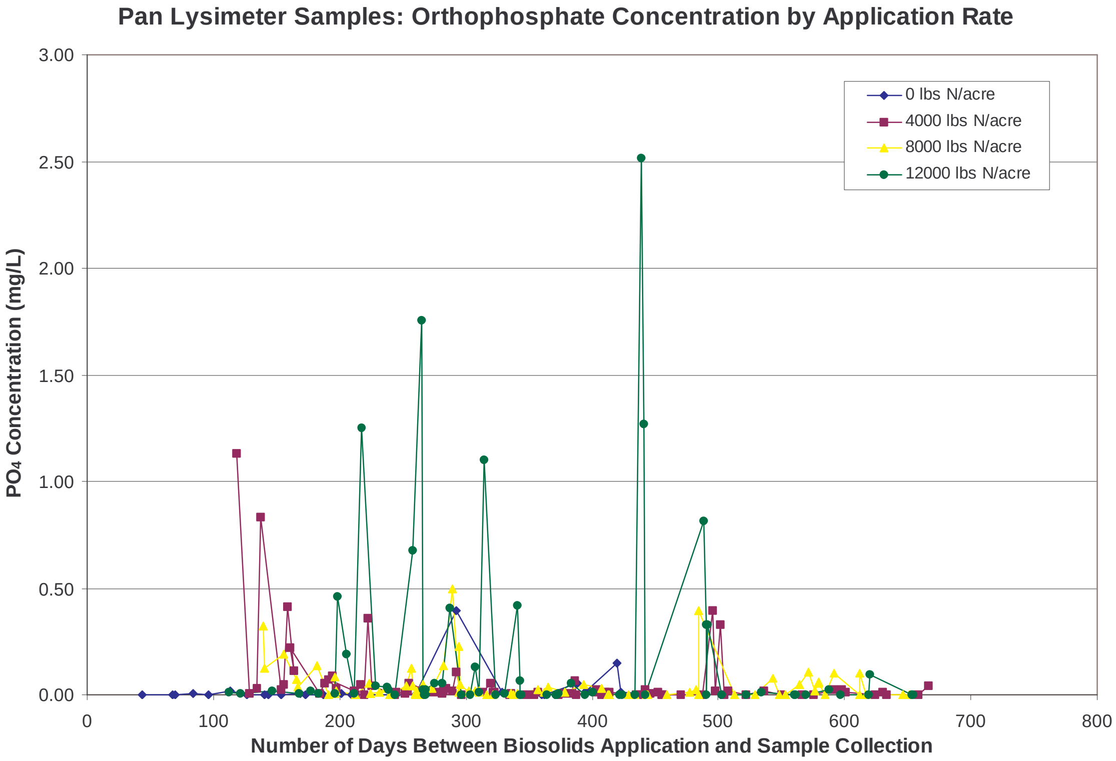


Figure 18. Orthophosphate Results for Pan Lysimeters by Application Rate

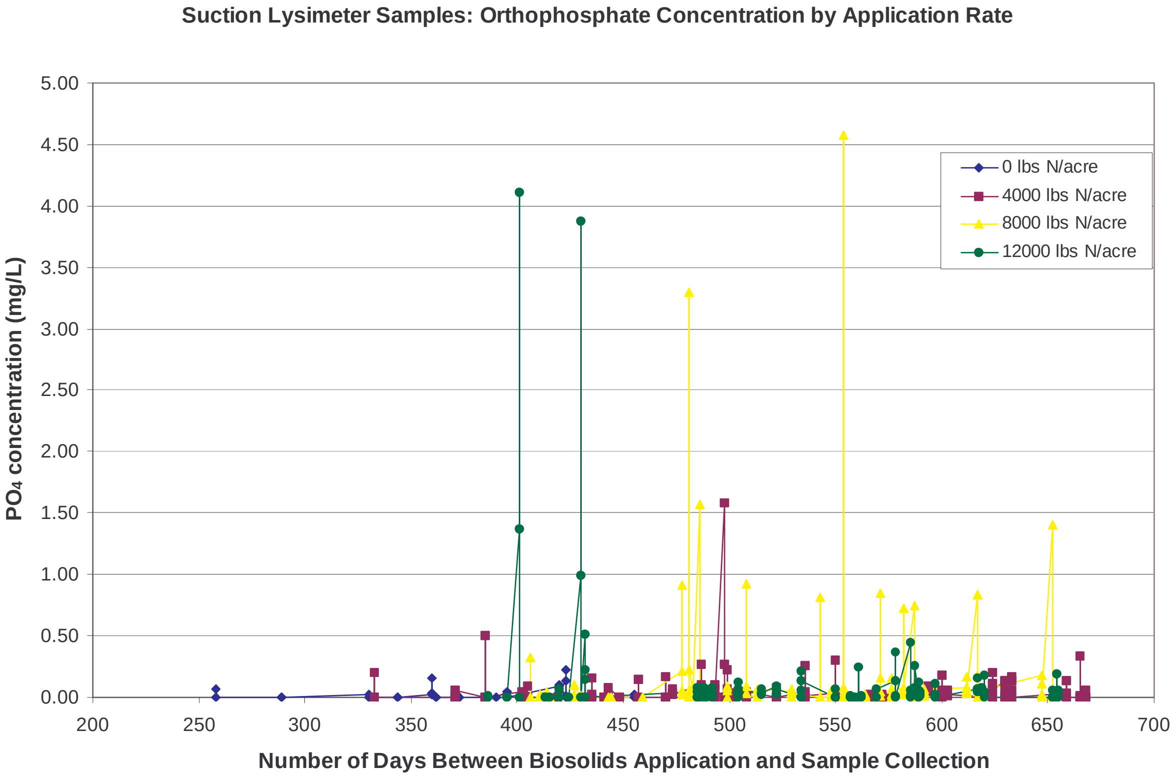


Figure 19. Orthophosphate Results for Suction Lysimeters by Application Rate

The only parameter that appears to be affected by biosolids application rate is the orthophosphate concentration in the pan lysimeters (Figure 18). Because sample collection occurred during a very wet period (the wettest year on record, Oct. 2002-Oct. 2003, followed by a very wet year, Oct. 2003-Oct. 2004), the pans captured a large volume of saturated flow. Along with the high flow was the movement of solids, not normally associated with porous media flow. Due to the movement of solids, phosphorus was carried to the pans. It is probable that this would not occur in drier times nor would the transport occur for long distances.

In summary, if nitrate was produced, very little left the biosolids trench. In addition, because of the high rainfall during this sampling period, these samples represent a worst-case scenario for nitrate transport. It is therefore unlikely that nitrate will move at all under more average rainfall and environmental conditions.

Standpipe Wells:

Standpipe wells were put in to evaluate response of biosolids pack to events and to each other. Much analysis remains to be done, but it is clear that the rows are not behaving like a pipe. Specifically, the uppermost standpipes have water in them much of the time, the middle pipes are low or empty and the lowest shallow wells have water in them. If they were hydraulically connected, the middle shallow wells would have water in them.

The standpipe well results suggest that the trenches are hydrologically isolated and do not lateral subsurface flow. This is logical since the end of a daily biosolids fill is covered with soil daily, creating a dam every 60-90 feet, hydraulically isolating each load of biosolids.

Work in Progress

Currently, statistical analyses are being performed on the analytical results. The water quality laboratory in Frostburg is completing analysis for total nitrogen, total phosphorus, ammonia, and ions. Although results are expected by spring 2005, laboratory capacity and analysis requirements may alter the schedule. Once the data set is complete (for the dates May 2003 through December 2004), statistical analysis of variance will be performed on all data. A thesis on water quality for the first 18 months following biosolids application will be completed by the end of summer, 2005.

In addition, a linked pair of water quality studies is scheduled to be performed this summer (2005). A microbial population study will be performed on biosolids that have been entrenched for 6 months, 24 months, and 72 months. Nine locations in the trench and nearby soil will be sampled with 4 replicates, for a total of 108 samples. The microbial population will provide information on the amount of denitrification occurring and any other nitrogen transformations.

Using the same samples, a denitrification potential will be developed using a standard laboratory analysis (acetelyne generation of ethylene) on a gas chromatograph. This will provide a measure of the potential for denitrification and the microbial study will quantify the population of denitrifying microbes in both time and space. These same samples will also have nitrogen and phosphorus analysis run to chemically characterize overall nutrient status in the biosolids and surrounding soil.

A separate project using a spectrophotometer as a stress analysis tool is underway. The results of this work will provide a method to relate nitrate stress and moisture stress to spectral reflectance, which can be measured quickly on the spot and remotely from the top of the tree. While this project is neither funded by WSSC nor directly related to water quality, it is a management tool for the biosolids-tree farm beneficial reuse system. It is expected to be completed between September and December of 2005.

EFFECT OF SITE PREPARATON AND PLANTING TECHNIQUE ON SURVIVAL AND GROWTH OF HYBRID POPLAR

The work described in this section investigated 1) the effect of planting technique on mortality and early growth of hybrid poplar cuttings; 2) effect of tree density and biosolid application rate on foliar nutrient levels of two-year old hybrid poplar cuttings.

Methods and Materials

Experimental Design & Plot Layout

The experimental design, plot layout, and tree planting and measurement detail is the same as that for the 3.1-acre research area described in the Plot Layout Section of the Water Quality Methods and Materials. In order to provide for comparison of different planting techniques used inside the research area to that outside the research area, four plots of approximately 40 trees each were established adjacent to the research plot at various locations that represented the range of site conditions.

Tree Planting Method

The operational technique for planting hybrid poplar cuttings outside the 3.1-acre research area was developed by ERCO personnel. Subsoiling, in which a furrow of compacted soil is broken up prior to planting, was implemented to break up the extremely dense overburden so that the newly planted cuttings could quickly form roots and access the soil moisture and nutrients in the biosolids. The operational technique involved attaching booms to a bulldozer so that a 10’ by 10’ grid pattern was established (Figures 21 & 22). The bulldozer has a subsoiling bar that created a trench about 1 foot deep. The bulldozer then created another planting row 10 feet from the existing row by lining the boom up on the existing row. When completed, the cuttings were easily hand planted where the 10 foot planting rows intersect (Figure 20), creating an accurate 10 foot planting pattern.

Figure 20. Poplar cutting planted at intersection of planting rows.

Figure 21. Bulldozer with extended arms for subsoiling 10' X 10' grid

Figure 22. Subsoiled 10' X 10' grid ready for planting

The research site was planted in June 2003. The cuttings could not be planted, however, using the operational technique due to the fact that the bulldozer could not circumnavigate sampling instrumentation that had previously been installed on site. Instead, cuttings were hand-planted using a dibble bar (Figure 23) to create the hole for the cutting, which was then inserted and packed with dirt to seal out air. Both areas were planted on the same day.

Figure 23. Planting with dibble bar fails to break up compacted soil.

Vegetation management was implemented by applying herbicides in the spring of 2003, 2004, and 2005 to control vegetation growth in 3-foot strips on each side of the trees. Vegetation management was only applied for trees planted with a dibble bar in the research area, not for trees planted with subsoiling adjacent to the research area. Pendulum®, a pre-emergent herbicide, was sprayed over the top of the planted cuttings in June 2003. This herbicide could be sprayed without concern for damage to the cuttings because it does not damage actively growing hybrid poplar trees. Goal®, a pre-emergent herbicide with some post-emergent control, was sprayed in March of 2004 and 2005 at a rate of 8 pints per acre. It was sprayed prior to budbreak to avoid damage to the trees. All herbicides provided fair to good control of vegetation.

The two distinct, but adjacent tree crops that were planted using the subsoiling method provided the opportunity to determine the effect of planting technique on the mortality and growth of the planted cuttings.

Tree Measurement

The total height and basal diameter (5 mm above the growth from the cutting) was measured for each cutting after the first and second growing seasons (2003 & 2004) in the research plot and for a subset of trees in adjacent plots. Deer had a major impact on height growth in this area due to browsing of the stems, so frequency of browsing was assessed. It was assumed that browsing would have a negative impact on first year height growth.

Results and Discussion:

Survival, Height Growth, and Deer Browsing Impacts

Table 10. Effect of planting method on first year mortality, height growth, and deer browsing.

	Research Plots: Cuttings Planted with subsoiling	Adjacent to Research Plots: Cuttings Planted without subsoiling
Mortality after one year	**1.7%**	**14.2%**
Height after one growing season (cm)	**52.4**	**33.9**
Live stems browsed	**51%**	**20%**

Table 10 indicates that after one year, the mortality of cuttings on the plots with subsoiling was much lower (1.7%) compared to the cuttings planted without subsoiling (14.2%). Height growth of the cuttings planted without subsoiling was also much higher (52.4 cm.) than the cuttings planted without subsoiling (33.9 cm). The lower mortality and better height growth of cuttings planted with subsoiling occurred even though these stems sustained a much higher amount of deer browse (51% for subsoiled plots compared to 20% for plots without subsoiling). It would be expected that a higher percentage of stems browsed would likely reduce overall height growth and survival, but that did not occur.

It was assumed that the better growing conditions created by subsoiling were in part the cause of these differences in mortality and height growth. The long-term impacts of planting without subsoiling are that trees will take longer to establish themselves and that rotation length may need to be extended to accrue similar amounts of biomass compared to trees planting with subsoiling. This can have economic implications as rotation length has a direct impact on how quickly the site can be reapplied. The first year results indicate that subsoiling is an essential part of site preparation for planting and is critical to good survival and rapid site colonization by hybrid poplar.

In general, the benefits of subsoiling using the operational technique described are as follows:

- Provides a symmetrical layout that will ease vegetation management and other stand entries throughout the rotation.
- Is essential to reduce compaction of dense soils which reduces seedling mortality (increases survival) and early height growth
- Allows young trees to overcome the negative impact of deer browsing

Work in Progress

This assessment was only completed using the first year growth data which limits that statistical analyses that can be applied. The second year growth data has been collected and will be statistically analyzed with the first year data to see if the above-noted trends are sustained.

EFFECT OF APPLICATION RATE AND TREE DENSITY ON GROWTH AND NUTRIENT STATUS OF HYBRID POPLAR

Methods and Materials

Experimental Design, Plot Layout, & Tree Planting and Measurement

The experimental design, plot layout, and tree planting and measurement detail is the same as that for the 3.1-acre research area described in the Plot Layout Section of the Water Quality Methods and Materials.

Foliar Leaf Collection and Analysis

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

To establish a baseline for the foliar nutrient uptake and enable trends to be identified in the future, foliar nutrient samples were collected during the second growing season (August, 2004) using an accepted protocol (VanHam 2003, personal communication). Foliar leaf sampling during the first year is not useful because the newly planted cuttings are undergoing many nutritional changes that make results impossible to analysis. All samples were analyzed by a reputable commercial laboratory. The sampling protocol was as follows:

- Sample time during the peak of the growing season – early to mid-August
- Sample the first fully expanded leaf, which is usually 5-7 leaves down from the terminal leader of the central vertical branch. Sampling of leaves that are still actively expanding

means the leaf will be pulling nutrients from the tree and give unrealistic value. Conversely, if the leaf is past the expanding stage, it will be in a process of decay and a will be net exporter of nutrients. Therefore, the resulting values may be low.

- Do not sample leaves on leaders with deer browsing
- Sample at mid-day when actively growing
- Sample 7-10 trees in each plot if possible and make a composite sample.

The protocol had to be altered in some cases due to the high incidence of deer browsing and lack of samples. Rather than a regular sampling scheme across each plot, it was necessary to take leaves from available trees without deer browsing, which resulted in about 6-7 leaf samples from each plot that were combined into a composite sample.

Each application rate – tree density combination is replicated three times. Therefore, there were only three foliar measurements on which to base the statistical tests for any treatment, which were completed using SAS Analysis Systems.

Results and Discussion

It was not expected that any of the treatments (application rate or tree density) would cause any significant differences in growth or foliar nutrient uptake. It is not until the trees have established their root systems and the crowns and roots of the trees start to compete with each other for nutrients that treatment effects will occur. Due to the relatively poor growth the first few years caused by the weather, site preparation and planting method, it is estimated it could be 3 or 4 more years before treatments effects are expressed in foliar leaf measures.

Table 11 shows the results of the foliar leaf analysis for the two-year old trees. The low number of samples per treatment combination resulted in means with little statistical significance. These data do, however, provide information on the relative nutritional levels of the two year old trees. The literature on hybrid poplar foliar nutrition (Zabek, 2001) can be summarized as follows:

- Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth is known to occur at 2.5 - 3.5% foliar nitrogen and 0.25 - 0.40% foliar phosphorous.
- Foliar N:P ratios of above or below 9.5 seem to coincide with differences in tree growth response to N and P applications. The ratio of N:P may prove to be an effective diagnostic tool.
- Foliar nutrient levels of N and P at or above the levels for fast growth, combined with a N:P ratio around 9.5 should be expressed in measures of increased growth (height, diameter, and biomass) over treatments with lower optimum levels.

Table 11. Foliar nutrient levels for different treatments after two growing seasons.

Lbs/N/ac	**4000**		**8000**		**12000**			**P value sig<0.05**
Trees/ac	**290**	**430**	**290**	**430**	**290**	**430**	**Mean**	
% N	**2.94**	**2.81**	**3.05**	**2.72**	**2.72**	**3.13**	**2.90**	**0.87**
%P	**0.29**	**0.27**	**0.28**	**0.25**	**0.25**	**0.31**	**0.28**	**0.59**
N:P ratio	**10.1**	**10.4**	**10.9**	**10.9**	**10.9**	**10.1**	**10.6**	**n/a**
%K	**1.31**	**1.37**	**1.41**	**1.22**	**1.28**	**1.48**	**1.35**	**0.85**
%Mg	**0.34**	**0.27**	**0.32**	**0.29**	**0.36**	**0.29**	**0.26**	**0.32**
%Ca	**1.06**	**0.90**	**0.95**	**0.82**	**1.09**	**0.80**	**0.94**	**0.32**
pp Cu	**9.3a**	**7.3ab**	**7.7ab**	**6.3**	**9.3a**	**7.0ab**	**5.5**	**0.005**

What is clear from Table 11 is that the values for % foliar nitrogen range from 2.72 – 3.13, well within the range of values typical of fast growth on fertilized plantations. The values for % foliar phosphorous range from 0.25 – 0.31, again, within the range of fast growth. The N:P ratios range from 10.1 – 10.9, above the value of 9.5 in the literature that corresponds with increases in growth over trees with lower ratios. It is important to understand that studies that demonstrate increased tree growth with fertilization are usually on established plantations with crown closure, which is not the case in this study.

Field observations indicate these trees (in growth year two) are just in the process of accessing the available nutrients in the biosolids, and that foliar nutrient levels may very well increase to maximum levels, which was found in samples from the four year old plantation study described previously. The biosolids provide a stable nutrient base for the tree seedlings that should sustain them for many years. As the nutrients in the biosolids are utilized over years of growth, there will come a time when treatments with higher application rates should sustain the rate of growth for a longer period of time, given the same tree density. This should be reflected in growth differences as well as foliar nutrient content.

The interactive effect of tree density and biosolid application is less clear. The treatments with the same application rate but different tree densities may end up producing similar amounts of biomass, although on a different number of trees. Growth and foliar nutrient content of the different treatments will be followed throughout the six year rotation to determine the impacts of different management strategies. Of great concern is the desire to produce a tree of large enough diameter that it can be harvested for pulpwood on at least a break even basis to eliminate the present cost of chipping small diameter trees.

EFFECT OF VEGETATION MANAGEMENT AND PHOSPHOROUS AMENDMENTS ON GROWTH OF FOUR-YEAR OLD HYBRID POPLAR TREES

Materials and Methods

Maximizing the growth of hybrid poplar should result in faster utilization of the biosolids, which can decrease the rotation length and increase the economic return on the property. Contrary to most forest ecosystems, the nutrient base of this deep row system is found underground in the biosolids trench, while the upper soil layers provides little in the way of available nutrients. However, moisture from rainfall does come down through the upper layers and vegetation on the surface can limit what reaches the tree roots, once the moisture in the biosolids is extracted.

Research on tree growth in forest plantations has found that controlling surface vegetation typically results in increased growth and biomass of the trees. However, adding nutrients without controlling surface vegetation usually does not result in increased growth, because the additional nutrients and water are taken up by the surface vegetation before the deeper tree roots can reach them.

The addition of nutrients can result in significant increases in height and biomass accumulation. This has been found to be the case in phosphorous-limited soils in pine plantations on the coastal plain. Inspection of the trees in the deep row application system has found that phosphorous levels may be limiting the ability of the trees to uptake nitrogen, which would likely result in faster growth rates.

This study was implemented in order to determine the effect of vegetation management and phosphorous additions on the growth and biomass accumulation of hybrid poplars using the deep row application method.

Experimental Design

The treatment design is a 2×2 factorial with 2 levels of P (P, no P), 2 levels of vegetation management (strip herbicide spray, no spray), for a total of four treatments. There are three replications for each treatment combination for a total of 12 plots. Each treatment combination was assigned randomly to a tree plot containing 25 hybrid poplar trees four years of age. Each 25 tree treatment area consisted of a 5 X 5 block of trees. Each plot was separated by a buffer row of trees that received no treatment. All trees were planting on a10' X 10' spacing after deep row application of 171 dry tons per acre. The planting site is located on the ERCO tree farm.

The four year old trees had never received any phosphorous amendments or chemical vegetation management prior to this study. The only vegetation management used since planting was mechanical mowing with a tractor and bushog. The crowns of the trees had closed but the understory has an established layer of grasses and weeds.

The plot layout below shows the random assignment of the four treatments in each 25 tree block: 1) C – control; P - phosphorous amendment only; V - vegetation management only; and PV - phosphorous and vegetation management combined

V1	P1	PV1	C1
P2	V3	C2	V2
PV3	C3	P3	PV2

Figure 24. Plot layout of 240' X 180' showing randomly assigned treatments

Application of Treatments

On the plots receiving vegetation management, it was necessary to use a combination of herbicides to kill the established grasses and broadleaf plants, and to use a pre-emergent herbicide to stop new plant establishment. Roundup® herbicide mixed with Goal® herbicide was sprayed in 3 foot strips on each side of the tree on April 7, 2004 for vegetation management. The Roundup killed existing vegetation and the Goal herbicide provided pre-emergent control throughout the growing season (Figure 25). The phosphorous amendment was applied using commercial corn starter. It was applied in late-March before trees leaf out but when roots are actively growing. A dibble bar was used to dig a hole 6 inches deep (3 holes per tree) to apply the prescribed rate of phosphorus (0.6 cups per tree total).

Figure 25. Plots in early spring after vegetation control

Prior to the growing season, all the trees were tagged with an aluminum tag and the diameter at breast height marked with red paint so that the diameter would be taken at the same place each time. The diameter and heights were taken prior to the growing season and after the first growing season, so that changes in height and diameter could be assessed. Biomass was calculated in cubic meters from height and diameter measures prior to and after the growing season using a formula from the literature (Zabek, 2001).

Figure 26 Root mat of plots with vegetation management was dead, however annual vegetation had regrown (above). Plots without vegetation still had an established root mat that was utilizing nutrients from the upper soil layers.

In mid-August at the peak of the growing season, two foliar leaf samples were taken from four trees in each of the treatment plots to provide one composite sample for each treatment using the protocol previously described. The first fully expanded leaves at the top of the tree were sampled using a lift, which is usually 5-7 leaves down from the terminal leader. If you sample leaves that are still actively expanding, the leaf will be receiving nutrients from the tree and give unrealistic value. If the leaf is not expanding it will be a net exporter of nutrients and values may be low. All samples were taken at mid-day. The sampling resulted in 12 total leaf samples that were analyzed for nitrogen, phosphorous and other nutrients by an independent lab.

Figure 27. Leaves selected for foliar sampling are taken from the terminal leader. Leaves 5-9 down from the top are selected.

Results:

Height, Diameter, and Biomass

The one-year height growth of all the treatments was significantly higher than the control. However, only the vegetation/phosphorous treatment significantly increased diameter (Table 12). None of the treatments significantly increased biomass compared to the control after one year.

Table 12. One year growth measures for each treatment.

One year change in:	Control	Vegetation Mgt	Phosphorous Additions	Vegetation/ Phosphorous
Height (meters)	**2.22^{a}**	**2.66^{b}**	**2.54^{b}**	**2.71^{b}**
Diameter (centimeters)	**4.304a**	**3.976^{a}**	**3.946^{a}**	**4.400^{ab}**
Biomass (cubic meters)	**0.025^{a}**	**0.025^{a}**	**0.025^{a}**	**0.027^{a}**
Statistical analysis using mixed model repeated measures at P<0.05				

Foliar Nutrient Status

The low number of samples likely contributed to the lack of statistical significance (<0.05) for many of the measures such as %N, %P and micronutrients (Table 13). The N:P ratio was very significant, but since it was developed from other measures of N and P that were not significant, its relevance may be questionable. While significance may have been limited, trends in the data were telling. The vegetation/phosphorous treatment had the highest %N value at 4.0, which would be expected since the removal of vegetation and addition of P allowed improved uptake of the trees. A similar trend existed for %P, with the highest value found again for the vegetation/phosphorous treatment.

Table 13. Foliar nutrients for four year old hybrid poplar.

	Control	Vegetation Management	Phosphorous Amendment	Veg. Mgt/ Phos. Amd.	P Value significance<0.05
% N	**3.6**	**3.6**	**3.7**	**4.0**	**0.55**
%P	**0.35**	**0.33**	**0.31**	**0.42**	**0.09**
N:P ratio	**10.4** ^{b}	**10.9** ^{ab}	**12.1** ^{a}	**9.5** ^{b}	**0.006**
%K	**2.1**	**2.0**	**2.0**	**2.4**	**0.10**
%Mg	**0.22**	**0.27**	**0.27**	**0.26**	**0.29**
%Ca	**0.75**	**0.93**	**0.94**	**0.76**	**0.19**

Composite sample from 4 trees for each treatment sample.
Statistical analysis using Tukey test

Perhaps the most relevant result was the ambient levels of N, P, and the N:P ratio found in the samples. They are representative of the maximum values found in the literature. Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth is known to occur at 2.5-3.5% foliar nitrogen and 0.25-0.40% foliar phosphorous. Foliar N:P ratios of above or below 9.5 usually coincide with differences in tree growth response to N and P applications. The values found in this study were at or above the levels that would usually result in significant increases in growth and biomass.

In this study, growth and diameter differences where found between the treatments, but not with biomass. The measurements will be taken again after the second growing season and additional differences may become significant.

Conclusions

At year four of the crop rotation, the deep row biosolids system does appear to provide the trees sufficient levels of nutrition, comparable to levels found in hybrid plantations fertilized with surface-applied biosolids and manures. The combined treatment of phosphorous amendment and vegetation management resulted in increases in height growth and diameter. However, another year's data is needed to better assess the long term effects on biomass and if the height and growth increases continue. If differences in growth and biomass are minor, then the cost of applying the treatments compared to the control may not be cost-effective.

Future Work

The data reported is only for the first year of the two year study. The vegetation management treatments will be reapplied with herbicide in March, 2005 and the foliar leaf samples and growth data taken later in 2005. It is hoped that treatment effects will become clearer at that point.

EFFECT OF VEGETATION MANAGEMENT AND PHOSPHOROUS AMENDMENTS ON GROWTH OF NEWLY PLANTED HYBRID POPLAR TREES

Maximizing the early growth and establishment of planted cuttings should allow the tree roots to reach the biosolids faster and result in faster utilization of the biosolids, which can decrease the rotation length, increasing the economic return on the property. At the very least, reducing competition through vegetation management and hastening plant establishment and root development with phosphorus amendments should improve plant health and, hence, survivability after the first year. Contrary to most forest ecosystems, the nutrient base of this deep row system is found underground in the biosolids trench. While the upper soil layers provide little in the way of available nutrients, they do provide the entry for surface water to reach the tree roots and can be critical in first year growth.

Research in hybrid poplar plantations has found that controlling surface vegetation during stand establishment can result in better growth (Thomas et. al, 2001). However, adding nutrients without controlling surface vegetation usually does not result in increased growth, because the additional nutrients and available water are taken up by the surface vegetation before the deeper tree roots can reach them.

The addition of nutrients that are limiting tree growth can result in significant increases in height and biomass accumulation. This has been found to be the case in phosphorous-limited soils in pine plantations on the coastal plain. Inspection of the trees in the deep row application system has indicated that phosphorous levels may be limiting the ability of the trees to uptake nitrogen, which results in higher growth rates. This study was initiated to address these questions for newly-established plantations.

Materials and Methods

Experimental Design

The experimental design and plot layout for this study is the same as that for the previous section that used already established 4-year old hybrid poplar trees. The only difference is that the treatments were randomly assigned and the physical location was adjacent to the study in previous section. Both studies were initiated within a few days of each other in March 2004.

Application of Treatment

The application of treatments did vary from other studies because the site was newly graded with no vegetation present. The rows where subsoiled using the operational technique to provide a regular 10 -foot spacing for the cuttings (Figure 28). Cuttings were planted by hand at the intersection of the subsoiled rows. The phosphorous amendment was applied using commercial corn starter (N-P-K, 0-48-0). It was applied immediately after planting by sprinkling it in the subsoiling trench on four sides of the planted cuttings the prescribed rate of phosphorus (0.6 cups per cutting total).

Since many of the cuttings had begun to leaf out when planted it was not possible to use Goal herbicide to control the vegetation, which would damage leafed out cuttings. Therefore, Pendulum®, a pre-emergent herbicide, was sprayed immediately after planting using a backpack sprayer in three-foot strips on each site of the cuttings. Pendulum® has no effect on vegetation present, but since the site was newly graded, no vegetation was present to control. It was only fairly effective after the end of one growing season. The gravelly soil at the surface likely contributed to this lack of efficacy.

Figure 28. Newly planted plots, showing subsoiling trenches made by the bulldozer.

In mid-August, at the peak of the growing season, foliar leaf samples were collected using the protocol described. However, all the trees were severely browsed (Figure 29) and the collection of 6 leaves per plot was difficult in some cases. Leaves were taken from terminal leaders with little or no browsing. All samples were taken at mid-day when the trees were actively growing. The sampling resulted in 12 total leaf samples that were analyzed for nitrogen, phosphorous and other nutrients by an independent lab. Unfortunately, the leaf samples were so small in volume that there was not sufficient biomass to measure nitrogen on one of the composite plot samples. This resulted in only two measures for %N on the vegetation management plots, making statistical analysis impossible for %N.

Figure 29 Severe deer browsing.

Results and Discussion

The severity of the deer browsing made the use of height and diameter data unreliable as indicators of treatment effect. These metrics were collected so that they can be used in the analysis of second year data, however, they are not included in this report. Browsing caused many of the small trees to appear more like bushes after the first year, which can cause the lack of a central leader to continue growth the second year. Therefore, in March 2005, the trees were pruned so that one central leader would be expressed.

Foliar Nutrient Status

The low number of samples likely contributed to the lack of statistical significance (<0.05) for any of the nutrient measures (Table 14). The vegetation/phosphorous treatment had the highest %N value at 3.47, which would be expected since the removal of vegetation and addition of P allowed improved uptake of the trees. A similar trend was not found for %P in the vegetation/phosphorous treatment.

The most informative result of this analysis is the ambient levels of N, P, and the N:P ratios for the treatments. They are representative of the values found in the literature for fertilized trees that exhibit fast or maximum growth. Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth is known to occur at 2.5-3.5% foliar nitrogen and 0.25-0.40% foliar phosphorous. Foliar N:P ratios of above or below 9.5 usually coincide with differences in tree growth response to N and P applications. The values found in this study are at or above the levels that would suggest significant increases in growth and biomass.

Table 14. Foliar nutrient levels by treatment for one-year old hybrid poplar.

	Control	Vegetation Management	Phosphorous Amendment	Veg. Mgt/ Phos Amend	P Value sig<0.05
% N	3.17	3.29 **	2.94	3.47	-----
%P	0.29	0.31	0.31	0.28	0.45
N:P ratio	10.9	10.6	9.5	12.4	----
%K	2.4	2.3	2.1	2.4	0.51
%Mg	0.19	0.18	0.20	0.23	0.13
%Ca	1.0	1.1	1.2	1.1	0.12

Composite sample from 4 trees for each treatment sample.
Statistical analysis using Tukey test
** only two values instead of three

Conclusions

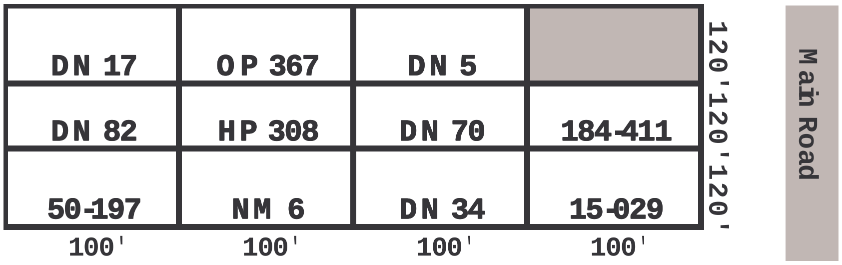
The deep row biosolids system does appear to provide the trees levels of nutrition comparable to fertilized plantations, even during the first growing season. The effects of phosphorous amendments, vegetation management, and combined phosphorous and vegetation management on height and diameter growth could not be determined in this study due to the impact of deer browsing. While deer fencing would have solved this problem, the intent of the study was to mimic operational conditions. Growth measurements and nutrients samples will be taken after the second growing season to determine if significant treatment effects occur as the stems grow out of the reach of deer. Results of this research will help to determine if the vegetation and phosphorous treatments actually result in significant growth impacts. If differences are minor, then the cost of applying the treatments compared to the control may not be cost-effective.

FIVE YEAR HYBRID POPLAR CLONAL TRIALS

The purpose of this study was to test a variety of hybrid poplar clones to see which perform best using deep row application on abandoned gravel spoils in this region. The lack of nutrients in the existing soil after mining combined with the biosolids that may contain as much as 20 percent lime to meet regulatory requirements, creates a unique mix of conditions. The clone used in the initial plantings at the ERCO tree farm was HP308, but problems with cottonwood beetle, slow growth, and the changing makeup of biosolids required experimentation with new clones.

Experiment Design

Table 15 Layout of different clonal trials.



DN 17	OP 367	DN 5		120'
DN 82	HP 308	DN 70	184-411	120'
50-197	NM 6	DN 34	15-029	120'
100'	100'	100'	100'	

In Section 5 of the ERCO tree farm (Figure 6) an area of 400’ by 360’ was set aside for a planting of different hybrid poplar clones to test their growth and survival under the unique conditions of the site. The design and layout of the clone trial was developed by Mike VanHam of Sylvis Environmental in British Columbia, Canada, a private consultant who is retained by ERCO, Inc. Table 15 shows the clones that were randomly assigned to each area. There was no effort to create smaller replicated plots which would have provided better statistical rigor to the design. The test plots were divided into 11 equal sized blocks, which were 100 feet by 120 feet. Cuttings were planted on a 10-foot spacing, so that each block contained 120 trees.

Table 16 Source and type of hybrid poplar clones.

Source and Type of Hybrid Poplar Clones	
Source Nursery	**Type of Clone**
Itasca	NM6
Itasca	DN5
Itasca	DN17
Itasca	DN34
Itasca	DN70
Itasca	DN182
Itasca	OP367
Itasca	184-411
Itasca	15-29
Itasca	50-197
ERCO	HP308

The eleven clones were selected based on recommendations by Sylvis Environmental, Inc. The source nursery and type of clone are provided in Table 16. Only the thickest and best looking planting stock was planted. The planting stock consisted of a cut branch stem about one foot long and 1/2 inch in diameter. During the month of April, the cuttings were planted firmly into the ground with the top bud showing. The vegetation competition between the rows was controlled by periodic mowing .

The total tree height after each growing season was measured using a telescoping pole and/or a handheld instrument. Survival was assessed after the first and second growing season. The data were entered and analyzed using SAS (Statistical Analysis System). Initial analysis of the data distribution indicated that using the square of the height measurements provided a better data distribution for analysis. All the data are reported in Table 17 with graphs made to highlight single characteristics of height growth and survival.

Results

Survival

Survival after the second growing season was greater than 90% for three clones with three other clones in the 80-90% range (Figure 30). These clones in order of survival percentage were: OP367 (96%); DN70 (94%); DN5 (93%); DN82 (88%); NM6 (87%); and DN34 (82%). The survival of clone 15-029 at 70% was lower than the others, but should receive some consideration due to its good performance in total height measures. The survival of other clones were under 80%, which would indicate they are not well adapted to survive in this environment. It is possible that deer browsing may have had an impact on survival since some clones may be more favored than other, however, since fencing to

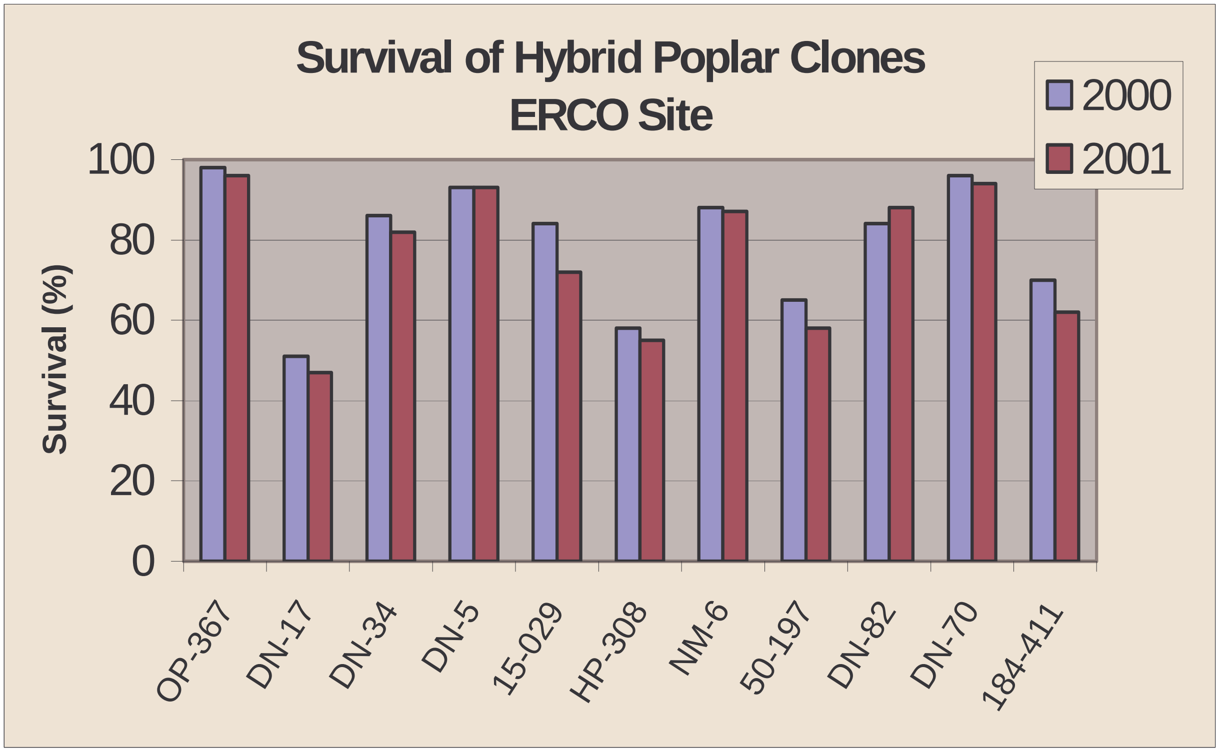


Figure 30. Percent survival for each of 11 hybrid poplar clones during 2000 and 2001. One hundred percent represents 120 trees.

exclude deer is not operationally possible, clones used must be able to survive browsing pressure early on.

Total and Annual Height Growth

After four growing seasons, both the OP-367 and DN-17 clones were significantly taller than the other clones (933 and 833 cm. respectively), but not significantly different from each other (Figure 31). Throughout the four year period, OP367 consistently had the best height growth, with it being significantly taller that all the other clones after the end of year 1 and year 2.

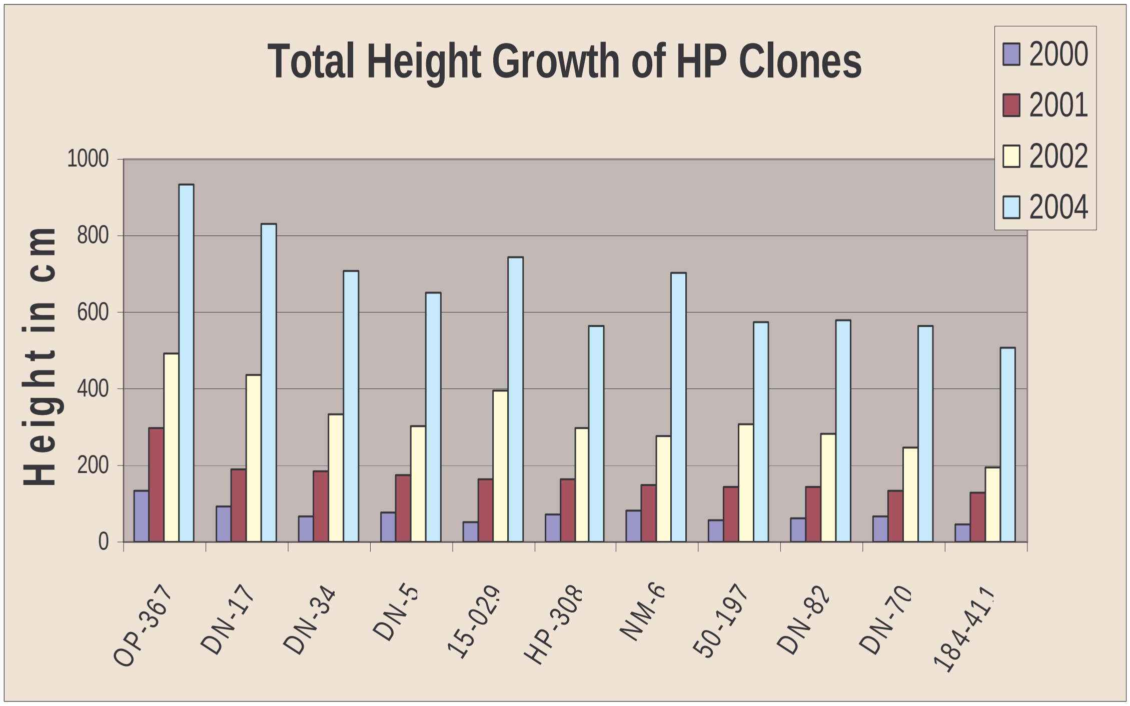


Figure 31. Total average height for each of 11 hybrid poplar clones, 2000-2004. Bars for years 2000 and 2001 represent an average of 120, while years 2002 and 2004 represent an average of 40 randomly selected trees.

After five years, DN17 maintained its place as the second tallest clone in terms of total height growth. The five tallest clones after the fifth year were: OP367 (933 cm); DN17 (833 cm); 15-029 (743 cm); DN34 (708 cm); and NM6 (701 cm).

Annual Height Growth

OP-367 consistently demonstrated superior annual height growth compared to the other clones except for DN-17 and 15-029, which had better annual growth in year 2-3 (Figure 32). The height growth of OP-367 in the second year was 165 cm., 50 cm. more than the next best performer DN17, with 115 cm. By the fifth year, OP367 had an annual height growth of 439 cm., which was only slightly higher than NM6 at 422 cm. However, NM6 performed poorly in the previous years.

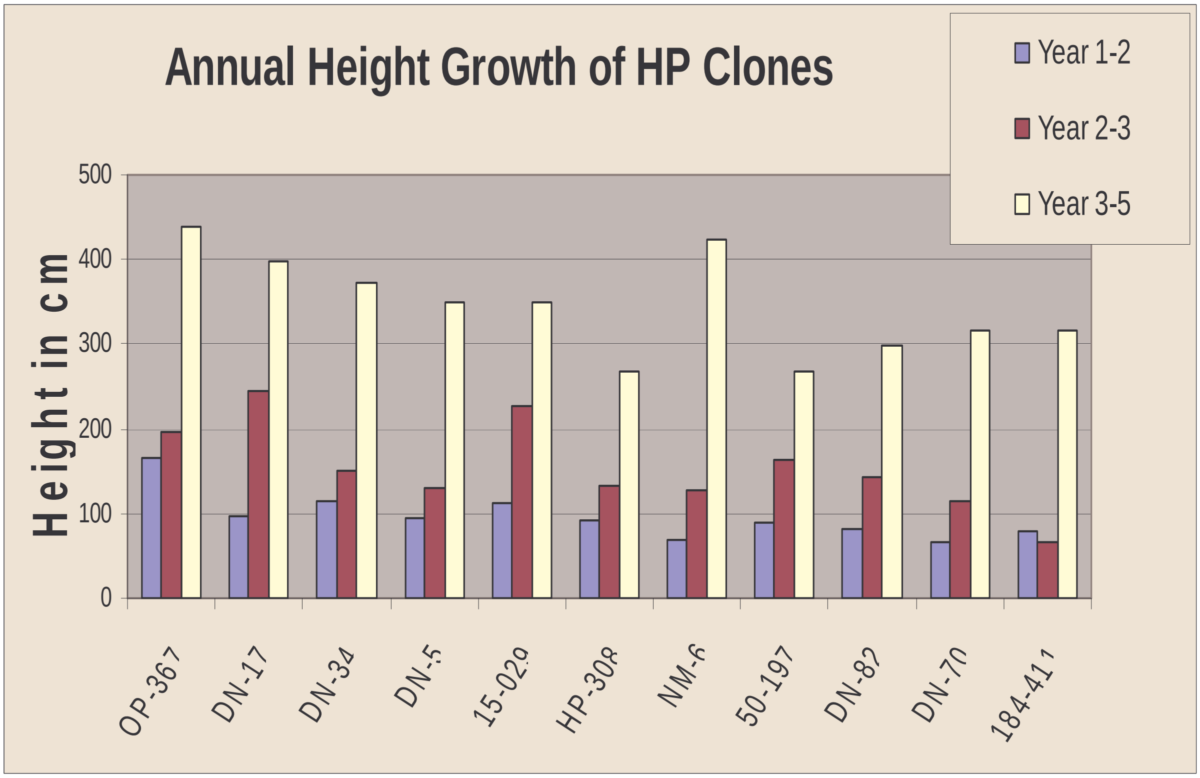


Figure 32 Annual height put on by each of 11 hybrid poplar clones.

Conclusions

After five years, the OP367 clone was the superior performer of all the clones tested for survival and total height. The DN-17 clones had the next highest height growth after five years, but its survival was poor at 47% after two years. It is unclear if deer browsing or site conditions may have been responsible for this lower survival, but its superior height growth makes it worth further consideration. The DN-34 clone also had excellent survival and acceptable height growth which warrants further consideration.

Some clones have been determined to be unacceptable due to problems with insects and disease or form, although they may have good survival and height growth. OP-367 was not only the best performer but lacked any serious insect or disease problem. Although OP-367 had the highest survival at 96%, there were two other clones (DN70 & DN5) that had survival over 90%. However, the very poor height growth of these clones indicates they are not desirable choices for this site, regardless of the good survival.

In contrast, the poor survival of DN17 (47%) is a concern since it was a superior performer in height growth. More analysis needs to be done to determine if deer browsing may have impacted the survival or if the lack of irrigation may have impacted survival. Field notes indicated that deer had caused serious mortality on some clones. When a stem was damaged by deer browsing or rubbing it typically died back to the base. In many cases these stems died, impacting overall survival. For those stems that did grow, the lower heights could also impact the overall mean height of the entire block.

Table 17 - Overall height, survival and growth measures for clonal varieties.

Clone	Survival Rate (%)		Total Height (cm)				Height Growth yr. 1 – 2	Height Growth yr. 2-3	Height Growth yr. 3-5
	2000	2001	2000	2001	2002	2004			
OP-367	98	96	131	297	494	933	165	197	439
DN-17	51	47	92	190	434	833	98	244	399
DN-34	86	82	69	184	334	708	115	150	374
DN-5	93	93	78	172	303	652	94	131	349
15-029	84	72	53	166	393	743	113	227	350
HP-308	58	55	72	165	297	566	93	133	268
NM-6	88	87	81	150	278	701	69	129	422
50-197	65	58	56	145	309	577	89	164	268
DN-82	84	88	60	141	283	582	81	142	299
DN-70	96	94	67	134	248	564	67	114	316
184-411	70	62	46	126	193	509	80	67	317

Future Work

No diameter measures had been taken for the clonal variety plots through the 2004 growing season, so no biomass measurements could be calculated. Diameters will be measured for the 2005 growing season and biomass calculated. Visual observations indicate that the OP-367 clones will outperform the other clones.

HYPOTHETICAL BUSINESS SCENARIO FOR DEEP ROW BIOSOLID APPLICATION FOR A FORESTRY OPERATION

Experimental Design

The deep row biosolid application beneficial use technique at ERCO is an operational business that has functioned under a research permit from the Maryland Department of Environment since 1983. There are no other comparable operations anywhere in the world so the development of an economic analysis required using information obtained from ERCO, but it is not representative of the ERCO operation itself. Commonly accepted machine rates per hour and production rates per person were used to determine costs based on reasonable assumptions. The objective was to determine how different factors affect the profitability of this enterprise, given the present market.

Methods

Interviews were carried out with the manager of the ERCO operation to determine reasonable production rates and logistical guidelines in the analysis. Custom rate hourly equipment costs for bulldozers and backhoes were used to determine total costs based on the number of hours estimated for their use. As application rates increased assumptions were made on equipment needs and hours required.

The amount of land required under various alternative application rates was determined based on the research being carried out in this project.

Results and Discussion

Business Resources

The economic analysis first identified the business resources required under three headings (Table 17): 1) land & buildings; 2) site development; and 3) equipment and personnel. This would enable the determination of costs associated with each expense.

Production

The analysis intended to look at the income generated under the different application rates that were part of the research study: 4000, 8000, and 12,000 lbs of nitrogen (N) per acre for the six-year rotation. The existing ERCO operation presently operates near the 4000 lbs of nitrogen rate. First, it was necessary to calculate exactly how many wet tons per acre were required to reach the nitrogen application rates in the study. It is important to note that the wet tons per acre required to reach target N levels depends directly on the percent nitrogen found in the biosolids. In this case the average was about 1.2% (wet weight basis) using lime-stabilized biosolids that are currently available. If the percent N were to decrease, it would require more wet tons per acre to reach the same N application rate - likewise, fewer tons per acre with a higher percent N. Based on the results from the water quality portion of this work (Table 6), the nitrogen concentration is very consistent and not likely to change. However, if the process at the wastewater treatment plant were to change, then a change in the biosolids nitrogen content would be anticipated.

Field experience indicates that applying the 2351 wet tons per acres associated with the 12,000 lbs N/acre is the highest volume that can be physically applied using the deep row technique as presently done due to operational and equipment limitations. Therefore, while higher rates of N beyond the 12,000 lbs N per acre are possible, it would only occur if the percent N of the biosolids used were increased, not by physically applying more than 2351 wet tons per acre.

To reach the three application rates per acre, it was necessary to use operational information to determine how much application would take place in a normal week given the abilities of equipment and personnel. This was determined by figuring the average number of wet tons per truck (18 wet tons), times the number of loads per day, and the number of work days per week. This information was used later when estimating equipment and personnel needs and their associated costs under the different scenarios.

Land Requirements

An important aspect of deep row application is the land requirements. Since one application is made every rotation, there must be adequate land available during the rotation length before reapplication is needed. In our scenario we used a rotation length of 7 years on a 125 acre land base. However, if the rotation length can be reduced by improving the growth of the trees through better vegetation management, phosphorous amendments, or other means, this would reduce the rotation length and have a significant impact on land requirements and/or application rate that could be sustained. Likewise, if rotation length is increased, it will increase the land base required by 17.3 acres for each additional year. Rotation length was kept constant for this analysis until other research information provides better information.

In this analysis, it was assumed that the site is only 125 acres, which worked out to 121 acres in this case. Hence, 17.3 acres per year are required using a 7 year rotation, regardless of the application rate. The only factor changing is the amount applied per acre.

Financial Projection – Income and Expenses

This project attempted to estimate annual income and expenses based on the expense factors identified and the present income structure of the industry (Table 18). The $25 per wet ton received for application of the biosolids does not include the cost of trucking to the site, which may be figured into actual contracts in a number of ways.

The main expenses that change with the higher application rates are equipment operators, and dozer and excavator equipment costs. Many of the other costs are not significantly impacted by higher application rates. The general trend in equipment operator needs is that an additional equipment operator is needed when you go to the next higher application rate.

The bottom line of this analysis is the profit, calculated as annual income minus annual expenses. At the lower application rate the operation makes little profit ($4,075), however, profits increase dramatically at the 8000 lbs N rate to $208,325. At the highest application rate of 12,000 lbs N the profit almost doubles to $412,575.

What this analysis clarifies is that if the higher application rates are environmentally feasible, then the profit potential would likely attract others into the industry. It is important to note that the higher profits at the higher rates would not likely be sustained as more competitors entered the industry and market competition would likely reduce profits.

Some Highly Variable Costs

The values provided for taxes, permits & assessments, tree harvesting, opportunity cost per year are included at their actual cost, but may be reduced as indicated below:

- Taxes – many gravel spoils are taxed as commercial properties, however, because this type of operation is considered a tree farm, it is eligible for a woodland assessment, which would reduce the taxes to about $1-2 per acre. However, a forest stewardship plan must be developed and implemented (Kays and Schultz, 2003).

- Monitoring costs – since the present deep row application is operated under a research permit, the monitoring costs depend upon what the Maryland Department of Environment determines is needed. Once research is completed it is likely that draft COMAR regulations can be developed so that actual monitoring costs can be known by those considering the enterprise.
- Permits and assessment fees – similar comments as provided for monitoring.
- Tree harvesting – one of the objectives of the current research is to make it possible to grow a tree suitable for pulp production in the rotation time so that a commercial harvester could take the trees at a break-even cost. Presently, harvesters are paid to chip the trees on site which is expensive.
- Opportunity cost – this is the value this land could bring if used for other purposes. This value can be changed depending upon the business operation.

Other Considerations

Presently, biosolids may be trucked long distances (hundred of miles) for application to farm fields or disposal in landfills. The sites for deep row application are within 40 miles of most treatment facilities and would dramatically reduce trucking and the associated pollution from emissions, wear and tear on highways, accidents, and noise associated with truck traffic. In addition, the deep row application with trees has desirable environmental benefits associated with the reclamation of gravel spoil, improved wildlife habitat, the production of forest products, carbon sequestration, improved water quality, and the general attributes of open space and working lands. These are external costs that are not incorporated into a financial analysis for any one enterprise, but real costs none the less to local, state, and federal governments, that is, the taxpayer.

Table 18 Hypothetical business scenario for deep row biosolid application with trees.

Dale Johnson, Farm Management Specialist
Jonathan Kays, Natural Resource Specialist
University of Maryland Cooperative Extension

Business resources

Land & Bulidings
125 acres gravel spoil
Office trailer
Storage trailer

Site development
Well
Electricity
Telephone
Geological assessment
Well monitoring
Erosion and sediment control/site grading
Permits

Equipment
Bulldozer
Backhoe
Pickup
Pickup
ATV
Scale

Human
Equipment operators
Manager

Production

Application rates per acre
855 wet tons per acre 4000 lbs N
1710 wet tons per acre 8000 lbs N
2351 wet tons per acre 12000 lbs N

Application rates per week	
18 wet tons per load, 3 loads per day, 5 days a week	285
18 wet tons per load, 6 loads per day, 5 days a week	570
18 wet tons per load, 9 loads per day, 5 days a week	855

Application rate per acre	855	1710	2351
Application rate per week	285	570	855
Acres need per week	0.33	0.33	0.33
Acres needed per year	17.3	17.3	17.3
Years per rotation	7	7	7
Acres per rotation	121	121	121

Table 19 Financial projection.

Annual income				
Application rate per week	285	570	855	
Price/wet ton	25	25	25	
Income per year (line 1 x line 2 x 52 weeks per year)	370,500	741,000	1,111,500	
Forest product income				
Annual expenses				
Manager	60,000	70,000	80,000	
Equipment operator 1	50,000	50,000	50,000	
Equipment operator 2		50,000	50,000	
Equipment operator 3			50,000	
Office trailer, $200 month	2,400	2,400	2,400	
Storage trailer, $150 month	1,800	1,800	1,800	
Dozer $75/hour, 5 hours/day, 250 days	93,750	187,500	281,250	
Excavator $75/hour, 2 hours/day, 250 days	12,500	25,000	37,500	
Service vehicles 40,000 miles/year, $0.35/mile	14,000	14,000	14,000	
ATV	1,500	1,500	1,500	
Taxes, residential assessment, $75/acre, 125 acres	9,375	9,375	9,375	*
Utilities, $100/month	1,200	1,200	1,200	
Insurance	15,000	15,000	15,000	
Monitoring, 4/year	6,000	6,000	6,000	*
Wells, cost recovery # Years	500	500	500	
Permits & assessment	4,000	4,000	4,000	*
Professional improvement	2,000	2,000	2,000	
Tree planting, 17 acres/year, $600/acre includes cuttings	10,200	10,200	10,200	
Tree harvesting, 17 acres/year, $1,000/acre	17,000	17,000	17,000	*
Lime 5 ton/acre, 18 acres, $30/ton	2,700	2,700	2,700	
Opportunity cost of land, $500/acre/year	62,500	62,500	62,500	*
Total expenses (Total of lines 7…27)	366,425	532,675	698,925	
Income - expenses (line 3 - line 28)	4,075	208,325	412,575	

* indicates costs that may be highly variable depending location & circumstances

Other considerations

Trucking costs $1/mile	Biosolid sustainability
Trucking emission reduction	Forest renewable resources
Carbon sequestration	Recalmation
Open space/working land	Noise, Truck Traffic
Wildlife habitat	Water quality

EDUCATION OF STATE AND LOCAL ENVIRONMENTAL PROFESSIONALS ABOUT THE USE OF DEEP-ROW BIOSOLID APPLICATIONS

One-day field days were held in early October during each year of the project: 2002, 2003, and 2004. The format of the field days included a morning session at the Prince George's County Cooperative Extension office where a project overview and research results were shared. This was followed by a field session at the ERCO site to demonstrate the deep row technique and showcase the research. Each of these annual sessions was attended by about 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, as well.

Figure 33. Steve Gerwin speaking to tour group (October 2003).

Figure 34. Eric Flamino explains the deep row process to a group of professional foresters.

Exit surveys and interviews of attendees confirmed the positive value of these field days, which have consistently resulted in an expanded network of interested clientele, project ideas, and funding sources. Deep row projects or plans for the installation of projects are pending in British Columbia, Virginia, and Pennsylvania, and are a direct result of the annual field tours or other tours of the property. During the last workshop held in October 2004, a CD-Rom was made that included all the powerpoint presentations. A copy of that CD was provided to WSSC and other project sponsors. Individuals and groups continue to visit the site on a regular basis.

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