

## Use of Deep-Row Biosolid Applications to Grow Forest Trees: A Case Study

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**Abstract**—Deep-row application of biosolids on reclamation sites is a unique alternative method of land application that solves many of the problems associated with surface application techniques. When combined with the growth of nitrogen-demanding hybrid poplar trees, it provides a natural recycling system that utilizes nutrients on-site, produces forest products and wildlife habitat, and reduces erosion while reclaiming abandoned, biologically dead soils created by sand and gravel operations.

In the Washington, DC/Maryland area, environmentally sound, cost-efficient utilization of biosolids has created constant challenges since the passage of the Clean Water Act of 1972. Presently, biosolids are distributed on farmland, marketed for compost, and incinerated; however, the most cost-effective methods of biosolids management are either application to agricultural land or burial in landfills.

Biosolids production for 1995 in Maryland (MDE 1997) was 857,355 Mg of which 672,129 were utilized in-state as follows: agricultural land (59%), landfill disposal (5%), distributed and marketed (21%), incinerated (10%), and marginal land applications (5%). The data fail to acknowledge the fate of the remaining 190,653 Mg (22%) of the total which was hauled out of state, most likely a portion going to large landfills. Also, the District of Columbia produces an average of 362,872 Mg per year—a large percentage of which is currently disposed of out of Maryland. More current figures to show the fate of biosolids are not available; however, the percentage sent to landfills versus other land application methods is known to increase with excess landfill capacity in a region and associated lower tipping fees (ENR 1997).

Difficulty in siting new landfills and possible future restrictions on out-of-state hauling may result in restric-

tion and/or increased cost of landfill disposal of biosolids. Current agricultural land application of municipal biosolids can boost soil productivity for field crops and improve soil textural characteristics. However, regular broadcast applications once every 1–3 years, necessary to provide crop nutrient requirements, can cause logistical, safety, and economic concerns due to transportation cost, poor weather, frozen soils, availability of labor, and other problems. Resentment by rural landowners and offensive odors in developing areas has resulted in many local application restrictions. There are also developing concerns over phosphorus pollution in receiving waters from repeated applications. The developing drawbacks of landfill and agricultural land application point to the need for alternative disposal technologies (Sikora and Colacicco 1979, 1980).

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). Burying biosolids in deep-rows covered by a soil overburden, known as deep-row application, is a promising disposal technology that was researched in the early 1970s (Sikora and Colacicco 1980, Taylor et al. 1978). While the production of annual corn

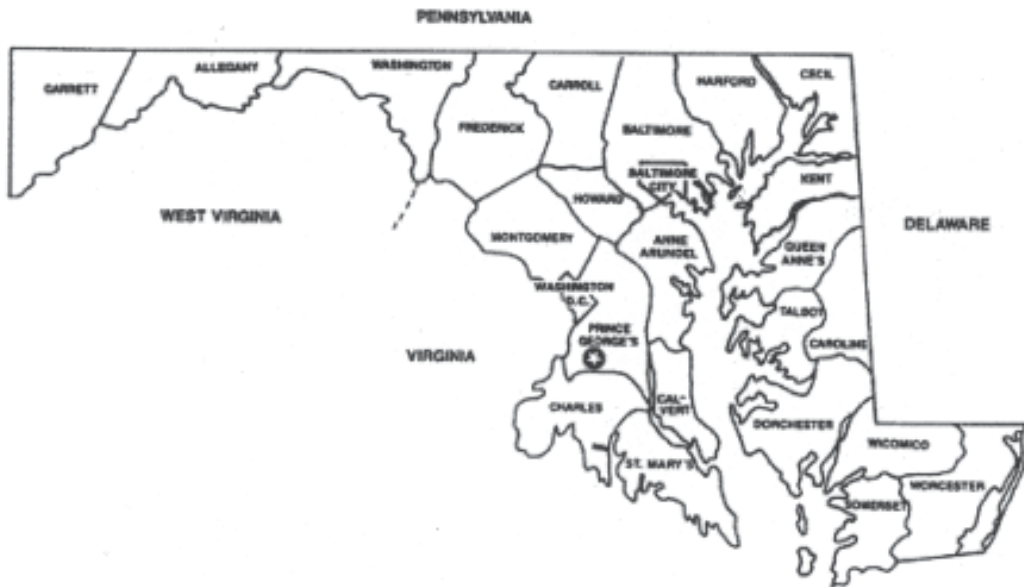


Figure 1. ERCO study site marked with a star.

crops on treated areas was researched (Sikora et al. 1980a), no research is available for producing forest products and/or wildlife habitat. Deep-row biosolid applications to enhance forest production could solve many of the problems associated with land reclamation and other land disposal methods and enhance the multi-state Chesapeake Bay cleanup effort.

In responding to the need to utilize large volumes of biosolids from the Washington, DC, area and reclaim gravel spoils, ERCO pioneered the deep-row biosolids technique in the early 1980s using hybrid poplar trees planted on treated land. The treatment site was a 49.4-ha abandoned gravel spoil in Prince George's County (Figure 1) owned by the company and within 40 km of many large municipal wastewater treatment plants. The spoil site consisted of a moderately well-drained Beltsville silt loam where the gravel mounds had been removed. What remained was a gravel overburden underlaid by a thick clay fragipan. The overburden soils were treated to maintain a pH of 6.2. The company received a permit from the Maryland Department of Environment (MDE) for application of biosolids to grow hybrid poplar trees. The data provided in this paper were used for permit-reporting procedures but are used here only to describe the technique, challenges, and directions for future research.

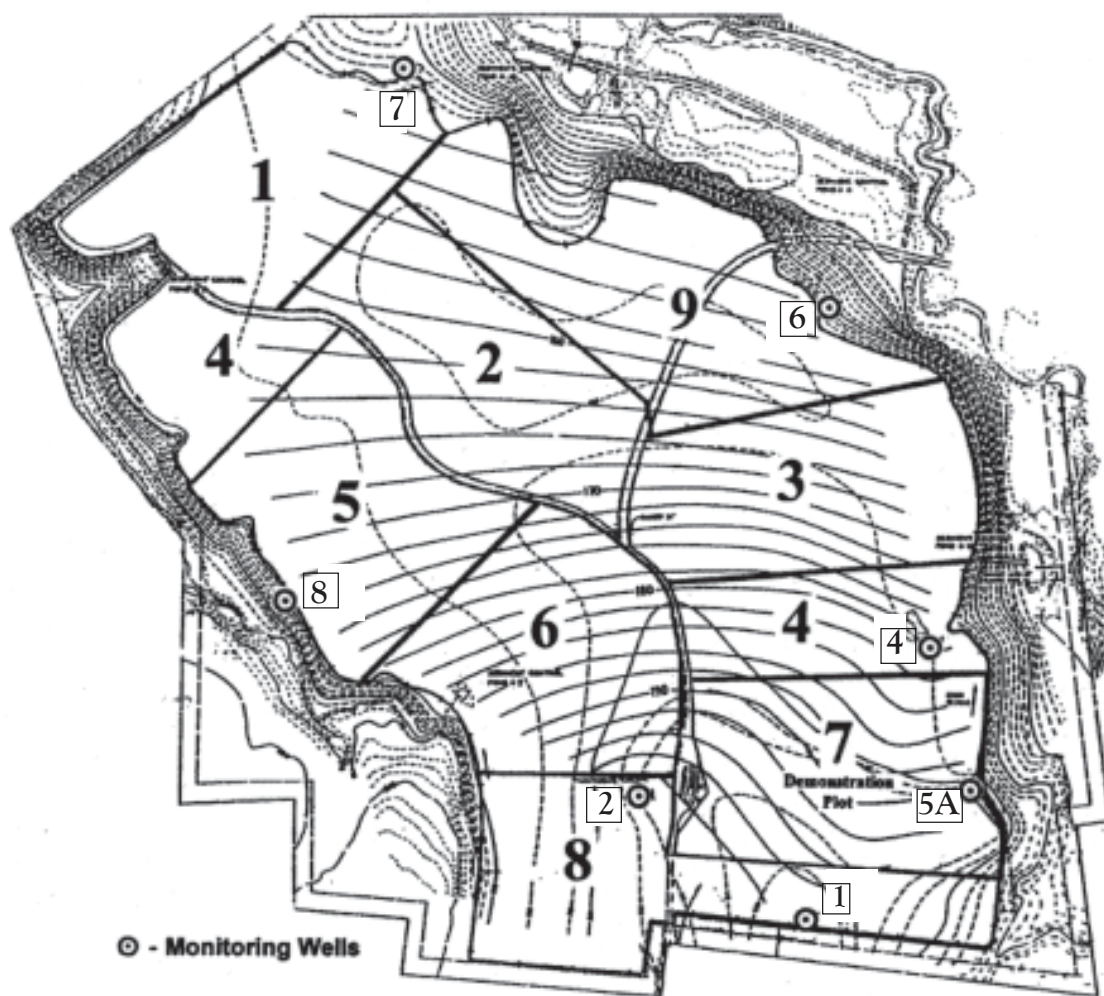
### SITE DESCRIPTION

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 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. The plateau has an upper section near the entrance which is on a 0–2% slope. There is an elevation drop of between 1.5 and 3 m. The remaining seven sections have an elevation drop of between 1.5 and 3 m, followed by a level section (0–2% slope) to the edge of the bermed area.

The surface water flow on the site has been significantly reduced due to the tree growth. 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, either forested steep slope or detention ponds and buffers.

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 about 22 m 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 4.5 m of the ground surface was the result of the confining action of the overlying Calvert formation.



**Figure 2.** Plot layout of ERCO site showing nine 4.05-ha sections planted with hybrid poplar, as well as seven monitoring wells. Site is located on an abandoned gravel strip mine.

## METHODS

The deep-row technique involved placing biosolids, averaging about 20% solids (not lime stabilized), at a rate of 383.3 Mg/ha. A special demonstration plot (section 7) permitted placing biosolids at 659.1 Mg/ha. The pH of the biosolids being applied ranged from 7.0 to 8.0. Sections of about 4.1 ha were treated each year starting in 1984 and continuing through 1993 (Figure 2). The deep rows were dug using a tracked backhoe with a special bucket, which excavated the deep row and simultaneously backfilled the biosolids placed in previously excavated adjacent deep-rows. The row dimensions were 762 mm deep and 1,067 mm wide, spaced on about 2.44-m centers. The deep-rows were filled with 457 mm of biosolids for the 383.3 Mg/ha rate and 559 mm for the 659.1 Mg/ha rate. The remaining 200–300 mm was filled with overburden. After each section was filled, the

site was leveled using a special low-ground pressure bulldozer and disked in preparation for planting.

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

Hybrid poplar stem cuttings were directly stuck at 7,400–10,000 cuttings/ha. The purpose of the dense

planting was to utilize the N over a planned 7-year rotation. Competing vegetation was marginally controlled by periodic mowing. No herbicides were used. Foliar leave samples were taken every August to assess N uptake by the trees. Three recently matured leaves were taken from five randomly selected trees in each 4.05-ha section. All leaves were mixed into one composite sample to provide one foliar N value for each section.

Nitrogen mineralization in deep-rows was assessed every August. Due to the gravel nature of the soil, a narrow backhoe was used in five locations in each section to take samples. A composite sample was made for each location by taking a similar volume of biosolids from the bottom, middle, and top of the biosolids deep-row. Composite samples from the five locations were mixed into one sample, and N mineralization was measured to provide one value for each 4.05-ha section. The holes dug for the soil sampling enabled yearly monitoring of the decomposition and root growth patterns of the trees around the deep-rows. No hard data were recorded, but subjective evaluations were made and photographs were taken.

State regulations required intense monitoring to detect possible leaching of metals, N, and other nutrients into the water table. Seven monitoring wells ranging from 6 to 31 m deep were installed and sampled biannually for nutrients, pH, metals, and coliform. The hybrid poplar on each 4.05-ha section was harvested when the crop was between 6 and 9 years old, depending on foliar leaf analysis and soil tests. According to the MDE permit, the trees could be harvested when foliar N levels dropped below 3.5% and total N mineralization reached about 70%. The trees were harvested and chipped wet and the chips used as a mulch on-site. Only one section was harvested and the chips trucked off-site. The site was disked, leveled, and deep-rowed for reapplication of biosolids. Biosolids used for reapplication were lime stabilized due to changes in regulations. While harvest of the trees on one section did not take place for 10 years, diameter growth dropped after 7 years, probably because of overcrowding and reduction in available N through mineralization.

## RESULTS AND DISCUSSION

The major environmental concern of deep-row biosolids application is the potential for contamination of groundwater by N and metals leached from biosolids. The permitted application rates of 383.3 and 659.1 Mg/ha resulted in no degradation of water quality. Sampling from the seven monitoring wells, which have been in place since 1984, has not shown any elevated level of

the measured factors as of 1996. 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.

No trend of increase in chloride concentration in the well samples was seen after biosolids application. Twice Well #2 (an up-gradient well) exhibited nitrate concentrations above the detection limits: on 10 November 1982 (the day after well was drilled and before any biosolids were applied to the site) the nitrate level was reported at 1.5 mg/l and on 24 May 1989 the level was reported at 1.9 mg/l. On this latter sampling date, several samples from the other wells also were reported to contain nitrate concentrations above the detection limits. Well #4 was reported to contain nitrate concentrations at 1.3 mg/l and Well #5A was reported to contain nitrate concentrations of 1.6 mg/l. Wells 2, 4, and 5A are each screened in 3.1-m intervals and range in depth to the top of the screen from 7.6 to 9.4 m. All are in a silty clay sand layer that is surrounded by layers described as "white clay" and "green clay" (Pepperman 1995). Because the events were singular in time and the wells appeared to intercept isolated layers, this would suggest that lateral inflow was documented. Well #1, an up-gradient well, was reported to contain nitrate concentrations of 1 mg/l. This well was screened at 21.3 to 24.3 m deep, which corresponds to the top of the Nanjemoy formation (Wilson and Fleck 1990). The increased nitrate levels in up-gradient Well #1 suggest classic lateral inflow occurred, which would be consistent with an aquifer formation (the Nanjemoy) beneath an aquitard (the Calvert). The clay fragipan likely contributed to the lack of movement through the soil profile.

The application rates in this study are consistent with trenching-site applications made from 1974 through 1980 on well-drained, silt loam soils of the Manor and Glenelg soil series. Five years after the application, monitoring of groundwater detected no increases in N and Cl, although elevated levels were found just beneath the trenches (Sikora et al. 1982). Groundwater pollution has been recorded in a separate groundwater study in which trenches were located in a sandy soil—a worst case scenario (Silora et al. 1979, 1980b). Metal movement through soil is general considered minimal except in instances when pH is <5.5 (Chaney et al. 1977), which is not a problem on most sites due to liming requirements. The

**Table 1.** Summary of biosolid and soil analysis for all nine 4.05-ha sections at the ERCO site. Average and range of values for each measure are provided.

Material sampled	Depth (cm)	Age span (yr)	Total N (%)	Organic N (%)
Initial biosolid analysis	—	0	3.32 (3.16–3.63)	3.10 (2.89–3.46)
Biosolid residue	50.8–86.4	6–9	1.21 (0.23–1.78)	1.10 (0.18–1.67)
Soil surrounding deep-row	45.7–101.6	6–9	0.02 (0.01–0.04)	0.02 (0.007–0.041)
Soil 37.6–45.7 cm below deep-row	147.3–152.4	6–9	0.04 (0.01–0.09)	0.03 (0.006–0.086)

general conclusion concerning groundwater pollution by biosolids at deep-row sites is that groundwater immediately beneath the sites might have increases in inorganic N and Cl which should decrease with time.

None of the trenching studies to date have used deep-rooted plant material for uptake of N to minimize leaching. Most such studies have grown corn in field studies (Sikora et al. 1980a) and in simulated deep-row experiments (Taylor et al. 1978). The use of fast-growing, high N-demanding hybrid poplars at high densities on the ERCO site provided deep root penetration around deep-rows. The anaerobic conditions and lower temperatures in the deep-rowed biosolids keeps N in organic forms that are not easily leached and that are known to inhibit root growth (Taylor et al. 1978). The roots of trees only penetrate friendly environments and usually absorb ammonium- and nitrate-N. Visual examination of deep-row sites 3 years after hybrid poplar had been planted revealed that biosolids in the deep-row had roots surrounding the deep-row area, but not penetrating it.

Total nitrogen content of the biosolids at the time of application averaged 3.32% and ranged from 3.16 to 3.63% (Table 1). 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%, which suggests that much of the biosolids had mineralized. Nitrogen levels averaged 0.02% only 15 cm from the deep-row laterally and 0.04% below the deep-row. The large root mass around the deep-row appeared to act as a sink, taking up N as it is mineralized, which greatly reduced chances of leaching.

The uptake of N by the hybrid poplar was further demonstrated by foliar nitrogen levels. Hybrid poplar can utilize nitrogen at rates similar to those of corn, but unlike corn, this nitrogen is extracted by a perennial deep root system. When the trees were actively grow-

ing, foliar N levels exceeded 3.5%. After 6–9 years, foliar N levels dropped to <3.5%, indicating that plants were utilizing N faster than the mineralization rate of the biosolids. At the time of reapplication, the biosolids looked similar to dried peat, with no moisture in evidence. The loss of water from the biosolids was also evident surficially as large depressions formed in each deep-row.

The combination of high density planting (7,400–12,350/ha) and lack of vegetation management resulted in small tree diameters (<12 cm DBH) that were not marketable. Harvesting on all sections, except section 4, was done by hand labor and a wood chipper, with the chips left on the ground. Harvested chips from section 4 were sold to a local sanitary commission for composting with average yields of 45 Mg/ha. This yield was well below the 67–204 Mg/ha reported in 8–10-year-old managed plantations (Heilman et al. 1995, Gates and Bryant 1990). Lucrative pulp markets exist for hybrid poplar in the Northwest and other areas. In the Mid-Atlantic region most pulp mills use a continuous digester with heavier species such as oak and hickory. When poplar is mixed with these species, it cooks down and produces little product, so few pulp mills in the Mid-Atlantic are interested in buying it (Gates and Bryant 1990).

Although rapid root development around the deep-row is desirable, lower planting densities of 700–1,000 trees per acre are being tested to produce larger diameter trees that may be suitable for sawtimber markets. The additional time it would take for roots to colonize the site may not be significant given the stable N form of the biosolids in the anaerobic environment. Other species with higher commercial potential such as sycamore, sweetgum, and paulownia are also being tested.

## CONCLUSIONS

The deep-row biosolid application technique has proven environmentally friendly in the reclamation of the gravel spoil at the ERCO site after stringent long-term regulatory oversight. In 1990, the National Association of Counties recognized Prince George's County, Maryland, with an achievement award for the Tree Farm Biosolids Utilization Project at the ERCO site. More research is needed on intact soils, particularly Coastal Plains and Piedmont soils, and on reclamation sites with species with different nutrient demands at varied rates to determine the implications for water quality, forest and wildlife management, and economic realities. Regulatory reform should also be considered to reduce stringent regulatory requirements for proven practices and

to encourage private entrepreneurship. The technique allows the utilization of large volumes of biosolids per hectare to produce forest products at a site near treatment plants in urban areas, which greatly reduces the land requirement compared to conventional land application. Because there is no crop at the time of application, this technique can be used at a steady rate over the entire year, which is a second advantage over conventional land application to agricultural lands. Development of this technique could contribute to a multi-state effort to reduce nutrient loading of the Chesapeake Bay. However, the comparative cost of deep-row applications is presently higher than tipping fees at out-of-state landfills. It will require political cooperation of states involved in the Chesapeake Bay drainage to discourage landfill dumping and encourage alternative methods.

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