

## **Deep-Row Application of Biosolids to Grow Forest Crops on Mine Spoils: Potential Utilization for the Baltimore, MD - Washington, D.C. Metro Area**

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### **ABSTRACT**

Agricultural land application is a significant method of utilizing biosolids, but available land is being reduced by development. In Maryland, application rates may be reduced by new regulations that require rates be based on phosphorous, rather than nitrogen. Deep-row application of biosolids on gravel spoils is a unique alternative land application method. This alternative solves many problems associated with traditional agricultural and marginal land surface applications. 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, provides wildlife habitat, and reduces erosion, while reclaiming and utilizing abandoned, biologically dead soils created by borrowing pits. Abundant sand and gravel borrowing pits in the Baltimore-Washington, D.C./Metro area provide an opportunity to utilize a significant portion of the biosolids produced in these areas, but more research is needed to determine site specific assessments.

### **KEYWORDS**

Biosolids, deep-row, forest crops, mining, reclamation, utilization, sand, gravel, trenching, nitrogen, phosphorus

### **INTRODUCTION**

In the Washington, D.C./Baltimore metro area, the utilization of biosolids in an environmentally-sound, cost-efficient method has become increasingly complicated by new and existing state and federal regulations, county ordinances, development pressure, human conflicts, logistical realities, and other factors. The passage of the Water Quality Improvement Act (WQIA) of 1998 by the Maryland General Assembly has been described as the most comprehensive farm nutrient control legislation in the country. It was initiated to control farm nutrient runoff of phosphorus that has been targeted as a possible cause of pfiesteria outbreaks (Simpson, 1998). It is likely that this legislation will reduce application rates of manure and biosolids to farmland in the future in Maryland, and increase application on nearby Virginia farmland. Since agricultural application is one of the primary methods of biosolid utilization, reduction may also increase the use of landfilling and other methods not considered beneficial. There is an increasing need for new utilization technologies that can provide beneficial use of biosolids in a cost-effective and environmentally sound way.

The cities of Washington, D.C. and Baltimore and the six surrounding counties of Baltimore, Howard, Montgomery, Anne Arundel, Prince George's, and Charles (See **Figure 1 "Location Map"**), produced 899,041 wet tons of biosolids in 1996, with 256,109 wet tons (28 percent) generated by Washington, D.C. (MDE, 1998; DC-WASA, 1998) (See **Table 1 "Production & Utilization of Biosolids"**).

The biosolid produced in Washington, D.C./Baltimore metro area (Metro area) were utilized as follows: agricultural and marginal land application (43 percent), landfill disposal (1 percent), composted (17 percent), incinerated (1 percent), hauled out-of-Maryland (16 percent), and off-site storage (6 percent). Agricultural land application makes up a significant portion of the biosolids utilized in the metro area, with the biosolids hauled out-of-Maryland largely applied on Virginia farms, with some sent to landfills (**See Table 1 “Production & Utilization of Biosolids”**).

The difficulty in siting new landfills, possible future restrictions on out-of-state hauling, and mergers of landfill corporations may result in restriction 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 one to three years necessary to provide crop nutrient requirements. This can cause logistical, safety, and economic problems due to transportation cost, poor weather, frozen soils, availability of labor, etc. Resentment by rural landowners and offensive odors in developing areas has resulted in many local application restrictions. The recent passage of the Water Quality Improvement Act (WQIA) in Maryland may significantly reduce the availability of land for application and increase transportation costs to Virginia farmlands or the higher disposal fees at landfills.

The developing limitations on landfill and agricultural land application identify a need for alternative utilization technologies (Sikora and Calacicco, 1979(a), 1980; Kays et.al, 1997). In responding to the need for utilizing large volumes of biosolids from the Washington, D.C. area and reclaim gravel spoils, ERCO, Inc. pioneered the deep-row biosolid technique in the early 1980's using hybrid poplar trees planted on treated land (Kays et. al, 1997). ERCO, Inc. is a private firm involved in the beneficial reuse of biosolids on marginal and disturbed sand and gravel surface mines to produce tree crops on its property. The treatment site was a 122-acre abandoned gravel spoil in Prince George's County (**See Figure 1 “Location Map”**) owned by the company and within 25 miles 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 deep-row technique differs from conventional tillage techniques in that a one-time application of biosolids are placed below the surface in an amount necessary to sustain hybrid poplar growth for a period of six years. This method, while designed to reclaim the surface mine, has evolved into a long-term beneficial utilization technique on these marginal lands. The original deep-row application did reclaim the site, but the effect would be short-lived due to the utilization of the applied biosolids by the trees. The reapplication of deep-row biosolids makes it possible to produce a sustainable crop of trees on a short-rotation cycle, which continues to improve the soil. It is unknown how many reapplications would be needed before the soils would be improved to the point that forest cover could be sustained. Since 1983, the deep-row application technique with forest crops has been developed, refined, and continues. Some of the data provided in this paper was used for permit reporting procedures, and are used to describe the technique, challenges, directions for future research, and potential application to other sites in the Metro area.

## **METHODS**

### **Deep-Row Application with Forest Crops**

The deep-row technique involved placing biosolids (not lime-stabilized at the time), averaging about 20 percent solids and 3.2 percent nitrogen, at a rate of 171 dry tons per acre. A special demonstration plot permitted placing biosolids at 294 dry tons per acre. The pH of the biosolids being applied ranged from 7.0-8.0. Approximately 10-acre sections were treated each year starting in 1984 and continuing through 1993, resulting in a total application area of 100 acres. 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 30 inches deep and 42 inches wide, spaced on or about 8-foot centers. The deep-rows were filled with 18 inches of biosolids for the 171 dry tons per acre rate and 22 inches for the 294 dry tons per acre rate. The remaining 8-12 inches 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.

Hybrid poplar stem cuttings were directly stuck at 3-4,000 cuttings per acre. The purpose of the dense stocking in earlier plantings was to quickly utilize the nitrogen (N) over a planned 6-year rotation, and allow for possible planting mortality, which has not been found to be a significant problem. Competing vegetation was marginally controlled by periodic mowing. No herbicides were used. To assess N uptake by the trees, foliar leaf samples were taken every August. The three most recently matured leaves were taken from five randomly selected trees in each 10-acre section. All leaves were mixed into one composite sample to provide one foliar N value for each section (Kays et al., 1997).

Nitrogen mineralization in deep-rows for each 10-acre section was assessed every August by using a backhoe and a standard sampling procedure to produce a composite sample from the bottom, middle and top of the biosolids deep-row (Kays et al., 1997). Visual assessments were made of root growth patterns and decomposition. The utilization and fate of phosphorus has not been assessed, but is under study. Starting in 1998 foliar leaf samples are being analyzed for phosphorous as well as nitrogen. The direction of future research on phosphorous will be assessed from initial field results and an analysis of existing literature.

Harvesting of the hybrid poplar on each 10-acre section occurred when the crop was between 6 and 9 years old, depended on foliar leaf analysis and soil tests. According to the Maryland Department of Environment permit, the trees could be harvested when foliar N levels dropped below 3.5 percent and total N mineralization reached approximately 70 percent. The trees were harvested and chipped wet. Initially in the development of the program the chips were used as a mulch on-site. More recently, one section was harvested and the chips trucked off-site and sold after harvesting. The site was disked, leveled, and deep-rowed for reapplication of biosolids. Biosolids used for reapplication since 1992 were lime-stabilized due to new Federal 503 Regulations requiring that biosolids meet Class B Pathogen Reduction Requirements (PRP). This was the most cost-effective method for municipalities to satisfy the new regulations. The process of lime-stabilization reduces total N in the range of 1.5 to 2.5 percent N.

### **Potential Application to Other Sites**

The positive attributes of deep-row application with forest trees provided the incentive to look at the potential application of this technique to other spoil sites in the Metro area. Three types of information were needed: 1) the number of acres of land use available, 2) sites with soil characteristics suitable for deep-row application, and 3) proximity in miles to the major treatment facilities in the Metro area.

## **Determining Acres Available and Soil Suitability**

Sand and gravel surface extraction is common land use in parts of southern Maryland, but the actual number of sites and acres available were unknown. The Maryland Department of Natural Resources Water Management Administration - Minerals, Oil, and Gas Division (MDNR-WMA), provided a listing of all surface mining permits, both active and closed. Only those sites mining sand and gravel were considered in this study. Given the demands of permitting, equipment and other factors related to deep-row application, minimum threshold sizes of 50 and 100 acres was set. The data was categorized for those parcels over 50 acres, and those over 100 acres .

Soil survey maps for each county were obtained from the county office of the USDA Natural Resource Conservation Service. Each permit record provided by MDNR-WMA included map coordinates that could be referenced to standard ADC county maps. It was envisioned that the coordinates could then be referenced to the county soil maps for determining soil type and association for each permit location. Parcels located on soil types with suitable characteristics desirable for this application could then be totaled and targeted for further study. Unfortunately, ADC reference coordinates included in permit records were made at the time of application and could not be referenced to current ADC maps which have been changed.

The USDA-Natural Resources Conservation Service in Prince George's and Charles County were contacted for local records. Unfortunately, many of the properties have changed owners and records were difficult to reference with state permit records. Therefore, direct referencing of permit sites with county soil maps was not possible.

To provide some idea of the total acreage within the target counties that may have soil characteristics compatible with deep-row application, county soil surveys were analyzed. Soil criteria were developed that were deemed compatible with deep-row application and soil associations identified within each county that met these criteria.

## **Distance to Treatment Facilities**

The location of treatment plants in the Metro area were located on an ADC road map for the entire area and transferred to the general location map (**See Figure 1 "Location Map"**) . The majority of sand and gravel locations lie well within 50 miles of the treatment facilities.

## **RESULTS AND DISCUSSION**

### **Long-Term Water Quality**

The major environmental concern of deep-row biosolids application is potential for contamination of ground water by N, P, metals, and other nutrients leached from biosolids. The permitted application rates of 171 dry tons per acre and 294 dry tons per acre resulted in no degradation of water quality. Biannual sampling from the seven monitoring wells (ranging in depth from 20 - 100 feet), in place since 1984, have not reported any elevated level of nutrients, ph, metals, or coliform as of 1997. 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 on these sites 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 ground water study in which trenches were located in a sandy soil, which is the worst case scenario (Sikora et al., 1979(b), 1979(b)). It

is incorrect to compare past trenching studies that reported leaching of N and Cl into groundwater with deep-row application since they did not use deep-rooted plant material and were many times on highly permeable soils. Most such studies have grown corn in field studies (Sikora et al., 1980) and in simulated deep-row experiments (Taylor et al., 1978).

Concerns over phosphorus are minimized by this type of application. Most phosphorous pollution is caused by surface runoff. The subsurface application of biosolids in deep-row application will tend to tie up phosphorous in stable forms that do not move through the soil profile. 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 and high clay content. In general, groundwater pollution by biosolids at deep-row sites is minimal due to the stable organic forms that decompose slowly underground and the presence of perennial tree roots that quickly absorb N and other nutrients that become available.

### **Utilization of Biosolids by Trees**

The use of fast-growing, high N-demanding hybrid poplars at high densities on the ERCO, Inc. site provided deep root penetration around deep-rows. The anaerobic conditions and lower temperatures in the deep-rowed biosolids maintains N in organic forms that were not easily leached and are known to inhibit root growth (Taylor et al., 1978). The roots of trees only penetrate friendly environments, provide a source of oxygen for mineralization to occur, and can then absorb ammonium and nitrate N. Visual examination of deep-row sites after only three years after hybrid poplar had been planted revealed biosolids in the deep-row had roots surrounding the deep-row area, but were not quite penetrating. After six years, roots were found throughout the deep-row.

Total nitrogen content of the biosolids at the time of application averaged 3.32 percent and ranged from 3.16-3.63 percent (**See Table 2 “Summary of Biosolids and Soil Analysis”**). When the sites were harvested and prepared for reapplication of biosolids at 6 to 9 years after the initial application, total soil N of the biosolids was 1.21 percent, which indicates that much of the biosolids had mineralized. Nitrogen levels averaged 0.02 percent only 6 inches from the deep-row laterally and 0.04 percent below the deep-row. The large root mass found 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 is capable of utilizing nitrogen at rates similar to corn, but unlike corn, this nitrogen is extracted by a perennial deep root system. When the trees were actively growing foliar N levels were in excess of 3.5 percent. After 6-9 years foliar N levels dropped to below 3.5 percent, indicating that plants were utilizing N faster than the mineralization rate of the biosolids. At the time of reapplication the biosolids appearance was similar to dried peat, with no moisture in evidence. The loss of water from the biosolids was also evident visually as large depressions formed over each deep-row.

The initial determination of the 171 dry tons per acre to meet the N demands of hybrid poplar was based on utilization studies in other areas of the country. Follow up studies at the site used in permit renewal process indicated that a much higher rate was needed to sustain tree growth for the 6-year rotation (Pepperman, 1995). This application rate was based on biosolids that were not lime-stabilized and contained about 3.2 percent N. However, all biosolids since 1992 are lime-stabilized and only contain about 1.5 percent N. This indicates that even larger application rates are needed to meet the N demands of the trees. Given the present concern over phosphorus, phosphorous budgets must be addressed. It is a fair assessment that the present permitted application rate is incapable of meeting the N demands of the trees through the rotation time.

## Forest Product And Wildlife Considerations

The combination of high density planting (3-5,000 per acre), lack of vegetation management, and the possible lack of sufficient N resulted in small tree diameters (less than 5 inches DBH) that were not commercially marketable. Analysis of diameter growth in the dense hybrid poplar plantings indicated diameter growth did not show a precipitous drop after a few years, which might be expected. Instead, diameter growth appeared to be slow but steady throughout the rotation, which indicates that inter-plant competition started almost immediately after planting due to the high planting density. Harvesting on all 10-acre sections, except section 4 was done using 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 20 wet tons per acre. This yield was well below the 30-91 wet tons per acre reported in managed plantations of 8-10 years (Heilman et. al, 1995; Gates and Bryant, 1990).

Localized 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. Therefore, most pulp mills in the Mid-Atlantic are not seeking to purchase hybrid poplar (Gates and Bryant, 1990). If larger diameter stems can be produced through better forest management it is likely that some income can be derived from the sale of pulpwood in traditional forest markets. There may also be some opportunities for sales in specialty markets which needs more investigation.

The wisdom of requiring off-site removal of all chips required by recent changes in regulations is questionable. Chips left on site will be distributed throughout the soil profile when the site is reapplied with biosolids. Burying about 20-30 wet tons of woodchips per acre, with their high carbon/nitrogen (C/N) ratio, serve as a sink for any available nitrogen. The burying of the woodchips during reapplication of biosolids serves as added insurance toward preventing any potential movement of nitrogen from the area (Gouin, 1994).

While rapid root development around the deep-row is desired, lower planting densities of 450-1000 trees per acre are being tested to produce larger diameter trees that may be suitable for commercial forest markets. The additional time it would take for roots to colonize the site may not be significant given the stable nutrient form of the biosolids in the anaerobic environment.

The gravel spoil in this study was previously incapable of supporting any significant vegetation or wildlife habitat, and was subject to massive erosion. While wildlife abundance and habitat was not objectively measured, it is clear that the site has been reclaimed and transformed into a stable forested habitat with abundant deer, beaver, quail, doves, and other wildlife present.

## Testing Other Suitable Tree Species

Trial studies were undertaken with other species of higher commercial potential to determine growth and survival compared to hybrid poplar. One-year old seedlings of American sycamore (*Platanus occidentalis*), sweetgum, (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*) were planted in spring, 1997, and survival and growth assessed after one full growing season in spring, 1998. Paulownia (*Paulownia tomentosa*) was tested in a separate study (Kays, 1996). Survival and height growth for sweetgum, and yellow-poplar were extremely poor compared to hybrid poplar (**See Table 3 “Survival and Growth of Hardwood Seedlings”**). Survival of sycamore was comparable to hybrid poplar (97 percent and 89 percent, respectively), but the height growth of sycamore was less than half that of hybrid poplar. Height growth and subsequent first-year survival of sweetgum was seriously impacted by heavy rabbit browsing over the winter. Most stems were cut back to the ground and many did not

survive into the second growing season. Second-year results were not available for this paper, but a visual assessment indicates that hybrid poplar growth and survival was unchanged, but the sycamore had higher mortality and poor height growth. This study indicates that only sycamore demonstrated adequate survival and growth after one year to warrant further experimentation and study.

A planting study of paulownia at the deep-row ERCO, Inc. site found extreme variability in survival and growth. Seedlings were grown in a greenhouse in early spring, hardened-off, and then outplanted after danger of frost in the spring. While some seedlings in the study grew as much as 84 inches in one year, others areas grew only 9 inches. Visual soil assessment using a backhoe indicated that compacted and high-clay soils with poor drainage resulted in poor growth and survival, while loose, well-drained soils resulted in exceptional growth. Given the variability of soils on mine spoils, planting of paulownia will require careful site and soil examination. One positive benefit of paulownia is its ability to utilize large amounts of nitrogen present in deep-row applications. Foliar nutrient levels of nitrogen for paulownia during the first and second growing season were 2.77 and 2.33 percent, respectively. While lower than the foliar N levels of 3.5 percent and higher found in hybrid poplar, it does warrant further consideration. Foliar nutrient levels of other hardwood species tested have not been assessed, but this is also needed.

### **Assessing Acreage Available and Soil Suitability**

The counties of Prince George's, Anne Arundel, and Charles provided the majority of spoil sites, with only a few sites in Baltimore County, albeit of large acreage. Howard and Montgomery County did not have any sand and gravel sites over 50 acres, so they were not included in the table. Tracts over 50 acres comprised 9,246 acres or 72.3 percent of the total acreage permitted, while tracts over 100 acres comprised 5,698 acres or 44.6 percent of the total acreage permitted (**See Table 4 "Number of Acres and Sites Permitted"**).

Soil characteristics deemed compatible with deep-row application include: 1) those with a compact fragipan, subsoil or substratum that would minimize downward movement through the soil profile and; 2) a water table that is at least 3 feet below the surface or is well-drained. An analysis of soil associations for the counties under study was done to determine those with possible compatible characteristics. Overall, Prince George's and Charles County had the most promise with the following soil associations which represented a significant portion of the county land base. The associations and relative percentage of the land base are provided below. Inspections of other counties in the study area found compatible soil associations in lesser abundance.

- *Prince George's County (53 percent of county soils in associations below)*
  - Beltsville-Leonardtown-Chillum association - moderately deep, well-drained to poorly-drained, dominantly gently sloping soils that have a compact subsoil or substratum (represents 16 percent of the county soils).
  - Christiana-Sunnyside-Beltsville association - deep, level to steep, well-drained, sandy and clayey soils and level to sloping, moderately deep, moderately well-drained soils that have a compact subsoil (represents 15 percent of the county soils).
  - Sassafras-Croom association - gently sloping to steep, well-drained, dominantly gravelly soils, some of them with a compact subsoil and substratum (represents 22 percent of the county soils).

- *Charles County (68 percent of county soils in associations below)*
  - Beltsville-Gravelly Land-Bourne association - level to moderately sloping, moderately well-drained, loamy soils that are only moderately deep to a dense, root-inhibiting fragipan, and steep gravelly soil material (represents 28 percent of the county soils).
  - Beltsville-Exum-Wickham association - level to moderately sloping, moderately well-drained and well-drained loamy soils, some which are only moderately deep to a hard, dense, root-inhibiting fragipan (represents 22 percent of the county soils).
  - Beltsville-Evesboro-Sassafras association - level to moderately sloping, moderately well-drained to excessively well-drained, loamy and sandy soils, some which are only moderately deep to a hard, dense, root-inhibiting fragipan (represents 16 percent of the county soils).
  - Leonardtown-Beltsville association - level to gently sloping, poorly drained and moderately well-drained, loamy soils that are only moderately deep to a dense, root-inhibiting fragipan (represents 2 percent of the county).

It was recognized that soil surveys, even if they were referenced to individual gravel and sand spoils, would have limited value, since they are useful only to about five feet below the surface, beyond which the material is interpreted. Since most mine sites have had the upper soil profile removed or heavily disturbed, it is questionable what the post-mining soil profile would be. Therefore, site-by-site inspection would be required for each site. More research is needed to determine specific criteria and sampling procedures.

The large percentage of soils associations in Prince George's (68 percent) and Charles Counties (53 percent) that appear to have general soil characteristics compatible with deep-row application, indicates a good likelihood that individual site assessments would be successful. Given the close location of these counties to the Metro area and treatment sites, this would be advantageous.

### **Potential Application of Deep-Row With Forest Crops to Other Spoils**

The total wet production of biosolids in the Metro area totals 899,041 wet tons, which is roughly equal to 206,779 dry tons, assuming the biosolids average 23 percent solids. Using the application rate of 171 dry tons per acre utilized at the ERCO, Inc. site, this would require 1,209 acres per year to totally utilize all the biosolids produced (**See Table 5 "Potential Utilization of Biosolids"**). Sand and gravel permits indicate there are 5,698 acres of sand and gravel spoils over 100 acres in size, located largely in Anne Arundel, Baltimore, Charles, and Prince George's Counties. Assuming that only half these sites may be useable for deep-row application with forest trees, this would provide 2,849 acres for application. If the forest crops are grown on a 6-year cycle, this would allow for application on 475 acres per year. At an application rate of 171 dry tons per acre, this would allow for the utilization of 81,225 dry tons, or 39 percent of all biosolids produced annually (**See Table 5 "Potential Utilization of Biosolids"**).

Spoils over 50 acres in size total 9,246 acres. If half of these sites were usable for deep-row application with forest trees, this would provide 4,623 acres for application. With forest crops grown on a 6-year cycle, this would allow for application on 771 acres per year. At an application rate of 171 dry tons per acre, this would allow for the utilization of 131,841 dry tons, or 64 percent of all biosolids produced annually (**See Table 5 "Potential Utilization of Biosolids"**).

While this very rough assessment of potential utilization is based on many assumptions, it provides a reason for optimism and need for future study. At the present ERCO, Inc. site, the 171 dry tons per acre rate is inadequate to meet the needs of hybrid poplar over the 6-year rotation (Pepperman, 1995). By increasing the application rate, utilization on available acreage can be increased.

An economic analysis of the costs and revenues associated with application method is essential. Sensitivity analysis techniques that looked at profitability under different cost and revenue scenarios would help waste treatment facilities in making utilization plans. Obviously, regulatory requirement for wells, monitoring, and testing would be a major cost factor.

## **CONCLUSIONS**

The deep-row biosolid application technique has proven environmentally friendly in the reclamation of the gravel spoil at the ERCO, Inc. site after 15 years of stringent regulatory oversight. The technique allows the continued beneficial utilization of large volumes per acre of biosolids to produce forest products at a site near to treatment plants in the Metro area, which greatly reduces the land requirement and logistical considerations, compared to conventional land application. Not all existing and new sand and gravel sites are appropriate for deep-row application. They may lack suitable soils and geology for the technique to function without generating nutrient effluent. More research is needed of potential sites provided in this study to determine site-specific assessment criteria and threshold requirements.

Controlled research studies are needed to assess application rates for different tree species and implications for water quality, forest and wildlife management, and economic realities. Studies at the ERCO, Inc. site indicates that higher applications rates are needed to meet the N needs of hybrid poplar trees on a six-year rotation. Research is needed to develop practical application guidelines that are based on nutrient demands of the trees and the nutrient makeup of the biosolids, which changes as new treatment systems are developed. Most of the work to date has dealt with N concerns, but the present questions with phosphorous must be addressed. It is likely that studies that research the stable forms of phosphorous associated with deep-row application would make this technique even more favorable for water quality concerns.

Regulatory reform should be considered to reduce stringent regulatory requirements for deep-row application practices that have been proven safe on sites with similar soil characteristics. The economic feasibility of deep-row application is highly dependant on costs associated with well installation, monitoring, testing, and other regulatory requirements. Presently, deep-row application is poorly-defined in existing Environmental Protection Agency (EPA) guidelines, and as a result, considerable monitoring requirements are demanded. Better research would allow for regulations based on better science that would enable private entrepreneurs to pursue deep-row application in a known regulatory environment.

The multi-state effort to reduce nutrient loading of the Chesapeake Bay can be improved by utilizing deep-row application as an additional beneficial use strategy. However, it is clear from data collected for this paper, that there is a need to develop regional regulations for biosolid utilization to eliminate disparities that exist as a result of differences in Maryland, Virginia, and Washington, D.C. regulations.

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**Table 1 - Production & Utilization of Biosolids in Maryland (1996) / Washington, D.C. (1997)**  
(All figures In wet tons)

County / City	Utilization in County or City <sup>1</sup>							Total Generated
	Ag & Marg. Land	Composted	Landfill	Incinerate	Hauled Out-of-Maryland	Off-Site Storage	Other <sup>2</sup>	
Anne Arundel	69,562	0	0	4,207	888	0	72,359	147,016
Howard	7,810	21,014	0	0	7,811	0	10,661	47,296
Montgomery <sup>3</sup>	3,265	59,830	0	0	31,025	0	19,701	113,821
Prince George's <sub>3</sub>	24,354	0	0	17,223	22,086	52,570	15,679	131,912
Charles	36,800	0	0	0	11,815	0	(-17,637)	30,978
Baltimore City	0	40,413	0	3,232	31,225	0	14,442	89,312
Baltimore Co.	0	27,508	0	0	35,465	0	19,624	82,597
Washington, D.C.	241,423	0	10,026	4,660	unknown	0	0	256,109
Total	383,214	148,765	10,026	29,322	140,315	52,570	134,829	899,041
Percent of total	43	17	1	3	16	6	15	

Source: Maryland Department of the Environment, 1997; D.C. Water and Sewer Authority, 1998.

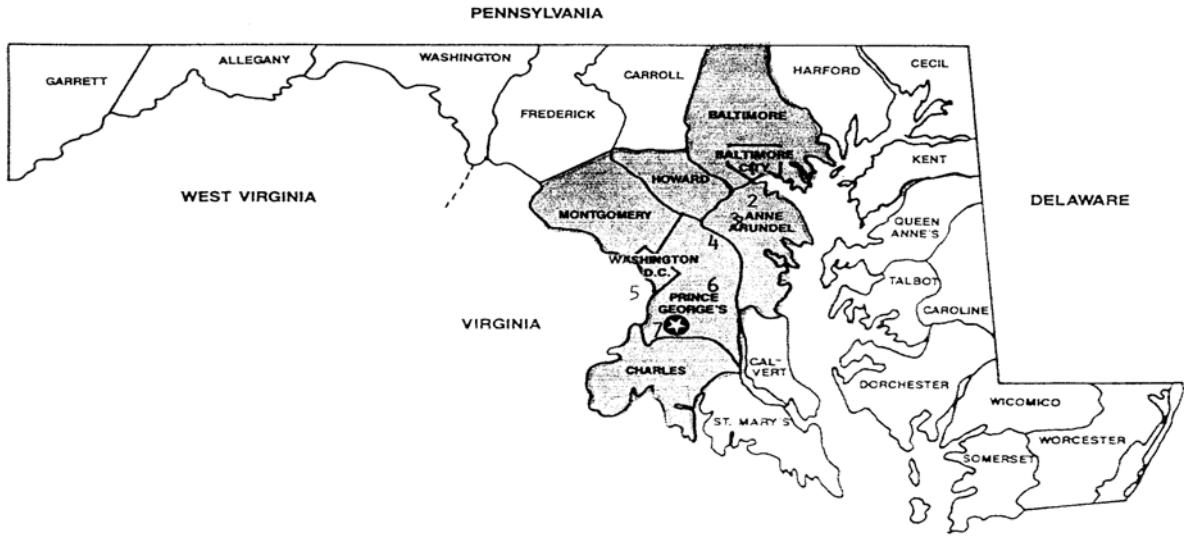
<sup>1</sup> - Summarizing and combining of 1997 MDE data and 1998 D.C. data required making some estimates.

<sup>2</sup> - Other indicates biosolids exported to other counties and treatment plants, minus imported from other counties and states.

<sup>3</sup> - 159,653 wet tons produced in Montgomery and Prince George's Counties is actually processed by Washington, D.C. This amount was subtracted from the Washington, D.C. total using best available estimates.

Figure 1 - Location Map - ERCO, Inc. study site marked with star is located in Prince George's County, MD. The six shaded counties make up the Washington, D.C. - Baltimore, MD Metro area. The seven major wastewater treatment plants (WWTP) serving the Metro area are marked 1 through 7: 1 - Patapsco WWTP (In Baltimore City); 2 - Dorsey Run WWTP; 3 - Parkway WWTP; 4 - Bowie WWTP; 5 - Blue Plains WWTP (In Wash. D.C.); 6 - Western Branch WWTP; 7 - Piscataway WWTP

**FIGURE 1**  
Counties of Maryland



**Table 2 - Summary of biosolid and soil analysis for all nine 10-acre sections at the ERCO, Inc. site. The average and range of values for each measure are provided.**

Material Sampled	Soil Depth (inches)	Age Span (years)	Total Nitrogen (%) (range)	Organic Nitrogen (%) (range)
Initial biosolid analysis	0	0	3.32 (3.16-3.63)	3.10 (2.89-3.46)
Biosolid residue	20-34	6-9	1.21 (0.23-1.78)	1.10 (0.18-1.67)
Soil surrounding deep-row	18-40	6-9	0.02 (0.01-0.04)	0.02 (0.007-0.041)
Soil 14-18 inches below deep-row	58-60	6-9	0.04 (0.01-0.09)	0.03 (0.006-0.086)

**Table 3 - Survival and Growth of Hardwood Seedlings Planted in a Deep-Row Application on a Reclaimed Gravel Spoil**

Species	Seedlings (No.)	First-year Survival (Percent)	Height Growth (cm)	Height Growth (standard deviation)
Hybrid poplar	54	89	102.9	52.7
Am. Sycamore	94	97	46.6	28.9
Sweetgum	111	36	6.1	13.6
Yellow-poplar	90	2	7.8	18.0

**Table 4 - Number of Acres and Sites Permitted for Sand and Gravel Mining in Maryland**

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 (72.3 percent of total acreage)
Acres in Tracts over 100 acres (No. parcels)	2,762 (13)	1,102 (9)	795 (6)	1,039 (3)	5,698 (44.6 percent of total acreage)
Source: Maryland Department of Natural Resources Water Management Administration , 1998					

**Table 5 - Potential Utilization of Biosolids on Sand and Gravel Mines Over 50 and 100 acres in Size in the Metro Area Given Assumptions**

<i>Item Being Calculated:</i>	<i>Calculations:</i>
Total wet ton production - Metro area:	899,041 wet tons
Conversion to dry tons assuming 23 percent biosolids:	$899,041 \times 0.23 = 206,779$ dry tons
Acreage needed assuming application of 171 dry tons per acre (d.t.A) per year:	$206,779 \text{ d.t.} / 171 \text{ d.t.A} = 1,209$ acres
Sites over 100 A Sites over 50 A	5,698 A 9,246 A
Assume half the acreage is suitable for application: - Sites over 100 acres - Sites over 50 acres	$5,698 \text{ A} \times 0.5 = 2,849 \text{ A}$ $9,246 \text{ A} \times 0.5 = 4,623 \text{ A}$
Apply biosolids every 6 years using deep-row application with tree crops: - Sites over 100 acres - Sites over 50 acres	$2,849 \text{ A} / 6 \text{ years} = \text{Apply to } 475 \text{ A per year}$ $4,623 \text{ A} / 6 \text{ years} = \text{Apply to } 771 \text{ A per year}$
Dry tons and percentage of biosolids that could be utilized on spoils by threshold size: - Sites over 100 acres  - Sites over 50 acres	$475 \text{ A} \times 171 \text{ d.t.A} = 81,225$ dry tons $81,225 / 206,779 = 39$ percent of biosolids produced. $771 \text{ A} \times 171 \text{ d.t.A} = 131,841$ dry tons $131,841 / 206,779 = 64$ percent of biosolids produced.