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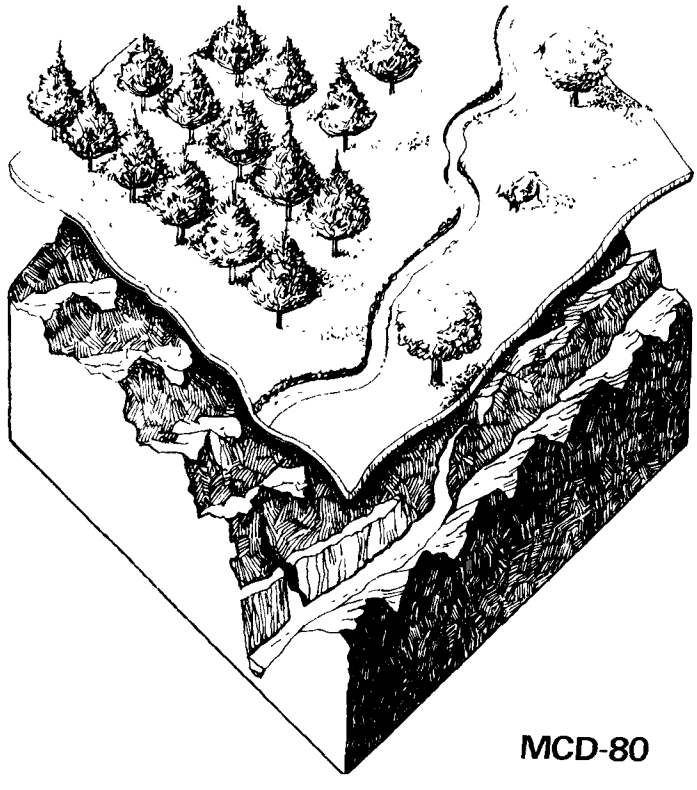

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UTILIZATION OF MUNICIPAL WASTEWATER AND SLUDGE FOR LAND RECLAMATION AND BIOMASS PRODUCTION

Symposium Proceedings and
Engineering Assessment

Robert K. Bastian
Project Officer

SEPTEMBER 1980

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Office of Water Program Operations
Municipal Construction Division
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and Robert K. Bastian

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FOREWORD

Under the Federal Water Pollution Control Act Amendments of 1972 and 1977, thousands of new municipal wastewater treatment plants are being constructed or expanded across the country to help control or prevent water pollution. Many treatment technologies are being used in our efforts to restore and maintain the chemical, physical, and biological integrity of the Nation's waters, yet most of them have one thing in common -- they produce sludge. This increase in sludge is creating a serious management problem for many municipalities.

Yet, managed properly, sludge can be beneficial. The application of both municipal wastewater and sludge to the land can utilize plants and the soil to help remove previously unwanted materials by effectively recycling them.

Land reclamation and biomass production projects that effectively recycle municipal wastewater or sludge can, in many cases, be designed and operated to be both cost-effective and environmentally acceptable. In recent years the necessary research and monitoring studies have been undertaken to develop sound guidelines for the beneficial recycling of municipal wastewater and sludge in land reclamation and biomass production. Appropriate management practices have been developed to allow these systems to be properly designed and operated from an environmental standpoint, which also helps assure the long term productivity and protection of the lands to which these materials are applied.

Finally, in addition to providing beneficial uses for municipal wastewater and sludge, these projects provide the added opportunity to help deal with the serious erosion and water quality problems that can result from unproductive and poor textured soils as well as surface mining, clear cutting, construction, dredge spoils disposal and other activities that can seriously disturb the land.

Existing regulations, criteria and guidelines and those being developed under the authorities of the Clean Water Act, the Resource Conservation and Recovery Act and other recent environmental legislation will provide the necessary mechanisms to properly control land reclamation and biomass production uses of municipal wastewater and sludge, so that human health can be fully protected.

Recycling the soil-building and nutrient resources in municipal wastewater and sludge by utilization in land reclamation and biomass

production projects have been well demonstrated and documented as shown by this volume. I sincerely hope it will lead to an increase in such uses in the future.

Douglas M. Costle
Administrator
United States Environmental
Protection Agency

PREFACE

To meet the increasing demand for energy, it is anticipated that coal mining activities will be greatly accelerated. Most of the coal will be recovered by strip mining methods that have increased concerns related to the reclamation of these disturbed lands. New reclamation regulations along with increasing costs of chemical fertilizer have resulted in an increased interest in the use of municipal wastewater and sludge as fertilizer substitutes and soil amendments to facilitate the establishment of vegetation on these drastically disturbed lands. The purpose of the symposium was to review and discuss the current knowledge related to the feasibility of using wastewater and sludge for revegetation and biomass production on these types of disturbed land. The symposium was also designed to serve as a basis for an engineering assessment, which would address these practices and innovative and alternative wastewater and sludge treatment technologies.

Many types of research and full-scale operating projects are underway on the use of municipal wastewater and sludge in the reclamation of disturbed land for biomass production, the problems faced with public acceptance and institutional constraints and recommendations for overcoming such problems as well as the reactions of local, State, and Federal agencies to such practices were described in the symposium presentations. The engineering assessment summarized the available engineering criteria and information on such design considerations as physical characteristics, energy requirements, costs, environmental impacts, by-products and uses. A panel discussion explored the concerns and reactions of major coal company and land use representatives to the concept of utilizing municipal wastewater and sludge in mined land reclamation, while a highly successful field trip demonstrated some of the successful use of such practices already undertaken in Somerset County, Pennsylvania.

Held September 16-18, 1980, in Pittsburgh, the Symposium was attended by more than 250 participants from 30 states. The symposium was a continuing education service of The Pennsylvania State University, School of Forest Resources, College of Agriculture, and Institute for Research on Land and Water Resources. The symposium, engineering assessment, and related contract activities were financially supported by the Office of Water Program Operations and Office of Research and Development, U.S. Environmental Protection Agency; Office of Water Research and Technology and Office of Abandoned Mine Lands, U.S. Department of the Interior; Office of Conservation and Solar Applications, U.S. Department of Energy; Forest Service and Office of Environmental Quality, U.S. Department of Agriculture; and Appalachian Regional Appropriate Technology Program, National Science Foundation, Office of Solid Waste Management, Pennsylvania Department of Environmental

Resources; Water Department, City of Philadelphia and Modern-Earthline Companies. Partial financial support was provided under U.S. Environmental Protection Agency Grant No. CR807408010 under Project Officer, G. Kenneth Dotson, Wastewater Research Division, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

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Symposium Co-Directors

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I / POTENTIAL USE OF SLUDGE FOR RECLAMATION

1
THE BASIC NEED FOR AND VALUES GAINED FROM RECLAIMING STRIP-MINED AND OTHER DISTURBED AREAS

David R. Maneval

During the 1960s and 1970s there was continual agitation in the U.S. Congress for the enactment of a surface mining act which would regulate the coal mining industry. It was the view of the Congress that the air pollution, water pollution, and land devastation associated with the surface effects of coal mining were not necessary but could be brought under control as they had been in several of the individual States. Part of President Carter's platform in the fall of 1976 was the enactment of surface mining legislation. In the summer of 1977 Congress passed the Surface Mining Control and Reclamation Act, and on August 3, 1977, it was signed into law as P.L. 95-87 by the President. This was accomplished by growing public support for the concept that surface mining could be controlled and the industry could still make a reasonable profit. The Act also called for the establishment of the Office of Surface Mining Reclamation and Enforcement (now known informally as OSM) in the Department of the Interior. In this paper I will discuss some of the adverse effects of surface mining which brought about the Act.

Many surface mining operations resulted in disturbance of surface areas that burden and adversely affect Congress and the public welfare by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes, by causing erosion and landslides, by contributing to floods, by polluting the water, by destroying fish and wildlife habitats, by impairing natural beauty, by damaging the property of citizens, by creating hazards to life and property, by degrading the quality of life in local communities, and by counteracting governmental programs and efforts to conserve soil, water, and other natural resources. This, in part, is one of the findings of Congress in the statement of purpose for passing the Act.

Experience in many States, in particular the State of Pennsylvania, has shown that surface mining can be regulated and operators can comply with

the regulations while at the same time making a fair and reasonable profit. In this paper I will discuss Pennsylvania's experience which led to the passage of landmark legislation in that State in the 1960's and OSM's experience to date with the interim regulatory program. I will also discuss our perception of the values to be gained from the reclaiming of strip mine areas as well as the surface effects of underground mining.

Introduction

During the 1940s and 1950s, there was awareness in some States that surface mining was increasing in popularity. More and more coal was being mined by this method. In a typical State like Tennessee, in 1955, about 20% of the production was from surface mining. In contrast, today about 80% is from surface mining. The trend in many States, dictated by the location of the coal deposits and market conditions, has been to go to surface mining. At the same time that surface mining was increasing in popularity, there was a realization in some quarters that this was not an unmixed blessing. It was found that there were problems associated with it.

My home State of Pennsylvania was at the leading edge of the public effort to control the problems associated with surface mining of coal, and laws were passed by the State legislature to bring the growing surface mining industry into compliance with regulatory controls so that the environment would not be damaged forever. I will summarize the evolution of the surface mining regulatory program in Pennsylvania.

The first regulation of surface mining in Pennsylvania was the requirement, in 1941, that mined areas be revegetated with trees. During World War II, regulations were pretty much suspended, as the primary emphasis was understandably on production. Some outcrop and slope-reduction requirements were passed in the 1950s and early 1960s. Probably the landmark piece of legislation was passed in 1963, making highwalls illegal--all highwalls had to be covered. Some States are struggling even now to pass similar legislation, 17 years after the law was passed in Pennsylvania.

Another result of the 1963 legislation was that mine operators were required to have a mining license to mine in Pennsylvania, just as a driver's license is needed to drive.

I was part of the State of Pennsylvania government during that era. We had marches on Harrisburg and saw busloads of mine operators and workers who thought these laws, while nice for the environmentalists, would be the death knell for the industry. What really happened in Pennsylvania after the "landmark" law was passed?

The first year after the law was passed, the number of licensed operators dropped from 300 to 125. People said, "Aha! We told you so!" But in

fact what really happened was that many of the small operators consolidated; a number of companies would band together to do the preplanning and hire the professional engineers needed to comply with the new regulations.

The plea was also made that there would be a serious drop in employment. However, in the years 1964-68, the employment in the surface coal mining industry remained nearly level, at 5,900. Because of market conditions, and not because of the regulations, there was a drop in employment in 1969, but then employment rose through 1975, to 8,100. As you can see, employment rose in that 11-year period.

What did the law do to production? Again, in the years 1964-68, there was virtually no drop in production with the imposition of the regulations that required that the mined land be returned to original contour; it stayed at about 24 million tons per year. As with employment, 1969 was the low spot because of market conditions, and production dropped to about 20.5 million tons per year. However, it had recovered by 1975, and production was up to 37 million tons per year.

What are the conditions in this typical case State, Pennsylvania, that we are examining? About 25% of the mining is on slopes of less than 12°, 58% is on slopes of 12°-20°, and 17% is on slopes of more than 20°. So the State has a typical array of flat, rolling, and steep terrain. Does Pennsylvania have only big operators? No. The State, again in 1975, had 545 operators, half of whom produced less than 25,000 tons per year. Only 47 operators produced more than 200,000 tons per year.

Most surface mining in this country is area mining on flat terrain, contour mining on rolling terrain, and steep-slope mining on steep terrain, as it is in Pennsylvania. During this period there were interested observers looking over the fence. These were concerned people in other States and also in the U.S. Congress. They looked at Pennsylvania and said, "If this State can do it and bring this growing form of coal production under control, why should neighboring States be at a competitive advantage because they don't require many of these same environmental controls?" That was their concern.

With proof that surface mining could be controlled, Congress, through a slow, evolutionary process, finally in 1975 passed a surface mining control act. It was vetoed by President Ford. Part of President Carter's platform was that if elected, and Congress enacted a surface mining act, he would sign it. In July 1977, Congress passed the Surface Mining Control and Reclamation Act of 1977, and on August 3, 1977, it was signed into law as Public Law 95-87 by the President. This was accomplished by growing public support for the notion that surface mining could be controlled and industry could still make a reasonable profit. The Act also called for establishment of the Office of Surface Mining Reclamation and Enforcement, now known informally as the Office of Surface Mining or OSM in the U.S. Department of the Interior, to carry out the requirements of the Act.

Initial Regulatory Program

For the years many States had various degrees of surface mining regulation, but most had not passed legislation to bring surface mining under adequate control. Ohio, Maryland, West Virginia, and some other States had, of their own volition, passed legislation to control many of the problems after observing the results in Pennsylvania, but this left those States at a competitive disadvantage with the States that had not passed similar legislation. According to the commerce clause of the Constitution, a State will not be put at a competitive advantage, or disadvantage, relative to its neighbors. Therefore, the intent of the Act was for it to have a leveling influence, so that each ton of coal would be produced according to the same performance standards.

Congress knowing that some of the regulations would have virtually no impact on some States and would be very unsettling in many other States, decided to put the regulatory program in place in two stages, first as an initial regulatory program and then as a permanent regulatory program. The initial program is in effect now.

The initial regulatory program was outlined through a series of proposed regulations that were issued in September 1977 and that became final in December 1977. These went into effect for all new coal mines in February 1978 and for all existing coal mines in May 1978. The items chosen by Congress for the initial program were those based on the immediacy of the need, and they comprise eight performance standards that cover items which, if not brought under control or regulated, might have the largest potential for harm to the environment and to public health and safety. These are: prime farmland use; return of mined land to approximate original contour; topsoil removal, including retention and spreading; protection of hydrologic balance; disposal of spoil; use of explosives; and a pair of related regulations that apply to steep-slope mining and mountain top removal. The initial program also includes an arrangement whereby State inspectors and OSM inspectors jointly enforce the regulatory program.

Permanent Regulatory Program

In June and July of 1978, OSM issued landmark preproposed regulations. This is the first time we know of this being tried. We put out these preproposed regulations, in mimeograph form, to invite comment. This was not required by any law but was an effort to get maximum public participation from the industry, from labor, from other government agencies, and from the public. As a result of the preproposed regulations, we had an avalanche of comments that were considered very seriously.

On September 18, 1978, we published in the Federal Register our

formal proposed regul
comment period but
extended the period
included 25 days of
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In January of 1979 we
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K which deals with
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Accompanying the
You don't have to
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to mine and reclaim

productivity. Then, stratum by stratum, the mining will basically exfoliate the layers. First the A horizon is taken off and stored separately, then the B horizon, then the C horizon. After the coal has been removed and the toxic materials buried, the overburden materials are returned to the pit in the same order in which they came out. The mine operator must be careful in the replacement of these materials so that there is no undue compaction that will preclude the restoration of the resulting farmland to its original productivity.

The mining of alluvial valley floors is very much of a problem in the West. In many areas the way that water travels from mountain slope A to town B in the valley is by transfer of water through an aquifer that may also be the coal bed to be mined. Consequently, the disturbance of alluvial valley floors is carefully regulated. If an operator has a Federal coal lease on an alluvial valley floor and there is no way to do the mining without disturbing the aquifer, the Federal government may trade one block of the coal reserves on the alluvial valley floor for a nearby one which does not have the geomorphological function of the alluvial valley floor.

Certain lands designated by Congress cannot be disturbed, or a State may find an area "unsuitable for mining." If there is absolutely no way to mine an area and then restore it properly, it is possible through a series of steps to declare that land as unsuitable for mining.

Fish and wildlife need protection during mining. This includes buffer zones near streams that have aquatic flora and fauna.

Protection of clean water must be assured, and this includes requirements for protection of wells. EPA's water-quality guidelines are included by reference.

Blasting requirements are based on data from the Bureau of Mines.

For areas where, because of the swell factor, excess spoil will have to be disposed of, there are requirements concerning head-of-hollow and valley fills. These large structures must be built in a stable manner so that they will not be subject to sliding.

Some of the requirements that will have an impact on underground mining are the control of subsidence damage, quality of discharged water, and gravity discharge from underground mines. The regulations will also control the demolition and reclamation of offsite preparation plants including black-water clarification ponds and settling facilities.

Roads at mines are also covered, by a three-class road system that is very similar to that used for other purposes in many States. The requirements are based on the lifetime and use of the roads. If a road is going to be used for exploration, the requirements are minimal; if it is going to be used by loaded coal trucks for the next 5 years, the requirements won't be too much different than for some other heavy-duty roads.

Revegetation requirements are related to the terrain. They are somewhat different for the East than for the West. One of the major problems in

mining in the West is the combination of low rainfall and use of rangeland for grazing. Generally revegetation must be suitable for the proposed postmining land use.

In connection with this conference you may be interested in the OSM view of the use of sludge-derived fertilizers and soil conditioners.

We have reviewed the material in the preproposal draft regulation which was announced by the Environmental Protection Agency (EPA) in the *Federal Register* of May 7, 1980. We understand the problems which are discussed in this document and would like to provide for your consideration our views as follows:

1. The "governmental use" of sludge is probably not acceptable as a part of our abandoned mine land reclamation projects. Our difficulty with the utilization or acceptance of this sludge on our abandoned mine land project areas is that the candidate areas for our AML funds are not necessarily public lands. As a matter of fact, very few of the lands which will be repaired and restored under Title IV of Public Law 95-87 are public lands. The vast majority of them are private property. Inasmuch as we do not have control of such private lands, we could not assure ourselves or EPA that sludge use on such AML sites would not, at some future time, be used for "food chain production."

2. This agency would have no objection to the use of the "unrestricted sludges" or sludge-derived products in either active or abandoned mine reclamation projects. However, we merely require that a mine operator comply with our regulations in his or her revegetation efforts. This most often includes, after proper application of topsoils, the utilization of soil amendments and lime and mulch. It is the operator's option whether or not to comply with our requirements by utilization of an "unrestricted sludge" or "sludge product" in complying with our regulations. We could not require an operator to utilize such materials rather than commercial fertilizer and commercial mulch.

3. Because of the potential of solubilization or resolubilization of heavy metals or other organically toxic materials, in all instances we must be assured that "restricted or governmental use" sludges not be disposed of in active mine reclamation projects or be disposed of in abandoned coal mines.

Current Status of State Programs

The permanent regulations serve as a model to the States who, since March 13, 1979, have been comparing their current regulations with OSM's regulations and making adjustments if necessary. Many States will have to go back to their legislatures for new regulatory authority, as agencies can

write regulations only if there is a law that gives them such powers. Section 731.13 of the Federal regulations is a so-called "State window" which, as we have been admonished by the Congress, will allow a State to propose alternatives to our regulations in order to tailor its program to fit the various kinds of topography, terrain, climate, etc., of the State. It would be a little ridiculous to require that Maryland, for instance, prepare a whole set of regulations on mining in alluvial valley floors since it doesn't have any. Nor will we be requiring the State of Iowa to prepare regulations on mountaintop removal, because they don't have any mountains.

The States have generally completed the process of reviewing their own regulations and comparing them with OSM's permanent regulations. OSM has done a side-by-side comparison to see if the regulations are comparable to our permanent regulations.

The Secretary of the Interior is making decisions in September as to which programs are approvable. State programs not approved can be resubmitted and reconsidered. A second round of decisions will be made in January 1981 on resubmitted State plans.

Conclusions

These, then, are the highlights of how the Act came into being, the two-tier system that the Congress built into it, with an initial regulatory program and then a permanent regulatory program, and some of the major technical components of the regulations. States have the opportunity to continue to run their own programs. After the State programs have been designed, presented, and approved, financial aid is available to the States from this Act and from the Congress to help them improve their staffs, getting them up to a reasonable level, provide in-service training for their people, provide instrumentation and other monitoring devices, and to just assist the programs overall.

To quote directly from PL-95-87 (Section 101.(c)), the Congress found that many surface mining operations result in disturbances of surface areas that burden and adversely affect commerce and the public welfare by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural, and forestry purposes, by causing erosion and landslides, by contributing to floods, by polluting the water, by destroying fish and wildlife habitats, by impairing natural beauty, by damaging the property of citizens, by creating hazards dangerous to life and property by degrading the quality of life in local communities, and by counteracting governmental programs and efforts to conserve soil, water, and other natural resources.

The mission of OSM is to end and reverse these problems while assuring the continued production of coal. This, then, is the basic need and value to be gained from reclaiming strip-mined land.

2
CONSTRAINTS TO THE USE OF TREATED MUNICIPAL SLUDGE IN WESTERN SURFACE MINE RECLAMATION

Daniel J. Snyder, III

Western surface mines in the Powder River Basin are expected to play a growing role in our national energy picture between now and the year 2000. According to the recently published report of the World Coal Study entitled, "Coal: Bridge to the Future," U.S. coal productions will have to triple by 1995 to meet U.S. and free world energy demand. Since eastern production comes largely from high cost underground operations, much of this additional demand must be met by expanding the western surface mining industry.

The Surface Mining and Reclamation Act of 1977 required the use of the best available land reclamation practices. The arid climate in many western states plus generally poor soil conditions presents a real challenge to western surface mine operators. Most large operators now maintain a professional staff of soil scientists. The reclamation of mined lands can be accomplished only at substantial cost. These costs are passed on to consumers in the form of higher prices and utility rates. According to other industry sources, reclamation costs are now approaching 25 percent of the FOB mine price of the coal. Any savings in reclamation costs will immediately be passed through to the consumer in the present highly competitive steam coal market.

Western states acted long before the passage of the Surface Mining and Reclamation Act to require good land reclamation practices. Westerners have a strong attachment to their land and are willing to support energy development only so long as it does not do lasting harm to agricultural, grazing, and recreational activities. In several western states the reclamation requirements are even more stringent than those being enforced by the Federal Office of Surface Mining.

The deeply felt western concern for maintaining a high quality environment can serve to either encourage or retard the use of municipal sludge in reclamation activities. In some cases the use of sludge as a fertilizer and bulking agent could serve to increase the productivity of marginal grazing and forage crop areas. This would be welcomed by western environmental interests. More difficult to assess is the likely western reaction to bringing treated municipal sludge from urban areas into rural western mining regions. Public education and understanding will be critical.

I want to now leave this more general discussion of the future of western mining as it relates to western public attitudes, and discuss some specific cost and attitude factors associated with a real surface mining operation.

Westmoreland Resources is 60 percent owned by the Westmoreland Coal Company. The other owners are Morrison and Knudsen and Penn Virginia. This company operates a large surface mine on the Crow Indian reservation

about 30 miles South of Hardin, Montana. The lease from the Crow Indian Tribe contains in excess of 500 million tons of coal. The mine is presently producing 5 3 million tons per year. This coal is shipped to midwestern utilities in unit trains (10,000 tons per train). The mine has the online capacity to produce 11 million tons per year when market conditions warrant.

Two thick seams of coal are mined at a roughly 4 to 1 coal to overburden ratio. Two large draglines (110 cubic yard) are utilized to remove the overburden. The top 3 feet of soil is segregated. The coal is blasted and loaded on trucks for shipment to the storage barn and train load out. Overburden is replaced and the topsoil is put back in place.

The sparse rainfall and predominant soil conditions in the area of the mine present substantial reclamation problems. A nitrogen and phosphate fertilizer with an analysis of 25-25-0 is presently applied to the top soil. This fertilizer costs $248/ton. It is applied at a rate of approximately 125 pounds per acre. The major reason for this application of fertilizer is to stimulate the quick growth of vegetative cover for erosion control.

Northern Great Plains soils are predominantly alkaline. This would serve to mobilize the trace metals but make the use of a liquid lime sludge most undesirable. The addition of soluble salts would also be highly detrimental since precipitation is not sufficient to wash such salts from the soil.

Substantial transportation economics could be realized by shipping treated sludge back from the midwest in empty unit trains. Mining operations would have to have the ability to unload these rail cars quickly, clean them, and fill them with coal for their return trip. Compost or treated sludge would have to be utilized to avoid activity from transportation corridor residents. This two-way unit train traffic would do a great deal for railroad economics, since the return haul from the power plant is now a total loss.

In summary, treated sludge can be used to reclaim western surface mined lands if proper scientific evaluation is done, and if the public can be made to understand and support the effort. Savings in fertilizer and transportation costs will be passed on to consumers because of the highly competitive coal market. This would be welcome news in today's high energy price economy.

II / PENNSYLVANIA MINE RECLAMATION PROGRAM

OVERVIEW

Robert S. Madancy

The papers presented in Section II clearly indicate that municipal wastewaters and sludges can be considered as valuable resources rather than waste materials. The paper by Bastian, Montague, and Numbers and the ones by Sopper and Kerr describe the use of wastewater and sludges in biomass production and land reclamation. The conventional outlook in the past has been to consider only the costs involved in disposing of these materials without examining the benefits that could be derived from their beneficial reclamation and reuse. Reuse and recycling of wastewaters has generally been considered to be of practical value primarily in the water-short western and southern areas of the United States. The papers presented in this session indicate that reuse of these resources can also have significant economic and environmental value in northeastern states that have generally been considered to be "water-surplus" areas. One of the wastewater use applications, that of biomass production, offers a cost competitive method of not only reducing water pollution but increasing energy production by using both the water and its nutrient constituents. Other applications such as revegetation of strip mined and other marginal lands indicate major potential for using a waste product from one location to prevent water quality degradation at another site while restoring the land for future beneficial use.

Water reuse research and development programs of the Office of Research and Technology and the Environmental Protection Agency have been working on new methods and techniques for reclaiming wastewaters to augment existing water supplies and reduce pollutant loads to surface waters. Many municipalities and universities throughout the United States have also been involved in significant efforts for utilization of wastewaters and sludges. The mine reclamation project described by Sopper is an excellent example of the practical results that can be obtained in cooperative efforts by local government and universities. It is particularly appropriate that The Pennsylvania State University has been involved in this landmark project since most of the current efforts in land application of municipal wastewaters have emanated from the pioneering research in this field conducted by Penn

State in the 1960s.

The papers presented at this session and others during the symposium indicate that reclamation and beneficial reuse of wastewaters and sludges are now progressing well beyond the research stage in many instances and show major promise and potential for future large-scale applications throughout the United States.

3
THE POTENTIAL FOR USING MUNICIPAL WASTEWATER AND SLUDGE IN LAND RECLAMATION AND BIOMASS PRODUCTION AS AN I/A TECHNOLOGY: AN OVERVIEW

Robert K. Bastian, Albert Montague, and Thomas Numbers

Millions of acres of disturbed lands and unproductive areas exist throughout the United States that cry out for reclamation or improvement. At the same time, municipalities across the country are faced with the problems of managing the treatment and disposal of ever growing volumes of municipal wastewater and sludge that contain the very nutrients and soil building properties needed to help improve these areas.

Various approaches for utilizing municipal wastewater and sludge in land reclamation and biomass production projects have been clearly demonstrated as effective means of treating and recycling these "wastes" as valuable resources. They also have been shown to help alleviate some of the serious water quality, erosion and low productivity problems associated with areas such as abandoned strip mine spoils, mine tailings, dredge spoils, quarries, borrow pits, clear cut forests, construction sites, etc., while producing biomass that can be converted to energy or used for other purposes.

Many reuse and disposal alternatives for managing municipal wastewater and sludge are being greatly limited due to increasing fuel and other operating costs as well as local, State and Federal regulations or other restrictions. At the same time methods have been developed and demonstrated for beneficially recycling these misplaced resources in the reclamation, stabilization and revegetation of various types of disturbed and unproductive areas that appear to be both environmentally acceptable and cost competitive with conventional means of dealing with land reclamation and waste management problems. These practices should be seriously considered as innovative and alternative (I/A) technologies for municipal wastewater treatment and sludge management which are eligible for increased levels of Federal funding and other support through EPA's construction grants program.

Introduction

Due to their wide acceptance by the engineering community and public health officials, conventional wastewater treatment practices (especially activated sludge and trickling filter facilities) followed by the discharge of treated effluents into surface waters, have served as the major technologic

used for treating municipal wastewater in an effort to meet the requirements of both Federal and State water pollution control laws. Incineration, landfilling, land application, lagooning and ocean disposal practices and associated treatment processes have been widely used to treat and dispose of the sludges resulting from these conventional wastewater treatment practices.

However, many of these same widely accepted, conventional wastewater treatment and sludge management technologies depend heavily upon the use of large amounts of energy as well as sophisticated equipment, chemicals and skilled labor. In addition, new regulatory requirements have greatly constrained the use of certain waste management practices (e.g., ocean disposal, incineration and land disposal of sludge) and have led many communities and their consultants to begin seriously looking for more innovative and efficient ways to manage municipal wastes.

Many communities have given serious consideration to various high technology solutions, including waste-to-energy projects, in hopes of solving their waste management problems in a way that could lead to both energy recovery and cost savings in the long run. However, many problems have been associated with implementing such high technology projects, including the need for large capital investments and skilled labor, high O&M requirements and costs, as well as siting problems, indebtedness associated with existing facilities, and difficulties in gaining local public acceptance and regulatory agency approvals of new technologies. These and other problems have led many communities and their consultants to reject the use of innovative waste management concepts and to continue their use of the more widely accepted, conventional treatment and disposal practices incorporating where possible improvements that save energy, lower O&M costs, and improve overall system efficiency and treatment performance.

In response to the dramatic cost increases for energy, raw materials, construction, and labor some enterprising communities and their consultants are seriously re-evaluating the potential role of more self-sufficient, managed natural ecosystems as a part of municipal wastewater treatment and sludge management systems. A few imaginative individuals have been striving to develop innovative wastewater treatment and sludge management practices, including techniques that harness natural biological processes, to help treat municipal wastewater and sludge in a more cost-effective and energy efficient manner while effectively recycling or reusing municipal wastewater or sludge and their constituents. While more land intensive, such natural biological recycle/reuse systems frequently cost less to operate, require less sophisticated equipment and operators, and use less energy and non-renewable resources. The management of such natural biological processes also provides an opportunity to enhance the environment by helping to improve disturbed or impoverished soils, increase soil productivity, wildlife production and habitat availability, create new recreation

Table 3-1. Status of Major Treatment Process at Municipal Wastewater Treatment Facilities.[a]

	Now in Use		Under Construction	
Treatment Processes	No.	MGD [b]	No	MGD [b]
Primary Sedimentation	5,736	20,856	278	918
Trickling Filters	2,863	4,514	86	241
Activated Sludge	7,670	24,912	662	2,950
Land Treatment	488	583	56	56
Ponds	7,263	4,581	476	941
Oxidation Ditch	337	131	65	25
BioDisc (RBC)	71	74	85	26
Microstrainers	95	976	20	40

a/ Based on 1978 Needs Survey (1) results, results of the 1980 Needs Survey update should be available by early 1981.

b/ Projected design flow of wastewater treatment plants using each treatment process.

opportunities, and produce biomass for use as soil amendments, animal feeds, alternative energy sources, etc.

Municipal Wastewater and Sludge Production, Characteristics, and Disposal Practices

Over 25 billion gallons of domestic and industrial wastes are discharged daily into the Nation's municipal sewers by some 144 million Americans and at least 87,000 industrial contributors serviced through centralized wastewater collection and treatment facilities. The treatment of these wastes currently produces nearly 7 million dry tons of processed sludge, as well as treated wastewater for reuse or disposal. In addition, it is estimated that nearly 700,000 dry tons of septage are produced annually from the septic tanks which treat wastes from about 25% of the U.S. homes.

The 1978 Needs Survey (1) identified over 14,500 existing publicly owned and operated wastewater treatment works (POTWs); more than 82% of these POTWs treat flows less than 1 mgd while fewer than 350 treat flows more than 10 mgd. Over 7,000 of the POTWs consist simply of wastewater treatment ponds while some of the others involve rather sophisticated treatment processes (Table 3-1).

Only a small percentage (about 2.3%) of the entire volume of municipal wastewater is currently being directly applied to the land via land treatment

...Municipal Wastewater Treatment

	Under Construction	
	No.	Mgd [b/]
	262	622
	[illegible]	1,312
	[illegible]	319
	[illegible]	193
	[illegible]	611
	[illegible]	46
	[illegible]	73
	[illegible]	41
	[illegible]	470
	[illegible]	590
	[illegible]	570
	[illegible]	210
	[illegible]	0
	[illegible]	151

...Needs Survey

...each sludge

...is discharged from ... for disposal and/or ...sludge produced is applied ...from or another and the ... the ocean (Tables 3-2 ...ng periods of time in ...sludges are applied to the ...currently scheduled to be ...ocean mandate and the ...has been decreasing ...with the development ...ocean and landfilling ...escalating fuel prices have ...management practices ...no doubt.

...treated municipal

Table 3-3. Estimated Quantities and Disposition of Treated Sewage Sludge in 1980.

	Quantity of Treated Sludge [b/] dry tons/yr	Percent of Total
Landfill	1,399,600	33
Incineration	933,100	22
Land Application	1,017,900	24
Sludge Lagoons	466,500	11
Ocean Disposal	424,100	10
Total	4,241,200	100

c/ Based on data from a draft Report to Congress by EPA/OWPO.

b/ It is estimated that more than a 35% volume reduction of raw sludge from 6,861,000 to 4,241,800 dry tons results from treatment, long term storage, etc

Table 3-4. Annual Production of Organic Wastes in the U.S.[a]

	Total Production	
Organic Waste	1,000 dry tons	Percent of Total
Animal Manure	175,000	21.9
Crop residues	431,087	53.7
Treated sewage sludge & Septage [b/]	4,935	0.6
Food Processing	3,200	0.4
Industrial organic	8,216	1.0
Logging & wood manufacturing	35,714	4.4
Municipal refuse	145,000	18.1
Total	803,152 [c/]	

a/ Based on data from "Improving Soils with Organic Wastes" by USDA, 1978.

b/ Updated estimates provided by EPA/OWPO.

c/ In addition, EPA/OWPO estimates over 25 billion gallons per day of treated municipal wastewater are produced by the Nation's publicly owned and operated wastewater treatment facilities that could be recycled and reused as an irrigation and nutrient source.

wastewater, sewage sludge, and septage offer a potentially valuable source of nutrients, organic soil amendments and water for use in land reclamation, and biomass production efforts. The total estimated quantities of primary nutrients (N, P, and K) present in these materials are shown in Table 3-5. Total reuse of the amounts of nutrients calculated as present in these organic wastes would amount to over 13% of the nitrogen (N), 11% of the phosphorus (P), and 12% of the potassium (K), or about $.8 billion worth of the primary nutrients currently supplied by commercial fertilizer sources (assuming the price of these nutrients at $300/ton for N, $800/ton for P, and $200/ton for K). In addition, treated effluents have considerable value as a source of irrigation water, especially in areas of limited water supplies; both sewage sludge and septage can be converted into excellent organic soil amendment materials by composting or other processing; and municipal wastewater, sewage sludge and septage all contain many micronutrients in addition to N, P, and K.

However, a major drawback in the use of these materials as a source of nutrients, organic soil amendments, and irrigation water is their potential variability in content of heavy metals, toxic organic compounds and pathogens as well as nutrients and organic matter (Tables 3-6 to 3-11), which has led to constraints being placed on certain uses. In some locations concerns over possible odors or other nuisances as well as chemical or pathogen

Table 3-5. Estimated Total Amounts of Primary Plant Nutrients in Municipal Wastewater, Sludge, and Septage.[a]

	Total nutrients [b] in:				
	Commercial Fertilizer Use in 1978 1000T/yr	Raw Wastewater [c] 1000T/yr	Treated Effluent 1000T/yr	Sewage Sludge 1000T/yr	Septage 1000T/yr
Nitrogen (N)	10,642	1,534	1,012	399	18
Phosphorus (P)	2,453	275	204	72	11
Potassium (K)	4,844	590	572	18	3

a/ Based in part on data from a draft Report to Congress by EPA/OWPO and "Improving Soils with Organic Wastes" by USDA, 1978.

b/ Assumes 66% total N in raw wastewater remains in treated effluent and 26% ends up in sewage sludge, 74% total P remains in treated effluent and 26% in sewage sludge, 97% K remains in treated effluent and 3% in sewage sludge.

c/ Assumes 39 mg/l nitrogen, 7 mg/l phosphorus, 15 mg/l potassium.

contamination of the soil, crops, surface water or groundwater have led to difficult institutional barriers and public acceptance problems when waste reuse and recycling projects have been proposed. Public opposition and institutional red tape have often caused serious project delays and in some cases resulted in projects being abandoned. Unless properly handled such concerns can lead to the rejection of proposed recycling or reuse projects by local or State officials. Therefore, care should be taken to assure that the quality of municipal wastewater, sewage sludge or septage used in beneficial reuse projects is acceptable and that good management practices are followed when implementing such projects. Good management practices and proper controls have been developed that will allow safe recycling of municipal wastewater, sewage sludge and septage in many situations

Table 3-6. Typical Composition of Domestic Wastewater Before and After Treatment (all values except settleable solids and Coliform bacteria are expressed in mg/L).[a]

Constituent	Concentration			
	Before Treatment		After Secondary Treatment	After Advanced Treatment
	Range	Typical		
Solids, Total	350-1200	720		
Dissolved, total	250-850	500		
Fixed	145-525	300		
Volatile	105-325	200		
Suspended, total	100-350	220	20	<3
Fixed	20-75	55		
Volatile	80-275	165		
Settleable solids, mL/L	5-20	10		
Biochemical oxygen demand, 5-day 20 C	110-400	220	20	1
Total organic carbon	80-290	160		
Chemical Oxygen demand	250-1000	500	80	10
Nitrogen (Total as N)	20-85	40	30	2
Organic	8-35	15		
Free Ammonia	12-50	25		
Nitrates	0-0	0		
Nitrites	0-0	0		
Phosphorus (Total as P)	4-15	8	2	
Organic	1-5	3		
Inorganic	3-10	5		
Chlorides [b]	30-100	50		
Coliform bacteria, MPN/100 mL	10^5-10^9	10^7	20	<2
Heavy metals	0.1-2.5	1.3	.8	<0.1
Refractory organics [c]	0.2-7.4	1.4	.2	<0.1
Alkalinity (as $CaCO_3$)	50-200	100		
Grease	50-150	100		

[a] From Metcalf and Eddy, Inc., 1979. Wastewater Engineering, Treatment Disposal Reuse. Second edition. New York: McGraw-Hill, 920 pp.

[b] Should be increased by the amount of domestic water supply.

[c] Surfactants, primarily.

Table 3-7. Typical Chemical Composition of Raw and Digested Sludge.[a]

Item	Raw Primary Sludge		Digested Sludge	
	Range	Typical	Range	Typical
Total dry solids (TS), %	2.0-7.0	4.0	6.0-12.0	10.0
Volatile solids (% of TS)	60-80	65	30-60	40.0
Grease and fats (ether soluble, % of TS)	6.0-30.0	---	5.0-20.0	---
Protein (% of TS)	20-30	25	15-20	18
Nitrogen (N, % of TS)	1.5-4.0	2.5	1.6-6.0	3.0
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4.0	2.5
Potash (K_2O, % of TS)	0-1.0	0.4	0.0-3.0	1.0
Cellulose (% of TS)	8.0-15.0	10.0	8.0-15.0	10.0
Iron (not as Sulfide)(mg/l)	2.0-4.0	2.5	3.0-8.0	4.0
Silica (SiO_2, % of TS)	15.0-20.0	---	10.0-20.0	---
pH	5.0-8.0	6.0	6.5-7.5	7.0
Alkalinity (mg/l as $CaCO_3$)	500-1,500	600	2,500-3,500	3,000
Organic Acids (mg/l as HAc)	200-2,000	500	100-500	200
Thermal content (Btu/lb)	6,800-10,000	7,000 [b]	2,700-6,800	4,000 [c]

[a] From Metcalf and Eddy, Inc., 1972. Wastewater Engineering, Collection Treatment Disposal, New York: McGraw-Hill, 782 pp.

[b] Based on 65 percent volatile matter.

[c] Based on 40 percent volatile matter.

Table 3-8. Typical Metals in Municipal Sludges (mg/kg dry sludge).[a]

	Range	Mean	Median
Ag, Silver	nd-960	225	90
As, Arsenic	10-50	9	8
B, Boron	200-1430	430	350
Ba, Barium	nd-3000	1460	1300
Be, Beryllium	nd	nd	nd
Cd, Cadmium	nd-1100	87	20
Co, Cobalt	nd-800	350	100
Cr, Chromium	22-30,000	1800	600
Cu, Copper	45-16,030	1250	700
Hg, Mercury	0.1-89	7	4
Mn, Manganese	100-8800	1190	400
Ni, Nickel	nd-2800	410	100
Pb, Lead	80-26,000	1940	600
Sr, Strontium	nd-2230	440	150
Se, Selenium	10-180	26	20
V, Vanadium	nd-2100	510	400
Zn, Zinc	51-28,360	3483	1800

nd = not detected

[a] From Metcalf and Eddy, Inc., 1972. Wastewater Engineering, Collection Treatment Disposal, New York: McGraw-Hill, 782 pp.

Table 3-9. Metal Content of Digested Municipal Sludges.[a]

Element	Purely Domestic [b]	Controlled Municipal [c]	Observed Maximum
Zn, ppm	750	2500	50,000
Cu, ppm	250	1000	17,000
Ni, ppm	25	200	8,000
Cd, ppm	5	25	3,410
Pb, ppm	150	1000	10,000
Hg, ppm	2	10	100
Cr, ppm	50	100	30,000

a/ From U.S. E.P.A., April 1976, Municipal Sludge Management: EPA Construction Grants Program, An overview of the Sludge Management Situation. EPA 430/9-76-(MCD-30).

From Chaney, R.L. and P.M. Giordano. 1976. Microelements as related to plant deficiences and territories. In: L.F. Elliott and F.J. Stevenson (eds) Soils for Management and Utilization of Organic Wastes.

b/ Observed in sludges from newer suburban communities.

c/ Typical of sludges from communities without excessive industrial waste sources or with adequate source abatement.

Table 3-10. Variability of Cd, Cu and Ni in Eight Sewage Sludges.[a]

Metal	Sludge No.	Range	Median	Mean	Coefficient of Variation
		mg/kg [b]			% [c]
Cd	1	109-372	170	210	45
	2	4-39	15	19	67
	3	483-1,177	806	846	27
	4	3-150	40	53	95
	5	24-756	663	503	63
	6	12-163	12	43	160
	7	22-256	154	136	69
	8	11-32	11	16	54
Cu	1	4,083-7,174	6,525	6,079	19
	2	5,741-11,875	8,386	8,381	27
	3	2,081-3,510	2,390	2,594	21
	4	452-802	683	662	18
	5	391-6,973	476	1,747	167
	6	300-1,800	682	778	67
	7	422-1,392	894	871	47
	8	979-1,475	1,144	1,154	15
Ni	1	1,932-4,016	3,543	3,184	27
	2	663-1,351	1,053	1,015	29
	3	468-812	651	649	21
	4	75-219	95	119	50
	5	40-797	86	252	144
	6	46-92	88	81	22
	7	47-547	367	349	55
	8	65-93	79	80	12

a/ Adapted from Sommers, L.E., D.W. Nelson and K.J. Yost. 1976. Variable Nature of Chemical Composition of Sewage Sludges. JEQ 5:303-306 .

b/ Oven-dry basis.

c/ Standard deviation expressed as a percentage of the mean.

Table 3-11. Characteristics of Domestic Septage.[a]

Parameter	Mean [b]	Standard Deviation [b]	Range [b]	Number of Samples
Total solids (TS)	38,800	23,700	3,600-106,000	25
Total volatile solids % of TS	65.1	11.3	32-81	22
Suspended solids (SS)	13,014	6,020	1,770-22,600	15
Volatile suspended solids, % of SS	67.0	9.3	51-85	15
5-day biochemical oxygen demand	5,000	4,570	1,460-18,600	13
Total chemical oxygen demand	42,850	36,950	2,200-190,000	37
Chemical oxygen demand	2,570 [c]	-	-	21
Total organic carbon	9,930	6,990	1,316-18,400	9
Total Kjeldahl nitrogen	677	427	66-1,560	37
Ammonia nitrogen	157	120	6-385	25
Total phosphorus	253 [d]	178	24-760	37
pH (units)	6.9	-	6.0-8.8	25
Grease	9,090	6,530	604-23,468	17
Linear alkyl sulfonate	157	45	110-200	3
Iron (Fe)	205	184	3-750	37
Zinc (Zn)	49.0	40.2	4.5-153	38
Aluminum (Al)	48	61	2-200	9
Lead (Pb)	8.4	12.7	1.5-31	5
Copper (Cu)	6.4	8.3	0.3-38	19
Manganese (Mn)	5.02	6.25	0.5-32	38
Chromium (Cr)	1.07	0.64	0.3-2.2	12
Nickel (Ni)	0.90	0.59	0.2-3.7	34
Cadmium (Cd)	0.71	2.17	<.05-10.8	24
Mercury (Hg)	0.28	0.79	<.0002-4.0	35
Arsenic (As)	0.16	0.18	0.03-0.5	12
Selenium (Se)	0.076	0.074	<0.02-0.3	13

	Typical Range [e]
Total Coliform	$10^7 - 10^9$
Fecal Coliform	$10^6 - 10^8$
Fecal Streptococci	$10^6 - 10^7$
Ps. aeruginosa	$10^1 - 10^3$
Salmonella sp.	$1 - 10^2$
Parasites [f]	Present

a/ From Process Design Manual for Sludge Treatment and Disposal, September 1979(EPA 625/1-79-011) and Design Manual for Onsite Wastewater Treatment and Disposal Systems, October 1980.

b/ Values are concentrations in mg/l, unless otherwise noted.

c/ Soluble COD is 6 percent of total COD.

d/ Median.

e/ Counts/100 ml.

f/ May include Toxacara, Ascaris Lumbricoides, Trichuris trichiura, T.vulpis.

(2,3,4,5,6,7,8,9,10). At the same time the establishment and use of local advisory groups, demonstration projects, site visits, public relations campaigns and even compensation measures may become necessary steps in gaining and maintaining the level of public acceptance required to allow even a well designed and managed project to be implemented.

EPA Policy, Regulations and Guidance Impacting Recycling of Municipal Wastewater and Sludge by Land Application

As a result of increasing interest by Congress in addressing environmental problems, the Environmental Protection Agency (EPA) has been charged with numerous mandates to deal with a wide variety of waste management problems ranging from the control of both point and nonpoint sources of water pollution to the management of hazardous wastes (Appendix). While individual pieces of legislation generally have been developed to address specific environmental problems on a media basis (air, land or water), taken as a whole they serve as the basis for addressing waste management activities in a comprehensive and potentially integrated manner (11).

EPA has actively encouraged the beneficial reuse of waste materials (such as municipal wastewater, sewage sludge and septage), as mandated by the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and other recent environmental legislation. At the same time, the Agency has recognized that certain waste materials and waste management practices have a greater potential for creating environmental or public health problems. In developing guidelines and regulations to help control waste management practices, the Agency is actively seeking to identify acceptable levels of risk while encouraging the maximum recycling of wastes as a resource.

Land Treatment, Reuse and Reclamation of Municipal Wastewater

In recent years EPA has placed considerable effort in developing land treatment technologies and improving methods of recycling municipal wastewater. Land treatment practices have become acceptable as viable wastewater management techniques that must be considered and where possible implemented if EPA construction grant funds are involved (12,13). This policy has been established in an effort to encourage full implementation of land treatment processes for treating municipal wastewater while recovering and recycling wastewater nutrients in a beneficial manner.

There should be a great potential for incorporating land reclamation and biomass production into the design of land treatment and reuse projects while meeting the intent of Congress which directed EPA to encourage waste treatment practices that result in facilities which 1) recycle potential

pollutants through the production of agricultural, silvicultural and aquacultural products; 2) reclaim wastewater; and 3) eliminate the discharge of pollutants. Although most land treatment projects involving crop production developed to date have focused upon the use of conventional agricultural crops, a number of forrest irrigation systems also have been built and are in operation. With the current increased interest in improving forestry production through fertilization and/or irrigation practices (especially for marginal soils), the potential beneficial use of municipal wastewater in such practices may yet be realized.

Regulations and guidelines as well as considerable design information are already available that can be easily applied to the design, management and control of land treatment projects incorporating both the treatment and utilization of municipal wastewater in various types of land reclamation and biomass production practices. These include best practicable waste treatment technology (BPWTT) criteria and guidelines on the maintenance of ground water quality for land treatment systems (41 FR 6190; February 1976) and "Alternative Waste Management Techniques for BPWTT"(EPA 430/9-75-013, October 1975), the *Process Design Manual for Land Treatment of Municipal Wastewater* (EPA 625/1-77-008, October 1977), and other materials.

Sewage Sludge Management

A number of years ago the first regulations were issued that applied directly to the incineration and ocean disposal of sewage sludge. Recently, efforts have been made to update these requirements and to address other sludge management practices such as land application (2,14,15).

It is currently EPA's intention to issue comprehensive regulations on sewage sludge management practices under the broad authority of Section 405 of CWA and other statutory authorities. "Criteria for Classification of Solid Waste Disposal Facilities" (40 CFR Part 257) were issued on September 13, 1979, under the joint authority of Sections 1008(a)(3) and 4004(a) of RCRA and Section 405(d) of CWA. These criteria cover land application, landfilling and other land disposal practices (including surface impoundments) and require a phase-out of unacceptable practices such as "open dumps" within a five year period. Pathogen destruction requirements and limits on cadmium and PCB additions for sludge application to land used for the production of food chain crops are included, but to date only in interim final form. These requirements are expected to be finalized by the end of 1981. Proposed regulations governing the giveaway or sale of sludge derived products under the authority of Section 405 of Clean Water Act are also being developed.

The Hazardous Waste Regulations (40 CFR 260-265) issued in final form in May 1980, did not list municipal sludge as a "hazardous waste", but also did not exclude sewage sludges which are tested and found to exhibit the characteristics of "hazardous waste" from being controlled by these

regulations. It is planned, however, that once the comprehensive regulations on sewage sludge management practices are issued under the authority of Section 405 of CWA, sewage sludge will be excluded from coverage under the general hazardous waste regulations; in this case sewage sludge that would otherwise qualify as a hazardous waste will receive an equivalent level of protection under the comprehensive sewage sludge regulations.

EPA has issued a number of technical bulletins and guidance documents concerning municipal sludge management practices and has recently prepared "A Guide to Regulations and Guidance for the Utilization and Disposal of Municipal Sewage Sludge" (15). This "can-do" document provides a concise outline of current EPA sludge management regulations and guidelines, problems frequently encountered where implementing sludge utilization projects, and guidance on dealing with these regulatory requirements and operations problems.

EPA, continuing the work of its predecessor agencies, has been developing environmentally acceptable methods for the management of municipal sludge since the enactment of the first federal water pollution control laws. The initial phase of the research program were concerned with sludge processing and treatment alternatives and dewatering techniques, since most disposal methods required some processing, treatment and dewatering prior to ultimate disposal. The more recent research and demonstration program emphasis has shifted toward the development of improved technologies for returning sludge to the environment in an ecologically acceptable manner. The emphasis is now and will continue to be on beneficial utilization, e.g., land application for soil enhancement, crop production and reclamation of disturbed lands, energy conservation and resource recovery, as well as technology transfer efforts. The FY '80 research and demonstration (R&D) funding for municipal sludge technology and health programs was about $5.6 million. The current R&D program does include a series of land reclamation projects in Pennsylvania and other land application projects, as well as projects involving composting, thermal conversion, energy conservation and recovery, and other sludge management practices. Information from these and other studies has been and will continue to be made readily available to the communities faced with municipal sludge management problems. Also, an updated EPA Sludge Treatment and Disposal Process Design Manual was issued in September 1979 and a special land application manual, including coverage of land reclamation and biomass production practices, is scheduled for completion during 1982.

The Construction Grants Program

Through the EPA construction grants program of the EPA, in partnership with States and municipalities, the funding of municipal wastewater treatment works has grown from a relatively small federal grants program to become the largest public works endeavor that is specifically directed

at improving the environment. Under the original federal assistance program, for the period from 1956 to 1972, 13,764 projects totaling $14 billion in eligible costs were provided with $5.2 billion in grants. The current program effort, which was launched by the Federal Water Pollution Act Amendments of 1972 (PL 92-500), has assisted over 20,000 projects costing some $33 billion with nearly $28 billion in federal grants funded for the most part at the rate of 75 percent for eligible costs (16). Projects assisted include the planning, design and construction of new treatment plants, upgrading of existing treatment facilities, interceptor and collector sewers, pump stations, corrections to infiltration/inflow and combined sewer overflow problems, and sludge management systems.

It has been general practice for consulting engineers to rely on the more traditional and widely utilized conventional wastewater treatment and sludge management technologies in the construction of these facilities. The intent of PL 92-500 and the more recent provisions of the Clean Water Act of 1977 (PL 95-217), however, was clearly to push toward more self-sufficient and permanent long-term solutions based upon sound ecological reuse/recycle concepts and to encourage the technological community to find better and less expensive ways to do the job (17,18). In fact, Congress has actively encouraged greater use of wastewater and sludge management practices which result in the construction of revenue producing facilities that recycle potential sewage pollutants through the production of agricultural, silviculture, and aquaculture products.

The I/A Program

The EPA has developed a program to implement the new provisions of the Clean Water Act, which provide special new incentives for increased use of innovative and alternative (I/A) technologies and methodologies to help overcome the impediments facing increased implementation of these practices through the construction grants program. The new provisions include increased federal funding for design and construction of I/A projects (increased from 75 percent to 85 percent), a 15 percent cost-effective preference for I/A practices over least cost conventional practices, 100 percent funding to modify or replace I/A facilities should they fail, and specific set-asides in State allotments of construction grants funds to fund only I/A projects.

When Congress passed the Clean Water Act, specific goals were set forth for I/A technologies and methodologies. These goals, which have been incorporated into the EPA construction grants regulations and guidance (19,20), focus on reclamation and reuse of wastewater and wastewater constituents, recovery and conservation of energy, and reduction in costs compared to existing conventional technologies.

Under its construction grants program, EPA has defined "alternative"

technologies and methodologies as proven methods which provide for reclamation and reuse of wastewater, productive recycling of wastewater constituents or recovery of energy. "Innovative" technologies and methodologies have been defined as developed methods which offer an advancement in the state-of-the-art, but which have not been fully proven in the circumstances of their intended use. These innovative practices are to be primarily directed at achieving increased reclamation, recycling and recovery of wastewater, beneficial use of wastewater constituents and energy recovery as well as cost reduction, reduction in use of resources, and other environmental benefits.

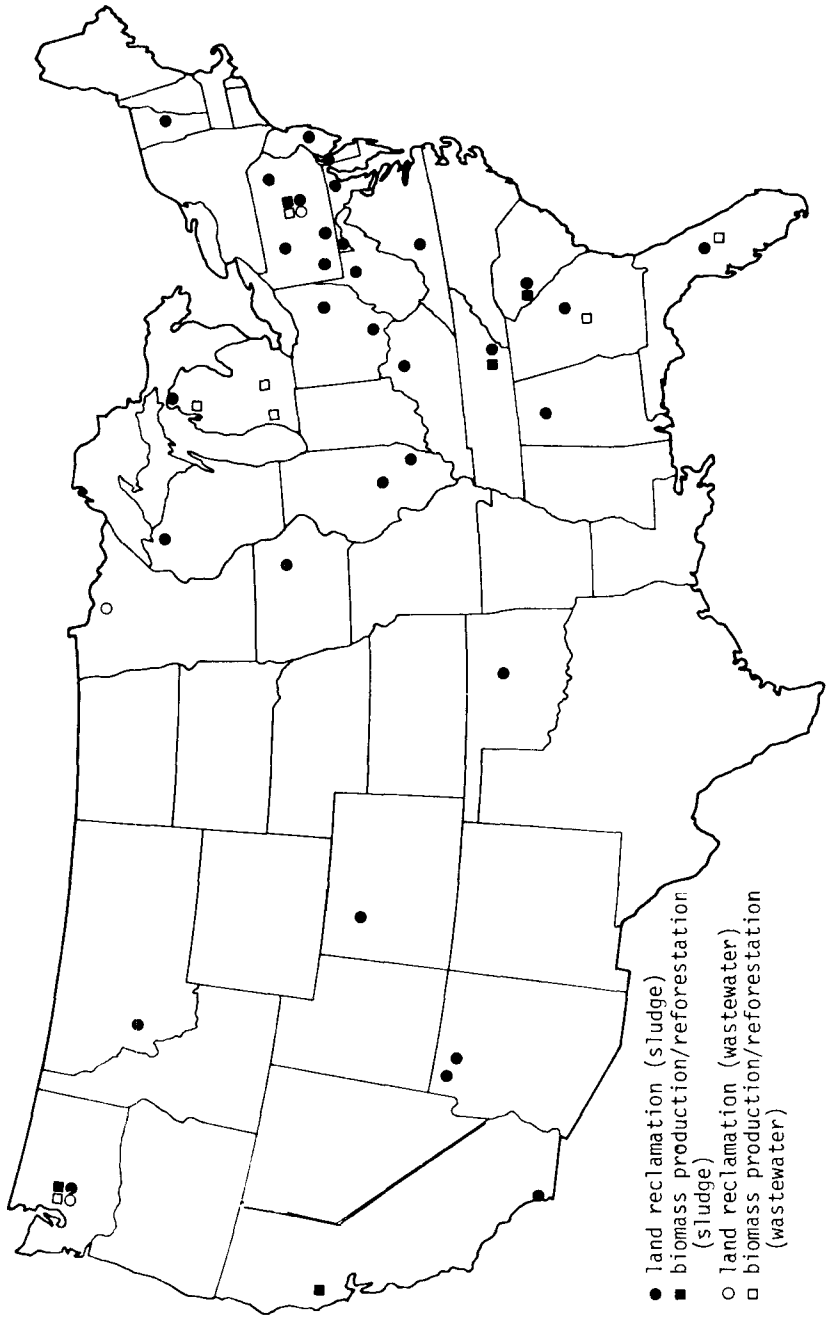
Land Reclamation and Biomass Production Potentials

An area that has shown great promise and response as an I/A technology is the use and treatment of municipal wastewater and sludge in land reclamation and biomass production. A wide range of such land reclamation and biomass production projects have been investigated and employed to date (see Map 3-1). Such systems generally involve the reclamation, stabilization and revegetation of areas that are causing serious non-point water pollution and other problems. They involve the application of wastewater or sludge to disturbed areas such as strip mine spoils, mine tailings, dredge spoils, borrow pits and construction sites, quarries and gravel pits, clear-cut and burned forests, as well as marginally productive forests. Municipal sludges have even been used to stabilize shifting sand dunes (21) and to help create near shore islands for recreation use. Studies are currently going on to evaluate the use of sewage sludge in stabilizing certain ash covered forest production areas near the now famous Mt. St. Helens volcano.

Such systems represent prime examples of the basic land treatment, recycle/reuse concepts which have been strongly encouraged by Congress and EPA. There is a great amount of research and demonstration experience and guidance information available on various land application/recycling practices (2,3,4,5,6,7,8,9,10,22,23). This background along with the growing number of successful land reclamation/biomass production demonstration projects that have been undertaken across the country, serve as a clear indication of the potential value and benefits to be achieved through the thoughtful use of these "sewage wastes" as a valuable resource in land reclamation and biomass production.

Possible Areas for Implementation

Millions of acres of disturbed lands and unproductive areas currently exist throughout the United States. Millions more will be disturbed by mining, forestry, construction, natural disasters, etc., in future years. Many of these areas will require reclamation, stabilization and revegetation to help control



Map 3-1. Location of Some Known Land Reclamation and Biomass Production/Reforestation Projects Utilizing Municipal Wastewater or Sewage Sludge.

Table 3-12. Comparison of Major Land Uses in the United States, 1969.[a] (lower 48 States)

Major Land Use	Land Area Million ha	Land Area % of Total
Agricultural		
Cropland	191.1	20.8
Grassland pasture and range	244.6	26.7
Forest land grazed	80.1	8.7
Farmstead, farm roads	4.6	0.5
Total agricultural land	520.4	56.7
Non-Agricultural		
Forest land not grazed	212.6	23.2
Special uses[b]	68.4	7.5
Miscellaneous[c]	114.6	12.4
Mining, 1930-71[d]	1.5	0.2
Total non-agricultural land	397.1	43.3
Total land area	917.5	100.0

a/ From Paone, Struthers and Johnson, 1978.

b/ Special uses include land for development of urban areas, recreation and wildlife, transportation networks, and public installations and facilities.

c/ Miscellaneous uses include uninventoried land and areas of little or no use such as marshes, swamps, tundra, desert, etc.

d/ Mining areas include both surface mining (open pit, strip mining, dredging, and hydraulic mining) and underground mining.

runoff, soil erosion and other problems. In 1969 cropland, pasture and range-land represented nearly 50% and forested land (both grazed and ungrazed) over 30% of the total land area of over 2.2 billion acres (917 million ha) in the lower 48 States (Table 3-12). Overall, non-agricultural land uses including mining, non-grazed forest land, urban development, recreation and wildlife, transportation networks, public installations and facilities represented over 40% of this large land area.

Prime areas where municipal wastewater and sludge could be effectively utilized and treated as a part of land reclamation and biomass production projects would include: surface mines, mine tailing, borrow pits, quarries, etc.; clear cut, burned and low production forest areas; and dredge spoils, fly ash, highway corridors, rights-of-way, construction sites, and other disturbed lands or areas of poor productivity. These areas are located throughout the county and for the most part are readily accessible to sources of municipal sludges (and to a lesser extent municipal wastewater) by available major transportation routes. Although transport costs and public acceptance/institutional constraints can play a major role in limiting the potential use of these materials for land reclamation and biomass production purposes, opportunities exist to establish local demonstration projects and backhaul arrangements to help improve public acceptance and establish

cost-effective transport of municipal wastewater or sludge to strip mines, forests, etc. Ideally, federal and State owned and controlled lands as well as private lands could become involved in projects for treating and recycling municipal wastewater and sludge through land reclamation and biomass production.

The potential for tie-ins between urban areas which produce municipal wastewater and sludge (in quantities somewhat proportional to their population) and prime areas where these misplaced resources could be used for land reclamation and biomass production can be envisioned by comparison of maps in an atlas depicting urbanized areas, strip mines, commercial forests, and government-owned or -administered lands, plus the major transportation routes between these areas. A simple comparison of municipal wastewater and sludge sources (i.e., the urban areas), the location of federal lands and forests, available transportation systems, abandoned coal mine areas and coal reserves would suggest a good potential exists for creating projects to reuse municipal wastewater and sludge in the reclamation of abandoned and active coal mine areas, to revegetate areas ravaged by forest fires, and even to produce biomass on federal lands where they can be developed in a publicly acceptable manner and demonstrated to be both cost effective and environmentally acceptable. The possibilities for establishing backhaul arrangements to transport sludge to active coal mine areas also appear to be substantial.

Surface Mines, Mine Tailings, Borrow Pits, Quarries, etc.

Disturbed land can result from both surface and underground mining practices. Mining occurs in all States and although the acreage disturbed is a small percentage of the total national land area (Table 3-13), it is geographically concentrated and can result in major water quality problems, as well as physical and esthetic impacts upon the environment. The effects of acid mine drainage, surface runoff and erosion have created serious water pollution and land degradation problems which have contributed to the overall economic hardships of many local mining communities, especially after mining activities have ceased (24,25,29,30,37).

A Bureau of Mines survey revealed that the U.S. mining industry disturbed over 3.65 million acres (1.48 million ha) in the 41 year period between 1930-1971, while reclaiming 40% of this area (Table 3-13). In 1971 alone, 206,000 acres (83,000 ha) were mined and 163,000 acres (66,000 ha) reclaimed (2). While nearly 80% of the total area disturbed was associated with surface mining (either excavation or overburden and refuse disposal), 95% of the area reclaimed was previously disturbed by stripmining activity. About 13% of the area disturbed and 3% of the area reclaimed were associated with disposal of milling and processing wastes, while areas used for disposal of underground mine wastes accounted for 5% of the area disturbed and less than 2% of the area reclaimed. On a commodity basis,

Table 3-13. Land Utilized and Reclaimed by the Mining Industry in the U.S., 1930-71.[a]

	Area in ha, by type of commodity							
	Metals		Non-Metals		Fossil Fuels b/		Total	
Type of Activity	Mined	Reclaimed	Mined	Reclaimed	Mined	Reclaimed	Mined	Reclaimed
Surface mining excavation	58,700	7,040	429,000	102,000	391,000	290,000	879,000	399,000
Overburden and refuse disposal from surface mining	49,800	2,130	118,000	52,200	129,000	108,000	297,000	162,000
Subsidence and disturbance from underground mining	4,940	720	1,850	40	35,600	1,620	42,400	2,400
Disposal of refuse from underground mining	8,860	610	846	70	67,200	8,090	76,900	8,770
Disposal of wastes from milling and processing	89,400	7,000	81,300	9,430	12,900	2,620	184,000	19,100
TOTAL c/	212,00	17,500	631,000	104,000	635,000	410,000	1,480,000 (3.65 million acres)	591,000 (1.46 million acres)

a/ From Paone, Struthers and Johnson, 1978.

b/ Excludes oil and gas exploration.

c/ Data may not add to totals shown because of independent rounding.

Table 3-14. Commodities Surface Mined in 1975.[a]

Crude ore commodity	Millions short tons	Recovered by surface mining
Clay	43	98%
Phosphate rock	186	100%
Sand and gravel	789	100%
Stone	867	96%
Copper	240	89%
Iron ore	230	96%
Bituminous coal	356	55%
All other commodities	95	50%
	2,806	86%

a/ Data from USDA/SCS. 1977. The Status of Land Disturbed by Surface Mining in the U.S.; Basic Statistics by State and County as of July 1, 1977. SCS-TP-158.

the Bureau of Mines study indicated the following breakdown of land used for mining between 1930-1971:

Bituminuous Coal	40%
Sand and Gravel	18%
Stone	14%
Clay	5%
Copper	5%
Iron Ore	3%
Phosphate Rock	2%
Other Minerals	13%

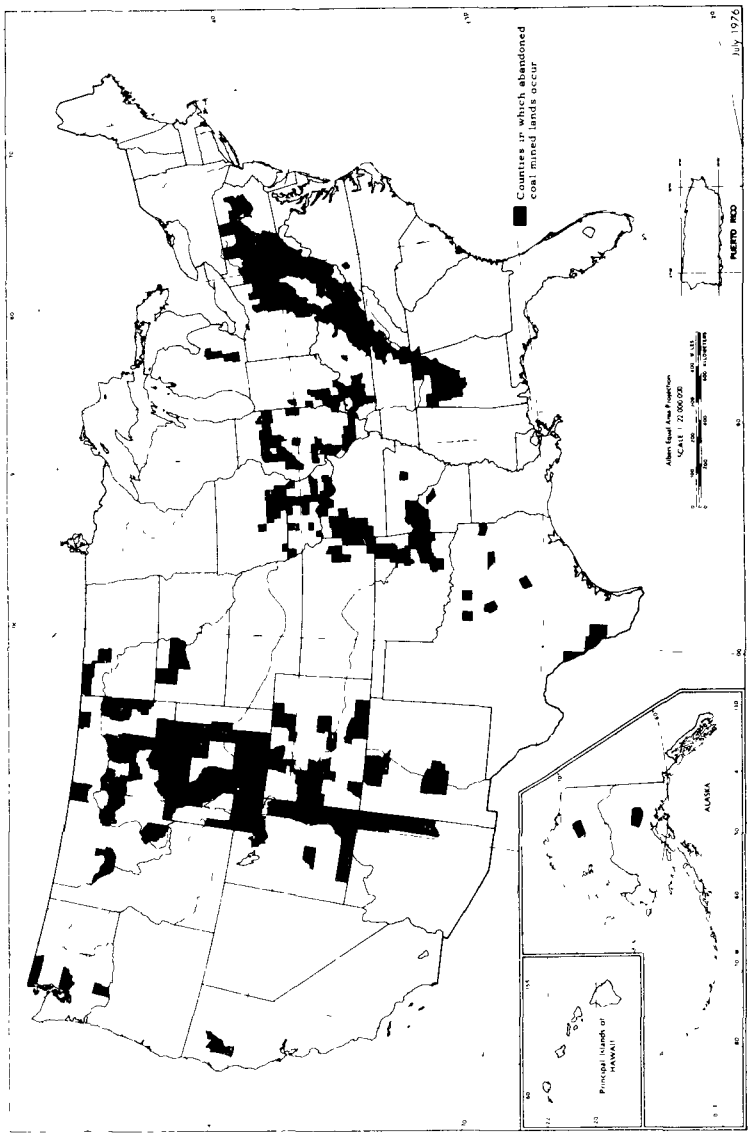
The principal legislative and technical experience in reclaiming disturbed land has centered on surface mine lands, especially lands strip mined for coal (27.28). In 1975, surface mining accounted for about 96% of the domestic production of non-metallic ores (29) 88% of the metallic ores, and 55% of coal (Table 3-14). In a survey report on the status of land disturbed by surface mining in the U.S., the Soil Conservation Service (SCS) estimated that as of July 1, 1977, the mineral industry had disturbed over 5.7 million acres (2.3 million ha) in the U.S. (Table 3-15). This estimate included land disturbed by all mining of subsurface resources by removing overburden lying above natural mineral deposits, mining directly from exposed natural mineral deposits and underground mining with significant effects on the surface.

The 1977 SCS survey (29) of surface mined land found that there was no legal requirement to reclaim some 2.7 million acres (1.1 million ha) of the unreclaimed mined lands (i.e., abandoned or orphaned mine lands), including about 1.1 million acres (.5 million ha) affected by coal mines, (Map 3-2) 800,000 acres (320,000 ha) affected by sand and gravel mining and another 800,000 acres (320,000 ha) affected by other types of mining. However, acid runoff from many of the abandoned coal mines has resulted

Table 3-15. Status of Land Disturbed by Surface Mining in the United States from January 1, 1965, to July 1, 1977.[a] (Thousands of acres)

Status of mined land	1965	1972	1974	1977
Land requiring reclamation.....	2,040.6	2,181.2	2,542.7	3,821.6
Land not requiring reclamation.....	1,147.2	1,823.7	1,876.0	1,898.2
Total land disturbed....	3,187.8	4,004.9	4,418.7	5,719.8

a/ Data from USDA/SCS. 1977. The Status of Land Disturbed by Surface Mining in the U.S.; Basic Statistics by State and County as of July 1, 1977. SCS-TP-158.



Map 3-2. General Location—Abandoned Coal Mined Lands.

in particularly troublesome water quality problems. Pennsylvania, Ohio, Kentucky and Illinois each were found to have over 100,000 acres (40,000 ha) and West Virginia, Alabama and Missouri over 50,000 acres (20,000 ha) of unreclaimed coal mine land. These same States and several others also were found to have large acreages of coal mined land that did require reclamation by State law. This same survey found that Florida had over 200,000 acres (80,000 ha) of unreclaimed land that had been mined for phosphate or other commodities (Table 3-16).

Estimates of acreage and status of land disturbed by surface mining on an annual basis apparently is not well documented. The Department of the Interior (30), however, did estimate that 153,000 acres of land were disturbed during 1964 by surface and strip mining, in the following categories:

Sand and Gravel	60,000 acres	39.2%
Coal	46,000 acres	30.1%
Stone	21,000 acres	13.7%
Clay	9,000 acres	5.9%
Phosphate Rock	8,000 acres	5.9%
Other Minerals	8,000 acres	5.2%
	152,000 acres	100.0%

The more recent SCS (29) attempt to depict the nationwide changes in the status of surface mined land between 1965 and 1977 is shown in Table 3-15. This indicates an average rate of land disturbance of over 200,000 acres (80,000 ha) per year, with only a limited acreage being reclaimed until after 1974 when guidelines on reclamation requirements became much more stringent in many areas.

Recent articles in the Wall Street Journal and Washington Post note the following statistics about coal production and usage:

1. Coal currently provides 25% of the world's energy,
2. Today the U.S. gets about 19% of its energy from coal,
3. Two-thirds of the world's energy needed to fuel economic growth over the next 20 years could be supplied by coal if production triples and exports expand,
4. In 1947 the U.S. produced 630 million tons of coal, but by 1961 production dropped to 402 million tons due to readily available and cheap oil; the 1973-74 Arab oil embargo triggered the 1975 coal production in the U.S. to exceed the 1947 levels,
5. By 1979 the U.S. produced 776 million tons of coal and in 1980 is projected to produce 825 million tons,
6. In 1979 there were 5,534 coal mining operations in the U.S., down from the 8,000 in the mid-50's; a further 15% decline is expected during 1980 as large operations become more dominant in this industry,
7. The U.S.G.S. lists known recoverable coal reserves in the U.S. at

Table 3-16. Status of Land Disturbed by Surface Mining in the United States as of July 1, 1977 by States.[a]

Land Needing Reclamation (acres; dashes indicate none)

State	Reclamation not required by any law			Reclamation required by law				
	Coal mines	Sand and gravel	Other mined areas	Coal mines	Sand and gravel	Other mined areas	Land not requiring reclamation	Total land disturbed
Alabama.....	72,292	16,611	19,929	34,807	5,498	6,252	85,673	241,062
*Alaska.....	2,700	4,300	4,000	---	---	---	4,000	15,000
*Arizona.....	400	6,400	60,900	---	---	---	121,800	189,500
Arkansas.....	5,623	21,483	11,479	2,859	20	1,592	9,449	52,505
California.....	10	7,970	80,998	500	17,642	51,316	59,061	217,497
Caribbean Area..	---	2,550	1,000	---	---	---	710	4,260
Colorado.....	7,089	8,334	15,861	1,195	11,672	6,513	14,023	64,687
*Connecticut....	---	16,740	787	---	---	---	4,590	22,117
Delaware.....	---	2,912	63	---	---	---	1,498	4,473
Florida.....	---	11,162	235,700	---	3,365	20,922	61,266	332,415
Georgia.....	1,680	3,353	24,008	764	4,623	13,772	23,247	71,447
Hawaii.....	---	15	115	---	---	---	---	130
Idaho.....	---	5,100	1,500	---	18,200	3,500	2,500	30,800
Illinois.....	118,711	20,330	14,192	40,899	8,582	4,557	88,860	296,131
Indiana.....	25,882	11,875	6,522	74,581	4,176	1,894	64,711	189,641
Iowa.....	13,997	10,147	6,421	341	8,457	9,638	10,519	59,520
Kansas.....	41,256	11,150	10,159	815	3,634	3,980	20,117	91,109
Kentucky.....	101,637	980	4,712	154,218	2,299	2,780	154,495	421,121
*Louisiana.....	---	37,324	2,549	---	---	---	10,467	50,340
Maine.....	---	28,833	2,075	---	2,293	923	6,794	40,918
Maryland.....	6,412	7,430	1,181	5,703	9,741	1,734	19,824	52,025
*Massachusetts..	---	32,041	10,330	---	---	---	11,750	54,121
Michigan.....	142	39,424	23,422	---	15,662	4,072	27,600	110,322
Minnesota.....	---	30,047	44,801	---	12,444	7,891	66,919	162,102
Mississippi.....	---	45,966	7,821	---	---	---	14,415	68,202

Table 3-16. (Continued)

(Acres; dashes indicate none)

State	Reclamation not required by any law			Reclamation required by law				
	Coal mines	Sand and gravel	Other mined areas	Coal mines	Sand and gravel	Other mined areas	Land not requiring reclamation	Total land disturbed
Missouri.....	70,688	4,473	28,187	8,772	1,046	6,055	22,051	141,272
Montana.....	1,955	4,655	18,340	4,766	4,492	6,598	12,528	53,334
*Nebraska.....	---	17,969	4,029	---	---	---	11,005	33,003
*Nevada.....	---	1,221	2,555	---	---	---	1,953	5,729
*New Hampshire..	---	12,725	417	---	---	---	547	13,689
*New Jersey.....	---	24,610	5,570	---	---	---	8,263	38,443
New Mexico.....	22	11,860	1,806	3,709	1,057	26,072	2,207	46,733
New York.....	---	30,917	19,251	---	15,979	5,037	18,477	89,661
North Carolina..	---	11,908	4,792	---	7,096	3,909	7,000	34,705
North Dakota....	1,050	2,010	200	6,725	---	---	38,595	48,580
Ohio.....	196,709	22,621	18,923	77,050	16,659	8,427	190,578	530,967
Oklahoma.....	36,118	6,659	14,105	6,298	2,766	4,110	16,255	86,311
Oregon.....	---	3,521	17,568	3	6,814	1,538	7,387	36,831
Pennsylvania....	240,000	11,000	20,500	60,000	15,000	25,000	250,000	621,500
*Rhode Island...	---	2,592	---	---	---	---	3,470	6,062
South Carolina..	---	9,065	2,128	---	4,395	3,194	9,815	28,597
South Dakota...	890	10,153	5,259	---	6,826	695	7,149	30,972
Tennessee.....	29,583	4,950	2,305	3,127	810	1,135	104,596	146,506
Texas.....	3,310	152,457	37,104	3,725	6,289	4,989	48,456	256,330
Utah.....	635	3,999	4,414	133	4,637	10,216	7,521	31,555
Vermont.....	---	3,877	2,078	---	377	60	1,536	7,928

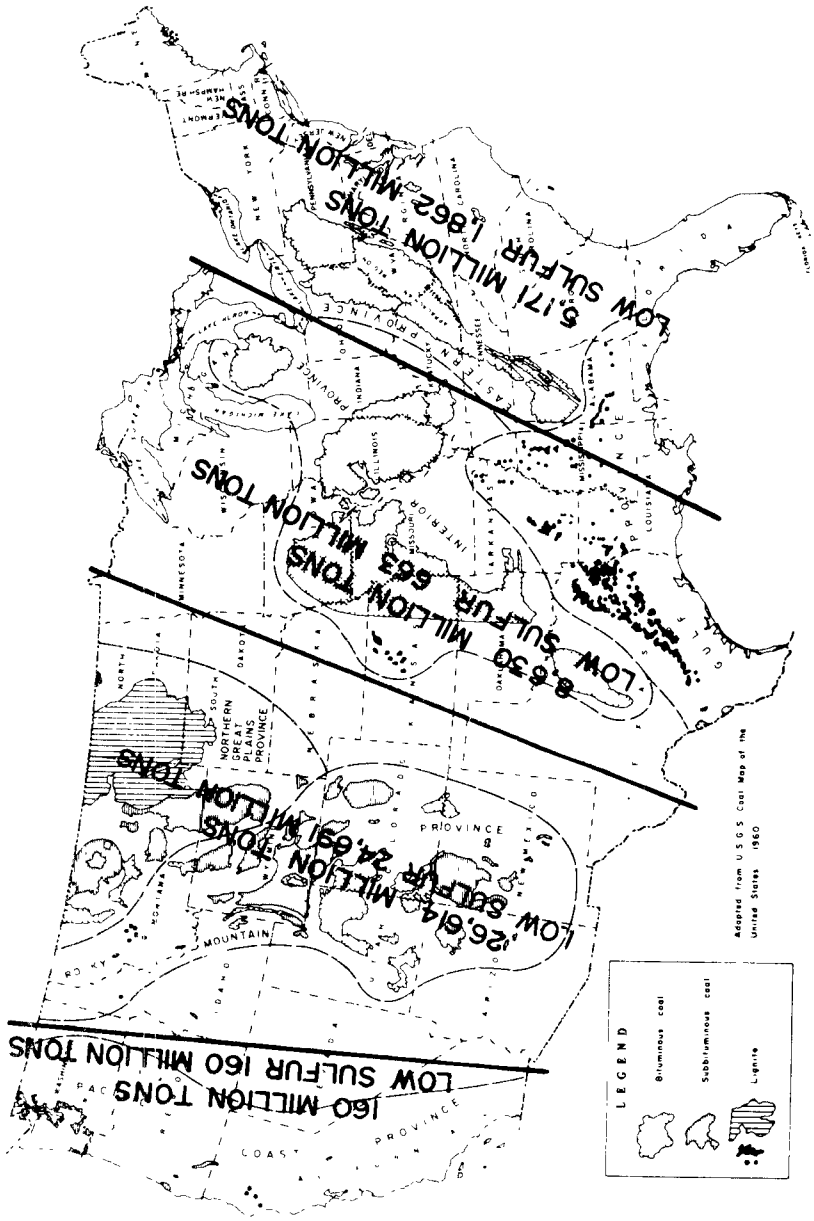
Table 3-16. (Continued)

(Acres; dashes indicate none)

State	Reclamation not required by any law			Reclamation required by law				
	Coal mines	Sand and gravel	Other mined areas	Coal mines	Sand and gravel	Other mined areas	Land not requiring reclamation	Total land disturbed
Virginia.....	23,724	3,788	1,251	8,222	3,929	2,003	70,060	112,977
Washington.....	48	9,701	8,174	1,190	11,822	1,073	10,245	42,253
West Virginia...	84,868	4,554	995	7,658	---	---	137,105	235,180
Wisconsin.....	---	41,607	7,555	---	11,884	2,865	21,605	85,516
Wyoming.....	9,657	3,673	12,376	62,028	7,665	12,787	5,511	113,697
TOTAL	1,097,088	799,042	830,407	570,088	257,851	267,097	1,898,203	5,719,776

a/ From USDA, 1980. Soil and Water Resource Conservation Act: Appraisal 80. Review Draft. Part I.

* No State law when survey completed; therefore, no reclamation by law.



Map 3-3. Strippable Coal Reserves of the Conterminous United States, by Region.

a total of 225 billion tons, of which nearly three-quarters are located on federally administered lands in the west (Map 3-3),

8. The National Coal Association claims that the U.S. currently has an excess coal production capacity of 100 million tons and that the total U.S. coal production could be doubled in 10 years; they also claim that as much as 1.79 trillion tons of coal may ultimately be recoverable in the U.S.

In conjunction with "Project Independence," the Bureau of Mines has projected the amount of land that will be used by the surface coal mining industry (Table 3-17) (27). In addition, future commercial scale development of synfuels from oil shale and tar sands could result in extensive areas of disturbance and literally mountains of residuals requiring reclamation and stabilization in Utah, Colorado, Wyoming, California, New Mexico, Texas, Kentucky, Alabama, and possibly other states (31). Spent shale from surface retorting of oil shale produces about 0.9 metric tons (1 short ton) of waste for each 159 liters (1 barrel) of oil produced. Therefore, each of the 16 million liter (100,000 barrel) per day surface retorting operations that have been proposed for Colorado and Utah oil shale development would generate enough spent shale to fill a canyon 600 m (~2000ft) wide, 60 m (~200ft) deep, and 16 km (~10 mi) long each day (32)! These and other sources of information would suggest a continuing availability of large acreages of land disturbed by mining or mineral-processing activities where municipal wastewater and sludge could potentially be utilized as a part of land reclamation, stabilization, and revegetation efforts.

Table 3-17. Projected Regional Land Use for Coal Production from Surface Mining.[a]

	Area in ha, by year				
Region	1975	1977	1980	1985	1990
Northern Appalachia	8,000	8,300	9,400	10,800	14,000
Southern Appalachia	5,500	5,700	6,800	8,500	10,300
Midwest	7,200	7,400	8,300	9,900	11,700
Gulf	800	1,400	3,900	5,800	7,200
Northern Great Plains	400	500	600	900	1,100
Rocky Mountain	500	600	600	700	900
Pacific Coast	600	800	1,200	1,900	2,200
TOTAL [b]	23,000	25,000	31,000	39,000	47,000

a/ From Paone, Struthers and Johnson, 1978.

b/ Data may not add to totals because of independent rounding.

Clearcut, Burned and Low Production Forest Areas

The use of wood and other forms of biomass as an alternative energy source to replace diminishing supplies of oil and natural gas is growing in many parts of the U.S. Past projections have shown a potential for economical use of various forms of biomass based upon increased oil and gas prices (34). However, a recent overview of the U.S. potentials for solar biomass energy judged that the harvest of cropland residues for their energy value, the use of large-scale production of electricity and synthetic fuels, and the resubstitution of natural products for petroleum-based synthetics were not highly appropriate directions for the U.S. to take as a whole in meeting future energy requirements (36). This same review article, on the other hand, did suggest that considerable opportunities exist to use biomass residues and improved management practices to increase forest growth and production rates in millions of acres of productive forest land.

In recent years there has been a growing interest in the potential for increasing productivity in managed forests through fertilization, irrigation and other more intensive tree farming practices (23,35,37). The use of municipal wastewater and sewage sludge to help shorten wood production cycles and increase production (especially on marginally productive soils) as well as to revegetate and stabilize areas that have been clearcut or devastated by forest fires could play an important role in achieving increased forest productivity, at least in certain locations (23).

The area classified by the U.S. Department of Agriculture (29) as forest land occupies about 662 million acres (265 million ha); over 285 million acres (114 million ha) of federally controlled and 376 million acres (150 million ha) of non-federal forest land (Table 3-18). About 75% of the commercial non-federal forest land is primarily under control of farmers and other private owners (commercial forest land is forest land that produces or can produce more than twenty cubic feet per acre per year of industrial wood under proper management and has not been withdrawn from timber production). Industry owns nearly 18% of this land while State, county and municipal governments own about 8% (Table 3-19). Nearly 30% of the noncommercial forest land is in non-federal ownership. The largest part of this acreage is held by farmers and other private owners. There are an estimated 4 million private owners of noncommercial forest land, with 72% of the holdings at 500 acres or less (29,32).

Large acreages of forest are harvested or devastated by forest fires, land slides or other natural disasters each year which require reforestation if full production or recovery is desired within a reasonably short time. The National Forest System, which occupies some 187 million acres (75 million ha) and harvested well over 10 million board feet of lumber in fiscal year 1979 alone, had over 1.6 million acres (.6 million ha) in FY 79 requiring reforestation (33). USDA/Forest Service manages a cooperative fire protection program that currently provides fire protection for about 197

Table 3-18. Federal and Non-federal Forest Land in 1977, By Regions, Subregions, and States.[a]

	Federal	Non-federal	Total
		(1,000 acres)	
North			
Northeast			
Connecticut	2	1,418	1,420
Delaware	5	360	365
Maine	228	16,520	16,748
Maryland	155	2,160	2,315
Massachusetts	60	2,756	2,816
New Hampshire	694	3,976	4,670
New Jersey	94	1,967	2,061
New York	200	15,445	15,645
Pennsylvania	557	14,349	14,906
Rhode Island	7	303	310
Vermont	275	3,931	4,206
West Virginia	964	9,805	10,769
Total	3,241	72,990	76,231
North Central			
Illinois	340	3,026	3,366
Indiana	364	3,533	3,897
Iowa	26	1,483	1,509
Michigan	3,358	15,322	18,680
Minnesota	2,980	13,807	16,787
Missouri	1,414	10,829	12,243
Ohio	206	5,860	6,066
Wisconsin	1,642	13,252	14,894
Total	10,330	67,112	77,442
Total for North	13,571	140,102	153,673
South			
Southeast			
Florida	2,319	12,146	14,465
Georgia	1,498	21,567	23,065
North Carolina	1,825	16,818	18,643
South Carolina	757	10,770	11,527
Virginia	2,081	13,237	15,318
Total	8,480	74,538	83,018
South Central			
Alabama	840	19,792	20,632
Arkansas	2,661	14,069	16,730
Kentucky	936	10,645	11,581
Louisiana	740	12,594	13,334
Mississippi	1,299	14,416	15,715
Oklahoma	323	4,933	5,256
Tennessee	1,061	11,639	12,700
Texas	807	9,240	10,047
Total	8,667	97,328	105,995
Total for South	17,147	171,866	189,013

Table 3-18. (Continued)

	Federal	Non-federal	Total
		(1,000 acres)	
Rocky Mountain and Great Plains			
Great Plains			
Kansas	786	857	857
Nebraska	45	439	484
North Dakota	35	368	403
South Dakota	1,057	333	1,390
Total	1,208	1,926	3,134
Rocky Mountains			
Arizona	9,853	1,804	11,657
Colorado	14,961	3,343	18,304
Idaho	16,978	4,229	21,207
Montana	16,324	6,343	22,667
Nevada	5,352	229	5,581
New Mexico	10,559	3,426	13,985
Utah	11,446	1,066	12,512
Wyoming	8,523	1,163	9,686
Total	93,996	21,603	115,599
Total for Rocky Mountain and Great Plains	95,204	23,529	118,733
Pacific Coast			
Pacific Northwest			
Alaska	112,245	6,900	119,145
Oregon	18,698	10,062	28,760
Washington	9,474	12,413	21,887
Total	140,417	29,375	169,792
Pacific Southwest			
California	18,819	9,857	28,676
Hawaii	0	1,443	1,443
Total	18,819	11,300	30,119
Total for Pacific Coast	159,236	40,675	199,911
Caribbean	28	428	456
Total for United States and Caribbean	285,186	376,600	661,786

[a] From USDA, 1980. Soil and Water Resource Conservation Act: Appraisal 80. Review Draft. Part I.

Table 3-19. Commercial Forest Land Acreage and Ownership for 1974 [a]

Area	Acreage	Land Ownership (10^6 acres) Federal	State and Local	Industry	Farm	Private
Northeast	177.9	12.3	19.6	17.6	51.0	77.4
Southeast	192.5	14.6	3.0	35.3	65.1	74.8
West	129.3	80.6	6.4	14.4	15.0	12.8
Total	499.5	107.5 (21.4%)	29.0 (5.8%)	67.3 (13.5%)	131.1 (26.2%)	165.0 (33.0%)

a/ Data from U.S. Forest Service. 1974. Forest Resources Report and C.C. Burnwell SCIENCE Vol. 199:4041-1048.

million acres (79 million ha) of federal, State and private owned timber or forest producing lands or watershed from which water is secured for domestic use or irrigation (39). While there has been more than a 90% reduction since 1924 in losses to fires on forested and unforested land protected under this cooperative program—from 93,112 acres burned per million acres protected in 1925 to 1,208 acres burned per million acres protected in 1978 (38)—large acreages of forested and nonforested land are still devastated by wild fires each year. In 1979 alone, wildland fires burned 3% of the acres protected by the USDA/Forest Service (33,40)

Earthquakes, land slides and other natural disasters also can destroy large acreages, generally on a localized basis. The May 18, 1980, eruption of Mt. St. Helens alone resulted in severe damage and destruction to more than 150,600 acres of forested land within the blast zone (41). While sometimes occurring in many sites of small acreages, it would appear that a continuing supply of available forested areas disturbed by harvesting and natural disasters will be available as possible sites where municipal wastewater and sludge could be both treated and used beneficially as a part of forest land stabilization and reforestation activities as well as efforts to increase forest productivity and shorten wood production cycles.

Dredged Material, Fly Ash, Highway Corridors, Rights of Way, Construction Sites and Other Disturbed Lands or Areas of Poor Productivity

In addition to mining and forestry related activities, there is also considerable potential for the use (and treatment) of municipal wastewater and sludge by application to many other types of disturbed land or areas of poor productivity.

Dredged Material. Around $300 million are required each year to dredge

some 340 million m^3 (442 million cu yd) of bottom sediments in an effort to maintain almost 40,000 km (24,000 mi) of waterways and 1,000 harbors. An additional 60 million m^3 (78 million cu yd) of sediment are removed to develop new projects (42,43). Historically on a basis of economics, about two third of the dredged materials were deposited in open water disposal sites. Recent environmental laws and regulations, however, have placed restrictions on the open water disposal of the more polluted dredge materials resulting in more disposal in diked containment or on-land areas involving around 28 million m^2 (7,000 acres) per year (44). Many sites where dredged spoils have been deposited in the past have resulted in areas that are highly acidic (pH 3.0), low in organic matter and fertility. Such areas have been easily eroded and difficult to stabilize and revegetate, and often contribute significantly to the water quality and sediment load problems of nearby waterways–in some cases the very areas from which the materials were originally dredged.

Although dredged materials have been used successfully for a number of productive purposes, such as the development of offshore islands, manufacture of construction materials, and even land reclamation activities (42,43,45,46) there will probably be considerably more land disposal of dredged material in future years. Municipal sewage sludge has already been effectively used to help stabilize and revegetate acidic dredge spoils along the Chesapeake and Delaware Canal (47). The opportunity for more use of municipal wastewater and sludge to help stabilize and revegetate sites used for land disposal of dredged material will most likely increase.

Fly Ash. Like dredged materials, the disposal of fly ash, cinders, and bottom ash which are produced in large quantities by coal fired power plants has also become a major problem in many parts of the country. Since the end of World War II, nearly 700 million metric tons (770 million short tons) of ash may have accumulated in the U.S. (48). In 1977, approximately 62 million metric tons (68.2 short tons) of ash and 2.5 million metric tons (2.75 million short tons) of flue gas desulfurization sludge were produced by approximately 400 power plants producing some 200,000 MW of power. It has been estimated that new coal fired power plants coming on line by 1985 will increase this total to 70 million metric tons (77 million short tons) of ash and 10 million metric tons (11 million short tons) of flue gas desulfurization sludge per year (49).

Typically these materials have been disposed of on land as a waste in numerous landfills, pits, ponds and piles, although like dredged materials fly ash has been successfully utilized in a variety of productive activities (48). While fly ash does contain many of the elements essential for plant growth and has been effectively used as a soil amendment source of CaO, K_2O, P_2O_5, fine sand and silt, it lacks any nitrogen. Some work is currently underway in Ohio to evaluate the use of municipal sludge to enhance the

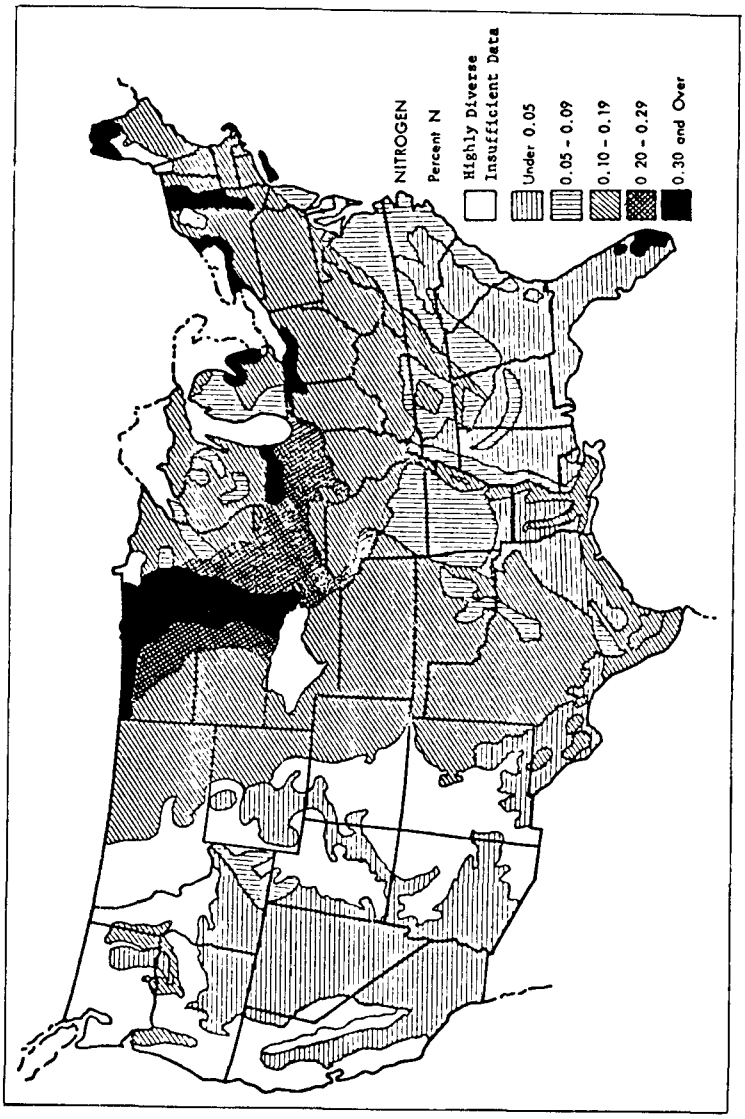
value of fly ash in reclaiming strip mine spoils. Certainly there will be an ever growing potential for the use of municipal wastewater and sludge to help stabilize fly ash disposal sites as the use of coal increases in power production for major urban areas.

Highway Corridors, Rights of Way, Construction Sites and Other Disturbed Lands or Areas of Poor Productivity. The nearly 6.4 million km (4 million miles) of public roads and highways in the U.S. occupy over 10.4 million ha (26 million acres) of land. Most high speed and limited access highways have wide rights of ways on both sides. Many more millions of acres of land are occupied by railroads, transmission lines, etc. involving rights of ways, that along with areas of new development can involve considerable land disturbance by construction and maintenance activities. In addition, many areas of the country have soils of low productivity due to limited nutrient and/or organic matter content (See Maps 3-4 and 3-5).

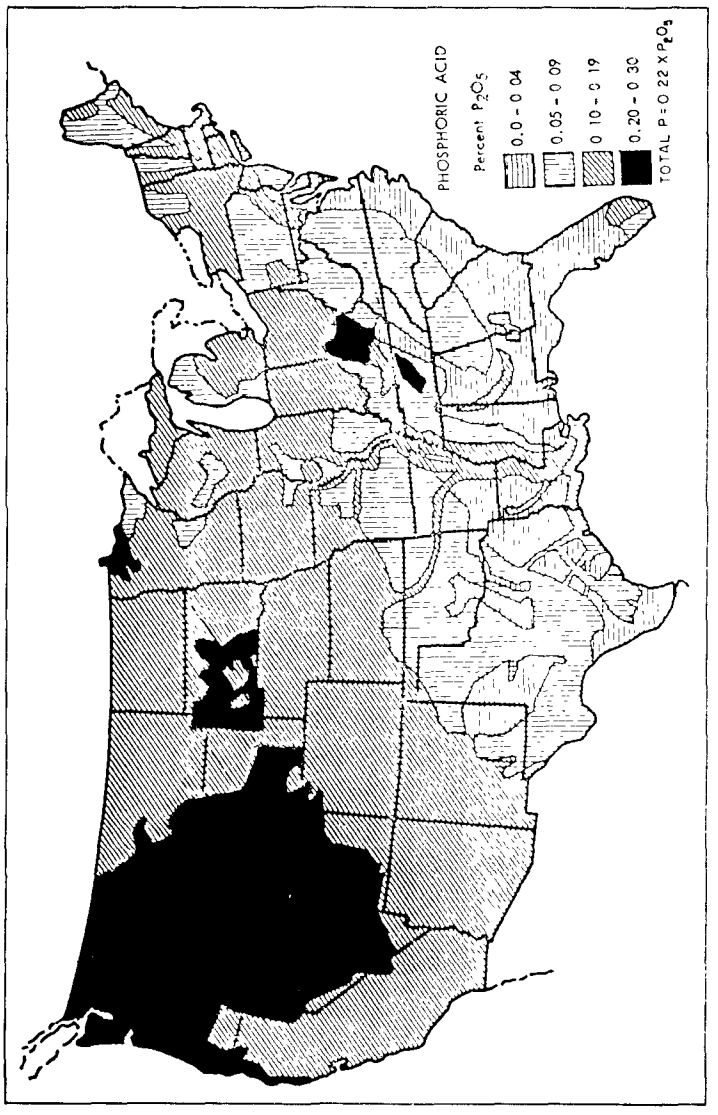
The construction and maintenance of highway corridors and other rights-of-way as well as construction activities at major development sites frequently lead to environmental impacts such as conditions of poor soil stability and severe water and wind erosion due to the disturbance of natural contours, drainage areas and climax vegetation (50,51). The same effect has often resulted from poor farming, ranching and forestry practices in areas with poor soils. The vast amounts of experience gained from dealing with these problems in the past had led to a number of basic procedures for arresting erosion from construction, farming, forestry, and other activities in areas of poor soils. These procedures include such practices as proper grading of slopes, use of specialized drainage, tillage and planting techniques, and addition of topsoil, soil amendments, mulches, use of nets and binders, and special fertilization and maintenance practices (50,51,52,53,54,55). Again, some efforts have been made to utilize municipal wastewater and sludge in stabilizing construction sites (56,57), building in part upon the more extensive experience in using these materials for agriculture, mine land reclamation and biomass production purposes.

Major Benefits and Problems Facing Land Reclamation and Biomass Projects Involving Municipal Wastewater and Sludge

Past efforts in reclaiming strip mined areas and other disturbed lands have met with mixed results. Considerable detailed information is available on the planning, economics, social and legal aspects as well as engineering and other technical requirements of land reclamation practices. A number of recent publications have done an excellent job of reviewing the needs for, benefits derived, and state-of-the-art practices for reclaiming and revegetating various types of disturbed lands (24,25,58,59). These references cover a wide range of land reclamation and revegetation practices that are appropriate for humid and arid regions, as well as presenting a review of recent research results. Taken together they address the reclamation and revegetation of



Map 3-4. Percent Nitrogen in Surface Foot of Soil.



Map 3-5. Percent Phosphorus in Surface Foot of Soil.

many types of disturbed lands (e.g., mined land, mine tailings and overburden, sand and gravel pits, borrow pits, dredged material, fly ash, etc.) in a rather comprehensive manner. The potential use of municipal wastewater and sewage sludge as sources of irrigation water, mulch, nutrients, organic soil amendments and conditioners are frequently mentioned in these and other related publications.

Actual project experience under a wide variety of conditions has clearly demonstrated that when properly managed sewage sludge and municipal wastewater can be safely and effectively used in land reclamation and biomass production/reforestation efforts. The severe soil conditions often associated with abandoned or orphan mine spoils, including lack of nutrients and organic matter, low pH, low water holding capacity, toxic levels of heavy metals and poor physical characteristics have frequently negated even repeated efforts to revegetate such areas when using conventional reclamation practices. But projects utilizing both liquid and dewatered or composted sewage sludge as an organic soil amendment and slow release nutrient source have successfully reclaimed and revegetated such barren mine land sites. Improved erosion control, soil structure and biomass production have all been achieved by reclamation and revegetation projects using municipal wastewater and sewage sludge on naturally unproductive or disturbed areas as well as sites degraded by man as a result of farming, mining, smelting, construction, forestry and waste disposal activities. Municipal wastewater and sewage sludge have also been effectively used in arid areas and for combatting desertification problems on a limited scale.

Obviously adequate controls must be placed on how municipal wastewater and sewage sludge are used to avoid possible odors and other nuisances, and contamination of workers, soil, crops, surface water or groundwater. Efforts to develop regulations and technical guidance, design manuals, etc. to cover the many uses of municipal wastewater and sewage sludge are well in hand although far from complete (4,5,6,7,8,9,10,15,20,22,23,61). However, the major problems restricting greater use of these materials in land reclamation and biomass production/reforestation projects also include serious transportation/distribution constraints as well as the numerous public acceptance and institutional constraints that face all land application practices. Getting the wastewater or sludge from its point of generation to an area where it can be utilized is often a complex and expensive matter. Even potentially cost effective arrangements for backhauling sewage sludge from a city to mining areas in the same rail cars or trucks that are used to transport coal into the city must deal with loading/unloading delays, weather complications, and equipment availability and compatability problems (60). In addition, wastewater or sludge delivery, on-site storage, and timing of applications to the land can lead to complications if the reclamation site is located in an area of active mining, construction, or other

on-going activity.

The use and treatment of municipal wastewater and sewage sludge in land reclamation and biomass production/reforestation projects provides a special opportunity to avoid many of the concerns associated with agricultural uses of these materials while helping to deal with many of the problems associated with areas that are marginally productive and in need of reclamation, stabilization and revegetation. Neither the technological problems of designing and operating land application systems nor the public acceptance and institutional constraints facing their implementation should prevent increased future use of municipal wastewater and sewage sludge in land reclamation and biomass production/reforestation projects. Where these systems can be made to work, they should offer effective solutions to the need for cost-effective and environmentally acceptable waste management practices. In order to assist the encouragement of greater use of such systems we need to make sure that the results of past and ongoing full scale operational projects as well as research and demonstration efforts are more seriously considered by communities and their consultants when evaluating which waste management options are most suitable for their problems.

APPENDIX: Pertinent Legislation Concerning Sludge and Wastewater Utilization

Federal Water Pollution Control Act as amended in 1972 (PL 92-500) and 1977 (PL 95-217) focuses on the restoration and maintenance of the chemical, physical and biological integrity of the Nation's waters. Research standards and enforcement, water quality planning and construction grant program authorities are included which center on the control of both point or nonpoint discharge sources of water pollution. CWA authorizes federal funding for the planning, design and construction of publicly owned wastewater treatment works (POTWs) including sludge management facilities. It also authorizes the issuance of comprehensive sewage sludge management guidelines and regulations, the issuance of National Pollutant Discharge Elimination System (NPDES) permits for point source discharges, and the development of areawide waste treatment management plans including best management practices (BMPs) for non-point sources of water pollution and requires the development and implementation of pretreatment standards for industrial discharges into POTWs. The 1977 amendments added several important waste management provisions including special incentives for greater use of innovative and alternative waste treatment technologies and methodologies, broad authority to regulate sewage sludge management practices, and pretreatment credits for industrial dischargers to POTWs.

The Resource Conservation and Recovery Act of 1976 (PL 94-580) focuses on the regulation of "discarded materials" management practices

protect human health and the environment while promoting the conservation and recovery of resources from solid wastes. Technical and financial assistance, training grants, solid waste planning, resource recovery demonstration assistance and hazardous waste regulatory program authorities are included. RCRA provides for technical and financial assistance to State, local and interstate agencies for the development of solid waste management plans and training grants in occupations involving solid waste management systems. It also prohibits future open dumping of any wastes, and authorizes regulating the treatment, storage, transport, and disposal of hazardous wastes which have adverse effects on health and the environment, promotes a national R&D program for improving solid waste management practices, and calls for a cooperative effort among the federal, State, and local governments and private enterprise to recover valuable materials and energy from solid wastes.

The Clean Air Act Amendments of 1970 (PL 91-604) and 1977 (PL 95-95) focus on the protection and enhancement of the quality of the Nation's air resources in order to protect public health and welfare and the productive capacity of the country. A national R&D program, technical and financial assistance, emission standards, and air quality planning assistance program authorities are included. CAA provides for technical and financial assistance to State and local governments in connection with the development and execution of their air pollution and control programs, encourages and assists the development and operation of regional air pollution control programs, and initiates an accelerated national R&D program to achieve the prevention and control of air pollution. It also authorizes the development of State implementation plans (SIPs) for the purpose of meeting minimum federal ambient air quality standards and the issuance of regulations to control hazardous air pollutants and new source performance standards (i.e., emission standards).

The Marine Protection, Research and Sanctuaries Act of 1977 (PL 92-532) and its amendments of 1977 (PL 95-153) focuses on regulating the dumping of all types of materials into ocean waters and limiting the ocean dumping of materials which would adversely affect human health and welfare of the marine environment and its commercial values. Permitting and regulations, marine research and marine sanctuaries establishment provisions are included. The 1977 Amendments effectively establish December 31, 1981, as the deadline for terminating ocean dumping of sewage sludge "which may unreasonably degrade or endanger human health, welfare, amenities, or the marine environment, ecological systems, or economic potentialities."

The Toxic Substances Control Act of 1976 (PL 94-469) focuses on the need for testing, premanufacture notification, regulating production and placing necessary use restrictions on certain chemical substances and mixtures which present an unreasonable risk of injury to health or the environment. Along with its many regulatory, testing and reporting requirements, EPA

is also required under Section 9 of TSCA to coordinate actions taken under TSCA with actions taken under other Federal laws. At present the disposal of materials or mixtures with more than 50 ppm PCB are required to comply with special PCB manufacturing, processing, distribution and use regulations that have been issued under TSCA.

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4
MINE LAND RECLAMATION WITH MUNICIPAL SLUDGE—PENNSYLVANIA'S DEMONSTRATION PROGRAM

William E. Sopper and Sonja N. Kerr

The use of municipal sludge to revegetate mined land in an environmentally acceptable manner was demonstrated on several 4-hectare plots in the anthracite and bituminous coal mining regions of Pennsylvania. Five sites representative of abandoned, barren bituminous and anthracite mines, as well as currently mined sites, were treated with various types of municipal sludge at high and low application rates and broadcast seeded with a mixture of grasses and legumes. A monitoring system was installed at each demonstration site to determine the effects of the sludge applications on groundwater and soil percolate water chemical and bacteriological quality, chemical properties of the soil, and quality and growth of vegetative cover. Data collected during the study period indicate that the sludge applications ameliorated the harsh site conditions and resulted in a quick vegetative cover that completely stabilized the demonstration site. Moreover, each site's vegetative cover has persisted and improved each year since its establishment. No deterioration in vegetation yield or quality has been observed. Although sludge applications increased some trace metal concentrations in the vegetation, all concentrations were below plant tolerance levels and no phytotoxicity was observed. Sludge applications had no significant adverse effect on soil percolate or groundwater chemical or bacteriological quality. The results from these demonstration projects indicate that stabilized municipal sludges, if applied properly, can be used to revegetate mined lands in an environmentally safe manner with no adverse effects on the vegetation, soil, or groundwater quality.

Introduction

Pennsylvania is rich in coal. Recoverable coal reserves of over 34.5 billion metric tons exist under 41 of the 67 counties. However, removal of this coal in the past created a myriad of environmental problems. These included erosion and sedimentation, acid mine drainage, and the loss of productive cropland and forestland. Scars of past mining operations are evident throughout the Commonwealth. In Pennsylvania, over 97,000 hectares have been disturbed by strip mining and have been abandoned or inadequately reclaimed. The new Federal Surface Mining Control and Reclamation Act of 1977 has established strict regulations for the revegetation of currently mined land. It will be difficult to meet these strict requirements using current reclamation techniques. New methods will have to be developed and larger

amounts of lime, fertilizer, and seed will undoubtedly have to be used. In addition, soil amendments and irrigation may be required on some sites.

During the past decade, a considerable amount of research has been conducted that has shown stabilized municipal sludge from secondary wastewater treatment plants is an excellent soil amendment and chemical fertilizer substitute. Many municipalities are reconsidering their current methods of sludge processing and disposal due to escalating costs and environmental pressures. Particularly hard-pressed to find an environmentally acceptable alternative are large coastal metropolitan areas that currently dispose of sludge in the ocean, which must cease by December, 1981. Concern has been raised over the potential health hazard of using sludges on agricultural land and the potential introduction of toxic elements into the human food chain. A possible alternative that might alleviate these concerns is to utilize the sludge to reclaim and revegetate marginal, unproductive lands or barren lands disturbed by coal mining activities.

Federal and State Guidelines and Regulations

However, if sludge is to be used in the reclamation process there are two sets of State and Federal guidelines and regulations that must be considered. First, we have the Federal and State regulations concerning revegetation as required under the new Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Section 515 of the Law states that a permanent vegetative cover of the same seasonal variety native to the area of land to be affected must be established and must be capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area. The Office of Surface Mining Reclamation and Enforcement (OSM), established under the Law, has recommended performance standards for meeting the revegetation requirements.

These recommendations stated in subchapter K, part 816 of the Preferred Alternate Final Rules of the Final Environmental Statement (1) prepared by OSM are as follows:

1. Ground cover and productivity of living plants on the revegetated area shall be equal to that of an approved reference area.
2. The period of responsibility initiates when ground cover equals the approved standard after the last year of augmented seeding, fertilizing, irrigation or other work which ensures success.
3. In areas of more than 66 centimeters of average annual precipitation, the period of extended responsibility will continue for not less than five years. In areas with 66 centimeters of precipitation or less, the period of responsibility will continue for not less than 10 years.
4. In both cases, the ground cover and productivity shall equal

the approved standard for the last two consecutive years of the responsibility period.

5. The ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of that of the approved reference area.

Secondly, we have the State and Federal guidelines and regulations related to land application of sludge that must be followed. Most of these guidelines set limits on sludge application rates based on nitrogen and other plant nutrient requirements of the vegetation as well as trace metal loadings. For example, the Environmental Protection Agency (EPA) has issued recommendations for the maximum amounts of trace metals that can be applied to agricultural soils via sewage sludge (2). These maximum amounts are related to the soil cation exchange capacity. These criteria are given in Table 4-1.

In addition, some states have even more stringent guidelines concerning sludge application on the land. For instance, in 1977 the Pennsylvania Department of Environmental Resources (PDER) issued "Interim Guidelines for Sewage Sludge Use for Land Reclamation" (3). These guidelines state that due to the high permeability of mine spoils and low retention of organic matter, sufficient nitrogen in excess of the crop requirement must be provided in order to establish growth. To provide sufficient nitrogen a maximum application rate of 134 dry metric tons per hectare may be utilized for land reclamation. In addition, the application is further limited according to the trace metal content of the sludge and application rates may not exceed the limits given in Table 4-2.

The guidelines further state that the soil pH must be adjusted to 6.0 during the first year of sludge application and must be maintained at 6.5 for two years following final sludge application. Liming is required to immobilize the trace metals in order to reduce their availability for plant uptake and to prevent their leaching into groundwater.

Other requirements include the following:

1. Sludge is to be incorporated within 24 hours after application.

2. Sludge is not to be applied when the ground is saturated, snow-covered, frozen or during periods of rain.

3. Sludge is not to be applied within 30 meters of streams, 91 meters of water supplies, 8 meters of bedrock outcrops, 15 meters of property lines, or 91 meters of occupied dwellings.

4. Sludge for revegetation of inactive mines or active coal refuse piles is not to be applied to slopes exceeding 15 percent.

5. Dairy cattle must not be allowed to graze land for at least two months after sludge application.

These guidelines have been designated as interim so that changes can be made as more information becomes available.

So if municipal sludge is going to be used to reclaim mined land, one

Table 4-1. EPA Recommended Total Trace Metal Loadings for Agricultural Land.

Metal	Soil Cation Exchange Capacity (meq/100g)		
	0-5	5-15	>15
	Amount of Metal (kg/ha)		
Pb	560	1120	2240
Zn	280	560	1120
Cu	140	280	560
Ni	140	280	560
Cd	6	11	22

Table 4-2. PDER Recommended Maximum Trace Element Loading Rates for Land Reclamation.

Constituent	Maximum Loading Rate for Land Reclamation	Maximum Loading Rate Land Reclamation for Farming
	kg/ha	kg/ha
Cd	3	3
Cu	112	67
Cr	112	67
Pb	112	67
Hg	0.6	0.2
Ni	22	13
Zn	224	134

is faced with the challenge of finding a harmonious marriage between the two sets of guidelines and regulations.

Initial Project Proposals

Five years ago several attempts were made in Pennsylvania to develop projects using municipal sludge for strip mine land reclamation. One project in Clearfield County proposed reclaiming 405 hectares (1000 acres) of abandoned mine land with digested sludge from Philadelphia. The project was technically sound and had the support of the Pennsylvania Department of Environmental Resources, the county commissioners, and the township supervisors. Public meetings were held to explain the project, a series of informational articles were written for the local newspapers, radio interviews were given, and a "hot line" was established to allow citizens to call at any time to have questions answered. Were all these activities successful in gaining public support? No, they were not successful. Public opposition was so great that project approval could not be given by the regulatory agency. While the reasons for local opposition are not clear, the following factors probably contributed to the failure to gain support:

1. The concept of using sludge to reclaim mined land was relatively new in Pennsylvania.
2. The size of the project (405 ha) was too large.
3. Sludge from a large metropolitan city was to be used rather than local sludge.
4. It would have been the first large-scale application of sludge in Pennsylvania. The only other applications in the Commonwealth were on small research plots.
5. The public was confused by false information and conflicting information about the project reported in the local newspapers.

Pennsylvania Demonstration Program

It was quite obvious that we had to bridge the gap between available technical information and public understanding. To accomplish this, a cooperative project was initiated in 1977 with funding from the U.S. Environmental Protection Agency to establish 4-ha (10 acre) demonstration plots in both the anthracite and bituminous coal mining regions of Pennsylvania. Cooperating in this effort were the Pennsylvania Bureau of Solid Waste Management, the Pennsylvania office of the USDA Agricultural Stabilization and Conservation Service, and the Appalachian Regional Commission. This effort was expanded in 1978 in cooperation with the City of Philadelphia Water Department and Modern-Earthline Companies.

Projects were conducted using several types of sludges on a variety of site conditions. Types of sludges used were 1) liquid digested, 2) dewatered by centrifuge, vacuum filter, and sand bed drying, 3) heat dried, 4) composted with wood chips, and 5) compost-sludge cake mix. Site conditions evaluated were:

A. Bituminous strip mine banks
   1. Abandoned mine land—Recontoured without top soil
   2. Currently mined land—Recontoured with top soil
B. Anthracite refuse banks
   1. Burned and recontoured
   2. Unburned and recontoured

Bituminous Strip Mine Banks

Abandoned Mine Land—Recontoured Without Top Soil

This site, located in Venango County, is representative of bituminous strip mine banks, which have been backfilled and recontoured after mining without top soil replacement. Several attempts had been made to revegetate the area using lime, commercial fertilizer, and seed, but without success.

The surface spoil was compacted, extremely acid (pH 3.8), and devoid of vegetation. A 4-hectare demonstration plot was established. The plot was scarified with a chisel plow to loosen the surface spoil material and then treated with agricultural lime (4.5 to 12.3 metric tons per hectare) to raise the spoil pH to 6.5.

Sludge for the project was obtained from three local waste treatment plants. Liquid digested sludge was obtained from Farrell and Oil City, and was transported to the site in tank trucks. Dewatered sludge was obtained from Franklin where the sludge is dewatered by centrifuging, and from Oil City where the sludge is dewatered by spreading on sand drying beds. The dewatered sludge was brought to the site in coal trucks. The 4-ha plot was subdivided into four 1-ha subplots for application of liquid digested sludge at two rates and dewatered sludge at two rates. Liquid digested sludge was applied with a vacuum tank liquid manure spreader at 103 cubic meters per hectare (equivalent to 7 metric tons/hectare) and 155 cubic meters per hectare (equivalent to 11 metric tons/hectare). Dewatered sludge was applied at 90 and 184 metric tons per hectare.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses and two legumes. The seeding mixture was Kentucky-31 tall fescue (22 kg/ha), Pennlate orchardgrass (22 kg/ha), Penngift crownvetch (11 kg/ha) and Empire birdsfoot trefoil (11 kg/ha). The site was mulched with straw and hay at the rate of 3.8 metric tons per hectare.

The amounts of trace metals applied at the highest liquid and dewatered sludge application rates are given in Table 4-3 along with the U.S. Environmental Protection Agency and Pennsylvania Department of Environmental Resources interim guideline recommendations. It is quite obvious that the amounts of trace metals applied even at the highest sludge application rate were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

The amounts of nutrients applied by each of the sludge application rates are given in Table 4-4. Potassium is the only plant nutrient deficient in all sludge application rates. The commercial fertilizer equivalents are also given in Table 4-4. The highest sludge application rate (184 mt/ha) was equivalent to applying 22 metric tons per hectare of an 11-9-0 commercial chemical fertilizer. One of the principal advantages of using sludge is that it is a slow-release fertilizer and will supply plant nutrients for 3 to 5 years. Most of the nitrogen is in the organic form and therefore not immediately available for plant use until it is mineralized and converted to available plant forms. Only approximately 20 percent of the organic nitrogen is mineralized in the first year and 5 to 10 percent of the remaining organic nitrogen is released the second year (4). Decreasing amounts of organic nitrogen are subsequently released each following year. After this period the natural process of nutrient recycling should be well established for sustaining the

Table 4-3. Comparison of Trace Metal Loadings of the Highest Liquid and Dewatered Sludge Applications at the Venango County Demonstration with EPA and PDER Recommendations.

Constituent	Sludge Application Rates mt/ha		Recommendations	
			EPA[1]	PDER
	11	184	(CEC 5-15)	
	kg/ha			
Cu	21	129	280	112
Zn	21	147	560	224
Cd	0.1	0.6	11	3
Pb	10	55	1120	112
Ni	1	12	280	22
Cr	16	74	NR[2]	112
Hg	0.01	0.09	NR[2]	0.6

1/ Average CEC of site ranged from 11.6 - 15.2 meq/100g

2/ No recommendations given by EPA

Table 4-4. Commercial Fertilizer Equivalents of the Sludge Application at the Venango County Demonstration Site.

Sludge Application Rate	Fertilizer Equivalent (Fertilizer Formula)			
	Amount	N	P_2O_5	K_2O
mt/ha	kg/ha	kg/ha(%)	kg/ha(%)	kg/ha(%)
184	22,400	2388(11)	2103 (9)	21 (0)
90	11,200	1165(10)	1026 (9)	11 (0)
11	2,240	284(13)	143 (6)	6 (0)
7	2,240	187(8)	95 (4)	2 (0)

vegetati-

All sludge treated areas had a complete vegetative cover established within several weeks after sludge was applied. Vegetation growth and dry matter production were measured at the end of each growing season (1977 to 1979). Results are given in Table 4-5. Both vegetation height growth and dry matter production increased during the three-year period. During the second growing season the two grasses produced prolific seed heads. Sampling indicated a seed production ranging from 168 to 336 kilograms of seed per hectare.

Samples of the individual grass and legume species were collected at the end of each growing season for foliar analyses. Results for tall fescue and birdsfoot trefoil for the highest sludge application rate are given in Table 4-6. Foliar trace metal concentrations generally decreased over the three-year period. Overall the trace metal concentrations were well below the suggested tolerance levels and no phytotoxicity symptoms were observed (5,6).

In general, the vegetation cover has improved over the three growing seasons following sludge application. No deterioration in vegetation quality

or yield has been measured or observed. In comparison, the remainder of the site, not treated with sludge, remained barren.

Spoil samples were collected at the end of each growing season to evaluate the effect of the lime and sludge applications on spoil pH. Results for the highest sludge application (184 mt/ha) were as follows:

	Spoil pH			
Spoil Depth	Before Sludge	1977	1978	1979
cm				
0-15	3.8	6.2	6.7	7.3
15-30	3.8	4.2	4.6	5.1

Surface spoil pH continually increased over the 2.5-year period following sludge application. Results indicate that the lime and sludge applications did raise the spoil pH significantly and that the higher pH was

Table 4-5. Vegetation Height Growth and Dry Matter Production at the Venango County Demonstration Site.

Sludge Application	Height		
	1977	1978	1979
mt/ha	cm		
7	29	37	52
11	32	30	43
90	34	41	41
184	35	52	44
	Dry Matter Production		
	kg/ha		
7	6349	9537	18538
11	7731	8654	17141
90	4757	7409	13327
184	6013	9336	11322

Table 4-6. Average Concentration of Trace Metals in the Foliar Samples Collected from the 184 mt/ha Plot at the Venango County Demonstration Site.

Species	Year	Cu	Zn	Cr	Pb	Co	Cd	Ni
		µg/g						
Tall Fescue	1977	9.4	44.4	0.8	4.5	1.5	0.20	9.8
	1978	8.6	44.4	0.8	4.5	1.6	0.41	3.7
	1979	9.2	72.5	0.5	1.8	0.6	0.08	2.5
Birdsfoot Trefoil	1977	13.9	95.9	1.0	7.4	2.1	0.43	6.3
	1978	7.7	30.4	0.3	8.5	3.0	0.07	4.8
	1979	9.2	41.5	1.7	1.8	0.3	0.04	6.3
Suggested Tolerance Level [5,6]		150	300	2	10	5	3	50

maintained.

Spoil samples were also analyzed for trace metals. A comparison of trace metal concentrations before and after sludge was applied is given in Table 4-7. Even at the highest sludge application rate (184 mt/ha) the trace metal concentrations in the surface spoil (0-15 centimeters) were only slightly increased. In general, the trace metal concentrations in the spoil were all extremely low in comparison to published normal ranges for soils (7).

Groundwater samples were collected bi-weekly from monitoring wells to evaluate the effect of the sludge applications on water quality. Results of these analyses are given in Table 4-8.

Well No. 1 was drilled as a control outside the area of influence of the sludge applications. Groundwater flow under the dewatered sludge-treated area is toward Well No. 2 located approximately 11 meters downslope from the plot. Results indicate that the high application of dewatered sludge did not significantly increase the concentration of NO_3-N in groundwater. Concentrations of NO_3-N were below the U.S. Environmental Protection Agency limit for potable water (10 mg/l) for all months sampled. It also should be noted that the average depth to groundwater in Well No. 2 was only 3 meters.

Results of analyses of groundwater samples for trace metals during the three years after sludge was applied are also given in Table 4-8. There appears to be no significant increase in any of the trace metal concentrations in Well No. 2, which was influenced by the sludge applications. Average annual concentrations were below the USEPA drinking water standards.

All groundwater samples collected during the period July, 1977 to September, 1980 were also analyzed for coliforms. No fecal coliform colonies were observed for any sample.

To maximize the value of the demonstration project, a second site was chosen on abandoned bituminous spoil for a fall sludge application. This would allow the evaluation of a fall seeding on the establishment of a vegetative cover and the efficacy of that cover to control the environmental effects of the sludge application. During the spring of 1979, a site was located in the bituminous coal region of Southwestern Pennsylvania in Derry Township, Westmoreland County. The area had been mined approximately 10 years ago and is typical of bituminous spoil banks that had been recontoured without topsoil replacement. Four hectares of the approximate 6-hectare area were selected for sludge application.

Sludge for the project was obtained from the City of Philadelphia Water Pollution Control Plant, which is located approximately 450 kilometers from the site. The plant produces a dewatered centrifuged sludge that is composted with wood chips. The composted sludge is then mixed with equal parts of centrifuged sludge-cake to increase the nutrient value of the final product. The total nitrogen content of the composted sludge is approximately 0.6 percent; whereas, the centrifuged sludge cake total nitrogen content is

Table 4-7. Analyses of Spoil Samples for Extractable Trace Metals on the 184 mt/ha Plot at the Venango County Demonstration Site.

Time of Sampling	Spoil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
	cm	µg/g						
Before Sludge Applied	0-15	2.5	2.9	0.2	0.5	0.7	0.02	1.1
	15-30	3.0	2.4	0.1	0.6	0.7	0.02	1.0
	30-60	3.7	3.6	0.2	0.9	1.0	0.03	1.6
Four months after sludge applied	0-15	10.8	7.7	0.4	3.5	1.3	0.04	0.9
	15-30	4.0	2.0	0.1	1.3	0.2	0.01	0.4
	30-60	4.9	2.9	0.1	1.9	0.3	0.01	0.5
Eighteen months after sludge applied	0-15	8.8	7.7	0.2	2.3	1.2	0.02	1.2
	15-30	2.5	1.7	<0.1	1.3	0.5	0.01	0.7
	30-60	1.8	1.8	<0.1	1.5	0.5	0.01	0.7
Normal range soil[7]		2-100	10-300	5-3000	2-200	1-40	0.01-7.0	10-1000

Table 4-8. Groundwater Analyses for Trace Metals and Nitrate-Nitrogen Following Sludge Application at the Venango County Demonstration Site.

Well No.	Year[1]	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
Well 1 (control)	1977	0.22	4.13	0.01	0.14	3.19	0.006	3.23	1.4
	1978	0.23	2.02	0.01	0.19	1.04	0.002	1.00	<0.5
	1979	0.17	1.48	0.03	0.13	0.58	0.002	0.50	<0.5
Well 2 (Dewatered Sludge) (184 mt/ha)	1977	0.10	3.39	0.03	0.09	2.12	0.001	2.67	1.1
	1978	0.14	3.29	0.01	0.20	1.16	0.002	1.26	<0.5
	1979	0.18	1.83	0.03	0.13	1.92	0.001	0.97	<0.5
EPA Drinking Water Standard		1.00	5.00	0.05	0.05	5.00[2]	0.010	2.00[2]	10.0

[1] Values represent the mean of all samples collected from each well for the year.

[2] No limits given for drinking water standards; these are recommended values for irrigation water for agricultural use.

approximately 2.0 percent.

Results of the analyses of the compost-cake mix were used to calculate the amounts of selected nutrients and trace metals applied. The results indicated that the compost-cake mix supplied 968 kg/ha of nitrogen, 1816 kg/ha of phosphate, and 215 kg/ha of potash to the area. This would be equivalent to applying 10 mt/ha of a 10-18-2 commercial fertilizer. The value of sludge as a substitute for commercial fertilizer is obvious.

A comparison of the application rate with the EPA and PDER recommendations for maximum trace metal loadings on the land is given in Table 4-9. This comparison indicates that the recommended limits were essentially met with the sludge application rate of 134 mt/ha. It should

Table 4-9. Comparison of Trace Metal Loadings at the Westmoreland County Demonstration Project with EPA and PDER Recommendations.

Constituent	Sludge Application 134 mt/ha	Recommendations EPA (CEC 5-15)[1]	PDER
	kg/ha		
Cd	0.2	22	3
Cu	76	560	112
Cr	42	NR[2]	112
Pb	59	2240	112
Hg	0.06	NR[2]	0.6
Ni	13	560	22
Zn	245	1120	224

[1] Average CEC of site ranged from 16.7 to 19.0 meq/100g.

[2] No recommendation given by EPA.

be noted that the sludge application of 134 mt/ha is well below the limits recommended by the EPA and with the exception of zinc meets all PDER guidelines. The recommended maximum loading rate, established by the PDER guidelines, for zinc is 224 kg/ha, whereas the actual application was 245 kg/ha.

Pre-treatment surface soil samples were collected and analyzed for pH and buffer pH to determine the liming requirements. Results indicated that the average soil pH was 4.3. Thirteen metric tons of agricultural lime per hectare were applied on September 24 and 25 to adjust the soil pH to 6.0. Monitoring instruments were installed, including suction lysimeters at the 90 cm depth and groundwater wells, prior to sludge application.

On September 24 and 25, 1979, the compost-cake mix was transported by 20-ton capacity coal trucks from Philadelphia to the site on a return trip after delivering coal. The sludge was loaded into manure spreaders and spread on the site; this was completed on September 26, 1979. Immediately after the spreading, the area was disked to incorporate the sludge into the surface 10 cm of soil material.

After the incorporation of the sludge, the area was broadcast seeded. The seed mixture used was Kentucky 31 Tall Fescue (11 kg/ha), Birdsfoot Trefoil (6 kg/ha), and Winter Rye (63 kg/ha). Completion of seeding by October 1, 1979 would allow approximately 6 to 8 weeks for vegetation growth to become winter hardy.

A site inspection on November 29, 1979, approximately 8 weeks after seeding, indicated that a protective cover of winter rye had been established. Vegetation was approximately 5 cm in height. There was no evidence of any erosion on the sludge treatment area. It appeared that sufficient vegetation was established to protect the site from erosion and runoff over the winter season. This was confirmed by a site inspection on March 28, 1980. The entire sludge-treated area was covered by a vegetative cover ranging

from 5 to 10 cm in height. On the basis of ocular estimates, the percentage areal cover ranged from 80 to 90 percent. There was no evidence of surface runoff or erosion from the sludge-treated area. However, some erosion did occur from barren areas upslope of the sludge-treated area. The sediment-laden surface runoff from these areas was dispersed as soon as it encountered the sludge-treated plot, which had been roughened by contour chisel plowing to incorporate the sludge. As soon as the site was dry enough, April 24, 1980, the remaining portion of the seeding mixture was broadcast. The spring seeding mixture used was Orchardgrass (11 kg/ha) and Birdsfoot trefoil (6 kg/ha). By early summer, there was a complete lush vegetative cover on the entire site. At the end of the first growing season, (1980), average vegetation height was 68 cm and average dry matter product was 11036 kg/ha. This would indicate that sludge can successfully be applied in the fall as well as the spring.

Results of the analyses of groundwater well samples are given in Table 4-10. Water level depth in Well 1 fluctuated between 1.7 and 1.8 m during the period of sampling. Sludge application did not have any apparent effect on the concentration of any constituents. The concentration of NO_3-N in Well 1 was slightly higher than the potable water standard (17 mg/l vs 10 mg/l). However, it decreased to 7.1 mg/l during the first month following sludge application and remained at a low level during the period of sampling. Concentrations of all trace metals except Pb were below the maximum

Table 4-10. Groundwater Analyses for Trace Metals and Nitrate-Nitrogen at the Westmoreland County Demonstration Project During 1979 and 1980.

Well No.	Month[1] and Year	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
		mg/l							
Well 1	Sept 79	0.05	0.23	0.03	0.14	0.03	<0.001	0.05	17.6
	Oct 79	0.11	0.22	0.02	0.27	0.06	<0.001	0.06	7.1
	Nov 79	0.07	0.14	0.02	0.14	0.01	<0.001	0.05	<0.5
	Dec 79	0.09	1.05	0.02	0.14	0.06	<0.001	0.07	<0.5
	Jan 80	0.04	0.30	0.01	0.20	0.02	0.001	0.03	<0.5
	Feb 80	0.01	0.07	0.01	0.02	0.04	<0.001	0.03	1.3
	Mar 80	0.01	0.11	0.03	0.01	0.03	<0.001	0.02	1.9
	Apr 80	0.05	0.13	0.02	0.06	0.03	<0.001	0.03	1.3
	May 80	0.05	0.31	0.01	0.04	0.05	<0.001	0.01	<0.5
Well 2	Sept 79	0.02	0.17	0.02	0.03	0.24	<0.001	0.17	1.7
	Oct 79	0.03	0.11	0.01	0.07	0.04	<0.001	0.04	1.0
	Nov 79	0.01	0.01	<0.01	0.07	<0.01	0.001	0.07	<0.5
	Dec 79	0.01	0.36	0.01	0.07	0.02	<0.001	0.01	<0.5
	Jan 80	<0.01	0.12	<0.01	0.08	0.10	0.001	0.04	<0.5
	Feb 80	<0.01	0.04	<0.01	0.02	0.07	0.001	0.06	<0.5
	Mar 80	<0.01	0.02	0.03	0.08	0.07	0.003	0.09	<0.5
EPA Drinking Water Standards		1.0	5.0	0.05	0.05	5.0[2]	0.01	2.0[2]	10.0

[1] September values represent pre-treatment conditions.

[2] No limits given for drinking water standards; these are recommended values for irrigation water for agricultural use.

allowable limits for potable water. Lead concentrations exceeded the USEPA standards on both the control and sludge-treated area.

Currently Mined Land—Recontoured With Top Soil

This site located in Somerset County was representative of current bituminous coal mining operations conducted under Pennsylvania's amended Surface Mining Conservation and Reclamation Act that requires backfilling to the approximate original contour and top soil replacement. After top soil replacement was completed in April, 1978, a 4-hectare demonstration site was established for sludge application. This project was conducted by Modern-Earthline Companies, Environmental Consultants for the City of Philadelphia Water Department.

The site was first scarified with a chisel plow to alleviate surface soil compaction resulting from heavy equipment traffic in the top-soiling operation. Agricultural lime was applied at the rate of seven metric tons per hectare to raise the soil pH to 6.5 (average soil pH was 5.1).

Sludge for the project was obtained from the Philadelphia Northeast Water Pollution Control Plant. The liquid digested sludge was dewatered by centrifuging, then composted with wood chips at a rate of 1 part of sludge to 2 parts of wood chips. The composted sludge, with the wood chips still included, was then shredded. The compost was transported to the site (400 kilometers) by coal trucks on a return trip after delivering coal. Compost was applied in early June using manure spreaders. Compost was applied at the rate of 202 metric tons per hectare. Immediately following spreading, the compost was incorporated with a chisel plow and disk. The site was then broadcast seeded with the same grass and legume mixtures as used in Venango County.

At the rate applied, the mixture supplied 726 kilograms of nitrogen, 464 kilograms of phosphorus, and 181 kilograms of potassium. This is equivalent to 6700 kilograms of an 11-16-3 commercial fertilizer per hectare.

The amounts of trace metals applied in the compost, along with the U.S. Environmental Protection Agency and Pennsylvania Department of Environmental Resources interim guideline recommendations are given in Table 4-11. The total trace metal loadings are well below the EPA recommendations; however, all trace metal loadings except for Cr and Hg exceeded the PDER recommendations.

Within several weeks a complete vegetation cover was established. Vegetation height growth and dry matter production were measured at the end of the first growing season (1978), average vegetation height growth over the compost treated plot was 20 cm and ranged from 8 to 46 centimeters. Dry matter production averaged 1592 kilograms per hectare and ranged from 731 to 3742 kilograms per hectare. By the end of the second growing season (1979), there was a four-fold increase in dry matter production. Average height increased to 66 cm and average dry matter

Table 4-11. Comparison of Trace Metal Loadings at the Somerset County Demonstration Project with EPA and PDER Recommendations.

Constituent	Compost Application Rate 203 mt/ha	Recommendations EPA (CEC 5-15)[1]	PDER
	kg/ha		
Cu	131	280	112
Zn	343	560	224
Cd	5	11	3
Pb	131	1120	112
Ni	30	280	22
Cr	40	NR[2]	112
Hg	0.3	NR[2]	0.6

[1] Average CEC of site ranged from 14.0 to 14.8 meq/100 g.

[2] No recommendations given by EPA.

Table 4-12. Average Concentrations of Trace Metals in Foliar Samples Collected at the Somerset County Demonstration Site.

Species	Compost Application	Year	Cu	Zn	Cr	Pb	Co	Cd	Ni
	mt/ha					µg/g			
Tall Fescue	0	1978	11	24	0.74	0.63	1.12	0.11	0.31
	203	1978	15	52	1.06	5.12	1.69	0.77	5.48
	203	1979	9	55	1.58	5.08	2.67	0.57	4.75
Birdsfoot Trefoil	0	1978	8	20	0.74	1.10	1.70	0.14	2.66
	203	1978	10	67	0.74	7.70	2.01	0.53	5.32
	203	1979	7	83	0.25	5.42	2.75	0.18	4.08
Orchardgrass	203	1978	17	60	0.82	3.94	1.12	0.54	4.59
	203	1979	8	71	1.25	1.75	1.17	0.62	2.92
Crownvetch	203	1978	18	295	0.98	9.57	4.22	3.77	8.85
	203	1979	8	159	1.00	4.92	1.92	0.58	5.42
Suggested Tolerance Levels[3,5]			150	300	2	10	5	3	50

production increased to 9089 kilograms per hectare.

Individual samples of each of the two grass and two legume species were collected from the compost treated area for foliar analyses to determine plant uptake of trace metals. Tall fescue and birdsfoot trefoil were collected from an adjacent area that had not received compost but had applications of lime and commercial fertilizer. Results of the chemical analyses for the grasses and legumes are given in Table 4-12. At the end of the first growing season, 1978, foliar trace metal concentrations for all species treated were below the suggested tolerance levels for agronomic crops, except for the foliar concentration of cadmium in crownvetch. Foliar concentrations of trace metals generally decreased by the end of the second year, including

Table 4-13. Analyses of Soil Samples for Extractable Trace Metals at the Somerset County Demonstration Site.

Year[1]	Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
	cm				µg/g			
1978	0-15	3.7	1.0	<0.01	2.80	1.15	0.014	0.40
	15-30	4.6	1.1	<0.01	2.80	1.15	0.015	0.35
	30-60	5.3	1.9	<0.01	2.75	1.65	0.017	1.60
1979	0-15	25.2	54.3	3.85	33.80	0.85	0.723	3.10
	15-30	3.2	3.3	0.15	2.75	0.75	0.050	1.85
	30-60	3.4	3.8	0.10	2.75	0.75	0.042	2.60
Normal Range in Soils[7]		2-100	10-300	5-3000	2-200	1-40	0.01-7.00	10-1000

[1] 1978 represents pre-treatment conditions.

cadmium. The suggested tolerance levels shown in Table 4-12 represent the levels at which a yield reduction might occur and do not represent the levels at which toxicity occurs. There were no phytotoxicity symptoms observed for the vegetation grown on the compost treated area.

To evaluate the effects of the compost on the trace metal concentrations of the soil, soil samples were collected at various depths in April, 1979, ten months following the application of the compost. The results of these analyses are given in Table 4-13. Trace metal concentrations were increased by the compost application, with the greatest increase occurring at the 15-cm depth; however, these increased concentrations of the trace metals on the compost area are within the normal ranges found in soils.

Groundwater samples were collected bi-weekly from monitoring wells to evaluate the effect of the compost application on water quality. The primary monitoring well influenced by the compost application is located along the downslope border of the compost treated plot. Average depth to groundwater was 12 meters. Results of analysis for trace metals and nitrate-nitrogen for the period April, 1978 to May, 1980 are given in Table 4-14. Results of the analyses indicated that the application of compost did not have any significant effect on the concentration of nitrate-nitrogen, which was consistently below U.S. Environmental Protection Agency potable water standards. No significant increases in trace metal concentrations were observed after compost was applied. There is an obvious trend toward decreasing concentrations during the second and third years. Separate samples of groundwater were collected on each sampling date and analyzed for coliforms. No fecal coliform colonies were found in any samples.

Table 4-14. Groundwater Analyses for Trace Metals and Nitrate-Nitrogen at the Somerset County Demonstration Site.

	Date	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
	1978	- - - - - - - - - - - - - - - - mg/l - - - - - - - - - - - - - - - -							
Before	Apr 19	0.06	0.26	<0.01	<0.01	0.07	0.007	0.17	0.5
Compost	May 11	0.07	0.58	0.01	0.02	0.17	0.001	0.18	0.5
Applied	May 25	1.28	1.53	<0.01	0.08	0.05	0.001	0.30	0.5
	Jun 12	0.11	0.86	0.01	0.01	0.08	0.001	0.08	0.5
After	Jun 26	1.11	0.38	<0.01	0.14	0.08	<0.001	0.05	0.5
Compost	Jul 10	0.10	2.04	0.04	<0.01	0.10	0.001	0.10	10.5
Applied	Jul 24	0.94	0.29	<0.01	0.16	<0.01	0.005	0.04	0.5
	Aug 4	0.09	0.32	0.01	0.08	0.10	0.005	0.04	0.5
	Aug 21	1.66	1.39	0.04	0.09	0.23	0.002	0.47	0.5
	Sep 7	0.05	0.44	0.02	0.07	<0.01	<0.001	0.01	0.5
	Sep 19	1.01	0.36	0.04	0.14	<0.01	<0.001	0.01	0.5
	Oct 18	0.01	0.60	0.04	0.02	<0.01	0.001	0.01	0.5
	Nov 10	0.03	0.31	0.01	0.02	<0.01	0.001	0.01	0.5
	Dec 6	0.72	0.35	0.01	0.14	0.02	0.002	0.08	0.5
	1979								
	Mar	0.10	0.20	<0.01	<0.01	<0.01	0.001	0.01	0.5
	Apr	<0.01	0.10	<0.01	<0.01	<0.01	0.001	0.01	0.5
	May	<0.01	0.40	<0.01	<0.01	<0.01	0.001	0.01	0.5
	Jun	0.09	0.52	<0.01	0.03	0.02	0.001	0.05	<0.5
	Jul	0.10	0.74	<0.01	0.06	0.03	0.001	0.01	<0.5
	Aug	<0.01	0.14	<0.01	0.02	0.03	0.002	0.03	<0.5
	Sep	<0.01	0.35	0.01	0.04	0.02	<0.001	0.06	<0.5
	Oct	0.16	0.32	<0.01	0.03	0.02	<0.001	0.03	<0.5
	Nov	0.03	0.49	0.01	0.02	0.39	0.001	0.04	<0.5
	Dec	0.01	0.88	0.01	0.06	0.19	<0.001	0.15	<0.5
	1980								
	Jan	0.07	0.55	0.01	0.05	0.08	0.001	0.10	<0.5
	Feb	0.04	0.56	0.01	0.09	0.05	0.003	0.08	<0.5
	Mar	0.02	0.81	0.03	0.01	0.02	0.002	0.04	<0.5
	Apr	0.17	0.89	0.06	0.02	0.12	<0.001	0.25	<0.5
	May	0.12	1.08	0.09	0.03	0.03	<0.001	0.13	2.2
EPA Drinking Water Standards		1.00	5.00	0.05	0.05	5.00[1]	0.010	2.00[1]	10.00

[1] Limits for irrigation water for agricultural land. No criteria set for drinking water.

Anthracite Refuse Bank

Burned and Recontoured

In 1974, a project was initiated in Lackawanna County in the city of Scranton, Pennsylvania. The project was located on an anthracite refuse bank that had burned for many years before an underground mine fire was extinguished. After the fire, the refuse bank had been recontoured and it remained barren for many years. Heat-dried sludge from the Scranton waste water treatment plant was transported by truck to the area in May, 1974. The sludge was spread and incorporated with a tractor and cultivator. Sludge application rates were 0, 40, 76, and 148 metric tons per hectare. The area

was then planted with 10 species of tree seedlings and broadcast seeded with 5 species of grasses and 5 species of legumes.

By September, 1974, the entire sludge treated area had a lush vegetative cover, while the surrounding area remained barren. Even after the fifth growing season there was no apparent deterioration of the vegetative cover; in fact, the dry matter production of the herbaceous vegetation had more than doubled.

Of the 10 tree species planted, the best survival and growth response was obtained with hybrid poplar, black locust, and European alder. The average height of the hybrid poplar cuttings at the end of five growing seasons indicate that the application of 148 mt/ha of sludge nearly doubled the height growth of the hybrid poplar. The average height of the hybrid poplar trees grown where no sludge was applied was 2.5 meters, whereas the height of the poplars grown with 148 mt/ha of sludge was 4.5 meters. The average basal diameter of the hybrid poplar in the 0 DT/A plot was 2.5 centimeters, and in the 148 mt/ha plot the average was 6.1 cm. This indicates that after five years, the production of biomass more than quadrupled with the application of sludge.

Unburned and Recontoured

This site is located in Lackawanna County in the city of Scranton, Pennsylvania. Being devoid of vegetation, the area was subject to severe erosion and was a constant eyesore in the city of Scranton. In order to demonstrate that sludge can be used in an environmentally acceptable manner in the cities as well as in the rural areas, four hectares of this area were selected for reclamation with sludge.

In April, 1978, the 4-ha area was recontoured. A chisel plow was used to loosen the surface refuse material because of the compaction caused by the leveling process. Analyses of surface refuse samples indicated a pH of 3.6; therefore 11 mt/ha of lime was applied to the area. Monitoring instrumentation was installed to collect soil percolate water at the 90-cm depth; groundwater wells were drilled to monitor the effect of the sludge on the groundwater leaving the site. Dewatered, vacuum-filtered, sludge was obtained from the Scranton waste water treatment plant. The sludge was applied with manure spreaders and incorporated. The area was broadcast seeded with the same mixture of grasses and legumes as the Venango County demonstration. The area was then mulched with hay and straw at the rate of 3.4 mt/ha.

Sludge was applied at 80 and 108 mt/ha. The amounts of trace metals applied by the sludge application are given in Table 4-15 along with the EPA and PDER guideline recommendations. Both sludge application rates were well below all recommendations for maximum trace metal loadings. The highest sludge application rate applied 1691 kilograms of nitrogen, 456 kilograms of phosphorus, and 141 kilograms of potassium per hectare.

Table 4-15. Comparison of Trace Metal Loadings on the Unburned Anthracite Refuse Site in Lackawanna County with EPA and PDER Recommendations.

Constituent	Sludge Application Rate (mt/ha) 80	108	Recommendations EPA (CEC 5-15)[1]	PDER
	kg/ha			
Cu	67	92	280	112
Zn	64	86	560	224
Cd	1.2	1.7	11	3
Pb	49	67	1120	112
Ni	4.4	5.9	280	22
Cr	16	21	NR[2]	112
Hg	0.1	0.2	NR[2]	0.6

[1] Average CEC of site ranged from 11.1 to 11.6 meq/100 g.

[2] No recommendations given by EPA.

By August, 1978, two months after the sludge application, there was a complete vegetative cover established. There was no significant difference in vegetation growth between the two sludge application rates. At the end of the first growing season (1978), average vegetation height was 41 cm and average dry matter production was 3655 kg/ha. By the end of the second growing season (1979) these values more than doubled.

Groundwater monitoring wells were drilled on site and samples collected bi-weekly after sludge was applied. Results indicate that the sludge applications had little effect on the groundwater quality with all sample concentrations of nitrate-nitrogen remaining well below USPHS limits for potable water. Zinc was the only trace metal which increased in concentration in the groundwater. However, the highest Zn concentration recorded (1.35 mg/l) is still well below the drinking water standard for Zn of 5 mg/l. Separate samples were collected for bacterial analyses. No fecal coliforms were found in any sample to date.

Practical Operations

As a result of these successful demonstration projects, a full-scale program was initiated by the City of Philadelphia and Modern-Earthline Companies to revegetate large acreages of strip-mined land in Somerset County with compost-cake mix from Philadelphia. This program included extensive public relations with contact and explanation of the project to land owners, mining company officials, township supervisors, and county commissioners. Once their support was obtained the public relations program was expanded to include talks to local civic clubs such as Rotary, Lions, and Kiwanis. This

was followed by newspaper articles and TV news coverage of the proposed project. Eventually a local Advisory Committee was formed. This Advisory Committee consisted of recognized community leaders. Membership included local farmers, Soil Conservation District representatives, game commission, Soil Conservation Service, district forester, county agent, and community resource development agents. After gaining local community support, approximately 122 hectares were revegetated in 1979. All of the areas treated with the compost mix were abandoned strip-mine areas where previous attempts to revegetate by conventional methods were unsuccessful. These projects were performed by Modern-Earthline Companies for the Philadelphia Water Department. During 1980 approximately 280 to 400 hectares will be reclaimed using a compost-cake mix from the City of Philadelphia.

Conclusions

Results from these demonstration projects prove that stabilized municipal sludges can be used to revegetate various types of land disturbed by mining activities in an environmentally safe manner with no adverse effects on vegetation, soil, or groundwater quality and with little risk to animal or human health. It appears that the use of these small-scale local demonstration projects are the best method of obtaining public acceptance and support for large practical applications.

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5
UTILIZATION OF MUNICIPAL WASTEWATER AND SLUDGE FOR FOREST BIOMASS PRODUCTION ON MARGINAL AND DISTURBED LAND

Sonja N. Kerr and William E. Sopper

The feasibility of increasing woody biomass production from forest energy plantations through the use of municipal wastewater irrigation was investigated in Central Pennsylvania on marginal land. Energy plantations were established to evaluate the growth and development of hybrid poplar cuttings planted at densities of 0.09, 0.19, 0.37 m^2 of growing space per tree. Treated municipal wastewater was used to irrigate half of the plantations during the growing season (April to October) at the rate of 5 cm per week. Wastewater irrigation significantly increased diameter and total height growth. Total woody biomass (stemwood, bark, and branches) production was more than doubled by wastewater irrigation.

A second field demonstration was initiated in 1974 in Scranton, Pennsylvania, using municipal sludge for the reclamation and reforestation of an anthracite coal refuse bank. Sludge application rates were 0, 40, 75, and 150 dry metric tons per hectare. Ten species of trees were planted and five species of grasses and five species of legumes were seeded. The survival and growth responses were evaluated at the end of each growing season. After five years, the production of woody biomass increased more than tenfold with the single application of sludge.

Introduction

With the escalating costs of imported oil and increasing demands for energy, more and more people are turning to the nation's own resources for affordable energy. Since current domestic supplies of natural gas and liquid petroleum products appear to be insufficient to meet current energy demands, a search for alternative energy sources has been initiated. One viable alternative for future increased energy production is the utilization of forest biomass. Wood is the most abundant biomass resource in the United States (1). However, the Federal Energy Administration (2) estimated that wood currently supplies about 1.1 to 1.7 quads of energy to the total annual energy needs in the United States (75 quads). A Society of American Foresters Task Force (3) has reported that forest biomass could contribute the equivalent of approximately 9.5 quads to our energy needs. This Task Force report also indicated that if commercial forestland were fully stocked and intensively managed, biomass available for energy could increase to the equivalent of 18.9 quads by the mid-21st century. Forestland is still the

largest single land use in the United States with forest and brushland occupying over 33 percent of the total land area (4).

Forests are a renewable resource with the wood produced having many advantages as an energy source. Wood contains only traces of sulfur, has no "spill" or "leakage" problems associated with its use, is a continuous solar energy accumulator, and its use enables carbon and heat to be cycled in a relatively short time. Furthermore, its combustion can be in compliance with existing air pollution requirements using available technology and its combustion product (ash) can be directly used on the land as a source of potential plant nutrients.

To provide guaranteed supplies of wood for energy, it may be necessary to establish silviculture energy farms as well as manage natural stands. Fege et al. (5) estimated that energy farms might reasonably supply enough biomass to produce 4.5 quads of energy annually, approximately 5 percent of the current U.S. Energy requirements. The energy farm concept involves growing forest species in a very intensive manner on a short-term coppice rotation. Biomass productivity under close-spaced, short-rotation conditions has been estimated to range from 11.2 to 29.1 dry tons per hectare per year with current technology.

A key to maximum biomass production is rapid establishment and early utilization of the growing capacity of the site. Optimized conditions for nutrients, water, and tree growing space will be required for maximum yield. This can be accomplished in short-rotation energy plantations by using close spacings and high tree densities. However, annual biomass production will be influenced by rainfall and may require irrigation to assure maximum production. The accelerated harvesting of the short-rotation plantations at intervals of 4 to 8 years may rapidly deplete the site of plant nutrients and require fertilization to maintain maximum production. Therefore, the need to irrigate and fertilize might increase forest biomass production costs considerably. Inman (6) made an economic evaluation of production costs for silvicultural energy farms and found that the two primary production cost items were fertilization and irrigation, accounting for up to 40 percent of the total forest biomass production cost.

A possible economic solution to these two requirements (irrigation and fertilization) to maximize biomass production might be to utilize treated municipal wastewater. More than 98 billion liters of wastewater are discharged daily into streams and lakes throughout the United States and represent one of the principal point sources of water pollution. Passage of the Federal Water Pollution Control Act of 1970 and Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972, set into motion federal action to alleviate water pollution and to eliminate the discharge of pollutants into the nations's waterways by 1985. With federal cost-sharing funds authorized through the Act more waste treatment plants are being constructed and a higher degree of treatment is being required.

As a consequence, the volume of secondary treated wastewater will increase greatly during the next 20 years. Secondary treated wastewater has had most of the suspended solids and organic matter removed but still contains high concentrations of dissolved nutrients. In many cases, advanced treatment is required to reduce nutrient concentrations to acceptable levels prior to discharge to receiving waters to prevent water pollution. One of the alternatives for advanced treatment of wastewater is land application.

Passage of the Clean Water Act of 1977 further encouraged land treatment systems by providing financial incentives. Under this Act, innovative treatment systems, which include land treatment, are given 85 percent funding for design and construction as opposed to 75 percent funding for conventional systems. Land treatment systems may require large tracts of land. For instance, Pound et al. (7) estimated that land requirements for a 10 mgd wastewater treatment plant might range from 567 to 1377 hectares depending upon climatic, soil, and irrigation application rate. Such land could be used for the establishment of energy plantations. The forest energy plantations could benefit from the nutrients in the wastewater, which might increase biomass productivity and shorten rotation periods, and at the same time provide a land treatment system for the renovation of the urban wastewater.

Based upon current levels of short rotation tree crop productivity, Inman (6) has estimated that 2 to 5 million hectares of land are required to produce one quad of energy. As the demand for food and fiber production increases, the availability of prime land for energy production will likely decrease. With the amount of prime farmland decreasing and the value of land increasing, it may become necessary to utilize marginal lands or lands unsuitable for agricultural production to establish energy plantations.

Energy Plantations

Marginal Land

A study was initiated to determine if wastewater irrigation would increase biomass production on marginal land, and at the same time if the energy plantation could satisfactorily renovate the wastewater for direct groundwater recharge.

In 1973, a hybrid poplar (*Populus spp.*) plantation was established on an abandoned agricultural field at the Penn State Wastewater Project Facility on a Hagerstown silt loam soil (*Typic Hapludalf*). Cuttings were planted at three spacings of 12, 24, and 48 cm in rows 76 cm apart, which provided 0.09, 0.19, and 0.37 square meters of growing space per tree, respectively. Six replications were established. Three replications received wastewater irrigation and three replications were maintained as an unirrigated control. In 1978, a similar plantation was established adjacent to the existing

Table 5-1. Typical Concentrations of Selected Chemical Constituents Applied in the Wastewater.

Constituent	Concentration	Constituent	Concentration
pH	7.5		
	mg/l		µg/l
Ortho P	4.3	Cu	81.6
Total P	5.6	Zn	183.0
NO_3-N	8.0	Mn	70.0
NH_4-N	8.0	Cr	45.8
Org N	3.2	Pb	28.9
Total N	18.9	Cd	6.8
Cl	47.1	Co	19.1
K	10.3	Ni	25.6
Ca	47.8	Hg	3.9
Mg	11.9		
Na	32.8		
Fe	0.5		

Table 5-2. Hybrid Poplar Cutting Survival on Marginal Land With and Without Weed Control.

Plot	Growing Space	Survival		
		First Year[1/]	Fifth Year[1/]	First Year[2/]
	m^2	%	%	%
Control	0.09	92	87	94
	0.19	94	93	95
	0.37	88	87	96
Wastewater Irrigated	0.09	83	57	95
	0.19	93	79	98
	0.37	79	64	97

[1/] Without weed control

[2/] With weed control.

plantation, which duplicated the exact spacings and treatments. Secondary treated municipal wastewater was pumped from the University Waste Treatment Plant to the site. The irrigated plantations received an application rate of 5 cm per week during the growing season (April to October). Samples of the wastewater applied were collected at the time of irrigation and analyzed for various chemical constituents. Typical concentrations of these constituents are presented in Table 5-1.

To obtain samples of soil water percolate, suction lysimeters were installed at the 120 cm depth in each growing space subplot of both the wastewater irrigated and control plantations. Samples were collected within 24 hours after the irrigation period.

Total tree height and basal diameters, (outside bark and 25 cm above

the ground), were measured on all trees in 1977 at the end of the fifth growing season. Eighteen trees were selected that were representative of the average height and basal diameter in each growing space for determination of biomass production. After the sample trees were harvested and all measurements completed, the entire plantation was harvested. The trees were cut 5 cm above the ground allowing for coppice regrowth the following spring. At the end of the 1978 and 1979 growing season, tree heights and basal diameter were measured on all trees in both plantations.

First-year tree survival and final survival at harvest after 5 years are given in Table 5-2. Overall survival was higher on the control plot for all tree densities. It is quite apparent that on the control plot most of the mortality occurred during the first year. Trees that survived the year of establishment usually survived until harvest. Survival was slightly lower on the wastewater irrigated plot during the first year. However, considerable mortality occurred during the last 4 years. There appears to be no correlation between survival and tree density. One possible explanation for the higher mortality in the wastewater irrigated plantations might be the fact that wastewater irrigation stimulates herbaceous vegetation growth thus providing a more favorable habitat for mice and rabbits. No cultural treatments were used to control herbaceous vegetation in this plantation.

In the second hybrid poplar plantation established in 1978, weed control was used to reduce competition of the herbaceous vegetation with the newly planted cuttings. Survival was tallied at the end of the first growing season and the results are given in Table 5-2. Employing weed control during the first growing season, significantly increased tree survival in the wastewater irrigated plot to where it surpassed survival in the control plot. As without

Table 5-3. Average Height and Diameter Growth of Hybrid Poplar Cuttings After Five Growing Seasons on Marginal Land.

Growing Space	- - - Height Growth - - - Control	Wastewater Irrigated
m^2	m	m
0.09	2.9	4.4
0.19	3.2	4.8
0.37	2.8	5.3
Growing Space	**- - - Basal Diameter[1/] - - - Control**	**Wastewater Irrigated**
m^2	mm	mm
0.09	21.5	34.5
0.19	25.5	37.8
0.37	27.5	51.2

1/ Outside bark.

Table 5-4. Actual and Potential Woody Biomass Production for each Growing Space in the Hybrid Poplar Plantations on Marginal Land After Five Years.

Treatment	Spacing	Woody Biomass Productivity Actual	Potential 1/
	m^2	- - - - - dt/ha - - - - -	
Control	0.09	28.4	32.6
	0.19	22.7	24.4
	0.37	8.9	10.2
Wastewater Irrigated	0.09	83.7	147.0
	0.19	57.8	73.0
	0.37	37.0	58.0

1/ Based upon 100% survival.

weed control there appears to be no direct correlation between survival and tree density.

Effects of growing space and wastewater irrigation on tree height and diameter growth after five years are given in Table 5-3. Wastewater irrigation almost doubled total tree height growth at all spacings. In the wastewater irrigated plantation there was a direct correlation between growing space and average total height growth with height growth increasing as growing space increased. In both the control and irrigated plantations, average diameter growth increased as growing space increased. Wastewater irrigation significantly increased average diameter growth at all three growing spaces.

In March 1978, after 5 growing seasons, all trees were harvested and weighed. Subsamples of trees from each plantation were chipped and oven-dried to determine average moisture content. Average moisture content was 54 percent by weight. Total biomass production (stemwood, bark, and branches) for each growing space is given in Table 5-4 for both the control and wastewater irrigated plantations. Biomass production in the plantations was inversely related to growing space, with the highest productivity occurring in the plantations with 0.09 m^2 of growing space per tree. Wastewater irrigation more than doubled the biomass production at all spacings. Mean annual biomass increment was 16.7, 11.6, and 7.4 dt/ha for 0.09, 0.19, and 0.37 m^2 of growing space, respectively. In the control plantation, the mean annual biomass increment was 5.7, 4.5, and 1.8 dt/ha for growing spaces of 0.09, 0.19, and 0.37 m^2 respectively. Biomass values given in Table 5-4 are based only upon the number of surviving trees after 5 years. Wastewater irrigation resulted in a lower survival rate than that found in the control plantation. If one could control mortality through some type of cultural treatment, the biomass production could be increased significantly. For example, the effects of weeding on total height and diameter growth of the hybrid poplar cuttings planted at the 0.19 m^2 spacing are shown in Figures 5-1 and 5-2. Weeding significantly accelerated diameter

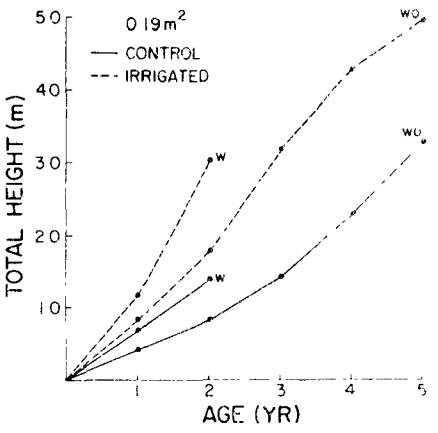

Figure 5-1. Total Height Growth of Hybrid Poplar Trees Planted on Marginal Land with 0.19 m^2 of Growing Space Per Tree With (W) and Without (WO) Weed Control.

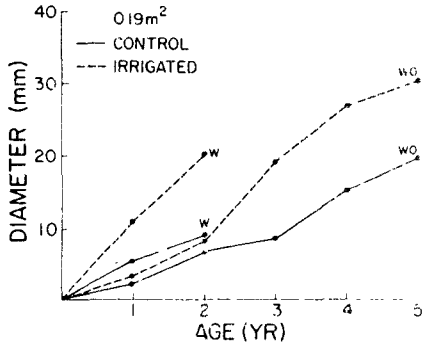

Figure 5-2. Diameter Growth of Hybrid Poplar Trees Planted on Marginal Land with 0.19 m^2 of Growing Space Per Tree With (W) and Without (WO) Weed Control

and height growth in both the control and wastewater plantations. With 100 percent tree survival, the potential biomass production could approach 150 dt/ha with 0.09 m^2 of growing space per tree.

Coppice biomass production during the second rotation was greatly accelerated in both the control and wastewater irrigated plantations. At the end of the second year, the potential woody biomass production was approximately equivalent to that predicted for the fourth year of the first rotation. Thus, the total woody biomass produced at the end of the second rotation will undoubtedly greatly exceed that harvested at the end of the

first rotation.

Wastewater irrigation was effective in increasing biomass production on marginal land. However, for the system to operate properly, the plantation must renovate the wastewater satisfactorily. The fate of nitrogen is one of the most important aspects that must be considered in regard to land application of municipal wastewater. This is particularly true for land application systems where the primary goal is renovation of the wastewater for direct recharge to the groundwater reservoir. Renovation, in terms of nitrogen, means that the concentration of nitrate-N in soil water leaving the root zone should not exceed 10 mg/l (U.S. Public Health limit for potable water). Average monthly concentrations of nitrate-N in the percolating water at the 120 cm depth are given in Table 5-5. Results indicate that the hybrid poplar plantations were quite efficient in renovating the wastewater even after seven years of irrigation, which added 1386 kg of nitrogen per hectare to the system. The annual average concentration of NO_3-N in the percolating water at the 120 cm depth was 7.0 mg/l after the first year and only increased to 8.5 mg/l after 7 years of wastewater irrigation. In comparison the average annual concentration for the unirrigated control plantation was 3.9 mg/l. Even though the concentration of NO_3-N increased after 7 years, it is below the USPH limit of 10 mg/l for potable water.

Renovation is primarily due to uptake of available nitrogen by both the hybrid poplar trees and the herbaceous vegetation. The contribution of the vegetative cover to the renovation process is particularly important in respect to plantation management. While the prolific growth of herbaceous vegetation in response to the wastewater irrigation is necessary to achieve maximum uptake of available nitrogen, it also competes with the newly planted cuttings the first year and provides a favorable habitat for rodent populations, all of which result in greater tree mortality. This is a trade-off that must be optimized to achieve adequate wastewater renovation and maximum biomass production.

Table 5-5. Average Monthly Concentration of NO_3-N in Percolating Water at the 120-cm Soil Depth.

Month	Control	Wastewater Irrigated	
		First Year	Sixth Year
	mg/l	mg/l	mg/l
May	4.7[1/]	0.7	10.6
June	4.3	3.4	5.7
July	4.9	6.2	8.9
Aug	3.5	5.8	6.1
Sept	3.8	12.1	5.4
Oct	3.7	8.1	7.9
Nov	2.7	10.5	10.2
Dec	3.3	9.0	8.4
Average	3.9	7.0	8.5

[1/] Average of all samples collected at all three growing spaces.

Disturbed Land

With the increasing number of wastewater treatment plants being built and upgraded to help alleviate water pollution problems, an additional problem is created by the increased production of sewage sludge. It is estimated that over 5 million dry tons of municipal sludge are currently being produced in the United States and that by 1985, this volume may reach 9 million dry tons per year as wastewater treatment facilities across the country are upgraded. Currently, most sludge is disposed of by land filling (40%), incineration (25%), land application (20%), and ocean dumping (15%). Most of these methods are costly, wasteful, and unproductive. Sludge can be a valuable resource that should be utilized.

A better alternative to the present methods of disposal of wastewater treatment plant sludges is land application. The option of recycling sludge on the land provides an opportunity for beneficial use of the nutrients rather than disposal of a valuable resource. A considerable amount of research has demonstrated that stabilized municipal sludge is an excellent soil amendment and chemical fertilizer substitute. However, some concern has been raised regarding the potential health hazard of using sludges on agricultural land and the potential introduction of unwanted elements into the human food chain. An alternative to agricultural lands is to utilize sludge to revegetate marginal unproductive lands or barren lands disturbed by coal mining activities.

It is estimated that nearly half of the world supply of coal, 3.6 trillion metric tons, lies beneath American Soil. At the present rate of mining, recoverable deposits should last four hundred years. However, population and industrial expansion, along with urbanization have placed an increased demand on these energy reserves with the demand for coal expected to more than double by 1985. Surface mining of coal is expected to account for 70 percent of this anticipated increased production.

The strip mining industry already has disturbed over 1.8 million hectares of land in the United States. It is estimated that the removal of the remaining recoverable coal resources could result in a disturbed land area covering 184,000 square kilometers. Much of these recoverable coal reserves lie beneath the hill and mountain ridges. Ridge-top mining, once thought to be too costly, is becoming more economical due to the increased demand for coal. The ridge-tops, currently occupied by forests, will be harvested before mining begins. The Surface Mining Control and Reclamation Act of 1977, PL-95-87, states that a permanent vegetative cover of the same seasonal variety native to the area of land to be affected must be established. Where coal is surface mined, the reestablishment of a vegetative cover can pose a significant problem. General site characteristics associated with post-mining areas include low amounts of plant nutrients and organic matter, low pH, low water holding capacity, poor physical characteristics, and toxic levels of trace elements. These conditions may be compounded by high surface

temperatures on dark spoil which can pose a potential threat of heat injury to tree seedlings and impede plant establishment and survival.

On the other hand, a key to maximizing tree growth and woody biomass production is rapid establishment and utilization of the growing capacity of the site. In order to alleviate the poor growing conditions present on a site after surface mining, large applications of lime and fertilizer are often necessary. In some instances, organic soil amendments and mulches are needed in order to obtain satisfactory vegetation establishment and meet the strict reclamation requirements set forth in Public Law 95-87. With the escalating cost of chemical fertilizers, proper revegetation will become extremely expensive.

The use of treated municipal sludge to safely ameliorate harsh site conditions and improve vegetation establishment and growth is well documented. Its use on mined land to revegetate these disturbed areas into potential energy forests can minimize many of the public health concerns since products from the forest are not generally a factor in the human food chain.

After many years of research into the feasibility of using treated municipal sludge for the reclamation and reforestation of mined lands, a field demonstration was initiated in May, 1974 in the City of Scranton, Pennsylvania. The site was typical of anthracite coal refuse banks that had burned for many years before an underground mine fire was extinguished. The resultant material was extremely low in plant nutrients and contained virtually no organic matter. Dewatered and heat dried sludge was trucked from the Scranton wastewater treatment plant to the site, where it was spread and incorporated with standard farm equipment. The area was subsequently planted with 10 species of tree seedlings and broadcast-seeded with five species of grasses and five species of legumes. Sludge application rates were 0, 40, 75, and 150 metric tons per hectare, with the highest sludge application rate equivalent to applying 20 mt/ha of a 15-4-0 commercial fertilizer.

The single application of sludge significantly improved the harsh site conditions. By September, 1974, the entire sludge treated area had a lush vegetative cover, while the surrounding area remained barren. Even after the sixth growing season there was no apparent deterioration of the vegetative cover; in fact, the dry matter production of the herbaceous vegetation more than doubled. This in part is due to the fact that sludge acts as a slow-release fertilizer. Since most of the nutrients supplied by the sludge are in the form of organic compounds, only a certain percentage are mineralized and released for plant uptake each year. The single application of sludge provided plant nutrients to sustain vegetation growth for a period of five years. By the end of this period, a permanent vegetative cover was established and the natural process of nutrient recycling is now sufficient to sustain the vegetation.

The survival and growth responses of the tree species were evaluated at the end of each growing season. The hardwoods were far superior to the conifers in terms of both survival and growth. This is partially due to the fact that the sludge also stimulated the growth of the herbaceous vegetation, which overtopped and crowded out the slower growing conifers. Of the ten tree species planted, the best survival and growth response was obtained with hybrid poplar, black locust, and European alder. Results of the hybrid poplar height and diameter measurements are given in Table 5-6. At the end of five growing seasons, it was evident that the hybrid poplars grown on the area that received a single application of 150 mt/ha of sludge nearly doubled in height growth over the poplars planted in an area that received no sludge. After five years, the average height of the hybrid poplars planted in an area that received no sludge was 2.5 meters whereas the height of the poplars grown in the sludge treated area was 4.5 meters. The average basal diameter of the poplars in the unsludged area was 2.5 cm and in the 150 mt/ha area, 6.1 cm. The potential woody biomass of the hybrid poplars at the end of five growing seasons was calculated using average height and basal diameter measurements and assuming 100 percent survival. The results are given in Table 5-7. The results indicate that on an area where no sludge was applied to the burned anthracite refuse, 5 mt/ha of woody biomass

Table 5-6. Average Height and Diameter Growth of Hybrid Poplar Cuttings Grown on Anthracite Refuse After Five Growing Seasons.

Sludge Application Rate	Height	Diameter
mt/ha	m	mm
0	2.46	25
40	3.41	42
75	3.80	47
150	4.53	61

Table 5-7. Potential Woody Biomass Production of the Hybrid Poplars Grown on Anthracite Refuse After Five Years.

Sludge Application Rate	Potential[1/] Biomass Production
mt/ha	mt/ha
0	5.0
40	19.8
75	27.6
150	55.3

was produced; whereas, in the area that received an application of 150 mt/ha of sludge, 55 mt/ha of woody biomass was produced. This indicates that after five years the production of woody biomass increased more than tenfold with the single application of sludge.

Conclusions

With increased population and industrial expansion, along with urbanization, the demand for energy is expected to steadily increase. Due to the limited supply of existing fossil fuel resources, alternative renewable energy sources are being investigated. Results of these two field studies indicate that there is a common relationship between the two concepts of land treatment of municipal wastewater and sludges and increased woody biomass production on silvicultural energy farms.

The use of wastewater and sludge on marginal and disturbed lands provides an economical method of establishing and growing wood fiber and at the same time efficiently renovates wastewater for groundwater recharge and utilizes sludge without adverse effects to the environment.

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III / PHILADELPHIA STRIP MINE RECLAMATION PROGRAM

OVERVIEW

G. Kenneth Dotson

In Section II, the small reclamation demonstration projects of the state of Pennsylvania were discussed. Several other small research and demonstration projects will be discussed in the symposium, but there are few large full-scale mine reclamation projects with sludge, where economic and engineering feasibility can be evaluated. In this section, one such project will be discussed from the point of view of the city that produces sludge, the contractor who reclaims the mine spoil, and the state agency with regulatory responsibility.

The permanence of the increase in productivity of the spoil that is invariably observed from sludge use remains to be determined. The Pennsylvania demonstrations show that all application rates used have supported grass and legumes for three years. The project will be continued for two more years to determine whether the grass and legumes will continue to grow satisfactorily after five years from the time of sludge application.

One of the early studies, using anaerobically digested liquid sludge for reclamation purposes, was conducted at two sites in Stark County, Ohio in 1965. One site, in Pike Township, was divided into diked plots upon which sludge was applied from a tank truck at rates varying from three to fifteen gallons per square foot. The spoil was classified as marginal for reclamation because of strong acidity, but it was not so acidic as to prevent tree growth.

A second site, in Sandy Township, was very small, but too acidic to reclaim with conventional reclamation methods. The pH varied from 2.8 to 3.3 and had thwarted reclamation efforts for eight years.

After application, the liquid sludge was allowed to dry enough to form cracks and a mixture of four grasses and one legume was surface sown. Vigorous growth resulted wherever the dried sludge thickness was one inch or more. I visited the sites in 1968, and again in 1972, and found a thick stand of grass in the plots. No crop had been removed so nutrients were recycled. If a crop had been harvested and removed from the site annually, frequent maintenance applications of nutrients might have been required to maintain a satisfactory growth rate.

Even though sludge is very effective when it is used to renovate recalcitrant mined lands, there are many questions concerning future use of the land to be answered before plans for sludge use can be developed with confidence. There is little need for concern about the metals added to the land. However, if society decides that the land should be returned to production of crops, or developed into residential sites the same restrictions on sludge application that are used on agricultural land will be needed. So, some of the decisions about the use of sludge on mined land are political decisions to be made by society. There is little need for concern about the metals added to the land, if the vegetative cover to be established is to meet regulating requirements on land that will not be used for crops or residential development.

6
PHILADELPHIA'S SLUDGE MANAGEMENT PROGRAM—A MULTI-FACETED APPROACH

Frank Senske and Diane Garvey

History

Ocean dispersal of sewage sludge was first practiced by Philadelphia in 1961. In 1972, the Marine Protection, Research and Sanctuaries Act (PL92-532) was passed by Congress and ocean barging was banned as a disposal method. Soon after, U.S.E.P.A. Region III formulated a permitting system whereby the City would reduce the quantity of barged sludge by 50% before 1979, and totally stop barging before 1981.

The City filed an appeal against the agency's decision based on extensive studies at two disposal sites which revealed little evidence of damage to the marine environment.

At the same time, the public became very concerned about dumping of wastes in the ocean. Political and emotional aspects of the issue were highly visible in newspaper and magazine articles. Many unexplained phenomena, such as the occurrence of a sonic boom over the ocean, were attributed to ocean barging of municipal sludge. Subsequently, the courts ruled that PL93-532 would be rigidly interpreted.

The City was forced to quickly substitute ocean disposal with alternate methods while, at the same time, new secondary wastewater treatment plants were being constructed. The new plants now produce 190 DTPD of sludge and by 1985 it is expected that daily production will reach 305 DTPD. To evaluate new sludge alternatives, the City examined three general categories: thermal processing, land disposal and land utilization. The following section is an evaluation of the major alternatives that were considered.

Alternatives

Thermal Processing

Incineration is a form of volume reduction whereby solid waste is sterilized and reduced in volume. Actually, this is a processing step before final disposal or utilization on land. For a large city, incineration is a viable alternative because the land requirements are minimal. Also, if sludge is coincinerated with municipal refuse, it is possible to recover energy for direct use by the City. Another thermal process, starved air combustion systems (pyrolysis), is suitable for highly toxic sludges because less particulates are emitted and

many non-biodegradeable pollutants such as PCB's are destroyed.

Conversely, incineration has disadvantages which may pose insurmountable problems, including the release of heavy metals to the atmosphere. Even the use of scrubbers, precipitators and cyclones does not prevent long-range atmospheric transport of pollutants. For instance, conventional air pollution control devices permit 40% of cadmium in the waste to be emitted (1).

Another drawback of sludge incinerators is the high cost of fuel oil needed. Even when codisposed with refuse, substantial quantities of fuel are needed to evaporate the moisture from sludge before the material reaches an autogeneous state. In an EPA study of 150 sludge incinerators, 10% of these were shut down due to high fuel costs or inability to meet air quality standards and an additional 20% were in violation of their State Implementation Plan.

Although land requirements for an incinerator are minimal, the siting of an incinerator is difficult due to localized citizen objections. Also, disposal of ash, usually in a slurry form, requires a suitable area for lagoons or a landfill.

Finally, thermal processing sacrifices the valuable organic fiber and essential micro and macro-nutrients, contained in sewage sludge. Unlike commercial fertilizers, the nutrients are in a temporarily bound form and are released slowly over a 2 to 4-year period.

One form of thermal processing has been undertaken by the City as an alternative. The Ecorock process designed by the Franklin Institute Research Laboratory is a demonstration project whereby dewatered sewage and municipal solid waste incinerator residue will be combined in a rotary kiln. The inert material in the wastes will reach molten state at 1800°F which, when cooled, becomes a hard rock. The rock when crushed is expected to be an excellent road aggregate which will pass Federal Highway Administration testing for skid resistance. Construction of the pilot plant is scheduled to be completed in July, 1981.

Land Disposal

Sludge disposal in landfills may serve as a short-term disposal method; however, a survey of landfills available for Philadelphia sludge showed an uncertain future. PaDER does not recommend landfilling sewage sludge with municipal refuse and at present, no landfills are open for sludges.

Surface impoundments (lagoons) are used for interim storage but are not suitable as a long-term solution due to the humid climate in this area. In arid climates where the evaporation rate is high, lagoons may be a long-term solution.

Land Utilization

This alternative is inherently different from other options since sludge-based

soil conditioners utilize the nutrients and organic material contained in municipal wastes. Sludge-based products are 40-50% organic matter and this imparts beneficial characteristics to the soil. Increased water retention and granulation, decreased plasticity and cohesion, high cation exchange capacity and organic forms of nitrogen, phosphorous and sulfur are all characteristics of organic soil (3). Small amounts of organic compounds are of great benefit to plant life and it is believed that growth inducing substances, such as vitamins, hormones and amino acids, are taken up directly through the roots of plants (3). The application of sludge benefits the land in this manner by imparting organic characteristics to the soil.

Large amounts of land are required for a successful land application program. Philadelphia, producing an expected 70,000 DTPY, would require about 2000 acres per year of state permitted farmland, reclamation land and landscaped area combined.

Public acceptance is required before a land utilization program can be fully implemented. It has been found that citizens outside Philadelphia County are concerned about surface and groundwater contamination, introduction of heavy metals on the food chain, odor problems and pathogens. Educational programs must be conducted to show that by using a high quality sludge under proper management techniques, such drawbacks are avoided. Other more radical opponents of sludge utilization voice unfounded accusations ranging from sludge causing fetal abnormalities to land application being an underhanded plot to dispose of Three Mile Island's radioactive material. Only many years of successful and responsible land application projects can change these attitudes.

Other alternatives to ocean dispersal are the high technology methods. Private companies have made many proposals involving "special processes" whereby dangerous substances would be annihilated or permanently found in an inert form. Usually these proposals are unproven and costly. Even if the process is economically and scientifically feasible, the POTW is ultimately responsible for its sludge. Sludge is produced daily and a POTW is reluctant to place itself in a situation where final sludge disposal will be totally dependent on a private enterprise.

Philadelphia's Experience

After investigating the alternatives, Philadelphia formulated the following *Sludge Master Plan* (4):

1. Product and Market Development
   - A. Give Away Program
   - B. Market Evaluation
   - C. Disinfection Evaluation
   - D. Recycle Center

E. Industrial Waste Regulations
F. Composting Program

2. Sludge Diversion
   A. Dewatering Program
   B. Liquid Application Program
3. Alternative Methods for Using Diverted Sludge
   A. Reclamation Program
   B. Landfill Program
   C. Agricultural Uses
   D. Non-Agricultural Uses
   E. Resources Recovery Programs

The plan involved utilization rather than disposal techniques as recommended by the Federal government in the Resource Conservation and Recovery Act. Therefore, the quality of sludge is of major importance. One way in which Philadelphia maintains a consistently high quality sludge is through Industrial Waste Regulations.

Starting in 1977, before Federal agencies promulgated industrial effluent metal limitations, the City implemented its own set of metals limitations on industrial effluent entering the sewage system (See Table 6-1). This step has significantly lowered metals concentrations in the sludge as can be seen in the before and after liquid sludge analysis shown in Table 6-2. The Northeast Plant is especially influenced since it serves the City's major industrial area.

Enforcement of the regulations is conducted by a special unit in the Water Department. Automatic samplers are placed at industrial connections and various interceptors to monitor BOD and suspended solids or metals, and appropriate surcharges are collected. When monitoring data indicate a mobile source, the Industrial Waste Unit cooperates with the Police Department in prosecuting "midnight dumpers".

Another method of improving the final product is sludge digestion. At both treatment plants sludge is anaerobically digested for at least 15 days at 98°F. This is a Process to Significantly Reduce Pathogens according to EPA. This process also reduces odors and produces a more acceptable material.

The digested product at 5% solids can be utilized in the City's Liquid Philorganic Program. The material not only contains up to 50% organic matter, but also ranges between 3 and 4% nitrogen by weight. When the liquid is sprayed or injected on grain or sod farms, it can supply 100% of the crop's nitrogen demand without exceeding PaDER metals limitations.

The City provides supervised application of Liquid Philorganic to suitable farmers in the five-county metropolitan area surrounding Philadelphia. A suitable farmer is one who uses responsible farming techniques on land of less than 15% slope and fairly well-drained soils. The program, according to DER guidelines, promotes the practice of good soil

Table 6-1. Philadelphia Industrial Effluent Limitations: Effective Date. January 1, 1977.

METAL	PRE-effective date connections	POST-effective date connections
	mg/l	mg/l
Arsenic	1	1
Silver	5	3
Cadmium	0.1	0.1
Nickel	10	3
Lead	3	1
Zinc	30	5
Copper	15	3
Chromium	15	3
Mercury	0.005	0.005
Selenium		0.1

Table 6-2. Typical Analyses of Philadelphia Liquid Digested Sludge.

Metal	Northeast		Southwest	
	1976	1979	1976	1979
	- - - - - - - - - mg/kg dry wt. basis - - - - - - - - -			
Cadmium	100	30	25	20
Copper	2200	1100	1100	750
Nickel	350	350	100	100
Lead	2600	700	2700	750
Zinc	5700	(4700)*	2700	(2800)*
Chromium	2200	1000	1200	350

*These values are expected to drop due to decreased zinc usage in the Water Distribution System.

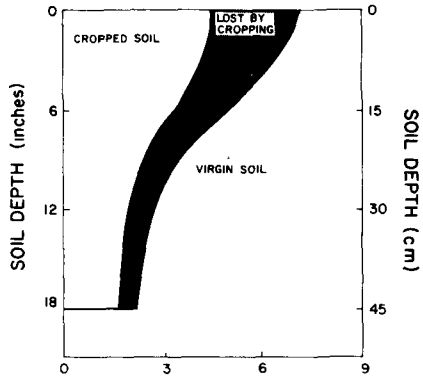

Figure 6-1. Percent Organic Matter in Soil (N X 20).

conservation techniques such as contour plowing, slope limitations and buffer zones.

A farmer using Philorganic has reduced fertilizer requirements and can save approximately $40/acre [in 1979 dollars]. In addition to fertilizing ability, liquid sludge can renew the supply of organic material removed by cropping. Figure 6-1 shows the extent to which organic matter is lost by normal farming practices. About 25% of the organic matter is lost from the 0 to 6 inch layer as a result of cropping (4).

The application of the liquid is coordinated with the farmer's management plan but equipment operators and field supervision is conducted by Water Department employees and contractors. The applicator vehicle is especially designed to prevent soil compaction through the use of flotation tires. Tanker trucks transport the liquid to the site where it is then transferred to the applicator vehicles. The vehicles owned by the City each have the ability to both inject and spray liquid sludge at constant rates. However, the liquid program is limited due to low application rates (see Table 6-3) and high transportation costs. Furthermore, public opposition has slowed almost every liquid project undertaken outside the City boundaries.

In order to develop other sludge management alternatives, the digested sludge must be dewatered. The dewatering facilities at the Southwest Water Pollution Control Plant include two Bird HB6400 units rated at 100 DTPD and an Infilco filter press rated at 150 DTPD. The total plant dewatering capacity is 350 DTPD and a sludge cake is produced which averages 25% solids.

At the Northeast Plant, two Sharples centrifuges dewater 50 DTPD each and three Carter belt filter presses at a rated capacity of 50 DTPD bringing the total dewatering capacity of this plant to 250 DTPD.

After dewatering, sludge is loaded on dump trucks and transported to the interim composting sites at each plant. The extended pile aeration

Table 6-3. Philadelphia Agricultural Application Rates.

		Liquid Sludge		Compost	
Parameter	Pa.DER Limits	NE	SW	NE	SW
	lbs/a/yr	- - - - Solids loading rate (dt/a/yr) - -			
Cadmium	1	17	25	34	34
Copper	20	9	13	9	22
Nickel	4	6	20	13	33
Lead	20	14	13	18	17
Zinc	40	4	7	9	10
Chromium	20	10	29	25	40
Nitrogen	crop	6	5	23	30

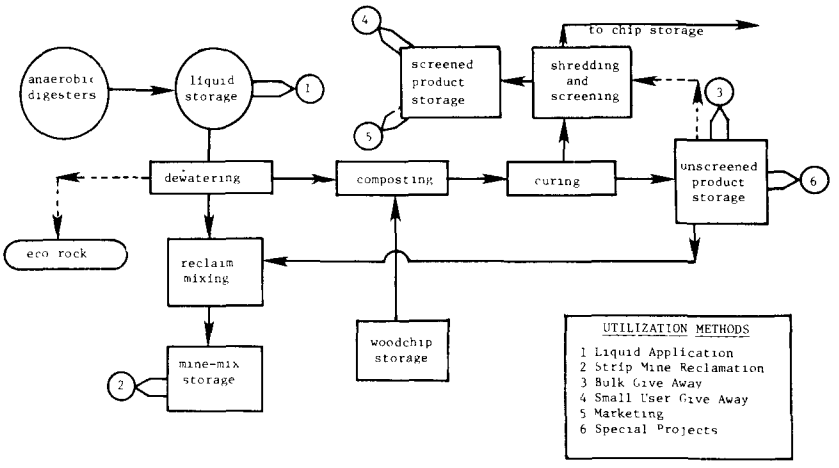

Figure 6-2. Sludge Handling, Processing, and Utilization.

method works well using woodchips as a bulking agent with a ratio of sludge to woodchips of 1:2. The woodchips are a major expense at $8 per yd^3 so a shredder/screen system is used to reclaim the chips. Moreover, the screened compost is a fine, homogeneous soil conditioner which is used for several programs: marketing, small user Philorganic Giveaway and special projects. At this time, screening capacity is limited to 200 yds^3/day; therefore, the Philorganic Give Away also offers unscreened material to large users.

A schematic diagram of sludge handling and processing is shown in Figure 6-2, as well as a list of utilization methods. Bulk giveaway and small user giveaway are part of the Philorganic program. Compost and instructional brochures can be picked up by the homeowner or landscaper at one of two distribution centers in the City. At present, no EPA guidelines have been recommended for distribution and marketing of sludge-amended products; therefore, the Water Department has adopted a conservative policy on Philorganic recommendations. For instance, Philorganic is not recommended for use on vegetables.

The volume given away each year has been steadily increasing. This is attributed to improved sludge quality and continuous efforts towards developing public awareness. Public education is achieved through a hotline number which, when dialed, provides a recording with information for the potential user. The hotline number is broadcast on television and radio public service announcements and through Philorganic posters on City vehicles. Another tool used to increase public awareness is a standing floor display equipped with signs, illustrations and instructional brochures. The exhibit

has been shown in lobbies and offices around town, and at libraries, trade shows and conventions in the metropolitan area. The major educational event used by the Philadelphia Water Department is the Philadelphia Flower Show where more than 200,000 people have an opportunity to learn about all of the City's sludge utilization projects.

Dry and Liquid Philorganic is also used in several special projects. Ball fields, parks and City-owned golf courses have been rejuvenated. Landfills and abandoned lots have been reclaimed using specialized equipment capable of incorporating compost to a depth of eighteen inches.

The Marketing Program has just recently gone on line. The Southwest compost material under the tradename of "Gardenlife" will be sold under contract in 40-pound bags, by a firm which expects to sell 50,000 bags of screened product before July of 1981. This may eventually phase out the giveaway program, but both will continue until marketing proves successful.

Strip mine reclamation projects utilize a special combination of sludge products: one part unscreened compost and one part dewatered digested sludge. This "mine mix" has a higher nitrogen content than straight compost and operational costs are reduced by deleting the composting steps for 50% of the material. At the same time, transportation costs are less than those of liquid and are feasible for the 250 mile haul.

In 1978, a demonstration was performed on 10 acres of land in Somerset County. The 90 dry ton per acre application rate stimulated the growth of a mixture of grasses and legumes. Extensive monitoring was conducted by Penn State University and included laboratory analysis of surface water, soil water, ground water, vegetation, sludge products and yield studies. Parameters tested include 11 metals, various forms of nitrogen, nutrients and fertilizer equivalents. Results for the monitoring program indicated the worth of the application program to the reclamation process and showed no detrimental effects to site water or vegetation.

In full-scale projects, application rates are calculated in accordance with PaDER Guidelines, "Sewage Sludge Use for Land Reclamation," (Chapter 75, Subchapter C, Section 75.32). Table 6-4 shows how these limits affect Philadelphia's program. Philadelphia sludge is low in metals; thus, maximum rates of 60 dt/acre can be applied without surpassing the recommended metal loading rates.

For each reclamation project, a permit application is prepared for the City by Modern-Earthline Company and submitted to PaDER. Copies of the application are also sent to Township Supervisors and the local health department for their review.

Once a permit is approved, local truckers are hired to transport the sludge. Usually these are coal trucks delivering coal to Philadelphia and transporting mine mix back to western Pennsylvania. Upon delivery to the site the sludge is deposited in a designated, bermed area.

Table 6-4. Philadelphia Reclamation Application Rates.

Parameter	Mix-Material	Pa. DER Limits[1]	Amount Applied[2]
	mg/kg	lbs/acre	lbs/acre
Cadmium	5	3	0.6
Copper	625	100	75
Nickel	94	20	11
Lead	473	100	57
Zinc	1495	200	179
Chromium	377	100	45

[1] Pa.DER Max. solids loading rate is 60 DT/AC

[2] At 60 DT/AC

Once a mine is backfilled and topsoil replaced, inspectors from the Office of Surface Mining visit the site and check for proper drainage features, erosion control and suitable slopes. Approval may be given with specified conditions such as mulching, diversions, gravel waterways or sedimentation ponds. When DER receives written approval from the Office of Surface Mining, a solid waste specialist also performs a site investigation. Again recommendations are made for erosion and runoff control and a permit may be approved with additional conditions. Often conditions include: staking haybales where gullies form for purposes of filtration, contour incorporation of mine mix, buffer zones where slopes exceed 15%, netting and woodshavings in gullies..

Occasionally, a finished portion of a site that is not completely backfilled can be approved for temporary storage of the sludge product. A suitable storage site must be backfilled to the original contour, leveled and bermed. The mine mix is then covered with plastic to prevent infiltration of rain water.

In order to facilitate proper loading rates during application projects, two-acre plots are staked out and the appropriate amount of sludge product is spread in each area. For instance, at a loading rate of 60 dt/ac each 2 acre area receives 10 truckloads of mine mix. Prior to sludge application, the area is also limed and the pH is brought up to at least 6.5.

Local farmers are employed to spread the material using manure spreaders. In addition, a special vehicle, the Ag Chem "Terragator" is also used to spread mine mix. This large five wheeled vehicle has a 17-ton capacity and can apply a full load in 5 minutes. Incorporation along the contour is performed using a disk or tractor.

A seed mixture of two legumes and two grasses are then broadcast at a rate of 60 lb/acre. The varieties are chosen according to their suitability

to the season and sludge compatability. The most popular varieties are crownvetch, alfalfa, winter rye, birdsfoot trefoil, orchard grass, and tall fescue. Vegetation is analyzed annually for metals by Penn State Laboratories and within two years the area is suitable for grazing.

Summary

Despite difficulties encountered in implementing sludge utilization alternatives, the City of Philadelphia is now involved in several full-scale sludge utilization programs. The following is a brief description of each alternative:

The Ecorock Sludge-Residue Fusion Demonstration Plant is now under construction. This process will utilize the inert portion of digested dewatered sludge to produce a dense rock suitable for use as road aggregate.

Liquid sludge is applied on farmland for pastures, grain and sod farms. The application is free to qualifying farmers in the five-county Philadelphia area and can supply up to 100% of the crop's nitrogen requirements.

The Philorganic Giveaway Program provides residents of the Philadelphia area with a high quality soil conditioner. Dry Philorganic is not recommended for use on vegetable gardens but instructions are provided for use on house plants, landscaping projects, trees, shrubs, lawns and flower gardens.

The screened compost product is marketed in 40-lb. bags under the registered trade name of Gardenlife. Vendors of the product include nurseries, florists, supermarkets and hardware stores.

The strip mine reclamation program utilizes the largest quantity of sludge product. The digested sludge-compost mixture is trucked to western Pennsylvania and applied to backfilled stripmines. This method of reclamation results in lush vegetative growth whereas conventional techniques result in minimal growth.

In the future, the Water Department will continue to pursue its multi-faceted sludge management policy and hopefully develop each Program to the point where it could utilize the majority of the sludge generated by the City. This should provide the greatest degree of flexibility in dealing with changing attitudes and regulations.

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7
IMPLEMENTATION OF THE PHILADELPHIA STRIP-MINE RECLAMATION PROGRAM IN SOMERSET COUNTY, PENNSYLVANIA

Douglas T. Murray and Todd Giddings

Public opinion on the utilization of municipal sewage sludge and compost for revegetation of strip-mined land ranges from reluctance to strong opposition in rural Pennsylvania. The demonstration-site approach was chosen for implementation of Philadelphia's program in order to overcome this situation and to gain the confidence of rural communities for full-scale operations in subsequent years. Citizen involvement, through monitoring, and an education program were key aspects for maintaining acceptance gained through the first year's demonstration phase.

Background

The successful implementation of Philadelphia's strip-mine reclamation program was based on Modern-Earthline Companies' more than 15 years of experience in the waste disposal field and on more than 10 years of research on sludge utilization by The Pennsylvania State University. In view of the traditional public opinion that sludge is a waste product for disposal and that utilization poses a health hazard, a demonstration-site approach was chosen to form the basis of an education program to gain acceptance of sludge utilization for strip-mined land reclamation. The reluctance of the general public was compounded by the hesitancy of rural communities to accept sludge from a large, metropolitan area even though these rural areas were where the greatest benefit could be derived from utilization of the sludge. Candidate sites in several counties were rejected by local officials except in Somerset County where the County Commissioners supported the operation of a demonstration site.

Approach

The demonstration-site approach was selected for several reasons. The proposed site was only ten acres in area, and being very small in size, would not pose a large imagined threat to health in the minds of the public. Monitoring of all environmental aspects of the project was conducted in a very thorough and intense manner so that all possible questions of environmental impact and health aspects could be answered for the questioning public. This demonstration-plot approach is similar to that often

utilized by county extension agents who introduce a new corn variety on a small part of one farmer's field so that many of the farmers in the county can then visit that field at the end of the growing season and observe first-hand the success of this new and formerly untested seed.

Site Selection

The site selection process was the first key step to developing the demonstration site. A site was chosen that was readily visible from an improved township road and in a location that was readily accessible from the nearby communities. Also, the site was adjacent to an area that was strip mined the previous year and reclaimed by commercial fertilizer and conventional reclamation methods to provide a comparison of the standard reclamation methods with the results from utilizing municipal sewage sludge.

Design

The design of the operation emphasized the employment of local people for all appropriate work in conducting the project. Local truckers were hired to haul the composted sewage sludge from Philadelphia to the site, and local farmers were hired with their equipment to spread and incorporate the compost and to seed the site. In this way, many local people gained a first-hand personal experience with the operation, economic benefit, and were able to explain it to their neighbors.

Operation

The operation was designed by technical consultants to Modern-Earthline Companies, and all operational phases were supervised by both management and technical personnel, who were on site at all times during the operation to direct the work. An extraordinarily thorough monitoring program was designed and implemented at the site to provide answers to almost every question that could be posed by the skeptical public. Soil characteristics, soil-water quality, and ground-water quality were sampled and analyzed prior to application of the compost, and then soil-water and ground-water were monitored frequently throughout the application operation and first two years of vegetation growth. Soil samples and vegetation samples were analyzed at the end of the first and second years' growth to demonstrate that no harmful build-up of heavy metals or other elements in the soil or vegetation had occurred. The vegetation growth was more dense and lush than the neighboring, conventionally reclaimed site and provided a good contrast for the local citizens to observe and compare the benefits of utilizing the compost.

Education

Recognizing the health concerns and general opposition of the uninformed public to a project of this type, a comprehensive public education program

was implemented early in the project. Informational meetings utilizing 35 mm slide programs and question-and-answer sessions were conducted throughout the county with such groups as the Conservation District, the Lions Club, and the Rotary Club. In this way, a foundation was prepared to indicate that there was no risk posed to public health by this project, and that all aspects were very thoroughly designed and monitored. Descriptive pamphlets were passed out to site visitors and interviews and news releases were prepared for local TV, newspaper, and other news media.

Full-scale Operation

The second step in the demonstration-site approach was to utilize the very satisfactory monitoring data and successful revegetation results as the technical basis for expanding the utilization of compost and sludge to a full-scale operation in the second year. Therefore, early in 1979 several public meetings were held throughout Somerset County to present the results of the demonstration site operation and to explain the proposed expansion to a full-scale operation at several locations throughout the county. A Strip Mine Reclamation Advisory Board was formed, and these public officials and citizens met monthly with operational and technical personnel to discuss the operation and monitoring results of the project. This group provided a liaison with the citizens and assisted in explaining their experiences with the project and in educating their neighbors. The Advisory Board conducted site visits and tours of the six sites that were reclaimed in several areas of the county during 1979. Following these site visits, they provided suggestions and guidance for future operations.

The next step in the process was to build upon the experience that had been gained in revegetating approximately 300 acres in 1979 in order to facilitate permitting, operation, and monitoring of the approximately 700 acres reclaimed utilizing compost and sludge in 1980. Many procedures and designs were standardized to facilitate installation and operation of the ground-water quality monitoring wells, installation and maintenance of sediment and erosion control structures, and to maintain and coordinate input from the Somerset County Conservation District and Soil Conservation Service personnel. These procedures were developed to assist operational, technical, and Department of Environmental Resources review personnel in conducting the various activities necessary to permit, operate, and monitor many sites located in several counties.

Summary

The demonstration-site approach to developing a large-scale (multi-site and

multi-county) program for the utilization of Philadelphia compost and sewage sludge has proven to be very successful. Key aspects of the program were the continuous involvement of experienced operations and technical personnel in every project phase, involvement of local citizens both working on the operations and in providing review and input, close coordination with the Department of Environmental Resources technical staff, and an on-going public education program. The success of the program has spread throughout Somerset and neighboring counties, and many strip-mine operators are now desirous of being involved in the program. Continued public education activities will be necessary as new sites are developed in new areas. Modern-Earthline Companies is now utilizing specialized equipment and following the proven approach of local involvement and close coordination so that the continued success of this strip-mine reclamation program throughout a wider area of western Pennsylvania is assured.

8
ONE ALTERNATIVE TO OCEAN DISPOSAL OF SLUDGE: RECYCLING THROUGH LAND RECLAMATION

Sonja N. Kerr and William E. Sopper

With the cessation of ocean disposal of sludge mandated for December 31, 1981, large coastal metropolitan cities are faced with a dilemma. They must come up with an environmentally acceptable alternative. Usually there is very little land in close proximity to the city for use as either an on-going land-based utilization facility or area available to be dedicated as a sanitary landfill. Incineration is becoming more and more costly as the price of natural gas increases and it becomes increasingly more difficult to meet the strict federal and state air pollution requirements. The City of Philadelphia, Pennsylvania, with the help of Modern-Earthline Companies, has demonstrated that sludge can be used to revegetate barren strip mine land in Western Pennsylvania, 400 kilometers from the city limits, in an environmentally safe manner and at the same time it can be economically competitive with other methods of sludge disposal.

Introduction

Over 4.5 million dry metric tons of municipal sludge are currently produced annually in the United States. It is estimated that this figure will double in the next few years as wastewater treatment facilities are upgraded to meet federal water pollution regulations. Currently, approximately 700,000 metric tons of sludge are being disposed of annually by ocean dumping. Federal law now mandates that ocean disposal of sludge must cease by December 31, 1981. Large coastal metropolitan areas are particularly hard pressed to find an environmentally acceptable alternative of sludge disposal as ocean dumping is phased out. One of several innovative sludge disposal alternatives was investigated and is currently being used by the City of Philadelphia, Pennsylvania. Several years ago attempts were made to apply Philadelphia sludge to various large tracts of land in Pennsylvania. Even though the research had been conducted showing that treated municipal sludge can be an excellent soil amendment and chemical fertilizer substitute, the projects were all rejected by local opposition. Faced with a daily production of sludge approaching 360 metric tons and ocean disposal being eliminated, Philadelphia, in 1976, began looking for a land based alternative. With the help and ingenuity of Modern-Earthline Companies, environmental consultants to the city, an intensive public relations program was initiated in Somerset County, Pennsylvania.

Somerset County is one of the larger coal producing counties in the

Commonwealth with hundreds of hectares of lands devastated by past mining and improper reclamation. Much of its currently mined coal is delivered to the Philadelphia area. Ordinarily the trucks, after delivering the coal, would return to Somerset empty. One of the obstacles for Philadelphia to overcome was the cost of transporting sludge 400 kilometers to a site. By combining the sludge transportation with the empty backhaul of a coal truck, the concept of mine land reclamation with Philadelphia sludge became a viable alternative to investigate further.

Initial Acceptance

In 1977, Modern-Earthline Companies initiated an intensive public relations program to help insure the success of a strip mine reclamation project in Somerset County using Philadelphia sludge. This program included contact and explanation of the project to land owners, mining company officials, township supervisors, and county commissioners. Once their support was obtained, the program was expanded to include talks to local civic clubs such as Rotary, Lions, and Kiwanis. This was followed by newspaper articles and TV news coverage of the proposed project. Eventually a local Advisory Committee was formed consisting of recognized community leaders, including local farmers, Soil Conservation District representatives, Game Commission, Soil Conservation Service, district forester, county agent, and community resource development agents. After gaining local community support, a four-hectare site was selected for the initial demonstration project. The site is representative of current bituminous coal mining operations conducted under Pennsylvania's amended Surface Mining Conservation and Reclamation Act that requires backfilling to the appropriate original contour with top soil replacement. An intensive monitoring system was initiated to demonstrate to the public that there would be no detrimental effects to the soil, vegetation, or ground water due to the utilization of sludge rather than commercial fertilizer for reclamation.

Prior to sludge application, suction lysimeters were installed at the 90-centimeter depth on the site to monitor any effect on soil percolate water. Deeper groundwater wells were drilled and household wells in the area were sampled. Soil samples were collected from various depths so that they could be compared with samples taken a year after the sludge application. Surface soil samples were collected and analyzed for soil nutrient levels, as well as the cation exchange capacity, pH, and buffer pH. The results indicated that the soil pH was 5.1; therefore 6.7 metric tons per hectare of agricultural lime was applied. Liming is required in Pennsylvania to immobilize the heavy metal constituents in the sludge to reduce their availability for plant uptake and to prevent their leaching into the groundwater.

Sludge for the project was obtained from the Philadelphia Northeast

Water Pollution Control Plant. The liquid digested sludge is dewatered by centrifuging then composted with wood chips. The composting mixture consisted of 1 part of sludge for 2 parts of wood chips. Prior to transportation to the site, the compost, with the wood chips still included, was shredded. The compost was transported 400 kilometers to the site by coal trucks returning from deliveries in the Philadelphia area. As the compost was delivered to the site, composite samples were collected and analyzed for various chemical constituents. The results of the analyses were used to determine the actual rate applied and to calculate the amounts of selected nutrients and trace metals applied. These results are given in Table 8-1, along with the Pennsylvania Interim Guidelines for Sewage Sludge Use for Land Reclamation (1977)(1), and the cumulative metal loadings for agricultural land recommended by the U.S. Environmental Protection Agency. A comparison of the demonstration project trace metal loadings with the Pennsylvania Guidelines indicates that the compost application exceeded the recommended amounts for all metals with the exception of Cr and Hg. However, if one compares the loading rate with those recommended by the EPA for agricultural land, then it is quite acceptable. According to the EPA publication on Municipal Sludge Management (2), it has been demonstrated that the total cumulative metal loadings shown in Table 8-1 from applying municipal sludge to agricultural land have not led to environmental problems (when soil pH is controlled). The EPA recommended cumulative metal loadings vary with the soil cation exchange capacity (CEC). The average CEC of the surface soil on the demonstration site is 14.4 (ranged from 14.0 to 14.8). At the application rate of 203 metric tons per hectare, approximately 726 kilograms of nitrogen, 464 kilograms of phosphorus, and 181 kilograms of potassium were applied per hectare. This would be equivalent to applying 6720 kilograms of an 11-16-3 commercial fertilizer

Table 8-1. Comparison of Trace Metal Loadings at the Somerset County Demonstration Project with EPA and PDER Recommendations.

Constituent	Compost Application Rate 203 mt/ha	Recommendations EPA (CEC 5-15)[1]	PDER
	kg/ha		
Cu	131	280	112
Zn	343	560	224
Cd	5	11	3
Pb	131	1120	112
Ni	30	280	22
Cr	40	NR[2]	112
Hg	0.3	NR[2]	0.6

[1] Average CEC of site ranged from 14.0 to 14.8 meq/100 g.

[2] No recommendations given by EPA.

per hectare.

Prior to sludge application, the site was first scarified with a chisel plow to alleviate surface soil compaction resulting from heavy equipment traffic in the top-soiling operation. Compost was applied in June, 1978, by manure spreaders at a rate of 203 metric tons per hectare. Immediately after spreading, the compost was incorporated by chisel plowing and disking.

To revegetate the demonstration area, a mixture of grasses and legumes was applied. The site was broadcast seeded with a mixture of two grasses and two legumes at the following rate:

Species	Amount
Kentucky-31 Tall Fescue	22 kg/ha
Pennlate Orchardgrass	22 kg/ha
Penngift Crownvetch	11 kg/ha
Birdsfoot Trefoil	11 kg/ha

The rationale for the selection of this seeding mixture is that the two grass species will germinate quickly and provide a complete protective cover the first year allowing time for two legume species to become established and developed into the final vegetative cover.

After seeding there were unusually high temperatures in the early summer months and not much rain, which contributed to the delay of seed germination until July. However, by early August there was a complete healthy vegetative cover on the treated site. At the end of each growing season vegetation height and productivity were measured, as well as the chemical composition of the individual species. Results of the measurements for height growth and dry-matter production are given in Table 8-2. By September, 1978 average height growth over the plot was 20 centimeters and ranged from 8 to 46 centimeters; dry-matter production averaged 1592 kg/ha and ranged from 731 to 3743 kg/ha. By the end of the second growing season the vegetative cover was well established with results indicating a fourfold increase in vegetation height and approximately a sixfold increase in dry matter production (Table 8-2).

Individual samples of each of the two grass and two legume species were collected from the compost treated area for foliar analyses to determine plant uptake of trace metals. Tall fescue and birdsfoot trefoil were collected from an adjacent area that had not received compost but had applications of lime and commercial fertilizer. Results of the chemical analyses for the grasses and legumes are given in Table 8-3. At the end of the first growing season, 1978, foliar trace metal concentrations for all species tested were below the suggested tolerance levels for agronomic crops, except for the foliar concentration of cadmium in crownvetch. Foliar concentrations of trace metals generally decreased by the end of the second year including cadmium in the crownvetch, which decreased from 3.77 to 0.58 μg/g. The suggested tolerance levels shown in Table 8-3 represent the levels at which

Table 8-2. Vegetation Height Growth and Dry Matter Production for Two Growing Seasons After Compost Application.

	1978	1979
Height Growth (centimeters)	20	66
Dry Matter Production (kg/ha)	1592	9089

Table 8-3. Mean Concentrations of Trace Metals in Vegetation Foliar Samples Collected at the End of the 1978 and 1979 Growing Seasons.

Species	Compost Application	Year	Cu	Zn	Cr	Pb	Co	Cd	Ni
	mt/ha					µg/g			
Tall Fescue	0	1978	11	24	0.74	0.63	1.12	0.11	0.31
	203	1978	15	52	1.06	5.12	1.69	0.77	5.48
	203	1979	9	55	1.58	5.08	2.67	0.57	4.75
Birdsfoot Trefoil	0	1978	8	20	0.74	1.10	1.70	0.14	2.66
	203	1978	10	67	0.74	7.70	2.01	0.53	5.32
	203	1979	7	83	0.25	5.42	2.75	0.18	4.08
Orchardgrass	203	1978	17	60	0.82	3.94	1.12	0.54	4.59
	203	1979	8	71	1.25	1.75	1.17	0.62	2.92
Crownvetch	203	1978	18	295	0.98	9.57	4.22	3.77	8.85
	203	1979	8	159	1.00	4.92	1.92	0.58	5.42
Suggested Tolerance Level[3,4]			150	300	2	10	5	3	50

a yield reduction might occur and do not represent the levels at which toxicity occurs. There were no phytotoxicity symptoms observed for the vegetation grown on the compost treated area.

To evaluate the effects of the compost on the chemical properties of the soil samples were collected in April, 1979, and April, 1980, one and two years following the application. Soil samples were collected from various locations on the plot at the 0-15, 15-30, and 30-60 centimeter depth. These samples were analyzed for the same constituents as the pre-treatment soil samples to determine the effects of the compost application on the soil chemical properties. The results of these analyses are given in Table 8-4. Results of the analyses indicate that soil concentrations of iron, manganese, and aluminum, elements associated with acid mine drainage, were all reduced following the compost application. Trace metal concentrations were increased

Table 8-4. Comparison of Soil Analyses for Cations and Extractable Trace Metals Before and After Sludge Application at the Somerset County Demonstration Site.

Year[1]	Soil Depth	Fe	Mn	Al	K	Ca	Mg
	cm			µg/g			
1978	0-15	19.6	66.8	133.0	74.1	846.0	44.4
	15-30	20.8	81.2	114.0	78.0	828.0	67.2
	30-60	20.0	80.0	107.2	78.0	816.0	230.4
1979	0-15	13.6	26.4	20.7	78.0	1612.0	90.0
	15-30	13.8	64.4	121.7	70.2	750.0	75.6
	30-60	14.4	77.7	105.8	74.1	684.0	189.6
1980	0-15	14.7	25.2	6.0	77.7	1335.3	29.3
	15-30	15.7	67.0	163.3	69.5	546.0	57.3
	30-60	17.7	89.3	86.0	81.3	470.7	210.0

		Cu	Zn	Cr	Pb	Co	Cd	Ni
	cm				µg/g			
1978	0-15	3.7	1.0	<0.01	2.80	1.15	0.014	0.40
	15-30	4.6	1.1	<0.01	2.80	1.15	0.015	0.35
	30-60	5.3	1.9	<0.01	2.75	1.65	0.017	1.60
1979	0-15	25.2	54.3	3.85	33.80	0.85	0.723	3.10
	15-30	3.2	3.3	0.15	2.75	0.75	0.050	1.85
	30-60	3.4	3.8	0.10	2.75	0.75	0.042	2.60
1980	0-15	29.4	13.2	3.70	37.00	1.32	0.156	4.30
	15-30	3.2	3.4	0.20	2.83	1.20	0.010	6.72
	30-60	3.3	4.5	0.15	2.27	1.53	0.012	4.30
Normal Range in Soils[5]		2-100	10-300	5-3000	2-200	1-40	0.01-7.00	10-1000

[1] 1978 represents pre-sludge conditions.

by the sludge application, with the greatest increases occurring at the 0-15 cm depth; however, these increased concentrations were minimal. All soil concentrations of the trace metals on the compost area are within the normal range found in Pennsylvania on non-sludge treated soils.

Surface soil samples were collected from the compost treated area in May, 1980, two years after the application, for the determination of soil pH. According to the Pennsylvania guidelines, the soil pH must be adjusted to 6.0 during the first year of sludge application and must be maintained at 6.5 for two years following final sludge application. Results of the analyses indicate the soil pH was 7.3 at the end of the second year.

Soil percolate water samples were collected from lysimeters installed at the 90-cm depth for chemical analyses. Results are given in Table 8-5. Results of these analyses indicated that average concentrations of NO_3-N in the percolate following compost application were consistently below potable water standards (10 mg/l) except for one occasion when NO_3-N

concentration reached a peak of 12.9 mg/l. Concentrations of trace metals in the percolate were extremely low. Average monthly concentrations of all trace metals except lead were below EPA drinking water standards. Although the average concentrations of lead in the percolate exceeded potable water standards on a few sampling dates after the application of compost, it should be noted that it also exceeded these standards prior to the compost application. In general, there has been a trend toward decreasing concentrations of trace metals in the percolate during the two-year period following compost application.

Separate samples of percolate were collected on each sampling date and analyzed for total and fecal coliforms. No fecal coliform colonies (per 100 ml aliquots) were found in any samples.

Two monitoring wells were drilled to evaluate the effect of the compost application on groundwater quality. Well No. 1 was drilled adjacent to the

Table 8-5. Results of Chemical Analyses for Percolate Water at the 90 Centimeter Depth at the Somerset Demonstration Site.

Location	Date	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
	1978					mg/l			
Before Compost	May 30	0.03	0.92	0.01	0.05	0.25	0.009	0.82	2.9
	Jun 7	0.04	1.55	0.01	0.06	0.19	0.012	0.26	2.0
	Jun 12	0.07	0.92	<0.01	0.05	0.94	0.010	1.46	6.0
After Compost Applied	Jun 26	0.11	3.48	0.02	0.06	2.15	0.027	2.43	6.0
	Jul 10	0.04	1.44	0.01	0.01	0.56	0.012	0.84	6.0
	Jul 24	0.04	1.40	0.01	0.05	0.79	0.011	0.62	5.1
	Aug 4	0.03	1.16	<0.01	0.03	0.69	0.014	0.41	6.4
	Aug 21	0.04	1.21	0.02	0.21	0.51	0.007	0.96	12.9
	Sep 7	0.03	0.76	0.03	0.12	0.31	0.006	0.58	7.2
	Sep 19	0.04	0.78	0.05	0.02	0.26	0.005	0.51	8.5
	Oct	0.04	0.94	0.04	0.08	0.36	0.007	0.55	6.9
	Nov	0.04	0.52	0.01	0.23	0.10	0.004	0.01	6.3
	Dec	0.01	0.52	0.01	0.06	0.32	0.004	0.44	1.9
	1979								
	Mar	<0.01	0.21	<0.01	<0.01	0.13	0.001	0.14	1.0
	Apr	<0.01	0.23	<0.01	<0.01	0.12	0.001	0.15	1.1
	May	<0.01	0.24	<0.01	<0.01	0.10	0.001	0.16	1.2
	Jun	0.01	0.40	<0.01	0.03	0.17	0.001	0.25	1.4
	Jul	0.01	0.31	<0.01	0.05	0.18	0.001	0.24	0.8
	Aug	0.01	0.31	<0.01	0.06	0.15	0.001	0.24	0.6
	Sep	0.01	0.41	0.01	0.02	0.17	0.001	0.25	<0.5
	Oct	0.01	0.16	<0.01	0.02	0.05	0.001	0.08	<0.5
	Nov	0.05	0.10	0.01	0.02	0.24	0.001	0.18	<0.5
	Dec	0.08	0.12	0.01	0.04	0.30	0.001	0.11	<0.5
	1980								
	Jan	0.01	0.22	0.01	0.03	0.10	0.001	0.18	<0.5
	Feb	--	--	--	--	--	--	--	--
	Mar	0.01	0.30	0.03	0.02	0.05	0.001	0.12	<0.5
	Apr	<0.01	0.10	0.04	0.02	0.04	<0.001	0.09	<0.5
	May	0.01	0.29	0.05	0.02	0.04	<0.001	0.10	<0.5
EPA Drinking Water Standards		1.00	5.00	0.05	0.05		0.010		10.0

4-hectare plot and was representative of background groundwater quality. Well No. 2 was drilled within the compost-treated plot on the down-gradient side and reflected the effect of the compost application on groundwater quality. Water table depth ranged from 17 to 18 meters in Well No. 1 and from 12 to 13 meters in Well No. 2 over the sampling period.

Results of the analyses of groundwater samples indicated that the compost application did not have any significant effect on the concentration of NO_3-N which, was consistently below EPA potable water standards after compost was applied. There was also no significant change in the concentrations of cations in the groundwater. In general, trace metal concentrations were higher in Well No. 1, representing background groundwater quality, than in Well No. 2, most influenced by the compost application. Trace metal concentrations in Well No. 2 were extremely low both before and after compost application. No significant increases in trace metal concentrations were observed after the applications. Separate samples of groundwater were collected on each sampling date and analyzed for total and fecal coliforms. No fecal coliform colonies (per 100 ml aliquot) were found in any samples.

Expanded Operations

At all stages of the project the local public was encouraged to visit the site. One factor that must be dealt with in many land application projects is the public fear that someone is hiding something. It is hard to convince someone who for years has believed that sludge is a waste product to be disposed of, that sludge actually is a valuable resource to be used rather than disposed of as a waste. One way that Modern-Earthline dealt with this concern was to be totally open and have any and all results available on request. Local citizens were encouraged to take their own samples and send them to different laboratories if they did not believe the results and wanted to see for themselves--and they did. The local advisory group came to the site and collected their own samples of compost, vegetation, and soil. After they received the results of their samples, they were convinced that nothing was hidden. All results were similar between laboratories and samplers. This openness and "nothing hidden" attitude was one important step in gaining public support and acceptance for expanding from a small scale demonstration project to a large scale on-going operation.

Based on the successful acceptance of the demonstration project, Modern-Earthline Companies proposed to revegetate 150 hectares in Somerset County with Philadelphia compost in 1979. One site typical of the area to be revegetated in 1979 was a 20-hectare tract of abandoned strip mine land on the Robert Decker farm. The area is typical of abandoned bituminous coal mined land, which has been recontoured without topsoil

replacement. The site was extremely eroded with large ditches throughout the site. In April 1979, the eroded gullies and ditches were filled and the entire area was dragged with an "I" beam to fill in small gullies and some ... level the surface. Average soil pH ranged from 3.5 to 4.8 ... agricultural lime was applied at a rate of 11 metric tons per hectare. The average cation exchange capacity of the soil ranged from 13.5 ... meq/100g. The area was chisel-plowed to roughen the surface ... spreading.

In order to increase the nutrient quality of the compost ... Philadelphia, it was decided to try a one-to-one mix of equal parts centrifuged sludge cake with compost. Compost is a very acceptable product to work with, in that it is dry (70% solids), easily spread, and has very little odor whereas a centrifuged sludge cake is wet (20% solids) and can be odorous. But in terms of nutrients, the sludge cake is a better product than the compost. For example, the total nitrogen content of the sludge cake is approximately 2%, whereas the compost total nitrogen content is 0.6% since much of the nitrogen is driven off due to high temperatures of composting. In an attempt to combine the best of these two products the mix of one-to-one was tried. The final mixed product was quite acceptable in terms of solids (approximately 50%) and nitrogen content (approximately 1%) and had no objectionable odor.

The mix was transported to the site in coal trucks on a return haul to the Philadelphia area and spread with manure spreaders. The ... completed by June 1, 1979. Composite samples of the compost-cake mix were collected at the site, as it was delivered, for chemical analysis. Results of these analyses were used to calculate the application rate and the ... of selected nutrients and trace metals applied. The compost-cake mix was applied at the rate of 132 metric tons per hectare. A comparison of ... metal loading at the Decker site with the EPA and PIDER recommended guidelines is given in Table 8-6. This comparison indicates that all trace metals applied were under the Pennsylvania recommendations as well as those of EPA. At the application rate of 132 metric tons per hectare, approximately 1057 kilograms of nitrogen, 925 kilograms of phosphorus, and 132 kilograms of potassium were applied per hectare. This would be equivalent to applying 10,000 kg/ha of an 11-9-1 commercial fertilizer.

After the compost-cake mixture was incorporated into the ... centimeters of soil with a chisel plow, the area was seeded with a mixture of grasses and legumes. The treated area had a complete vegetative cover by early July, 1979. Average height growth over the plot was 64 centimeters and ranged from 36 to 91 centimeters. Dry matter production averaged 14,896 kg/ha and ranged from 3409 to 33,422 kg/ha. Individual samples of each of the two grass and two legume species were collected from the treated area for foliar analyses to determine plant uptake of trace metals. Results of the chemical analyses of the vegetation are given in Table 8-7. Foliar

Table 8-6. Comparison of Trace Metal Loadings at the Decker Site with EPA and PDER Recommendations.

Constituent	Compost Application Rate 132 mt/ha	Recommendations EPA (CEC 5-15)[1]	Recommendations PDER
	kg/ha	kg/ha	kg/ha
Cu	78	280	112
Zn	221	560	224
Cd	1	11	3
Pb	75	1120	112
Ni	17	280	22
Cr	36	NR[2]	112
Hg	0.07	NR[2]	0.6

1 Average CEC of site ranged from 14.5 to 16.3 meq/100 g.

2 No recommendations given by EPA.

Table 8-7. Mean Concentrations of Trace Metals in Vegetation Foliar Samples Collected at the End of the 1979 Growing Season from the Decker Site.

Species	Cu	Zn	Cr	Pb	Co	Cd	Ni
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
Birdsfoot Trefoil	10.0	46.4	0.7	4.3	1.7	0.06	4.2
Tall Fescue	11.5	36.8	0.8	2.7	1.3	0.03	4.3
Orchardgrass	14.2	53.3	1.0	3.7	1.6	0.11	5.5
Alfalfa	11.1	79.8	0.8	6.3	1.8	0.14	5.9
Suggested Tolerance Levels [3,4]	150	300	2.0	10.0	5.0	3.0	50

trace metal concentrations for all species tested were below the suggested tolerance levels for agronomic crops. These suggested tolerance levels, shown in Table 8-7 represent the levels at which toxicity occurs. There were no phytotoxicity systems observed for the vegetation grown on the treated area.

To evaluate the effects of the compost-cake mix on the chemical properties of the soil, soil samples were collected from the plot at the 0-15, 15-30, and 30-60 centimeter depth. These samples were analyzed for the same constituents as the pre-treatment soil samples collected in April, 1979. The results of these analyses are given in Table 8-8. Soil concentrations of iron, aluminum, and manganese, elements associated with acid mine drainage, were all reduced following the application of the compost-cake mixture. Soil extractable trace metal concentrations were increased following treatment, with the greatest increase occurring at the 15 cm depth; however, these increased concentrations were minimal. All soil concentrations of the trace metals on the treated area are within the normal range found in non-sludge

Table 8-8. Comparison of Soil Analyses for Cations and Extractable Trace Metals Before and One Year After Treatment at the Decker Site.

Year	Soil Depth	Fe	Mn	Al	K	Ca	Mg	Na
	cm	µg/g						
1979	0-15	45.3	34.1	659.2	51.3	584.0	176.9	35.6
	15-30	60.8	68.0	542.4	147.2	1856.4	222.0	35.8
	30-60	55.0	168.8	374.2	59.0	4062.8	426.8	39.8
	60-90	44.2	239.5	121.4	70.8	3677.2	460.0	41.0
1980	0-15	15.2	23.1	216.0	107.9	1268.7	94.0	25.7
	15-30	18.5	53.1	485.3	88.7	996.7	196.7	28.2
	30-60	20.1	162.5	308.0	90.1	1884.0	240.0	27.7

Year	Soil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
	cm	µg/g						
1979	0-15	3.8	3.7	0.13	0.25	0.35	0.001	0.59
	15-30	4.1	4.7	0.17	0.43	0.63	0.001	3.56
	30-60	4.4	7.3	0.23	1.17	1.40	0.001	1.63
	60-90	4.5	5.9	0.16	1.56	1.68	0.004	1.81
1980	0-15	26.3	13.5	5.83	17.72	0.83	0.020	7.08
	15-30	6.4	8.9	0.78	2.20	1.32	0.003	3.48
	30-60	4.2	6.9	0.27	1.07	2.70	0.002	2.58
Normal Range in Soils[5]		2-100	10-300	5-3000	2-200	1-40	0.01-7.00	10-1000

treated soils.

Two monitoring wells were drilled to evaluate the effects of the compost-cake mix application on groundwater quality. Water table depths range from 5 to 10 meters in Well 1 and 14 to 25 meters in Well 2 over the sampling period.

Results of the analyses of groundwater samples are given in Table 8-9. Concentrations of nitrate-nitrogen were consistently below EPA potable water standards of 10 mg/l. In general, concentrations of all trace metals except for lead were consistently below the EPA drinking water standards. Concentrations of chromium and cadmium exceeded EPA drinking water standards on one sampling date and by the next sampling date were again below the EPA drinking water standard. On several sampling dates, both before and after sludge application, the concentration of lead exceeded drinking water standards. However, it should be noted that these increases were minimal and pose no threat to public health.

Several other areas in Somerset County were treated with the mixed product in 1979 and had similar results. All of the projects can be termed highly successful both in terms of public acceptance and revegetation of problem areas.

Based on the success in 1978 and 1979 it is estimated that approximately 50% of Philadelphia's annual sludge production will be used

Table 8-9. Results of Chemical Analyses of Groundwater Samples Collected from the Decker Site.

Location	Date	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
	1979	- - - - - - - - - - - - - - - - mg/l - - - - - - - - - - - - - - - -							
Well 1	Apr 25	0.05	0.05	0.05	0.05	0.05	<0.001	0.05	<0.5
	May 10	0.05	0.10	0.05	0.07	0.05	0.001	0.10	<0.5
	May 16	0.10	0.10	0.05	0.08	0.05	<0.001	0.10	<0.5
	May 18	0.30	0.50	0.05	0.15	0.05	0.001	0.05	<0.5
	June 12	0.09	0.12	0.02	0.18	0.05	<0.001	0.07	<0.5
	July 2	0.01	0.03	0.02	0.17	0.04	0.005	0.07	<0.5
	July 20	0.06	0.19	0.03	0.11	0.06	<0.001	0.06	<0.5
	July 26	0.06	0.13	0.02	0.13	0.02	<0.001	0.03	<0.5
	Aug	0.01	0.39	0.02	0.11	0.02	0.003	0.05	<0.5
	Sept	0.04	0.20	0.02	0.10	0.06	<0.001	0.01	<0.5
	Oct	0.05	0.24	0.01	0.12	0.02	<0.001	0.03	<0.5
	Nov	0.02	0.10	0.02	0.21	0.25	<0.001	0.15	<0.5
	Dec	0.09	0.18	0.03	0.27	0.27	0.001	0.03	<0.5
	1980								
	Jan	0.02	0.23	0.02	0.16	0.05	<0.001	0.05	<0.5
	Feb	0.01	0.42	0.03	0.11	0.05	0.001	0.06	<0.5
	March	0.01	0.13	0.08	0.10	0.04	0.002	0.04	<0.5
	April	0.01	0.31	0.01	0.06	0.03	<0.001	0.04	<0.5
	May	0.03	0.80	0.03	0.08	0.03	<0.001	0.05	<0.5
	1979								
Well 2	Apr 25	0.05	0.05	0.05	<0.01	0.05	0.001	0.10	<0.5
	May 10	0.10	0.10	0.05	0.04	0.05	0.001	0.05	<0.5
	May 16	0.10	0.10	0.05	0.02	0.05	<0.001	0.10	<0.5
	May 18	0.10	0.20	0.05	0.02	0.05	<0.001	0.05	<0.5
	June 12	0.15	0.29	0.02	0.01	0.03	<0.001	0.05	<0.5
	June 2	<0.01	0.15	0.01	0.15	0.04	0.011	0.12	1.2
	July 20	0.09	0.24	0.01	0.08	0.02	<0.001	0.02	<0.5
	July 26	0.10	0.33	<0.01	0.08	<0.01	0.001	<0.01	<0.5
	Aug	<0.01	0.89	<0.01	0.10	0.01	0.002	0.01	<0.5
	Sept	0.01	0.34	0.01	0.07	<0.01	<0.001	0.03	<0.5
	Oct	0.04	0.27	<0.01	0.02	0.01	0.001	0.01	3.6
	Nov	0.07	0.14	0.01	0.10	0.08	<0.001	0.01	1.2
	Dec	0.02	0.16	0.03	0.12	0.22	<0.001	0.07	<0.5
	1980								
	Jan	<0.01	0.07	<0.01	0.06	0.04	<0.001	0.02	<0.5
	Feb	<0.01	0.16	0.02	0.09	0.03	<0.001	0.04	<0.5
	March	0.02	0.24	0.13	0.05	0.01	<0.001	0.07	1.2
	April	0.10	1.33	0.02	0.04	<0.01	0.001	<0.01	3.6
	May	0.10	1.03	0.01	<0.01	0.06	0.001	0.12	<0.5
EPA Drinking Water Standard		1.00	5.00	0.05	0.05		0.010		10.0

this year, 1980, to revegetate approximately 280 to 400 hectares of mined land in the Commonwealth.

Conclusion

There appears to be a great opportunity to partially solve the urban sludge disposal problem by recycling this so-called waste product on mined land. Not only would this help to alleviate problems caused by the cessation of ocean disposal of sludge but it would also provide an opportunity to utilize the valuable nutrients for a beneficial use. The City of Philadelphia, Pennsylvania with the help of Modern-Earthline Companies, has demonstrated that a large industrial city can successfully recycle its sludge on rural mined land economically and in an environmentally acceptable manner. Within three years a large scale land-based utilization program has been successfully established and Philadelphia will be able to cease ocean disposal of sludge by December 31, 1980, one year prior to the mandated cessation date of December 31, 1981.

ACKNOWLEDGMENTS. Special thanks to Modern-Earthline Companies and the City of Philadelphia Water Department who provided the financial support for these projects.

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9
LAND RECLAMATION OF STRIP-MINE SPOIL IN PENNSYLVANIA: A REGULATORY AGENCY REVIEW

William F. Pounds

In July of 1968, the General Assembly of the Commonwealth of Pennsylvania passed Act 241, the Solid Waste Management Act. This Act provided for planning and regulation of solid waste storage, collection, transportation, processing and disposal systems. The permitting and enforcement powers of this Act were delegated to the Department of Health (1). The 1968 Solid Waste Management Act was amended twice in 1970 and again in 1972. Permitting and enforcement powers were delegated along with all environmental protection responsibilities to the new Department of Environmental Resources created in January, 1971. On July 7, of this year, The General Assembly passed and Governor Dick Thornburgh signed into law Act 97, the 1980 Solid Waste Management Act (2).

Act 241(1) and the Chapter 75 Rules and Regulations which followed, both define "solid waste" as garbage, refuse, and other discarded materials including, but not limited to solid and liquid waste materials resulting from industrial, commercial, agricultural and residential activities. This definition, of course, includes sewage sludge, both the liquid and solid phases. In fact sewage sludge is defined in Chapter 75 as "the coarse grains, grit, and dewatered or air-dried sludges, septic and holding pumpings, and other residues from sewage collection and treatment systems which require disposal" (3).

The responsibility for environmentally safe disposal or utilization of this material has rested with the Department of Environmental Resources since its inception in 1971. The initial provisions of Chapter 75, adopted in August of 1971, vaguely addressed the permitting of sewage sludge disposal sites, but offered no clear-cut regulations for such permitting. Because of this, most sewage sludge disposal or utilization from 1968 to 1977, was carried out with letters of approval from the Department, or illegally. On May 24, 1977, Chapter 75 was revised to establish an active permitting program for sewage sludge.

Over 1,000,000 tons of sewage sludge are generated in Pennsylvania annually (assuming 20 percent solids). Current estimates indicate that of the total volumes of sludge generated in Pennsylvania; 10 percent is incinerated, 20 percent is disposed of via ocean disposal, 40 percent is sent to landfills, and 30 percent is destined for land spreading by agricultural utilization or land reclamation (4).

The increased costs of fuel have many sewage treatment plants now utilizing incineration, looking for other methods of disposal. The practice of ocean dumping will be ended by January 1, 1981. The revision of Chapter

75 limited sludge disposal in landfills to those sludges which are digested or stabilized and dried to 20 percent or greater solids content by weight (3). Only those sanitary landfills utilizing leachate collection and treatment systems under permit to the Department may be approved for sludge disposal. All these factors combined have made land spreading of sludge the most economically feasible of those methods available using current technology for sludge disposal or utilization.

With this in mind, Pennsylvania has developed regulations and guidelines to add sludge to the soil at environmentally safe loading rates. The development of these regulations and guidelines took more than three years. Extensive research of the literature was performed to determine how much sludge could be applied to the land without adversely affecting food chain crops or groundwater. Researchers in the field of sludge application to the land were contacted for their input on these regulations. These included Doctors William Sopper and Dale Baker from Pennsylvania State University, Doctor Rufus Chaney with the U.S. Department of Agriculture Research Center in Beltsville, Maryland, and others. Other states also were contacted to determine how they were handling the sewage sludge land application problem. Those with active programs were requested to send copies of their regulations for our evaluations and review.

All this information was considered in developing the current guidelines for operation of and calculating loading rates for land spreading sludge in Pennsylvania. They were used initially in early 1977. DER developed two different sets of guidelines, one for agricultural utilization (5) and one for land reclamation (6). Questions and opposition immediately arose from the public, who thought loading rates were too liberal, and sludge producers and haulers, who thought the guidelines too restrictive.

On November 1, 1976, the Department received a United States Environmental Protection Agency grant to apply sludge to surface mined land for reclamation. The purpose of this grant was several fold. For the Bureau of Solid Waste Management, the main objectives were to test different application rates of sludge materials under strictly monitored controlled conditions and to demonstrate to the public on a small scale what could be accomplished with the application of sewage sludge to land that is scarred by strip-mining (7). With several thousand acres of abandoned strip-mined land in Pennsylvania and many thousand more inadequately reclaimed, there is a need for an effective and economical way to reclaim the land. This need has been enhanced with the advent of the energy crisis and the talk of greater coal production in the future.

Previous proposals for sewage utilization in large strip-mined land reclamation projects had met with tremendous public opposition, largely because of the lack of research on the subject and lack of local citizen involvement. Demonstration projects were set up in three areas throughout the state. Local involvement and public interest were solicited from their

beginnings. These projects still are monitored for possible groundwater, soil, and vegetative contamination from heavy metals in the sludge. In addition, an experimental permit was issued to the City of Philadelphia for a ten acre land reclamation project in Somerset County (8). Their loading rates exceed those approved by Departmental guidelines.

The remainder of this paper will deal primarily with the current reclamation guidelines and the practical aspects of sludge application to strip-mine land as this author sees them.

The guidelines developed for land reclamation are entitled "Interim Guidelines for Sewage Sludge Use for Land Reclamation" (6). Although the term interim is used, these are the current guidelines used by the Department for permitting sludge use sites. The Department hopes to utilize knowledge gained from the demonstration projects, experience from actual application of the sludge on permitted sites, and monitoring data from both demonstration and permitted sites, in considering future guidelines.

The rate of application is calculated by two factors, nitrogen loading and the trace metal content of the sludge. Because of the high permeability of mine spoils and low organic matter content, nitrogen in excess of the crop requirement was believed to be necessary in order to establish and promote adequate vegetative growth. The Department researched literature and consultated with people most knowledgeable in the field of land reclamation through the use of sewage sludge (primarily Doctor Sopper), before determining that at least 1,000 pounds of nitrogen may be required to establish and promote plant growth. Assuming on an average that nitrogen content of sludge is 2 percent, a maximum of 60 dry tons per acre may be utilized for land reclamation. This would provide ample nitrogen for plant growth and also create minimum threat to groundwater contamination through the leaching of nitrogen before plant uptake.

Table 9-1, taken from the guidelines (6), gives the lifetime loading rates for land reclamation based on the chemical analyses of the sludge. This table is broken into two loading rates based on the ultimate use of the land. If the land is to be used for farming, the maximum loading rate for metals is approximately 60 percent of that for land reclaimed but not placed back in agricultural production. In addition, if the land is to be used for farming, a complete soil analysis is required after final sludge application.

There are several operational requirements built into the guidelines to prevent contamination of ground and surface waters during application of the sludge and prior to the adequate protection developed by new vegetation. These requirements include provisions for spreading and incorporating sludge, preventing of runoff from the site, and adjusting the pH to 6.5 or greater to prevent leaching of metals (6).

In addition to guideline requirements, DER uses several policies and procedures for permitting of land reclamation sites. The most important of these is the requirement of two on-site investigations of the site prior to

Table 9-1. Maximum Lifetime Trace Metal Loading Rates for Land Protection.

Element	Maximum Loading Rate Land Reclamation	Maximum Loading Rate Land Reclamation for Farming
	lbs/a	lbs/a
Cadmium	3	3
Copper	100	60
Chromium	100	60
Lead	100	60
Mercury	.3	.2
Nickel	20	12
Zinc	200	120

the spreading of sludge. The first investigation is made by the Department's Regional Soil Scientist and Hydrogeologist during the application review process. The second investigation is made prior to sludge application, but after all proposed erosion and sedimentation control and monitoring devices are in place. DER feels that control of surface water runoff is the most important aspect of the land reclamation project. Detailed erosion and sedimentation control plans must be included as a part of the application to keep sludge and soil on the site until the seed has a chance to germinate. In many cases, mulching is required to prevent sludge runoff and erosion of particularly steep or critical areas.

The second investigation usually is performed jointly with the Bureau of Mining and Reclamation and the consultants for the applicant. Whenever possible, DER also recommends that the initial on-site investigation be a joint one with the applicant's consultants. Critical areas of concern can be pointed out at this time to eliminate the costly time involved with the exchange of written review comments by the Department and responses from the applicant.

After a site has been recontoured and meets all the reclamation requirements of the Bureau of Mining and Reclamation, the permit is issued for sludge application by the Bureau of Solid Waste Management. This is another critical phase in the land reclamation process. Since most permits are issued for one application of sludge followed by seeding of the site, a great deal of material must be applied in a short period of time. In most cases, this requires stockpiling sludge at a particular site, and assembling the necessary man power and equipment for the sludge spreading and seeding process, that may only last a few days.

The storage areas must be approved by the Department. Minimum requirements to be met for storage are diversion of surface water above and below the area, berms constructed around the area, and possibly that the stockpiled sludge be covered with plastic to prevent rain infiltration.

As a part of the permitting process, soils are analyzed for metal content and pH. Prior to the sludge application, lime is added to adjust the pH of the soil receiving the sludge. This is done normally through the use of conventional lime spreading equipment. The soil pH at a land reclamation site is to be adjusted to 6.0 or greater within the first year of initial sludge application, and 6.5 within the second year. A pH of 6.5 is to be maintained for two years after final sludge applications (6).

After the lime has been applied, DER recommends that the land be scarified. This is especially important for liquid sludge. Sludge is then spread, depending on the percent solids of the material, by tanker or conventional farm spreading equipment. The sludge must be incorporated into the soil within twenty-four hours. For most abandoned surface-mined sites, this speedy incorporation will require large disc-type equipment. Under present reclamation practices, where topsoil is placed back on the reclaimed area, a chisel plow normally would adequately incorporate the sludge.

Once the sludge has been incorporated, the area is then seeded immediately. The Department does not recommend a specific seeding mixture. However it does recommend that the mixture contain both grasses and legumes. Certain critical areas where there is a possibility of erosion should be mulched immediately after seeding.

The site should then be inspected monthly to determine whether there is evidence of erosion channels being formed. These areas should be mulched, to prevent large channels from forming. Erosion and sedimentation control facilities are also inspected at this time. Where severe erosion occurs, the area should be filled, reseeded, and mulched. The progress of germination and growth of vegetation also should be checked during these inspection visits.

Chemical and bacteriological analyses for the monitoring systems should continue for a minimum of one year after sludge is applied. The sampling program consists of a collection of three samples from monitoring wells and lysimeters prior to sludge application, and sampling the wells monthly for a period of one year.

Samples collected before sludge is applied and for the first three months following the application should be analyzed for pH, Chlorides, Nitrate-Nitrogen, Ammonia Nitrogen, Organic Nitrogen, Iron, Aluminum, Manganese, Copper, Zinc, Chromium, Cobalt, Lead, Cadmium, Nickel, and total and fecal coliforms. Water samples collected during the fourth month through the eleventh month following sludge application should be analyzed for pH, Ammonia Nitrogen, Nitrate Nitrogen, certain trace metals (Zinc, Copper, Lead, Cobalt, Nickel, Cadmium, Chromium), and total and fecal coliforms. Water samples collected in the twelfth month should be analyzed for those constituents in the background and first three months samples.

Water sampling will be terminated after one year unless results of the third quarterly report to the Department indicate a need for further sampling.

If further sampling is required, samples will be collected quarterly until sufficient data is collected to formulate a solution to the problem.

Soil sampling is also important to determine migration, if any, of metals through the soil profile. Initial soil samples, taken prior to the sludge application, should be analyzed for pH, and cation exchange capacity. Samples from the complete soil profile are collected from pits that were excavated to install lysimeters. The samples are taken from various depths in the profile, prior to application and one year after application and analyzed for pH, Bray Phosphorus, Calcium, Magnesium, Potassium, Sodium, Iron, Aluminum, Manganese, Copper, Zinc, Chromium, Cobalt, Lead, Cadmium, Nickel, and Kjeldahl Nitrogen. At the end of the second year after sludge application, surface soil samples are collected and analyzed for pH to determine if it remains 6.5 or greater.

Vegetation samples are also taken after the first growing season and analyzed for Nitrogen and Phosphorus content and uptake of Potassium, Magnesium, Aluminum, Copper, Chromium, Lead, Nickel, Calcium, Iron, Manganese, Zinc, Cobalt, and Cadmium.

The monitoring program was developed as a result of the data gained from the Department of Environmental Resources demonstration projects, the experimental Philadelphia project, and from permitted reclamation site monitoring wells over the last year-and-a-half.

Through the current permitting process, and the actual application of sludge to the site, there are several areas where problems can and do arise.

When an application was received prior to September 5, 1980, County Commissioner approval was needed before a site could be permitted. Since many of the applications received public opposition, many counties were unwilling to grant approval for the application of sludge. Also, prior to the demonstration projects, many local operators wanted nothing to do with sludge application, since it meant obtaining a variance to the reclamation plan. This usually was a very time consuming and costly procedure as far as coal strippers were concerned.

Even with three years of demonstration under our belt, there is still considerable public opposition to sewage sludge on strip-mine land. Philadelphia, for example, has received opposition to move its operation from one township to another within the same county.

On September 5, 1980, Act 97 became effective. Although the requirement for County Commissioner approval of sludge disposal in surface mined areas has been eliminated in the new law, an active public participation program is encouraged. The applicant is required to submit seven copies of his application to the Department. One copy is sent to the County Planning Commission, one copy to the township where the proposed site is located, and one copy is made available at all times in our Regional Office for public review. The county and local government agencies are given sixty days to comment on the application. These comments are taken into

consideration prior to issuance or denial of any permit. If the Department issues a permit, it must respond to the opposition in writing and this response is published in the *Pennsylvania Bulletin*.

With the new Act, there will be additional public participation in the form of public hearings and meetings during the review process. All these requirements of Act 97 are designed to keep the public informed about the application and permitting process of the Bureau of Solid Waste Management not only for land reclamation, but for all programs for which the Bureau issues permits.

In the past, the Bureau actively participated in public meetings, particularly on controversial programs such as sewage sludge and land reclamation. During the permitting of several of the Philadelphia sites, members of the Department participated in meetings and informed the public of the demonstration projects and what success we had with no harm to the environment.

In conclusion, the use of sludge for land reclamation could be one of the best things that ever happened from the standpoint of economically reclaiming ravaged lands. However, it is extremely important that it be done in an environmentally safe fashion, with the public kept aware of the benefits as well as any problems that may arise if the project is not handled properly.

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IV / INSTITUTIONAL, LEGAL, ECONOMIC, AND PUBLIC RELATIONS BARRIERS

OVERVIEW

David E. Burmaster

A project proposed to utilize municipal waste water and sludge for land reclamation or biomass production must withstand scrutiny and challenges of many varieties, which may include public opposition, institutional red tape, or transportation problems. In the past few years, a number of technically and economically sound projects have failed in the planning stage because the proponents did not or could not respond to social, psychological, or political questions raised by neighbors, environmentalists, or local officials. Slowly, engineers have learned that a sludge-use proposal must include detailed, simultaneous consideration of technical, economic, institutional, legal, social, and political concerns from the outset.

Two groups of consultants, headed by the Environmental Law Institute and Urban Systems Research & Engineering, Inc., respectively, have analyzed a number of case studies from the last decade to learn ways to meet "Transportation Impediments" and "Institutional Constraints and Public Acceptance Barriers" in these types of projects. Both papers in this session include an applied and theoretical analysis of the cases and concludes with practical recommendations for the design of new projects.

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INSTITUTIONAL, LEGAL, TECHNICAL, AND ECONOMIC CONSTRAINTS IN TRANSPORTATION OF SLUDGE FOR LAND APPLICATION TO EASTERN SURFACE MINE SITES

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Introduction

Although in many regions of the world the application of human waste to land to enhance soil fertility is an ancient, time-honored practice, it is a practice that is in its conceptual infancy in the public mind in the United States. Municipal sludge, the abundant residue of municipal wastewater treatment plants, can be used to enrich poor soils such as those found at surface mine sites. To be sure, there are a great number of isolated instances of sludge application to land in the United States. It is a low-keyed practice. Conventional wisdom is that it is not a subject the public wants to hear about, and that drawing attention to the practice may arouse public objection.

Many of the ongoing land application practices are not difficult to detect. "Milorganite," Milwaukee's processed and bagged sewage sludge, sold for many years to turf growers, golf courses and in home garden stores, is clearly labeled and advertised as a sludge-derived product. Many small cities apply sludge locally to land, as do a few large cities, such as Chicago and Denver. Because its use is encouraged by many local wastewater authorities, government agencies that are sensitive to health concerns recommend appropriate care be taken in its use.

Recent water pollution laws and regulations limiting pollutant discharges have resulted in a substantial increase in the quantity of municipal sludge. As the effect of these laws and federal grants and local expenditures to build and operate wastewater treatment plants have their impact, municipal sludge will continue to increase in amount.

Conventional sludge disposal techniques--ocean dumping, incineration and landfill--are becoming increasingly unavailable because of regulation and physical limitation.

The problem is one of moving from generally small-scale to larger-scale use of the land application practice. An increasingly attractive alternative is using urban sludge for improving poor soils, especially surface mined land located primarily in rural areas. More and more people are recognizing the value of recycling organic resources and the need to reclaim eroding mine

lands. Properly processed or composted sludge, which produces a material of low odor and relatively low toxicity should cause less objection from application area citizens and their officials when land application projects are considered.

Obviously, transporting urban sludge to rural surface mines for reclamation solves two land-use problems at once. Facilitating this would bring many environmental benefits and an efficient use of natural resources. Where the coal transport system can be used to backhaul municipal sludge, this will also avoid the economic and energy waste of empty carriage.

However, land application of municipal sludge has frequently encountered public objection in the proposed receiving areas, especially when the sludge originates in distant cities. Few rural communities are willing to serve as "city dumps." Indeed, public resistance may arise over even transporting municipal sludge through their communities.

Transporting municipal sludge is thought by many to have institutional, legal, technical, and economic problems, which may result in delay, high costs, or even insurmountable barriers.

This study sought to identify the main institutional, legal, technical and economic constraints to transporting municipal sludge to reclamation sites, and to point out the most promising ways of avoiding, mitigating, or removing these constraints.

Although opportunities exist for the use of municipal sludge for coal surface mine land in the West as well as in the East, this study deals primarily with opportunities east of the Mississippi River. This choice was made not only because of funding and time limitations, but also because the distance from major metropolitan areas to mine sites is generally shorter in the East. This offers potentially lower transportation costs, and therefore greater immediate feasibility from a cost standpoint. The study does, however, point out some additional problems in western application of this technology and some advantages.

This paper deals only with our findings, conclusions and recommendations. The final report will provide their basis in detail, and will include four other memoranda appendices. The four are independent memoranda on institutional, legal, technical and economic constraints.

The term "city" is used throughout this paper to mean large urban area wastewater authorities, whether a regional authority or a combination, individually or collectively, of authorities within a large urban area. Reference to the size of a "city" references the relative population size of the urban area, not just the core city. Rather than repeat the phrase "municipal sludge" throughout this paper, the term "sludge" is used generally alone to indicate "municipal sludge." Any quote of a part of this paper should insert the word "municipal" in brackets before the word "sludge" where it is not stated.

The term "program" is used throughout this paper to mean a program

of transporting municipal sludge to rural surface mine land sites and application of the sludge to these sites.

Findings and Conclusions

This section sets forth the major findings and conclusions of our study that relate to constraints on municipal sludge transportation. Many other conclusions providing detail to help shape the transportation element of a program of land application of sludge will be covered in the final report.

General Findings and Conclusions

The key to succeeding with the land application element, and indirectly the transportation element, is public acceptance. We found no barriers to developing a well-planned transportation element capable of being well executed. The only real barrier to successfully implementing the transportation of sludge for land application is failure to successfully implement the land application element.

Although the transportation element of a sludge land application program must deal with numerous legal, technical, and economic complexities, none are necessarily constraints. There is no significant public opposition to well planned and executed transportation of sludge. Technically, the "hazardous waste/material" threshold level should allow, without being classed "hazardous," higher toxic organic chemicals, heavy metal or pathogen content in sludge in transportation than in land application. It is so perceived by the public and public officials. (There are no legally established "hazardous" thresholds for transporting sludge.) For these reasons, when well planned and executed, transportation of sludge in connection with a well planned and executed program of land application has a high certainty of being free of constraint. Its certainty of being free of constraint is far greater than for the land application element.

For the transportation of sludge, legal issues do not drive technical or economic issues significantly, except in basic vehicular safety. The legal system, administered by the Interstate Commerce Commission (ICC), does provide a degree of protection from the economic pitfalls of market dominance and a means to seek avoidance if and when they materialize. In this sense only an economic issue does drive one area of the legal framework: offsetting market dominance underlies the creation of the ICC. However, the belief that law has fostered more control of economic forces than is necessary, has recently resulted in a substantial deregulation of the transportation industry. Thus, economic forces are now substantially free from legal constraint. Thus price and rates are freely negotiable for all but a few transportation choices.

Technical issues and economic issues drive each other, and interplay

extensively. They are the two sides of the same coin. Broadly and simply, certain equipment is available which has associated cost to load and move it a specified distance and unload it. Distance and volume have economies-of-scale implications which in turn have equipment-characteristics choice implications. In reverse, equipment capacity and characteristics of way force other economic results.

Institutional issues drive all other issues: legal, technical, and economic. The need for public acceptance of applying sludge to land is the core issue on which programs involving sludge transport, no matter how well planned and marketed, may flounder. This institutional issue drives the choice within a range of legally available options, and of modes and configurations of transportation, choices which may not be the least costly. The one legal issue that poses a potential constraint, state common law of nuisance, does so only because it, too, is so subject to local public attitudes. It is a legal issue that is largely driven by institutional issues, which therefore, contribute to making it a law of uncertain application.

Public acceptance can be geographically subdivided. There are three categories of communities that are always present: the receiving community, the transit-only community, and the originating community. Two other community categories that may be involved are transfer communities and storage communities (with pipeline, a remote composting or treatment area is a potential sixth category). Public acceptance in the receiving community is the most tenuous, and the category of communities our study most closely examined. The transit-only and originating communities have potential problems which are avoidable with well planned and executed programs. The existence of transfer and storage areas, hence transfer and storage communities, can be avoided, but at a cost if the total trip distance is long.

We found adequate indications in our study of the transportation element that successful land application elements can be developed, that we assume (not conclude, because we did not study this aspect in depth) this barrier can be overcome in a sufficient number of instances, and assume it will be. We conclude that with the help of this study, transportation elements can be well planned and executed, and that a well planned and executed transportation element can help gain and maintain public acceptance of land application.

All other direct transportation factors are a matter of relative constraints. Generally, it is a matter of identifying the best ways to handle the transportation element so as to avoid potential constraints, rather than always the quickest, simplest or least-cost alternatives. A little less than what we indicate is the best way for avoiding institutional constraints may, in some cases of local variation, work even better (especially when a particularly favorable back-haul is available). In many instances, only the best way will work, at least in early phases of programs. In the many cases of relatively short trip distance, higher cost will not be much higher. The principal reason

to explore other than the path of least institutional constraint is significantly higher cost.

It also became clear that many land application factors have an important indirect impact on the transportation element, and vice versa.

The best way to handle the transportation element will be easier for some cities than others. Distance between city and land application sites is the major determining factor. The longer the distance, the exponentially greater the cost of the best sludge transport mode for avoiding institutional constraint, as compared with an available lower-cost option. Some cost savings ways may be possible where the normal likely risk of public acceptance involved can be eliminated or greatly minimized. It depends on careful route planning to find and take advantage of local conditions found along potential trip routes. In addition, as programs become accepted, the potential for transporting larger sludge volumes increases, and there is a somewhat reduced need for maximum route and volume/schedule flexibility. The larger sludge volumes and reduced need for flexibility creates an opportunity to reduce unit cost through use of lower cost, high-volume capacity modes of transportation such as barge or rail. Careful study of feasibility must, however, precede any change in transport mode. Transfer and storage of sludge become key public acceptance issues with these lower cost, high-volume modes.

The potential advantages of surface mine land application in obtaining public acceptance are many. Sludge can beneficially fit into the local coal economy, physiology and psychology. Because of coal mining, unusually disturbed land occurs. There is frequently a more pronounced locally voiced need to stop erosion than in non-coal mining areas. Sludge utilization can provide a positive fit in the local economy, helping to restore the problem site while creating new work for local people, including drivers. Where there is a backhaul opportunity for coal haulers, it may also provide more local jobs, and potential cost savings for the local coal haulers (and the city).

Because coal has become an accepted part of the local scene, sludge, if it follows in reverse the path of coal, is more likely accepted. The use of established coal haul roads is likely more acceptable to the public than "new" routes in non-coal areas.

The transportation equipment used to move coal, because of the similar density of composted sludge, makes it the most suitable for transporting composted sludge (with additional measures to prevent the escape of sludge in transit), and technically and economically nearly ideal for backhaul. Less dewatered sludge is heavier by volume and more costly to transport by weight-restricted modes. How much more costly depends on how much more water is transported.

There is an absolute need to plan, market, and execute a sludge land application program well, with mine-site community acceptance the guiding principle. Our study gives some guidance to these three activities even though

the study is confined to transportation. Program planning, marketing, and execution, while keyed to institutional factors, must carefully, with thorough knowledge of these issues, make legal, technical, and economic choices. A thorough understanding of the general social-political aspects, technology and economics of coal surface mining, specifically of the target site community area is also necessary. Because in the East a program must usually deal with surface mining in transition, an understanding of the history of reclamation, the concept of abandoned lands, the legal principles of mineral and surface rights in land, and reclamation technology and law are also required.

The Philadelphia-Somerset case study shows a successful program can be accomplished. This does not mean a very similar effort will succeed in every other location. The promoters of the Philadelphia-Somerset program found cautiously receptive local rural public officials in a county where there are problem surface mine sites and where there were landowners receptive to sludge being applied to their land to assist in its reclamation. This was a rural jurisdiction where difficult-to-reclaim surface mine lands were being severely eroded. Mine land erosion was known to have resulted in community problems that were of concern to local citizens and public officials. These factors may have been the key factors resulting in local receptivity. The number of situations where this set of circumstances and human attitudes exist is difficult to predict. The skill of the sludge-producing city or its contractor in evaluating and utilizing these circumstances successfully is also difficult to predict. Therefore, although we can say that in a well planned and executed program there is little likelihood of constraint of transportation occurring, this does not mean the particular overall program will succeed. The land application element is a much higher public acceptance hurdle.

Institutional Findings, Conclusions, and Constraints

Public and Public Official Resistance. As is well known, a significant segment of the public has a negative reaction toward municipal sewage sludge. Community acceptance problems exist even toward programs dealing with its own sludge. There is generally less acceptance of sludge from another community. There is even greater resistance in rural areas to accepting sludge from large cities (a factor that argues for use of a general contractor as a deflecting intermediary). It is likely that the rural resistance is less if the population density of the community is small and dispersed, and the area selected where the sludge will be placed is "out of the way" and will cause the least possible impact on the least number of even this small number of people. The experience of one of the authors using buffered unused public land would serve as an example. This situation may exist in a few areas in the East, especially where there is public ownership of previously mined land. It will occur with greater frequency in the West, especially with leasing and mining of federal land managed by the Bureau of Land Management, and where huge tracts of land are owned or controlled by coal companies.

Rural public resistance to receiving large-city sludge is based on social, economic, and political grounds. It is in part emotionally based, as well as being based on potentially valid physiological or technical grounds. The physiological or technical issues will usually be the expressed rationale for opposition. There is resentment based on the perception that cities and their industries have historically dumped wastes of all types in rural areas. This resentment includes the perception of wealth being amassed and kept in cities, often from rural resources, while its refuse is the rural area's only legacy. That municipal sludge is a refuse that can be used to the social and economic benefit of the rural areas, may help overcome this resentment. This advantage should not be lost by now benefiting only wealthy rural landowners. Care in selecting a mix of application site landowners and order of site use should be exercised.

The physiological or technical concern about city sludge is based on factual perceptions which are in part accurate but incomplete. The perception for some is that sludge is highly odiferous and contains dangerous pathogens, without knowledge of the composting (and other) processes that sufficiently eliminate odor and pathogens. For others the perception is that industrial and other processes in cities contribute toxic organic chemicals and heavy metals to the sludge in amounts that pose a threat to public health and the environment that these substances will contaminate vegetation, wildlife, surface and groundwater and enter the human food chain. The fact is that toxicants and heavy metals are present in the municipal sludge of various size cities, not just large ones, but generally are available at levels that are low enough that land application programs can be designed and operated in a manner that does not present a danger to public health or the environment.[1] According to EPA and state requirements, many municipal sludges can be applied safely to land used to grow food chain crops. Sludge with higher levels of contaminants that could not be cost-effectively applied to cropland, according to these requirements, can be applied safely to land not used to grow food chain crops. Research studies have also provided useful recommendations for land application projects.

Public resistance is nearly always focused on the application of sludge to land. Transportation of sludge in connection with land application, if opposed as part of the opposition to land application, will be a secondary target. When land application programs are accepted, the local public will continue to monitor the transportation element, but if it is well planned and executed the opposition will be slight, if any. However, if sludge transportation is poorly planned or executed, opposition to transportation can become equally serious. In transit-only jurisdictions, opposition to sludge transportation will materialize if transportation is poorly planned or executed. The citizen's transportation concerns will likely be odor, routing, spillage, leakage and blow off precautions, spill clean-up procedures, and on site or off-site storage in the community.

Local public officials of in-transit only communities were not concerned so long as the sludge was not hazardous. If hazardous, they would want to be informed and have some say in routing and scheduling. They expressed a preference that it stay on the interstate highway. Although the case study was a single, interstate route-specific example, it is our impression that composted sludge transportation will not create transit-only community opposition. Other processed dewatered sludge transportation is not likely to create opposition. We would expect the likelihood of opposition to increase in areas where interstate highways are not available and the sludge is more objectionable.

Public officials are likely to reflect somewhat the opinions of their constituency, however, individually public officials are likely to have personal biases that can hurt or help a land application program.[2]

A well-planned, marketed, and executed program, including the transportation element, keyed to public acceptance in the application site community is essential. The Philadelphia-Somerset case study showed that such a program can adequately minimize public opposition and gain public official support. It also showed that a well planned and executed transportation element can completely avoid public (and public official) opposition, and help in the marketing of the entire program.

A program entirely within one state, where possible, should have a greater chance of success. Neither the city nor the rural area are as foreign to each other. At the state level there is greater opportunity for legislative trading and an agency that is interested in helping to solve both the city's sludge management problems and the state's mine land reclamation problems.

An open, well conceived and implemented presentation of the land application and transportation plan is essential. Initiating contact with community leaders, public officials and others, openness to public inquiry and a willingness to create opportunity for disclosure and public inquiry are all essential. Explanatory material should be developed (e.g., film and/or slides, brochures, reports of test data) on all program elements.

Sludge storage on the application site can be a major problem. It can be the major transportation-related technical or physical constraint. The potential problem must be avoided by planning the transportation element to minimize on-site storage volume and duration. Truck transportation flexibility offers the best technical solution to these problems for short distance hauling, and for longer distance as well, unless off-site storage facilities can be established. Off-site storage may present a public acceptance problem in another community.

Using composted sludge which is low in contaminants can be of major assistance in gaining public acceptance. Its earth-like odor and physical characteristics that resemble a potting soil are strong assets. It handles better in unloading at the application site than does wetter sludge. It is less objectionable in transit and in case of spillage. It is less objectionable in

on-site storage.

Public acceptance of programs is more likely to occur if sites are at first selected that even prior to mining had poor soil structure and now cause revegetation and erosion problems as a result of the land disturbance from mining. Because adequate topsoil was not available for reclaiming this type of site, the program will provide even more beneficial gains to the mine-site community.

Monitoring the sludge for toxic organic chemicals, heavy metal, and pathogens, by the city's or its contractor's consultant, and locally established independent monitoring of soil, crops, surface and ground water of the sites and off-site areas for these contaminants to prove that they remain at acceptable levels, is essential to building local trust and acceptance. Where possible, monitoring by a well-known and trusted university group, often with a preference for being from the minesite state, should be provided. This promotes an accurate and positive image of the company's willingness to be independently and professionally judged, and by a group more likely to be locally trusted and an institution that has locally established relationships.

Wastewater Engineer and Transportation Company Attitudes. Consulting wastewater engineers are generally not opposed to these programs but are skeptical that they are likely to receive public acceptance in the mine site area. The depth and meaning of this skepticism is unknown. The possibilities for this approach will generally need to be demonstrated through feasibility studies before these engineers will recommend investing in staff time or further contract commitments to program development, and probably before they will recommend composting, although composting may be viable for other types of land application programs, and therefore an easier decision. The successful Philadelphia-Somerset program should help ease such skepticism.

Transportation companies are generally more skeptical of entering as the investing catalysts for this type of sludge reuse program. A few have tried unsuccessfully, large-volume sludge reuse projects. They see public acceptance as too fragile a web to justify the investment in such projects. We suspect it may also require too great a planning and marketing investment for the potential amount of business to be gained. There appears to be no opposition to merely providing the transportation service for transporting sludge in a program where the non-transportation investment comes from other sources. The city will clearly have to share in the investment and risk.

Transportation companies are also reluctant to enter into complicated government program contracts. Contract models providing performance criteria rather than details of performance may be of some help. As a caveat, however, the company staff for any full program contract, whether a transportation company or a managing contractor, must include, in a

controlling position, people with citizen participation mechanism skills, for proper planning, marketing, and program management.

Legal Findings, Conclusions, and Constraints

Laws having a potential impact on the transportation of sludge are grouped under two broad categories: safety regulation and economic regulation. The former are concerned primarily with ensuring that transportation operations are performed in a manner that minimizes the risk of harm to both shipper and carrier employees and the communities through which the sludge is transported. The latter are concerned primarily with the adequacy of available transportation services and the rates paid for such services.

Health and safety regulations are administered by the Department of Transportation and the Environmental Protection Agency on the federal level and state agencies on the state level. Economic regulation of interstate commerce is under the Interstate Commerce Commission (ICC), which regulates licensing of firms, level of services provided, and rates charged (and generally similar state structures for intrastate commerce).

Our examination of laws and existing and proposed potential regulations in both categories indicates that current government regulation of transportation should not be a substantial impediment to the movement of municipal sludge for land application. On the other hand, we found that the absence of a regulatory scheme for transporting hazardous sludge was a constraint, although probably not a series one. Absence of a regulatory scheme leaves state common law of nuisance court test outcomes more uncertain than would be the case with a regulatory scheme.

The only laws that currently pose a potential constraint to sludge transportation are the nuisance laws contained in the common law of the states. Common law nuisance suits, based on allegation of hazard or nuisance, can be brought by aggrieved officials or citizens in local state courts before locally elected judges. Public opinion and local public official perceptions can weigh significantly in these suits.

In the land application jurisdiction, suits will more likely and more easily be waged against the land application element. Even if transportation of sludge is an included complaint, court decisions are far more likely to be adverse *only* to the land application element. A primary reason is the general perception that potential hazards in transporting sludge are not nearly as great as potential hazards from its application to land.

In the transit-only jurisdictions involved in the Philadelphia-Somerset program there was not significant opposition to the well-planned and executed transportation element. Sludge is also currently transported by many cities for other means of sludge disposition in their own and nearby jurisdictions without adverse transportation nuisance case decisions being a significant constraint. Substances perceived as even more objectionable travel interstate highways with little, if any, public objection.

For these reasons there is a high certainty that state common law of nuisance will not pose a constraint to well-planned and executed transportation of sludge for land application. However, these laws would be constraints to poorly planned or executed transportation.

Uncertainty does exist in the common law of nuisance, by its very nature of inexactness (not statutory) and the variability of local court jurisdiction. Although not a serious constraint to transportation, its uncertainty can and should be greatly narrowed and substantially removed by further development of a more complete hazardous waste and material transportation regulatory scheme for sludge under current federal laws.

There are two existing federal laws that allow development of sludge transportation regulations: the Hazardous Materials Transportation Act[3] administered by the Department of Transportation (DOT), and the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) administered by the Environmental Protection Agency (EPA).[4] Both relate to hazardous waste/materials transportation. The first is intended to apply to any material (including waste) that is hazardous *in transportation.* The second is intended to apply to any waste material that *is transported and* is hazardous in disposition (but *not* necessarily hazardous in transportation). The first requires special equipment, and for trucks, higher insurance. The second merely requires participation in EPA's manifest system which is designed to keep a record of where the waste is routed and disposed of.

Regulations might in error be developed that would pose constraints to well-planned and executed transportation of sludge. Effort should be made to see that they do not. Effort should also be made to assure that instead, regulations are developed that aid transportation of sludge that is well planned and executed, placing constraint only on those that are not. This would have the important secondary benefit of guiding local state courts in nuisance suits, administrative regulators, planners, and investment decision makers in developing programs, and would aid a more accurate public perception of sludge.

In the four states examined, we found no existing law authorizing a transportation regulatory scheme based on hazardousness in transportation or to control the whereabouts of sludge in transit. The probable fight over proposals of new state law specifically for sludge would be counterproductive. Regulations pursuant to any such law of any state, if any exists, should be similarly developed to provide an even more complete regulatory scheme.

In addition to state nuisance lawsuits, there is also the possibility, even absent federal regulations, that a federal court action involving transporting sludge could be brought under the Hazardous Materials Transportation Act[5] or the Solid Waste Act as amended by the Resource Conservation and Recovery Act[6] or both to compel its classification as "hazardous" even

though not so classed by regulation. If such a suit or both suits succeeded, this would not block sludge transportation but would instead impose for trucks the additional requirements of the EPA manifest system, substantially higher insurance, and more expensive equipment. It might, however, destroy any hope of public acceptance of the sludge for land application. The test for hazardousness in a federal court is likely to follow federal guidelines for land application or a yet unformed lower standard for hazardous waste in transportation, depending on the court's acceptance of there existing in fact such a differentiation. This is further reason why caution dictates the use of high-quality sludge, following the EPA guidelines.

A regulatory system would place some strictures on the new less certain operation of common law (and obviate the possibility of adverse federal court action, as long as the needed EPA and DOT regulations are followed). Establishing in the regulations a definition of sludge that is hazardous only in transportation makes it clear that other sludge is *not*. A federal regulatory scheme does not preempt operation of state common law of nuisance. In matters of safety, unless a federal law specifically provides for preemption it is presumed not to preempt state law. However, a federal regulatory scheme for sludge transportation would have the effect of supplying definitions which tend to become guidelines for the state courts. It becomes difficult for a judge to justify choosing a different definition. Therefore, reasonable federal and state regulatory schemes would tend to place guidelines on the new "roving gun" of a local nuisance lawsuit.

Federal and state economic regulation of transportation, although containing some uncertainty regarding its application to sludge transportation, poses no serious constraint to sludge transportation. At most, rate overcharge recourse to the ICC may be limited for a few carrier classification choices within the truck and barge mode. As in the case of safety regulation, being under such a federal regulatory scheme would provide greater certainty of fair rates. Here the rate certainty would come from access to recourse against market dominance-caused over-pricing. There would be little disbenefit from sludge coming under the existing scheme. The certainty gained is that certain carriers and equipment will be available at equitable cost. The uncertainty of cost when not under ICC regulation, however, is not likely a constraint to sludge transport.[7]

In the case of economic regulation a regulatory scheme exists, but sludge transportation needs to be specifically brought under it. The likelihood of sludge qualifying to come under the existing transportation economic regulatory scheme is highly probable. The probability would be even greater were public agencies to jointly urge its regulation by the ICC. Such regulation will not present a constraint. The possibility for negotiating fair rates will remain, and be enhanced by the new potential for access to ICC rate regulation.

Sludge has long been transported, but generally for short distances in

its local jurisdiction or origin or to nearby jurisdictions. This had produced little impetus for either safety or economic regulation of its transportation at the state and federal level. This leaves a degree of uncertainty for planners and investors, but not sufficient uncertainty to be a constraint to developing the transportation element of programs.

The uncertainty in both the safety and economic area of the law relates to regulation, but each in a different way, requiring different remedies. Under safety, because a regulatory scheme for hazardous sludge transportation has not been structured, the remedy is for regulations to be drafted and promulgated. For economic regulation, a comprehensive regulatory scheme exists, but sludge has just never been brought under it. The remedy is an ICC decision invoking its regulatory jurisdiction through a permit application.

Large cities developing programs for the disposal of sewage sludge should become acquainted with the existing framework of safety and economic regulation, since decisions made in response to this two-part regulatory framework may affect the ultimate cost of transportation and even create impediments where they could have been avoided. The differing application of laws and regulations to interstate and intrastate transportation should always be borne in mind.

Technical

Adequate equipment for transporting sludge to mine sites is readily available for two of the four modes studied, truck and rail. Barge is readily available where waterways exist. Pipelines are generally not available. Trucks and barges can be purchased and used on public rights-of-way. Railway and pipeline rights-of-way are not public but rail cars can be purchased and law requires railways to permit their use if possible. Purchase of right-of-way is impractical for rail haul, however, spurs will cost the same as if purchased (but built and maintained by the railroad company). Pipeline "purchase" requires both investment in right-of-way and pipeline construction. This may be possible for the full-scale phases of some larger successful projects that may be developed by very large cities for short- or long-distance transport of sludge.

Institutional considerations, for reducing likelihood of opposition to sludge transportation, compel use of certain additional equipment on truck and rail carriers, and care in selecting quality truck, rail or barge equipment. The public and public officials' concern in all jurisdictions is with the choice of route (kept off local roads as much as possible), spillage, leakage and blow-off prevention, and odor elimination. Tarpaulin or other covers should be used for truck, barge and some rail units and seals should be included on trucks and some rail cars. These provide greatly improved assurances against dry sludge blow-off, wet sludge leakage, and "dry" sludge becoming wet from rain. This may seem like excessive protection--that one or the other would suffice--and it is. Covers are most important, and also make

the cargo more indistinguishable from other cargoes, avoiding subjecting more people than necessary to seeing sludge, which can be an important aesthetic point.

Equipment that appears and is in good condition helps create a better impression and reduces breakdown problems. Equipment in obvious poor condition will create legitimate safety concerns, as well as an overall negative impression. Extra locks should be used on truck gates. Instructing drivers and handlers to immediately clean up a spill is also important. The use of well-composted sludge is best to minimize odor problems, which can be especially important in avoiding general program opposition. Composted sludge can also be more easily handled at transfer points, at the application site, and in the event of spills.

Trucks provide the greatest low-volume hauling and scheduling flexibility. These benefits help assure the least capital or contract commitments to transport a specific long-term sludge volume and to a specific destination. Use of only trucks avoids the necessity to transfer in transit. This flexibility minimizes storage, capital investment and long-term contract commitment in the early stages. The use of trucks also provides the opportunity to hire drivers from the local mine site area. These advantages are important for minimizing opposition to the transportation element and financial risk.

For very short distances and low sludge volume, dump trucks (with higher sides added) are best. For most short distances and longer distance, larger capacity dump trailers are best.

Trucks are cost competitive with other modes for shorter distances (e.g., 100 miles and sometimes more) and smaller annual sludge volumes (e.g., up to around 20,000 cubic yards but sometimes more). They start to gradually lose competitiveness at about 80 miles. They are competitive for a longer distance and larger volume where one or two rail spurs are a necessary part of the alternative. How much longer and larger depends on the length of the spur(s). When larger sludge volumes of well-established programs of large cities are involved, the cost competitiveness of trucks drops markedly compared to other sludge transportation modes over long distances.

In early stages of a program, the use of trucks will help minimize the risk of public opposition. If the trip is over a long distance, combining truck with other transportation modes may have to be considered, especially when volume of sludge available every two days grows to the minimum capacity of the larger-capacity equipment of other modes (e.g., a few rail cars, a single barge in a multiple barge tow). Whether to arrange for the unloading and loading transfer in a transit-only jurisdiction should be considered at this point but local condition will vary so markedly that no conclusion can be made about this factor. Local established practices for the transport of coal or other bulk industrial commodities are likely to be an important factor in deciding on the feasibility of transfer points. A possible alternative is

temporary storage in "parked" rail cars or barge. Public opposition may prohibit the use of barge for storage.

There may be, in addition to public acceptance, economic reasons for preferring trucks. The need to start with small volumes, the probable necessity of a heavy investment in rail spurs, and the economies of scale in rail and barge, with their larger capacity equipment, not being available until volume is larger, will usually argue, for economic reasons, against use of rail or barge in early stages. However, backhaul possibilities may alter this. An example is where an existing rail spur for coal exists.

For longer distances with larger volume, the possible extra cost of utilizing trucks, at least in the early stages of a program, may still be necessary to reduce the risk of public objection. When sludge volume is low, even for long distances, the economies of higher minimum capacity rail, and especially barge, are not as compelling, and a slightly higher truck cost may still be economically tolerable. In later stages of established programs, the use of modes other than trucks can be reassessed. Specific program feasibility studies will be necessary in the planning of the program and from time to time thereafter to determine the best choice of transportation modes and configurations. Established coal practices are important factors to consider.

A coal backhaul is best for institutional, technical, and economic reasons. Coal is also probably the most available backhaul commodity. The association of sludge transport with coal should lend to reducing the risk of public opposition. This is especially so if routing follows an existing coal-haul route. Using roads already in use by coal trucks, including the empty return trip, should result in less opposition since the only change is that for return trips instead of an empty truck there will be a full but covered truck. Activities relating to coal transportation also are somewhat objectionable, but have probably already gained general local acceptance. (If this is not the case, the reverse is true, so do not get caught in a local coal mining acceptability fight.) Coal transportation equipment is best suited for sludge. Coal may also constitute a large segment of the local economy. Providing an opportunity for backhaul is likely to be seen as a benefit to the local economy.

There is also a marked preference for using interstate highways as much as possible. A preference for local coal-haul roads generally applies once off the interstate highways. This dictates that sites closest to interstate highways will generally be preferable. If coal-haul roads are not available, roads through the least residentially and commercially developed areas are best.

For rail transportation of sludge, hopper cars are best for all but high-volume programs. When sites for large-volume programs are firmly assured, less-expensive gondola cars, which require long-term investment in costly unloading facilities, may become preferable.

Suitable sludge loading and unloading equipment is readily available. Suitable sludge loading and unloading facilities may not be available. They may have to be constructed. New fixed facilities will be an extra cost (e.g., spurs, pads, ramps). Necessary loading or unloading operations present no physical constraints nor is there necessarily a very significant cost difference between modes, although truck is likely to be lowest in cost, except in large-volume programs. Equipment choices within transport modes, however, present considerable cost differences. This is especially true for rail transport, which may be justified for high-volume established programs. In-transit loading/unloading operations will nearly always involve two transport modes, unloading from one mode to load another. In a few cases more than two modes of transport could be involved. One origination loading and destination unloading is included in the costs we used (and in the rate) for each mode; however, the more transport modes used, the greater the number of transfers, and the higher the cost.

Because of the need to start land application programs with small volumes of sludge, and to increase volume slowly, volume over time is an important factor for consideration. This compels long-term planning of programs, with frequent estimates of future volume levels in order to determine the best transit mode for each changing phase of the program.

Although public opinion as to transportation of sludge and legal concern for avoiding sludge that might be found by a court to be hazardous in transportation probably allows for the transportation of sludges less acceptable than composted sludge and sludge of higher contaminants without increasing public-acceptance risk in the transportation element, there are important transportation physical and institutional advantages to composted sludge. It is more acceptable in storage and transfers due to low odor and less potential for runoff. It is easier to load and unload because it is dryer and does not jam up in trucks or bridge the bottom doors of rail hopper cars. The need to wash trucks or rail cars prior to coal or other use is avoided.

It is possible for a city to develop sites in other communities, with existing sites available to help market the concept, in order to increase volume at an earlier point in time. Because of the need to spend a great deal of time in any community marketing and managing programs, care must be used to not over-extend available staff with these skills. Opportunities for cost savings in transportation routings should be assessed when selecting other site communities and specific sites. However, the fact that local backhaul has important public acceptance aspects should not be lightly cast aside for the sake of relatively small transport cost savings.

In multiple-community programs, local backhaul preference may involve more than one transportation firm in that different firms may be established haulers in different communities. Program commitment to a single carrier should be limited. It is preferable for the city itself (or its general program

contractor) to subcontract for the sludge transportation element that best fits a specific site, route, cost, and stage of a program. If a city does not have the staff with time and necessary skill to handle certain program components, including management of sludge transportation, it should plan to contract for these services with a private company. It might also want to contract with a company to operate the entire program, including the subcontracting for sludge transportation.

Economic

This study found no significant economic constraints to sludge transport. However, our study did *not* compare cost of land application with other disposition options. There are ample alternatives available when choosing transportation modes. It is a matter of selecting the best mode and configuration within that mode, or combination of modes and specific configurations, for the particular program.

There seems to be enough competition within these transport modes and between modes that overcharging is not a significant factor.

Until site acreage and sludge volumes are at full program levels, purchase of transportation equipment is an option which should not be pursued for reasons of risk of capital investment and loss of management flexibility. During the early stages of a program, contract negotiation with carriers is preferred. Purchase of fixed facilities may not be totally avoidable, but should be kept to the minimum necessary through transport mode and configuration choices that require less costly fixed facilities.

Cities can develop and operate their own programs, however, private contract development and operation is usually preferable. The city will probably, at this stage and for some time in the future, have to share much of the financial risk in order to attract contractors. The city will have to do all it can to help reduce risks as well. This may include accepting the cost of composting sludge and paying the higher transportation (and other) cost required to gain mine-site community and landowner acceptance. It may also require paying for site community, route and transport mode feasibility studies, demonstration projects, and detailed planning and marketing.

Efficient management by the city is particularly important at this development stage. Possible mismanagement of public funds and trust will quickly raise enough obstacles to immobilize the operation. This is an additional reason for the municipal governments to pay careful attention to the points previously discussed, and to do all that is possible to achieve the key element for success: application-site community public acceptance. It is generally preferable to involve private sector participation and management with close coordination and oversight by the city.

Sludge volume and distance transported are generally the greatest variables in the cost of programs. For volume, the variance is generally

greatest over time. Among all cities as a group, distance is the greatest variable; however, distance generally is not as large a variable as is volume with a specific city, especially not over time. Once an application-site community is selected and the land application program is established, the trip distance should stay nearly constant, while the volume of sludge applied to the land should increase markedly over time. If the city's volume available requires land application sites in other communities, communities near the program application-site community, knowing of the program's success, are the most likely future site communities. This should keep the trip distance in a fairly tight range over time. Sludge volume used in land application on surface mine sites, however, would keep on increasing. With a highly successful program, volume will stabilize eventually. In the meantime, improvements in wastewater treatment and any growth in population will be further variables for sludge volume.

Another reason for sludge volume to be a greater cost variable for all cities is that while each produces a different given total volume of sludge (which also increases with improved treatment), a city can design a land application program for as little or as much of that city's total sludge as it chooses. The further reason that sludge volume is the greatest *cost* variable is the relationship of volume to lower cost-higher volume transport modes and that discounts are available in transport contract negotiations for higher volumes of cargo and long-term haulage commitment, adding variables to price for unit of sludge-volume hauled.

Each city has a given location with reference to mine sites which defines its distance range. The unknown distance variable then is how far into a large surface-mining area must the city venture to find suitable sites and an accepting community? It should be remembered, however, that the shortest distance is not necessarily the least costly, when transport mode choices and institutional factors are considered.

Figures 10-1 and 10-2 show the total costs of truck, rail and barge modes for use in transporting sludge for distances of 80 and 320 miles respectively. The lines show the relationships between volume of sludge extends to 1,000,000 cubic yards of sludge per annum.

Examining Figure 10-1, it seems truck loses its competitiveness at around annual volume of 20,000 cubic yards, with widening unit cost differential as volume further increases. Barge seems competitive with rail at high volume. The studies available did not provide cost for volume less than 500,000 cubic yards for barge. However, because of the large capacity of a single barge and the need to ship at least every two workdays, this approaches the minimum annual volume for barge use.

Barge and rail are still competitive when the distance increases to 300 miles. However, truck now has become very much less competitive. For 500,000 cubic yards, truck will cost $13,581,000, compared with $4,000,000 for barge and rail.

Figure 10-1. Total Cost Comparison Between Three Modes of Transportation (Truck, Rail, Barge) at a Distance of 80 Miles.

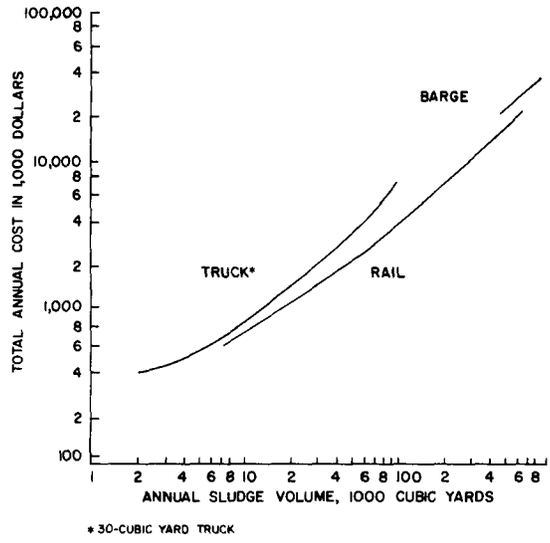


Figure 10-2. Total Cost Comparison Among Three Modes of Transportation (Truck, Rail and Barge) at a 320 Mile Haul.

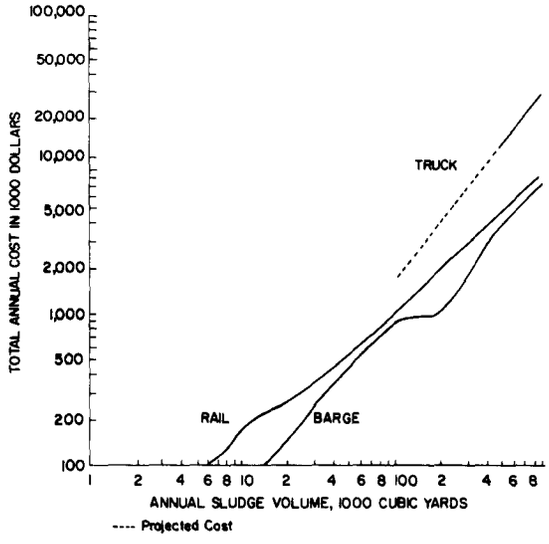
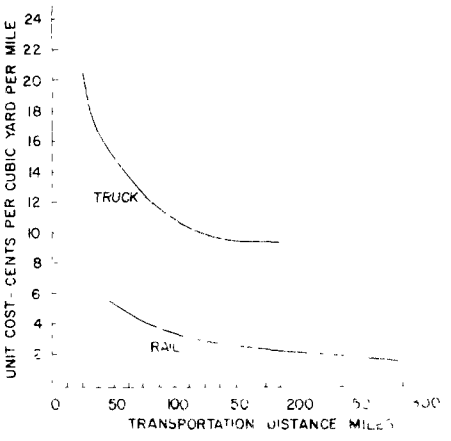


Figure 10-3. Unit Cost Difference Between Truck and Rail by Distance to 5,000,000 Cubic Yards.



Although we cannot establish a firm breakeven mileage, it is clear that trucks are competitive with rail and barge under 100 miles, but it rises at an increasing rate once the mileage is greater than 87 miles. The effect of increasing distance on unit cost can be seen in Figure 10-3.

The cost curves in Figures 10-1 and 10-2 can be more meaningful when used together with Table 10-1 where a list of cities is shown with their annual volume of sludge (for most cities) and appropriate distance to surface mines.[8]

There are a few instances where transport carrier ownership by the city may be advisable. Ideally, a city may own a coal fired utility. There is also the possibility of working out transportation arrangements between the city and the nearby privately owned coal fired power plants, leveraging for vehicle ownership by either party servicing the other. Debt ownership of coal mines may also be helpful, but this is not the predominant pattern in the East. (It should be an important factor in the West.) Local destination-area drivers could still be hired to drive city or utility owned trucks if local law or labor contracts do not prohibit this practice.

Recommendations: The Chronology of a Successful Sludge Transportation Operation

General Attitudes

1. Developing programs of land application of municipal sludge both transportation and land application, should be viewed as one whole process

Table 10-1. Annual Sludge Volume and Distance to Surface Mine Areas.

SMSA	Nearest site area distance	Next closest large site area	Amount of sludge annual volume	
			cubic yards***	metric tons
New York	100	340	83,304	64,080
Newark	110	310	49,140	37,800
Philadelphia	80	280	80,496	61,920
Pittsburgh	20	100		
Baltimore	140	220	28,548	21,960
Washington	110	200	108,108	83,160
Atlanta	130	300	26,208	20,160
Cleveland	50	180	32,520	25,020
Columbus	30	100	391,248	300,960
Cincinnati	100	220	34,164	26,280
Detroit	190	220	391,248	300,960
Indianapolis	60	160/310	34,164	26,280
Milwaukee	240	*220/360	117,468	90,360
Chicago	160	**180/300	241,784	193,680
Memphis	160	290		
St. Louis	50	220		
Boston	250/400	500	57,096	43,920
New Orleans	300	*350/550		

*Two directions.
**Two barging distances.
***Using conversion factor of 1400 lb of composted sludge per cubic yard.

During the course of the study of institutional constraints, many factors were found that applied primarily to the land application element which also impacted the transportation element. Many transportation factors were also found which impacted the land application element. Studies may treat land application from sludge transportation as two separate processes, but this must not be allowed to happen in program development.

2. Sludge transportation programs should be planned so that all concerned understand the need for and seek to insure public acceptance of transportation and land application of sludge.

Preparatory Actions

3. Appropriate actions should be taken to insure legal authority for all of the city's entire land application program activities. The appropriate ordinances and enabling actions should include the authority for entering into necessary contracts, undertaking studies and plans, implementing ongoing programs once developed, and for their funding. By planning these

necessary authorizations early (well before the first application site is selected), the city is more likely to withstand later "hometown" attacks on its program.

4. At an early stage, the city should determine the scale of the desired potential land application element of its overall sludge management activities. Setting a goal for the annual volume of sludge it hopes can be handled annually through the land application process will determine the scale goal of the land application program. A decision should be reached on the type and quality of sludge to be handled in the land application process. The ability to produce sludge over time with contaminant levels acceptable for land application will be a limit on the volume goal.

For the reasons discussed in the study, it is generally essential that composted sludge or, in some cases or later phases, otherwise well-stabilized sludge of a low level of contaminants be used. EPA and state requirements and guidelines should be utilized, especially for land application sites which may eventually involve food chain crop production. The use of a high-quality sludge will further enhance the possibility of public acceptance even if the site to be used will not involve food chain crop production (certain fiber crops, forests, or biomass energy crops).

5. The city should determine what agency and staff, or contractor will administer and carry out program operations. In many cases, the city will probably select and contract with a private contractor for the entire land application program: planning, marketing, subcontracting, and ongoing program management. Managing transport and application is also part of a single process. The Philadelphia-Somerset program is an example of a program using multiple subcontractors with one prime contractor responsible to the City of Philadelphia for program development and implementation.

In developing such a contract with a private contractor, the two parties will need to decide on the share of risk each is to assume. It is most important that the prime contractor hired be capable of gaining and keeping public acceptance. Transportation is a service that can be further subcontracted by the prime contractor or supplied directed by the city. However, it is important for maintaining the mine-site community's acceptance that the prime contractor be able to control, manage, and discharge personnel or subcontractors if operations need improvement. Poor transportation service, the failure to meet delivery schedules and provide a certain level of service, can destroy hard-won public acceptance.

Pre-Program Planning

6. A feasibility study is a necessary early step. A primary purpose should be to help assess the public acceptance potential of various site communities. Public acceptance in all effected communities must be gained. In the beginning, a limited operation involving only the basic originating, transit-only, and receiving communities should be planned. Early operations

will probably depend solely on trucks, although an existing non-truck coal backhaul option (e.g., rail, barge or a combination of either with trucks) may be available. The feasibility study should evaluate a number of different potential mine-site communities for the potential for matching-up suitable problem sites, interested site owners and receptive local public officials and other key local leaders. State agency attitudes must also be assessed. It is very helpful if they are receptive and supportive. It is very important that they at least be tolerant.

The feasibility study should gather alternative routing data and evaluate it to determine short-term and long-term transportation modes and the potential for avoiding possible points of conflict. For the short term, this may include availability of interstate highways for a large segment of the trip and existing coal-haul roads for a short distance. A study of the availability of coal backhaul options should be included. For the long term, if distance is much over 100 miles, modes other than truck must be examined. Economic analysis of the different routing options is necessary.

As a result of this analysis, site communities and routing options for each should be ranked and a target land-application community selected. It is generally best to choose one community (the study will have identified back-up options) and concentrate efforts to gain public acceptance on it, rather than dividing efforts among more than one community at one time.

7. After these preliminary studies, short-term, incremental and long-term sludge volume goals should be reestablished, based on the site feasibility study, volume of acceptable-quality sludge, and now better-known distance probabilities.

Program Implementation

8. An interim, small-volume program for producing composted sludge, or in some cases, otherwise well-stabilized sludge, should be established by the city if it has not already done so.

9. Site use agreements must be obtained from owners of a few of the targeted application sites. Care must be used in selecting landowners as well as sites. Large acreage owners should be avoided in the early phase. Landowners who are respected for community concern should be selected. Care should be taken that the early-phase site is not owned by an absent owner, or even a wealthy local landowner if this risks labelling the program as only benefiting the absent or rich owner, to the detriment of the average resident.

10. Backhaul arrangements should be further investigated and preliminarily established as soon as possible. This may require continuing negotiations until a suitable volume is assured. Caution should be used in backhaul-hauler selection and contract terms to avoid and control poor performance. Contracts should not be entered before the public has had an opportunity to suggest other transport modes or routes felt preferable.

11. Detailed short-term and early interim plans should be developed, including the transportation element, for the selected mine sites. The transportation plan and the remote sludge storage plan must be integrated.

12. Tentative provisions should be made for the use of proper transportation equipment. Use of precautionary equipment should be planned as appropriate for the mode chosen (e.g., for trucks: tarpaulin covers, foam seals, and extra gate locks). The use of local mine-site area people for driving and other services should be arranged as this can help win local acceptance of the entire program.

Institutional Arrangements

13. The city should arrange for professional third-party monitoring to insure a quality operation and to facilitate public approval. The appropriate university, preferably located in the application site state, for reasons of local trust and already established relations, should be used. A locally trusted local consultant would be the second best choice. Try to also have the appropriate local agency or the state conduct independent monitoring.

14. An active program of public involvement to help assure public acceptance should be implemented.

(a) Mine-site community public officials and other key leaders including local media should be contacted, shown plans and studies and invited to visit the city's wastewater treatment and sludge processing facilities, as well as any site where a similar project is ongoing (e.g., Somerset County, Pennsylvania, if similar).

(b) Well prepared public meetings conducted by the city or its contractor should follow. Several preliminary meetings should be scheduled, located at places and times convenient to the public.

(c) Meetings should seek wide public involvement with participation by as many agency key staff, site landowners, and local people as possible. The city or its contractor should have its key staff and consultants present with adequate information and supporting material. The key city or contractor staff person must be a person with proven skill at handling citizen concerns. The pre-planned program should be described as a proposal subject to change as a result of citizen participation.

(d) The presentation should stress and provide for citizen input. It should also provide a fast education for citizens on the technical concepts involved in the program, including the technical aspects of transportation, so that they can contribute to problem solving as well as raise questions and criticisms. Company participants should be thoroughly prepared to candidly respond to citizen inquiry or comment. Slides showing the proposed sites, unloading and storage locations, and other contemplated program components including early-phase sites should be utilized. The slides and their presentation should identify the existing problems associated with the sites and how they will be corrected by the sludge application program.

In the Philadelphia-Somerset program, the sludge-based composted mix (e.g., municipal sludge and wood chips) was called "compost mix" rather than sludge. It is important to use care in selecting terminology that is honest but that also places the program in the best light. Possible problems associated with sludge quality, transportation, storage, unloading, and site preparation and application techniques should be frankly presented. The vegetational growth potential should be emphasized. The benefit to the local economy should be fully discussed, but not overemphasized.

(e) Once initial local approval is gained and the first on-site sludge application is underway, further meetings should be scheduled, and invitations extended to visit the site. Buses or smaller passenger vehicles should be provided to facilitate site visitation.

(f) Similar programs should continue throughout future phases of the program, no matter how large the approved acreage becomes.

Transition to Large-Scale Operations

15. At later phases, as the volume of sludge transported increases substantially (and perhaps earlier where the trip distances are longer), carriage by truck may become too uneconomical. At this point, the city should reconsider its choice of carrier and re-examine which transport mode (truck, rail, barge or pipeline) or combination of modes is best suited for its operations. If interstate travel is involved, the impact of Interstate Commerce Commission regulation on rates, entry, and level of service should be assessed. The city should compare different types of carriage arrangements (e.g., private ownership, private carriage, contract carriage, and common carriage, as applicable to the different modes).

(a) When truck carriage is utilized, dump trucks will generally be most economical and suitable for short hauls or short-haul truck segments combined with other modes. With longer hauls (of up to 100 miles and sometimes more), dump trailers (pulled by truck tractors) will be most economical and suitable for the earlier phases of a program, but only for very early, small-volume phases of very much longer distance hauls. For distances much greater than 100 miles serious consideration should be given to rail or barge (if available) as alternatives to truck hauling. If rail is the alternative and rail spurs must be built, a longer distance than 100 miles will be the breakeven point for truck and the alternative mode. How much greater depends on the length of the needed rail spur construction. Truck should generally be the best connecting transport mode where barge is involved. Local backhaul options should be investigated as they can alter these preferences.

(b) If rail haul is chosen, hopper cars with tarpaulin covers and foam seals should generally be used. Hopper cars with steeper interior slope are preferable to facilitate unloading. Composted sludge is best in the unloading of these cars, but they will handle otherwise dewatered sludge.

The problem is the wetter the sludge, the more difficult is unloading. For high-volume, well-established programs, the use of less expensive gondolas with their more expensive fixed unloading facility may prove more cost effective. For very high-volume, well-established programs, unit trains (preferably in a backhaul arrangement) and pipelines should be analyzed for availability, suitability and economic preference.

(c) Barge transport generally is less costly than rail transport where route length options are equal or nearly so. Where a barge transport waterway is available, its use should be analyzed. It should generally be equal in terms of public-acceptance risk to rail transport where truck transport is the final link to the application sites for both transport modes (e.g., rail spurs are not used). A potential advantage of rail haul is the possible opportunity to keep transfer points and storage facilities significantly further away from major water bodies, reducing the risk of public objection based on concern over runoff that could lead to increased water pollution. Such secondary factors should also be considered when making transportation mode choices.

(d) The equipment used should be maintained in good appearance as well as good operating condition. Public acceptance of transport is thereby better assured in transit-only communities as well as in the application-site community.

16. Because a city may eventually establish land application programs in more than one community, and carefully selected and managed local transportation, perhaps a different carrier in different communities, can help promote local public acceptance of programs, a city or its contractor should not over-commit to a single carrier. Options should be kept open as much as may be appropriate for desired flexibility. Since poor performance of a carrier can damage public acceptance of a land application program, contract withdrawal rights should be as favorable as possible to the city or its contractor.

17. In considering transport modes, the location and management of any necessary transfer points and sludge storage off the land application site should be carefully considered. These requirements of the rail and barge transport modes may have a significant impact on cost (e.g., additional fixed facilities and transfers), transportation arrangements (e.g., less direct routing, also a cost factor), and public attitudes. The cost of establishing rail spur (an investment approximately equal to the full capital cost of construction) should be investigated to avoid a transfer of sludge to truck if an acceptable transfer point (points if no spur exists at the wastewater treatment plant) or acceptable off-site storage area is unavailable. On-site storage can be a serious public acceptance problem unless available site acreage is of sufficient amount to daily accommodate application and tillage of at least half the trip sludge volume. This can be a major problem with the use of rail or barge, both having much larger volume capacity (without economic penalty) than truck.

18. Cities should keep informed of the sludge handling programs of other cities and cooperate to achieve a better economic and regulatory environment. Efforts to monitor and guide development of the safety and health regulations based on federal and state laws should be collectively pursued. In developing sludge land application programs in the meantime (and thereafter as well), they should be developed to present the least likelihood of being impeded by common law nuisance suit decisions.

APPENDIX—Long-Term Potential and Primarily Western Potential for Longer-Distance, High-Volume Transport of Municipal Sludge for Use in Surface Mine Land Application

William B. Nye

The Long-Term Potential

The potential for long-term land application of municipal sludge is enormous. The amount of sewage sludge produced in the United States in the late 1970s was estimated to be about 5 million tons annually and is expected to reach nearly 10 million tons by 1986, largely because of the improvement in wastewater treatment facilities. Sludge production is a direct factor of the size of the population served and level of wastewater treatment. Adding secondary treatment to a primary wastewater treatment plant can double the amount of sludge produced. Advanced or tertiary treatment creates even greater volumes of sludge.[9]

The phasing out of ocean dumping and the increasing difficulty in obtaining suitable landfill space is creating a greater interest in a long known, but relatively little used method for beneficial use of sludge--land application.

It is believed that most municipal sludge can be safely applied and tilled into the soil. Sludge serves to improve soil structure and organic nutrient content. Because some sludges may in fact be "hazardous" waste, due to high levels of chemical and heavy metal contaminants--in part from industrial wastes entering municipal wastewater treatment plants--there are limits to the type and amount of sludge that can be applied to land. The land that can be used for sludge application may also be limited by the amount of contaminants in the sludge and the use of the land. A key issue is whether the land will be used to grow human food chain crops. The impact of the sludge on surface water runoff and groundwater, if either enters the human food chain, will be an issue as well. In theory, sludge with higher levels of contaminants can be applied to land not used to grow food chain crops. Most agricultural land is used to grow food chain crops. It should be noted, however, that increasing requirements for industrial pre-treatment of wastes discharged into municipal wastewater treatment

plants will help reduce the amount of contaminants in municipal sludge produced by these treatment plants. This will further increase the amount of sewage sludge that is suitable and available for land application. It should also be noted that a certain amount of so-called contaminants become "unavailable" in the soil and do not enter vegetation or leach, and that vegetation controls erosion, avoiding their release in surface water runoff.

It is felt that land which has been used to mine coal (and some other minerals), primarily by the surface mine method, represents a high ratio of land not used to grow food chain crops, thus available for application of sludge with higher levels of contaminants.

Prior to treatment, sludge also contains a high level of pathogens. However, these pathogens are reduced to low levels by modern treatment processes that are in wide use. Composting sludge provides even further assurance of reduced levels of pathogens because of the heat produced naturally in the composting process and the resulting drier state of the sludge. Lime stabilization, heat treatment (a high commercial energy user) and other processes can achieve similar pathogen-removal results.

Large cities produce the largest concentrated volumes of sludge and have the greatest problem finding nearby sludge disposal sites. The three largest cities in the United States produce ten percent of the Nation's sludge.[10] Our study concentrated on the larger cities east of the Mississippi River, which includes two of the three largest cities, New York and Chicago. We also confined our inquiry primarily to the issue of land application of sludge to coal surface mine land.

There are over one million acres of abandoned coal surface mine land. Almost all of it east of the Mississippi River, mostly in the Appalachian states. Abandoned mine land refers to land that was mined but not reclaimed before effective reclamation laws were enacted. Today, the pace of coal surface mining is increasing as the nation emphasizes greater use of coal for domestic energy. Greater export of coal is also anticipated. Sewage sludge can be effectively utilized in reclaiming both abandoned and active surface mine sites.

A determination of the amount of potential sludge and the amount of potential surface mine land available for sludge application would be difficult to do with exactness. The amount of sludge that can be applied to land varies with the levels of contaminants in the sludge, the intended crop use of the land, and site characteristics. However, some benchmarks are available.

This study found Philadelphia to have a relatively large program of transporting sludge for use in reclaiming surface mine sites. Philadelphia annually produces approximately 65,000 dry tons of sludge. Philadelphia officials project using approximately half of this for surface mine land application on approximately 400 acres in 1980. They anticipate using 8,000 dry tons of composted sludge per 100 acres, which amounts to a 2-inch-thick

layer that is immediately tilled into the soil. At this application rate, 80 million dry tons of sludge compost could theoretically be applied to one million acres of coal surface mine land. This is roughly equivalent to reclaiming all the abandoned surface mine land, were it used for this purpose. Thus there is the potential to apply essentially all of the Nation's sludge produced for approximately the next ten years to existing abandoned coal surface mine land.

Many cities already are engaged in other forms of land application of sludge. These other forms range from application to agricultural land to bagging it for marketing to, among other places, home garden stores. A few cities in the East and many cities in the West are generally considered too far distant from mine sites to economically transport their sludge to mine lands for application. In reality, given these other forms of land application, abandoned mine sites alone probably could offer several decades of available sites for sludge utilization.

There are many new mine sites being opened. A future of increasing coal mining offers an even more permanent potential for sludge application, especially in the West. In program development, decision makers can rely on the potential acreage that will allow long-term plans and investments, including those for transportation--once the program itself has achieved the necessary initial regulatory and public acceptance success and so long as the program is well and sensitively managed.

Near-Term Potential for Larger Volume Programs

Large Acreage and Absence of Public Opposition

There may be opportunities for land application of sludge on immediately available, large, contiguous acreage where public acceptance would not be expected to be a significant issue. This may occur in the East, perhaps on a few large tracts of federal or state-owned lands used in such a way as to provide a land buffer for surrounding population. It is more likely that large tracts of surface mine land will occur in the West within federal- or state-owned land when it is surface mined and within large tracts of land owned or otherwise controlled by mining companies where the surrounding area is very sparsely populated. To minimize what public concern might develop, it would generally be prudent to start the program in the interior of the tract. Although in this more isolated situation public nuisance concerns should be minimal, there will still be regulatory and public concern for environmental impacts. It will be necessary to monitor runoff, leachate and vegetation. EPA guidelines for food chain and non-food chain need to be followed. A court challenge is still a real possibility.

These large, isolated tract operations will in nearly all instances, involve very long distance hauls. Due to the distance involved and the large

sludge-volume potential, unit-trains seem most appropriate, although some barge and unit-train combinations would also be appropriate and economical for some cities. Where western low-sulfur coal is transported to eastern cities, opportunity for a backhaul for sludge is very likely available. For the East Coast, with the exception of a few cities, however, this is not yet a very wide-spread occurrence. However, commodities other than coal may provide a unit-train backhaul opportunity to a point that is reasonably close to the large tract site. Transporting western coal to eastern cities is likely to increase, but mostly with eastern cities not located in coal-producing states. Even with the cost savings of backhaul and unit-train, shipping sludge from much of the East to the West will still be expensive. Composting may be avoided but composting and eastern application may be a smaller cost than the cost of transporting eastern-most sludge to western states.

Many of the preferences noted in this study relate to minimizing public opposition can be tempered considerably if public opposition is not a major issue. Economics can become a more guiding principle. With reduced likelihood of public concern for the odor and appearance of the sludge, a wetter, less processed sludge may be usable in some cases. This should provide greater feasibility for the use of pipeline. Pipeline may not be feasible for the very long East-to-West distance, or over mountains from West Coast cities.

The West

The figure for the Nation's total sewage sludge includes sludge produced in the West. Large-scale western coal surface mining began fairly recently. There are very few abandoned surface coal mines in the West, but there are a growing number of operating mines. The sites involved tend to be very large and generally in areas of sparse population. Distances between western and Mississippi valley-area large cities and mine sites are generally far greater than the distance between eastern and Mississippi valley-area large cities and eastern coal mining areas. In summary, the potential for sludge application to surface mine sites in the West has less immediate general potential. There is, however, a potential for advantageously located programs to develop in the West.

For those western urban areas with relatively arid land and a general water shortage problem, there may be less objection to the use of wetter sludge on nearby agricultural land. Wastewater, after being adequately treated for public health and safety, is currently used in western irrigation. Where this is the practice, public acceptance of sludge application to land may be facilitated.

Because of the need for high volumes of water to make pipeline usable, in western water-short areas water rights and water diversion may be a problem. The possibility exists for cooperative use with coal slurry pipelines (this possibility may exist in the East in a very few instances), were there

substantial re-use of the coal slurry water in a substantially closed system. Another possibility may occur where the sludge-originating community is located in a water surplus area where water diversion is not a significant public concern and the water that is available in a potential mining area is not sufficient for mining operations and mine-land reclamation activities. The cooperative use of pipeline could provide public benefits at both ends of the pipeline. It might bring needed water to the coal mining area and solve the sludge management problem of the water surplus city, perhaps doing both tasks at lower cost. Such a program could potentially include water diversion for use in mine-land reclamation as well as use in sludge and wastewater transport. Because of a general water shortage situation in much of the potential western coal mining areas, there may be opportunities for use of both sludge and wastewater in mine reclamation.

Use of a single pipeline for two-way traffic may present difficult scheduling and possible cleaning problems for each change of product. A more costly dual pipeline may be necessary, but may be cost effective if water availability in the mining area is a significant problem. Major cost savings will be available if an already acquired right-of-way permits and will physically accommodate an additional pipeline.

Energy Use Competition

From a long-term land application program standpoint, there is the potential for competitive uses of sludge for energy production through incineration and heat recovery. The challenge is to remove enough water to achieve combustion without use of auxiliary fuel. Current sludge-drying technology uses large amounts of energy to dry the sludge prior to burning. Should efficient technology be developed, there will still be a heavy front-end investment in sludge-to-energy combustion facilities. This issue could eventually raise a public policy issue over competing uses of sludge. The issue would be whether sewage sludge use best serves the public in soil restoration or in providing energy. One factor will be that using sludge to enhance soil can assist in the production of biomass for energy use while also controlling soil erosion.

Notes

1. The amount, types, and staging of industrial processes, and degree of existing industrial pretreatment, are sludge contaminant variables with any size industrial community. With land application of sludge, the amount of sludge per acre is another contaminant-related variable. In terms of contaminant availability to vegetation and surface and groundwater, the

degree of soil acidity is another contaminant-related variable.

2. A public official who would like to minimize controversy might take a position opposing land application of sludge although only a minority of his or her constituency might be opposed. He or she would expect an even smaller minority is likely to be actively in favor of the program. Another public official might be open to further exploration of the issue and eventual support of the program.

3. 49 U.S.C. secs. 1471, 1655, 1761-62, 1801, and 1812.

4. 42 U.S.C. secs. 6901 et seq.

5. Ibid., at 3.

6. Ibid., at 4.

7. According to utility argument against the pending federal rail deregulation bill, coal transportation (and thereby backhaul of sludge) is a rail market dominance situation. If this is true, the bill could cause higher transportation costs for sludge carriage by rail.

8. Source of the sludge volume is the EPA-Environmental Impact on Criteria for Classification of Solid Waste Disposal Facilities and Practices. Note the recorded volume of sludge is only part of the waste from treatment plants. As sludge management becomes more effective, more wastes will be processed to sludge.

9. *Sewage Sludge--How Do We Cope with It?*, GAO; CED-78-152 (9-25-78), p. 1.

10. Ibid., p. 4.

11
INSTITUTIONAL CONSTRAINTS AND PUBLIC PARTICIPATION BARRIERS TO UTILIZATION OF MUNICIPAL WASTEWATER AND SLUDGE FOR LAND RECLAMATION AND BIOMASS PRODUCTION

Patricia L. Deese, J. Raymond Miyares, and Samuel Fogel

Introduction

Researchers have repeatedly demonstrated the technical feasibility and potential benefits of applying municipal sewage sludges to enhance biomass production and reclaim disturbed sites. The formidable tasks of obtaining regulatory approvals and overcoming public concern often discourage serious examination of the alternative. However, those who have successfully negotiated the approvals process have achieved excellent results, both in terms of land reclamation and biomass production. These successful projects are proof that overcoming institutional constraints and public acceptance barriers can be well worth the effort.

The goals of this research effort have been to identify the institutional pitfalls and public opposition obstacles, and to suggest methods for addressing these non-technical aspects of project implementation. The study focused on projects utilizing sewage sludge for reclamation and biomass production, although many of the findings presented here are relevant to a broad range of municipal wastewater and sewage sludge land application projects.

Constraints and Barriers

Public Opposition

Although some land application projects have proceeded virtually unopposed, most have generated some level of local controversy. If a sufficient number of individuals feel their interests threatened, the "Core Opposition Group" they form can often mount a significant campaign against a project. Historically, Core Groups have been formed to oppose a specific project. In contrast, traditional environmental organizations, such as the National Wildlife Federation, National Resources Defense Council, Sierra Club and Audubon Society have typically not mobilized their membership against such projects.

While Core Groups may vary in composition from site to site, they most frequently include owners of property abutting the project site or along the transportation route to be used for site access. Such parties generally

expect that a project will result in personal inconvenience or loss of property value. Other private citizens may also participate in Core Groups, however, for a variety of reasons including environmental and health concerns, and general animosity toward accepting another municipality's sludge. Once a Core Group has coalesced, a strategy for fighting the sludge project may be developed, consisting of one or more of the following components:

Regulatory Intervention. Before a project can obtain the necessary federal, state or local approvals, opponents may seek to intervene in the regulatory proceedings. Simultaneously, they may launch a political effort to influence regulatory decision makers, either through direct lobbying or by indirect means such as public information campaigns. The goal of the component is either to deny a project sponsor the necessary permits outright, or to raise the costs of obtaining such permits sufficiently to make the project financially infeasible. Since land application projects are likely to be anything but routine, the Core Group may attempt to convince a large number of licensing and permitting authorities to assert their jurisdiction. Frequently, such efforts can be successful if the roles of the various federal, state and local authorities are not well defined. Of course, as experience with land application increases, the regulatory scheme will become more routine and the possibility of overlapping and conflicting jurisdictions should decrease.

Court or Administrative Challenge. Once a particular approval has been given, opponents may challenge this decision in an appeal either to a higher administrative authority (if there is one) or to the courts. Courts often decline to consider an appeal, however, before administrative remedies have been exhausted. The ground for such an appeal may be jurisdictional, procedural or substantive. A *jurisdictional* challenge questions the power of the particular agency or board to grant the approval given. A *procedural* challenge is aimed at the process by which that approval was given and may involve allegations of violations of due process or of any applicable administrative procedures. A *substantive* challenge questions the sufficiency of the evidence in support of an approval decision, or the correctness of the standard applied. Any of these proceedings can, of course, be quite lengthy and can raise the cost of gaining final approval. However, litigation and appeals are costly to the complaining parties as well.

Nuisance Action. Even after approval of a project is final, opponents can challenge the project in a common law nuisance action. Such an action may be difficult to maintain if the characteristics of the project that are alleged to constitute the nuisance--for example, its odor--have been expressly sanctioned in the regulatory proceeding. In most cases, however, nuisance allegations arise when the actual characteristics of a project fall below the standard promised during the regulatory proceeding. While it is occasionally possible to have a project declared to be an "anticipatory nuisance," based on a finding that the untoward effects alleged are imminent and unavoidable, generally nuisance actions must await the initiation of a project. Nevertheless,

the availability of a nuisance action permits project opponents to resume their dispute long after they lose the regulatory battle.

Institutional Setting

Obviously, no project will proceed unless some public or private organization is willing to serve as its sponsor. The sludge generating municipality, the consulting engineers, the site owner, or the receiving community may initiate consideration of a land application project. In many cases the primary sponsors have retained the services of a specialized contractor to actually implement the program. This is a reflection of the relatively low levels of capital investment and high personal service requirements of project sponsorship. In contrast to other wastewater and sludge treatment technologies, land application primarily involves identifying sites, attending public hearings, meeting with public officials, negotiating with landowners and transportation companies, and applying for the necessary permits. All of these activities are generally aimed at only a few weeks of actual sludge application annually. While a firm that specialized in performing the necessary services can apparently profit from the initiation of a reclamation project, the more traditional consulting engineering firm, which concentrates on equipment design, has few incentives to participate.

A key actor in a sludge reclamation project is the application site owner. The range of possible public or private site owners presented in Figure 11-1 is reflected in the variety of institutional arrangements exhibited in the case studies. The type of ownership becomes a key factor in cases where, in order to meet permit requirements, certain restrictions must be placed on

Figure 11-1. Land Ownership.

Public	Private
Federal Government (National Forest, National Park DOE, Department of Interior, Indian Lands, etc.) Federal Lands managed by private concerns (Mineral or timber rights leased to private concerns) State (parks, conservation land, forests, abandoned coal mines, etc.) Local (wastewater management authority, land within one community but owned by another, conservation and recreation sites, etc.)	Private Owner in Fee Sample (industry, coal company, timber company, farmer, private individuals, environmentalist organizations, etc.) Private Owner in Fee Subject to mineral or timber rights in another party Owned by Private General Contractor

the future uses of the sites. Such restrictions are not uncommon on publicly-owned lands. However, a private owner may demand compensation in some form before accepting a restriction on the use of his land, and enforcement of such restrictions may be impossible.

The siting of a land application project has the potential for creating controversy. Moreover, this potential increases with any increase in the number of regulatory bodies which may have jurisdiction over the site. Since each review conducted, or permit applied for, represents a possible snag in the approval process, it also represents an increased potential that the proposed project may not be initiated.

The U.S. Environmental Protection Agency (EPA) has promulgated guidelines for land application of municipal sewage sludge and the Office of Surface Mining of the Department of Interior has developed guidelines for mine reclamation practices. These federal guidelines represent minimum levels for acceptable performance. The states have been tasked with developing programs to implement these guidelines. EPA's regional offices are assigned the duty of insuring state compliance with EPA guidelines. In addition, some state and local governments have developed more stringent regulations. However, since each requirement is set to serve the issuing organization's best interests, the rules vary considerably. It is difficult to reconcile all of the regulatory requirements applicable to a given application site. This problem can be exacerbated when the staffs of the various regulatory bodies exhibit competitiveness or jealousy over their jurisdictional authority.

Many of the regulatory agencies that have jurisdiction over some aspect of a municipal sludge land application project are listed in Figure 11-2.

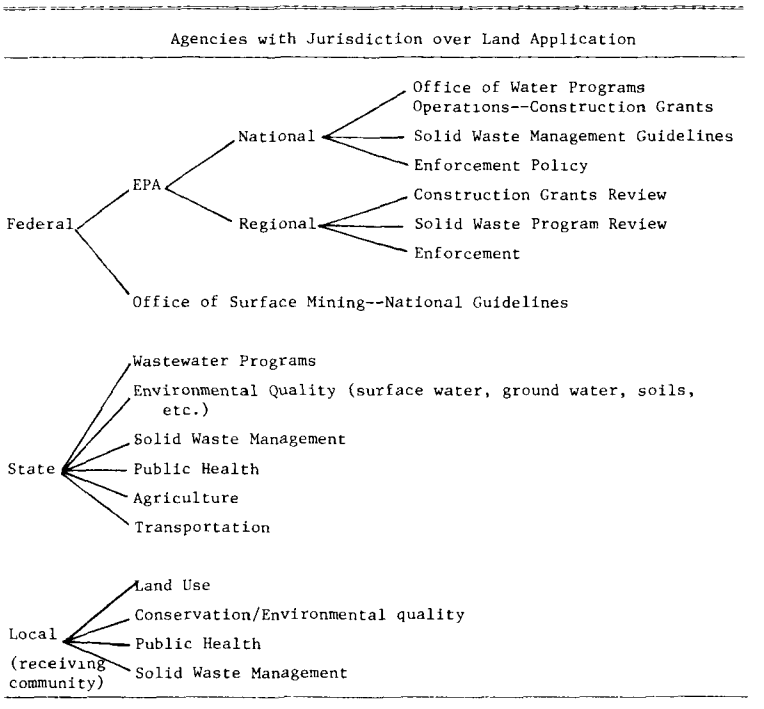
Federal Programs and Regulations

Wastewater Management. Under the Federal Water Pollution Control Act (FWPCA)[1] as amended, nearly all POTW's were required to have achieved secondary treatment by 1977. They are also under a mandate to use the "best practicable" waste treatment technology by 1983.

To assist municipalities in meeting their obligations under the FWPCA Act, EPA is authorized to pay 75% of the costs to plan, design, and construct municipal wastewater treatment facilities. Over 20,000 grants for planning, design and construction, amounting to about $28 billion, had been made under the program by September 1980. Thus, as a practical matter, EPA has a considerable influence over POTW technology through both its regulatory and its construction grants programs.

The 1977 amendments to the FWPCA, contained in the Clean Water Act (CWA), placed new "technology forcing" mechanisms into EPA's hands by providing incentives for the use of "innovative and alternative" (I/A) technology in the construction grants program.[2] EPA had defined land application of POTW sludges as an alternative wastewater treatment and

Figure 11-2. Institutional Framework.



sludge technology within the definition of this provision. An I/A process option can be funded if the life cycle cost exceeds the life cycle costs of the conventional option by less than 15%. In addition, EPA may fund 85%, rather than 75%, of eligible cost for the I/A portion of any project. Finally, EPA is authorized to pay 100% of all costs to replace or modify I/A facilities if they fail to meet their performance specifications.

In a series of regulatory measures beginning in 1975, and as yet incomplete, EPA has restricted the incineration,[3] ocean dumping,[4] land disposal,[5] and landspreading[6] of sludges. Each of these measures has effectively made the disposal of sludge more complex and more costly, and in part has contributed to a shifting of the focus away from disposal methods that are regulated to methods that remain unregulated, or are regulated less severely. EPA has promulgated a set of interim final regulations for land disposal of POTW sludges under the joint authority of the CWA[7] and the Resource Conservation and Recovery Act (RCRA)[8]. Two provisions are most relevant to POTW sludge reclamation projects:

1. No contamination of underground drinking water sources beyond the outermost perimeter of the site is permitted;

2. The cadmium and polychlorinated biphenyl (PCBs) levels of POTW sludges applied to land used for the production of food chain (i.e., human food chain) crops are strictly regulated.

Of the metals present in municipal sludge, cadmium is of greatest importance because of its potential toxicity and the relatively low levels in the natural background. EPA has expended much effort to develop health protection criteria for this metal pollutant.

With respect to cadmium, a less stringent standard is set for those lands where the only food-chain crop produced is animal feed; a plan exists for assuring that the crops produced will not be ingested by humans; and future owners are notified by a stipulation in the land record or property deed that the site has received high cadmium waste applications and that food chain crops should not be grown due to possible health concerns.

In situations where sludge is used as an amendment for growth of agricultural crops, annual and cumulative limits for cadmium have been recommended. These limits are designed to minimize the potential for plants to incorporate this metal into plant tissue which may later be consumed by animals or humans. The imposed limits take into account three factors:

1. The type of crop is important since metals such as cadmium more readily enter the leafy portions of crops than the grain or root portions. Thus, the selection of a crop permits a degree of control over cadmium uptake.

2. The annual and cumulative loadings of metals provide a quantitative framework for assessing the soil's capacity to bind metals. The cation exchange capacity (CEC) of the soil is a measure of the degree to which metals are bound to soil particles and consequently the degree to which the metals can be leached into solution where they would be available to plants. Thus, annual and cumulative loadings of metals need to be evaluated so that the metals holding capacity of a given soil is not exceeded. Metal loadings to soil must be known to keep metal levels in the soil below concentrations that are toxic to plants.

3. The pH of the soil strongly governs the uptake of metals by plants. Since most of the metals of concern are present in soil as insoluble precipitates under neutral-to-basic conditions, their availability to plants is lessened. Alternatively, acid soils (pH less than 6.0) facilitate metal movement into plants and groundwater.

EPA's cumulative limits (interim final) for food chain application range between 4.5 and 18 lbs./acre cadmium (depending on the soil CEC) per acre application.

With regard to PCB's, EPA's concern has been directed toward methods of incorporation into soil, depending on the PCB content of sludge. This criterion is based on the observation that municipal sludge may be ingested by grazing cows if it is deposited or merely sprayed on soil or growing

cons. The potential result of such ingestion is the appearance of PCB's in milk. To minimize this possibility, EPA requires that sludges containing 10 ppm (dry weight) or more PCB be incorporated into soil. Other applications of PCB's and their implications for sludge management practices are being developed by EPA.

The interim final regulations outline two levels of treatment for pathogen control and stabilization of POTW sludge prior to land application. The less stringent treatment is authorized where public access to the land is controlled for at least 12 months after application, and grazing by animals whose products are consumed by humans is prevented for at least one month. The more stringent treatment is mandated if crops for direct human consumption are grown within 18 months of the application and there will be contact between the sludge and the edible portion of the crop.

EPA is now developing proposed regulations to govern the distribution and marketing of sewage sludge products.[9] These regulations would be in addition to the landspreading standards described above in order to fill important regulatory gaps until comprehensive sewage sludge regulations can be promulgated and put into place. It is expected that these regulations would add a substantial recordkeeping requirement to the present provisions governing land application.

Other EPA Land Disposal Programs. RCRA also contains additional provisions that may apply to the land application of POTW sludges. In particular, under Subtitle C of RCRA, EPA has issued "cradle to grave" regulations governing the disposal of hazardous wastes. While most POTW sludges will not constitute hazardous wastes, there is nothing in the regulatory definition of the term that would automatically exclude them. That definition is based upon four characteristics: ignitability, corrosivity, reactivity, and extraction procedure (EP) toxicity.

Sludge is obviously difficult to ignite, and seldom corrosive or reactive; therefore concern is EP toxicity. A POTW sludge is presumed to be nonhazardous unless EP tests, conducted either by the POTW staff or another organization, indicate otherwise. The potentially hazardous chemicals of concern are those listed in EPA's drinking water quality criteria and include:

Arsenic	Endrin
Barium	Lindane
Cadmium	Methoxychlor
Lead	2,4-D
Mercury	2,4,5-T
Selenium	
Silver	

If the EP testing results on a specific sludge show that the concentration of one or more of the above chemicals equals or exceeds 100 times the drinking water standards (for the respective chemical), the sludge is considered to be a hazardous waste and subject to the provisions of the

hazardous waste regulations. Based on recent information, very few sludges are likely to be designated hazardous under EPA's EP testing procedure. However, new criteria, such as one for PCB's, are expected to add to EPA's list in the near future. This may increase the fraction of those sludges found to be hazardous wastes.

If a particular sewage sludge is found to be a hazardous waste, then the site of a land reclamation project utilizing such a sludge would be a hazardous waste disposal facility. EPA has promulgated extensive regulations governing the operation, maintenance, monitoring and eventual closure of such facilities, including numerous safeguards designed to protect surface and groundwater quality from contamination, and to restrict uses of the site in perpetuity.

In the preamble to the hazardous waste regulations, EPA has acknowledged that it eventually intends to issue a comprehensive regulation under the authority of Sec. 405 of CWA, dealing with all forms of sewage sludge disposal. Such a regulation, EPA states, will deal with both hazardous and non-hazardous sewage sludges and will include provisions "equivalent" (but not necessarily identical) to those contained in the existing RCRA hazardous waste regulations. Once such regulations are in place, EPA states that it intends to exclude sewage sludges from the provisions now in effect. For now, however, these provisions govern land disposal of sewage sludges that are found to be hazardous wastes.

No regulations presently cover the large number of potentially toxic synthetic organic chemicals (other than PCB's) in sewage sludge. This situation exists because a vast majority of these chemicals are present in only trace quantities and generally constitute no health hazard. Note that such organic contaminants present in sewage sludge would probably not be highly toxic to soil microorganisms since they would have been toxic in the sewage treatment plant organisms, and would already be known.

Surface Mining Control and Reclamation Act. The SMCRA,[10] passed in 1977, established a nationwide program to protect the environment from the adverse impacts of surface coal mining and prohibits such mining where land reclamation is not feasible.

The Department of the Interior issued its regulations under SMCRA in March 1979. They set performance standards for surface mining of coal to protect the environment and the public health and safety. Specifically, the regulations require mine operations post a bond to insure that they will conserve natural resources in the course of their mining activity; stabilize surface areas during mining and reclaim mine lands contemporaneously as mining proceeds; and restore prime farmland and revegetate all land promptly upon completion of the mining operation. The regulations require that the soil be able to support the same or higher uses after reclamation that it was capable of supporting before the mining operation began.

Where the land was used for agricultural purposes before mining began,

the SMCRA regulations require that such agricultural uses be possible after reclamation. Yet, under the regulations governing sludge application, such future uses may need to be prohibited or restricted for some time, or even permanently, depending upon the quality and quantity of sludge and sludge contaminants applied to the land. Where such a prohibition or restriction would be permanent (based on current and future guidelines) the SMCRA requirements may not be met. Where such a restriction would be temporary, for example 18 months, the SMCRA regulations would appear not to be met during the time of the restriction. Holding of the bonds posted by a mine operator to guarantee reclamation may be required during that period. However, if the land was a forest and not involved in food chain crop production before surface mining operation began, the SMCRA regulations requiring that it be suitable for reforestation after reclamation could easily be met even if restrictions were placed on the land for future food chain crop production by the sludge management regulations.

SMCRA establishes an Abandoned Mine Reclamation Fund, financed by fees levied against all coal mine operators subject to the Act, to be used for reclaiming and restoring land adversely affected by past coal mining, including revegetation of such land. The Fund is to be used to reclaim land that was mined or affected by mining before August 3, 1977; that was left in unreclaimed or inadequately reclaimed condition; and for which the mining operator has no continuing responsibility for reclamation. The Fund may be used to acquire land by purchase or eminent domain, if such acquisition is deemed necessary for successful reclamation.

There is no regulatory obligation for abandoned mine lands that are being reclaimed to be restored to their use before mining began. Thus, the fact that sewage sludge application might restrict future land use should not pose a barrier to projects on abandoned mine lands. Of course, if the land is to remain in private hands, the owner would have to agree to any restrictions on her own and later uses of the land, preferably by deed restriction.

The National Environmental Policy Act. The NEPA[11] requires that an environmental impact statement be prepared for all "major Federal actions significantly affecting the quality of the human environment". The award of a construction grant for a large POTW by EPA can be such a major federal action warranting a full EIS. It is common for EPA to conduct only an environmental assessment before awarding small grants. Where the grant involves funds to implement land application projects, the impacts will be examined by EPA in either the EIA or EIS process before a final funding decision is made. A problem arises on how to prepare an EIS if the actual application sites are not yet know. In addition, alternative means of sludge management must be considered and their environmental consequences evaluated and compared to the land application option. An EIS frequently takes months or even years to complete, but the federal action at issue

cannot proceed until this process is complete.

Actions taken by the Interior Department under SMCRA might also be considered "major" and thus require an EIS. A decision to license a major mining operation is one example. A decision to reclaim a major abandoned mine is another. In both these instances, an EIS might have to be prepared before the final decision is made.

State Programs: Relevant State Agencies

Wherever a public agency or private body decides to investigate, sponsor, or promote a land application project utilizing sewage sludges, it will face the problem of compliance with the various federal regulatory programs and funding conditions outlined above. In contrast, experience with state and local regulations may vary widely. This is because the 50 states are separate sovereigns, each with their own administrative structure and regulatory priorities. Thus, there is no uniform body of state procedures or substantive regulations that will apply to a project involving land application. Nevertheless, a few common aspects of several state programs can be highlighted.

As noted above, a number of regulatory bodies may have authority over a sewage sludge land application project. In many states, most of the environmental regulatory power is vested in a single agency, such as a Department of Environmental Affairs. Such an agency may be separately constituted, or it may be part of a state Public Health Agency, which has a wider jurisdiction. Many states also have Departments of Natural Resources that have primary authority over minerals, watersheds, certain lands such as forests, and other natural resources. Finally, many states have Departments of Agriculture that may be concerned with the proper protection of farm products.

In nearly every state, at least one form of license or permit would be required to apply POTW sludge to a particular site. Thus, for example in Pennsylvania, the Department of Environmental Resources must issue a permit for sludge utilization in land reclamation projects. The state has issued guidelines which specify maximum lifetime loading rates for land reclamation under conditions where farming of the reclaimed site is not intended. A maximum of 3 lbs. of cadmium per acre is specified along with a maximum sludge loading of 60 dry tons per acre. The implications of this limitation are potentially significant when one considers that sludge loadings for reclamation projects are also based on the nitrogen content of the sludge. For example, good management practices utilize about 1000 lbs. total nitrogen per acre. (It is generally assumed that only 200 lbs. of nitrogen is actually available for plant uptake during the first year.) Thus, if the nitrogen content of the sludge is 1% then 50 dry tons/acre is necessary. If, however, the sludge has been composted and has a nitrogen content of 0.5% then 100 dry tons/acre are needed to provide sufficient nitrogen. This

loading would be in excess of the 60 dry ton limit and would not be possible irrespective of cadmium content under the current Pennsylvania guidelines as is shown in Figure 11-3.

When the values of Figure 11-3 are compared, for example, with loading rates of one hundred tons/acre (for a 0.5% nitrogen content sludge) needed to restore both the organic matter and nutrients to strip mined lands, a potential constraint is apparent if the cadmium content of the sludge is 20-30 ppm. The conservative nature of these guidelines apparently arose out of the perception on the part of officials that there would be a lack of on-site controls during and following sludge application. It is important to note, however, that if a sludge is low in nitrogen content, commercial fertilizers containing nitrogen can be added to augment the nitrogen content and consequently reduce the need for higher overall sludge loadings.

Permits issued for land application of sludge typically are accompanied by a number of special conditions designed to assure project safety. These requirements are likely to become more structured as states gain experience with RCRA and other applicable environmental regulatory programs, and as comprehensive sludge disposal regulations, under CWA, are developed by EPA. At present, the permit conditions may be the product of case-by-case, ad hoc agency deliberations, under a general mandate to protect the environment, public health and safety. Typically, such conditions might include requirements that the operator of the site provide for proper surface drainage and initiate a monitoring program. States may require that private contractors post a bond or otherwise demonstrate financial responsibility for damages that may be caused by a land application project.

In addition to direct permitting of land application sites, a number of state agencies may assert authority over and the right to control such operations because of their concern with a particular aspect of public welfare potentially affected by the operation. For example, most states have drinking water programs that require monitoring and protection of water supplies

Figure 11-3. Relationship of Cadmium Content of Sludge to Sludge Loadings to Soil.

Cd Content in Sludge	Sludge Lifetime Loadings Under PDER Guidelines
(ppm)	(tons/acre)
10	150*
20	75*
25	60
40	37.5
80	18.7

* Not allowed because of 60 tons/acre limit on total sludge.

from certain contaminants. Similarly, air pollution control boards may conceivably be concerned with the potential for odors or aerosols being generated during land application. In states with substantial mining operations, a state or local agency may be specifically authorized to regulate the operation of land reclamation projects on mine sites.

Local Programs

Powers of Organizations Operating the POTW. States have comprehensive police powers, may take a variety of regulatory actions and may make spending decisions they deem appropriate when in reasonable pursuit of protecting the public's health, safety and welfare. Local governments frequently lack such powers. Local government entities, whether a municipality or a special purpose authority, typically have only limited powers, and must adhere closely to the restrictions of their state enabling legislation.

A number of powers which would be quite useful to the successful implementation of a land application project may thus be lacking in particular situations. These powers would be especially important where the operator of the POTW generating the sludge is the project sponsor. They might include the power to engage in commercial activities beyond the operation of the POTW; the power to acquire land by purchase or eminent domain within or outside the physical jurisdiction of the POTW authority; the power to operate sewage facilities outside such boundaries; and the power to give something (sludge) away. Depending on the design of a particular project, any or all of these powers may be required. If the POTW authority does not have the necessary powers, new legislation may be required to grant them, or the project may have to be restructured or limited in scope.

Relevant Agencies in the Receiving Community. A number of local boards and commissions may assert authority over the site where POTW sludges are to be applied. In a few communities, a local board such as a county health department has primary authority over the siting of waste disposal facilities. It may issue a comprehensive operating or solid waste landfill permit. It may conduct some form of environmental impact assessment prior to the issuance of such a permit, and it may attach monitoring or other conditions to the permits.

Other local boards that may have jurisdiction over the land reclamation site are planning boards, zoning boards, and conservation commissions. The influence of these boards, however, may be minimized in those circumstances where a governmental entity is undertaking the project. In general, a federally-owned site will be exempt from local land use controls unless the federal agency voluntarily submits itself to local control. Other governments are usually immune from local zoning regulation, at least when they are exercising a "governmental" rather than a "proprietary" function. Waste management has generally been regarded in the law as such a "governmental"

function, and there appears to be no reason to expect that the result would be different where the waste management involves land reclamation or biomass production as well.

Many land application sites, however, will be neither owned nor operated by government entities, and thus will be subject to zoning. Although many local governments have declined to exercise zoning power over remote, sparsely populated areas where surface mines frequently are located, the extent and breadth of zoning control continues to expand. Thus, it is increasingly likely that a land reclamation project will be subject to zoning regulation.

Few (if any) local zoning ordinances will include land application as one of the listed land uses. Waste disposal, however, is a commonly listed land use, and is generally severely restricted to only a very small zone within a community. Thus, if a land application project is characterized as a waste disposal land use, it is quite possible that it will not be permitted in many zones where it may be suitable.

The argument that a sewage sludge land application project constitutes waste disposal is bolstered by the fact that such a project is treated as waste disposal for the purpose of the environmental regulations discussed above, and by the fact that, like conventional landfills, some of the concerns associated with the project remain after application is completed. On the other hand, land reclamation is not unlike other types of site preparation associated with any creation of new land uses. Site preparation itself is never considered a land use for zoning purposes, and is generally permitted if the ultimate land use is permitted. Under such a view, sewage sludge land application can proceed as long as the utlimate land use -- agriculture or forestry or the like -- is permitted. Such uses are, of course, among the most widely allowed. The latter argument has prevailed in the only reported decision to consider this issue, but there remains a substantial question of characterizing land application uses under each zoning regime.

General Legal Issues

Ownership of Application Site. A key problem in organizing a sewage sludge land application project is in sorting through the various land ownership interests associated with a particular site. Typically, in the case of surface coal mines, the land title is held by one party while a mine operator has purchased or leased only the mineral rights in the land. Thus, while a mine operator may have a statutory obligation under SMCRA to reclaim the land after surface coal mining operations are complete, it may be powerless to effect reclamation in other circumstances or to restrict the later uses of the land by convenant. These powers may remain with a site owner who may have few other assets.

A project sponsor will thus have to identify the appropriate ownership interests in a proposed reclamation site and negotiate agreements with such

owners as seems appropriate. When the sponsor is a public authority with power to acquire land interests by eminent domain, this negotiation may be facilitated somewhat.

Easements and Covenants. An easement allows someone to use the land of another for a special purpose not inconsistent with the general property interests of the owner. A covenant is an agreement of two or more parties by deed in which one of the parties pledges himself to the other that something is either done or will be done. Each of these instruments may be needed if a proper, enforceable promise from the owner of the land is expected to restrict the property to certain uses.

As noted above, current EPA land disposal regulations require, in certain instances, that future owners of property to which POTW sludges have been applied be notified of high cadmium waste applications in the land record or property deed. There is an important difference, however, between giving *notice* that crops should not be grown on a particular property and recording a *restriction* of the property's use. A notice may remain recorded in the land record indefinitely, but is not legally enforceable in the way a restriction would be. A deed restriction, however, is enforceable only by the party owning the benefit of the restriction, and, in many jurisdictions, will be automatically extinguished after the passage of a certain period if it is not rerecorded.

Enforcement of such restrictions can, of course, be troublesome after the passage of time. Moreover, a problem associated with creating legally enforceable land restrictions is that some entity must be said to "own" the restriction, and only that entity will have the power to enforce it. This is true whether the owner conveys an easement restricting certain uses of the property or guaranteeing access to it, or alternatively records a covenant promising and requiring the necessary restrictions. The easement must, of course, be conveyed to *someone* -- the project sponsor or the local community, for example. The covenant, however, must recite the benefit received by the landowner in exchange for the restriction, and only the party who has given that benefit can enforce the restriction. Moreover, in many jurisdictions, the covenant must be attached to a particular parcel of land.

Thus, it will be no simple task to draft the legal document that may be necessary to restrict future land uses in order to gain agency approval for land reclamation of biomass production projects using POTW sludges or to respond to local concerns about the potential impacts of such a project. Nor is it always realistic to expect that such land use restrictions can be enforced in perpetuity.

Externalities from Operation. The fact that many land application projects using POTW sludges have faced opposition from abutting property owners indicates that such parties frequently believe that they will suffer, or are suffering unreasonable harm from the project at issue. If the project

sponsor is a public body, these persons may legally oppose the project by asserting that it is effecting a diminution in the value of their property substantial enough to constitute a "taking" of value under the fifth amendment of the Constitution. Regardless of the identity of the sponsor, they may also argue that the project should be stopped as a nuisance.

In legal terms, a nuisance is more than merely a hurt, annoyance or inconvenience. The law of nuisance embodies two entirely distinct -- and arguably unrelated -- concepts. A *public nuisance* is "an unreasonable interference with a right common to the public".[12] Under this definition, land application will be considered unreasonable unless its utility outweighs the gravity of the harm it produces. In contrast, a *private nuisance* consists of an invasion of a person's interest in the private use and enjoyment of land. A private nuisance is actionable if it is either: (a) intentional and unreasonable, or (b) unintentional but negligent, reckless, or abnormally dangerous.

Under both nuisance concepts, the legal injury involved is a rough balance of the benefits and burdens derived from a particular activity. An activity will be actionable as a nuisance if its harms are not justified by its utility. A land application project using sewage sludge could thus be the subject of a nuisance action for a number of reasons. Certainly any allegation of air or water pollution, odors, or spills can be a sufficient basis for action. Alternatively, a nuisance case might allege that the land application was inappropriate by its very nature for the area in which it is or is to be located. Finally, a nuisance action may allege that insufficient ameliorative measures have been taken to reduce the harmful effects of the project, or that inadequate warnings have been given so that others may take such measures.

The alleged harms that arise from even proper operations of a POTW sludge land application project have been repeatedly noted. They include odor, water pollution or contamination, the attraction of rodents and other disease-carrying pests, and the raising of the heavy metal content of the soil. For each project under litigation, a court would have to make an individual determination concerning the magnitudes of these burdens, the availability and use of ameliorative measure such as incorporating sludges in the soils or applying dry rather than wet sludges, and the benefits to the public and to the land owner. Where the harms arising from an unreclaimed mine are substantial, the benefit of reclamation will be likely to outweigh its burden.

Indeed, if the focus of a "taking" or nuisance case is on the adverse effect of property values associated with a project, it should be noted that land values around a reclaimed surface mine may not be diminished at all. On the contrary, they may be increased.

Of course, very different conclusions concerning liability to third parties can be drawn where the evidence is that negligence was involved in a project. Such negligence might, for example, be the application of the sewage sludge

to a spot that was not intended, permitted, or licensed to receive it. Insufficient monitoring of the project might also constitute negligence.

The law evaluates whether conduct is negligent by focusing on a "reasonable person" possessing ordinary skills and prudence. If the conduct alleged does not conform to what such a person would do under similar circumstances, then it is negligent. Obviously, any lawsuit alleging negligence would turn on its own peculiar facts, and the question of negligence would be resolved as a matter of fact by a jury.

Past Experience

As part of this research effort, the staff developed case studies on the institutional and public acceptance aspects of a number of actual and attempted POTW sludge land application projects. The files were compiled from a series of telephone interviews with key project participants as well as from secondary sources.

The selected sites included most of the well-known sludge land application projects, as well as some which have received less publicity. In order to increase our sample size we also included several projects which involved land application of POTW sludge for agricultural purposes since the institutional and public acceptance issues raised by such projects are much the same. After eliminating from further analysis those case studies that were primarily demonstration projects, we analyzed the remaining 16 sites to determine if we could discern any significant patterns among them. Key information about all the case studies is presented in Figure 11-4. Individual case study summaries are in our final report to the President's Council on Environmental Quality.

Permitting Process

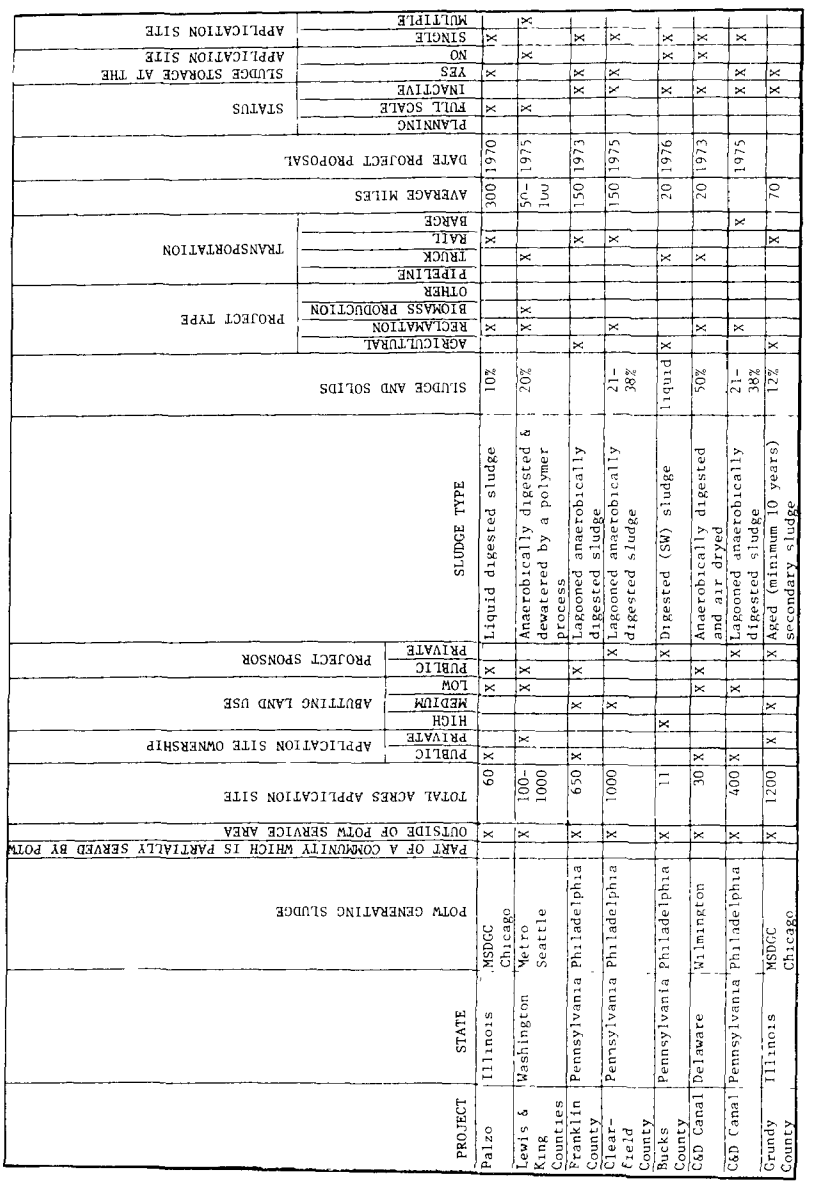
The 16 case studies suggest that the actual procedures for obtaining approval of a land application project may differ from the procedures set forth in the applicable statutes and regulations. For example, even in the absence of a statutory requirement that project sponsors obtain the consent of the local community prior to obtaining a state permit, state regulatory agencies have demonstrated sensitivity to the wishes of the community which is to receive the solid waste. This informal policy has resulted in communities having de facto power over regulatory decisions, even where such power is not conferred by the law.

Where state law provides no formal mechanism for local regulation of a land application project, local governments may enact ordinances which give them control over project operations. Such ordinances have been passed even in the absence of clear statutory or constitutional authority for such regulation. When one county government, for example, authorized the

Figure 11-4. Case Studies.

PROJECT	STATE	POTW GENERATING SLUDGE	PART OF A COMMUNITY WHICH IS PARTIALLY SERVED BY POTW	OUTSIDE OF POTW SERVICE AREA	TOTAL ACRES APPLICATION SITE	APPLICATION SITE OWNERSHIP: PUBLIC	APPLICATION SITE OWNERSHIP: PRIVATE	ABUTTING LAND USE: HIGH	ABUTTING LAND USE: MEDIUM	ABUTTING LAND USE: LOW	PROJECT SPONSOR: PUBLIC	PROJECT SPONSOR: PRIVATE	SLUDGE TYPE	SLUDGE AND SOLIDS	PROJECT TYPE: AGRICULTURAL	PROJECT TYPE: RECLAMATION	PROJECT TYPE: B.OMASS PRODUCTION	PROJECT TYPE: OTHER	TRANSPORTATION: PIPELINE	TRANSPORTATION: TRUCK	TRANSPORTATION: RAIL	TRANSPORTATION: BARGE	AVERAGE MILES	DATE PROJECT PROPOSAL	STATUS: PLANNING	STATUS: FULL SCALE	STATUS: INACTIVE	SLUDGE STORAGE AT THE APPLICATION SITE: YES	SLUDGE STORAGE AT THE APPLICATION SITE: NO	APPLICATION SITE: SINGLE	APPLICATION SITE: MULTIPLE
Vestel	New York	Binghamton	X		70-90		X		X				Vacuum filtered digested secondary sludge; lime & ferric chloride added	20%	X					X			4	1975		X		X		X	
Lowry	Colorado	Metro Denver	X		160	X			X				Vacuum filtration of anaerobically digested sludge	9%				X		X			25	1969		X		X		X	
Adams County	Colorado	Metro Denver	X		2000	X			X		X		Air drying of anaerobically digested sludge		X				X				25	1972	X					X	
Fulton County	Illinois	MSDGC Chicago		X	15,528	X		X					Liquid digested sludge	10%		X			X			X	200	1969		X		X		X	
Wood County	Ohio	Toledo		X	2500		X		X				Vacuum filtered anaerobically digested sludge	21%	X					X			30	1973		X		X			X
Boone County	Indiana	Indianapolis	X		2600		X	X				X	Aged sludge	18%	X					X			50	1975		X		X			X
Somerset	Pennsylvania	Philadelphia	X		1000		X		X			X	Mine mix composted sludge and dewatered sludge cake	50%		X				X			200	1978		X			X		
Savannah River Lab	South Carolina	Aiken County	X		18	X				X			Anaerobically digested heat treated sludge	30%							X		12	1979		X		X		X	

Figure 11-4. (Continued)



PROJECT	STATE	POTW GENERATING SLUDGE	PART OF A COMMUNITY WHICH IS PARTIALLY SERVED BY POTW	OUTSIDE OF POTW SERVICE AREA	TOTAL ACRES APPLICATION SITE	APPLICATION SITE OWNERSHIP: PUBLIC	APPLICATION SITE OWNERSHIP: PRIVATE	ABUTTING LAND USE: HIGH	ABUTTING LAND USE: MEDIUM	ABUTTING LAND USE: LOW	PROJECT SPONSOR: PUBLIC	PROJECT SPONSOR: PRIVATE	SLUDGE TYPE	SLUDGE AND SOLIDS	PROJECT TYPE: AGRICULTURAL	PROJECT TYPE: RECLAMATION	PROJECT TYPE: BIOMASS PRODUCTION	PROJECT TYPE: OTHER	TRANSPORTATION: PIPELINE	TRANSPORTATION: TRUCK	TRANSPORTATION: RAIL	TRANSPORTATION: BARGE	AVERAGE MILES	DATE PROJECT PROPOSAL	STATUS: PLANNING	STATUS: FULL SCALE	STATUS: INACTIVE	SLUDGE STORAGE AT THE APPLICATION SITE: YES	SLUDGE STORAGE AT THE APPLICATION SITE: NO	APPLICATION SITE: SINGLE	APPLICATION SITE: MULTIPLE
Palzo	Illinois	MSDGC Chicago	X	X	60	X				X	X		Liquid digested sludge	10%									300	1970		X		X		X	
Lewis & King Counties	Washington	Metro Seattle		X	100-1000		X			X	X		Anaerobically digested & dewatered by a polymer process	20%		X	X			X			50-100	1975		X			X		X
Franklin County	Pennsylvania	Philadelphia	X	X	650	X			X	X			Lagooned anaerobically digested sludge		X					X			150	1973			X	X		X	
Clearfield County	Pennsylvania	Philadelphia	X	X	1000		X		X			X	Lagooned anaerobically digested sludge	21-38%	X	X				X			150	1975			X	X		X	
Bucks County	Pennsylvania	Philadelphia	X	X	11		X	X				X	Digested (SW) sludge	liquid	X					X			20	1976			X	X	X		
C&D Canal	Delaware	Wilmington	X	X	30	X				X	X		Anaerobically digested and air dryed	50%		X				X			20	1973			X	X	X		
C&D Canal	Pennsylvania	Philadelphia	X	X	400	X				X		X	Lagooned anaerobically digested sludge	21-38%		X						X		1975			X	X	X		
Grundy County	Illinois	MSDGC Chicago	X	X	1200	X				X		X	Aged (minimum 10 years) secondary sludge	12%	X						X		70				X	X	X		

county Board of Health to issue permits for the transportation, storage, use and/or disposal of digested and undigested sludge, a subsequent challenge resulted in the invalidation of the ordinance on the grounds that the county had exceeded its authority. Clearly, such actions by county governments can slow or stop project implementation.

Even when a single agency has sole permitting authority, the formal review process whereby that agency decides whether or not to issue a permit may involve several different independent agencies and offices within these agencies. The case studies indicate that the inability of various offices, either in one or several agencies, to agree upon a common policy regarding sludge application has complicated and hindered issuance of permits.

Generally Applicable Public Attitudes Concerning Sludge

The case studies (and common sense) indicate that the willingness of a community to cooperate with a land application project varies with the community's perceptions of the project's potential benefits and costs. For a land application project to gain public acceptance, the majority of the community must determine that the reclamation or other benefits (e.g., monetary compensation) are greater than any burdens (odors, noise, truck traffic, etc.).

The major public acceptance barrier which surfaced in all the case studies is the widely held perception of sewage sludge as malodorous, disease causing and otherwise repulsive. These attitudes are a barrier to any beneficial use of wastewater or sewage sludges. Experience has shown that public apprehension on these points can be allayed somewhat—although not totally dispelled—through public education campaigns. Demonstration projects which provide first hand experience are an invaluable public education tool in this regard.

The case study experience also indicates that members of core opposition groups seize upon the public's lack of experience with wastewater or sewage sludges and attempt to propagate the view that sludge is repulsive in an effort to frustrate project implementation. It is also clear that there is an irrational component to public attitudes about sludge which means that public education will not always be entirely successful.

The relative novelty to the public of the concept and practice of land application of sludges may, in itself, be a barrier to public acceptance of such projects. Even after extensive public education by regulatory officials addressing the scientific data available to date, there often remain lingering doubts by the public about the safety of the procedure, based upon fears that the risks are not yet apparent. The growing awareness about hazardous wastes and the inadequacy of their past disposal practices will inevitably increase public skepticism about land application of sludge.

Transporting Sludge into Other Communities

In 13 of 16 cases studied, the sludge-generating [illegible] to use an application site outside its own sewage [illegible] case, the sludge-generating community attempted [illegible] in another state. The case studies demonstrate [illegible] application sites will frequently compel [illegible] obtain land application sites beyond its jurisdictional [illegible]

The success of any sludge application project depends [illegible] ability to gain the cooperation of: (1) the site [illegible] owners; (3) the surrounding community; and [illegible] officials. Transporting sludge into other communities [illegible] institutional barriers. While a sludge-generating [illegible] to persuade, if not coerce, communities within [illegible] sludge, it has no such influence or control over other governments [illegible] the opportunities for project opponents to obstruct [illegible] by intervening in local regulatory procedures [illegible] lines are crossed. When state lines are crossed [illegible]

Success in obtaining use of an application site [illegible] will vary with the ability of the project sponsor [illegible] potential conflicts with local interests. There may be [illegible] between the sludge-generating community often [illegible] receiving (often rural) community. These rivalries may be [illegible] of a variety of factors, including perceived cultural [illegible] rivalry, and economic inequality. Whatever the basis of [illegible] between the communities, the unresolved conflicts may [illegible] a project is proposed.

Ownership of the Site

Of the 16 cases considered, 6 projects were associated with [illegible] obtain access to sites which were publicly owned (by [illegible] government) prior to the inception of the project. [illegible] succeeded in securing access to the sites.

In four other cases, the sludge-generating communities [illegible] leased sites from private land owners. Two of these projects [illegible] full-scale operations, one project is attempting to overcome [illegible] public acceptance barriers to implementation and another [illegible] frustrated by legal action which was unrelated to ownership [illegible]

Six of the case study project designs involved [illegible] privately-owned sites which were to remain in private [illegible] the project. Of these, three reached full-scale operations, [illegible] because the private landowner withdrew from the project and [illegible] failed because of legal action or inability to obtain the [illegible]

These results do not reveal any meaningful [illegible] identity of the application site owner and the success or [illegible]

projects. However, there are some interesting findings with regard to application site ownership and project initiation and operations. Authorities responsible for management of publicly owned sites may initially be more receptive to projects than the owners of private sites. This is particularly true with respect to federal lands, where some agencies have actively sought to become involved in land application projects. Indeed, in the case of the Savannah River Laboratory project in South Carolina, and the Palzo Project in Illinois, where successful land application projects have been conducted on federally owned lands, the initiative for the projects came from the federal agencies which had responsibility for management of the sites.

There is no apparent correlation between site ownership and the uninterrupted implementation of projects. The cases included one project where application on publicly-owned land was terminated after start-up and two cases where projects on privately-owned lands were interrupted after start-up. However, whereas the project on publicly-owned land was stopped by legal action initiated by local government, the projects on privately-owned land were stopped because the land owners of the application site decided to withdraw from the project.

It would appear that where the application site is owned by a private party, that private party constitutes a potential weak link in the project's operations. Such a land owner may, for personal reasons or as a result of public pressure, withdraw from the program at any time. For these reasons, a project promoter may wish to consider approaches which give them at least limited control over the site, such as leasing.

Abutting Land Uses

For the purposes of the cross-case analysis, the areas abutting the application sites were categorized according to use and density on a comparative basis as: low (forests, barren strip mine sites and sand dunes); medium (active strip mining, low-intensity farming such as grazing and ranching); and high (residential areas and intensive agriculture). Five of the 16 land application sites were next to low-use/density areas. Eight sites were next to medium-use/density areas and three projects were next to high-use/density areas.

Public opposition to project implementation varied directly with the nature of the abutting land uses. Among the four cases where abutting land use was categorized as low, there was no significant public opposition to project implementation. Three of the four projects achieved full scale operations; the failure of the fourth project was directly attributable to a political decision not to permit importation of sludge from another state.

Among the eight cases where abutting land uses were categorized as medium, there were two cases where community groups actively opposed the project; five cases where individual abutters voiced opposition; and only one case where there was no significant public opposition. In three cases

lawsuits were filed against the project. Five of the projects abutted by medium land uses achieved full scale operations; the failure of two of the other three was at least partially attributable to public opposition.

In each of the three cases where abutting land uses were categorized as high, abutters organized to oppose project implementation. Each of these projects became the subject of a lawsuit and failed as a result of legal action.

Public Relations

For this analysis, public relations has been defined as that component of the project which was designed to create favorable public attitudes. This is different from the public participation component where a public forum is provided for discussion of unfavorable as well as favorable aspects of several alternative projects. While public relations management strategies varied from case to case, concerted public relations efforts were made in at least 14 of the 16 case studies.

Public officials and private contractors involved in project planning often expressed the opinion that an effective public relations campaign was an essential component of a successful project. The attitude was also expressed that, while a public relations campaign did not ensure project success, failure to undertake a public relations campaign ensured project failure.

It was apparent that the importance given to public relations varied with the likelihood of significant public opposition. Projects carried out on isolated sites generally did not involve significant public relations efforts. Sites in densely settled areas or which were likely to be the objects of inter-jurisdictional conflict were the focus of extensive public relations campaigns.

Responsibility for Public Relations. Primary responsibility for conducting public relations campaigns falls either to public officials who have no particular training in the field (six cases) or to specialized consultants (eight cases). Five of the eight projects involving private contractors were eventually implemented as full scale operations, while only two of the six projects whose public relations were handled by public officials were similarly successful. Given the limited number of cases considered and the great number of variables which affect project implementation, caution is advised in drawing a correlation between responsibility for public relations management and project success.

The interviews with public officials and private contractors suggested that the contractors were often able to serve as a "buffer" or mediator between a wary and suspicious receiving community and the sludge generating authority. The case studies provide some indication that, where an inter-jurisdictional or public acceptance barrier was likely, the generating community recognized the need to enlist a private consultant. Three of the six cases where public relations were managed by public officials involved

the use of relatively isolated, publicly-owned application sites which posed little risk of public opposition. However, six of the eight cases where public relations were handled by private consultants involved privately-owned sites in medium or high-use areas, with a high risk of vocal public opposition.

Specific Public Relations Techniques. There was a wide range of techniques which were used in connection with public relations campaigns, both by private and public promoters. These included distributions of brochures describing the project; public meetings to explain the project and to field questions from the public; lectures to citizens groups (e.g., Kiwanis Club, League of Women Voters); interviews with project officials on TV and radio; visits to demonstration projects; educational programs in the schools; and establishment of a "hot-line" telephone service to answer questions.

These tactics were used about as often for projects that failed as for projects that succeeded. No single or combined use of any set of techniques appears to be more effective than any other.

Public Relations Strategies. One of the 16 case study projects operates on the philosophy that litigation is to be avoided at all costs, even if it means the abandonment of particular application sites. The rationale for this strategy is that litigation, even if successful, results in negative publicity for land application of sludge. This publicity, in turn, tends to harden public resistance to project implementation when it is attempted at other sites. Adherence to this philosophy has resulted, however, in abandonment of between 40-50% of the application sites considered by the project.

The experience of several projects suggests that the effectiveness of public relations compaigns may be directly related to the timing and visibility of such campaigns. Several project managers expressed the opinion that public attitudes about a project tended to form and "harden" very soon after initial public disclosure. Moreover, the terms and issues of the ensuing public debate tended to be determined by the tone and content of the initial public disclosure. Hostile attitudes and misconceptions engendered by an unfavorable initial public disclosure may be difficult to allay by a subsequent public relations campaign.

The timing of public relations alone did not, of course, ensure a positive public response to project implementation. In one case where there was an early and aggressive public relations campaign, public opposition to the project proved insurmountable. However, seizure of the initiative by the project sponsor in the public debate over the advisability of the project can be one factor contributing to the success of the project.

It should be noted that some project managers disagreed with the proposition that public relations campaigns should be highly visible early in project planning. These people argued that a highly visible public relations campaign, in the absence of clear signs of public opposition, would in itself alarm and harden public opinion against the project.

The public relations campaigns of the various projects differed most markedly with respect to who was included (or excluded) as the objects of the public relations efforts. Some projects were narrow in scope: public relations were limited to the application site owner, or to the immediately surrounding community. Other projects made full scale efforts to win over local journalists, politicians, land owners, administrative officials, businessmen, etc.

Some public relations efforts may be described as passive, in the sense that there was little effort to reach out to particular segments or constituents of the public. Rather, information about the project was made available for individuals and groups which made the effort to obtain it. Other public relations efforts were designed to reach particular audiences and to win them over to support of the project.

Application Methods

It is difficult to say to what extent odors emanating from sludge may be imagined. However, it is the most common ground voiced by opponents in taking action against land application projects.

Of the nine projects studied which have reached full-scale implementation, eight involved the use of aged or anaerobically digested liquid sludge. Of these, the three which were in low land-use areas proceeded with no adverse public reaction. However, the remaining five, which were surrounded by either medium or high land use, were plagued by abutting land owners' complaints of odors. In each case, administrative or court action resulted in modification to the application methods which ensured greater incorporation of the sludge into the soil.

Two of the three projects which reached the full scale implementation stage but were interrupted by litigation employed the use of liquid anaerobically digested sludge. In one case, the project management would have changed from spraying to direct incorporation if the courts had allowed continuation of the project.

Not surprisingly, the presence of storage lagoons near the application site also arouses public opposition. Six of the eight projects involving the use of storage lagoons became the object of lawsuits or administrative actions based on odor complaints. In two of these cases, litigation was directly related to the existence of the storage lagoons.

Strategies for Project Sponsors

Land application projects have been initiated by landowners, receiving communities, sludge producers and private contractors. In this section, we have summarized our research findings in terms of strategies for any of these parties interested in sponsoring a project. As the analysis of the case studies

indicates, no one approach will guarantee public acceptance or regulatory approval of a given proposal.

Nevertheless, at least two general lessons were learned from the case studies. First, patience is required to implement a land application project. Second, for a wide variety of reasons, land application simply will not be acceptable on every site where it is technically appropriate. While no strategy can guarantee success, due consideration of the following issues should help sponsors reduce the risk that their proposed projects will not be approved.

Hire Experts

Some wastewater management authorities have found it useful to hand over various aspects of the project's promotion to specialized contractors. This step may be desirable in some cases, though it may not be essential. However, any project sponsor should investigate the possibility of hiring an expert to assist in the permitting process. In most cases, the retention of a local lawyer who can provide expertise on both the formal and informal requirements for obtaining local approvals is desirable. Certainly an environmental specialist familiar with the state regulatory procedures and staff would be helpful.

Reduce Risk of Public Opposition Through Proper Design

From the case studies, it is clear that the degree of public opposition to past projects has been directly related to the intensity of abutting land uses. The selection of isolated sites greatly improves the possibility of project acceptance. Similarly, the project should be designed to minimize any potential impact from odors. While soil incorporation greatly reduces odors from application of anaerobically digested sludge, the use of an aged or thoroughly aerobic sludge form, such as properly composted sludge, should be considered. Also, extensive on-site storage of sludge in any form is not recommended.

Clarify the Incentives

When a land application project is proposed, one can assume that it is because the sponsor seeks to take advantage of some benefit to be derived from the project. Other parties, however, may stand either to gain or to lose from the proposal. By identifying who these parties are, the project sponsor can clarify for each what benefits they are likely to derive from the project and can develop strategies for altering the balance of such benefits against any project-related burdens (for example, by initiating compensation).

Based on the unique character of a given proposal the sponsor should make sure that everyone whose interests are served in any way is informed exactly how they will benefit. Figure 11-5 summarizes the possible incentives that various parties associated with a reclamation program might have.

Figure 11-5. Incentives.

Wastewater Authority

- Alternative sludge disposal option
- Sludge disposal at lower cost
- Sludge disposal acceptable to EPA

Active Coal Strip Mine Operator*

- Meet reclamation requirements for less money
- Less risk of reclamation failure
- Prompt bond return

Active Coal Strip Mine Site Owner**

- Reclamation quality higher than required by OSM

Other Application Site Owner***

- Increase property value at low investment
- Improved public image
- Reduce conflict with water quality agencies

Contractor

- Business revenues

Local Community

- Improved aesthetic environs
- Improved water quality
- Increased tax base
- Jobs and local business
- Other compensation

Abutters

- Improved environment
- Increased property values
- Other compensation

* Usually a mining company.

** May be the same as the operator or may be a different party who has leased or sold mineral rights to the mining company.

*** Abandoned mines, mill tailing, dredge spoils, etc.

Provide Indemnity and Obtain Insurance

In any land application project, the potential exists for some harms to project participants, property owners, workers or others, either out of some negligence or from statutory or regulatory violation. In either case, when personal injury or property damage occurs, tort claims and lawsuits are likely to follow.

In such a situation, an injured party normally has a selection of possible defendants, including the engineer that designed the project; the contractor that executed it; any subcontractors involved; the owner of the land; the operator of the mine; and the municipality that generated the sludge. Moreover, when only some of these defendants are named, they may bring others into the litigation by filing third party complaints. Any one of the defendants in a common lawsuit could conceivably be held liable for the entire amount of damages due -- even if that amount is out of proportion

to the injury -- when other defendants fail or are unable to pay their share.

Because land application involves some undeniable risks, and because the precise nature and magnitude of those risks may be unknown, participants essential to a project may be reluctant to join. Although not used in any of the case studies, one way for a project sponsor to overcome such reluctance is to offer to indemnify such participants for any liabilities they incur or damages they suffer themselves, as a result of their participation.

The project sponsor is ordinarily in the best position to assess the risks of the project. Thus, if it can satisfy itself that the risks are outweighed by the benefits, it can provide reassurance to other participants by voluntarily assuming those risks. The indemnity agreement should explicitly state if the sponsor is assuming liability for even those harms resulting from the negligence of other project participants, since such indemnity may be demanded as a condition of participation.

Indemnity agreements do not preclude an injured party from bringing suit against the project participants perceived to be actually at fault in causing the harm alleged. Rather, they provide a conceptual basis for those participants to be reimbursed by the project sponsor. Such a contract may be worthless, however, if the project sponsor is without the financial resources to provide such reimbursement. In such circumstances, project participants are still liable to injured parties, and may be left without recourse for damages they had sought to shift to the sponsor.

The obvious solution is insurance. By providing insurance for all harms arising out of a particular project, for a premium paid at the outset, a project sponsor can back an indemnity agreement with the security of a major insurance corporation, and thereby satisfy any objections to the sponsor's ability to provide the indemnity agreed upon. In any case, a sludge-generating authority and specialized contractor should obtain professional liability insurance.

Compile Comprehensive Record

There are two reasons for a project sponsor to compile as complete a record about the project as practical. First, a comprehensive record-keeping mechanism provides evidence that the sponsor has control over the project. It can therefore serve to reassure abutting property owners and the receiving community that every step possible is being taken to implement the project in accordance with a specific plan, to guarantee that the plan is followed, and to record the effects of the application of sludge as they are monitored. Second, in the event that something goes wrong with a land application project, the sponsor will be in a better position to explain and defend its actions -- and possibly avoid liability for itself and other project participants – if it has prepared and maintained a comprehensive record. Since those who are thinking of participating in projects may be quite concerned with

their potential liability, the existence of a mechanism for compiling such a record can serve as an inducement to their participation.

In addition to arranging for the compilation and maintenance of factual data about the design, operation and effects of the reclamation project, the sponsor should provide for continuous analysis of these data with as much critical objectivity as possible. Project design, inspection procedures, testing, quality control efforts, safety measures, and warnings should be scheduled for regular examination as critically and freshly as possible. The information contained in such evaluations, as well as accident or incident reports, should be widely circulated among project participants and within the community.

The sponsors should take care to avoid preparing a record that can be used unfairly against them. For example, care should be taken not to write a *tentative* report analyzing an incident or procedure that looks like a *final* report. Nor should a final report be written before all relevant evidence is gathered, especially if it is critical of present or past practices. Words that imply negligence should be avoided. For example, reporting that a lysimeter has "cracked" is more accurate and objective than stating that it "failed".

Comprehensive and Open Monitoring Program

While the details of a monitoring program will be governed by site-specific considerations there are some generalizations that can be made about monitoring programs. Monitoring serves two important non-technical roles. As discussed above, monitoring provides a much-needed record, if there are questions in the future about the project. Monitoring also provides a means of allaying some of the public's fears about adverse impacts. For these reasons alone, regardless of their technical importance, monitoring programs should be carefully designed and conscientiously implemented.

The specifics of a monitoring program must be determined on a site-by-site basis. A comprehensive monitoring program should have three components: sludge quality, field operations, and environmental effects.

Sludge quality should be assessed in two ways. First, it is important to know something of the historic composition of the sludge. At least a one year record of such compositional data as nitrogen, heavy metals and PCB content should be obtainable from the POTW. This information can then be used to establish loading rates. Second, a composite sample should be taken from the particular batch of sludge actually applied to a given site. Analysis of this sample should be recorded and evaluated to ensure that the heavy metals and PCB loadings were, in fact, within the limits specified in permits.

Field operations are the procedures by which the site is prepared and sludge is applied. The state or local permitting agency may wish to have an observer at the site to ensure that the specified procedures are, in fact, followed. In any case, it is in the sponsor's best interest to encourage such

observations.

Environmental effects include project effects on ground water, soil water, soil, and vegetation. Pennsylvania, for example, has developed a relatively standardized monitoring program which calls for ground water, soil water, vegetation and soils monitoring at quarterly intervals for a minimum of one year. The decision as to whether or not to continue monitoring is then based on the results of the first year tests.

The question of who does the monitoring raises many credibility issues. In at least three of the case studies, the local community felt uncomfortable having to believe the project management's results. Sponsors should not take these concerns as an attack on their integrity, but rather as legitimate concerns based on unfortunate past experience. A number of approaches can be used in the resolution of this issue. Probably most cost-effective is for the sponsor to arrange to have a third party perform the monitoring. This third party might be the local university or agricultural college, the state water quality control agency, the state department of agriculture, or a private laboratory. In any case, the project management can arrange to cover the costs of monitoring and use the results for their own records. Alternatively, the project management can offer to split samples collected with any of the regulatory authorities or public interest groups. The project management should be prepared to finance the duplicate analysis as well as their own. Finally, the local community can conduct a sampling program completely independent of the project's program. While this may seem excessive, it may also be politically necessary.

Public Relations Campaigns

As discussed above, there are no sure ways to gain public acceptance of land application projects, short of locating them in completely isolated areas. Where interaction with the public is projected, there are various techniques that may help the promoter to gain public acceptance.

While public relations campaigns are designed and carried out by the project sponsor to bring out a project's major benefits, candor is nevertheless essential in order to do this effectively. The case studies revealed a wide range of public relations techniques that have been used to promote POTW sludge projects, including development and distribution of glossy brochures describing the project; open public meetings; presentations to specific interest groups; presentation of films about similar projects; local media coverage; technical education campaigns for the public and in the schools; establishment of a hotline for quick response to individual questions; and presentation of materials stressing community benefits from the project.

It is important to design a public relations program which fits the character of the receiving community and the specifics of the application site. A major consideration is whether to take an aggressive or passive approach to public relations. There has been mixed success with both tactics.

An aggressive campaign allows a sponsor to stay on the offensive and to conduct an effective technical education before project opponents can play upon public prejudices against sludge, but may also engender opposition where none would have existed otherwise.

The case studies show a direct correlation between higher density abutting land uses and the amount of public controversy. Thus, a passive public relations campaign should be implemented only in situations where the application site is relatively isolated. For other sites, which are likely to be controversial anyway, an aggressive public relations campaign is recommended.

Technical Education

Before local citizens can discuss the pros and cons of a proposed project they must become familiar with the technical aspects of a new field. A technical education program presenting the fundamentals of the land application process will enable various participants to ask questions. Unlike a public relations campaign which is directed at the community as a whole, technical education is directed toward a more limited audience with greater than average interest in the project.

It is likely that many with whom a sponsor deals will have had little or no experience with POTW sludge or land application. The first phase of this program, therefore, should be to explain exactly what will happen if the project is implemented: how the land is prepared; what time of year the sludge is applied; when a grass cover can be expected, etc. This is one point where reclamation projects have an advantage over some other land application projects. Since the sludge used in reclamation is generally only applied once, the public can be assured that any inconvenience due to traffic, dust or odors will be a one-time occurrence of very short duration. While movies on the general topic can be used to introduce the subject, it is important also to set out the specifics of the particular application proposal. Oral, written and visual materials should be prepared for presentation at public meetings.

The next important effort is to inform the public as to the high degree of anticipated compliance with state and federal guidelines and standards. Particular mention should be made of guidelines and standards dealing with pathogen control, heavy metal content of sludge and soil, synthetic organic chemical content, storage facilities, application methods, site preparation, seeding methods, monitoring plans, and deed restrictions.

Where possible, standards of performance should be stated and the expected conformance of the project to these standards should be stressed. For example, with respect to sludge stabilization for odor and pathogen control, details of the composting process or anaerobic digestion process should be provided. For heavy metals, the composition of the sludge and the resulting soil and crop concentration of metals should be presented and

comparisons made where possible. It is particularly important to compare the proposed loading with prescribed loadings as recommended in state and EPA guidelines.

It would be a good idea to enlist local experts, university researchers, or agricultural/forestry extension staff to assist with a public education effort in order to improve credibility of the project.

Advisory Panels

Another proven means of gaining credibility for a project and to defuse public opposition is to ask parties with a potential interest to participate on a project advisory panel. This is particularly useful in the case of the first site to be located in a general area. Governmental personnel with actual or de facto power of approval should be asked to participate along with representatives of the core opposition group, abutters and other groups. Such a panel provides a perfect mechanism for finalizing monitoring procedures and reviewing project progress. It also provides a forum for the settlement of disputes. Advisory panels have proven very useful during the facilities planning stages for a wide range of wastewater treatment options under EPA public participation regulations and appear to be particularly useful during the initial phases of a land reclamation project.

Demonstration Projects

Conducting a demonstration project does not guarantee that promoters will be able to expand a project to full scale. However, it is much easier to start a demonstration project than it is to start a full scale project. Once under way, the demonstration project sets the stage for a larger program. The sponsor may wish to plan a strategy whereby full scale operations can be reached after three or four years. Experience has indicated that a well-run demonstration program can help sell a full-scale project. Thus, a demonstration should be initiated if there is no ongoing land application project within a reasonable distance from the proposed Site. A local demonstration program, preferably with extensive participation of local university researchers, will provide an excellent vehicle for educating the public about the process, and should receive local media coverage.

Such demonstration programs, when operated as a "pilot program" to develop full scale project design criteria may be fundable under the Step I facilities planning portion of the EPA construction grants process. We have identified a number of instances where such "pilot" scale wastewater treatment programs have been funded in this manner. Also, research funding to support demonstration programs may be available from EPA, other federal or state agencies. Otherwise, the costs of demonstration programs may have to be borne by the project promoter prior to seeking assistance for establishing full-scale projects.

Compensation to the Receiving Community

In many cases, the recipient community may not have any incentive to provide the necessary project approval. In cases where public opposition is anticipated, the promoters should carefully examine the community's incentives and consider the possibility of modifying the project to increase them. Recent research[13] in the field of community compensation summarized the various methods into four major categories.

Impact Prevention. This category covers the technical aspects of the project discussed under the strategy of proper design. To gain public acceptance a project sponsor must be sensitive to local concerns and be willing to modify practices to meet local requirements. Some modifications which might be considered are:

- Location changes
- Changes in sludge application technique
- Use of dry rather than wet sludge
- Truck route changes
- Drainage control system
- Buffer zone

Impact Mitigation. These techniques are used to compensate a community or individuals for adverse impacts of a project which are unavoidable. Although the risk of such impacts is often very small, it is advisable to establish a mechanism to provide compensation just in case. It is very unlikely that this form of compensation will be required for land application projects.

Side Payments. This form of compensation involves the payment of a benefit to the community to offset any burdens. These payments may be in the form of direct monetary payments or may be more indirect. One approach is transfer of a service or amenity to the community which is the direct result of a land reclamation project. For example, a portion of the reclaimed site could be deeded to the community as a park. Side payments may also be possible in the form of local economic support. For example, consider the maximum use of local resources such as local trucking firms, local labor, and local merchants.

Contingency Management. This is the method of local compensation most commonly used in reclamation projects to date. Sponsors use these techniques to reassure the community that the project is well managed and that procedures have been established to deal with problems. Providing the local community not only with access to the site for purposes of monitoring but also providing them with funds to conduct an independent monitoring program has been a key to project acceptance in the past. Such independent monitoring programs can be financed either directly or through a tipping fee on each truck load of sludge brought into the community. Other methods used to reassure the local communities include posting of performance bonds, purchasing of liability insurance, and establishing a "hotline".

Conclusion

While no one is going to say that gaining approval for land application projects is easy, it is certainly possible, and may, in fact, be no more difficult than gaining approval for other types of wastewater and sewage sludge management projects. Sponsors who are patient, taking the time to properly design projects, to conduct demonstrations, and to provide public education programs, will most likely be able to successfully establish projects.

At this time, the only note of caution is that land application as a management option is very vulnerable. Public acceptance of the concept is growing with every successfully implemented project, but it might only take one disaster to shelve the technology. Thus, while dealing with the red tape of federal guidelines and state permit requirements may be frustrating, it will be worthwhile if projects perform well.

With the number of disturbed areas in this country increasing daily, the potential for sewage sludges in reclamation and biomass production projects is enormous. If projects implemented during the next five years demonstrate that the procedures not only work, but can be conducted in a publicly acceptable manner, it is quite likely that land reclamation and biomass production will become a more widely used method of recycling sewage sludges. Land owners may then begin to assume an increasing share of the overall project costs.

Literature Cited

1. 33 U.S.C. Secs. 1251 et seq.
2. 33 U.S.C. Sec 1281(d).
3. See EPA's regulations under the Clean Air Act (CAA), 42 U.S.C. Secs. 7401 et seq., dealing with new stationary sources of air emissions, 40 C.F.R. Part 60, and with hazardous pollutants. 40 C.F.R. Part 61. See also EPA's Toxic Substances Control Act (TSCA), 15 U.S.C. Secs. 2601 et seq. regulations on PCBs, 40 C.F.R. Part 761, and the recently promulgated hazardous waste regulations under the Resource Conservation and Recovery Act (RCAA), 42 U.S.C. Secs. 6901 et seq., 40 C.F.R. Parts 260 et seq.
4. See EPA's ocean dumping regulations, 40 C.F.R. Parts 220-230, promulgated under the Marine Protection, Research and Sanctuaries Act, 33 U.S.C. Secs. 1401 et seq.
5. See EPA's PCB regulations, 40 C.F.R. Part 761, and its solid waste disposal regulations, promulgated jointly under RCRA and the CWA at 40 C.F.R. Part 257. See also EPA's hazardous waste regulations, 40 C.F.R. Parts 260 et seq.
6. See EPA's solid waste disposal regulations, 40 C.F.R. Part 257, and the forthcoming regulations on distribution and marketing of sewage sludge products, to be codified at 40 C.F.R. Part 258.

7. 33 U.S.C. Sec. 1345(d).
8. 42 U.S.C. Secs. 6907, 6944. These standards appear at 40 C.F.R. Part 257.
9. 40 C.F.R. Part 258 (forthcoming).
10. 30 U.S.C. Secs. 1202 et seq.
11. 42 U.S.C. Secs. 4321 et seq.
12. Restatement (second) of torts Sec. 821B.
13. "A Handbook for States in the Use of Compensation and Incentives in the Siting of Hazardous Waste Management Facilities" (Draft), September, 1980, prepared by USR&E for EPA.

V / RECLAMATION OF GRAVEL PITS AND IRON-ORE OVERBURDEN

OVERVIEW

CONSIDERING FISH AND WILDLIFE BIOMASS PRODUCTION ON SURFACE MINES USING SLUDGE AND WASTEWATER APPLICATIONS

William T. Mason, Jr.

As the United States enters a new decade, it is important to review past options and gain new perspectives for dealing with a subject of immense environmental concern -- the disposal of municipal sludge and wastewater. How can we, to best advantage of our society and renewable resources, restore reclaimed nutrients from wastewater treatment to the natural nutrient cycling process? Symposia such as this are commendable because they provide a forum and stimulation to additional research and inquiry leading to formulation of sound land-use planning to deal with the question. Many of the research papers presented in this book attest to our store of knowledge on the demonstrable benefits of sludge and wastewater applications to increased plant biomass production on surface mines.

Before moving to the papers in this Section, I would like to take a moment to "wave the flag" for fish and wildlife considerations on reclaimed mine lands and point out the obvious aesthetic, recreational and general benefit of enhancing fish and wildlife. Fortunately for the nation's fish and wildlife populations, surface-mined lands are found in rural domains. The citizens in these areas, including "miners," are well attuned to the enjoyment of fish and wildlife and expect diverse and abundant fish and wildlife populations as a heritage.

Few of the papers presented in this Symposium contain information on the animal component of mined lands receiving sludge and wastewater applications. Future research might focus on aspects of the uptake and transformation of potentially toxic substances contained in sludge and how these substances, in concert with background levels of metals, acid water, etc., may act synergistically to limit fish and wildlife populations. Studies on the behavior of substances in sludge, especially in relation to the early developmental stages of wildlife, will be most beneficial to determining the future scope of use of municipal sludge and wastewater for mine land

reclamation purposes.

During 1981, The Eastern Energy and Land Use Team, OBS, in cooperation with OSM, plans to initiate projects in northern Appalachia and southcentral United States to demonstrate cost-effective methods for reclaiming mined-lands for fish and wildlife enhancement. Efforts will be made to demonstrate the benefits of sludge and wastewater applications and perhaps test some of the technologies described in this Symposium. We will need to call on the experiences of many of the participants here to assist us in developing demonstration areas that will give high visibility to those methods that are regarded as most promising for future reclamation work.

I urge the Symposium participants and other researchers conducting studies of sludge and wastewater applications on mined lands to examine their current demonstration site for potential fish and wildlife benefits. Relatively little tuning of research projects may result in significant benefits to the fish and wildlife populations. For example, arrangement of grasses, legumes, shrubs and trees in the proper manner on experimental plants could provide for wildlife movement corridors, highly productive border areas, as well as food and cover. Maintenance of water, wherever permissible is encouraged. Long after the study is completed, fish and wildlife populations in the area will derive benefits from the attention.

Researchers and administrators, who are planning new experimental studies involving sewage sludge and wastewater may also wish to incorporate fish and wildlife concerns into future site demonstrations. State federal fish and wildlife agencies that are funding surface mining research should keep in mind the demonstrated benefits of sludge applications to surface-mined land for increased plant biomass production, and wherever possible, should advance the frontier of knowledge on the pathway of movements of substances in wastewater and sludge throughout the animal food chain and other ecosystem components.

Fish and wildlife need food, cover, water, and living space for normal life history functions; breeding, feeding and resting. Our job now is to package existing information on cost-effective methods in a form that is easily understood and used by reclamation planners and managers. The Office of Biological Services (OBS), U.S. Fish and Wildlife Service, has developed aids in the form of manuals, handbooks, guides, instruction packages and other tools for assistance that deal with fish and wildlife needs on surface-mined lands. OBS will gladly provide a variety of materials to meet information needs. In addition, for on-ground support, the U.S. Fish and Wildlife Service maintains Regional Offices in Portland, Oregon; Albuquerque, New Mexico; Twin Cities, Minnesota; Atlanta, Georgia; Newton Corner, Massachusetts; and Denver, Colorado. Other federal agencies that provide assistance related to coal surface mining, in addition to the U.S. EPA, include: Forest Service and Soil Conservation Service, U.S. Department of Agriculture, and the Office of Surface Mining Reclamation and

Enforcement (OSM), Bureau of Land Management, and Geological Survey, U.S. Department of the Interior. State reclamation and fish and game agencies are excellent sources of valuable information on the location and life necessities of fish and wildlife populations.

12
THE UTILIZATION OF SEWAGE SLUDGE:BARK SCREENINGS COMPOST FOR THE CULTURE OF BLUEBERRIES ON ACID MINESPOIL

Kevin W. Tunison, Bradford C. Bearce, and Harry A. Menser, Jr.

Growth media consisting of municipal sewage sludge, bark shredder screenings and composts of these wastes mixed with acid minespoil were tested to determine the potential value of these wastes as sources of nutrients for the culture of blueberries, (*V. corymbosum*) an acid-tolerant crop.

Sludge contained 3.5% Kjeldahl N, 1.5% P, 0.2% K, 2.5% Ca, 0.3% Mg, 2.5% Fe, 1250 ppm Zn, 520 ppm Mn, 392 ppm Cu, 34 ppm B, 600 ppm Cr and Pb, 50 ppm Ni, 20 ppm Co, and 5 ppm Cd. Concentrations are expressed in dry weight.

Foliage initially appeared normal but became severely chlorotic later in shoots reared on the sludge:minespoil medium. The content of Zn in these tissues was ca. 100 ppm. Foliar Mg levels were low (<.16%) in plants grown on media containing bark, sludge and minespoil but not when grown on standard peat moss:sand media. Composting diminished the severity of chlorosis as did foliar $MgSO_4$ sprays.

Berries showed no significant heavy metal contamination from Cd, Cr, Cu, Ni, Pb and Zn. Few berries grew on plants cultured in sludge:minespoil medium; however, bark:sludge composts mixed with minespoil produced nearly as much fruit as plants cultured on peat moss:sand medium.

Sewage sludge combined with acid minespoil was not suitable for blueberry production. Plant mortality was relatively high with this medium. However, when sludge and screenings were composted and mixed with minespoil, growth compared favorably with the standard peat moss:sand cultural medium.

Introduction

Specialty crop production on acid minespoil may provide a landowner with the opportunity to secure an economic return from marginally productive land. Adverse rooting conditions usually prohibit the culture of high return horticultural crops unless extensive measures are taken to favorably modify the spoil. Substantial amounts of lime, fertilizer, organic residues and a dependable moisture supply are needed to broaden the selection of crops suitable for acid minespoils. An acid-tolerant species such as blueberries (*Vaccinium corymbosum*) might possibly succeed on minespoil if nutrient and moisture requirements can be effectively managed.

Hardwood barks composted according to established methods are a suitable medium for container-grown plants (Hoitink & Poole, 1980). Composting results in the microbial breakdown of cellulose and removal of toxins from the bark. The addition of nitrogen (N) and phosphate (PO_4), usually in commercial inorganic forms, increases the decomposition rate (Hoitink & Poole, 1980).

Sewage sludge is a suitable alternative source of recycled nutrients for plant growth provided toxic heavy metal contamination in the produce can be prevented. A plethora of technical reports and reviews have been published on the use of sewage sludge for crop production (Page, 1974; Dowdy & Larson, 1975; Chaney & Giordano, 1977; Parretal, 1977).

Bearce (1980) tested hardwood composts derived from the screenings of a southern Appalachian bark shredding operation. Inorganic N and superphosphate were used in the process. Bedding plants grew successfully in the media.

This study reports results of an experiment to determine the feasibility of utilizing sewage sludge as a nutrient source for the preparation of composts from hardwood bark screenings for culture of highbush blueberries on acid minespoil amended with compost. The objectives of the study were to evaluate the adequacy of the compost as a plant growth medium and to monitor the accumulation of toxic heavy metals in berries and foliage.

Materials and Methods

Bark screenings composted with sewage sludge were mixed with acid minespoil and used as a medium for production of blueberries. Plants were grown in 5 gallon plastic containers in a greenhouse.

Preparation of Composts

Screenings were a by-product of a hammermill bark shredding processor located about 65 km east of Charleston, West Virginia. The fines, or screenings, sifted through a 0.5 cm mesh separator as the milled bark was conveyed to a packaging facility.

Sewage sludge was obtained from a secondary treatment plant at Waynesburg, Pennsylvania, about 40 km north of Morgantown, West Virginia. The sewage plant served the waste treatment needs of approximately 10,000 residents. The community harbored no major industrial sources of heavy metal contaminants. Lime was not used as a flocculent in dewatering the sludge. These were important factors in choosing a sludge for use in a relatively acid rooting medium.

An orphaned stripmine a few kilometers north of Morgantown, West Virginia, was used as a source of spoil. The textural content of the spoil consisted mostly of finely weathered sandstone passed through a 1.4 cm.

screen to remove coarse fragments. The pH of the spoil material was 3.2-3.5.

Dewatered sludge from drying beds at Waynesburg was trucked to the bark shredding site for composting with bark screenings. In composting operations, an ideal C:N ratio is 30:1 (Poincelot, 1972). To achieve this goal, three circular, level portions of bark screenings 5 m in diameter and 35 to 40 cm deep were prepared with a front-end loader. An equal amount of screenings was placed on each circular area. Sludge was spread upon the screenings in proportions of 1 part sludge to 1, 1.5 and 2 parts screenings, volume basis. The sludge was thoroughly mixed with the screenings by rototilling. A fourth treatment consisting of 3.6 kg NH_4NO_3 plus 3.0 kg of 20% superphosphate per cubic meter, used as standard commercial fertilizer comparison, was composted in the same manner.

Temperatures in the mix remained elevated for about 6 weeks, and remained undisturbed for another 2 weeks.

Preparation of Cultural Media

Blueberries were grown in 19 liter (5 gallon) drainable-type plastic containers in a greenhouse where effective practices could be used during this initial trial. Direct planting on a stripmine site was considered; however, security and other management factors favored the greenhouse option.

Cultural media were prepared by mixing the various materials in a cement mixer using volume-to-volume proportions according to the schedule shown in Table 12-1. Treatment BM contained bark composted with the N and PO_4 commercial fertilizers, PS consisted of sphagnum peat moss and washed coarse sand, while sludge:bark compost alone were the ingredients

Table 12-1. Media Used for Culture of Blueberries on Acid Minespoil.

Designation Code	Mixture	Ratio (V:V)
BM	Hardwood bark screenings composted with NH_4NO_3 + 20% superphosphate mixed with acid minespoil.	1:1
PS	Sphagnum peat moss mixed with washed sand.	1:1
SB	Compost of bark screenings and sewage sludge.	1:1
SM	Sewage sludge mixed with acid minespoil.	1:1
SMB (1:1)	Compost mixed with acid minespoil.	1:1
SMB (1:3)	Compost mixed with acid minespoil.	1:3

of SB. A sludge and minespoil mixture was used for treatment SM. The two SMB treatments both contained sludge:screenings compost but three volumes of minespoil also were used in addition to the 1:1 mix.

Highbush blueberries thrive best on acid soils in a range of pH 4.5 to 5.2. Two acidity levels, pH 4.2 to 4.5, and 5.2 to 5.5, were selected for cultural media. The lower range was chosen because a relatively acid rooting medium could promote the solubility and absorption of toxic heavy metals. Preliminary incubation of the media was done in order to predict the appropriate amounts of acidifying $Al_2(SO_4)_3$ and neutralizing $CaCO_3$ (ground limestone) needed to achieve desired pH levels. The incubations were performed by adding increasing amounts of $Al_2(SO_4)_3$ and $CaCO_3$ to the moistened media in small plastic containers kept closed to prevent drying, and recording pH for 7 weeks at weekly intervals.

Planting, Care and Sampling

Dormant 2-year-old plants of cvs. 'Jersey' and 'Berkeley' were planted in cultural media in July, 1979, watered thoroughly and placed under outdoor shadecloth. Sixteen Jersey plants were set in each medium while 32 Berkeley plants, used as pollinators, were transplanted into a peat:sand mix. Containers were later moved into the greenhouse to afford more equitable watering because moisture-saturated minespoil media drained poorly.

Vegetative growth was sustained until late November by placing plants on a 16 hour light photoperiod. A thermal, floral induction period in darkness was implemented during December, 1979, and January, 1980, by placing plants in a cold room at a constant temperature of 2-3°C.

Plants were returned to the greenhouse in early February, 1980, and the 16 hour photoperiod was resumed. The thermal induction period was successful because the blueberry plants flowered 2 weeks later. All bushes were transferred to a small, tightly enclosed greenhouse where a hive of bees was installed to accomplish pollination. A good fruit set resulted. Afterwards, the blueberries were returned to the greenhouse for routine care under natural lighting.

The experimental design used throughout most of the experiment consisted of randomized complete blocks. Initially, two plants cultured on each medium were placed randomly in each of six replicates. Additions of $Al_2(SO_4)_3$ to promote acidity or $CaCO_3$ to favor neutralization were made to one or the other of the pair of plants in each replication. No randomization was used when plants were thermally induced for 8 weeks at low temperatures in the dark.

Analytical determinations were made on samples collected periodically from blueberry plants and cultural media. Compositional analyses were performed on sewage sludge and C:N ratios were conducted on bark:sludge composts.

Blueberry leaves were collected on July 31, 1979, just after foliage

emerged from dormancy, and on September 14, 6 weeks later. Ripe blueberries were obtained during July, 1980, during first year harvest. Samples were dried, ground in a Wiley mill, and digested in 4:1 redistilled HNO_3:$HClO_4$ mixtures. Analytical details have been published previously (Menser and Winant, 1980). Leaf digests were acidified with 3M HNO_3 and the concentrations of Al, B, Ca, Cu, Fe, Mg, Mn, Na, P, Sn and Zn were analyzed by using inductively coupled plasma, atomic emission spectroscopy (ICP-AES). Concentrations of Cd, Cr, K, Ni, and Pb were measured in 0.lN HCl by atomic absorption spectroscopy. Total Kjeldahl N was determined by Technicon auto-analysis and total S was analyzed with a Leco combustion determinator. Digestion and analysis of blueberries was accomplished by using the same procedures as were used for leaves. Copper, Zn, Pb, Cd, Cr, and Ni were measured by using atomic absorption spectroscopy.

Sewage sludge was also digested in HNO_3:$HClO_4$ mixtures. Aluminum, B, Ca, Cu, Fe, Mg, Mn, Na, P, Sr, and Zn were determined in redissolved 3M HNO_3 by using inductively coupled plasma, atomic emission spectroscopy. Technicon auto-analysis was used to measure total Kjeldahl N. Cadmium, Cr, Ni and Pb data were furnished by Dr. Ray Shipp, Extension Soil Scientist, Pennsylvania State University.

Compost samples for C:N ratio determination were obtained at the close of the composting process. Dried, finely ground 10 mg samples were combusted in an elemental analyzer. pH values of cultural media were recorded on samples prepared as 1:1 (w/w) mixes of media and distilled H_2O.

Results and Discussion

Sewage sludge composted with hardwood bark fines, or screenings, was an acceptable medium for culture of blueberries. Waynesburg sludge contained sufficient amounts of essential nutrients for plant growth without excessive contamination from toxic heavy metals (Table 12-2). Total N, P, K, Ca and Mg were lower than the median level for these elements as compiled from 200 sludge samples from 8 states, while Al and Fe concentrations were higher than the 200 sample average (Dowdy et al., 1973). Toxic heavy metals Zn, Cu, B, Cd, Cr, Ni, and Pb were near the lowest limit of the ranges (Dowdy et al., 1976; Chaney, 1974). We suspect that the content of our bark:sludge compost did not differ appreciably from the product of the well known USDA Beltsville compost process (Parr et al., 1977).

Carbon:nitrogen ratios of bark screenings composted with NH_4NO_3 and superphosphate were slightly higher than C:N ratios of screenings of bark composted with sewage sludge (Table 12-3). These ratios did not differ much from the 30:1 ratio considered optimum for the composting process (Poincelot, 1972). The rate of release of N from organically bound forms

Table 12-2. Compositional Analysis of Sewage Sludge, Secondary Treatment Plant, Waynesburg, Pennsylvania. 1979.[1]

Composition, Dry Weight					
Element	Percent		Element	Ppm	
	$\bar{X}$	Composite		$\bar{X}$	Composite
Total N	2.09	2.20	Zn	1249	1890
P	1.31	1.59	Mn	529	646
K[2/]	.25	-	Cu	392	538
Ca	2.48	2.31	Sr	148	172
Mg	.26	.30	B	34	35
Al	1.90	2.43	Pb[2/]	435	-
Fe	2.65	2.86	Cr[2/]	575	-
Na	.12	.11	Ni[2/]	43	-
S			Cd[2/]	6	-

1/ Data are averages of five samples collected randomly from a 3.5 to 4.0 MT stockpile. A composite was obtained by subsampling the five replicates.

2/ Data are averages of duplicate samples analyzed by the Pennsylvania Department of Environmental Resources as reported to us by Ray Shipp, Extension Soil Scientist, the Pennsylvania State University.

Table 12-3. Carbon, H, N Analysis, and C:N Ratios of Hardwood Bark Screenings and Sewage Sludge Composts Used with Acid Minespoil for Culture of Blueberries.

Sample Material	Content	Analysis, % Dry Wt. C	H	N	Ratio C:N
Standard compost	Bark, NH_4NO_3, and superphosphate	29.7	3.5	0.9	34:1
Bark/sludge compost	Bark/sludge (2:1, v/v)	27.3	3.3	1.0	27:1
Bark/sludge compost	Bark/sludge (1.5:1, v/v)	24.9	2.8	.8	29:1
Sludge	Sewage sludge	18.5	3.0	2.1	9:1
Bark	Bark screenings	35.5	4.4	.4	95.5:1

in the sludge appeared to proceed rapidly. The time required to complete the composting process was about the same for screenings mixed with either sludge or inorganic N and P sources.

Foliage appeared normal and essential nutrients were within average ranges shortly after plants broke dormancy and leaves developed fully; however, severe chlorosis appeared about 6 weeks later in terminal growth of plants reared on media containing minespoil and sewage sludge. (Table 12-4). At this time, N, P, K, and S levels had declined in most leaves where Ca concentrations had increased. Magnesium deficiency was considered as a possible cause of the chlorosis because the symptoms centered on interveinal areas of the leaves while the tissues adjacent to the primary veins retained normal pigmentation. Application of $MgSO_4$ was mixed with hardwood bark composts.

The absence of acute chlorosis in foliage with comparable Mg levels tends to discredit the belief that Mg deficiency was the primary cause of foliar chlorosis, poor blossom production, and the ultimate mortality of most of the plants grown on minespoil mixed with sewage sludge. An increase in Zn concentration occurred in leaves from this medium; however, the leaf chlorosis did not resemble Zn phytotoxicity. Possibly, sludge must be composted if it is to be used with minespoil as a cultural medium for blueberries. Gouin (1977) and Gouin & Walker (1977) reported beneficial results of composting sewage sludge with wood chips for nursery stock production. Sludge compost improved soil physical properties but sewage sludge used alone was difficult to incorporate with soils and produced cloddy seedheads (Epstein et al., 1976). Improved physical properties may have been one of the principal reasons for the success of blueberries on minespoil:compost media as compared with minespoil:sludge mixes. The latter often appeared to be waterlogged or impervious to moisture infiltration.

Toxic metal accumulation in fruit was a primary concern in this study because blueberries grow best under acid soil conditions that favor toxic metal availability and absorption. The application of $Al_2(SO_4)_3$ to acidify and $CaCO_3$ to neutralize media and to secure acid (pH 4.2) and less acid (pH 5.5) rooting conditions partially succeeded (Table 12-5). The pH of peat:sand mixtures, sludge:bark compost, and compost:minespoil at a ratio of 1:3 did not completely meet our objectives. However, the pH of most of the media approached desired levels. Excess acidity may have contributed to the poor growth of plants reared on sewage sludge and minespoil. The use of $CaCO_3$ with this mix resulted in better growth, improved survival and reduced acidity. Chlorotic symptoms were not as severe in foliage of blueberries grown on this medium after $CaCO_3$ applications. Excessive acidity can lead to Al and Mn toxicity, as discussed by Foy et al. (1978). Our analyses do not show abnormal uptake of these elements probably due to increase in organic contents through composted bark and sludge. Brown and

Table 12-4. Foliar Analysis of Blueberries Grown on Composts of Hardwood Bark Screenings and Sewage Sludge Mixed with Acid Minespoil. Two Sampling Dates. 1979.

	Cultural Medium											
	Bark/Spoil BM		Peat/Sand PS		Compost SB		Sludge/Spoil SM		Compost/Spoil SMB (1:1)		SMB (1:3)	
Sampling Date	7/31	9/14	7/31	9/14	7/31	9/14	7/31	9/14	7/31	9/14	7/31	9/14
Element	%											
N	3.40	1.82	3.68	2.30	3.47	2.60	3.81	2.84	3.56	2.64	3.48	2.00
P	.27	.14	.30	.16	.33	.18	.32	.19	.29	.19	.30	.17
K	.80	.80	.81	.63	.88	.65	.95	.65	.84	.73	.85	.80
Ca	.41	.55	.27	.41	.68	.86	.84	.89	.58	.53	.43	.45
Mg	.25	.16	.26	.23	.26	.12	.24	.14	.23	.14	.23	.16
S	.43	.26	.51	.30	.50	.25	.50	.23	.70	.26	.55	.31
	Ppm											
Fe	145	84	163	90	158	86	221	93	287	75	156	71
Mn	164	69	184	90	143	43	320	323	186	67	226	257
Zn	59	28	74	26	69	35	139	102	67	39	70	36
Na	266	267	292	207	309	307	526	457	334	233	316	222
Al	136	99	132	129	128	117	167	100	162	90	170	92
B	19	26	12	14	14	16	19	22	23	26	20	27
Sr	6	12	3	8	9	13	16	25	10	12	6	11
Cu	5.2	4.0	5.7	4.8	5.2	3.8	6.6	5.2	5.6	5.2	6.2	6.2
Ni	1.67	1.42	1.38	1.00	1.67	1.00	4.75	3.38	1.00	1.58	2.50	3.29
Cr	1.42	1.25	1.25	1.25	1.25	1.25	1.67	1.25	1.42	1.25	1.32	1.25
Pb	1.75	1.25	1.75	1.84	1.84	1.34	1.79	1.42	1.92	1.25	1.92	1.25
Cd	.31	.13	.43	.28	.28	.15	.27	.21	.31	.13	.25	.14

Table 12-5. pH of Cultural Media During Vegetative and Fruiting Stages of Blueberry Production on Composts of Bark Screenings and Sewage Sludge Mixed with Acid Minespoil.

	Date of pH Determination							
	Vegetative		Flowering and Fruiting					
	7/25/79	2/24/80	6/24/80					
	Pre-Amendment		Amendment Used to Secure Desired pH					
			$AlSO_4$		$CaCO_3$		None	
			Desired	Actual	Desired	Actual	Desired	Actual
	pH	pH	pH					
BM (Bark/Spoil)	6.0	5.8	4.2	4.0	-	-	5.5	5.5
PS (Peat/Sand)	3.6	4.6	-	-	5.5	6.4	4.2	5.2
SB (Sludge/Bark)	7.0	6.0	4.2	3.6	-	-	5.5	5.3
SM (Sludge/Spoil)	4.3	4.1	-	-	5.5	5.4	4.2	3.9
SMB, 1:1 (Compost/Spoil)	6.3	5.5	4.2	4.2	-	-	5.5	5.2
SMB, 1:3 (Compost/Spoil)	4.9	4.7	-	-	5.5	6.7	4.2	5.2

Table 12-6. Toxic Heavy Metal Concentrations of Blueberries Grown on Media Consisting of Sewage Sludge, Acid Minespoil, Hardwood Bark Screenings and Sludge:Screenings Composts, 1980.

	Cultural Medium											
	Bark/Spoil BM		Peat/Sand PS		Compost SB		Sludge/Spoil SM		Compost/Spoil SMB (1:1)		SMB (1:3)	
pH of Media	4.2	5.5	4.2	5.5	4.2	5.5	4.2	5.5	4.2	5.5	4.2	5.5
Metal	----------Ppm, Dry Wt.----------											
Zn	11.2	12.2	10.7	11.2	13.1	11.9	41.0	23.8	12.8	15.8	11.2	13.0
Cu	2.0	2.7	2.9	2.4	2.1	3.0	8.0	4.9	3.2	3.1	3.4	3.4
Cr	4.1	3.4	5.7	5.3	4.7	4.1	9.2	5.7	3.9	2.3	3.1	1.9
Ni	1.4	1.2	1.2	1.2	1.2	1.2	7.7	3.8	1.5	1.2	1.9	1.8
Pb	----------< 1.2 ----------											
Cd	----------< .6 ----------											

Draper (1980) found differential responses of blueberries to Fe while seeking alkaline conditions for better growth. The threat of toxic heavy metal accumulation in blueberries could be significantly downgraded by using cultivars adapted to more alkaline conditions.

We found no toxic accumulations of heavy metals in blueberries (Table 12-6). Although Zn, Cu, Ni, and Cr levels were slightly higher in fruit from plants grown on sewage sludge:minespoil mixes, the concentrations remained within limits thought to be safe for human consumption (Chaney, 1974; Stewart & Chaney, 1976). Storage tissues generally do not accumulate toxic metals as readily as foliage.

In summary, compost of sewage sludge and hardwood bark mixed with acid minespoil used in containers was an acceptable medium for culture of blueberries. Foliage generally was healthy and fruit did not accumulate toxic heavy metals. Sewage sludge mixed with minespoil resulted in chlorosis and poor survival, and is not recommended for blueberry production.

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13
CROP PRODUCTION ON WASTE AMENDED GRAVEL SPOILS

Sharon B. Hornick

Utilization of sewage sludge compost and feedlot manure can provide many chemical and physical factors necessary for the establishment of agronomic crops on sand and gravel spoils. Such organic wastes and materials provide much needed plant nutrients and organic matter which are drastically lacking in many spoil sites. Addition of these materials can result in better crop establishment and yield, avoidance of moisture stress in crops, and reduction of soil erosion when compared to spoil areas receiving only inorganic fertilizer.

Introduction

Many land areas once mined for sand and gravel and left abandoned tend to show a lack of vegetation due to low soil pH, and inadequate levels of nitrogen, phosphorus, potassium, and magnesium. Severe erosion and gullying is caused by low organic matter content which restricts water infiltration and retention and, hence, root development and growth. Another difficulty occurs when the fill contains large pieces of asphalt, concrete or other debris. The result is restricted or obstructed root growth and water movement due to a very heterogenous soil profile.

Studies in our laboratory (Griebel et al., 1979) have shown that sewage sludge compost can be used to establish cover crops on strip mine lands. Usually on these marginal or disturbed land areas which have been amended with sewage sludge compost, the vegetative growth is greater than that of control areas (Hornick et al., 1979a). This difference in crop establishment and growth rate is attributed to the soil conditioning and fertilizing benefits of the sewage sludge compost (Hornick et al., 1979a, 1979b).

Materials and Methods

Two Waste Experiment

In the spring of 1979, several field plots were established on sand and gravel spoils. Macronutrient analyses showed the spoil material to be low in phosphorous and potassium content. The organic matter content ranged from 0.4% to 1.2%. In order to determine the feasibility of growing agronomic crops on these infertile sites, 0, 40, 80 and 160 mt/ha of sewage sludge compost or 40, 80, and 160 mt/ha of feedlot manure were added to (6.67

x 6.67 m) plots with three replications (two waste plots).

The sewage sludge compost used in this experiment was produced from an undigested sewage sludge from the Washington, D.C. metropolitan area and wood chips. It is a stabilized organic material with a low heavy metal content (Hornick et al., 1979a) resulting from the "domestic" characteristics of the sludge.

The control or 0 mt/ha plot received inorganic fertilizer to equal 179-112-112 kg/ha of nitrogen, phosphorus and potassium. Plots receiving 40 and 80 mt/ha of compost or feedlot manure were supplemented with inorganic nitrogen fertilizer to equal the 179 kg/ha added to the control plot. The plots were planted to 'Silver Queen' sweet corn.

Three Crop Experiment

Three additional and separate experiments were established growing 'SS 775' field corn, 'Silver Queen' sweet corn, and 'Top Crop' bush beans. Corn plots received 0, 80 and 160 mt/ha compost while the bush beans received lower compost rates of 0, 40, and 80 mt/ha. Again the 0 mt/ha plots received the recommended rate of inorganic fertilizer and the 80 mt/ha compost plots were supplemented with inorganic nitrogen fertilizer to equal the nitrogen application rate of the control.

On all field and sweet corn control plots, 89.6 kg of nitrogen per hectare was plowed down and later sidedressed with ammonium nitrate. The bush bean control plots were sidedressed with 224 kg/ha of 10-6-4.

From lime determinations with soil and soil-waste mixtures, the required amount of lime was added to the control plots and to the 40 mt/ha compost or manure treated plots. Plots receiving 80 and 160 mt/ha of manure or compost did not require lime additions due to the wastes' buffering capacity.

Leachate Sampling

Suction lysimeters were installed in spring of 1980 on the two waste plots at 30 cm and 120 cm depths. Plots which received only inorganic fertilizer or 80 or 160 mt/ha compost or manure were monitored. Weekly measurements of chloride and nitrate were performed by using specific ion electrodes and an Orion 901 ion analyzer.

Growth Responses

Both stalk and grain were harvested, weighed and analyzed for macro- and micronutrient elements. Soil samples were collected and analyzed.

Stalk and grain samples were harvested at maturity and fall soil samples were collected. All samples were analyzed for macro and micronutrient content. Heavy metals were determined by a dry ash procedure (Chaney et al., 1977) with subsequent analysis on an IL 355 atomic absorption spectrophotometer.

Results

Soil Temperature and Moisture

Daily morning and afternoon temperature measurements were taken on the two waste plots. Depths of 2.5 and 10 cm were monitored to determine the effect of waste additions on both surface and subsurface temperatures since temperature can significantly affect germination of seed and subsequent plant growth and root development. Figure 13-1 shows that the addition of 160 mt/ha of compost or manure resulted in a much lower afternoon soil temperature at the 10 cm depth than did the control plots which contain very little native organic matter. Afternoon temperatures taken at the 2.5 cm depth were similar to that of the 10 cm depth. Due to the cooling effect of night, morning temperatures taken at both the 2.5 and 10 cm depth were similar for both the control and organic waste-amended plots.

Due to the sandy nature of the soil, crusting was a problem on the control soil. Since the amount and type of waste applied has been shown to affect soil moisture (Hornick et al., 1979a, Unger and Stewart, 1974), gravimetric water samples were taken and calculated. Initially the manure contained 80 percent moisture compared to 40 percent in the compost. When added to the soil, the type of waste used affected the percent soil moisture as follows: the control, 7%; 40, 80 and 160 mt/ha compost, 10, 12 and 15%, respectively; and 40, 80 and 160 mt/ha manure, 15, 19 and 32% respectively.

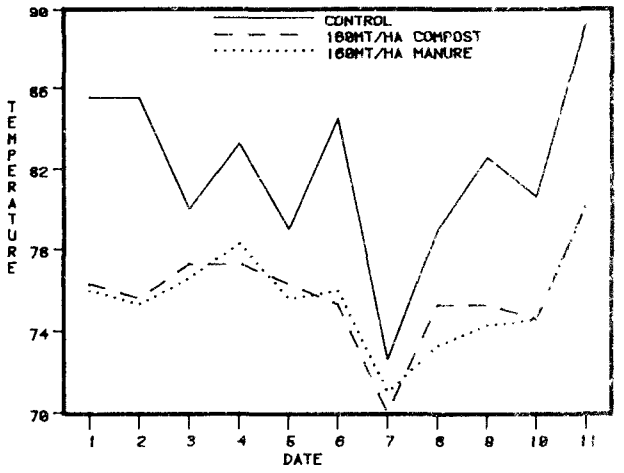

Figure 13-1. Effect of Organic Waste Amendments on Afternoon Soil Temperature Taken at a 4 Inch Depth.

Water Quality

Weekly measurement of nitrates and chloride showed that chloride movement at the 30 cm depth was similar both for plots receiving 80 mt/ha of compost and those which received 160 mt/ha compost or manure (Figure 13-2). Plots treated with 80 mt/ha of manure were lower. All of the waste treated plots had a much higher chloride movement than did the fertilized control.

Figure 13-3 shows the chloride movement at a 120 cm spoil profile depth for the control, 80 and 160 mt/ha of compost or manure plots. Once again for the 160 mg/ha compost plots, a much higher initial chloride movement was noted at the 120 cm depth than for the plots receiving lower rates of compost or manure. On manure treated plots, the amount of chloride movement was approaching the low level of the control.

Soil water samples taken soon after incorporation of the wastes and planting indicated a rapid movement of nitrate at the 120 cm level for the compost treated plots (Figure 13-4). However, plots amended with manure showed nitrate levels below that of the ammonium nitrate fertilized control. This result is surprising since the feedlot manure contained 5.16% total Kjeldahl nitrogen (TKN) compared to 0.7% in the compost. Previous research, such as that of Mathers and Stewart (1974), has shown that nitrate movement to the groundwater usually occurs when high rates (over 112 mt/ha) of manure are applied to the plow layer.

Two Waste Plots

Sweet corn stalk production in 1979 was higher for the 40 and 80 mt/ha compost treated plots than for both the control or the manure plots (Figure 13-5). However, the dry matter stalk yield was higher for plots treated with 160 mt/ha manure than for comparable rates of compost.

In contrast to the stalk yields, the highest corn ear yield (wet weight basis) was from plots which received 40 mt/ha manure (Figure 13-6). The yields from both the 80 and 160 mt/ha compost or manure treated plots were similar.

Three Crop Experiments

Yields for both the field and sweet corn stalks were higher than the controls (Figures 13-7 and 13-8). As was observed in the two waste plots ear yields did not follow the trend of stalk yields. Except for sweet corn grown on the 80 mt/ha compost plots, ear yields for compost treated plots growing both sweet corn and field corn were lower than for the fertilized control.

Bush beans showed a different trend. While the number of plants grown on each plot was similar for both the control and treated plots (Figure 13-9), the number of beans per plant and the resulting kg/ha beans produced (wet weight basis, Figure 13-10) were markedly different. Both the 40 and 80 mt/ha compost rates increased bean yield.

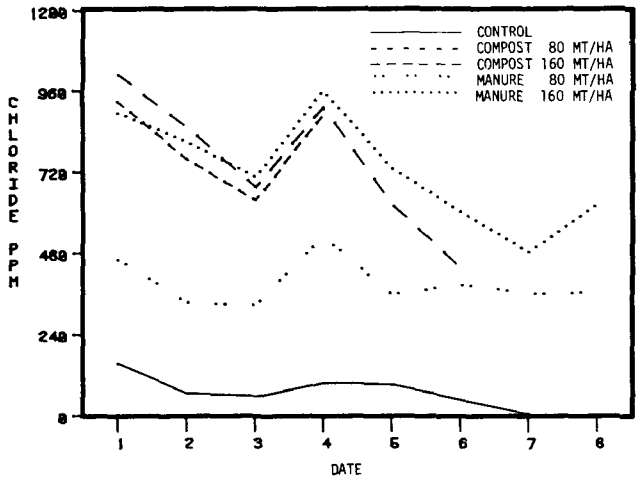

Figure 13-2. Effect of Fertilizer Treatment on Chloride Movement in the Spoil Profile at a One-Foot Depth.

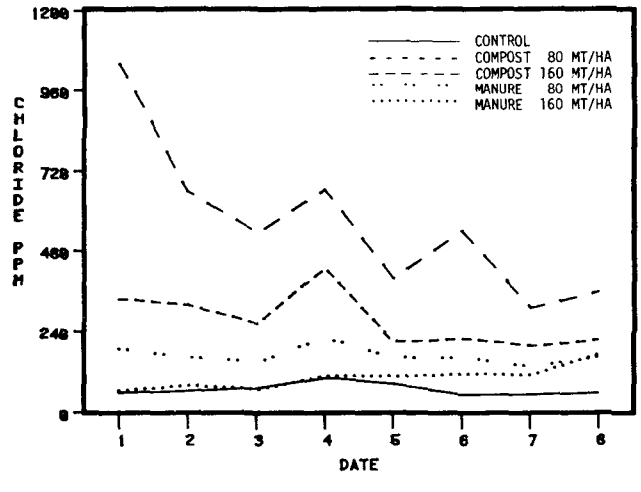

Figure 13-3. Effect of Fertilizer Treatment on Chloride Movement in the Spoil Profile at a Four-Foot Depth.

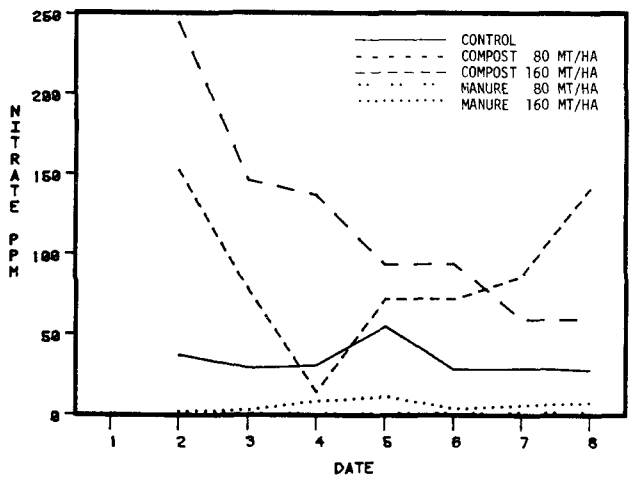

Figure 13-4. Effect of Fertilizer Treatment on Nitrate Movement in the Spoil Profile at a Four-Foot Depth.

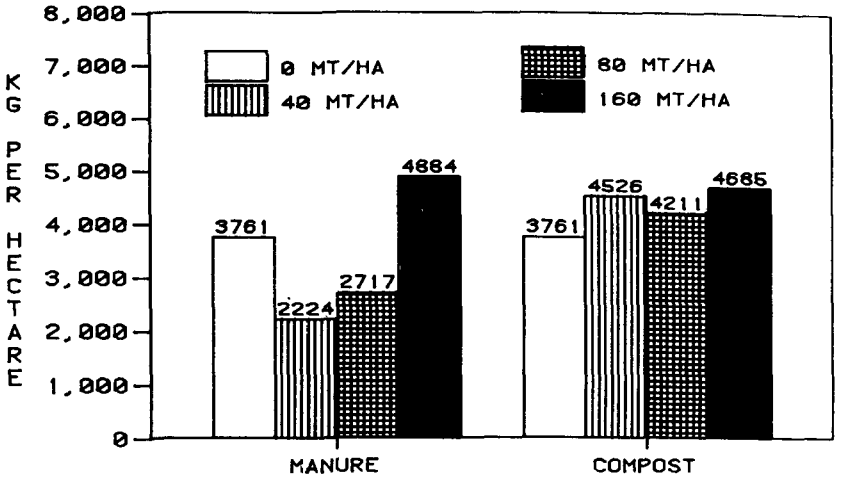

Figure 13-5. Effect of Organic Waste on 1979 Corn Stalk Yield.

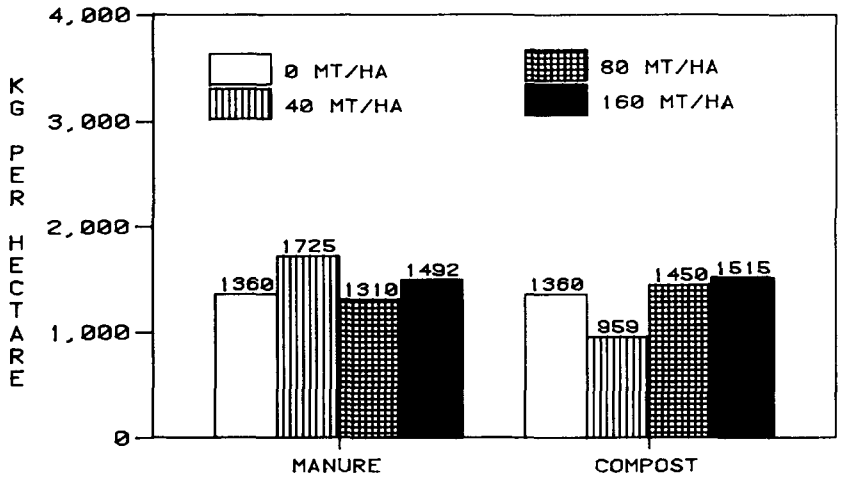

Figure 13-6. Effect of Organic Waste on 1979 Corn Ear Yield.

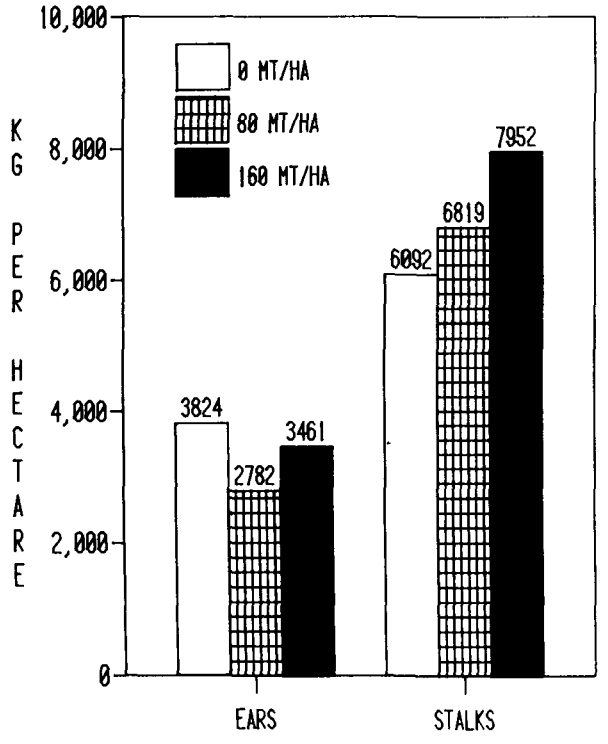

Figure 13-7. Effect of Compost Rate of Field Corn Ear and Stalk Yield.

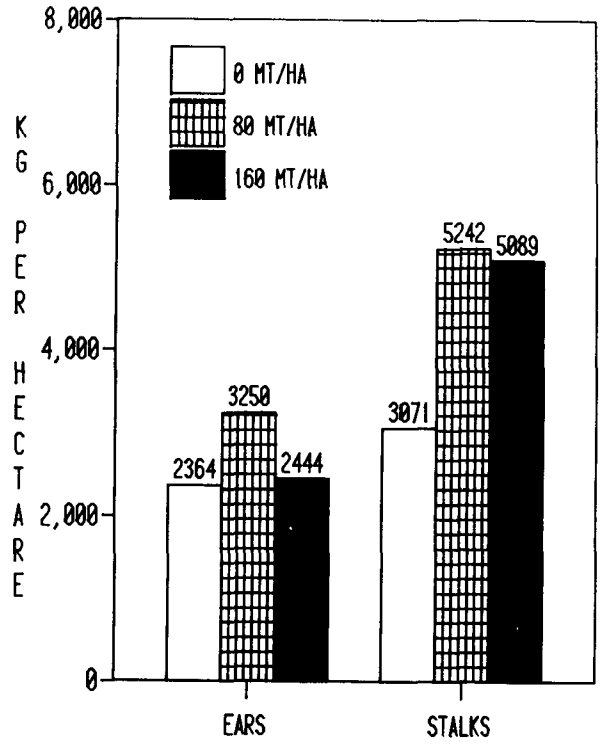

Figure 13-8. Effect of Compost Rate on Sweet Corn Ear and Stalk Yields.

Elemental Composition of Soils and Plants

Although each waste should have supplied adequate nitrogen to the soil for crop growth, each plot amended with either compost or manure received a sidedress of nitrogen fertilizer. This was done to supply a readily soluble nitrogen source greatly needed by a young corn plant. Table 13-1 shows that despite differences in fertilizer sources or plot treatment the nitrogen, phosphorus, potassium, and magnesium levels in the corn grain are similar. Calcium content in the manure is half the amount of that analyzed in the compost. This difference is probably due to the 10% calcium carbonate contained in the sludge compost.

Compared to the level of trace elements in the control soil, trace element content in the waste-amended plots increased relative to the amount of waste added (Table 13-2). Despite a rise in soil zinc and copper, corn zinc and copper did not differ greatly from that of the control. This same trend has been seen in other studies utilizing limed sludge compost (Hornick et al., 1979b). Due to the high pH of the compost, metal precipitation and adsorption occurs in the soil, thus, limiting trace metal uptake. The increase

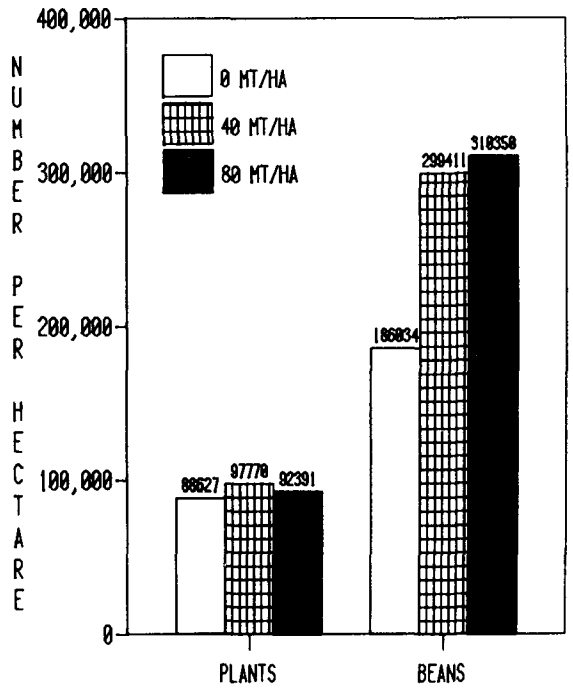

Figure 13-9. Effect of Compost Rate on the Number of Beans and Plants Produced Per Hectare.

in grain cadmium was not proportional to the cadmium increase in the soil. Soil pH of the plots ranged from 6.7 to 7.9. The plots receiving the highest amount of waste applied were highest in soil pH.

Conclusions

Sewage sludge compost and feedlot manure added to sand and gravel spoils reduce surface and subsurface soil temperature and increase soil moisture. These organic waste additions reduce extreme drying conditions which can hamper seed germination and subsequent plant development.

Although sweet corn ear production on compost treated plots was similar to areas receiving inorganic fertilizer only, stalk production was always enhanced by compost additions. Field corn stalk yield was double that of control plots. Compost additions also greatly increased the number of bush beans per plant. Manure increased stalk yield of sweet corn only at the 160 mt/ha rate but increased sweet corn ear yield substantially over that of the control at the 40 mt/ha rate.

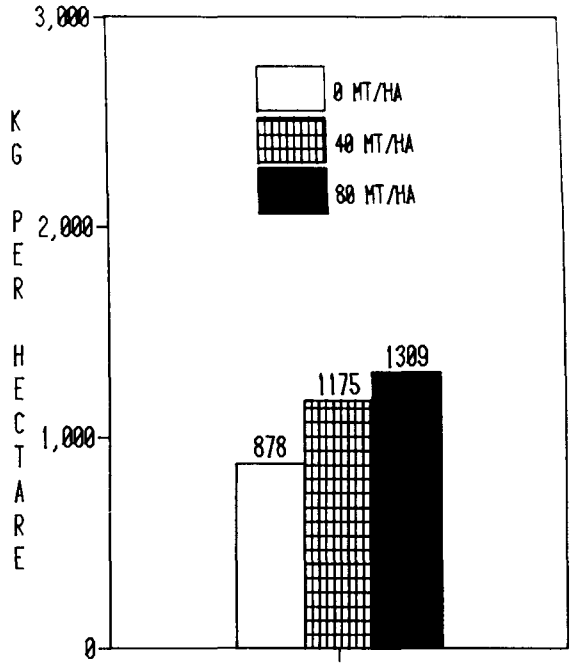

Figure 13-10. Effect of Compost Rate on Bush Bean Yield.

Phosphorus, calcium and magnesium contents of the sweet corn grain were similar for control and waste-amended plots. Nitrogen content of sweet corn grain grown on the waste-amended plots was significantly higher than the control. Due to the buffering capacity of the wastes and resultant high soil pH, trace element uptake was not significant in the sweet corn grain.

This study has shown that the biomass production is generally increased when organic wastes are utilized to reclaim disturbed land areas. In order to prevent ground water pollution from nitrates and chlorides, the waste application rate should be determined by the waste composition, the type of crop to be grown, and the spoil texture. As long as low metal wastes are used and soil or spoil pH is maintained near 6.5, trace metal uptake in crops which would enter the food chain should not be significant.

ACKNOWLEDGEMENTS. The author wishes to express her appreciation to Ms. Carole Sue Rodgers and Mrs. Paula Paolini for their valuable technical assistance. This research was supported in part by funding from the U.S. Environmental Protection Agency and by technical assistance from the Maryland Environmental Service, Annapolis, Maryland.

Table 13-1. Macronutrient Analyses of Sweet Corn Grain Grown in 1979 on Sand and Gravel Spoils Amended with Sewage Sludge Compost or Feedlot Manure.

Treatment	N	P	K	Ca	Mg
--mt/ha--			--%--		
0	0.54	0.33	0.75	0.031	0.14
40 compost	2.54	0.32	0.72	0.032	0.14
80 compost	2.48	0.34	0.77	0.035	0.14
160 compost	2.24	0.34	0.80	0.029	0.13
40 manure	2.28	0.38	0.84	0.017	0.15
80 manure	2.47	0.40	0.90	0.015	0.15
160 manure	2.66	0.42	0.96	0.017	0.15

Table 13-2. Trace Element Analyses of Sweet Corn Grain and Sand and Gravel Spoils Amended with Sewage Sludge Compost or Feedlot Manure.

Treatment --mt/ha--	Sample	Cd	Zn	Cu
		----mg/kg dry weight----		
0	soil	0.02	18.7	4.3
"	corn	0.04	25.1	4.5
40 compost	soil	0.25	38.1	13.1
"	corn	0.04	26.7	4.2
80 compost	soil	0.50	66.3	21.9
"	corn	0.07	28.6	4.4
160 compost	soil	0.97	114.2	39.7
"	corn	0.27	29.1	4.1
40 manure	soil	0.03	24.4	5.1
"	corn	0.13	28.8	3.3
80 manure	soil	0.05	19.8	3.7
"	corn	0.08	28.4	3.5
160 manure	soil	0.07	34.1	6.4
"	corn	0.18	32.3	3.7

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14
UTILIZATION OF SEWAGE EFFLUENT AND SLUDGE TO RECLAIM SOIL CONTAMINATED BY TOXIC FUMES FROM A ZINC SMELTER

William A. Franks, Marie Persinger, Asfa Iob, and Patrick Inyangetor

A soil is contaminated when foreign substances which adversely affect plant growth are introduced into the plow layer. Such soil exists in Henryetta, Oklahoma near a zinc roaster and smelter. Emissions from the smelter have destroyed vegetation and polluted the soil in surrounding areas for approximately two square miles. This study was undertaken to establish permanent vegetation plots in the polluted area.

To accomplish this, a chosen area of the polluted soil was divided into plots and treated with various combinations of sludge, effluent, lime, commercial fertilizer, urea, and hay mulch. Ten species of grasses and one species of legume were planted on the treated soil and growth response of each species was monitored. In conjunction with the plot studies, the metal content of both the soil and plant species was studied.

Introduction

The soil mapping unit established by the Okmulgee County Soil Conservation District for the project area is the Hector-Hartsells fine sandy loams and more specifically the Hector part of the above. This soil is a shallow, nearly level to steep, well drained, rapidly permeable upland soil. Before the surface vegetation was destroyed by zinc smelter fumes, the soil profile was a dark grayish brown, the subsurface layer was dark yellowish brown, gravelly fine sandy loam and fine sandy loam about 15 centimeters thick. The subsoil is dark yellowish brown fine sandy loam about 25 centimeters thick overlying sandstone bedrock. Most of the above described A1 and A2 soil horizon (38 cm) has eroded to the point of an average topsoil depth varying from 1 cm to 4 cm. The estimated soil loss from the project area using the universal soil loss equation exceeded 30.950 metric tons per square kilometer. Initial studies by Smith and Duffer (1973) showed that the contaminated soil had a low pH value and exhibited above normal concentrations of cadmium, copper, lead, and very high concentrations of zinc.

Recent studies by Sopper et al. (1974) showed that sludge and effluent could be utilized successfully to reclaim strip mine soil and anthracite coal refuse banks. A three year study was then undertaken for the purpose of: (1) establishing permanent vegetation plots on the contaminated soil by treating the soil with sludge, lime, and effluent (2) establishing permanent

vegetation on plots using commercial fertilizer and (3) studying the effect of the various treatments on the metal contamination, pH, and nutrient value of the soil.

Materials and Methods

Site Study—First Year

An area located approximately 274 m north of the location of the abandoned zinc smelter site was chosen as the test site whose soil conformed to the average contamination of the entire area. A very rocky site of size 41 m x 14 m with a moderate slope was enclosed with a fence. The site was then tilled twice to a depth of 15 cm on consecutive days prior to seeding. The site was then divided into six equal plots with dimensions of approximately 6 m x 14 m. The site was then ready for treatment and planting.

Lime was broadcast on top of the ground at the appropriate rate. Municipal sludge was spread in liquid form on top of the ground via tank-wagon pump spray machine. Commercial fertilizer was broadcast on top of the ground. All of these materials were incorporated into the soil at a depth of 15 cm using a field cultivator consisting of steel shanks spaced 18 cm apart. The total treatment for each plot is shown in Table 14-1.

One species of legume and ten species of grasses were chosen for this study (Table 14-2). In addition to these species there were two naturally occurring species *Panicum agrastoides* (panicum grass) and *Amaranthus hydridus* (pig weed family). Each of the six plots was divided into 11 equal rectangular blocks and each block was seeded with one of the 11 different plant species.

The seeds were broadcast on top of the ground at a seeding rate of 154 kg/ha. Immediately after seeding, approximately 3 cm of water was applied and 3 cm of hay mulch was placed on top of the seeds for the purpose of conserving moisture. The plots were then treated with effluent or water on a weekly basis. After 12 weeks from the date of initial planting, one-half of each block of each plot was treated with 45 kg/ha of urea-nitrogen.

Site Study—Second Year

An area adjacent to the first year site with a 20% slope was divided in four equal plots with dimensions 9 m x 10 m. The plots were prepared and treated in the same manner as described for the first year site. The exact amounts of each substance applied to the plots are given in Table 14-3. Bluestem grass, bermudagrass, kleingrass, and switchgrass were selected for the second year study.

Table 14-1. Total Soil Treatment for Site One.

Constitutent (amount)	Plots 1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B
	Amounts Per Acre											
Lime (metric tons)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	-	-	2.5	2.5
Effluent (centimeters)	31	31	31	31	-	-	-	-	-	-	-	-
Water (centimeters)	-	-	-	-	31	31	31	31	-	-	-	-
Sludge (centimeters)	-	-	3	3	3	3	-	-	-	-	-	-
Urea-Nitrogen (kilograms)	-	100	-	100	-	100	-	100	-	-	-	100
Fertilizer (kilograms)	-	-	-	-	-	-	52	52	-	-	52	52
Hay Mulch (centimeters)	-	-	-	-	-	-	4	4	-	-	4	4

Table 14-2. Legumes and Grasses Planted at Site No. 1.

Legumes		Grasses	
Common Name	Scientific Name	Common Name	Scientific Name
Prostrate lespedeza	Lespedeza daurica	Bluestem	Andropogon scoparius
		Big Bluestem	Andropogon gerardi
		Indiangrass	Sorghastrum nuta
		Eastern Gamagrass	Tripsacum dactylodes
		Deer Tongue	Panicum clandestinum
		Kleingrass #75	Panicum coloratum
		Switchgrass	Panicum virgatum
		Caucasian Bluestem	Andropogon caucasicus
		Old World Bluestem	Andropogon ischaemum
		Fescue	Festuca megalura

Table 14-3. Soil Treatment for Site No. 2.

	Plots							
Substances	1A	1B	2A	2B	3A	3B	4A	4B
	Amounts Per Acre							
Lime (metric tons)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Sludge (centimeters)	5	5	5	5	2.5	2.5	2.5	2.5
Urea-N (kilograms)	-	45	-	45	-	45	-	45
Hay Mulch (centimeters)	10	10	-	-	10	10	-	-
Water (centimeters)	3	3	3	3	3	3	3	3

Site Study—Third Year

This study represented the culmination of the experimental efforts. The results of previous years suggested that a single treatment which consisted of lime, 3 cm of sludge, 45 kg/ha of urea-nitrogen and hay mulch (used to conserve moisture) represented the treatment for the best growth response. Two grasses, kleingrass and switchgrass, were used because they had previously given the best results on the soil treated as described above.

Chemical Analysis

Soil and plants were analyzed for metals and nutrients. The methods used are given in Methods of Soil Analyses (Black, 1965).

Results—First Year

The first year experiments were designed to study plant growth response with respect to the following applied substances: lime, effluent, water, liquid sludge, commercial fertilizer, and urea-nitrogen. The liquid sludge and effluent were analyzed to determine their chemical composition. The results of these analyses are given in Table 14-4. Total amounts of the macronutrients, nitrogen, phosphorus, and potassium and the fertilizer equivalent applied to each plot are given in Table 14-5.

Vegetation Response

One week after initial planting fescue was very observable but the other species were not. At the end of a two week period all species were emerging in good fashion with the exception of prostrate lespedeza which did not germinate on any of the plots. Table 14-6 summarizes the growth response for the first year for plots 2B and 3B which yielded the best results.

Table 14-4. Chemical Composition of Dry Sludge and Effluent.

Constitutent	Sludge	Effluent
pH	7.30	7.10
	Parts Per Million	
Total-N	250.0	4.5
Nitrate-N	4.6	12.4
P	210.0	4.0
Copper	0.30	0.3
Zinc	0.50	N.D.
Organic Matter	3.00	N.D.
K	300.0	3.00

N.D. - Not Detected

Table 14-5. Fertilizer Equivalent for the Various Treatments of Site No. 1.

Plot	Treatment	Nutrients (kilograms) N	P	K	Fertilizer equivalent Amount kilograms per acre	Formula N	P_2O_5	K_2O
1A	2.5 cm of lime							
	2.5 cm of effluent	55	13	10	610	9	5	2
	totals	55	13	10	610	9	5	2
1B	2.5 cm of lime							
	2.5 cm of effluent	55	13	10	610	9	5	2
	urea	45			45	100		
	totals	100	13	10	655	50	15	2
2A	lime							
	4 cm of effluent	55	13	10	610	9	5	2
	8 cm of dry sludge	78	65	95	785	10	19	15
	totals	133	78	105	1212	11	14	10
2B	lime							
	4 cm of effluent	55	13	10	610	9	5	2
	8 cm of dry sludge	78	65	95	785	10	19	15
	urea	45			45	100		
	totals	178	78	105	1276	14	14	10

(continued)

Table 14-5. (Continued)

Plot	Treatment	Nutrients (kilograms) N	P	K	Fertilizer equivalent Amount kilograms per acre	Formula N	P_2O_5	K_2O
3A	lime							
	8 cm of dry sludge	78	65	95	785	10	19	15
	totals	78	65	95	785	10	19	15
3B	lime							
	8 cm of dry sludge	78	65	95	785	10	19	15
	urea	45			45	100		
	totals	123	65	95	1125	11	13	10
4A	lime							
	fertilizer	24	10	20	71	33	33	33
	totals	24	10	20	71	33	33	33
4B	lime							
	fertilizer	24	10	20	71	33	33	33
	urea	45			45	100		
	totals	69	10	20	300	23	8	4
6A	lime							
	fertilizer	24	10	20	71	33	33	33
	totals	24	10	20	71	33	33	33
6B	lime							
	fertilizer	24	10	20	71	33	33	33
	urea	45			45	100		
	totals	69	10	20	300	23	8	4

Table 14-6. Growth Response of Grasses and Legumes for Plots No. 2 and No. 3 - Site No. 1.

Species	Results
Fescue	No survival, completely gone
Bluestem	Trace stand only
Big Bluestem	Trace stand only
Old World Bluestem	Good stand, 81.4 centimeters height, moderate to good seed head
Indiangrass	Trace stand, 63.5 centimeters height, very few plants
Eastern Gama	Good stand, 76.4 centimeters height, good dark color
Caucasian Bluestem	Fair stand, 76.4 centimeters height, fair seed head
Deer Tongue	Fair stand, 32.5 centimeters height, bunchy grass, good color, no seed head
Kleingrass #75	Excellent stand, 91.5 centimeters height, good color, very good seed head
Switchgrass	Excellent stand, 61.0 centimeters height, good color, fair seed head
Prostrate Lespedeza	Did not germinate

Soil Analysis

The results of the chemical analysis for pH, macronutrients, and extractable metals of the soils of site no. 1 are shown in Table 14-7. These values were obtained from soil that had undergone treatment. The soil was analyzed at three different depths for each side of each plot.

Plot Analysis

The results of the analysis for kleingrass, big bluestem and bermudagrass are shown in Table 14-8. These were the only plant species of site no. 1 analyzed for the first year.

Second Year—Site No. 2

Treatment of Soil

The site was initially treated with combinations of lime, liquid sludge, nitrogen, hay mulch, and water. No further treatments were made during the growth season. The amount of macronutrients and the fertilizer equivalents of each treatment applied to the soil are shown in Table 14-9. The second year study examined the difference between 3 cm and 5 cm liquid sludge treatment for the soil.

Table 14-7. Chemical Analyses of Site One Soils.

	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
Plot	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
1A											
1-3 cm	26.47	240	1.78	1.85	.91		-	-	19.1	-	30.70
9-12 cm	15.02	200	1.51	4.31	.37		7.2	5.8	1.5	1061	26.40
28-32 cm	27.55	180	1.03	-	.44		-	-	5.6	-	21.00
mean	23.01	207	1.44	3.08	.57	5.27	7.2	5.8	8.7	1061	26.05
1B											
1-3 cm	33.03	720	1.03	5.39	.81		76.62	4.5	19.05	4887	22.00
9-12 cm	42.74	700	3.01	7.36	.43		53.49	6.1	1.00	1511	25.80
28-32 cm	14.01	700	1.57	3.86	.47		97.61	5.5	5.58	2186	13.70
mean	29.93	707	1.87	5.54	.57	5.91	75.91	5.4	10.03	2861	20.52
2A											
1-3 cm	9.05	320	2.98	1.85	6.70		14.96	10.30	15.70	7993	26.80
9-12 cm	16.13	300	1.30	2.98	.34		8.67	5.24	8.60	3626	20.00
28-32 cm	14.51	250	2.20	7.02	.42		-	-	-	-	19.90
mean	13.23	290	2.16	3.95	2.49	5.20	11.82	7.77	12.15	5808	22.28
2B											
1-3 cm	34.15	2200	9.38	23.37	6.15		-	-	-	-	9.90
9-12 cm	39.83	1000	.90	13.49	.47		51.82	5.40	17.30	5382	27.80
28-32 cm	172.88	920	1.57	5.71	.42		20.41	6.90	1.76	2096	22.50
mean	82.29	1373	3.95	14.19	2.35	6.31	36.13	6.15	9.53	3739	20.07

(continued)

Table 14-7. (Continued)

Plot	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
3A											
1-3 cm	16.54	350	3.41	5.08	.43		11.65	7.30	20.32	7678	42.10
9-12 cm	9.05	310	3.63	9.87	.60		10.33	8.80	12.69	2456	28.90
28-32 cm	9.05	300	3.34	8.05	.43		11.82	8.70	1.00	1671	19.90
mean	11.55	320	3.46	7.66	.48	5.36	11.27	8.27	11.34	3941	30.30
3B											
1-3 cm	22.23	-	25.34	17.96	5.90		50.67	2.50	1.51	1511	2.10
9-12 cm	4.22	-	18.48	10.63	1.20		100.10	2.60	.24	2951	4.60
28-32 cm	9.45	-	5.08	7.71	.49		10.66	6.50	2.00	2726	26.30
mean	12.00	-	16.30	12.10	2.53	6.46	53.81	3.87	1.25	2396	11.00
4A											
1-3 cm	10.03	370	2.13	3.56	.62		56.62	9.50	12.19	5427	42.70
9-12 cm	10.03	330	3.05	5.71	.40		33.64	8.00	2.80	2726	31.20
28-32 cm	14.01	300	2.27	10.25	.55		26.36	8.00	1.80	1961	12.30
mean	11.36	333	2.48	6.51	.52	5.45	38.87	8.50	5.60	3071	28.73
4B											
1-3 cm	8.07	1740	8.55	8.41	1.59		26.36	7.50	4.82	7228	28.20
9-12 cm	12.51	700	4.77	10.25	.58		14.46	6.60	12.19	2597	32.10
28-32 cm	9.25	660	2.41	7.71	.43		10.82	7.20	2.52	1961	18.65
mean	9.94	1033	5.24	8.79	.87	6.13	17.21	7.10	6.51	3895	26.35

(continued)

Table 14-7. (Continued)

Plot	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
5A											
1-3 cm	13.01	330	3.41	6.03	.60		19.26	7.00	1.00	7856	-
9-12 cm	14.51	300	2.48	7.02	.59		27.03	8.20	5.10	1601	24.40
28-32 cm	11.02	290	2.90	8.41	.55		30.66	7.50	5.10	1871	23.90
mean	12.85	307	2.91	1.15	.58	5.64	23.15	7.57	3.73	3776	23.94
5B											
1-3 cm	20.66	400	4.04	11.42	.77		30.00	7.40	36.10	9749	28.70
9-12 cm	15.52	350	4.16	3.27	.62		31.32	6.80	28.20	5291	30.67
28-32 cm	22.75	300	1.03	3.56	.58		26.53	7.00	2.00	1511	29.70
mean	19.64	350	3.08	6.08	.65	5.41	29.39	7.07	29.10	5517	29.72
6A											
1-3 cm	13.01	350	2.27	10.25	.49		6.20	8.25	1.00	3896	77.60
9-12 cm	14.01	310	1.85	12.64	.54		8.67	9.50	4.80	4257	48.90
28-32 cm	12.01	290	1.99	14.37	.43		11.82	7.40	1.00	2636	26.10
mean	13.01	317	2.03	12.42	.49	5.56	8.90	8.38	2.27	3596	51.08
6B											
1-3 cm	21.18	1560	2.29	5.39	.82		31.98	7.60	9.00	11729	23.90
9-12 cm	9.05	730	1.85	4.46	.62		43.23	8.50	16.76	8128	28.20
28-32 cm	8.07	680	-	4.16	.54		17.27	6.80	3.80	1961	23.40
mean	12.77	990	2.06	4.67	.66	6.16	30.83	7.63	9.85	7272	25.19

Table 14-8. Chemical Analysis of Site No. 1 Plant Tissue.

Plot		Macronutrients (parts per million) Total-P	Ortho-P	% Org-M	Extractable metal cations (parts per million) Na	K	Cu	Zn	Cd
2A	Kleingrass	-	1271	42.45	440	.97	36	729	20
3A	Big Bluestem	12054	692	41.40	122	-	27	712	8
	Bermuda Grass	15708	298	41.70	593	-	10	892	8

Vegetation Response

Switchgrass, kleingrass, bluestem grass, and bermudagrass were studied as these grasses gave the best growth response for the first year. Planting-seeding was completed on the same day. One week after planting, all grasses germinated. Six weeks after germination, the initial growth measurement was made for each of the four grass species on each plot. The summary of these results are given in Table 14-10.

Plant Analysis

The amount of macronutrients determined for each plant tissue is summarized in Table 14-11 and the extractable metals determined for each plant tissue are summarized in Table 14-12.

Third Year

Study Site No. 1

Table 14-13 summarizes the growth response of grasses and legumes that grew three years after planting. Plant cover and average basal area were measured for each plant of each plot.

The macronutrients and extractable metals in plant tissue of site no. 1 were measured again after three growing seasons. These results are summarized in Table 14-14 and Table 14-15 respectively.

The results from the determination of macronutrients and extractable heavy metals in soil from site no. 1 after three growing seasons are given in Table 14-16.

Study Site No. 2

Table 14-17 summarizes the results obtained from measuring plant cover and average basal area for site no. 2 plants. These results represent plants that grew two years after planting.

The results of the soil analyses are summarized in Table 14-18. These results were obtained from measurements made at three different soil depths and one year after the initial treatment of the soil.

Table 14-9. Soil Treatment for Site No. 2.

Plot	Amount of Nutrients Applied (kilograms/acre)			Total Amount of Fertilizer Equivalent (kilograms/acre)	Fertilizer Equivalent Fertilizer Formula (%)		
	N	P	K		N	P_2O_5	K_2O
1A	52	44	64	517	10	19	15
1B	97	44	64	769	13	13	10
2A	52	44	64	517	10	19	15
2B	97	44	64	769	13	13	10
3A	26	22	32	259	10	19	15
3B	71	22	32	375	19	13	10
4A	26	22	32	259	10	19	15
4B	71	22	32	375	19	13	10

Table 14-10. Field Plots with Vegetation Response for Site Two.

Species	Plot No. 1 sludge + lime + mulch			Plot No. 2 sludge + lime			Plot No. 3 sludge + lime + mulch			Plot No. 4 sludge + lime		
	Stand	Height	Color	Stand	Height	Color	Stand	Height	Color	Stand	Height	Color
Switch grass	fair	13 cm	dark	thin	8 cm	dark	thin	8 cm	fair	good	10 cm	good
Klein grass	excel lent	20 cm	dark	excel lent	28 cm	dark	excel lent	25 cm	dark	excel lent	18 cm	dark
Bluestem grass	thin	8 cm	good	thin	5 cm	fair	good	8 cm	fair	thin	8 cm	fair
Bermuda grass	thin	8 cm	fair	good	13 cm	dark	good	31 cm	good	good	31 cm	dark

Table 14-11. Macronutrients of Plant Tissue from Site No. 2.

Plot	Grasses	Macronutrients (PPM) Nitrate-N	Total-N	Ortho-P	Total-P	% Organic Matter
1A	bermuda	-	-	-	-	-
1B	switch	3635	13900	807	-	43.20
	klein	4146	18300	474	-	41.00
	bluestem	-	22300	987	-	39.90
2B	bermuda	3011	19800	430	-	35.00
	switch	3527	17200	620	-	41.10
	klein	2944	17100	872	-	36.30
	bluestem	-	13400	395	-	-
3B	bermuda	3112	21400	1017	-	38.40
	switch	-	15300	755	-	-
	klein	2878	16500	912	-	41.60
	bluestem	2714	12100	349	-	40.10
4B	bermuda	3248	11800	912	-	42.50
	switch	3960	15000	627	-	42.50
	klein	2878	12800	822	-	45.00
	bluestem	-	8700	1197	-	42.30

Table 14-12. Extractable Metals from Plant Tissue - Site No. 2.

Treatment	Species	Extractable metals (PPM)				
		Sodium	Potassium	Copper	Zinc	Cadmium
1B	Bermuda	738	247	7	1123	24
	Switch	411	264	2	791	11
	Klein	155	380	1	466	3
	Bluestem	209	436	7	639	10
2B	Bermuda	956	305	59	1371	40
	Switch	-	-	-	-	-
	Klein	647	239	21	1016	12
	Bluestem	676	276	30	915	8
3B	Bermuda	242	284	53	1973	41
	Switch	374	269	14	791	7
	Klein	382	253	-	-	7
	Bluestem	-	-	-	-	-
4B	Bermuda	-	-	-	-	-
	Switch	238	542	4	887	11
	Klein	419	435	14	1331	20
	Bluestem	1151	396	18	2355	46

Table 14-13. Growth Response of Grasses and Legumes for Site One - Three Years Later.

PLANT SPECIES	Plot 1 Cover Sq. Ft.	Plot 1 Average BA/Plant Sq. In.	Plot 2 Cover Sq. Ft.	Plot 2 Average BA/Plant Sq. In.	Plot 3 Cover Sq. Ft.	Plot 3 Average BA/Plant Sq. In.
Fescue	0	0	0	0	0	0
Little Bluestem	.0011	12.56	115.20	12.56	460.8	12.56
Big Bluestem	576	3.14	1728	50.24	7488	50.24
Old World Bluestem	0	0	1728	19.63	2304	50.24
Indiangrass	0	0	115.2	78.50	576	28.26
Eastern Gamagrass	576	19.63	7488	113.04	6912	78.5
Caucasian Bluestem	0	0	0	0	0	0
Deer Tongue	0	0	1152	.785	1152	.785
Selection 75 Klein grass	4608	7.10	7488	28.26	6912	12.56
Switchgrass	2304	50.24	9216	28.26	9216	28.26
Prostrate Lespedeza	0	0	0	0	8640	50.24

Table 14-13. (Continued)

PLANT SPECIES	Plot 4 Cover Sq. Ft.	Plot 4 Average BA/Plant Sq. In.	Plot 5 Cover Sq. Ft.	Plot 5 Average BA/Plant Sq. In.	Plot 6 Cover Sq. Ft.	Plot 6 Average BA/Plant Sq. In.
Fescue	115.2	.785	0	0	576	.785
Little Bluestem	576	3.14	0	0	.0011	12.56
Big Bluestem	0	0	0	0	.0044	50.24
Old World Bluestem	0	0	0	0	0	0
Indiangrass	0	0	0	0	1728	78.5
Eastern Gamagrass	1152	12.56	0	0	3456	78.5
Caucasian Bluestem	0	0	0	0	0	0
Deer Tongue	0	0	0	0	0	0
Selection 75 Klein grass	0	0	0	0	0	0
Switchgrass	0	0	0	0	0	0
Prostate Lespedeza	0	0	0	0	0	0

Table 14-14. Nutrients Content of Plant Tissues from Site No. 1 - Two Years Later.

Plot	Grasses	Macronutrients (parts per million) Nitrate-N	Total-N	Ortho-P	Total-P	% Organic Matter
2A	Bermuda	3422	15000	1197	-	44.30
	Big Bluestem	3894	20200	1469	-	37.40
	Klein	3214	10400	537	-	35.60
	Switch	3777	1100	935	-	-
3A	Big Bluestem	3669	17200	-	-	37.10
	Klein	2779	23700	613	-	40.00
	Switch	3214	7500	-	-	-
4A	Switch	3492	8800	486	-	-
6A	Klein	2944	-	532	-	-
	mean	3378	14225	824	-	38.92
	maximum	3894	23700	1469	-	44.30
	minimum	2779	7500	486	-	35.00

Table 14-15. Extractable Metals in Plant Tissues from Site No. 1 - Two Years Later.

Plot	Grasses	Extractable metals (parts per million)				
		Sodium	Potassium	Copper	Zinc	Cadmium
2A	Bermuda	597	369	27	1269	20
	Big Bluestem	320	310	10	633	3
	Klein	3461	-	11	583	-
	Switch	841	348	46	1584	4
3A	Big Bluestem	891	433	47	785	3
	Klein	337	356	4	577	-
	Switch	353	432	4	836	3
	Bermuda	593	-	10	892	8
4A	Switch	324	316	4	892	5
6A	Klein	593	-	10	892	8
	mean	1631	366	16	874	8
	maximum	3461	433	47	1584	20
	minimum	320	310	1	577	3

Table 14-16. Macronutrient and Extractable Metal Content of Site No. 1 Soils Two Years Later.

	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
Plot	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
1A											
1-3 cm	30.82	-	2.41	14.82	1.59		14.96	3.40	13.70	11324	23.30
9-12 cm	14.01	-	2.55	11.82	.45		-	-	-	-	22.60
28-32 cm	16.03	-	3.56	4.77	.64		-	-	-	-	21.50
mean	20.29	-	2.84	10.47	.89	5.79	14.96	3.40	13.70	11324	22.47
1B											
1-3 cm	51.74	665	3.41	18.22	.71		11.65	8.50	10.28	5877	28.80
9-12 cm	21.18	833	2.83	5.71	.66		12.15	6.20	1.48	2051	11.30
28-32 cm	25.40	959	3.86	10.25	.60		-	-	-	-	8.50
mean	32.77	820	3.37	11.39	.66	5.99	11.90	7.35	5.88	3964	16.20
2A											
1-3 cm	139.59	1054	24.34	27.47	5.90		14.46	6.60	14.30	700	2.20
9-12 cm	61.85	1449	7.70	5.71	1.20		-	-	-	-	7.20
28-32 cm	23.28	630	3.71	8.05	.65		11.32	-	-	6868	-
mean	74.90	1044	11.92	13.74	2.58	6.88	12.89	6.60	14.30	3784	4.70
2B											
1-3 cm	64.72	826	11.62	24.67	6.15		17.27	5.00	4.15	4482	14.10
9-12 cm	37.54	770	4.53	13.49	.73		14.46	3.50	30.00	1961	26.20
28-32 cm	46.88	1051	2.55	13.93	.66		17.77	5.00	3.35	2726	31.20
mean	49.72	880	6.23	17.36	2.51	6.32	16.50	4.50	12.50	3056	23.83

(continued)

Table 14-16. (Continued)

	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
Plot	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
3A											
1-3 cm	56.72	1253	10.82	18.75	6.15		8.18	3.40	3.08	3291	11.40
9-12 cm	26.47	868	2.41	6.03	.89		-	4.30	27.90	4842	23.20
28-32 cm	15.02	623	2.55	5.71	.39		-	5.00	4.15	-	18.70
mean	32.74	915	5.26	10.16	2.48	6.93	8.18	4.23	11.71	4067	17.77
3B											
1-3 cm	122.67	1729	12.64	16.23	5.90		8.84	5.90	2.55	2276	8.10
9-12 cm	24.34	-	2.82	5.39	1.20		12.97	3.40	14.00	9478	30.20
28-32 cm	33.03	578	2.55	7.02	.49		-	-	-	-	10.40
mean	60.01	1150	6.01	9.55	2.53	7.15	10.91	4.65	8.28	5877	16.23
4A											
1-3 cm	27.55	924	2.62	7.36	.53		14.95	7.20	17.70	11729	41.30
9-12 cm	24.32	616	2.06	5.71	.51		-	-	-	-	23.70
28-32 cm	22.23	777	1.85	6.52	.51		13.80	7.30	1.75	2276	21.40
mean	24.71	772	2.17	6.53	.52	5.37	14.38	7.25	9.73	7003	28.80
4B											
1-3 cm	40.90	795	1.03	8.41	.53		8.01	5.30	1.70	4482	19.30
9-12 cm	20.14	865	1.57	6.69	.53		23.88	9.80	2.20	2006	21.60
28-32 cm	18.07	959	1.85	9.87	.54		-	-	-	-	21.80
mean	26.40	873	1.49	8.32	.53	6.45	15.95	7.55	1.95	3244	20.90

(continued)

Table 14-16. (Continued)

Plot	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
Control											
1-3 cm	22.23	728	1.99	7.70	.94		11.82	3.60	16.70	13665	29.30
9-12 cm	22.23	529	1.99	5.39	.57		11.15	-	-	8173	-
28-32 cm	22.23	875	1.37	12.23	.52		41.41	6.10	2.80	2951	18.60
mean	22.23	711	1.78	8.44	.68	5.91	21.46	4.85	9.75	2863	23.96
Control											
1-3 cm	-	-	-	-	-	-	-	-	-	-	-
9-12 cm	-	-	-	-	-	-	-	-	-	-	29.75
28-32 cm	-	-	-	-	-	-	-	-	-	-	-
mean	-	-	-	-	-	-	-	-	-	-	29.75
6A											
1-3 cm	26.47	903	2.13	4.92	.76		-	-	2.00	5022	33.30
9-12 cm	22.23	1120	1.71	11.02	.52		12.64	5.10	26.50	12224	47.80
28-32 cm	17.05	1019	1.64	3.27	-		11.98	5.90	3.08	2681	33.30
mean	21.92	1014	1.83	6.40	.64	6.66	12.31	5.50	10.53	6642	38.47
6B											
1-3 cm	56.72	889	2.90	11.22	.75		-	6.40	3.90	6282	29.70
9-12 cm	33.03	840	1.85	11.82	.78		-	6.40	4.70	1691	30.50
28-32 cm	40.99	1036	1.99	6.03	.48		10.99	6.40	3.62	-	30.40
mean	43.58	922	2.25	9.69	.67	7.12	10.99	6.40	4.07	3986	30.20

Table 14-17. Growth Response of Grasses and Legumes for Site Two - Two Years Later.

	1978 Test Plots						Smelter Waste Area	
	Plot 1		Plot 2		Plot 3		Plot 4	
SPECIES	Cover Sq. Ft.	Average BA/Plant Sq. In.	Cover Sq. Ft.	Average BA/Plant Sq. In.	Cover Sq. Ft.	Average BA/Plant Sq. In.	Cover Sq. Ft.	Average BA/Plant Sq. In.
Bermuda	288	-	144	-	180	-	Trace	-
Bluestem	144	12.56	54	3.14	180	12.56	180	12.56
Switch-grass	108	28.26	36	3.14	36	3.14	90	7.06
Klein-grass	270	50.24	288	50.24	288	63.59	324	19.63

Table 14-18. Macronutrient and Extractable Metal Content of Site No. 2 Soils One Year Later.

	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
Plot	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
1A											
1-3 cm	28.63	1862	1.03	18.75	-		11.32	6.6	170.3	37.6	37.0
9-12 cm	28.63	662	.50	18.75	.55		9.83	6.1	1.48	2816	37.0
28-32 cm	36.40	791	.50	13.06	.48		9.17	5.7	4.95	3221	34.0
mean	31.22	1105	.68	16.85	.52	5.87	10.10	6.13	58.91	3251	43.33
1B											
1-3 cm	145.59	1218	.64	47.99	16.35		16.61	13.8	7.08	6012	16.0
9-12 cm	26.47	809	-	14.82	.54		27.69	4.0	11.08	4077	29.0
28-32 cm	35.27	812	.50	12.23	.54		28.68	5.7	-	-	25.0
mean	69.11	946	.57	24.94	5.81	5.91	24.33	7.5	9.08	5044	23.33
2A											
1-3 cm	26.47	599	2.98	29.00	1.43		5.70	7.7	2.28	1555	15.0
9-12 cm	26.47	588	.64	6.03	-		8.84	6.9	2.3	1421	14.0
28-32 cm	33.03	1176	1.03	13.93	.32		11.48	8.2	2.82	1781	17.0
mean	28.66	788	1.55	16.32	.82	5.66	8.84	7.6	2.47	1586	15.33
2B											
1-3 cm	117.36	1110	14.82	9.87	8.35		17.11	10.1	16.94	4572	13.0
9-12 cm	29.72	693	.77	-	.55		38.93	9.4	11.34	3356	18.0
28-32 cm	30.82	1110	1.71	16.71	.58		19.92	5.9	4.95	-	18.0
mean	59.30	971	5.77	13.29	3.16	6.07	25.32	8.47	11.08	3964	16.33

(continued)

Table 14-18. (Continued)

	Macronutrients (parts per million)						Extractable metal cations (parts per million)				
Plot	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
3A											
1-3 cm	24.34	837	1.30	13.93	.58		51.99	13.0	7.88	8938	13.0
9-12 cm	28.63	700	13.71	19.83	.60		29.67	5.3	22.5	3987	24.0
28-32 cm	86.80	945	.50	5.55	.42		7.02	4.5	2.02	2456	27.0
mean	46.59	827	5.18	13.10	.54	5.65	24.89	7.6	10.8	5127	21.33
3B											
1-3 cm	49.30	882	29.00	22.13	3.75		16.78	12.0	5.48	2906	15.0
9-12 cm	35.27	956	.50	6.03	.61		20.58	7.0	7.08	2096	19.0
28-32 cm	39.83	809	.50	7.53	.48		271.03	7.1	4.68	2186	20.0
mean	41.47	882	10.00	11.90	1.61	6.26	102.79	8.7	5.75	2396	18.0
4A											
1-3 cm	64.46	844	1.85	10.25	.73		-	-	-	-	16.0
9-12 cm	59.27	326	1.03	5.71	.44		-	-	-	-	21.0
28-32 cm	128.14	732	-	10.63	.45		8.01	4.22	2.55	1961	31.0
mean	83.96	634	1.44	8.86	.46	6.29	8.01	4.22	2.55	1961	22.67
4B											
1-3 cm	31.92	833	31.91	12.85	.54		12.81	7.9	6.55	1556	5.0
9-12 cm	22.23	865	1.99	11.42	.66		-	-	-	-	22.0
28-32 cm	33.03	868	1.57	9.50	.56		11.98	7.3	9.48	2591	24.0
mean	29.06	855	11.82	11.26	.59	6.05	12.39	7.6	8.02	2073	17.0

Table 14-19. Chemical Analysis of Klein + Switch Grass from Site No. 3.

$N\text{-}NO_3$	Tot-N	Ortho-P	Tot-P	Org-M	Na	K	Cu	Zn	Cd
3456	26495	779	-	-	35	-	1	464	3

Study Site No. 3

Table 14-19 contains a summary of the results of the chemical analyses of the plant tissue and Table 14-20 contains a summary of the results of the chemical analyses of the soil for site no. 3.

Summary and Discussion

Results obtained from site no. 1 (first year study) demonstrated that sludge reinforced with urea-nitrogen was very effective in reclaiming the contaminated area and establishing permanent vegetation plots. There was very little difference between growth response of plants grown on soil treated with either 5 cm or 8 cm of liquid sludge. This study further demonstrated that commercial fertilizer was very ineffective in reclaiming the contaminated area and for establishing permanent vegetation plots. Switchgrass and kleingrass were the most obvious early starters. Both continued to survive after three growing seasons and this fact led to their use in two additional sites. Eastern gamagrass was not as quick to produce vegetative cover. However, by the third growing season, eastern gamagrass had been established in all plots of site no. 1 with the exception of the control plot.

Plant responses from site no. 2 were used to determine if a treatment of 3 cm of liquid sludge would yield the same response as soil treated with either 5 cm or 8 cm of sludge. Table 14-17 summarizes growth response from site no. 2. No significant difference exists between the growth response of kleingrass for the four plots. The average square foot of coverage of switchgrass was approximately the same for the soil treated with 3 cm and 5 cm. The average basal area per plant for switchgrass was three times higher for the 5 cm treated soil than for the 3 cm treated soil. Bluestem grass exhibited higher average coverage for soils treated with 3 cm compared to soils treated with 5 cm of sludge. Based on these results, there appears to be very small differences in growth response of certain plants between soil treated with either 3 cm of sludge or 5 cm of sludge. This conclusion was also borne out in the final study site no. 3.

The soil at site no. 3 was treated with 3 cm of liquid sludge that was reinforced with 45 kg/ha of urea-nitrogen. After four months of growth, the response of both kleingrass and switchgrass was excellent. It is expected,

Table 14-20. Macronutrients and Extractable Metal Content of Site Three Soils (Random Samplings - Treated with 1" Lime + 1" Sludge + Urea + Hay Mulch.

	Macronutrients (parts per million)						Extractable metal cations (parts per millions)				
Sample Number	NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Na	K	Cu	Zn	Cd
One											
1-3 cm	23.28	1158	.77	9.87	.7		11.15	33.50	17.47	18708	31.00
9-12 cm	26.47	1134	.50	6.03	.8		29.01	7.70	170.0	1871	25.00
28-32 cm	16.03	1012	.77	10.06	-		12.48	29.0	2.02	1706	19.00
mean	21.93	1100	.68	8.65	.76	5.33					
Two											
1-3 cm	14.01	-	.64	16.47	.98		3.72	18.90	21.2	10199	34.00
9-12 cm	13.01	-	.50	-	.88		11.98	-	7.35	3131	22.00
28-32 cm	12.01	-	.64	-	.59		33.31	5.40	4.15	1646	20.00
mean	13.01	-	.59	-	.82	5.65					
Three											
1-3 cm	18.07	840	.64	10.63	-		3.88	6.60	20.67	6058	28.00
9-12 cm	14.01	851	.77	-	.85		13.96	4.00	2.02	1916	16.00
28-32 cm	-	942	.64	-	.61		23.22	5.30	1.75	1331	11.00
mean	16.04	880	.68	-	.73	5.67					
Four											
1-3 cm	9.05	-	.64	5.71	.52		7.68	2.20	29.70	13486	19.00
9-12 cm	11.02	-	.50	-	.34		10.82	4.30	3.08	1556	17.00
28-32 cm	12.01	-	.50	-	.30		11.32	5.00	2.02	1646	16.00
mean	10.69	-	.58	-	.39	5.46					

(continued)

Table 14-20. (Continued)

Sample Number	Macronutrients (parts per million) NO_3-N	Tot-N	Ortho-P	Tot-P	% Org-M	pH	Extractable metal cations (parts per million) Na	K	Cu	Zn	Cd
Five											
1-3 cm	8.07	427	2.41	41.46	.52		14.13	3.40	23.07	5923	29.00
9-12 cm	9.05	305	1.85	-	.46		8.67	4.60	4.60	1421	24.00
28-32 cm	11.02	350	1.03	-	.26		9.00	3.40	3.08	1241	23.00
mean	9.38	360	1.76	-	.41	5.87					
Six											
1-3 cm	14.01	-	1.57	14.37	.93		16.45	-	24.67	7948	32.00
9-12 cm	13.01	-	1.03	-	.49		13.63	5.70	3.60	2501	29.00
28-32 cm	9.05	-	.50	-	.32		8.01	-	3.88	2726	23.00
mean	12.02	-	1.04	-	.58	5.49					
Seven											
1-3 cm	12.01	826	1.03	-	.58		12.14	7.90	18.00	7633	56.00
9-12 cm	10.03	879	1.57	-	.89		11.15	6.60	1.48	27036	33.00
28-32 cm	9.05	921	.77	-	.65		20.14	6.20	1.22	1870	26.00
mean	10.36	880	1.12	-	.70	5.47					

based on previous results of this study, that survival of both grasses will be excellent.

Chemical analysis of the soil initially showed very low pH values and high concentrations of heavy metals especially zinc. The pH values of the soils showed a steady increase with the number of growing seasons. After two growing seasons, the average pH of the soils treated with lime had increased from 5.78 to 6.46. This increase in soil pH certainly was helpful for the establishment of permanent vegetation plots on the contaminated soils.

The results of the chemical analysis of plants for nutrients for site no. 2 are given in Table 14-11. The average value of the total-N for all plants was 14,606 ppm or 1.46% and was slightly lower than the average value of 2.0% for grasses. The average value for the organic matter for all plants (40.68%) was normal for grasses.

The average value of nitrate-N was 3278 ppm for all the plants. That value was significant because in ruminant animals nitrate may be reduced to nitrites by microflora in the rumen. Nitrates may then exert toxic effects on the animal. Campbell et al. (1968) have reported methemoglobinemia in cattle receiving water containing 2790 ppm of nitrate-N. Because of the high concentration of nitrate-N, those grasses grown on the heavy metal contaminated soils would appear to be undesirable as feed for ruminant animals (Nat. Tech. Adv. Comm., 1968).

The results for the extractable metals of plant tissues for site no. 2 are given in Table 14-15. The extractable sodium and K contents were well within the normal range. The average value of K for all plants was 333 ppm. That value compared favorably with a range from 300 ppm to 3000 ppm for dry roughages feed stuff. The values for copper, zinc, and cadmium were all above maximum or toxic level. The average zinc concentration of 1093 ppm for all plants was higher than either the maximum of 200 ppm recommended by Allaway (1968) or 300 ppm considered by Melsted (1973) for plant tissues. Furthermore, Allaway (1968) suggested a maximum of 20 ppm of copper for plant tissues. The average value of 19 ppm of copper for all plants was slightly less than the toxic level. The average of 17 ppm of cadmium for all plants was more than five times higher than the 3 ppm of cadmium in plants suggested by Melsted (1973).

The results of the chemical analyses of plant tissue from site no. 2 were typical of the results obtained for the analyses of plant tissue from site no. 1 and site no. 3.

Conclusions

The results obtained from plant growth measurements for the first year for study site no. 1 demonstrated that kleingrass and switchgrass could grow

on contaminated soil treated with 5 cm or 8 cm of liquid sludge especially when the sludge was reinforced by the addition of urea (U). The remaining nine plant species did not exhibit the same growth response as the above two grasses on the same treated soil. Therefore, it could be concluded that both the plant species and soil treatment are important variables in the reclamation of the soil under study.

The above conclusion was further substantiated from results obtained during the second year study. Kleingrass and switchgrass planted the previous year not only survived but exhibited growth response that was comparable to or greater than their first year growth response on soil that had been treated with 5 cm and 8 cm of liquid sludge reinforced by the addition of U. Furthermore, results obtained from study site no. 2 also supported results already obtained. Excellent plant growth response was obtained for kleingrass and switchgrass on soil treated with 3 cm of liquid sludge reinforced by the addition of U. Bermudagrass and bluestem grass exhibited small growth response in comparison to kleingrass and switchgrass on soil treated with 3 cm of sludge reinforced by the addition of U.

Plant growth studies completed for kleingrass and switchgrass after three growing seasons continued to yield results comparable to or better than those obtained from either one or two growing seasons for soil treated with 5 cm or 8 cm of liquid sludge reinforced with U. Also, the survival of other plant species such as eastern gamagrass indicates that other plant species could survive on the treated soil but would take two or maybe three growing seasons to give good growth response. The same plant growth response was obtained for soil treated with 3 cm, 5 cm or 8 cm of liquid sludge reinforced by the addition of U.

Treatment of the soil with lime, sludge, urea and hay mulch undoubtedly provided a favorable environment for certain plant species to survive and exhibit excellent growth response. One of the contributing factors was the increase in soil pH after each growing season. A definite correlation exists between the increase in pH of soil treated with lime and the age of the treatment. Another important factor was the increase in macronutrients, especially nitrogen (N), resulting from the treatment. Chemical analysis of the plant species showed that nitrate-N, cadmium and copper were at concentration levels above the recommended level for plant species to be used as feed stuff. Therefore, it could be concluded that even though excellent cover is obtained with certain plants as a direct result of soil treatment, these plants cannot be used as feed stuff.

Recommendations

Based on the results obtained from this investigation, the following recommendations are made:

1. Reclamation of the smelter site by treating the soil with lime (2 1/2 tons/acre), 3 cm of liquid sludge, urea (24 kilograms/acre), and hay mulch and then planting a mixture of kleingrass and switchgrass;
2. That the grasses be used only for cover and not for feed stuff; and
3. Follow-up studies be conducted on noncontaminated soil to determine the correlation between plant toxicity and macronutrient content and heavy metal contamination of sludge.

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15
PERFORMANCE OF WOODY PLANT SPECIES ON IRON-ORE OVERBURDEN MATERIAL IRRIGATED WITH SEWAGE EFFLUENT IN MINNESOTA

John P. Borovsky and Kenneth N. Brooks

The potential renovation and reclamation benefits of sewage effluent irrigation on iron-ore overburden deposits in northeastern Minnesota were investigated in this study. Secondary treated sewage effluent was sprinkler irrigated at 5 and 10 centimeters per week for 12 weeks following planting. The survival and growth of six woody plant species on irrigated and control plots were observed for three years. One hundred percent survival was observed for green ash (*Fraxinus pennsylvanica* Marsh.) and Siberian larch (*Larix siberica* Ledeb.) on control and 5 cm/wk treatment plots, respectively. Survival of sand cherry (*Prunus pumila* L.) on the 10 cm/wk treatment plots was significantly less than that observed on control and 5 cm/wk treatment plots. No differences in survival were found among Scotch pine (*Pinus sylvestris* L.), jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.). Height growth, determined as the change in plant heights from 1977 to 1979, was not significantly affected by effluent irrigation. Growth of Scotch pine was superior to all other species while sand cherry exhibited the poorest growth.

Introduction

Minnesota is the nation's leading producer of iron concentrate. Since 1920, iron-bearing formations have been typically mined by open-pit methods. Open-pit mining in the region generally produces several by-products, including stripping overburden. This material consists of glacial debris which form the parent materials of the natural soils of the region.

Although considered nontoxic and nonacid producing, overburden stockpiles are usually deficient in essential plant nutrients, and have a low moisture retention capacity. Consequently, abandoned mined lands in the region contain many overburden stockpiles which support only sparse vegetation. Such deposits are subject to erosion which may contribute to the sedimentation of nearby lakes and streams. Therefore, the rapid establishment of vegetative cover on overburden stockpiles is desirable to stabilize and reclaim these disturbed sites.

The growth of the mining industry has been accompanied with the development of scattered small communities which in themselves contribute to environmental issues. Small towns in the region are financially pressed to meet sewage renovation standards. The addition of secondary treated,

domestic sewage to the numerous streams and lakes in the region leads to several water quality problems, including eutrophication. On-land disposal of sewage effluent is an economically attractive alternative compared to more sophisticated treatment facilities.

In an effort to address these issues, overburden material was irrigated with secondary sewage effluent to determine: (1) if there is a filtering effect on nutrients resulting in the renovation of wastewater, and (2) if such irrigation promotes the establishment of vegetation on these sites. The renovation results were reported earlier by Brooks et al. (1979). In this report, we will focus on the vegetation establishment results. The survival and growth of six woody plant species on both irrigated and control plots over a three-year period are reported.

Summer irrigation of effluent on overburden material could be beneficial for the establishment of vegetation in essentially two ways. First, the nutrient capital of the material may be enhanced. Nitrogen and phosphorus levels in the overburden material were considered inadequate for normal forest tree growth (Brooks et al., 1979). Although our earlier report indicated effluent applications of 60 and 120 centimeters over 12 weeks did not significantly add to the total soil nutrient capital, some nutrients, particularly Bray's phosphorus, ammonium nitrogen and nitrate plus nitrite nitrogen, were likely increased near the soil surface. Additionally, when comparing soil percolate at one meter depth with applied effluent, 99 percent of the phosphorus and 80 to 90 percent of the total Kjeldahl nitrogen were removed. Calcium, magnesium and potassium were apparently leached from the soil in proportion to the quantities of effluent applied.

The second possible benefit to plants is the addition of moisture to the soil. Overburden waste typically contains little organic matter and may contain excessive amounts of rock. These factors tend to diminish the moisture retention capacity of the waste and potentially limit the initial survival of planted vegetation.

Although most effluent irrigation research has focused on established forests and croplands, recent work has been performed on unvegetated sites. These investigations suggest the potential benefits of effluent irrigation to the revegetation process may vary greatly with the plant species involved. Cooley (1979) reported increased survival and/or growth of tulip poplar (*Liriodendron tulipifera* L.), hybrid poplar (*Populus deltoides* x *nigra*), green ash (*Fraxinus pennsylvanica* var. *lanceolata* Sarg.) and northern white-cedar (*Thuja occidentalis* L.) on sandy soils after effluent irrigation in Michigan. Several other tree species failed to respond to the effluent irrigation. Other investigations (Kardos et al., 1979) determined effluent irrigation enhanced the survival of hybrid poplar (*Populus* spp.), European alder (*Alnus glutinosa* (L.) Gaertn.), white pine (*Pinus strobus* L.), white spruce (*Picea glauca* (Moench) Voss), black locust (*Robinia pseudoacacia* L.) and Japanese larch (*Larix kaempferi* Lamb. (Carr.)), planted in anthracite refuse. However, the

survival of red pine (*Pinus resinosa* Alt.) and Austrian pine (*Pinus nigra* Arnold) was not significantly affected by effluent irrigation.

Methods and Materials

Overburden material was deposited from two to three meters thick on Erie Mining Company property near Hoyt Lakes, Minnesota, as described previously by Brooks et al. (1979). The material was sandy loam in texture, and contained approximately 15 percent rock material by volume. The chemical characteristics of the waste are described in Table 15-1. Nitrogen and available phosphorus (Bray's No. 1) were considered to be limiting for the satisfactory growth of many forest tree species in the region (Wilde, 1958). Soil reaction posed no great limitation to the selection of suitable tree species for planting.

Twelve adjacent plots were laid out in a 3x4 pattern over the surface of the overburden deposit, which was approximately 10x20 meters in area. During the last two weeks of June 1976, each plot was planted with one replication of ten, 2-year-old bare root seedlings of green ash (*Fraxinus pennsylvanica* Marsh.) and sand cherry (*Prunus pumila* L.). Similarly, ten, 22-week-old containerized seedlings of jack pine (*Pinus banksiana* Lamb.), Scotch pine (*Pinus sylvestris* L.), black spruce (*Picea mariana* (Mill.) B.S.P.) and Siberian larch (*Larix siberica* Ledeb.) were planted on each plot. The containerized seedlings were hardened off prior to planting.

Plots irrigated at rates of 10 and 5 cm/wk were compared with control plots with no treatment, using four replications and a split-plot randomized block design. Effluent was applied to irrigated plots with a pressure regulated constant head sprinkler at rates approaching 0.3 cm/hr. Applications began July 1, 1976 and continued for 12 weeks, resulting in cumulative applications of 120 cm and 60 cm for the 10 cm/wk and 5 cm/wk treatments, respectively. Typically, the weekly applications were completed over a 24 to 72 hour period. While under irrigation, plots were monitored for surface water movement. When surface flow was observed, irrigation was stopped until hydrologic conditions permitted the continuation of irrigation.

The effluent was obtained from a secondary (activated sludge) sewage treatment plant operated by Erie Mining Company. The effluent was of domestic origin with no industrial wastes channeled into the facility. The average composition of the effluent and cumulative additions of nutrients for both irrigation rates are presented in Table 15-2. The 10 cm/wk treatment resulted in 87.5, 43.0 and 84.7 kg/ha elemental additions of N, P, and K, respectively.

Climatological records of precipitation, temperature and pan evaporation, measured about 1 km south of the study site, were provided by the Erie Mining Company for the three year period. On-site measurements

Table 15-1. Chemical Characteristics of Overburden Stripping Waste.

Depth cm	Total Kjeldahl N%	$NO_3^- + NO_2^-$ nitrogen	NH_4^+ nitrogen	Bray's No.1 phosphorus	Total phosphorus	Cl	Ca	Mg	Na	K	CEC	ph
		ppm					me/100g					
1	.056	12.13	4.97	3.8	547	16.9	5.37	1.48	.06	.38	4.62	6.9
9	.060	12.17	4.33	4.8	488	14.1	5.96	1.39	.06	.41	4.90	7.0
25	.069	14.77	5.33	5.1	533	11.2	5.89	1.39	.05	.35	5.61	6.9
49	.076	19.93	5.30	4.5	-	12.3	6.34	1.40	.07	.42	5.72	6.7
81	.078	22.60	6.07	3.9	-	16.2	6.53	1.57	.07	.51	7.53	6.5
100	.067	19.03	5.63	3.8	399	9.9	5.67	1.40	.06	.40	6.15	6.6

Table 15-2. Average Concentrations and Cumulative Additions of Nutrients from Effluent Applied During 1976.

Nutrient	Mean concentration		Cumulative additions of nutrients in effluent for two treatments	
	Typical secondary effluent[1]	Effluent irrigated	Maximum (120cm)	Minimum (60cm)
	----(mg/l)----		----(Kg/ha)----	
NO_3+NO_2-N	- -	.2	2.8	1.4
Total Kjeldahl-N	20.0	15.4	184.8	92.4
NH_4-N	- -	6.9	- -	- -
Total P	10.0	3.6	43.0	21.5
Calcium	24.0	25.2	302.4	151.2
Magnesium	17.0	10.2	122.4	61.2
Sodium	50.0	50.3	603.6	301.8
Potassium	14.0	7.1	84.7	42.4
Chloride	45.0	57.2	686.4	343.2
Boron	1.0	.8	9.3	4.7
Sodium adsorption ratio	2.7	2.1	- -	- -
Total solids	425.0	458.5	5502.0	2751.0

[1]From Pound, C.E. and R.W. Crites. 1973. Wastewater treatment and reuse by land application. Volume I: Summary. EPA-660/2-73-0062. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

of precipitation, infiltration rates and soil moisture to a depth of 1 m were made during the irrigation period.

Plant survival and growth were determined at the end of each of four growing seasons. Plant heights were measured to the base of the terminal bud. When apparent, browsing damage and changes in foliage coloration were noted on each plot.

The significance ($P \leq .05$) of differences in survival, plant height and height growth among species and treatments were tested using analysis of variance for a split-plot design. Whole plot analyses were conducted to isolate effects due to the level of effluent irrigation while split-plot analyses were performed to determine effects due to species of woody plant. Differences among response means were separated by using the Bonferroni's Critical T to compute the least significant ($P \leq .05$) difference. An arc sine transformation was applied to the survival data prior to statistical analyses.

Results and Discussion

Planting took place during the last two weeks of June, 1976, at which time there was abundant soil moisture. Soil moisture was in excess of field capacity on June 30, 1976 throughout the upper 90 cm of the overburden material. The months of July through September, however, were extremely dry with Thornthwaite's potential evapotranspiration exceeding precipitation

Table 15-3. Monthly Precipitation and Thornthwaite's Potential Evapotranspiration During 1976 at the Erie Mining Station, Hoyt Lakes, Minnesota.

Month	Precipitation (cm)	Potential Et (cm)
May	1.9	9.9
June	16.8	14.0
July	3.7	14.4
August	1.2	13.0
September	2.5	8.5

Table 15-4. Average Soil Water Depletion at the Study Site from June 30, 1976 to September 16, 1976.

Soil Depth	Control	Treatments 5 cm/wk	Treatments 10 cm/wk
		cm	
0-30	4.5	2.6	2.3
0-90	9.7	6.4	4.5

(Table 15-3). Soil water depletion was considerable during this same period (Table 15-4); however, soil moisture in the upper 30 cm did not approach permanent wilting point in any of the plots. It is possible the young plants, particularly those within the control plots, were under moisture stress at some time during the long, dry period.

Plant Survival

After four growing seasons, the average survival of all woody plant species was 86 percent. Average survival ranged from a high of 95 percent for Siberian larch to a low of 79 percent for black spruce and green ash. Seedling mortality primarily occurred during the first two growing seasons of the study. No species experienced more than 5 percent mortality during the last two growing seasons of the experiment.

Statistical analysis of fourth year survival results was confounded by the uniform performance of certain species-treatment combinations. Mean survival of green ash on the control plots and Siberian larch on the 5 cm/wk treatment was 100 percent. The variance associated with this mean survival was by definition zero. This variance was considered to be dissimilar to that observed for other species-treatment combinations. In order to comply with the assumptions of analysis of variance, two alternative analyses were

performed:

1. An analysis excluding green ash and Siberian larch.
2. An analysis where the survival of green ash and Siberian larch on one replication of the 5 cm/wk treatment and control plots, respectively, was altered from 100 percent to 95 percent.

Results of both methods of analysis indicated a significant interaction between species of woody plant and level of effluent irrigation. The average fourth year survival of woody plants irrigated with sewage effluent is shown in Figure 15-1. This figure also shows the nature of the significant interaction between species of woody plant and level of effluent irrigation. The average survival of all species-treatment combinations exceeded 55 percent; however, the survival of green ash and sand cherry was highly dependent upon the level of effluent irrigation. Average survival of sand cherry of the 10 cm/wk treatment was significantly less than the average survival on either the 5 cm/wk treatment or control plots. In addition, the average survival of green ash on the control plots was substantially greater than average survival on the treatment plots.

The second method of analysis failed to detect significant differences among the average treatment responses for green ash. However, the variance associated with the 100 percent survival of the control plots is zero. Thus, it would seem reasonable to assume that survival of green ash on the irrigated plots is significantly less than survival on the control plots.

Reasons for the relatively poor survival of green ash and sand cherry

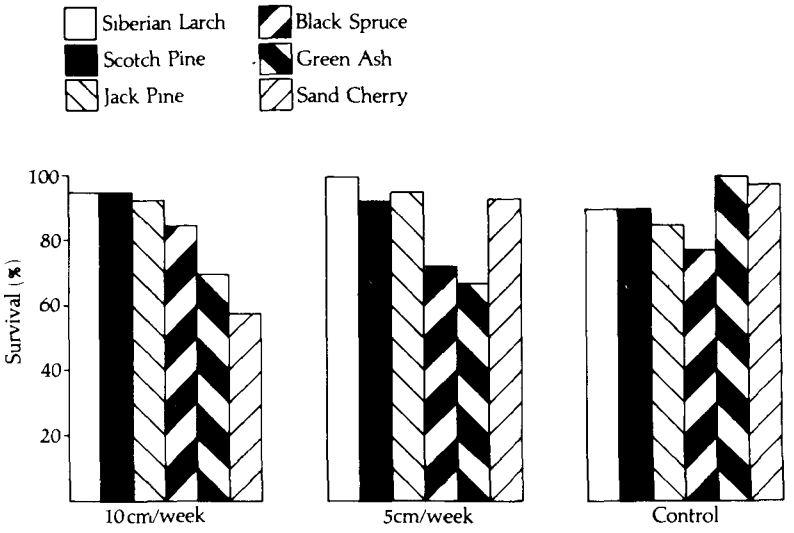

Figure 15-1. Average Fourth Year Survival (%) of Woody Plants Irrigated with Sewage Effluent.

on the irrigated plots are unclear. Leaf necrosis was observed on both species during the first two years of the study, and it is interesting to note this problem was only observed on the broadleaved species in the study.

Green ash is known to be somewhat sensitive to soil alkalinity, and leaf chlorosis has been reported where the species was grown on a soil with a pH of 8.1 (McComb, 1949). The pH of the effluent applied to the study site rarely exceeded 7.5; however, it is possible the alkaline nature of the effluent may have influenced the survival of green ash on the treatment plots.

Sand cherry is most commonly found growing in well-aerated, coarse-textured soils. Typical habitats include sand plains and beaches. Periodic soil saturation on the 10 cm/wk treatment plots may have induced a root respiration problem for sand cherry, and this may have affected the survival of the species on the maximum treatment plots.

Plant Height and Height Growth

All species except jack pine maintained a fairly consistent pattern of height growth throughout the monitoring period (Figure 15-2). During the 1978

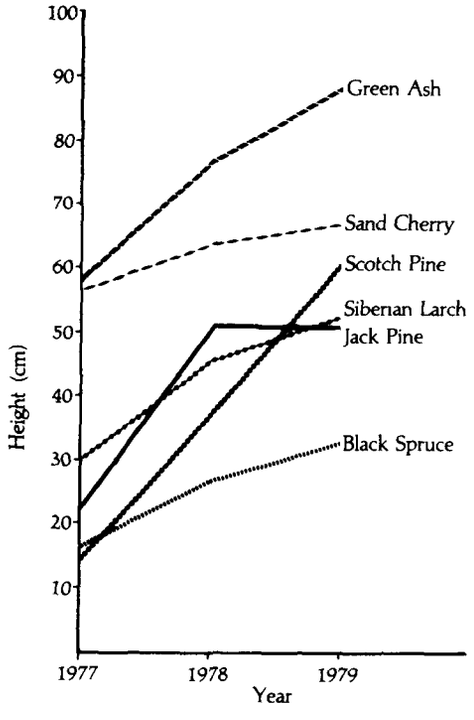

Figure 15-2. Average Height (cm) of Woody Plants Irrigated with Sewage Effluent.

growing season, jack pine height growth exceeded all other species; however, in 1979 the average height of jack pine was actually less than that observed in the previous year. This sharp change in height growth was more apparent than real as the reduction in plant height was caused by extensive snowshoe hare browsing. In many cases, the damage was so severe that plant vigor was likely affected. In the absence of heavy browsing, jack pine may perform more satisfactorily.

The average height of all woody plants after four growing seasons was 58.4 cm. Effluent irrigation did not affect plant height but significant differences in plant height did exist among species (Figure 15-3). Green ash (88.4 cm) was taller than all other species while black spruce (32.3 cm) was shorter than all other species. The average height of sand cherry (66.6 cm) was greater than Siberian larch (52.2 cm) and jack pine (50.3 cm).

In part, differences in plant heights reflect the type of planting stock used to introduce certain species to the site. Green ash and sand cherry were planted as 2-year-old bare root seedlings while all other species were planted as containerized seedlings. The initial height of the bare root stock varied from one to two feet while the containerized seedlings were less than a foot tall when planted. In light of this, it is not surprising that green ash and sand cherry were taller than other species after four growing seasons.

Height growth, determined as the change in plant heights from 1977 to 1979, was different among species but was unaffected by effluent irrigation (Figure 15-4). Scotch pine surpassed all other species in height growth, averaging 46.1 cm of shoot growth during the measurement period. Height growth of 9.9 cm for sand cherry during this same period was significantly less than all other species. In addition, the average change in height of green ash (30.6 cm) and jack pine (27.5 cm) was significantly greater than black spruce (15.0 cm).

The cause of differences in height growth among the plant species is unknown. Some probable factors contributing to these differences include:

-Type and dimensions of planting stock.

-Damaging agents (herbivores).

-Juvenile growth patterns.

-Ecological adaptations and requirements of the plants.

The relative importance of each of the above factors may be different for each plant species. Further, the interaction of these factors under long term effluent irrigation may substantially alter short-term results.

Conclusion

Efficient renovation of secondary sewage effluent applied to iron mining overburden is partially dependent upon the successful establishment of a vigorous plant community on the disposal site. Potential advantages provided

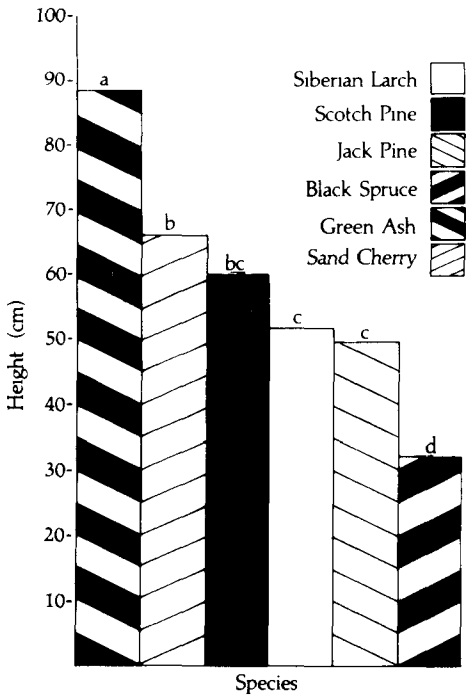

Figure 15-3. Average Fourth Year Height of Woody Plants Irrigated with Sewage Effluent (species with same letter do not significantly ($P \leq .05$) differ).

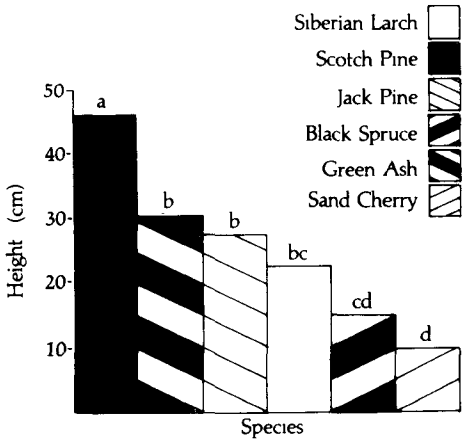

Figure 15-4. Average Change in Height (cm) of Woody Plants Irrigated with Sewage Effluent (species with same letter do not significantly ($P \leq .5$) differ).

by vegetative cover include:

-Protection from raindrop impact.

-Stabilization of soil surface.

-Enhanced drying of irrigation site.

-Absorption of applied nutrients.

Results reported here suggest two important points regarding the establishment of vegetation on sewage effluent disposal sites in iron mining overburden. First, woody plant species differ in their ability to tolerate effluent irrigation, and second, woody plant species differ in their ability to grow satisfactorily on these sites.

The feasibility of using iron mining overburden stockpiles for the disposal of secondary sewage effluent is good. Results reported previously suggest efficient renovation of effluent phosphorus can be expected. Additionally, several woody plant species may be capable of tolerating effluent irrigation when grown in overburden; and the successful establishment of a vigorous plant community on the disposal site should enhance the renovation efficiency of other nutrients.

Although all overburden stockpiles are not suitable as wastewater disposal sites, the physical and chemical properties of many stockpiles may permit this type of land use. Pilot studies are needed to further explore the feasibility of this method of effluent disposal and assess the prospects of effluent irrigation in the reclamation of iron mining wastes.

ACKNOWLEDGEMENTS. This research was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Act of 1964, PL 88-379, and in part by matching funds provided by the University of Minnesota.

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VI / FOREST APPLICATIONS OF SLUDGE

OVERVIEW

James O. Evans

Just over eight years ago the first comprehensive symposium on sewage wastes was held--also in Pennsylvania at University Park, site of The Pennsylvania State University. So it seems most appropriate that this symposium on the use of municipal wastewater and sludge for land reclamation and biomass production is being held in Pittsburgh. Some of the speaker-participants at this symposium also gave papers at that pioneering symposium, the list including Bill Sopper, Tom Hinesly, Dean Urie, Jim Peterson, and the writer.

The papers presented in Section VI address general environmental and ecological aspects of municipal wastes recycling and reuse, effects on biomass production, use in reclaiming unproductive disturbed forest land in the southeast, and use in reclaiming barren strip mine spoils in the arid southwest. One describes efforts to reclaim acidic strip mine spoils in Ohio with papermill sludge. Each of these papers is impressive, and most significantly, each describes highly positive responses from practical application methods involving use of these organic wastewaters and sludges to (1) revegetate and reclaim highly diverse previously barren or unproductive disturbed lands and (2) dramatically increase biomass production. Environmental side effects also have been measured and are continuing, and ecological changes, for "better" or for "worse", are being noted and evaluated.

It might be instructive and useful to look back briefly to the earlier symposium of August 1972 and note some of the observations and prognostications of the final speaker (the author of this paper) at that meeting who spoke on "Research Needs--Land Disposal of Municipal Sewage Wastes." Very little research was underway at that time on land disposal of wastes, and numerous unanswered questions were being raised. The speaker listed 19 "Immediate Research Needs." Perhaps four or five of those "needs" might now be examined to determine how much progress, if any, has been made in addressing and assessing them during the past eight years. The first item on the list reads "The mechanics for efficient and effective handling of sewage wastes and their disposal on various land areas must be developed–." It appears that this "need" is being addressed exceedingly

well. At that time a few researchers were using experimental (and often crude) methods of spray irrigation of wastewater and sludge, furrow and land spreading of sewage wastes (with or without discing or other tilling operations), and burial of sludge in shallow trenches. Now several companies are manufacturing sophisticated machinery designed specifically for jet spraying wastewater and sludge, sludge subsod or subsoil injection, and surface spreading and soil incorporation of sewage wastes. Also large scale and practical sludge composting methods have been developed.

A second "need" listed was "Determination of the role of micro-organisms in the functioning of natural (plant) communities is needed--the ability of key soil micro-organisms, and conversely, the impacts of the wastes or pollutants on the micro-organisms must be determined". Much has been learned relative to this need, but much more should be learned. The beneficial (or otherwise) role of specific fungi in sludge disposal and plant growth, for example, is just beginning to be seriously investigated.

"Assessment must be made of the tolerance of (agronomic) crops and forests to various heavy metals deposited with organic sewage sludges--." This need was listed prior to the emergence of the great cadmium "controversy". Indeed, much about heavy metals has been determined within the past eight years. Prescriptions for "allowable" concentrations and amounts of key heavy metals for disposal in sludge have been developed, although the controversy rages as strongly as ever over how strict some of these limits should be.

"Potential health hazards due to disposal practices require urgent, careful, and extensive investigation." Pathogens and nitrates were noted and discussed at some length under this "need". Much has been learned since then about combating the hazards presented by pathogens in sewage wastes. Here again, however, considerable controversy still rages about the inherent and site-specific dangers relative to certain pathogens, particularly the viral types. Practical solutions to the "pathogen problems" now appear to be available. Interestingly, several participants in the 1972 symposium, including the writer, spoke of nitrate loadings as being perhaps the single most limiting factor relative to allowable soil loading rates of *most* municipal sewage sludges; to date, this appears to have been an accurate assessment.

The 18th "need" reads, "Research is needed on the possibility of toxic conditions developing in certain (agronomic) plants resulting from excessive phosphate accumulation in soils (from high phosphate sludge applications)." To date, this appears to have been an unwarranted or unimportant concern.

The need to look upon "Sewage wastes recycling as a component of total ecosystem functions" and to view the "Recycling and utilization of biodegradable wastes by land application" as a viable waste disposal option is perhaps greater now than ever before.

16
ENVIRONMENTAL EFFECTS OF UTILIZATION OF SEWAGE SLUDGE FOR BIOMASS PRODUCTION

J. C. Corey, G. J. Hollod, D. M. Stone, C. G. Wells, W. H. McKee, and S. M. Bartell

Environmental effects of application rate, season, frequency, and method (surface versus incorporation) of sewage sludge will be investigated on four ages of loblolly pine (*Pinus taeda*) on two soil types. The stands were planted in 1953, 1972, 1978 and 1981, on moderately heavy and light texture soils. Sludge will be applied at application rates equivalent to 275 and 500 kg/ha as total nitrogen. Environmental effects and coppice growth response by hardwoods with and without sewage sludge also are being examined. Nutrient cycling and groundwater quality for plantings of red maple (*Acer rubrum*), sweet gum (*Liquidamber styraciflua* L.), american sycamore (*Platanus occidentalis* L.), black locust (*Robinia pseudoacacia*), and black alder (*Alnus glutinosa*) will be measured with sludge applications of 275 and 550 kg/ha of nitrogen.

Introduction

The efficacy of land application of sewage sludge in forested areas depends on environmental effects that the loading of nutrients, heavy metals, and organics contained in the sewage sludge have on the forest ecosystem, and the benefits the soil amendments have on increasing biomass production. This paper discusses the plan for evaluating environmental effects and cost effectiveness of land application of sewage sludge in pine and hardwood plantations at the Savannah River Plant, Aiken, South Carolina.

Use of sewage sludge as a fertilizer and soil amendment is attractive due to the increasing cost of fertilizers, problems of sewage sludge disposal and trends toward recycling materials. In 1975 the United States discharged 90.5 billion liters of domestic sewage (Freshman, 1977). The equivalent nutrient content was approximately 733 million kg nitrogen, 674 million kg of phosphorus, and 428 million kg of potassium, corresponding to 9%, 16%, and 10% of the national fertilizer consumption of nitrogen, phosphorus, and potassium, respectively. Approximately six percent of the nutrients present in sewage sludge produced annually could supply the total needs for the 510,000 ha of commercial and federal forest lands now being fertilized (Pritchett, 1979). Utilization of the nutrients in sewage sludge could result in a gross savings of 660 million dollars per year in fertilizer costs, of which 60-70% of the savings is for energy related expenses of fertilizer production.

Former studies evaluating methods to utilize the nutrients and organic matter present in sewage sludge have focused on application to agricultural lands (USDA, 1978, and Kelling, et al., 1977). However, the presence of heavy metals (USEPA, 1976), pathogens, and toxic organics (Pahren, et al., 1979) in sludges provides potential detrimental health effects to animals and humans (Argent, et al., 1977). Alternative land disposal methods have been evaluated (Torrey, 1979), with increasing interest in land application in forests.

Several characteristics of southern pine and hardwood plantations make them amenable for application of sewage sludge. Relatively remote locations minimize exposure to humans, and the fact that forest crops are nonedible reduces the introduction of toxic materials into food chains. Most forest soils have high retention capacities for metals and nutrients because they are deep, porous, well-drained, and contain a rich organic layer of leaf litter capable of complexing metal ions. Pine and hardwood plantations are managed to allow convenient movement of mechanized equipment within the stands. The pine and forest plantations offer a practical means of recycling nutrients in sludge while increasing biomass productivity.

Experimental Plan

The experimental plots are located on the Department of Energy's 775-square kilometer Savannah River Plant near Aiken, South Carolina (Figure 16-1). The mechanized planting and forestry management activities of the U.S. Forest Service since 1952 have produced 41,000 ha of pine plantations of different ages available for evaluating biomass production. The wide diversity of soil types on site is useful for studying the retention and movement of sludge derived nutrients, metals, and organics through soil profiles.

Sewage sludge will be applied in loblolly pine stands planted in 1953, 1972, 1978, and 1981, at rates of 275 kg/ha and 550 kg/ha as equivalent weight of nitrogen. Four study areas have been established for two age classes of loblolly pine (2 and 27 years) on light and medium textured soils. Each study area has 9 plots on a randomized block design with three replications and three treatments. The treatments will consist of three levels of sludge, none, 33 and 66 tons per acre which will be applied this fall. The plots are 0.5 acres or 0.27 ha in size with an interior measurement plot.

Prior to sewage sludge application, composite vegetation, litter layer, and subsoil samples will be collected from each subplot to determine initial conditions. Vegetation, litter, and composite soil samples from 0-7 cm, 7-15 cm, 30-38 cm and 60-76 cm depths will be analyzed for Ca, Cd, Cr, Cu, Hg, Mg, Mn, Na, Ni, Pb, K and Zn. Litter and foliage samples will be dry ashed and dissolved in dilute HNO_3. Soils will be digested in hot concentrated HNO_3 and analyzed for total levels of heavy metals. Concentrations of metals

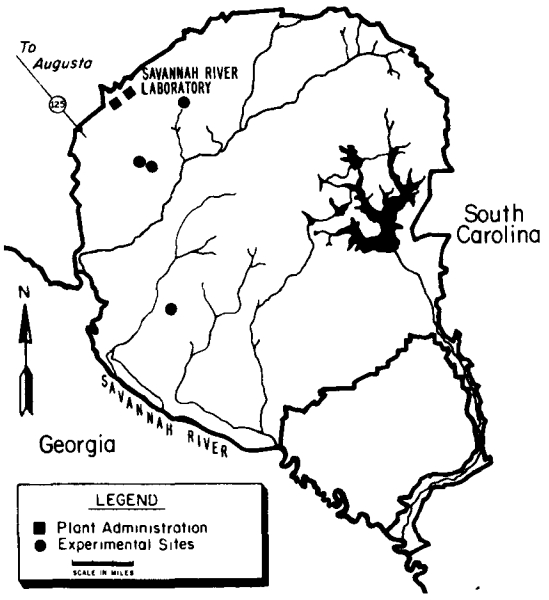

Figure 16-1. Savannah River Plant Site.

in an available form will be determined by extracting with either ammonium acetate or a chelating agent. Phosphorus will be extracted by an array of reagents to determine the residual form and availability. Nitrogen will be determined by a Kjeldahl procedure. Analysis of extracts for metals will be accomplished by atomic absorption spectroscopy and phosphorus by standard colorimetric procedures.

Stand conditions on each plot will be documented prior to treatment. Measurements of tree height, diameter at breast height, basal area, stem volume, and general stand conditions on control and treated plots will provide a measure of stand growth with rate of sewage sludge application.

A 4-ha area was planted with five species of hardwood trees on 1.2-m x 2.4-m centers in February, 1980; red maple (*Acer rubrum*), sweet gum (*Liquidamber styraciflua* L.), American sycamore (*Platanus occidentalis* L.), black locust (*Robinia pseudoacacia*), and black alder (*Alnus glutinosa*). Seedlings were planted in a randomized block design to evaluate biomass production by coppice growth of trees with and without sewage sludge. Heavy metals, nutrients, and toxic organics in vegetation, soil profile and water samples, will be monitored following application of sewage sludge at 275 and 550 kg/ha. Treatment effects on nutrient uptake by coppice growth will be evaluated by sampling various plant parts.

Sludge will be applied with conventional farm equipment including a

70-horsepower, all-purpose farm tractor, a front-end loader, a flail spreader with hydraulic lid opener for sludge delivery from either side, and a manure spreader. The flail will be used in the thinned pine plantations, and the rear delivery spreader in the younger pine stands and in the hardwood plantations.

The source of the sewage is the Aiken county Public Service Authority Horse Creek Pollution Control Facility. This is a 75-million liters/day (MLD) capacity plant with estimated sludge production of 20 wet ton/week. Industrial wastewater (principally textile industry waste) accounts for 75% of the wastewater flow into the plant with domestic inputs comprising the remainder. The sludge is thermally conditioned and dewatered following aerobic digestion.

Discussion

The principal objectives of the program are to evaluate the environmental effects and conduct benefit cost analyses for land application of sewage sludge in pine and hardwood plantations in the southeast. The environmental effects studies will determine the effects land application of sewage sludge has on the hydrologic cycle and cycling of nutrients, heavy metals, and organics in forest ecosystems. Cost-benefit analyses of using sewage sludge as a fertilizer and soil amendment will be made by determining the increase in wood fiber production by treatment compared to sludge handling expenses.

Environmental Effects

A nutrient cycling model will be developed for pine and hardwood plantations describing nutrient cycling related to wood fiber productions, to estimate the impact of sludge amendments on the natural nutrient cycles, to predict effects of sludge amendments on available soil nutrients, and to develop a hydrologic model for predicting nutrient flux to groundwater. The hydrologic model will integrate submodels generated from field measurements for precipitation, evapotranspiration, overland flow, and seepage losses to groundwater.

The presence of heavy metals like mercury, cadmium, copper, lead, and nickel in sewage sludge may be the ultimate constraint to land application of sewage sludge on forest soils due to possible phytotoxic effects and food chain contamination. Analysis of plant parts will define the role of trees as sinks for heavy metals.

While vegetation is geographically constrained until harvest, consumer organisms may transfer heavy metals to man. Monitoring heavy metal concentrations in small mammals, birds, and deer will provide data to estimate the relative importance of consumer populations in heavy-metal

cycling and indicate accumulation of heavy metal concentrations potentially dangerous to consumer organisms.

A wide range of organic compounds is associated with sewage sludges, and this range is dependent on several parameters, including the type of industries sewered, the type of sewage treatment process, and efficiency of operation and the composition of incoming domestic waste-water. The environmental effects of two classes of organics present in sewage sludge will be studied. The first class of organics, which includes humic and fulvic acids, proteins, carbohydrates, and lipid material, constitutes a major fraction of the organics in sewage sludge, but are not a major environmental concern since most degrade in nature. However, this group of organic compounds is important because they can control, via complexation and adsorption, the chemical speciation and thus the transport of heavy metals and nutrients in soil. Therefore, the interactions of organics and heavy metals in the pine and hardwood plantations will be important in defining environmental effects of sewage sludge application.

The second group is the refractory organics. These are found in the environment as a result of mans' use of plasticizers, pesticides and fossil fuels. Such compounds as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and phthalates are found in ppm concentrations in many effluents of wastewater treatment plants (Pahren, et al., 1979). The importance of these compounds in limiting land application of sewage sludge have not been well documented, but the cycling and transport of some specific organics will be studied in this program.

Quantification of fiber production related to climate, hydrology, and elemental inputs provides a means to determine an optimal quantity and schedule of sewage sludge applications to maximize productivity. The seasonal variations, as well as frequency of additional treatments on the original experimental plots will be evaluated over the course of the project.

Ultimately, it becomes necessary to understand how sludge amendments affect net production of wood biomass. Measurements of photosynthesis, respiration, and nutrient uptake by treatment will provide information on how amendments enhance productivity. These data will contribute to development of a biological process-oriented model for tree growth. It may be possible to use, with minor modification, existing forest production models (e.g. TEEM, FORET) (Shugart and West, 1977, and O'Neill, et al., 1972). The overall production model will serve to integrate models that describe system hydrology, seasonal climatic-change, nutrient cycling, consumer population dynamics and cycling of heavy metals and organics.

Benefit Cost Analyses

To realistically evaluate the efficacy of sludge disposal on Savannah River Plant forest soils, the ecological research directed at understanding and quantifying relationships between treatments, climate, nutrient cycling,

hydrology, heavy metal cycling, and forest productivity must be examined in the context of a broader economic environment. Traditionally, calories have served as a common unit linking ecology to economics (Odum, 1971). If more energy is required to increase fiber production than the energy returned in the products, then disposal of sewage sludge on forest lands would be inadvisable from an energy viewpoint. However, if the benefit cost ratio is equal to or greater than 1.0, sludge is a resource rather than a waste product.

The benefit cost analysis (BCA) entails more than a simple cost accounting of the amendment operation. Once ecologic and economic constraints have been identified, converted into caloric units, and stated formally, development of disposal plans that optimize user-defined objective functions is possible through the use of a variety of mathematical tools that come under the classification of operations research techniques (Wagner, 1970).

Quantification of a set of costs will be undertaken to develop equations that describe constraints on the solution set of possible amendment strategies. Some of these costs require simple bookkeeping: energy cost of sludge transportation to site, cost of application, site preparation, labor capital, cost of tree harvest, and transportation offsite. The sensitivity of the BCA to each of these constraints can be assessed in relation to the objective functions to be optimized. While the constraints will each generally yield a single value, they are not constant, but change, for example, with changes in costs of fossil fuel, wages, etc. These sliding scales will be incorporated into the BCA.

There are also ecological constraints. Given the state of the art in breeding of productive strains of trees, climate will set some maximum rate of production regardless of the supply of available nutrients. Results of the plot studies should identify an optimal rate of sludge application; however, metabolic constraints to the conversion of nutrients in sludge to tree biomass will ultimately place a limit on productivity. Depending upon concentration of heavy metals in the sludge, an interesting feedback between optimal rates of nutrient supply versus toxic accumulation of heavy metals could develop. This plus potential groundwater contamination with metals, nitrates, and organic compounds might impose legal, as well as economic constraints on optimal application rates. Potentially hazardous levels of heavy metal concentrations in consumer organisms, especially deer which are hunted by the public on the SRP, may impose additional constraints. A major objective of the BCA process will be to formally state the constraints in mathematical terms with the calorie as a common unit.

Objective functions are limited mainly by the imagination of researchers performing the BCA. However, in all foreseeable cases these functions will involve a maximization of some perceived benefit, a minimization of a perceived cost or some compromise of both. A reasonable function to

evaluate is one that would maximize the BC ratio for as long a period of time as possible, even though the maximum value may be less than 1.0. A more short-sighted function might be to derive a treatment rate that yields the largest BC ratio regardless of the time scale or potential for future use of the amended land. Evaluation of these functions will be performed after formulation of appropriate constraints.

To perform the BCA, benefits accrued through increased fiber production under varying amendment regimes must be quantified. These benefits (converted to units of energy) include the energetic equivalent of the fiber used for lumber, pulp, or biomass, positive externalities or ripple effect in the local economy (wages, sales, etc.) and interestingly, the cost of alternate methods of sludge disposal. Where necessary, economic consultants will be asked to work with the basic research team on the Savannah River Plant site to generate appropriate methods to estimate benefits to be used in the BCA.

Conclusions

These studies will provide the first detailed information related to sludge application to southeastern coastal plain forests. A series of models developed from literature and planned filed studies will provide the capability to estimate environmental effects of sludge application, biomass response, and benefit cost analyses.

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17
RESPONSE OF FOREST ECOSYSTEMS TO SLUDGE AND WASTEWATER APPLICATIONS—A CASE STUDY IN WESTERN WASHINGTON

Dale W. Cole

Since 1973 faculty at the University of Washington have investigated the feasibility of applying municipal wastewater and dewatered sludge to established forests and new plantations. Since its inception this program has had three major goals:

1. To determine the environmental soundness of utilizing a forest environment for disposal of these treatment plant products. The major focus of this phase has been on nitrates, heavy metals, and pathogens.
2. To determine changes in forest productivity that can be expected from sludge and wastewater application. A number of tree species and age classes have been assessed for their survival and growth response.
3. To establish economics, including both costs and benefits, of such applications to forests of western Washington. This aspect of the study has addressed the engineering difficulties of applying sludge to a forest environment and silvicultural problems and opportunities that result.

While all of these goals have not been fully met, this paper will present the current status of the studies and direction of proposed research efforts. It is clear from these studies that a major unresolved environmental problem is that of nitrate leaching following dewatered sludge applications. Tree species, including Douglas fir, sitka spruce, lombardy poplar, and black cottonwood, are particularly responsive to these additions. Other species such as western hemlock, western red cedar, ponderosa pine, and noble fir are not as responsive.

Utilizing appropriate application rates and tree species, it would be our conclusion that both dewatered sludge and wastewaters can be effectively and economically applied to forest settings in western Washington.

Introduction

The forest application of municipal sludge and/or effluent wastewaters has received considerable attention in recent years. The early studies by Kardos and Sopper in Pennsylvania (1973), Urie in Michigan (1973), and Bialkiewicz in Poland (1978) developed much of the initial interest in the use of forests for renovation and recycling of these materials. Consequently, a number of similar investigations have been initiated in a variety of sites. A

comprehensive review of the current studies can be found in "Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land," W. E. Sopper and S. N. Kerr (eds.), The Pennsylvania State University Press, 1979.

Similarly, a program examining the potential use of forests in the application of both wastewater and dewatered sludge was begun in western Washington in 1973 by researchers at the University of Washington. Since the program's inception it has had these basic objectives:

1. Establish the environmental soundness of utilizing forest areas for the utilization of these products. The major focus of this research has been on nitrate leaching, heavy metal uptake by the vegetative cover and leaching through the soil profile, and residence time and distribution of pathogens associated with sludge materials.

2. Determine long- and short-term growth response of various forest species of the Pacific Northwest to these applications. Both newly established plantations and existing forests have been studied at Pack Forest.

3. Evaluate management alternatives, engineering problems and general economic costs and benefits of applying sludge to forest sites.

Over the 7-year period this research program has represented the collective efforts of eight research scientists and a number of staff members of the College of Forest Resources. By necessity a wide range of scientific disciplines have been involved including plant physiology and nutrition, soil science, toxicology, economics, mensuration, engineering, and forest management technology.

Many of the detailed results from these studies have been reported in the literature. In addition, a regional symposium updating these studies was held in Seattle and at Pack Forest July 8-10, 1980, the proceedings from which will be published in early 1981. For this review I will update and highlight the major achievements with specific focus on environmental, silvicultural, and economic implications.

Forested areas have been seriously considered for sludge and wastewater applications in the Pacific Northwest for several important reasons:

1. There are extensive acreages of forested lands in western Washington, many of which are located within easy hauling or pumping distances from the municipal treatment plant facilities.

2. The forests of western Washington are typically located on the better-drained sites and not subjected to periodic flooding of alluvial agricultural areas.

3. Many of the forested areas are markedly deficient in major nutrients found in municipal sludge and wastewater, especially nitrogen and phosphorus. This is due in part to the glacial origin of many forested sites and the fact that agricultural uses occupy areas of higher productivity.

4. In that forests are a non-food chain crop, many of the public health concerns and land application regulations considered in Washington, D.C. are not critical issues.

Pack Forest, the teaching and research forest of the College of Forest Resources, was selected for these studies. This forest area is owned and managed by the College. Thus, long-term research projects can be conducted at this site without the hazards of changing ownership and rededication of the land. In addition, Pack Forest has the variety of soil types, tree species, age classes, and slope conditions necessary for the experimental design of this program.

Pack Forest is located on the lowlands and foothills of the Cascade Mountains, near Mt. Rainier, approximately 110 km south of Seattle. In that the forest is over 1700 ha (4,000 acres) in size, the necessary acreage for conducting this program was readily available. The climate is similar to that of the Puget Sound lowlands; a wet, mild winter and a relatively dry mild summer. Precipitation is 140 cm (55 inches) annually, approximately 50% greater than that of Seattle.

As mentioned above the research program has examined the feasibility of applying both wastewaters and sludges to forest environments. While these programs were conducted at the same time, on adjacent sites, and with many of the same scientists, for the purposes of this review the studies will be discussed separately. It should be recognized however that a great deal of the information derived from one study was used in design and interpretation of the other.

Wastewater Program

The application of secondary treatment effluents to a forest site was designed to be a part of a larger comparative study sponsored by CRREL (Cold Regions Research and Engineering Lab) of the US Army Corps of Engineers. The program at Pack Forest represents the forestry comparison to an overland flow system at Vicksburg, an agricultural system at Apple Valley, Minnesota and a grass system at the CRREL Lab near Hanover, New Hampshire.

The field facility at Pack Forest consisted of five plot areas each with distinctly different vegetative covers:

1. Douglas fir seedlings
2. Poplar seedlings
3. Grass
4. Barren (all vegetation removed)
5. 50-year-old Douglas fir forest

Each plot was further subdivided so one section received wastewater at the rate of 5 cm/week while the remainder received an equal amount

of water pumped from the adjacent river. Irrigation was conducted weekly, on a year-round basis, over a five year period. Consequently, each plot except for the 50-year-old Douglas fir received over 12 meters (40 feet) of irrigation and approximately 2000 kg/ha of nitrogen. The mature Douglas fir plot was not started until 1974. Movement of percolating waters through the soil profile to a depth of 180 cm was carefully monitored with both tension lysimeters and a large tank lysimeter system, 3.5 meters in diameter.

A number of important conclusions were derived from this study. Phosphorus contained in wastewater was quickly and completely removed from the soil solution by a sorption reaction on the soil colloidal surfaces (Breuer et al., 1979). Thus phosphorus did not leach through any of the plots including the one maintained in a barren state. Leaching of nitrogen showed somewhat of a different pattern. As long as the added nitrogen remained in ammonium form, little if any leaching was apparent. However, with the conversion of ammonium to nitrate, leaching became rapid and extensive. On those plots with a vegetative cover this loss of nitrogen was minimized through plant uptake or soil storage (Table 17-1; Cole and Schiess, 1978).

Irrigation of wastewater resulted in a dramatic increase in biomass production (Table 17-2). Average above ground production on the poplar plots irrigated with wastewater was 25 T/ha, approximately 7 times higher than the riverwater control. The wastewater irrigation resulted in an increase in above ground production of nearly 4 times for the Douglas fir seedlings and 3.5 times for the grass plot.

From this research it was possible to calculate renovation capacities of the five plots over the 5-year period of the experiment (Table 17-3). It is clear from these results that forests can effectively renovate wastewater at application rates normally used in agriculture. In this case, however, applications were made over the entire year and not just during the growing season, typical in agriculture practices. Results from the forest plots compared very favorably with results from the plot with grass cover. As seen in Table 17-4 nitrate concentrations at 180 cm depth were nearly always below 10 ppm EPA drinking water standards. Both the forested site and poplar seedlings demonstrated excellent renovation potential with only 10% nitrogen escapement below the rooting zone during the 5-year period of application. Escapement losses from grass and Douglas fir seedlings were only slightly higher and nearly always remained within the 10 ppm concentration standard (Schiess and Cole, in press).

It could be concluded from these studies that forested sites in Washington can effectively be used for wastewater renovation. In that forest response was very favorable, such applications have the potential of providing a significant economic return to the forest owner. An economic analysis was not made of this data however because of the small size of plots and limited design of the experiment. An economic analysis was made however in the case of sludge-treated plots and will be discussed in the next section.

Dewatered Sludge Program

The dewatered sludge program differed in several important aspects from the wastewater program described above. Environmental and public health issues were more significant in this program due to the pathogen and heavy metal components of dewatered sludge. Since nitrogen loading rates were

Table 17-1. Fate of Nitrogen Applied as Wastewater to Plots at Pack Forest from 1974 to 1979 (Schiess and Cole, in press).

Component	Plots				
	Poplar	Douglas fir	Grass	Barren	Douglas fir 50-yr- old
	kg/ha				
Input	2,171	1,811	2,217	2,286	1,333
Vegetation Accumulation/1	317	272	0	0	/3
Harvest	930	621	627	0	0
Leaching	253	437	271	1,252	120
Soil Accumulation/2 and/or Denitrification	671	481	1,319	1,034	-

/1 Aboveground

/2 Residual of input minus plant uptake and leaching loss

/3 To be determined

Table 17-2. Aboveground Biomass Production (T/ha) by Douglas Fir, Poplar, and Grass as a Result of Wastewater (WW) and Riverwater (RW) Irrigation (Schiess and Cole, in press).

		Poplar			Douglas fir Seedling			Grass
		Tree	Grass	Total	Tree	Grass	Total	
1976	WW	8.5	8.0	16.5	2.9	8.5	11.4	8.5
	RW	1.0	1.6	2.6	0.9	1.6	2.5	3.0
1977	WW	28.2	6.0	34.2	4.4	8.4	12.8	9.1
	RW	1.2	1.2	2.4	1.6	0.8	2.4	0.9
1978	WW	14.8	10.1	24.9	14.0	6.7	20.7	10.4
	RW	1.8	2.1	3.9	3.8	2.2	6.0	3.9
1979	WW	18.4	6.0	24.4	12.8	3.4	16.2	10.2
	RW	3.4	1.9	5.3	3.6	1.3	4.9	3.5
Average 1976-1979	WW	17.5	7.5	25.0	8.5	6.8	15.3	9.6
	RW	1.9	1.7	3.6	2.5	1.5	4.0	2.8
% Increase		921	441	694	340	453	382	342

Table 17-3. Renovation and Retention Capability of a Gravelly Soil for Nitrogen Under Wastewater Irrigation Applied to Four Vegetative Covers and a Barren Control (Schiess and Cole, in press).

Year		Vegetation Cover				
		Barren	Grass	Poplar	Douglas fir Seedling	Forest
1975	Applied(kg/ha)	428	428	428	428	-
	Retained %	68%	96%	53%	89%	
1976	Applied (kg/ha)	403	398	392	320	348
	Retained %	34%	76%	94%	84%	84%
1977	Applied(kg/ha)	456	443	438	325	402
	Retained %	75%	77%	98%	74%	97%
1978	Applied(kg/ha)	449	437	440	359	330
	Retained %	59%	96%	99%	76%	97%
1979	Applied(kg/ha)	550	509	473	379	253
	Retained %	39%	93%	98%	54%	83%
AVE.	Applied(kg/ha)	457	443	434	362	333
	Retained %	55%	88%	88%	76%	91%

Table 17-4. Mean Annual[1] Nitrogen Concentration in Soil Solution Passing 180 cm Depth Under Wastewater Irrigated Plots (Schiess and Cole, in press).

Vegetation Type	1975	1976	1977	1978	1979	Average
	mg/liter					
No vegetation	4.8	9.5	7.6	11.8	15.8	8.3
Grass	0.7	4.2	7.0	1.2	1.8	2.3
Poplar	7.7	1.1	0.6	0.5	0.7	2.1
Douglas fir Seedling	1.9	2.6	6.9	5.2	10.7	4.4
Douglas fir Forest		2.8	0.9	0.8	3.5	1.7

/1 A year covers the period September-August.

higher, potential for nitrate leaching was also greater. The technology of applying sludge to a forest environment had not been explored and agriculture experience could not be as readily used as was possible in wastewater irrigation. Applications of sludge proved to cause a marked change in forest productivity, affecting silviculture practices and caused a number of problems in land management not encountered in the wastewater irrigations. Another important difference between the two studies could be found in the scale of operations. It was possible to apply sludge to large enough areas and diverse enough systems to permit an economic analysis of the results. The following discussion summarizes this overall program.

Forest Application Alternatives

Dewatered sludge, containing approximately 18% solids, was applied to both well-drained, relatively flat soils of a glacial outwash origin and soil of more restricted drainage derived from andesitic bedrock found on upland sites. These latter areas are on slopes ranging from 10 to 30%. Sludge was applied to recently cleared land and established forests in both of these areas. Application rates varied from 2.5 cm (approximately 20 dry tons/acre) to 25 cm (somewhat more than 200 dry tons/acre). These application rates represent nitrogen loadings of 800 kg/ha for each 2.5 cm of sludge application. Thus the 25 cm application resulted in a nitrogen addition of 8000 kg/ha, significantly increasing the 2 to 3000 kg/ha of nitrogen capital found in these soils. Average elemental composition of the sludge, expressed as a concentration and quantity per unit of application is tabulated in Table 17-5.

Two very different systems of application were utilized in this program. For the establishment on new plantations, sites were cleared of all vegetation including stumps and logging debris. The highway haul trucks delivering sludge from the treatment plant were driven directly on the application area. Dumping patterns for sludge trucks were established for each desired application rate. Sludge was then incorporated into the soil with an 80cm (32 inch) construction disc or left on the surface and sowed with oats or grain rye. In either case it proved essential to dry and age the sludge before tree seedlings could be successfully established. In general, a drying and aging period of nearly one year, was necessary, depending in part when the sludge was applied and thickness of the application.

An alternative system of application was designed by Nichols (1980) for forest sites. This was necessary in that highway haul vehicles which delivered the sludge to Pack Forest could not travel through forested terrain

Table 17-5. Solids and Elemental Composition of Dewatered Sludge from METRO Sewage Treatment Facility (after Domenowske, 1980).

Component	Concentration
Solids	18-20%
N	2.6%
Ca	2.6%
P	1.8%
K	1.6%
Fe	2.7%
Na	0.9%
Cl	0.2%
Mg	350 ppm
Zn	1830 ppm
Cu	1170 ppm
Ni	153 ppm
Pb	2411 ppm
Cd	64 ppm
Hg	8 ppm

nor apply sludge uniformly to such sites. A reload reservoir system was constructed in which sludge was dumped by the highway haul vehicles. The sludge was then transferred to a forest application vehicle by means of centrifuged semi-open immersed suction pump, Vaughn pump model number 200.

This initial design of a forest application vehicle was developed with a carrying capacity of 7500 liters. Sludge is removed from the tank and applied to the forest by means of a directional nozzle system. Pressure is provided by a Vaughn pump, model number 500 powered from a PTO mounted on the transfer case of the application vehicle. An application range exceeding 40 meters is obtainable with this system. The truck can be filled in 7 minutes and discharged in approximately the same length of time. Although the initial application costs are higher with this system, it does provide a number of operational advantages over direct dumping with the highway haul vehicles, including:

1. provides a means for applying sludge to existing forested sites,
2. minimizes site preparation and land-clearing costs,
3. allows for applications at lower loading rates and greater uniformity in sludge distribution, and
4. makes it possible to apply sludge to sites that cannot support the weight of an application vehicle or where the vehicle cannot enter because of broken terrain or steepness of slopes.

Public Health Studies

The fate of heavy metals, pathogens, and nitrates associated with sludge applications to these forested areas has been systematically studied. Although it could be argued that forests are essentially removed from the human food chain and such public health considerations are unnecessary, it is also argued that people frequent such sites, harvest food products from them and obtain much of their drinking water from drainages originating in forested areas. Consequently a number of public health studies were addressed as a part of this overall research effort.

Heavy metal content of sludge derived from the METRO treatment plant was previously described in Table 17-5. To provide a worst-case example regarding leaching and uptake of these metals, 25 cm (200 dry tons/acre) of sludge was applied. After one year, transfer of these metals into the soil underlying the sludge and uptake by the various plant species found in this forest environment was assessed. Rates of Cd, Pb, and Ni leaching are clearly depicted in Figure 17-1. Movement of Cd from the sludge into the soil is minimal, limited perhaps to only a few centimeters of soil depth. Movement of Pb is even more restricted with no indication that migration has occurred into the underlying soil. It should be recognized this rate of vertical movement or lack thereof, occurred under an acidic condition of approximately pH 6. Monitoring groundwater at approximately 10 meters

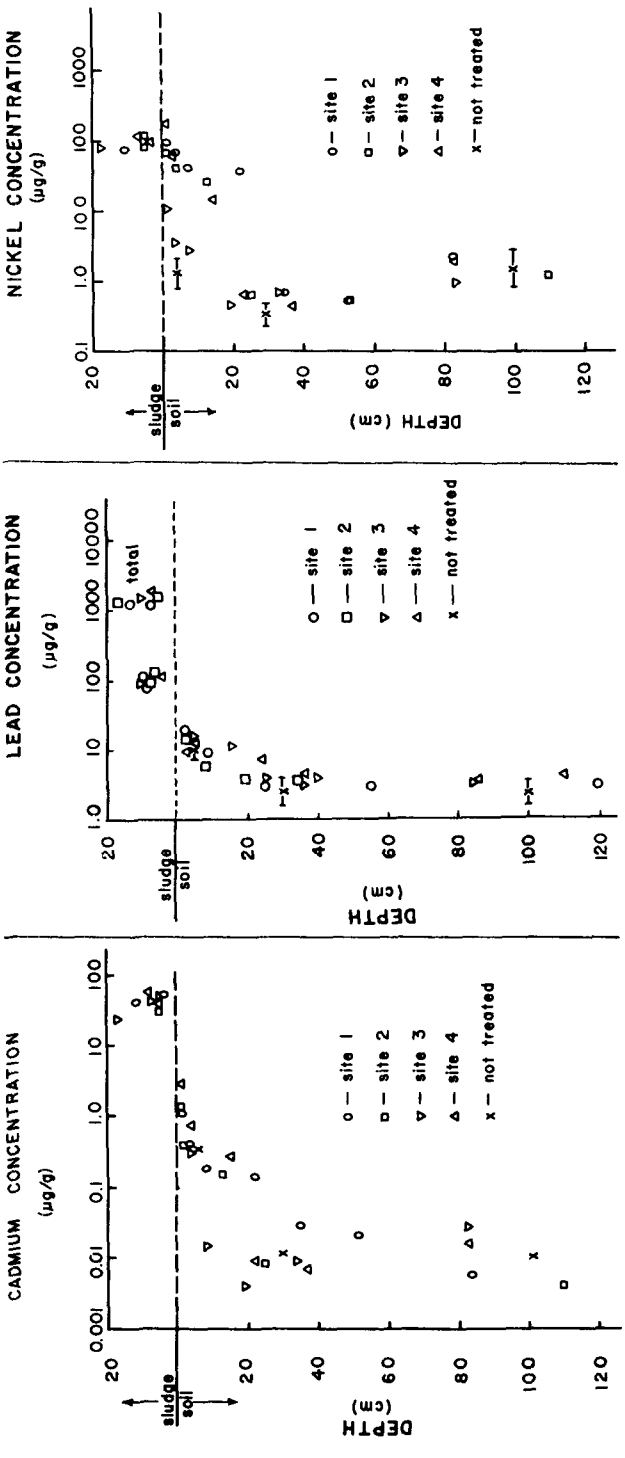

Figure 17-1. The Movement of Cd, Pb, and Ni from Sludge into the Underlying Soil (Zasoski, in press).

has not indicated any change in heavy metal composition (Zasoski, in press).

While it can be shown that heavy metals are relatively immobile within the soil, their availability for uptake is not as clearly defined. For example, a number of understory species such as blackberry and thistle accumulated heavy metals in selective and different ways (Table 17-6). While more uptake has been noted for some species than others, no detrimental toxic effects have been noted, nor would there be at these concentration values. The amount of heavy metals removed from sludge by plant uptake represents but a minor percentage of the total applied. Typically less than 0.1% of the heavy metal composition of sludge will be assimilated by the plant cover during the first year following application (Table 17-7; Zasoski, personal communication).

Residence time and mobility of sludge related pathogens has also been followed in our forest sites. While most of these studies have utilized fecal and total coliform bacteria as indication organisms, virus and other pathogenic organisms have also been studied to a more limited extent. Residence of fecal coliform in sludge is less than two years following application to forest sites. This residence time is further decreased if sludge has been applied to recently harvested sites or applied during the summer months. There appears to be little evidence of any downward migration of the fecal coliform in the soil. Soil samples taken directly beneath sites receiving sludge have a very low fecal coliform count. In addition this elevated occurrence of fecal coliform in the soil is short-lived, disappearing within 6 months. There has been no evidence of fecal coliform in the groundwater table directly beneath treated areas (Edmonds 1979).

The amount and form of nitrogen loss from sludge-treated sites has not been fully resolved. Preliminary evidence would suggest that within 2 months following sludge applications, 30 to 40% of the nitrogen disappears from that applied, depending upon the specific treatment. This disappearance is primarily in the gaseous form with only 1 to 2% found in leachates collected directly under these surface sludge applications (Vogt et al., in press). It has not been determined whether these losses are a result of denitrification or volatilization of ammonia. In that sludge is very wet during this initial period and has a pH higher than 7 (Edmonds and Mayer, in press), it is clear that either mechanism could be responsible for these losses. Losses of nitrogen from the sludge during the remainder of the 12-month period appear to be minimal (Table 17-8; Vogt et al., in press). In that the pH is rapidly reduced during this period to below pH 7, it could be suggested that the principal volatilization loss is that of ammonia volatilization and not from denitrification.

Although the percentage of nitrogen leaching from sludge into the underlying soil is very small, as noted above, the total amount of nitrogen entering the soil can be quite large (Table 17-9). This influx, however, varies widely depending on the depth of application and absence or presence of

Table 17-6. Heavy Metal Uptake by Understory Species Receiving 25 cm of Dewatered Sludge (Zasoski, in press).

Species	Metal		
	Zinc	Lead	Cadmium
	ppm		
Salal			
sludge	37	1.7	0.43
control	22	0.6	0.09
Blackberry			
sludge	56	1.2	0.25
control	34	1.5	0.04
Thistle			
sludge	330	1.7	2.92
control	30	3.1	0.19

Table 17-7. Heavy Metal Uptake by Oats from a Site Which Received 25 cm (200 dry tons/acre) of Sludge (Zasoski, unpublished data).

Metal	Uptake kg/ha	Added* kg/ha	% taken up
Cd	0.0139	27	5×10^{-2}
Pb	0.0038	610	6.2×10^{-4}
Ni	0.089	63	1.42×10^{-1}
Zn	1.361	1,110	1.24×10^{-1}
Cu	0.127	440	2.89×10^{-2}

*Assumes 20% solids and density of 1.02 g/cm^3

Metal content on a dry wt basis of:
Zn = 2220 ppm Ni = 126 ppm Pb = 1,220 ppm
Cu = 879 ppm Cd = 354 ppm

Table 17-8. Loss of Nitrogen from Sludge Applied to Forested and Cleared Sites (after Vogt et al., in press).

Site and treatment	% loss, 2 months total	% loss, 1 year leaching	% loss, 1 year total
Forested			
10 cm sludge	24	-*	43
25 cm sludge	16	3.1	41
Cleared			
10 cm sludge	38	1.3	48
25 sludge	35	0.5	40
sludge-soil mix(1:2)	46	9.1	47

*Not determined

Table 17-9. Leaching of Nitrogen (kg/ha/yr) from Sludge Applied to Forested and Cleared Sites (after Vogt et al., in press).

Site and treatment	Leached from sludge NH_4	NO_3
Forested		
25 cm sludge	416	312
sludge-sawdust mix(1:1)	36	45
Cleared		
10 cm sludge	73	35
25 cm sludge	42	72
sludge-soil mix(1:2)	9	405
sludge-sawdust(1:1)	26	44

a forest cover. The highest nitrogen leaching rates are found when sludge is incorporated into the soil (Vogt et al., in press). This is due in all probability to high mineralization and nitrification rates and low ammonia volatilization rates, both of which are encouraged by mixing sludge into the soil.

The subsequent leaching of nitrogen through the soil can remain high, especially when sludge has been applied to cleared areas being prepared as new plantations (Riekerk and Zasoski, 1979). This high nitrate leachate has in turn temporarily impacted the groundwater table immediately below recently cleared areas receiving sludge in excess of 200 dry tons/ha. Current research studies at Pack Forest are exploring ways to minimize these leaching losses. Lower application rates, applied more frequently are being tested as is the concept of applying sludge to forested sites rather than cleared areas or new plantations.

Growth Response of Tree Species

As we found in the wastewater experiments, areas receiving sludge also demonstrated a marked increase in total productivity. This increase was particularly noted for seedlings of Lombardy poplar, hybrid cottonwood, and sitka spruce. To a lesser extent seedlings of Douglas fir and western hemlock also increased in production although mortality with hemlock seedlings was almost always high. Neither Ponderosa pine nor western red cedar responded significantly to sludge additions. Western red cedar also was subject to high rates of mortality. A summary of the survival and growth response data of the above species is tabulated in Table 17-10 (Archie and Wilbert, in press).

Establishing reliable growth response information for seedlings has proven difficult. The principal complications have been associated with extensive weed cover which rapidly invades sludge-treated areas. The weeds not only compete directly with trees for space and moisture, but they also

Table 17-10. Height and Diameter Response of Tree Seedlings in Two Plantations at Pack Forest (after Archie and Wilbert, in press).

Species	Mashel Flats Plantation 1-year response*		XA5 Plantation 2-year response*	
	Height	Diameter	Height	Diameter
Douglas fir	47	181	20	88
Sitka spruce	306	490	33	71
Western hemlock	**	**	46	76
Western red cedar	**	**	-2	21
Ponderosa pine			15	43
Lombardy poplar	916	909	64	101
Black Cottonwood	**	**		
Hybrid Cottonwood	378	273	44	86

*Percent increase over control **Mortality <80%

provide an excellent habitat for voles. These small rodents can decimate an entire plantation by girdling the seedlings at or near ground level. The only effective control we have found has been controlling weeds through cultivation or herbicides. Our experience has found cultivation the most effective of these two options.

Another problem associated with establishment and management of sludge-treated plantations has been the extensive and selective browsing by deer. The sludge-treated seedlings have a protein value two to three times higher than controls. Consequently deer have selectively focused their browsing activities in sludge-treated areas. In that deer will remove leaders of treated trees, height growth comparison to control is not always realistic. Although a variety of techniques were employed to control this browsing activity including vexar tubing and BGR (big game repellent), the only method we found sufficiently reliable for our research purposes was fencing. This phase of the research clearly demonstrated, to the disappointment of those responsible for the silvicultural management of the forest, that sludge will increase total productivity to the ecosystem and not necessarily increase seedling growth. A major land management effort is obviously required to insure that seedlings share in this increased productivity. In general, our cost to establish a forest plantation treated with sludge has been approximately $1200/acre exclusive of the cost of applying sludge. Additional costs of $200/acre have also been experienced for weed and browse control for at least 3 additional years following plantation establishment (Archie and Wilbert, in press). It is not suggested that these costs will reflect those that would be experienced in a commercial forestry operation utilizing sludge.

Applying sludge to established stands avoided many of the plantation management problems and costs discussed above. The technique employed, as previously described, involved a tanker truck unit with a 2,000 gallon storage capacity. The tanker was loaded from a reservoir by means of a transfer pump. The sludge was discharged into the forest through a nozzle mounted on the front of the application vehicle. Forest ranging in age from 5 to 50 years received sludge utilizing this vehicle. On the younger stands where sludge got on the foliage, it was necessary to wash the foliage afterwards using water pumped from the same vehicle. If the sludge had been applied during periods of high rainfall this washing procedure could have been avoided. If the sludge was not removed from the foliage, it would remain permanently adhered to the surfaces, detrimentally affecting photosynthesis.

Examples of the growth response for the first two years following application to established forests are presented in Table 17-11. With this limited data it is premature to predict long-term response. In addition, the best combination of stand conditions and application rates necessary to maximize response has not been resolved. However, preliminary results in Table 17-11 do suggest several important trends. Basal area increases for these older stands can be dramatic. For example, a two-year growth response of 60% was found for the 50-year-old low site (site index IV) Douglas fir. Higher site index forest (site index III) did not show nearly as large a response. The capability of a Douglas fir forest to respond to sludge appears to be independent of stand age, at least up to the maximum age tested to 50 years (Archie and Wilbert, in press). The extent of response does not appear to be dependent on the initial density of the stand. However, pumping of sludge into dense forests is difficult and the distance of

Table 17-11. Two-Year Basal Area Response of Douglas Fir Stands Receiving 5 cm of Dewatered Sludge (Archie and Wilbert, in press).

Stand	Treatment	% increase in basal area	% increase over control
Site IV Douglas fir 50-year-old	Control	6.7	
	Sludge	10.7	60
	Thinned	8.5	
	Sludge + Thinned	12.2	44
Site III Douglas fir 50-year-old	Thinned	9.9	
	Sludge + Thinned	11.0	11
Site IV Douglas fir 25-year-old	Thinned	20.8	
	Sludge + Thinned	31.1	50

application is decreased.

The economic advantages of applying sludge to these older forests is clearly illustrated in Figure 17-2. For the first 2 years an economic return of $135/acre/year was realized by applying 5 cm of dewatered sludge. This calculation was based on an assumed standing timber value of $279/1,000 bd.ft., Scribner rule, a very conservative value considering the average timber market during the past year. In addition, as trees increase in size, a significant number will become number 2 saw logs, rather than number 3 saw logs as assumed in the above calculation. This will result in step increases in the stumpage value to $300/1,000 bd.ft. (Schreuder, Roise and Tillman, in press).

A five- and ten-year projection (Table 17-12) represents minimum duration of the growth response we would expect from these applications based on the responses noted for chemical fertilizer additions. In addition, it assumes a current market value of $270/1,000 bd.ft., a minimum estimate as discussed above. It is our expectation that these additions should result in a permanent change in productive capacity of these forests and as a minimum last through the rotation of the current forest occupying the site.

Conclusions

The response of forest ecosystems to the application of dewatered sludge and wastewater has been followed for nearly 7 years in western Washington. This program has resulted in a number of significant findings essential in the decision-making process by treatment plant operators and regulatory agencies in considering forests as candidate sites for disposal or cost-efficient recycling of these sewage products. The conclusions of this program are as follows:

1. Wastewater can be applied at rates of 5 cm/week, year-round, to forest sites in western Washington with only minor losses of nitrate and no loss of phosphorus below the rooting zone. In general, renovation by forest is equal to or better than that provided by grass. Five years of application at the above rates clearly demonstrated the improvements in forest productivity that can be expected by such a program.

2. Application of dewatered sludge to young plantations has resulted in a dramatic increase in total production of the ecosystem. However, this increase in production is not always associated with the seedlings, nor do all seedlings respond equally to sludge applications. This is especially true during tree establishment. Douglas fir, sitka spruce, hybrid cottonwood, and poplar all respond positively. Red cedar and hemlock have unacceptable mortality rates when planted into sites which have received sludge. Ponderosa pine has excellent survival but does not appreciably respond to sludge. Many times the competing weeds have shown the greatest increase in growth.

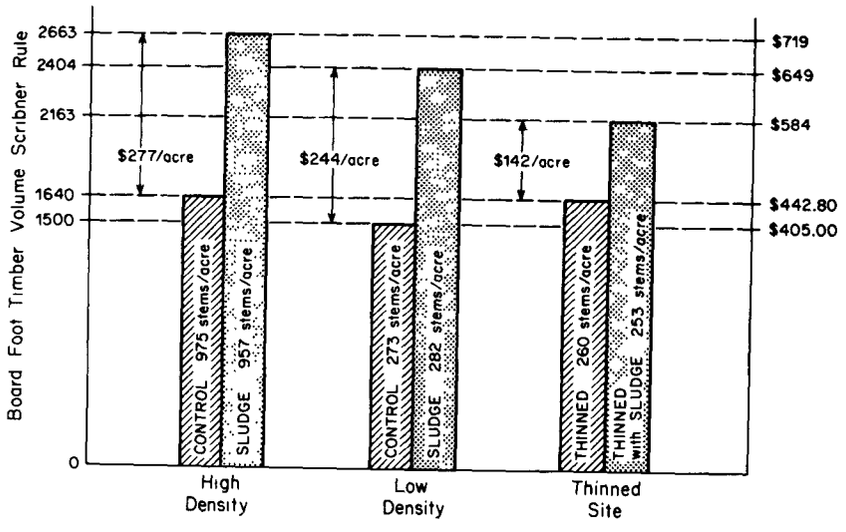

Figure 17-2. Two-Year Volume and Value Increase due to Dewatered Sludge Additions to a 50-year-old Douglas Fir Forest (Schreuder, Roise and Tillman, in press).

Table 17-12. Economic Benefits Associated with Dewatered Sludge Applications to a 50-Year-Old Douglas Fir Forest (Schreuder, Roise and Tillman, 1980).

Treatment		2 year response	5 year response	10 year response
CONTROL	Vol.	1568 Bdft	3920 Bdft	7840 Bdft
	$	$423	$1,058	$2,116
SLUDGE	Vol.	2533 Bdft	6334 Bdft	12,665 Bdft
	$	$684	$1,710	$3,419
INCREASE	Vol.	965 Bdft	2414 Bdft	4825 Bdft
	$	$260	$652	$1,303

The projections are based on a linear volume growth assumption. The site studied here is the typical site on which sludge would be applied in western Washington.

Successful plantation management involving sludge applications must include a means of controlling these weeds, especially during the initial 3 to 4 years following planting. Without weed control trees will, in all likelihood, die of either lack of soil moisture or directly killed through girdling by voles.

3. Established forests receiving sludge have also demonstrated a remarkable growth response. This increase in growth has resulted in an additional economic value to a 50-year-old forest of $270/acre during the first two years following application. Applying sludge to established forests

avoids many of the costs and management problems associated with applications to plantations.

4. The technology of applying sludge to existing forests has in part been resolved with the construction of a sludge application vehicle. Sludge can be discharged a distance of approximately 125 feet with this vehicle, making it practical to consider applications into existing forests.

5. The major public health issues associated with sludge applications are those of heavy metals, pathogens, and nitrate leaching. It would appear from our initial studies that neither heavy metals nor pathogens will be of a lasting concern when sludge is applied to forested areas. However, nitrate leaching below the rooting zone can be excessive especially when sludge has been applied to newly cleared areas. Research is still underway examining all three of these public health issues, especially the question of regulating nitrate leaching.

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18
USE OF SEWAGE SLUDGE FOR TREE SEEDLING AND CHRISTMAS TREE PRODUCTION

David H. Lambert and Craig Weidensaul

Replicated plots at two sites with differing soils (a fertile, well drained silt loam and an infertile, poorly drained silty clay loam) were treated with 0, 11, 22, 45, 90, or 180 dry MT/ha lime-stabilized filter cake from Cleveland's Southerly sewage treatment plant. These plots were rotovated and planted with seedlings of blue spruce, Douglas fir, Fraser fir, Scots pine, and white pine. Survival and new growth data were taken and weed biomass was measured after ten weeks. At this time, when the trees were still actively growing, shoot growth at the better site was slightly higher than control (+9%) at the 22 MT rate, and weed growth at both sites was greatest at the 90 ton rate (2X and 4X control). Transplant survival was significantly reduced at the 180 ton rate. Among the five species, growth of white pine was most improved by lower rates and most inhibited by higher rates of sludge.

Nursery beds on a sandy loam soil were amended with either no treatment, 120 kg/ha ammonium nitrate-N, a poorly digested Detroit filter cake at 35 or 80 dry MT/ha, or an anaerobically digested Mt. Vernon, Ohio sludge at the above rates. These beds were disked and spring-seeded with red oak, tulip poplar, black locust, blue spruce, Douglas fir, noble fir, Scots pine, white pine, and Virginia pine, and harvested in mid-July. Although dry weights of red oak were not affected by treatment, the small-seeded hardwoods responded to sludge. Sludge improved growth of all poplar treatments relative to the nontreated control, with the higher rate of Detroit sludge superior to the nitrogen treatment. Growth of black locust was significantly greater than the untreated control for two of the sludge treatments. In contrast, growth of the conifer seedlings was significantly greater with ammonium nitrate compared to any sludge treatment. Application of sludge prior to soil fumigation is mandatory to reduce subsequent weed and tomato problems.

Introduction

Sewage sludge usage for crop production affords separate benefits to the producer (a disposal site) and to the recipient (a low-cost soil amendment). If the cropland will not be used for food, both parties may be less restricted in the quality and quantity of sludge applied. From the recipient's point of view, crop responses to the mineral and organic matter content of the sludge must outweigh the costs and benefits of his normal practice, and

of any new drawbacks such as potential heavy metal and salt problems, or increases in management costs. Further, sludge is only beneficial if the existing limitations on crop growth are relieved by its components, primarily nitrogen, phosphorus, and organic matter, and if sludge usage does not impose new restrictions on growth.

Improved tree seedling growth is predictable in sludge-amended media such as mine spoil where fertility and organic matter are low. Berry and Marx (1, 3) have reported many-fold responses to sludge for loblolly and other pines grown in eroded forest soil and a lesser response (two-fold) in kaolin spoil whose severe deficiency in potassium and magnesium was not relieved by sludge (2). In some cases, higher sludge rates reduced survival and growth. For shortleaf pine in forest soil, this resulted from competition with weeds. Gouin (4) and Gouin and Walker (5) obtained improved growth of tulip poplar and dogwood in sandy soil amended with composted sewage sludge. The highest rate of compost (448 MT/ha) reduced root development and in some cases seed germination. Problems with weedy growth of tomatoes led the authors to recommend a green manure crop between the addition of compost and seeding to trees. Composted sludge did not improve the growth or numbers of Norway spruce seedlings relative to a 1 MT/ha treatment with a slow-release fertilizer. Seedling numbers of white pine were increased by composted sludge incorporated at a 112 MT rate. Krapfenbauer et al. (6), supplementing sandy and limestone soils with 20% composted sludge obtained the best growth of Norway spruce in 100% compost or the sandy soil-compost mix. Austrian pine did best in these two media and in the limestone soil-compost mix. Poorest growth occurred in the untreated soils or in compost-amended slash.

The following are reports of the effects of sludge on mid-first-season growth of seedlings or transplants in soils of at least moderate fertility. Typically, seedling nurseries are sited on lighter soils to assure good drainage and to reduce root damage when trees are lifted. Such soils are usually low in organic matter and exchange capacity, and require rotations of green manure crops to maintain their structure and productivity. This suggests that sludge might be added as a source of organic matter, either at a large initial loading or continuously at lower rates. In plantations, Christmas trees are normally grown on an 8-10 year rotation with fertilizer, if any, applied at planting. A common feature of this system is slow development in the initial years. In this case, application of sludge prior to planting provides an initial surge of available N and P with some residual value in subsequent years.

Materials and Methods

At the Zanesville State Tree Nursery, eight adjoining 1.2 X 90 m beds of sandy loam soil were plowed, disced, and fumigated with methyl bromide

in September, 1979. In October, a poorly digested filter cake from Detroit and an anaerobically digested liquid sludge (ca. 10% solids) from Mount Vernon, Ohio were delivered to the site (Table 18-1). These sludges were applied with a manure spreader at approximate rates of 35, 80, and 200 MT/ha. Bulk storage of sludge on the ground prior to spreading resulted in contamination of the sludge with nonfumigated soil. The seventh plot was left untreated and the eighth plot was fertilized with 120 kg/ha ammonium nitrate-N prior to seeding. In the spring, the eight beds were disced and seeded with red oak, black locust, tulip poplar, Douglas fir, noble fir, blue spruce, Scots pine, white pine, and Virginia pine. These species were replicated five times in 1.2 X 1.2 m plots located at random in each bed. Weeds developing either from tomato seeds in the sludge, from sod or seeds in the soil spread with the sludge, or seeds occurring naturally in the beds were removed by hand in all but the two high-rate treatments. These two were abandoned. In late July, ca. 20 plants from each plot were harvested and root and shoot dry weights were determined and expressed on a per seedling basis. Stem diameters were recorded for the oak and locust. Because some seedlings were washed out or lost during weeding, stand data were not recorded. Data were submitted to analysis by Duncan's Modified Least Significant Difference Test (DMLSD).

Two Chirstmas tree plantations were established near Wooster, Ohio, one on a good site with a fertile silt loam soil previously in corn, and another on a poor site with a less fertile, poorly drained soil recently cleared of trees and brush. During the winter and spring of 1980, 12 X 15 m plots, replicated four times, were treated with 0, 11, 22, 45, 90, or 180 dry MT/ha of Cleveland (Southerly plant) sludge (Table 18-1). These plots were rototilled and transplanted with twenty two-year-old seedlings each of Douglas fir, Fraser fir, blue spruce, white pine, and Scots pine. In mid-July, the length of new terminal growth was measured and survival was assessed. At this time, all weeds in four 0.5 m^2 subplots per plot were harvested, separated into sedges, grasses, or various broadleaves, dried and weighed. Data were submitted to analysis by DMLSD to determine differences between sludge rates, and also to multiple regression in certain cases to determine effects of various edaphic factors on seedling and weed growth.

Table 18-1. Chemical Analyses of Sewage Sludges.

Source	pH	OM	P	N	K	Zn	Cu	Pb	Cr	Cd	Ni	B
		%			ppm							
Cleveland	11.7	61	2.0	2.6	255	2250	720	22	240	318	680	107
Detroit	5.7	50	1.8	3.5	-	2790	860	63	180	91	550	-
Mt. Vernon	6.7	40	2.8	2.9	702	820	6080	36	>6600	6	6250	43

Results and Discussion

The effects of sludge on the chemical properties of the nursery soil are shown in Table 18-2. The increases in cation exchange capacity and organic matter were slight, indicating that much of the organic matter had decomposed. (Each MT/ha of dry sludge with 50% O.M. would increase the initial organic matter in the plow layer by about 0.04%.)

Growth of the large-seeded hardwood, red oak, was not affected by sludge rate (Table 18-3). Growth of tulip poplar was improved by all sludge treatments, at least partially in response to nitrogen (Table 18-4). Growth at the 80 MT rate of Detroit sludge was a significant improvement over the N-fertilized control. Black locust, which was well nodulated in all treatments, generally grew better in the sludge treatments, with significant increases in dry weight in one or two instances (Table 18-5).

In contrast to the hardwoods, sludge did not improve the initial shoot growth of the conifer seedlings (Table 18-6). With growth of the six conifers normalized and analyzed as reps, the ammonium nitrate treatment was significantly better than the others, while the 80 ton Mt. Vernon treatment was significantly poorer. Seedlings in this latter plot were not chlorotic but did appear to be reduced in number and size in a manner consistent with a root rot problem or poor root development. While this treatment was the one highest in Cu, Cr, and Ni, it also received the most nonsterilized soil, so that deleterious chemical effects could not be differentiated from biological ones on appearance alone.

The varying response of the hardwoods and conifers might be explained by their differing nutrient demands, which were greatest for the two small-seeded hardwoods. These grew rapidly with little seed reserves.

At the Christmas tree plantations, initial transplant survival was significantly reduced by sludge at only the highest rate (excepting Scots pine in the poorer soil) (Tables 18-7 and 18-8). The effect of this rate on survival varied considerably with site. The reduction in blue spruce and white pine survival were equivalent from site to site, while effects on Douglas fir, Fraser fir and Scots pine were minimal to moderate on the good site but

Table 18-2. Chemical Analyses of Nursery Bed Soils.

Treatment	pH	P	K	Ca	Mg	CEC	O.M.
		kg/ha					%
Initial	6.5	125	314	2692	213	7	-
Check	6.6	116	307	2410	186	6	3.1
120 kg N	6.5	115	252	2457	200	6	3.0
35 MT Detroit	6.5	151	274	2504	195	6	2.8
80 MT Detroit	6.6	243	274	2656	192	7	3.3
200 MT Detroit	6.1	281	270	2761	192	7	4.8
35 MT Mt. Vernon	6.7	146	243	3042	228	8	2.8
80 MT Mt. Vernon	6.7	288	278	3007	230	8	3.4
200 MT Mt. Vernon	6.9	352	222	3803	230	9	3.3

Table 18-3. Red Oak Shoot and Root Dry Weight and Stem Diameters.

Treatment	Shoot	Root	Stem
	gm		mm
Check	2.05 A	1.08 A	4.0 A
120 kg N	1.68 A	0.90 A	3.8 A
35 MT Detroit	2.49 A	1.53 A	4.5 A
80 MT Detroit	1.87 A	0.82 A	3.9 A
35 MT Mt. Vernon	1.63 A	1.01 A	3.8 A
80 MT Mt. Vernon	1.74 A	1.29 A	3.9 A

Table 18-4. Tulip Poplar Shoot and Root Dry Weights.

Treatment	Shoot	Root
	gm	
Check	0.58 C	.018 B
120 kg N	1.09 B	.025 A
35 MT Detroit	0.92 B	.025 A
80 MT Detroit	1.49 A	.026 A
35 MT Mt. Vernon	0.91 B	.023 AB
80 MT Mt. Vernon	1.16 B	.026 A

Table 18-5. Black Locust Shoot and Root Dry Weights and Stem Diameters.

Treatment	Shoot	Root	Stem
	gm		mm
Check	0.65 B	.083 B	2.4 A
120 kg N	0.88 AB	.089 AB	2.6 A
35 MT Detroit	1.20 A	.133 AB	2.3 A
80 MT Detroit	0.91 AB	.103 AB	2.2 A
35 MT Mt. Vernon	0.83 AB	.103 AB	2.4 A
80 MT Mt. Vernon	1.17 A	.158 A	2.8 A

Table 18-6. Dry Weights of Conifer Shoots.

Treatment	BS†	DF	NF	WP	VP	SP	Norm.
	mg						%
Check	20 A‡	68 A	48 A	51 A	91 A	79 AB	1.00 B
120 kg N	24 A	76 A	46 A	60 A	97 A	91 A	1.12 A
35 MT Detroit	23 A	69 A	42 A	57 A	90 A	74 AB	1.01 B
80 MT Detroit	18 A	65 A	39 A	52 A	96 A	85 AB	0.97 B
35 MT Mt. Vernon	25 A	70 A	44 A	56 A	89 A	75 AB	1.03 B
80 Mt Mt. Vernon	18 A	63 A	39 A	47 A	83 A	65 B	0.88 C

† Blue spruce, Douglas fir, noble fir, white pine, Scots pine, Virginia pine.

‡ Values followed by the same letter do not differ at P = .05.

Table 18-7. Conifer Survival at Increasing Sludge Rates (good soil).

Rate	Species					
MT/ha	BS	DF	FF	SP	WP	Avg.
			%			
0	88 A	96 AB	100 A	75 A	98 A	92 A
11	84 A	100 A	98 A	79 A	98 A	92 A
22	76 AB	100 A	100 A	73 A	94 A	89 A
45	90 A	99 A	100 A	80 A	95 A	92 A
90	93 A	100 A	97 A	81 A	100 A	94 A
180	61 B	92 B	99 A	62 A	83 B	79 B

Table 18-8. Conifer Survival at Increasing Sludge Rates (poor soil).

Rate	Species					
MT/ha	BS	DF	FF	SP	WP	Avg.
			%			
0	83 A	94 A	95 A	79 A	95 AB	89 A
11	79 A	98 A	96 A	80 A	94 AB	89 A
22	88 A	99 A	98 A	81 A	99 AB	93 A
45	85 A	99 A	96 A	77 A	100 A	91 A
90	86 A	94 A	95 A	47 B	88 AB	86 A
180	59 B	55 B	46 B	50 B	81 B	58 B

Table 18-9. Conifer Growth at Increasing Sludge Rates (good soil).

Rate	Species					
MT/ha	BS	DF	FF	SP	WP	Total
			mm			
0	56 A	42 A	45 AB	34 A	86 AB	262 AB
11	47 AB	40 A	51 A	35 A	91 AB	263 AB
22	56 A	43 A	51 A	38 A	103 A	289 A
45	50 AB	39 A	47 AB	30 A	88 A	254 AB
90	48 AB	42 A	39 B	25 A	79 AB	233 BC
180	46 B	37 A	39 B	26 A	63 B	211 C

Table 18-10. Conifer Growth at Increasing Sludge Rates (poor soil).

Rate	Species					
MT/ha	BS	DF	FF	SP	WP	Total
			mm			
0	43 A	32 A	33 A	26 A	71 A	205 A
11	42 A	31 A	33 A	25 A	72 A	203 A
22	43 A	32 A	33 A	26 A	70 A	204 A
45	41 A	30 A	26 A	19 AB	70 A	186 AB
90	37 A	26 AB	23 AB	16 AB	55 AB	156 B
180	27 B	18 B	15 B	9 B	40 B	109 C

severe on the poor site.

New terminal growth at the better site was increased by an average of 9% by the 22 MT rate of sludge (nonsignificant), but was not improved at the poorer site (Tables 18-9 and 18-10). Growth decreased above the 22 ton rate, by 19% at the better site and 47% at the poorer site. Growth reductions at the higher sludge rates were again more severe in the poorer soil and were variable with species. There was a casual relationship between sludge effects on survival and growth. In the better soil, e.g., Fraser fir and Douglas fir were least affected in both parameters, while in the poorer soil both growth and survival were more affected in Scots pine than in any other species. The assumption that sludge would be more beneficial in a less fertile soil was not supported. It may be that this sludge was more toxic in the poorer, acidic soil (pH 4.9 vs 6.7). Another possibility is that deleterious sludge effects acted synergistically with other limitations on tree growth at the poorer site. That even low rates of sludge did not improve growth suggests other growth restrictions were important.

Sludge increased weed biomass significantly, with maximum growth at 90 MT (Figure 18-1). At the 180 ton rate, weeds were fewer in number but not lower in weight. Although the relative proportions of weed species

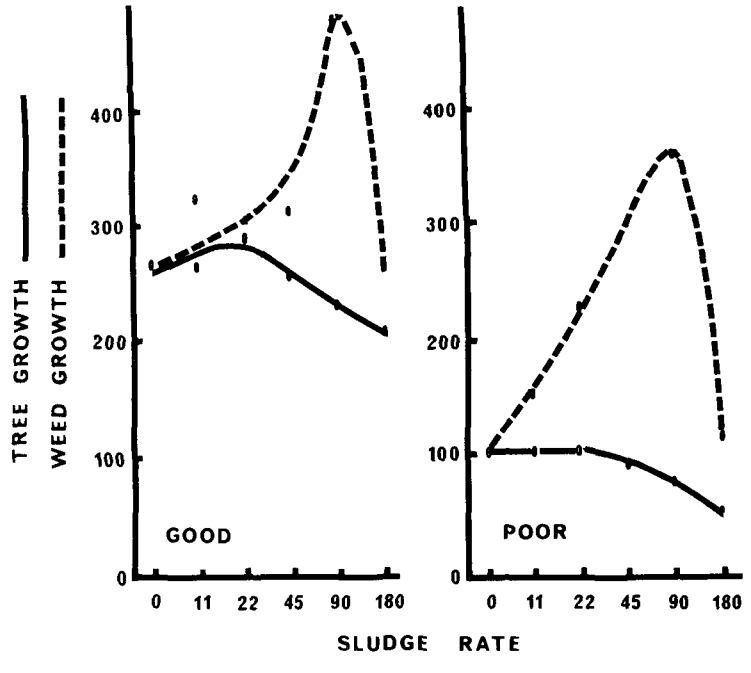

Figure 18-1. Comparative Growth of Weeds and Christmas Trees in Two Soils as Affected by Sewage Sludge Application (dry MT/ha).

appeared to shift as sludge was increased, such changes were not striking nor statistically significant.

These results are limited to initial growth, over a period when the seedlings or transplants rely to some extent on food reserves not affected by sludge treatment. Monitoring of these trees will continue to indicate how beneficial sludge application is after initial effects have occurred. Detrimental effects of sludge, such as the release of ammonia and other decomposition products, are greatest in the period after application. With a greater demand on the soil for nutrients and a reduction in toxicity, better subsequent responses to sludge appear likely but remain to be seen. After the initial flush of nitrogen, the imbalance between weed and tree growth should also decline. These considerations indicate that heavier rates of sludge should be incorporated, if possible, a season prior to tree seeding or transplanting. Although grass seed germinates poorly if sown too soon after sludge application (7), a heavy initial growth of grass may be useful if plowed under. Where soil fumigation is used, it should be scheduled after sludge application to eliminate weed seeds, particularly tomatoes, or plant pathogens which might be inadvertantly mixed into the sludge.

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19
RECLAMATION OF ACIDIC STRIPMINE SPOIL WITH PAPERMILL SLUDGE

H. A. J. Hoitink and M. E. Watson

Effects on plant growth of incorporating high papermill sludge rates into acidic stripmine spoil were investigated in greenhouse pot trials. The sludge (pH 7.2-8.5) was a mixture of primary and activated secondary sludges from the Mead Corp. plant at Chillicothe, Ohio (Kraft pulping process). The organic C/N ratio of the mixture ranged from 11 to 42. Sludge was incorporated into spoil (pH 2.5, 0.82% S) at levels of 0, 2.5, 5.0, 7.5, 10 and 15% (dry weight basis). Nitrogen was applied at rates equivalent to 0, 53+(178 slow release), 53+(356 slow release) and 53+(534 slow release) kg N/ha to each treatment. Kentucky 31 Fescue grass was seeded in each container and growth was evaluated by five harvests during 10 months growth.

In one trial (sludge mixture C/N ratio=42) the greatest quantity of grass dry material was produced with the 10% amendment and the 53+(356 slow release) kg/ha N rate.

Heavy metal concentrations in the spoil were high; those in the sludge were low, but those found in grass tissue were comparable to those in grass growing on agricultural soils.

An observation-type field trial was established in July 1979 on acidic spoil (pH 2.4, 0.71% S). Sludge (C/N ratio 17-42) was applied at rates of 7.5, 10 and 15% and a mixture of grasses and red clover seeded. Extensive grass growth was observed. Analysis of the leaf tissue from this trial did not show abnormal uptake of toxic elements. Leaf N concentrations were normal for the 10 and 15% amendment rates but low for the 7.5% rate.

Introduction

In the paper making process, only part of the original wood fiber is converted into paper products. The remainder, along with other by-products (mostly kaolinite) is lost in effluent. Because of the high biological oxygen demand (BOD) of paper mill effluent, direct disposal to natural waterways is not feasible. Therefore, primary and secondary treatment systems have been added to many mills to lower the BOD and remove suspended solids. Papermill sludge presently is disposed by burning, in landfills or by top dressing and incorporation into soil.

Sludge from mills with only primary treatment cannot be disposed of on land without causing serious crop yield reductions. This is due to the high organic carbon-nitrogen (C/N) ratio of the sludge (1). However, sludges

from the secondary activated biological treatment process contain sufficient N in relation to organic C so that N is not limiting to plant growth (2, 3).

The objective of this research was to study the effects on vegetative growth of incorporating mixtures of primary and secondary papermill sludge into acidic stripmine spoil. Results of greenhouse studies and a field demonstration trial are presented.

Materials and Methods

Sludge was obtained from the Mead Paper Plant (Kraft process) in Chillicothe, Ohio. The papermill effluent treatment plant consists of a primary and secondary activated sludge system. The ratio of primary to secondary sludge produced varied over the course of the two year study period. The primary sludge did not contain detectable nitrogen levels. The organic carbon-nitrogen ratio of the secondary sludge was 7.5:1. The organic carbon-nitrogen ratio of the primary-secondary sludge mixture varied from 13 to 42:1 (average C/N ratio for seven dates in 1979 was 23). The sludge (25-35% solids) contained approximately 50% clay (kaolinite) and 50% organic matter on a dry solids basis. Chemical analyses of the sludge are presented in Table 19-1.

Greenhouse Trial

A stripmine spoil used in greenhouse pot trials contained 0.81% S and had a pH of 2.5. Potassium and phosphorus were added to the spoil to adjust

Table 19-1. Chemical Analysis of Papermill Sludge.

Element[1]	Range
Total nitrogen (% N)	0.27-1.03
Phosphorus (P)	21-51
Potassium (K)	231-411
Calcium (Ca)	2705-5820
Magnesium (Mg)	635-874
Copper (Cu)	41-61
Zinc (Zn)	216-366
Manganese (Mn)	34-41
Cadmium (Cd)	0.1-1.4
Nickel (Ni)	35-63
Lead (Pb)	28-37

[1] All values except nitrogen represent ppm.

levels to 200 and 85 kg/ha, respectively. The papermill sludge used in this trial had a pH of 7.2 and an organic carbon-nitrogen ratio of 42:1.

Sludge incorporation rates were 0%, 2.5%, 5%, 7.5%, 10% and 15% on a dry weight basis (equivalent to 0, 56, 112, 168, 224 and 336 metric tons of dry sludge/ha-15 cm). Each sludge combination was mixed thoroughly with the spoil in a concrete mixer for 3 minutes and placed in pots (2.5 kg/pot). The pH readings of the 2.5, 5.0, 7.5, 10 and 15% sludge-amended spoil mixtures were 5.0, 5.4, 5.5, 5.6 and 5.6, respectively.

Five levels of nitrogen were added to each sludge incorporation rate. Ammonium nitrate was added at 53 kg/ha. In addition, slow release fertilizer (sulfur coated urea, O. M. Scott & Sons, Marysville, OH) was applied after seeding at rates equivalent to 178, 356 and 534 kg/ha. Kentucky 31 tall fescue was seeded at an equivalent rate of 55 kg/ha. Pots were watered as needed and 20-25°C temperature was maintained in a greenhouse.

Vegetation was harvested 10 weeks after seeding. Harvesting was repeated five times (once every 8 weeks) thereafter. Dry weight yields of foliage were determined for each cutting.

Results

Yields of the 2nd and 4th harvest for the various sludge incorporation rates are presented in Table 19-2. Grass died before emergence in the non-amended spoil. As indicated by the fourth and later harvests, sludge loading rates significantly affected yields. During earlier harvests, however, differences were less significant. Even at the highest incorporation rate (15%), maximum yields apparently were not obtained.

Table 19-2. Kentucky 31 Tall Fescue Yields from Acidic Stripmine Spoil Amended with Various Rates of Papermill Sludge.

Sludge rate (%)	Yield (g/pot) 2nd Harvest	4th Harvest
0	0.00 f[1]	0.00 f
2.5	3.38 b	2.93 e
5.0	3.73 ab	3.25 d
7.5	3.66 b	3.66 c
10	4.30 a	4.26 b
15	3.89 ab	4.69 a

[1] Values followed by the same letter are not significantly different at the 1% level of probability (Duncan's New Multiple Range Test).

Table 19-3. Effect of Nitrogen on Yield of Kentucky 31 Tall Fescue Yields from Acidic Stripmine Spoil Amended with Papermill Sludge.

Nitrogen applied (kg/ha)	Yield (g/pot)[1]	
	2nd Harvest	4th Harvest
0	2.22 c[3]	2.74 c
53	2.72 c	2.91 c
53+(178 SR)[2]	3.92 b	3.80 b
53+(356 SR)	5.11 a	4.57 a
53+(534 SR)	5.01 a	4.76 a

[1] Values are means of five sludge incorporation rates.

[2] From slow release nitrogen fertilizer.

[3] Values followed by the same letter are not significantly different at the 1% level of probability (Duncan's New Multiple Range Test).

Addition of nitrogen significantly increased yields (Table 19-3). The effect was more pronounced in the early harvests than in the later harvests. The effects of nitrogen application on yield for the various sludge incorporation rates are illustrated further in Figures 19-1 and 19-2. Grass yield increased with increased sludge incorporation levels, regardless of the N level applied. Furthermore, addition of nitrogen increased yields for each sludge rate. However, the rate of yield increase was greater when nitrogen was not applied (Figure 19-1) as compared to treatments where nitrogen was added (Figure 19-2). This may indicate that the nitrogen contained in the sludge was not as readily utilized when other sources of nitrogen were applied. The relationship between grass yield and applied sludge rate was predominately linear for the range of sludge rates used, indicating that maximum vegetative yield was not attained in this experiment.

Field Demonstration Trial

A 9-acre acidic stripmine spoil area (pH 2.4, 0.71% S) near Wellston, Ohio was selected for papermill sludge application. Sludge was applied at rates of 0, 7.5, 10 and 15% (dry wt) and incorporated within the top six inches of spoil. The spoil was seeded with a mixture of grasses and red clover in June 1979. Nitrogen, phosphorus and potassium were applied at 20 kg/ha. Extensive vegetation was established on all plots treated with sludge. Vegetation did not become established on the untreated areas. Leaf tissue was collected from this trial and analyzed for nitrogen and heavy metals. The leaf N concentrations were normal (3.45%) for the 10 and 15% sludge

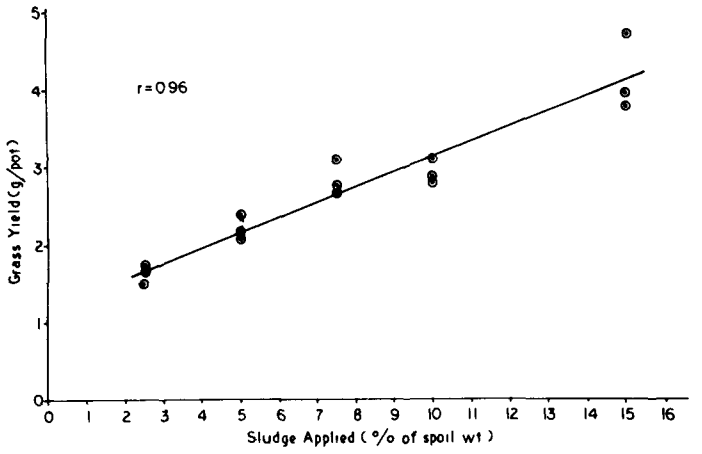

Figure 19-1. Effect of Sludge Incorporation Rate on Yield of Ky 31 Tall Fescue on Acidic Stripmine Spoil with no Additional Nitrogen Applied.

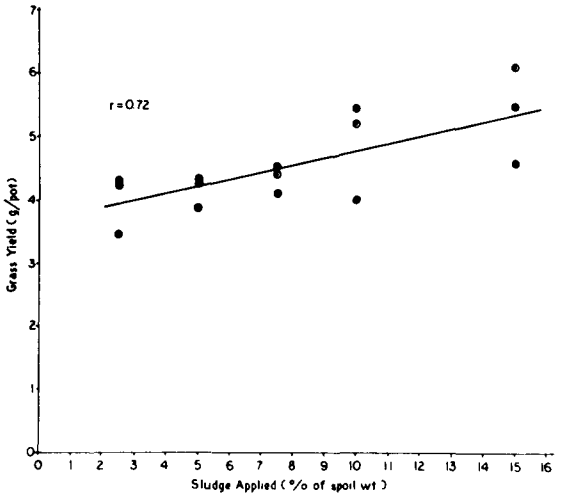

Figure 19-2. Effect of Sludge Incorporation Rate on Yield of Ky 31 Tall Fescue on Acidic Stripmine Spoil Amended with 409 kg N/ha.

incorporation rates but lower (1.97%) for the 7.5% rate. The analysis showed no abnormal heavy metal uptake by the plants grown in the sludge amended spoil (Table 19-4). The nutrient content will be monitored through time. Lush vegetative growth has been maintained throughout two growing seasons without any additional fertilizers applied.

Table 19-4. Comparison of Concentrations of Heavy Metals in Foliage of Grasses Produced on Agricultural Soils and on an Acidic Stripmine Spoil Reclaimed with Papermill Sludge.[1]

Element	Concentration of metals	
	Reclaimed spoil	Agricultural soils
Cd	0.7	0.01-3.0
Cu	6	10-30
Ni	2.5	0.5-5.0
Pb	0.1	0.5-10.0
Zn	19	20-30
Cr	1.0	0.05-2.0

[1] All values represent ppm.

The foregoing data indicate that a mixture of primary and activated secondary papermill sludge can be used successfully for reclamation of acidic strip mine spoil. Results obtained in this study are similar to those published for municipal sludges applied to acid spoils (4, 5).

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20
SEWAGE SLUDGE AIDS RECLAMATION OF DISTURBED FOREST LAND IN THE SOUTHEAST

Charles R. Berry

Sewage sludge as a soil amendment offers great potential for returning mine spoils, borrow pits, or badly eroded areas in the Southeast to full productivity. Excellent growth of loblolly, Virginia, and shortleaf pines, and sweetgum has been obtained on substrata on which 34 mt/ha of dried sewage sludge had been broadcast. On plots amended with this amount of sewage sludge, pine produced 25 times more seedling volume than on plots amended with 560 kg/ha of 10-10-10 plus 2,240 kg/ha dolomitic limestone. Shortleaf pine, however, survived poorly on eroded forest land amended with sludge. Mortality was due largely to competition from weeds stimulated by sludge amendments. Weed competition was not a problem on reclaimed borrow pits or other areas not already supporting herbaceous vegetation. Slit application of small amounts of sewage sludge is suggested for increasing early growth of tree seedlings where weeds are a problem or transportation of sludge in quantities sufficient for broadcast application is not feasible.

Introduction

Most published reports on use of sewage sludge in reclamation have been concerned with rehabilitation of coal strip mines in the Northeastern and Midwestern States. In southern Illinois, for example, Lejcher and Kunkle (1973) achieved good cover of K-31 tall fescue (*Fescue arundinaceae*) and weeping love grass (*Eragrostis curvula*) on strip-mined spoil in one growing season after applying 304 dry mt/ha of sludge containing about 5.0 percent total nitrogen. Treatments of 78 or 178 mt/ha, however, were not effective. Sutton and Vimmerstedt (1973) achieved good first-year growth of several cover crops on toxic mine spoil (pH 2.3) in Ohio after applying 294 dry mt/ha of sludge containing 1.76 percent N, 1.34 percent P, and 0.38 percent K. Also, in southern Illinois, Roth and others (1979) obtained good first-year response from several woody species to treatments of sewage sludge ranging from 462 to 668 mt/ha, with sycamore and autumn olive growing particularly well. Kerr, Sopper, and Edgerton (1979) evaluated responses after three growing seasons of several herbaceous and woody species planted on a burned anthracite refuse bank that had received treatments of heat-dried sewage sludge consisting of 0, 40, 75, and 150 mt/ha. They found that, in general, increasing sludge levels increased growth but decreased survival. Of the woody species tested, European balck alder (*Alnus glutinosa* (L.) Gaertn.), hybrid poplar (*Populus* sp.), and black locust (*Robinia pseudoacacia* L.) grew better

than white (*Pinus strobus* L.), Austrian (*P. nigra* Arnold), Virginia (*P. virginiana* Mill.), or red (*P. resinosa* Ait.) pines, white spruce (*Picea glauca* (Moench.) Voss.), Japanese larch (*Larix leptolepis* (Sieb. and Zucc.) Gord.), or black walnut (*Juglans nigra* L.).

Disturbed lands in the Southeastern United States include coal strip-mined spoils in Alabama, Tennessee, and Virginia; phosphate-mined spoils in Florida, North Carolina, and Tennessee; kaolin-mined spoils in Georgia, and North and South Carolina; and borrow pits in all States. Other problem sites are severely eroded former agricultural lands, including over 2 million hectares on the Piedmont Plateaus of Alabama, Georgia, Virginia, and North and South Carolina, and 2 to 3 million hectares of soils with sand two or more meters deep in Alabama, Florida, Georgia, and South Carolina. Another area badly in need of reclamation is the Copper Basin of Tennessee. It was denuded and removed from forest production in the 1800's by air pollution from copper smelting and today remains unsightly and the cause of severe stream siltation. While applications of sewage sludge probably would increase productivity on all of the above types of impoverished land, experiments with sewage sludge have been carried out on only a few of them.

This paper summarizes several U. S. Forest Service studies on the value of sewage sludge in reclaiming several kinds of disturbed sites in the Southeast. None of these sites contained toxic substances, but all have been problem sites, i.e., aesthetically displeasing, low or lacking in plant productivity, or highly erodable. In some cases, past efforts merely to establish a permanent ground cover have failed.

The sewage sludge for these studies was obtained from plants employing secondary treatment with anerobic digestion and sand bed drying. An analysis of this sludge (Berry, 1979) reveals about 2% N, 1% P, and 0.5% K. Recent additional analyses for metals reveal approximately 1.9 ppm Cd and 251 ppm Zn.

Experimental plots were prepared by thoroughly disking the sludge into the surface material, usually to a depth of 15 cm. In addition, the sites were usually subsoiled to a depth of 60 to 90 cm. Subsoiling is regarded as essential on many sites to facilitate planting and improve soil water and soil aeration. Spacing between subsoiled furrows and whether furrows were made in one direction or two varied by experiment. Treatment plots contained from 16 to 36 trees, and in most experiments treatments were replicated five times. Data were analyzed by analysis of variance and means were separated by Duncan's multiple range test or least significant differences.

The Tennessee Copper Basin

Starting in the early 1840s and continuing into the 1900s, air pollution from the processing of copper ore killed nearly all natural vegetation on

several thousand acres in the Tennessee Copper Basin. With the vegetation gone, erosion became severe and in time most of the A and B horizon soil throughout the basin was eroded away. In recent years, tree seedlings planted here barely survived unless nutrients were applied. Analyses of soil in this area reveal levels of total N, and exchangeable P and K as low as 60, 1, and 5 ppm, respectively. Tree seedlings planted in the area are commonly fertilized with a commercial 9 g starter tablet (Sierra Chemical Co., Miltipas, Calif.). Attempts to reclaim the basin, however, have met with only marginal success except near the perimeter where erosion and air pollution have not been so severe.

A single application of dried sewage sludge 1.3 cm deep (34 mt/ha), broadcast and incorporated into the soil before planting, stimulated volume growth of loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia pines 214%, 122%, and 253%, respectively, after 4 years over seedlings grown in plots receiving 896 kg/ha of 10-10-10 fertilizer applied in combination with 1,417 kg/ha of CaO (Table 20-1). A nonfertilized control was omitted from this experiment because previous work (Berry 1979) showed that nonfertilized seedlings make extremely slow growth and usually die soon after planting. Pines in the sludge treated plots are continuing to grow vigorously, are producing a thick layer of duff, and erosion has been checked.

Eroded Piedmont Forest Lands

Severe erosion of cropland in the Piedmont areas of Alabama, Georgia, North and South Carolina, and Virginia in the 1800s was brought about by poor agricultural practices. Originally, soil in this region was rich and productive, but after years of poor soil management much of the topsoil was removed

Table 20-1. Effect of Sewage Sludge on Growth of Pine Seedlings After 4 Years in the Tennessee Copper Basin.[1]

Treatment[2]	Survival %	Height cm	Diameter mm	Volume (D^2H) cm^3
		Loblolly pine		
Sludge	82.1a	190.7a	49.6a	5,582a
Fertilizer	79.4a	121.3b	32.9b	1,779b
		Shortleaf pine		
Sludge	62.8a	103.9a	26.8a	1,141a
Fertilizer	68.5a	74.3b	20.9b	558b
		Virginia pine		
Sludge	83.2a	178.0a	46.9a	4,491a
Fertilizer	89.0a	109.3b	30.7b	1,274b

[1] All values followed by the same letter within a column and species do not differ significantly at P = 0.05.

[2] Sewage sludge broadcast at a rate of approximately 34,000 kg/ha or 1.25 cm deep. Fertilizer (10-10-10) applied at 896 kg/ha with burned lime (CaO) applied at a rate of 1,417 kg/ha.

by erosion, leaving a hard, infertile, highly erodable substratum exposed or, at best, covered with only a thin layer of friable soil. It is estimated that 2 million hectares of this kind of land are covered with slow growing, low quality pines and hardwoods. Shortleaf pine, when grown on these sites often exhibits symptoms of nitrogen deficiency--short twigs and short chlorotic needles--a condition referred to as "littleleaf" disease. Although loblolly pines do not exhibit symptoms of nutrient deficiency to the extent that shortleaf pines do, growth of this species is also slow.

An experiment was conducted on a typical littleleaf site in eastern Georgia to compare the effects of 0, 17, 34, and 68 mt/ha of dried sewage sludge on growth of loblolly pine. Mean growth of loblolly pine was best at 68 mt/ha while shortleaf grew better at 17 mt/ha (Table 20-2). Sewage sludge stimulated luxuriant growth of ragweed (*Ambrosia artemisifolia*) and crabgrass (*Digitaria sanguinalis*), and failure to obtain statistical significance between mean growth values for pines is attributed in part to weed competition (Berry 1977). These results suggest that an application of herbicide following sludge application might be worthwhile where growth of herbaceous species is not desirable. On most reclamation sites, however, a heavy cover of natural vegetation may be highly desirable for stabilizing the soil.

Borrow Pits

The use of earthfill for construction projects results in the creation of borrow pits. Typically, borrow pits consist of exposed hard substratum material that is low in nutrients and organic matter and with poor internal drainage. Several experiments designed to study revegetation of borrow pits were installed at the Department of Energy's Savannah River Plant. Two experiments, one

Table 20-2. Growth of Loblolly and Shortleaf Pines on Eroded Forest Land Amended with Sewage Sludge After 5 Years.[1]

Sludge treatment mt/ha	Survival %	Height cm	Diameter cm	Volume (D^2H) cm^3	First year weed biomass g/m^2
		Loblolly pine			
0	96a	341a	8.3a	24,636a	121c
17	86a	369a	9.0a	33,901a	341b
34	67a	404a	9.9a	41,345a	321b
68	67a	359a	10.4a	41,307a	475a
		Shortleaf pine			
0	68a	202a	5.9a	8,867a	91d
17	77a	269a	6.8a	22,467a	228c
34	42b	281a	6.5a	14,308a	370b
68	-	-	-	-	563a

[1] All values followed by the same letter within a column and species do not differ significantly at P = 0.05.

Table 20-3. Chemical Soil Properties of a Borrow Pit After 3 Years as Influenced by Fertilizer and Lime or Sewage Sludge.[1]

Treatment	N	P	K	Ca	Mg	Organic matter	pH
	ppm					%	
Control (*no amendment*)	112b	7b	6a	4b	11b	0.4b	4.2b
Fertilizer and lime[2]	153b	13b	7a	16a	65a	0.6b	4.9a
Sewage sludge[3]	595a	84a	7a	22a	18b	1.6a	4.2b

[1] All values followed by the same letter within a column do not differ significantly at P = 0.05.
[2] 560 kg/ha of 10-10-10 fertilizer plus 2,240 kg/ha of dolomitic limestone.
[3] 34 mt/ha.

with loblolly pine and the other with sweetgum (*Liquidambar styraciflua* L.), have shown the value of dried sewage sludge as an amendment to improve tree growth on borrow pit sites.

Loblolly pine was planted on plots with (1) 560 kg/ha of 10-10-10 fertilizer and 2,240 kg/ha of dolomitic limestone, (2) 17 mt/ha of dried sewage sludge, or (3) nothing (Berry and Marx 1980). After 3 years, soil analysis showed that the sludge application maintained respective levels of N, P, Ca, and organic matter at 5, 11, 4, and 3 times higher than on control plots. The fertilizer-lime application increased Ca three-fold and Mg nearly five-fold, and raised pH from 4.2 to 4.9 (Table 20-3). While the fertilizer and lime treatment increased certain soil nutrients and pH, it did not increase growth of loblolly pine and only slightly improved growth of grass. Sewage sludge, on the other hand, provided a 25-fold increase in seedling volume and a 12-fold increase in grass cover over 3 years compared to the fertilizer and lime treatment (Table 20-4). Similar results were obtained by Ruehle (1980) in an adjacent study with container-grown loblolly pine seedlings. He reported that seedlings after 2 years had 20 times more volume on plots receiving 34 mt/ha sewage sludge than on plots receiving 560 kg/ha of 10-10-10 fertilizer with 2,240 kg/ha dolomitic limestone. Ruehle also found that ectomycorrhizal treatments interacted with soil amendments; the ectomycorrhizal fungus *Pisolithus tinctorius* stimulated 300 percent more volume growth than *Thelephora terrestris*, but only on plots amended with sewage sludge (Table 20-5).

In another experiment, sweetgum was planted on plots amended with 0, 17, 34, or 68 mt/ha of dried sewage sludge. Sweetgum, a consistent competitor on a wide range of upland Piedmont sites, is not normally planted to reclaim harsh disturbed sites because early height growth and crown

Table 20-4. Mean Growth and Survival of Loblolly Pine and Grass Biomass Production After 3 Years on a Subsoiled Borrow Pit as Influenced by Sewage Sludge and Fertilizer.[1]

Treatment[2]	Survival %	Height m	Root collar diameter cm	Seedling volume (D^2H) cm^3 (x 10^2)	Grass biomass g/m^2
Control	81a	0.63b	1.9b	4b	0
Fertilizer and lime	77a	0.72b	2.0b	4b	29b
Sewage sludge	74a	2.23a	6.4a	100a	353b

[1] Means followed by the same letter within a column do not differ significantly at P = 0.05.

[2] Fertilizer and lime: 560 kg/ha of 10-10-10 fertilizer plus 2,240 kg/ha of dolomitic limestone. Sewage sludge: broadcast evenly on the soil surface to a depth equal to 1.3 cm or 34 mt/ha. All plots double disked to incorporate amendments.

Table 20-5. Survival and Growth of Containerized Loblolly Pine Seedlings After 2 Years on a Borrow Pit.[1]

Treatment	Mycorrhizal condition	Survival[2] %	Height cm	Root collar dia. (cm)	Seedling volume (D^2H) cm^3
Sludge	*Pisolithus*	91.2a	107.2a	3.0a	1215.4a
	Thelephora	73.6a	76.0b	1.9b	390.4a
	Control	68.0a	70.7b	1.6b	236.5b
	$\bar{X}$[3]	77.6B	81.1A	2.2A	614.2A
Fertilizer	*Pisolithus*	96.0a	34.5a	0.9a	38.0a
	Thelephora	88.0b	31.4ab	0.9ab	35.0
	Control	89.6b	26.3b	0.7b	16.0b
	$\bar{X}$	91.2A	30.7B	0.8B	29.7B

[1] Means of survivors from 25 test seedlings initially planted in each of five plots. Each number followed by the same letter within groups of parameters does not differ significantly at P = 0.05.

[2] Damage caused by deer accounted for considerable within-treatment variation.

[3] Capital letters denote significant differences (P = 0.01) between groups according to Student't t-test.

closure are usually slow. Although survival was poor on sludge plots in this study--probably the result of heavy competition or allelopathic effects of fescue (Walters and Gilmore 1976)--the sweetgum seedlings that survived are growing very well after 4 years on plots receiving 34 or 68 mt/ha of dried sewage sludge. Their volume averages over 10 times that of controls (Table 20-6). The short-term growth rates of surviving trees exceed what is normally encountered in typical reforestation plantings with this species.

Table 20-6. Response of Sweetgum to Broadcast Applications of Dried Sewage Sludge After 4 Years.[1,2]

Sludge application mt/ha	Survival %	Height cm	Root collar diameter cm	Volume (D^2H) cm^3
0	81a	85.0b	1.6c	224b
17	52b	236.0a	1.9bc	1270ab
34	53b	281.5a	2.6ab	2382a
68	42b	239.0a	2.7a	2639a

[1] Values followed by the same letter within a column do not differ significantly at P = 0.05.

[2] Unpublished data courtesy Paul Kormanik, Richard Schultz, and William Bryan.

Table 20-7. Effects of Slit Applications of Dried Sewage Sludge and Forest Starter Tablets on Growth of Loblolly Pine Seedlings After 3 Growing Seasons.[1]

Treatment	Survival %	Stem height cm	Root collar diameter cm	Volume (D^2H) cm^3
Control	45a	26.2d	0.6d	14.3d
30 g sludge	56a	41.8c	1.2c	68.2cd
60 g sludge	70a	41.4c	1.2c	74.0c
90 g sludge	63a	46.3bc	1.5b	124.6bc
9 g tablet [2]	69a	49.4a	1.6b	147.9b
21 g tablet [2]	63a	56.5a	2.0a	297.9a

[1] Values followed by the same letter within a column do not differ significantly at P = 0.05.

[2] Sierra Chemical Company, Miltipas, California.

Slit Applications

When disturbed areas are so remote from a sewage treatment plant that it is not feasible to transport sludge in sufficient quantities for broadcast applications or when growth of natural vegetation would compete with tree seedlings, slit applications offer a viable alternative. In the Copper Basin, Berry (1979) showed that 90 g of dried sewage sludge placed in the "closing" hole when planting stimulated growth of loblolly pine about as much as a commercial 9 g forest starter tablet (Table 20-7). In a subsequent study on a borrow pit, sludge was enriched with a slow-release nitrogen [Nitroform Powder Blue (38-0-0), Hercules, Inc., Wilmington, Del.] to adjust total N to about 7 percent and then compressed into a circular pellet 2 inches in diameter and 1 inch thick (about 60 grams). After 1 year, trees treated with sludge pellets in slit applications were over 2.5 times larger in volume than controls and approximately 63 percent as large as trees treated with a commercial 21 g forest starter tablet (Table 20-8). A final evaluation of these two treatments, however, will not be made until several growing seasons have elapsed. While slit applications cannot supply quantities of nutrients and organic matter equal to broadcast applications, they do stimulate good early growth of tree seedlings.

Kaolin Spoil

About 8,498 ha had been surface mined for kaolin clay in Georgia by 1973, and up to 120,000 ha of land containing kaolin clay may eventually be mined. Spoil material from a surface mine near Macon, Georgia, was placed in redwood microplots 1.0 m x 1.5 m x 30 cm deep. The spoil was amended with 0, 34, 69, 138, or 275 mt/ha with each treatment replicated five times. Eight loblolly pine seedlings were planted in each microplot on a 30 x 30 cm spacing. Fresh weight of the aboveground biomass of the seedlings after one growing season was approximately doubled in the 34, 69, and 138 mt/ha treatments compared to controls, while the 275 mt/ha treatment did not improve growth over controls (Table 20-9). Although there was a significant decrease in survival related to increased amounts of sludge, seedlings used in the study had broken dormancy just prior to lifting from the nursery beds and may have been more sensitive to sludge amendments than fully dormant seedlings.

Discussion

The studies summarized in this paper have shown the value of dried sewage sludge for reclaiming several kinds of disturbed sites in the Southeast. The

Table 20-8. Stimulation of First Year Growth of Loblolly Pine Seedlings on a Borrow Pit with Pelletized Sewage Sludge.[1]

Treatment	Survival %	Height cm	Diameter cm	Volume$_3$ (D^2H) cm^3
Control	100a	29.4c	0.8c	191c
Sludge pellet	100a	33.6b	1.2b	520b
21 g starter pill	100a	40.8a	1.4a	831a

[1/] Values followed by the same letter within a column do not differ significantly at P = 0.05.

Table 20-9. Survival and Growth of Loblolly Pine Seedlings During 6 Months in Kaolin Mine Spoil Amended with Sewage Sludge.

Sludge rate mt/ha	Survival %	Height cm	Root collar diameter cm	Aboveground fresh weight g
0	99	28.6	0.8	23.6
34	84	42.7	1.4	53.4
69	81	45.6	1.4	54.0
138	60	36.0	1.2	49.3
275	39	27.2	0.6	19.8
L.S.D. (P = 0.05)	1.5	6.2	0.09	22.3

sludge used, while relatively low in total N and exchangeable P, was an excellent source of nutrients and organic matter. It should be an adequate amendment for most impoverished sites in the Southeast when applied at a rate of 34 mt/ha. Loblolly pine, one of the most important timber species in the South, is capable of extremely rapid early growth, even on the poorest of sites, after amendment with sludge. Virginia pine grows as rapidly on sludge-amended plots as loblolly pine in the Tennessee Copper Basin. Shortleaf pine, however, was not stimulated as much as loblolly by sewage sludge in the Copper Basin and was unable to compete with weeds, particularly on plots amended with 68 mt/ha, on an eroded forest site in Georgia.

Competition by naturally occurring weeds was not a problem on sites that were completely barren. Low survival of sweetgum on amended borrow pits, however, is attributed to competition and the allelopathic effects of fescue which had been planted as part of the reforestation experiment. In future reclamation efforts, the use of fescue for rapid stabilization should be avoided when hardwoods, especially sweetgum, are being planted as permanent species. Planting of other grasses should be delayed until tree seedlings are established.

Metz and others (1970) found 670 to 900 kg/ha of N, 15 to 22 kg/ha of P, and 62 to 108 kg/ha of K in the forest floor and the upper 7.6 cm of mineral soil in 20-year-old southern pine plantations. A sludge application rate of 34 mt/ha at 2% N, 1% P, and 0.5% K is equivalent to 680 kg/ha of N, 340 kg/ha of P, and 170 kg/ha of K, and theoretically would transform the nutrient status of the most barren site to that of an average southern pine plantation. Thus, such a treatment appears at this stage in these experiments to be more than adequate for mere reclamation, and promises to enable restoration of a devastated site to a fully productive forest.

Slit application of sewage sludge pellets or fertilizer starter tablets needs further study. Even though slit application of sewage sludge alone stimulated good growth in our experiments, enrichment of the sludge with a slow-release nitrogen fertilizer before pelletizing gave even better results. Since weeds are not stimulated by slit applications, tree seedlings derive considerable benefit from a minimal amount of sludge. Although seeded fescue rapidly covered the ground in the Copper Basin experiment, the close spacing of pines which grew rapidly on the sludge plots virtually eliminated the need for grass. In this experiment an early thinning (5 years) was necessary in order to maintain maximum growth of trees. Wood biomass from such early thinning could have value as fuel resulting in an early financial return.

Our results show that very rapid early growth of timber can be achieved on devastated sites in the Southeast by applying modest amounts of sewage sludge. Future research efforts will explore advantages and disadvantages of: (1) using sludge from different sources, (2) different methods of application, (3) the enrichment of sludge with fertilizer for slit applications, and (4)

possible interactions between subsoiling and soil amendments. In a few more years, results from these same experiments will indicate how long the benefits of sludge application on a devastated site can be expected to continue.

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21
USE OF ORGANIC AMENDMENTS FOR BIOMASS PRODUCTION ON RECLAIMED STRIP MINES IN THE SOUTHWEST

E. F. Aldon

This paper is a brief summary of some of our work with organic amendments on coal mine spoils in the Southwest. Much of the work is still in the experimental stage or being prepared for publishing. This symposium offered an opportunity to present our preliminary findings to you and they are given in an outline form. The Station began its initial work in cooperation with New Mexico State University with a greenhouse study using sludge and have recently expanded this work to several field studies. Some field studies include the use of sewage sludge. In other studies we are using other organic amendments. Both types of studies will be reported here.

We began with a pot study in the greenhouse using organic amendments in spoil material to test their effect on plant growth. The treatments tested were: a hay mulch added to pots at the rate of 10 tons per acre, sewage sludge added at rates of 40, 20, and 10 tons per acre, and nitrogen fertilizer was added at the rate of 300 pounds per acre, along with a phosphorus fertilizer at 3,000 pounds per acre. In addition, a topsoil treatment was included at a rate of 100 tons per acre. A randomized complete block design was used with four replications of each and all combinations of the treatments.

The pots were planted to blue grama (*Bouteloua gracilis*) grass and later thinned to six plants per pot. Dry matter yield was greatest for the fertilizer and sludge amended treatments (1). Bacterial populations (heterotrophic aerobic bacteria and several nitrogen cycle organisms) were highest in the fertilizer-amended spoils and lowest in the unamended spoil. However, greater fungi and actinomycete numbers were found in sludge-amended spoils than for other treatments. Sludge-amended spoils also had a greater variety of fungal species. Nitrification potential, CO_2 evolution, and dehydrogenase activities are now being conducted to correlate activity with treatment numbers and effects.

Encouraged by these results, a field study was installed this year on San Juan Mine near Farmington, New Mexico, using native hay crimped in the spoil at the rate of 1 ton per acre, sewage sludge applied at the rate of 5 tons per acre, a topsoil treatment 1 foot deep, and then a series of plots using mycorrhizae in the form of a root inoculant, a spore inoculant, and as a topsoil inoculant. Fourwing saltbush (*Atriplex canescens*) was planted. These plots were replicated four times. Each plot received 30 pounds per acre of phosphorus and nitrogen. A control of untreated spoil material was also used. The results of this study have not been measured as yet,

for it was just installed this past spring.

At the McKinley coal mine near Gallup, New Mexico, a study was installed 2 years ago to determine the effects of organic amendments and contour furrowing on grass establishment and soil moisture. The study was conducted at two locations on the mined area, a plot study in highly sodic shales and SAR's of around 30, and a demonstration area with SAR's of about one-third of those values found on the plots. Treatments on the plot area were replicated four times using approximately one-half hectare plots. Treatments in the demonstration area were on 10-hectare plots and were designed to demonstrate the treatments on an operational scale.

The Plot Study

Spoil amendments tested included the following: (1) partially decomposed pine bark, (2) barley straw, and (3) a check. The bark was spread on the spoil surface at a rate of 18 tons/ha and disked into the spoil. Nine tons/ha of long stem straw was broadcast on the plots.

Contour furrowing, both with and without the spoil amendments, was also tested. Large furrows (20 cm deep) were used with the bark and straw plots and standard furrows (12 cm deep) were used with a straw mulch. A single disk plow mounted on a crawler tractor was used to make large furrows. The plow was operated on the contour and furrows were broken every 5 meters by lifting the plow. A heavy disk harrow was used for incorporation of the straw and bark and for making small contour furrows.

Rangeland drill was used to seed the following wheatgrass species: western, fairway crested, intermediate, pubescent, and streambank (*Agropyron smithii, A. cristatum, A. intermedium, A. trichophorum,* and *A. riparium*). The seeding rate was 25 kg/ha with equal amounts for each species. Chemical fertilizer was broadcast on all plots at the following rate: 56 kg/ha nitrogen, and 112 kg/ha phosphorus. All plots other than those with organic amendments were mulched with 2.8 kg/ha of barley straw.

The numbers of plants established on the plots (including all grass species) in 1978 and 1979 did not differ with the treatment (2). Grass plants established ranged from 11 to 15 per square meter, considered an adequate stand for shale spoils. Intermediate and fairway crested made up 88 percent of the species composition. Intermediate was almost twice as tall as fairway crested wheatgrass. In general, both furrowed and non-furrowed plots with bark incorporation produced the tallest and thus the more vigorous plants.

Total grass production (2377 kg/ha) was greatest on plots with both bark incorporation and large contour furrows. The next lower level (1814 kg/ha) was on bark plots without contour furrows. The remaining plots were not different from each other and ranged between 495 and 770 kg/ha. The bark incorporation, especially when used with furrowing, was clearly the superior treatment on these plots.

Demonstration Area

Treatments on the three demonstration areas included: (1) incorporation of 11 tons/ha of straw applied and disked into the spoil in two separate applications and seeded; incorporation was done with the heavy disk harrow, (2) application of approximately 15 cm of topsoil to graded spoil, contoured, drill seeded, and broadcast straw mulch, and (3) graded spoil with the standard reclamation practice at the mine. The standard practice consisted of the following: contour furrowing on raw spoil with the heavy disk harrow, seeding with the rangeland drill, and a broadcast mulch of straw (5.6 tons/ha). All three treatments received broadcast fertilizer. The species seeded and broadcast fertilizer rates were the same as on the plot study. Soil moisture (% by weight) of field samples (8-15 cm depth) was determined by weighing. Bulk density was determined from cores (150 cc) of surface material.

The number of established wheatgrass plants was similar on all three treatments on the demonstration area. Grass plant density varied considerably by species, regardless of treatment, with intermediate wheatgrass being by far the most abundant. Grass plants were about four times as abundant on the demonstration area as on the plots, indicating important site differences.

Total production was very high on all treatments when compared to the plot area and especially to the surrounding unmined areas. The 4,038 kg/ha total production for straw incorporation is remarkably high considering the rainfall, potential ET and the spoil substrate. Most of this production (3,835 kg/ha) was due to intermediate wheatgrass on the straw-incorporated area. Both fairway crested and western wheatgrass made up minor components of the total production on this demonstration area.

During the wet 1978 fall, soil moisture was consistently high for all treatments. The dry 1979 fall period, however, caused low soil moistures and a difference in treatments. The straw-incorporated spoil retained more moisture than the raw spoil and especially the topsoil. Bulk density was also lower in the straw-incorporated area, resulting from the presence of decomposed straw in the sample and to the greater porosity it provided.

Wheatgrasses, especially intermediate, were found to respond well to amendments on sodic and less sodic coal spoils in the Southwest. Amendments, including pine bark and barley straw, in combination with contour furrowing were found to improve grass height growth and production. The less sodic spoils were much more productive overall than the sodic. Straw amended spoils with contour furrows produced the highest plant production (4038 kg/ha) of all treatments. This is an exceptional production (mainly intermediate wheatgrass) for an area of low rainfall (15 cm) and with a spoil substrate. Native production in the unmined area is only a small fraction of this level.

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Literature Cited

(1) M.S. in preparation - New Mexico State University
(2) M.S. in preparation - Rocky Mountain For. and Range Experiment Station

VII / RECLAMATION WITH CHICAGO SLUDGE

OVERVIEW

J. Schweigert

The use of municipal wastewater and sludge in land reclamation and biomass production raises numerous questions and concerns, especially about the potential long term environmental impacts and benefits that may result from such projects. Several large scale projects involving such uses of municipal sludge were initiated more than 10 years ago and have provided considerable opportunity to observe and investigate many of their long term results. The Fulton County Program has effectively utilized heavy applications of liquid sludge to convert many hundreds of acres of surface mine spoils into productive cropland. Corn, wheat and soybeans used for animal feed have been safely produced on this land which was reclaimed using sludge containing relatively high levels of heavy metals. Another long term project, the Palzo Project, involved the use of very high applications of a similar sludge to help restore highly acidic mine spoils to forest land. Careful monitoring at these projects of surface waters and groundwater, plus detailed studies of soils interactions, crop responses, plant uptake of contaminants and animal feeding studies have helped answer some of the questions and alleviate some of the concerns about the potential long term impacts of such uses of municipal sludge in land reclamation and reforestation projects on mine spoils. The results to date of these and other long term operational project monitoring and research efforts have also identified other issues that require further attention.

22
METROPOLITAN CHICAGO'S FULTON COUNTY SLUDGE UTILIZATION PROGRAM

James R. Peterson, Cecil Lue-Hing, John Gschwind, Richard I. Pietz, and David R. Zenz

In 1968, the Metropolitan Sanitary District of Greater Chicago (MSD) adopted a policy that its sludge was to be used for land reclamation or as an agricultural fertilizer. From 1970 through 1975, the MSD purchased 6,289 hectares of calcareous strip-mine spoils in Fulton County, Illinois for the purpose of land reclamation.

With the cooperation of the Fulton County Board, a reclamation plan was initiated in 1971 which included the following:

1. Level the mine spoils, where practical, to make row crop fields.
2. Apply liquid digested sewage sludge to these fields at rates which will rapidly rebuild the topsoil to approximately its original condition and fertility. Afterwards, sludge would be applied at a rate to maintain this condition.
3. Establish a water monitoring system to ensure that sludge constituents would not contaminate local waters.

Disc incorporation is used on 850 hectares of land, enabling up to 168 metric tons per hectare of sludge solids to be applied while controlling odors. Corn, wheat, and soybeans have been successfully grown. Soil organic matter has increased substantially, as have soil reserves of nitrogen and phosphorus.

Crops have been tested for heavy metal content, a major concern where sludge from an industrial area is used on land. In response to recent Federal regulations, future crops will be used only for animal feed.

Introduction

The United States sludge solids production has been estimated to be approximately 9,072 metric tons (10,000 tons) per day, and this amount is expected to increase to 11,800 metric tons/day (13,000 tons) by 1990 (Dean, 1973). Early workers in the field of sanitary engineering believed that biological treatment of municipal wastewater would leave no residue.

However, it soon became apparent that whether it be the Imhoff tank, the trickling filter, or the activated sludge process, sludge was produced in abundant quantities which required a means of disposal. In 1900, several methods of municipal sludge disposal were widely utilized in the U.S.; namely, plate presses and sand drying beds were used to concentrate sludge, and the resulting product disposed of in a landfill or given away as fertilizer to farmers (Hyde, 1938). By 1920, the principal method of municipal sludge

disposal was Imhoff digestion or separate digestion, followed by drying on sand beds and burying in shallow trenches (Hyde, 1938).

Since the 1920s, the types of municipal sludge disposal processes utilized have been many and varied, including flash drying to produce a dry fertilizer and incineration of dewatered sludge. Today, one can find a variety of processes which have found favor, but many municipalities still use the concept first utilized at the turn of the century; that is, utilization of municipal sludge for its fertilizer value.

It is safe to say that despite many years of research and operational experience, the most difficult problem facing municipal wastewater treatment agencies today is disposal of the sludge produced. In general, there is sufficient technology available to effectively remove most pollutants from municipal wastewater, but disposal of the resultant solids has been a difficult technical, social, political, and aesthetic problem.

Although the sludge processing technology utilized today may be very sophisticated, a residue always remains from processing which must be either disposed of or utilized. The product eventually finds its way to either land, water, or air; the consequences of which, must be evaluated. In addition, the processes selected for use today, no matter how sophisticated, must have low energy consumption rates.

Today, incineration is attractive to many, because the resultant product is an inert ash that is small in volume and less aesthetically unacceptable to citizens. However, the process releases significant quantities of air pollutants in the absence of very advanced and expensive air pollution control devices. Of even more concern, however, in today's energy situation, is the amount of fuel required for this process, which in 1974 averaged 215 liters of number 2 fuel oil to burn one metric ton of dry solids (51.6 gal/ton) (Olexsey and Farrell, 1974).

The ocean has been utilized by many coastal cities, notably Philadelphia, Los Angeles, and New York, as the ultimate repository of their municipal sludge. However, in the U.S., this method is considered by the Federal government to be detrimental to recreational use and aquatic life, and will be eliminated by 1981 (Olexsey and Farrell, 1974).

Landfilling of sludge is utilized by many municipalities for sludge disposal. The chief drawback to this method of sludge disposal is that there is often insufficient landfill space available in large urban areas for solid waste disposal.

The Metropolitan Sanitary District of Greater Chicago (MSD) believes that the fertilizer value of municipal sludge offers one of the best alternatives to municipal wastewater treatment agencies. The sewage sludge is applied on land in a controlled manner so as to reduce any potential environmental hazards. Utilization, rather than disposal, requires relatively small amounts of energy and offers the farmer a source of free or inexpensive fertilizer.

The MSD in 1970 purchased 2,898 ha (7,156 acres) of land in Fulton

County, Illinois, for the purpose of recycling a portion of the digested sludge generated within its jurisdiction. Currently, the MSD owns about 6,289 ha (15,528 acres) of land in Fulton County.

This paper presents information concerning the operational aspects, environmental impacts, and costs of operating a large-scale sludge utilization program.

Operation of the Fulton County Site

Waste-activated sludge and a small percentage of primary sludge is digested in heated (35±2 C) high rate digesters for 14 to 15 days at the MSD's West-Southwest (WSW) plant. The solids from these high rate digesters and, during warm weather, a portion of solids that have been previously stored in large holding basins (lagoons) near the WSW plant are pumped to barges for transportation to Fulton County, approximately 322 km (200 miles) down the Illinois River. The barges are docked at Liverpool, Illinois, and the solids are pumped 17 km (10.4 miles) through a pipeline to three holding basins at the MSD's land spreading site.

The land at Fulton County had previously been strip-mined, and much of it was being used for livestock pasture prior to the MSD operations. It is the intention of the MSD to grade the land to control runoff, increase the humus content by large additions of the organic matter contained in the digested sludge, and restore the land to full agricultural productivity.

Sludge was applied with traveling sprinklers from 1972 to 1975. By 1977, this method was replaced with incorporation by heavy duty, off-set discs which have several distinct advantages over traveling sprinklers. The disc incorporation device can apply a greater amount of sludge per application because the sludge is mixed into the soil at the time of application. Also, the reduced visibility, in contrast to the spray application, is an important aesthetic consideration. The disc incorporation devices can also distribute sludge to the perimeter of fields, while the spray application is often spotty due to difficulty of controlling the path of the spray under varying wind conditions. The tractor must pull the tandem disc through the soil and drag a 200 m (660 ft) length of 12.7 cm (5 in) diameter flexible hose. Such loads make it difficult to incorporate sludge during wet soil conditions.

The tandem disc currently being used is a heavy-duty agricultural type, approximately 3.34 m (11 ft) in width, which can till the soil to a depth of 20 cm (8 in). The disc is equipped with a manifold which distributes sludge to each disc-blade. Travel speeds are approximately 1.6 to 2.4 km/hr (1 to 1.5 mph). A disc with blades of 60 cm (24 in) or more in diameter, a blade spacing of 23-28 cm (9-11 in), and a working weight per blade of 90.6 kg (200 lbs) appears to be optimum for the highly compacted clay

soils at the Fulton County site.

Figure 22-1 shows a typical application field. Application fields are situated on both non-mined and mine-spoil areas. Each field receiving sludge is bermed and drains to a runoff retention basin. Each basin is designed to capture a storm event equalling the regional 100 year storm (15.5 cm). Runoff water is released only after it meets the State of Illinois permit standards (TSS≤99 mg/l, BOD≤33 mg/l, and fecal coliform≤494 counts/100 ml).

Sludge applied to the Fulton County agricultural fields since 1971 is typified by the 1979 data (Table 22-1). One metric ton of sludge contains 40 kg of total nitrogen; of this, 16.8 kg is ammonia nitrogen, making this sludge an excellent source of nitrogen. The sludge is well stabilized after high rate digestion and lagooning, and has a mean volatile solids content of 46.5%.

The annual and cumulative sewage sludge applications through 1979 to selected Fulton County fields are shown in Table 22-2.

Soil Response

The 6,289 ha (15,528 acre) reclamation site in west central Illinois is primarily comprised of strip-mined land, with rough corduroy topography and numerous lakes and ponds. Certain areas have been leveled for crop or pasture. Because sludge is being applied for reclamation purposes, the application rates are usually higher than crop nitrogen requirements.

A typical three-year field rotation schedule is to apply sludge for two years and then grow a crop the third year to utilize the available N and provide economic return. Soil sampling is done each spring prior to sludge application. Soil pH, organic carbon, and element concentrations, subsequently reflect soil conditions approximately five to six months after sludge application ceased the previous fall.

The effect of sludge application on soil pH in the selected fields is shown in Table 22-3. In most instances, the soil pH for the calcareous mine-spoil fields and non-mined (placeland) fields dropped somewhat after sludge application. The pH drop observed was most likely a result of organic-N being mineralized to form NH_4-N and NO_3-N, and the decomposition of readily degradable organic matter. These biological processes lead to the production of hydrogen ions and organic acids noted by other researchers (Miller, 1974; Parr, 1974; Touchton and Boswell, 1975; Varanka et al., 1976) on sludge amended-soils.

Table 22-3 suggests that soil pH in both strip-mined and non-mined fields decreased due to the application of sludge. On the calcareous mine-spoil fields, which normally receive more sludge than non-mined fields, the pH has dropped to a range of 5.9-6.8 after six years of sludge application.

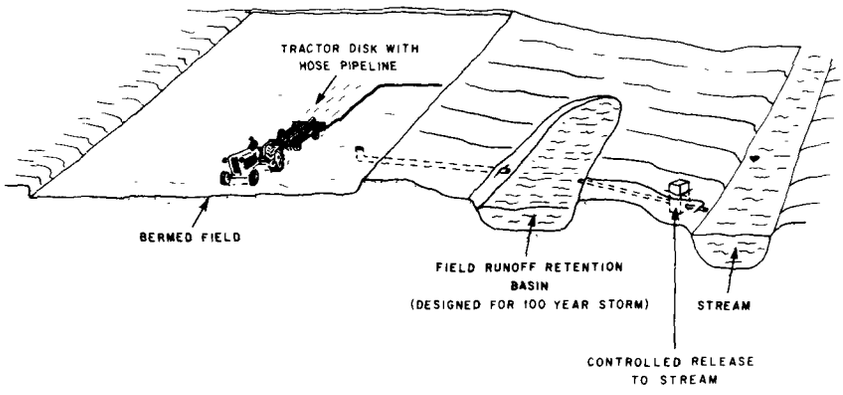

Figure 22-1. Typical Field Design with Runoff Water Capture System Fulton County, Illinois.

Table 22-1. Range of the Principal Constituents of the Digested Sludge Applied to Fulton County Fields from May 6 to October 21, 1979 and the Mean Content Per Dry Ton. Results are Based on Twenty-Two Weekly Composite Samples.

	Minimum	Maximum	Mean Dry Basis
pH	7.0	7.9	-
E.C., umhos/cm	3200	6800	-
	--------mg/l--------		kg/mT
Total P	1212	2060	30
N-Kjeldahl	1026	2435	40
$N-NH_3$	632	1072	16.8
Alk as $CaCO_3$	2250	5300	64
Cl	176	960	7.01
Fe	1561	4790	46.4
Zn	131	226	3.61
Cu	63.0	181	1.77
Ni	13	43	0.46
Mn	12.2	29	0.42
K	40	250	3.1
Na	40	110	1.75
Mg	370	720	10.4
Ca	970	2600	28.4
Pb	15.0	56.9	0.76
Cr	120	386	4.13
Cd	10.8	19.3	0.28
Al	410	830	12.3
Hg	0.049	0.368	0.0041
	----------%----------		
Total solids	3.84	6.04	1000
Tot. vol. solids	42.4	51.4	465

Table 22-2. Annual and Accumulative Sludge Dry Matter Application for Selected Fields at Fulton County, Illinois Land Reclamation Site.

Field Number[+]	Applied Sewage Sludge								Total Applied Sludge
	1972	1973	1974	1975	1976	1977	1978	1979	
	metric tons/ha								
Mine-Spoil									
1	0	0	43	65	120	0	116	0	344
2	0	0	54	41	129	83	36	107	450
3	10	3.4	55	23	83	0	83	14	271
5	0	1.8	52	90	81	0	53	75	353
7	0	1.3	48	50	13	64	59	0	235
25	0	0	22	65	0	112	85	27	311
26	0	0	61	28	98	108	88	17	400
28	0	0	38	82	95	0	79	135	429
30	0	0	45	43	101	126	23	115	453
34	0	0	0	71	18	64	58	59	270
$\bar{W}_x$	10	2.2	46	56	82	93	68	69	352
Non-Mined									
10	0	0	58	45	67	69	60	63	362
19	0	3.6	37	20	50	41	37	74	263
20	0	0	52	20	39	32	58	69	270
21	0	5.4	61	27	32	62	60	66	313
22	4.0	2.0	14	28	48	17	59	64	236
23	0	0	0	39	17	55	56	66	233
31	0	0	19	94	14	60	68	78	333
35	0	0	0	25	51	39	58	61	234
37	0	0	16	65	16	53	57	80	287
40	0	0	0	0	55	29	60	73	217
$\bar{W}_x$	4.0	3.7	37	40	39	46	57	69	275

[+]Weighted mean, $\bar{W}_x$, takes into account only those fields receiving sewage sludge for the year in the table.

Table 22-3. Soil pH in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.[+]

Field Number[+]	Soil pH						
	1973	1974	1975	1976	1977	1978	1979
Mine-Spoil							
1		7.4	6.5	7.0	6.9	6.8	5.9
2		7.7	6.8	7.3	6.6	6.8	6.6
3	7.8	8.0	6.8	7.2	6.6	6.5	6.5
5		8.0	7.2	7.2	6.5	6.9	6.5
7		8.1	7.2	6.8	7.2	7.0	6.7
25		6.8	6.8	6.5	6.5	6.5	6.4
26			7.2	7.2	6.8	6.9	6.8
28		7.3	7.3	7.2	6.5	7.1	6.7
30		7.4	7.0	7.4	7.0	6.8	6.8
34		7.4	6.8	7.0	7.0	6.6	6.6
$\bar{W}_x$	7.8	7.6	7.0	7.1	6.8	6.8	6.6
Non-Mined							
10		6.0	5.6	5.8	5.6	5.6	6.0
19		6.7	5.9	5.9	5.4	5.9	5.8
20		6.4	5.7	5.3	5.3	6.1	5.8
21		6.3	5.9	5.6	5.6	6.1	5.8
22	7.0	7.1	6.6	6.0	5.6	6.0	5.6
23		6.4	6.3	5.9	6.4	6.4	6.2
31		5.3	6.0	5.8	5.8	6.3	6.0
35		5.9	6.0	5.8	5.8	6.2	5.8
37		5.7	5.6	5.4	5.6	6.5	6.2
40				7.4	6.2	5.8	6.5
$\bar{W}_x$	7.0	6.2	6.0	5.9	5.7	6.1	6.0

[+] Composite soil samples from 0-15 cm depth were taken each spring prior to sludge application. Soil pH was determined using 1:1 soil/water ratio.

[+] $\bar{W}_x$, weighted mean, is based on analyzed soil samples reported for the year in the table.

Peterson et al. (1979) reported a mean pH of 7.4 on strip-mined lands prior to sludge application. In non-mined fields, the soil pH range was between 5.6-6.5 in 1979. Peterson et al. (1979) found the mean pH of these lands prior to sludge application to be 6.5. On non-mined fields, agricultural lime has been applied as required since 1977 to raise the soil pH to a more desirable level.

Sewage sludge application resulted in an increase in soil organic carbon contents (Table 22-4). Zenz et al. (1976) reported that the mean organic carbon levels of strip-mined and non-mined areas prior to sewage sludge application were 0.61 and 1.64%, respectively. The weighted means ($\bar{W}_x$) for the two land types in Table 22-4 show that sludge applications have generally increased the percentage of organic carbon in the soil each year. The 1979 sampling revealed organic carbon contents up to 4.72% in mine-spoil field 25 and 4.30% in non-mined field 20 (Table 22-4).

The addition of sludge organic matter has changed the bulk density

Table 22-4. Soil Organic Carbon in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.[+]

Field Number[‡]	Organic Carbon						
	1973	1974	1975	1976	1977	1978	1979
	----------	----------	----------	----------	%----------	----------	----------
Mine-Spoil							
1		0.68	0.75	1.30	2.31	2.82	3.62
2		0.54	0.95	1.28	2.74	3.38	3.72
3	1.25	0.86	0.96	1.23	2.62	3.08	3.80
5		0.38	1.04	1.14	2.69	2.97	3.89
7		0.30	0.59	1.20	0.98	2.69	3.63
25		1.28	1.44	2.48	2.11	3.99	4.72
26			1.16	1.59	2.41	3.59	3.13
28		0.66	0.68	1.38	2.34	3.10	3.35
30		0.53	0.84	1.06	1.89	3.57	3.57
34		0.48	0.17	1.32	1.09	2.50	2.83
$\bar{W}_x$	1.25	0.63	0.86	1.40	2.12	3.17	3.63
Non-Mined							
10		0.46	1.26	1.26	2.44	3.34	3.95
19		1.47	1.60	1.26	1.76	2.45	3.15
20		2.25	2.46	2.03	2.84	3.37	4.30
21		1.00	1.35	1.36	1.45	2.64	3.64
22	1.19	1.23	1.01	1.24	1.96	2.60	3.76
23		1.06	0.65	1.76	1.06	2.50	3.12
31		0.48	0.47	1.06	0.92	1.60	2.84
35		0.99	0.78	0.96	1.44	2.38	3.78
37		0.60	0.34	0.94	1.09	1.78	2.24
40				1.50	2.32	2.98	2.70
$\bar{W}_x$	1.19	1.06	1.10	1.34	1.73	2.56	3.25

[+] Composite soil samples from 0-15 cm depth were taken each spring prior to sludge application. Soil organic carbon by Walkley-Black method (Allison, 1965).

[‡] $\bar{W}_x$, weighted mean, is based on analyzed soil samples reported for the year in the table.

of strip-mined and non-mined fields. Peterson et al. (1979) reported bulk density of 1.61 and 1.29 g/cc for the upper 7.5 cm of strip-mined and non-mined areas, respectively, not receiving sewage sludge. Sampling of sludge-amended fields in 1977 showed a bulk density of 1.10, 1.19, and 1.10 g/cc in strip-mined fields 2, 3, and 26, respectively, and 1.23 g/cc in non-mined field 20. This indicates a lowering of bulk density by the addition of sewage sludge.

The soil levels of nitrogen, phosphorus, and potassium provide an index for examining the effect of municipal sewage sludge on the rebuilding of topsoil (Tables 22-5, 22-6, and 22-7). The available mineral N, exchangeable NH_4-N, and NO_3+NO_2-N of non-mined and strip-mined lands prior to sewage sludge application was 8.6 and 8.4 ug/g, respectively (Peterson et al., 1979). Soil N levels were not determined before 1975, so no comparison can be made with soil N levels after sludge application started in 1972 and 1973. The available mineral N generally increased each year with sewage sludge

Table 22-5. Available Mineral N in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.[+]

Field Number[‡]	1975	1976	1977	1978	1979
	ug/g				
Mine-Spoil					
1	32	65	123	21	156
2	62	48	232	44	137
3	37	43	225	28	224
5	37	77	206	20	120
7	60	86	68	26	248
25	74	90	38	68	210
26	114	55	127	42	261
28	76	71	211	33	385
30	60	49	126	52	239
34	17	80	88	53	221
$\bar{W}_x$	60	66	144	39	220
Placeland					
10	98	69	190	52	110
19	62	48	185	71	235
20	103	107	99	86	174
21	58	54	39	42	243
22	33	60	100	97	250
23	24	90	61	31	126
31	116	105	90	62	153
35	31	24	212	75	235
37	36	80	66	42	154
40		15	184	106	157
$\bar{W}_x$	62	65	123	66	184

[+] Available mineral N consists of exchangeable NH_4-N and NO_3+NO_2-N determined according to Bremner (1965). Determinations were made on 0-15 cm composite soil samples.

[‡] $\bar{W}_x$, weighted mean, is based on analyzed soil samples reported for the year in the table.

application for both mine-spoil and non-mined fields (Table 22-5). By spring of 1977, considerable amounts of mineral N were present in some fields of both land types. Crops are grown every third year to utilize some of the available N.

The amounts of available P in the sludge-amended fields have generally increased with yearly sewage sludge application (Table 22-6). The available P concentrations in the upper 15 cm of most sludge-amended fields increased each year. The yearly weighted means ($\bar{W}_x$) for both land types show that available P levels were generally similar in fields of both types and reflect the amounts of P added by sludge. Any initial differences in available P for mine-spoil and non-mined fields, prior to sludge application, were masked by sludge applied P; however, the availability of P on mine-spoil is lower, even though more sludge was applied to these fields.

The exchangeable K levels in the application fields were also increased by sewage sludge application. Although the amount of K in the applied

Table 22-6. Available P in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.[+]

Field[‡] Number	Available P					
	1974	1975	1976	1977	1978	1979
	ug/g					
Mine-Spoil						
1	9	10	115	160	240	280
2	9	13	121	171	226	333
3	20	12	115	162	191	258
5	7	17	182	150	218	344
7	9	20	220	139	217	287
25	14	15	121	109	139	497
26		30	94	196	167	523
28	11	9	117	172	177	572
30	10	11	74	122	242	558
34	19	3	123	88	352	452
$\bar{W}_x$	12	14	128	147	217	410
Placeland						
10	24	18	124	150	279	366
19	40	23	111	198	227	403
20	42	29	160	205	260	464
21	35	20	180	140	196	411
22	40	13	164	222	235	434
23	28	11	179	120	130	352
31	18	11	174	129	193	455
35	30	6	114	141	307	452
37	14	7	169	97	238	436
40			23	114	316	450
$\bar{W}_x$	30	15	140	152	238	422

+ Available phosphorus was determined by extraction with 0.03N NH_4F+0.025N HCl (Olsen and Dean, 1965). Determinations were made on 0-15 cm composite soil samples.

‡ $\bar{W}_x$, weighted mean, is based on analyzed soil samples reported for the year in the table.

sewage sludge is approximately 0.31% on a dry weight basis (Table 22-1), land application of sludge has generally resulted in higher concentrations of exchangeable K in most fields from 1974 to 1979 (Table 22-7). The weighted means ($\bar{W}_x$) for exchangeable K indicate that K concentrations were similar for mine-spoil and non-mined areas. Initial differences in available K, prior to sludge application, in fields on both land types were eliminated by 1977.

Crop Response

Typical crops for the area, such as corn, soybeans, small grain, and livestock forage, were grown to use the applied sludge components and to provide economic return for the project. Crop yields have been quite variable, ranging from excellent to nearly zero (Tables 22-8 and 22-9). Yields in 1977 were

Table 22-7. Exchangeable K in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.[+]

Field Number[‡]	Exchangeable K					
	1974	1975	1976	1977	1978	1979
	ug/g					
Mine-Spoil						
1	77	127	150	204	243	282
2	65	136	114	210	261	259
3	104	141	160	220	265	178
5	57	133	122	191	249	319
7	71	124	146	118	180	227
25	95	175	190	144	215	256
26		152	99	149	185	179
28	65	104	129	200	256	216
30	61	121	98	158	318	199
34	60	251	108	115	166	217
$\bar{W}_x$	73	146	132	171	234	233
Placeland						
10	125	119	150	213	250	353
19	108	132	112	238	261	241
20	104	214	148	217	297	239
21	109	187	188	152	231	331
22	89	168	120	180	149	239
23	55	202	152	116	146	189
31	61	133	152	140	194	220
35	102	177	132	165	186	245
37	92	176	130	151	168	180
40			114	138	177	154
$\bar{W}_x$	94	168	140	171	206	239

[+] Exchangeable potassium by extraction with 1$\underline{N}$ NH_4OAc (Pratt, 1965). Determinations were made on 0-15 cm composite soil samples.

[‡] $\bar{W}_x$, weighted mean, is based on analyzed soil samples reported for the year in the table.

affected by a dry year (20 cm H_2O for June and July), resulting in poor pollination. Adequate moisture and essential elements for crop needs on strip-mined soil were found to be critical for yields of crops grown immediately after land leveling. This stress condition gradually subsided as soil organic matter and element levels were built up with successive sludge applications (Tables 22-4, 5, 6, and 7).

Cadmium in Corn Grain

The concentration of cadmium in corn grain harvested from sludge-amended fields in Fulton County is shown in Table 22-10. With an approximate Cd concentration in the applied sludge of 280 ug/g on dry weight basis (Table 22-1), some fields had received 135 kg/ha of Cd by 1979.

In fields which had never received sludge, corn grain Cd levels ranged from 0.04 to 0.46 ug/g in 1979 (Table 22-11). By comparison, 1979 Cd

Table 22-8. Corn Yields in Selected Sludge Amended Fields[+] at Fulton County, Illinois Land Reclamation Site.

Field Number[‡]	Corn							
	1972	1973	1974	1975	1976	1977	1978	1979
	metric tons/ha							
Mine-Spoil								
1						0.85		3.64
2				2.95			1.37	
3	3.24	2.86	0.55	3.99		2.01		5.60
5						1.16		
7					1.62			2.97
25					2.39			4.10
26				2.80				4.22
28						0.70		
30				1.61			1.98	
34		4.12			5.32			
$\bar{W}_x$	3.24	3.49	0.55	2.84	3.11	1.18	1.68	4.12
Placeland								
10	4.40			3.75				
19	5.72	0.76	1.60				6.26	
20	4.19	1.44	1.25					
21	5.12	0.54	0.58		6.46			
22	4.66	3.72						
23	7.45	2.16			3.85			
31		4.47			3.30			
35		5.35		3.37				
37		5.50						
40								
$\bar{W}_x$	5.26	2.99	1.14	3.56	4.54		6.26	

[+] Commercial fertilizer was applied to fields 10 and 23 in 1972 and to fields 31, 34, 35, and 37 in 1973.

[‡] Weighted mean, $\bar{W}_x$, is based on yield data reported for each year in the table.

levels in corn grain from sludge-amended fields ranged from 0.46 to 0.81 ug/g; cumulative Cd applied to these fields ranged from 70 to 100 kg/ha and averaged 86 kg/ha.

Federal Regulations Concerning Sludge Application to Land

On September 13, 1979, the U.S. Environmental Protection Agency (USEPA 1979) published "Criteria for Classification of Solid Waste Disposal Facilities and Practices; Final, Interim Final, and Proposed Regulations" in the *Federal Register*. This regulation allows two alternatives for sludge application projects:

1. For land used to produce food chain crops other than animal feed--
   a. soil pH must be maintained at 6.5 or higher;
   b. by 1987, the annual application of Cd cannot exceed 0.5 kg/ha; and

Table 22-9. Soybean and Wheat Yields in Selected Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.

Field Number[+]	Soybeans		Wheat	
	1975	1977	1977	1979
	metric ton/ha			
Mine-Spoil				
34			3.85	1.41
Placeland				
19	0.81	0.54	4.69	
20	1.77		4.06	
22	0.96	0.55		
37				3.45
40			2.35	3.95
$\bar{W}_x$	1.08	0.54	3.52	3.82

[+] Weighted mean, $\bar{W}_x$, is based on yield data reported for each year in the table.

c. the cumulative application of Cd is limited by the soil cation exchange capacity.

2. For land used to produce animal feed--
   a. soil pH must be maintained at 6.5 or greater;
   b. there is a facility operating plan showing that the crops will be used strictly for animal feed and if alternative land uses arise, what measures will be taken to safeguard against possible Cd health hazards; and
   c. the land record or deed stipulates that the property has received high Cd application from solid waste and food chain crops should not be grown.

The MSD will adopt the second alternative and use the Fulton County land for the production of animal feed. In the case of alternative land uses, however, the MSD has recommended to the USEPA that a four-year period following cessation of sludge application is sufficient to reduce any possible cadmium hazard associated with food chain crops. Therefore, the MSD sees no need for the deed stipulation requirement.

Cost Associated with the Fulton County Site

Cost is a major concern in any publicly funded sludge disposal or utilization project. The total costs of the Fulton County project are $338.92 per metric ton of dry solids (Table 22-12). Capital costs are $38.13/mT or only about

Table 22-10. Cadmium in Corn Grain from Sludge-Amended Fields at Fulton County, Illinois Land Reclamation Site.

Field Number[+]	Cadmium in Corn Grain							Cd Applied Through Each Year						
	1973	1974	1975	1976	1977	1978	1979	1973	1974	1975	1976	1977	1978	1979
	ug/g							kg/ha						
Mine-Spoil														
1							0.52	0.0	12	32	68	68	100	100
2			0.29			0.63		0.0	16	28	66	93	103	133
3		0.09	0.37		0.14		0.81	0.9	18	25	50	50	73	77
5					0.69			0.5	16	42	66	66	81	102
7				0.35			0.46	0.3	14	30	33	54	70	70
25				0.22			0.65	0.0	6.4	26	26	62	86	94
26			0.41				0.60	0.0	18	26	26	61	85	90
28					0.52			0.0	11	36	64	64	86	124
30			0.15			0.43		0.0	13	26	56	97	103	135
34	0.01			0.37				0.0	0.0	22	27	48	64	81
$\bar{W}_x$	0.01	0.09	0.30	0.31	0.45	0.53	0.61	0.6	14	29	48	78	97	116
Placeland														
10			0.10					0.0	17	31	51	73	90	108
19		0.07				0.33		0.9	12	18	32	45	55	76
20		0.66						0.2	15	21	33	43	59	79
21		0.09		0.38				1.4	19	28	37	57	74	93
22		0.06						0.5	4.6	13	27	32	48	66
23	0.01			0.54				0.0	0.0	12	17	35	50	69
31				0.50				0.0	4.8	34	38	58	77	99
35			0.14					0.0	0.0	7.6	23	35	51	68
37	<0.02			0.32				0.0	4.7	25	30	47	63	86
40								0.0	0.0	0.0	16	25	41	62
$\bar{W}_x$	0.02	0.22	0.12	0.44		0.33		0.8	11	21	30	45	61	81

[+] Weighted mean, $\bar{W}_x$, is based on Cd data reported for each year in the table.

Table 22-11. Cadmium in Corn Grain in 1979 from Fields Which Never Received Sludge.

Field Number	Cd
	ug/g
Mine-Spoil	
18	0.46
50	0.30
145	0.04
$\bar{x}$	0.27
Non-Mined	
51	0.30
137	0.15
$\bar{x}$	0.22

Table 22-12. Projected District Solids Management System Cost for 1980 at Fulton County, Illinois.

Item	Capital+		M & O
	--------$/metric ton solids-----		
Anaerobic Digestion	15.87		45.19
Transportation	‡		146.62
Holding Basins	1.54		§
Land	4.19		
Site Preparation	5.51		§
Application	9.04		102.52
Monitoring	1.98		6.46
Sub-Total	$38.13		$300.79
Total		$338.82	

+ Lynam et al., 1978.

‡ Contractional agreement, all costs are included in M & O costs.

§ Any M & O costs are included under the application M & O cost.

11% of total costs. The M & O costs are $300.79/mT. Transportation accounts for 43% of the total costs.

The sludge currently being barged to Fulton County is 95% water and 5% solids (Table 22-1). The MSD is currently developing a method to increase the solids content to 60%. Digester drawoff will be centrifuged or lagooned

to obtain a 25% solids content; the sludge will then be spread 0.3-0.6 m deep in drying areas. By daily agitation of the sludge, a final solids content of 60% can be achieved in a few weeks. Compared to sludge with 5% solids this will result in a volume reduction of at least ten-fold and will substantially reduce the transportation costs.

This new program calls for two other principal modifications. The 60% solids sludge will probably be hauled to Fulton County by rail and be spread on fields from truck-type vehicles and later incorporated by plowing or discing.

Conclusions

1. The land application of digested sludge has proven to be an environmentally acceptable method of sludge management for MSD.

2. The MSD has found that incorporation of liquid sludge is more aesthetically acceptable and allows higher and more uniform application compared to spray application.

3. Observed increases in corn grain metal levels after sludge application will not affect human health, since the crops grown on the Fulton County site will be used only for animal feed.

4. The Fulton County project is a labor intensive operation with a current total cost of $338 per metric ton of solids applied. Future plans include going from a 5% to a 60% solids sludge, which will reduce transportation costs by a factor of three or four.

5. The Fulton County strip-mine soils have been improved substantially by the addition of liquid digested sludge as measured by soil fertility status.

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23
EFFECTS OF CHEMICAL AND PHYSICAL CHANGES IN STRIP-MINED SPOIL AMENDED WITH SEWAGE SLUDGE ON THE UPTAKE OF METALS BY PLANTS

T. D. Hinesly, K. E. Redborg, E. L. Ziegler, and I. H. Rose-Innes

Where digested sewage sludge was incorporated into the surface of leveled, strip-mined spoil banks at loading rates of 0, 224, 448, and 896 mt/ha (dry weight equivalents), pH values of spoil were 7.5, 7.0, 6.3, and 6.0, respectively. Organic carbon contents of spoil materials were increased from 2.4 to 2.8, 4.7, and 6.9 percent, according to the order of higher sludge loading rates. Ten months after sludge incorporation, untreated spoil contained 12.2% of water stable aggregates greater than 0.25 mm in diameter, as compared to 42.1% in spoil amended with 896 mt/ha of sludge. The available water holding capacity was increased from 14.8% in untreated spoil to 21.1% in maximum sludge-treated spoil. Electrical conductivity of saturated extracts ranged from 2.2 to 6.6 mmho/cm in untreated and maximum sludge-treated spoil, respectively. Corn grain yields were 3.2, 7.2, 6.7, and 4.0 mt/ha, respectively, from a plot treated with inorganic fertilizer and plots treated with 224, 448, and 896 mt/ha of sludge. Sludge applications caused marked increases of N, P, Ca, Mg, Fe, Cd, Cu, Cr, Ni, Pb, and Zn concentrations and decreased Na and K concentrations in spoil materials. Increased concentrations of elements in sludge-treated spoil caused significantly higher concentrations of N, P, Ca, Mg, Mn, Zn, Cd, and Ni in leaves, and N, P, Mg, Fe, Mn, Zn, Cd, and Ni in grain of corn. Comparison of ratios of concentrations in corn plant tissues to endogenous concentrations of chemical elements in spoil to similar concentration ratios resulting from sludge applications showed that elements added as constituents of sludge were less available for plant uptake than those originally present in spoil bank materials, except for Ni.

Introduction

Where municipal sewage sludges have been used as an amendment for reclaiming pre-law, strip-mined lands to row-crop production, yields were often considerably lower than had been expected. There are several reasons for low crop yields, but the main problem has been the lack of practices and structures to control erosion. Too often reclamation has been limited to the leveling of spoil banks to a topography that would permit use of equipment for applying sludge and farm machinery operations. As an afterthought, regulatory agencies have required the construction of berms

around sludge application sites and the construction of settling ponds to trap sediments that would otherwise be carried into streams. In a humid region, the building of berms around areas of spoil material, having exceedingly low water infiltration capacities, are inconsistent with the production of crops and the protection of water supplies. Sludge-amended spoil materials are eroded from the upper reaches of slopes and are deposited behind berms until the reduction in water storage capacity results in overtopping followed by massive discharge of materials into streams. Severe erosion at the upper end of slopes exposes buried stones that are a continuous obstruction to the operation of farm equipment.

Methods of applying sludges on strip-mined lands that are consistent with crop production and erosion control are limited. Irrigation of growing crops is limited to systems that apply sludge below the crop canopy. Spray irrigation systems cannot be used because leaf surfaces are coated with sludge solids that reduce light absorption and, thus, photosynthetic production rates. Where stoniness is a problem, subsurface interjection cannot be used because of costly repairs. Perhaps the worst system yet devised for applying sludges are those involving the use of disc plows for incorporation. The use of disc plows produces a subsurface compaction layer that exacerbates the low infiltration capacity of the predominantly weathered shale and/or glacial till material. This leads to increased runoff of water, with concomitant increases in rates of erosion.

The main objective in reshaping the surface of strip-mined lands should be to drain off excess water at a non-erosive rate. Sludge should be applied at rates and by methods that maximize the potential benefits of its organic matter contents to ameliorate physical properties of spoil that adversely affect the growth of plants. The technology needed to do this is available. Level-ridge terraces, equipped with surface inlets, can be used to control erosion. Sludge, dewatered to about 70% moisture, can be applied with ordinary farm manure spreaders.

On agricultural lands, maximum sludge loading rates should be regulated according to the potential for contaminating subsurface water supplies with nitrate-nitrogen. But on strip-mined lands that have subsided to form a compact structureless mass, water movement is too slow through such material to present a pollution hazard to ground water supplies. Protection of surface waters is the main concern and can be accomplished by maintaining control over runoff waters with structures and monitoring quality of water in impoundments prior to its release. Maximum loading rates of dewatered sludge on strip-mined lands should be limited by the tolerance of plants to sludge constituents and their effects on crop quality.

To identify plants that would rapidly establish vegetative cover and cropping systems that minimize erosion losses from sludge-amended spoil, a one-time, relatively high, sludge-loading rate study was established on strip-mined spoil banks in Fulton County, Illinois.

Description of Experiment

An experimental site, with good surface drainage, was selected on spoil banks which had been in place for about 30 years. The spoil material had a silty clay loam texture, $CaCO_3$ equivalent of 3.2%, and pH value of 7.5. Replicated (three) plots, having the dimensions of 21 x 18 m, were treated with 0 (control), 224, 448, and 896 mt/ha (dry weighg equivalent) of digested sewage sludge that had an average moisture content of 45%. Following the application of sludge and its incorporation with a rotary plow each main plot was subdivided into nine plots of 3 x 6 m and two additional plots of 6 x 18.2 m. Each of the smaller subplots were seeded with one of the following grasses: big bluestem (*Andropogon gerandi*), orchardgrass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), redtop (*Agrostis alba*), reed canarygrass (*Phalaris arundinacea*), smooth brome (*Bromus inermis*), tall fescue (*Festuca elatior*), timothy (*Phleum pratense*), and western wheatgrass (*Agropyron smithii*). Rye (*Secal cereale*) or wheat (*Triticum vulgare*) was seeded on the two larger subplots. During the first week of May, 3 m wide strips of rye and wheat were killed with paraquat and corn (*Zea mays*) was planted in the dead residues with a no-till planter.

From strips (3 x 18.2 m) of wheat and rye that were not sprayed with paraquat the top four leaves from 150 randomly selected plants were collected just before head emergence. Grain and straw samples were collected at the time of harvest. The leaf adjacent to the primary ear shoots was collected from ten corn plants in each of the dead wheat and rye plots when about 10% of the plants had tasseled. The leaves were washed in distilled water, dried at 60°C and ground in a Wiley mill. Corn grain and stalk samples were collected at the time of harvest.

Samples of spoil were collected from all main plots before sludge applications were made and each spring from subplots after sludge was applied. Six 2.5 cm diameter samples were collected from each subplot with stainless steel tubes to a depth of 91 cm and composited by 15 cm depth increments, except the lower increment was 30 cm. Additional samples of the surface 15 cm depth were collected periodically for determination of organic carbon, nitrogen, conductivity of saturated extracts, and changes in physical properties.

Sludge and sludge-amended spoil samples were analyzed for C, N, P, K, Mg, Ca, Na, Fe, Mn, Zn, Cu, Cr, Pb, Ni, and Cd concentrations. Plant tissue samples were analyzed for contents of the same elements except C, K and Na. Chemical analyses were previously described by Hinesly et al., (1977) and the procedures for measuring physical properties were those described in Agronomy Monograph No. 9 (Black et al., 1965).

Changes in Chemical Properties of Sludge-Amended Spoil

Concentrations of the several chemical elements of interest in sludge are

shown in Table 23-1, along with concentrations in sludge-amended spoil after various amounts of sludge were incorporated. Except for Mn, concentrations of all chemical elements were significantly affected by sludge applications. Potassium and Na concentrations in spoil were decreased by sludge applications, while concentrations of all other selected elements were increased. Although the highest sludge application markedly increased C and N concentrations in spoil, C to N ratios were changed only slightly from 10.9 and 10.3. The C to N ratio of sludge itself is intermediate to control and maximum sludge amended spoil. Phosphorus and Fe contents were somewhat higher in this sludge, which was dredged from a storage reservoir, as compared to sludge drawn directly from anaerobic digesters at the same Chicago wastewater treatment plant. However, concentrations in sludge samples were not high enough to account for the concentrations of these two elements found in spoil amended with 896 mt/ha of sludge. During storage P and Fe may have been concentrated by precipitation and sedimentation processes, but samples of dewatered sludge collected from manure spreaders evidently did not contain concentrations as high as those in sludge applied.

After sludge was incorporated with spoil the surface pH (15 to 18 cm depth) was reduced from 7.5 to 7.0, 6.3, and 6.0 by 224, 448, and 896 mt/ha of sludge solids, respectively. These pH values remained fairly constant for more than one year after incorporation. The pH of water saturated extracts, from spoil with and without sludge, are shown in Figure 23-1. These extracts were obtained to determine differences in electrical conductivities associated with various sludge loading rates and these results are shown in Figure 23-2. Electrical conductivities ranged from 2.2 mmho/cm in spoil samples from control plots to 6.6 mmho/cm in spoil amended with 896 mt/ha of sludge.

Changes in Physical Properties of Sludge-Amended Spoil

The results obtained by standard methods of determining aggregate stabilities by wet sieving with the Yoder apparatus for 10 minutes are shown in Figure 22-3. Water stable aggregates greater than 0.25 mm increased from 12.2% in samples from control plots as compared to 42.1% in maximum sludge-amended spoil.

Figure 23-4 shows that the amounts of water retained at saturation and 1/3- and 15-bar matrix tension increases in proportion to amounts of sludge applied. The rate of increase in moisture content at 1/3 bar was higher than that at 15 bar, thus, there was a small but significant increase in available moisture holding capacity with the two highest sludge application rates.

Crop Response

Corn, wheat and rye grain yields are exhibited in Table 23-2. All plots were fertilized with the equivalent of 840 kg/ha of a 12-12-12 blend of fertilizer

Table 23-1. Concentrations of Selected Chemical Elements in Sludge and Sludge-Amended Spoil Bank Materials.

		SPOIL				
		Sludge Application Rates				
		mt/ha				
ELEMENT	SLUDGE	0	224	448	896	LSD
	% (dry weight)					
C	12.20	1.11	2.63	4.33	5.96	1.23**
N	1.17	0.10	0.24	0.40	0.55	0.09**
P	3.60	0.08	0.78	1.90	3.51	0.88**
K	0.25	2.35	2.00	1.81	1.34	0.24**
Na	0.04	0.97	0.87	0.72	0.55	0.14**
Ca	4.04	0.61	1.09	1.69	2.32	0.52**
Mg	1.70	0.98	1.02	1.13	1.29	0.17**
Fe	6.85	3.76	4.48	6.32	8.26	1.75**
	mg/kg (dry weight)					
Mn	817	548	654	652	625	n.s.
Zn	4230	85	729	1530	2500	750**
Cd	276	0.72	42.5	95.4	161	36.5**
Cr	2760	44	390	847	1420	356**
Cu	1380	27	213	431	693	158**
Ni	284	44	89	138	203	38**
Pb	1090	15	134	284	476	145**

n.s. = not significant.
** = significant at $P \leq 0.01$.

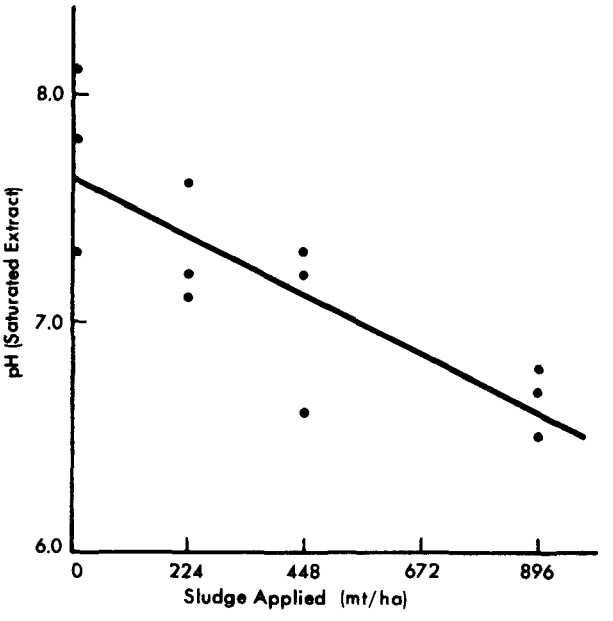

Figure 23-1. pH of Saturated Extracts from Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

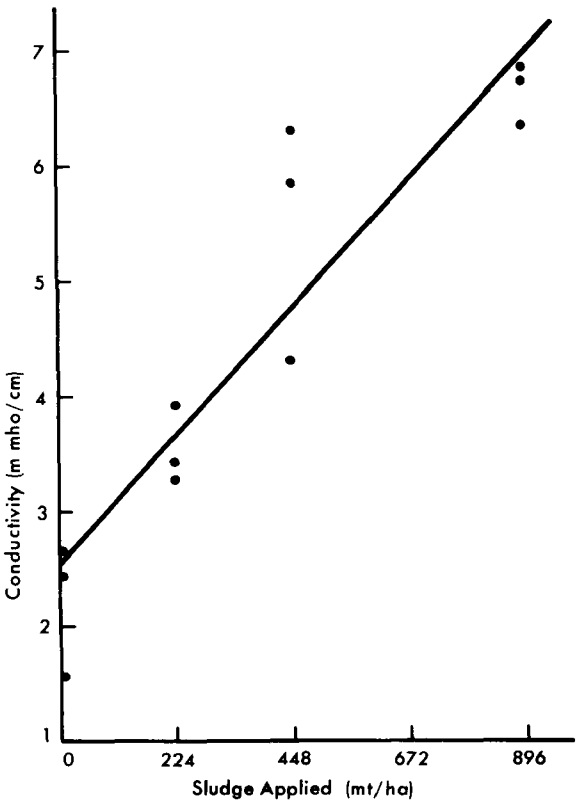

Figure 23-2. Electrical Conductivity of Saturated Extracts from Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

prior to seeding the wheat and rye. Corn yields on plots treated with the low and intermediate rates of sludge were significantly higher than those on fertilized control plots and plots treated with the highest rates of sludge. Differences in corn yields between wheat and rye mulch were not significant, although the latter provided considerably better coverage of the spoil surface. Wheat was preferentially grazed by wild geese for such an extended period into the spring that grain development was severely reduced. Rye was not grazed as intensively as wheat, but yields may have been affected since there was no significant differences due to treatments.

Six weeks after the initial fall seeding of the nine species of grass, at a rate of 25 kg/ha, tall fescue and perennial ryegrass were the only ones present at acceptable stands on most plots. After seeding again in the spring, these two were followed by fairly good stands of western wheatgrass. All grasses were established except big bluestem following the second fall seeding.

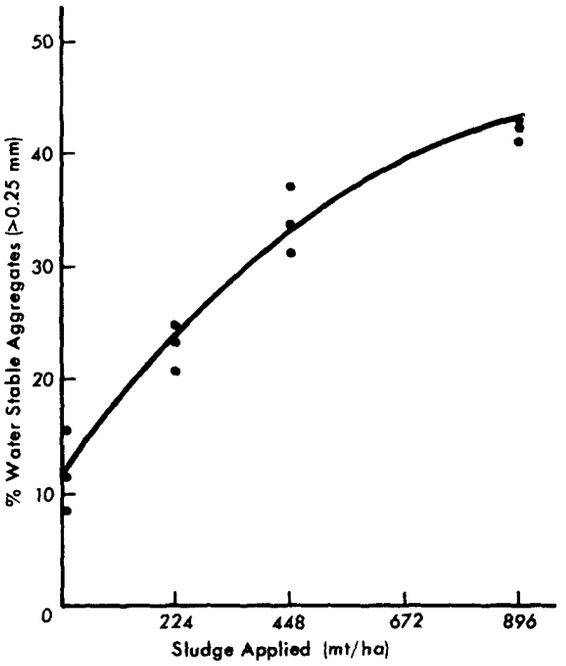

Figure 23-3. Percent Water Stable Aggregates in Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

From the standpoint of rapid establishment and vigorous growth on all sludge-amended plots, tall fescue, perennial ryegrass and western wheatgrass were the best by order of listing.

Inorganic Chemical Changes in Plant Tissues

Among the 12 elements for which concentrations were determined in plant tissues, only Fe, Cr, Cu, and Pb contents were not increased in corn leaves (Table 23-3) by sludge applications. Concentrations of Ni were increased in leaves at the maximum sludge application. Since there were no differences in concentrations in leaves with regard to corn grown in wheat and rye mulch crops, the data were combined for analysis of treatment effects.

As may be seen in Table 23-4, concentrations of elements were increased in corn grain by sludge applications except for Ca, Cr, Cu, and Pb. Iron concentrations were increased by sludge applications in corn grain from plots with dead wheat mulch, but not in those with rye mulch. Both Fe and Zn concentrations were significantly higher in grain from wheat mulch as compared to rye mulch plots. Concentrations of other elements were unaffected by differences in mulch and thus, the data for these elements

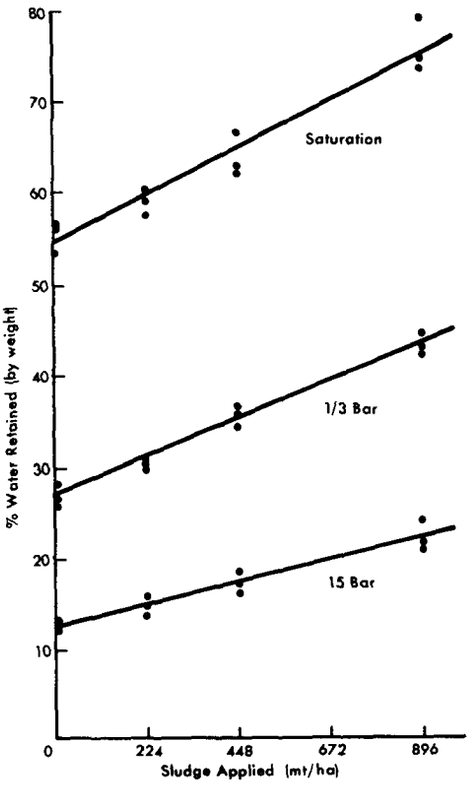

Figure 23-4. Percent Moisture Retention by Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

Table 23-2. Grain Yields for Corn, Wheat, and Rye on Spoil Banks with and Without Sludge. Corn was Planted in Dead Wheat (W) and Rye (R) Mulch With a No-Till Planter.

	GRAINS YIELDS			
	Corn		Wheat	Rye
SLUDGE TREATMENT	(W)	(R)		
	mt/ha			
0	2.68	3.29	n.d.	2.61
224	6.77	6.76	0.72[a]	2.36
448	5.64	6.81	1.93[b]	2.41
896	3.26	4.20	1.48[c]	2.33
LSD	2.70**	2.15*	--	n.s.

n.d. = No yield data due to bird damage.
a = only one plot.
b = only two plots.
c = three plots.
n.s. = not significant.
* = significant at $P \leq 0.05$.
** = significant at $P \leq 0.01$.

Table 23-3. Concentrations of Selected Chemical Elements in Corn Leaves from Plots With and Without Sludge.

	CORN LEAF				
	Sludge Application Rates				
	mt/ha				
ELEMENT	0	224	448	896	LSD
	% (dry weight)				
N	2.83	3.04	3.17	3.23	0.23**
P	0.23	0.28	0.32	0.35	0.04**
Ca	0.59	0.65	0.72	0.62	0.08*
Mg	0.47	0.45	0.47	0.56	0.08**
	mg/kg (dry weight)				
Fe	140	125	146	133	n.s.
Mn	25	43	73	179	23**
Zn	51	99	192	297	64**
Cd	0.2	2.7	11.6	15.4	4.1**
Cr	<0.12	<0.12	0.15	0.17	n.s.
Cu	11.5	11.6	12.0	13.2	n.s.
Ni	<0.62	<0.62	<0.62	1.68	0.35**
Pb	0.72	0.89	1.12	1.00	n.s.

n.s. = not significant.
* = significant at $P \leq 0.05$.
** = significant at $P \leq 0.01$.

Table 23-4. Concentrations of Selected Elements in Corn Grain from Plots With and Without Sludge. Corn Was Planted With a No-Till Planter in Dead Wheat (W) and Rye (R).

	CORN GRAIN				
	Sludge Application Rates				
	mt/ha				
ELEMENT	0	224	448	896	LSD
	% (dry weight)				
N	1.46	1.68	1.69	1.78	0.19*
P	0.27	0.31	0.36	0.38	0.03**
Mg	0.13	0.14	0.14	0.15	0.01**
	mg/kg (dry weight)				
Ca	65	61	51	50	n.s.
Fe (R)	19.9	21.9	22.6	22.2	n.s.
Fe (W)	24.9	32.5	31.7	34.9	5*
Mn	8.2	7.2	7.6	9.6	1.2**
Zn (R)	27.5	33.3	36.9	42.2	7.9*
Zn (W)	27.9	36.8	43.9	48.8	7.3**
Cd	0.03	0.24	0.36	0.36	0.12**
Cr	0.24	0.56	0.22	0.28	n.s.
Cu	2.8	2.8	2.6	2.8	n.s.
Ni	<0.62	0.72	1.43	3.25	0.64**
Pb	<0.62	<0.62	<0.62	<0.62	n.s.

(R) = corn on rye.
(W) = corn on wheat.
n.s. = not significant.
* = significant at $P \leq 0.05$.
** = significant at $P \leq 0.01$.

were combined. Nickel concentrations were higher in grain than in leaves.

Concentrations of selected elements in rye grain produced on control and sludge-amended spoil banks are presented in Table 23-5. Except for Ca, Mn, Cr, and Pb, concentrations of elements were increased as a result of sludge applications. Of those elements whose concentrations were affected by sludge applications, amounts of N, P, Fe, Zn, Cd, and Cu in grain were not increased by doubling the 448 mt/ha sludge application. Thus, only Mg and Ni concentrations were significantly increased in grain from plots treated with 896 mt/ha when compared to levels in grain from plots treated with 448 mt/ha.

Summary and Conclusions

The incorporation of sludge into the surface 15 to 18 cm of spoil materials produced a mixture that was about 8, 16, and 32 percent sludge for the three respective loading rates of 224, 448, and 896 mt/ha. Thus, the effect on physical properties were twofold. Physical properties of sludge itself were reflected in proportion to loading rates, and, secondly, some improvement in physical properties may have occurred as a result of stimulated microbial activity. However, because very little organic carbon was lost during the ten months that elapsed between incorporation of sludge and measurements of aggregate stability and available moisture holding capacity, microbes

Table 23-5. Concentrations of Selected Chemical Elements in Rye Grain from Plots With and Without Sludge.

	RYE GRAIN				
	Sludge Application Rates				
	mt/ha				
ELEMENT	0	224	448	896	LSD
	% (dry weight)				
N	2.08	2.28	2.64	2.62	0.42**
P	0.29	0.33	0.41	0.43	0.05**
Mg	0.12	0.12	0.15	0.17	0.02**
	mg/kg (dry weight)				
Ca	439	458	448	412	n.s.
Fe	41.5	42	47.6	47.9	5.4*
Mn	10.8	8.6	10.8	13.7	n.s.
Zn	37.7	57.7	75.7	83.4	15.30**
Cd	0.06	0.25	0.53	0.42	0.12**
Cr	0.18	0.14	0.18	0.25	n.s.
Cu	6.45	7.18	8.4	9.2	1.26**
Ni	<0.62	0.42	2.23	6.96	4.1**
Pb	<0.62	<0.62	<0.62	<0.62	n.s.

n.s. = not significant.
* = significant at $P \leq 0.05$.
** = significant at $P \leq 0.01$.

probably played only a minor role.

Because moisture contents at 1/3 bar increased more rapidly than at 15 bar of tension, available water holding capacity increased from 14.8% in spoil without sludge to 21.1% in spoil amended with 896 mt/ha of sludge. This increase in available moisture may have offset some of the deleterious effects on the growth of crops that were expected as a result of higher soluble salt contents in sludge-amended spoil.

The electrical conductivity (25°C) of 6.6 mmho/cm for saturated extracts of maximum sludge-amended spoil was in the range where a 25 to 50% reduction in corn yields was expected (EPA, Water Quality Criteria, 1972). Thus, at the highest sludge loading rate the increase in potential available water holding capacity was small in comparison to the increased osmotic pressure of soil solution. Corn yields on plots treated with 224 mt/ha of sludge were about 50% higher than those on plots treated with 896 mt/ha and it appears that this reduction was due to high concentrations of soluble salts. Both rye and wheat are more tolerant of high salt conditions than is corn and the results of this study show that if yields of small grains were affected by soluble salts, it was a rather nominal effect. However, it was probably a major factor affecting the establishment of some of the grasses. Western wheatgrass has high salt tolerance and while perennial ryegrass and tall fescue have only medium tolerance, they are more tolerant than the other grass species used in this study. Soluble salts appear to be the major factor affecting crop growth and survival of grasses at the seedling stage on spoil amended with sludge at loading rates which exceed 224 mt/ha.

For elements that had increased concentrations in spoils as a result of sludge applications and which were accumulated by corn plants by uptake and translocation into leaves and grain, concentration ratios (CR) were calculated and are presented in Tables 23-6 and 23-7. Endogenous concentration ratios were obtained by dividing the concentrations of a particular element in leaves or grain from control plots by total concentrations of that element in spoil materials that were not treated with sludge. Amended concentration ratios were calculated by subtracting concentrations in leaves or grain from control plots from those in similar tissues from sludge-amended plots and dividing by the remainder obtained by subtracting endogenous concentrations in spoil from concentrations in sludge-amended spoil. These concentration ratios are similar to those presented by Cataldo and Wildung (1978), except that they added a single concentration of each element (2.5 mg/kg) to the soil.

The CR's that could be calculated for corn leaves (Table 23-6) show that, except for Ni, the constituents of sludge were either not as available for uptake as endogenous elements or their uptake was limited by metabolically regulated processes.

In soil amended with soluble salts of metals, Cataldo and Wildung (1978) found CR's increased for As, Co, Cr, Mn, Mo, Ni, Pb, Sb, and Zn.

Table 23-6. Corn Leaf Concentration Ratios for Comparing the Uptake of Endogenous Elements to Those Added as Constituents of Sludge.

	CORN LEAF CONCENTRATION RATIOS			
		Amended CR Sludge Application Rates mt/ha		
ELEMENT	Endogenous CR	224	448	896
N	27.70	1.57	1.14	0.88
P	2.93	0.07	0.04	0.03
Ca	0.96	0.13	0.12	0.02
Mg	0.48	-0.38	-0.01	0.29
Zn	0.60	0.07	0.10	0.10
Cd	0.27	0.06	0.12	0.10
Ni	0.007	0	0	0.009

Table 23-7. Corn Grain Concentration Ratios.

	CORN GRAIN CONCENTRATION RATIOS			
		Amended CR Sludge Application Rates mt/ha		
ELEMENT	Endogenous CR	224	448	896
N	14.30	1.64	0.77	0.71
P	3.43	0.05	0.04	0.03
Mg	0.13	0.28	0.12	0.07
Fe (W)	6.62×10^{-4}	10.6×10^{-4}	2.66×10^{-4}	2.22×10^{-4}
Zn (R)	0.324	0.009	0.006	0.006
Zn (W)	0.329	0.014	0.011	0.009
Cd	0.043	0.005	0.003	0.002
Ni	0.007	0.009	0.012	0.018

(R) = Corn on rye.
(W) = Corn on wheat.

In this study Mn was not increased in spoil by sludge applications because concentrations in sludge were no higher than those in untreated spoil materials. Previous analysis of sludge from the same wastewater treatment plant showed that As, Ca, and Mo concentrations were too low to increase total concentrations in normal soils (Hinesly and Sosewitz, 1969) and this has been borne out by determining concentrations in soils treated with annual sludge applications beginning in 1967 (Hinesly and Hansen, 1979). Concentration ratios could not be calculated for Cr and Pb because they were not increased in corn tissues, although levels of these two metals were markedly increased in sludge-amended spoil.

Concentrations of Ca in corn grain were not affected by sludge treatments as they were in leaves, so CR's for this element could not be calculated for grain (Table 23-7). Iron concentrations in leaves were not affected by sludge treatments, but were in grain from corn grown in wheat mulch. Since Zn concentrations were higher in grain from wheat mulch as compared to rye mulch plots, CR's for Zn in grain from the two different

plots were calculated separately. As was the case for leaves, all CR's for grain produced on sludge-amended spoil were lower than those for grain from control plots, except for Ni. Concentration ratios for Ni tended to increase with increased sludge loading rates.

Because the pH was reduced from 7.5 to 6.0 on spoil amended with 896 mt/ha of sludge the decrease in concentration ratios with higher sludge loading rates is contrary to expectations. Also, since the highest corn yields were obtained with 224 mt/ha of sludge it is contrary to expectations that CR's decreased with higher loading rates that resulted in lower yields. Except perhaps for Ni, there is no evidence that metal concentrations in corn tissues were increased as a result of a reduction in growth.

The corn hybrid used in this study was the same as that used in another study where sludge from the same treatment plant was applied each year at maximum annual loading rates that were about 50 mt/ha. In some years, this hybrid accumulated Cd concentrations in grain of around 1 mg/kg. Therefore, it is unlikely that the accumulation of Cd and other elements in corn tissues from this high-rate study was limited by metabolic controls. Rather, it appears that with these exceedingly high sludge loading rates, some of the elements were less available for uptake. At such high loading rates the availability of some metals may be controlled to a much greater extent by the properties of sludge itself than those of the weathered geological materials. In the presence of excessive levels of oxidizable sludge organic matter, sparingly soluble sulfide forms of some metals may be rather stable and thus, availability of metals for uptake by plants may be maintained at low levels until the organic matter has been decomposed. However, it seems unlikely that they will become more available in time because results from other studies showed that Zn and Cd uptake decreased after sludge-applications were terminated (Hinesly et al., 1979). In view of the findings reported by others (Cunningham et al., 1975), it seems more likely that the high amounts of Fe and P supplied as constituents of sludge limited the availability of some of the metals by forming sparingly soluble precipitates.

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24
EFFECTS OF NATURAL EXPOSURE OF CATTLE AND SWINE TO ANAEROBICALLY DIGESTED SLUDGE

Paul R. Fitzgerald

During a 7-year period, the University of Illinois has cooperated with the Metropolitan Sanitary District of Greater Chicago in a study in which cattle and swine were exposed, under natural conditions, to anaerobically digested sewage sludge. Cattle were allowed to graze forage grown on reclaimed strip-mined land that was treated with different quantities of anaerobically digested sludge originating from the Chicago Metropolitan system. Experimental cows and calves were continuously exposed to the treated land while control cows and calves had similar exposure on land not treated with sludge. Each fall some cows and calves from both herds were necropsied and carcasses and tissues were examined for parasitic organisms, heavy metals, and organic compounds.

Specific Pathogen Free pigs were also exposed to AD sludge treated pens at various levels. The pigs were allowed to live in the "sludged" environment for approximately 4 months then were necropsied and carcasses and tissues were examined for abnormalities.

No significant differences in fertility were detected in the cattle herds. There was no evidence of disease in either herd. Nutrition was excellent due to the abundance of forage grown on the "fertilized," reclaimed land. Although the exposure of the swine to the sludge was much more concentrated, no disease or undesirable growing conditions developed in the pigs.

Parasitic organisms observed in the cattle herds were those usually found in grazing cattle (trichostrongyle worms and coccidia), but there were no differences between the control and experimental herds. Some experimental pigs, exposed to anaerobically digested sludge, became lightly infested with Ascarid worms. However, none appeared to be significantly affected. No other organisms were detected in either cattle or swine.

In both cattle and swine, some heavy metals were accumulated in some organs at levels variously greater than in the control animals. For example, kidneys and livers accumulated cadmium in proportion to the time and kind of exposure that the animals had had to AD sludge. Although accumulation of Cd in the kidneys, for example, was greater in experimental cattle than in control cattle, the levels were well below the concentration at which one would begin to detect clinical evidence of disease. After 6 to 7 years of exposure to AD sludge, no clinical or histopathological evidence was detected.

Introduction

Federal and State legislations have placed constraints on methods by which wastes may be discarded (1). Industrial chemicals and other wastes must be accounted for and be disposed of or inactivated in a safe manner. Soon, the dumping of wastes in the oceans around the United States must cease. Burning of wastes is generally inefficient, expensive, and in some cases, converts solids or liquids to airborne wastes. A feasible alternative is to return the waste to the land (2). Unfortunately, it is not a simple alternative. Discoveries that there are accumulations of heavy metals and organic chemicals in sludge-treated soils, that there may be potentially harmful pathogens in the sludge or that public pressure against spreading sludge on land have caused restrictions in the use of the land as a disposal site.

Disposal of industrial wastes is a problem quite different from disposal of sewage wastes although frequently, in large metropolitan areas, the problem is a single one. In some instances, industrial users of the public sewage systems consider the sewer to be a logical and convenient disposal site. The American public has found the home toilet or sewer man-hole to be a convenient disposal site. Whatever needs to be gotten rid of can be flushed down the toilet--"out-of-sight, out-of-mind". Unfortunately, some organic chemicals, heavy metals, etc., don't just go away by flushing them down the toilet. Modern-day, efficient sewage treatment plants extract those materials and concentrate them in sewage sludges. When the sludge is applied to the land, whatever is present becomes incorporated in the soil.

A factor important to the beneficial usage of sewage sludges is the degree of "risk" associated with the utilization of the sludge for land application (3). For example, is there a significant chance for disease transmission from a sludge to plants, humans, or animals? Would the sludges contribute substantially to food contamination by heavy metals or specific chemicals? Is there significant pressure from the public to maintain or improve the aesthetics of the environment? If one or more of such questions are unanswered, then a "risk" is involved and a decision must be made as to whether the risk to the health of the community is significant or insignificant.

Because of the complexities and interactions of some of these factors, the Metropolitan Sanitary District of Greater Chicago and the College of Veterinary Medicine, University of Illinois, have collaborated in studies during the past eight years in an attempt to get some answers to these important questions. This paper summarizes some of the results of these cooperative studies.

Effect of Anaerobically Digested Sludge on Some Plants and Macroorganisms

One of the first questions which arose as a result of application of

anaerobically digested sludge to soil was that dealing with the effect of the sludge upon the soil structure and upon the organisms present in it. The effect of the sludge on the soil profile has been discussed (4,5). We initially were concerned about the possible transmission of plant parasitic nematodes. A summary of the results of the studies with two plant nematodes is reported here to indicate the effect of anaerobically digested sludge (ADS) on the soil and some organisms present in it (6). In these experiments, seedlings of red clover (*Trifolium pratense* L.) or of soybean (Clark 63) (*Glycine* sp.) were grown in heat-sterilized Elliott soil or in sterilized Elliott soil to which the equivalent of 11, 23, or 45 metric tons of anaerobically digested (AD) sludge per hectare was added. Larvae of the Lespedeza cyst nematode (*Heterodera lespedezae*, Golden and Cobb, 1963), or the soybean cyst nematode (*Heterodera glycines*, Ichinohe, 1952) were inoculated into a small hole in the soil near the seedlings in each of half of the plots. There were 4 replicates for each combination of controls or treated soils which contained the sludge and the effect of the sludge on the nematodes and the plants, in the presence or absence of sludge, was examined. The experiments were terminated at the end of 60 days and plants were individually harvested, washed, and dried. Reduction of nematode cysts was used as a measure of activity of the worms, and they were counted by recovering them from the soil and the roots of individual plants.

Treatment of the Elliott soil with ADS, at the rates indicated, increased plant growth significantly over that of untreated control Elliott soil. The optimum level appeared to be 11 MT/H. Applications of the equivalent of 23 or 45 MT/H of sludge to the soil caused a slight depression in plant growth; however, the growth was still much greater than plants grown in the absence of ADS (Figure 24-1).

There were fewer nematode cysts recovered from the soil and plants

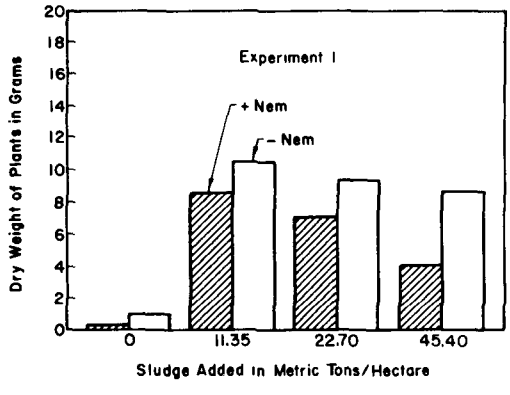

Figure 24-1. Effect of Anaerobically Digested Sludge Upon the Growth of Red Clover in the Presence or Absence of the Plant Parasitic Nematode Heterodera Lespedezae.
▨ = Sludge Treated; □ = Untreated Controls.

in the pots in which sludge had been added. In general, there was a reduction in the number of nematode cysts present in the soil depending upon the quantity of sludge added. The presence of the anaerobically digested sludge applied at the level of 45 MT/H produced the greatest inhibition in cyst production.

The effect of the ADS upon plant growth was directly related to the quality of the soil prior to the addition of the sludge. When ADS, at the levels listed, was added to a "good quality" greenhouse soil instead of Elliott soil, it was detrimental to plant growth. In the greenhouse soil, the presence or absence of nematodes had no significant effect on the plants grown in soil receiving ADS or in the control soils (Figure 24-2).

These experiments suggest that indeed anaerobically digested sludge has value as a fertilizer and soil conditioner in poor quality soils and may have nematocidal activity against some types of plant parasitic nematodes.

Changes in Soils and Plants Repeatedly Treated with Anaerobically Digested Sludge

With each application of sludge, organic and inorganic components (including chemicals and heavy metals) in the soil change (7). Table 24-1 shows the heavy metals content of some soils repeatedly treated with ADS, originating from the MSDGC system, in contrast to similar soils not treated with ADS. Whether the sludge is beneficial depends upon the nature of the soil. Plants grown in treated soils, therefore, are sometimes exposed to unusual quantities of materials like heavy metals. Plants take up the nutrients, as well as other materials, and incorporate them in the plant tissues. Forage plants and cereals of various kinds may incorporate some of the materials into the plant tissues

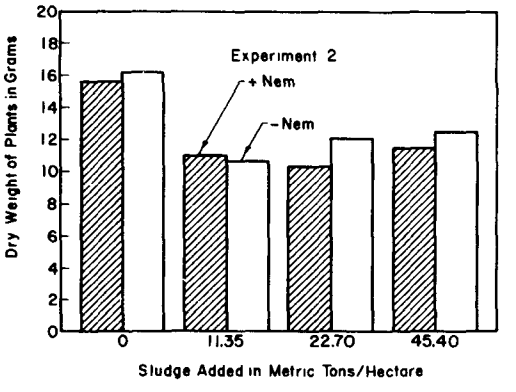

Figure 24-2. Effect of Anaerobically Digested Sludge Upon the Growth of Soybean (Clark 63) in "Good" Quality Greenhouse Soil, in the Presence or Absence of the Plant Parasitic Nematode Heterodera Glycines.
▨ = Sludge Treated; □ = Untreated Control.

or the grains. These in turn may be ingested by animals and a portion of whatever is present may be incorporated in the tissues of the animals. Table 24-1 also shows the levels of some heavy metals in forage grown in the soils treated or not treated with anaerobically digested sludge. Insofar as possible, plant samples were taken from plants grown in soil immediately adjacent to the plant. The figures in Table 24-1 are averages calculated from monthly samplings of soil and plants taken from the same plots. Control plants were grown in soils not treated with sludge but in the same general area as the experimental soils.

Animal Studies

The animal studies were initiated to gain information about utilization of ADS to reclaim strip-mined land and to put it into the production of forage plants. The forage and cereals grown were then to be utilized to feed cattle. Although several pasture grasses and legumes were grown, the most productive forage was the hybrid grass Sudax. Sudax was selected for a summer forage because it grew rapidly, utilized large quantities of nitrogen

Table 24-1. Summary of Heavy Metals in Soils and Plants Irrigated or Non-Irrigated with Anaerobically Digested Sludge. Mean Values in μg/g (ppm) in Experimental and Control Groups. Values Shown were Calculated from Monthly Samplings.

	Soils				Plants			
	1975	1976	1977	1978	1975	1976	1977	1978
Cd								
Exp $\bar{x}$	22	36	35	27	12	15	9	16
Cont $\bar{x}$	3	2	2	2	6	3	2	3
Cr								
Exp $\bar{x}$	268	382	391	340	47	136	24	23
Cont $\bar{x}$	16	19	18	7	4	8	2	1
Cu								
Exp $\bar{x}$	155	224	192	175	30	75	18	21
Cont $\bar{x}$	17	19	31	22	8	9	7	8
Ni								
Exp $\bar{x}$	47	73	59	21	8	19	8	10
Cont $\bar{x}$	24	19	22	46	3	8	2	3
Pb								
Exp $\bar{x}$	79	126	141	135	13	45	13	< 8
Cont $\bar{x}$	16	18	20	23	5	8	4	< 8
Zn								
Exp $\bar{x}$	368	479	485	469	114	198	52	113
Cont $\bar{x}$	46	53	55	50	28	32	27	25
Hg(NG/G)(PPB)								
Exp $\bar{x}$	660	590	361	----	19	115	68	23
Cont $\bar{x}$	364	92	27	----	28	49	24	30

and was palatable to the cattle. Although it produced large quantities of feed, it was relatively short lived (3-4 months). During other periods, the cattle grazed in pastures of grasses, legumes, and cereals such as corn stubble that were treated or untreated with sludge.

Direct Grazing by Ruminants on Forage Grown in Sludge-Amended Soils

Foraging animals react differently to sludge-treated forage. In our studies, it was found that ruminants (cattle) ingested sludge-amended forage readily and there was no exclusion because of palatability. Under the conditions of our studies, animals never refused to eat forage which had been exposed to ADS. Although sometimes vegetation had been heavily coated with sludge by overhead irrigation, most of the sludge dried within 24 hours and fell off the plants to the ground. Some animals ingested sludge by licking the ground or the hair coat, or by breathing dust that was stirred up during feeding activities. In some instances, ear corn or seed "heads" of Sudax grass contained dried sludge following application of anaerobically digested sludge by overhead irrigation. Water was probably not an important source of any unusual materials that might have been present in sludge.

We selected beef-type cows and their calves and randomly placed them on pastures treated with ADS or in similar pastures not exposed to ADS. Insofar as possible, 60 mature-to-aged experimental cows and 20 mature-to-aged control cows were allowed to graze on sludge-treated or nontreated Sudax grass, corn stubble, ear corn, grass-legume pastures, etc., for the same lengths of time although in different pastures. The study has been conducted as a "field study" and animals are cared for and handled in a manner similar to that which would occur on a farm or ranch operated by a farmer or rancher. All of the animals in each of the two groups were examined twice yearly and observations were made daily to detect any illnesses or health problems. Cows and calves were bled in the spring for serological studies and new calves were vaccinated, ear tagged, castrated, etc. Insofar as possible, milk samples were obtained from cows during the spring examinations. During the summer, experimental cows, with their calves, grazed in the experimentally treated pastures and control cows, with their calves, grazed in the untreated pastures. In the fall, the animals were again examined individually and groups of cows and calves were selected for necropsy.

Thus far we have been unable to associate illness of cattle with quantities of sludge ingested on forage. No gross changes in feeding activities have been observed and animals have all appeared healthy and strong as long as an adequate food supply was available.

Parasites in Cattle

A question which quickly arose was that of the concern for potential for

transmission of disease from the sludge to the animals. Since it was discovered that some parasitic organisms could pass through the sewage treatment process unaltered (8), we initiated a study to determine the levels of parasitism in the experimental and control herds. Among the parasitic organisms affecting cattle are the coccidia and trichostrongylinate worms. They are the most common potentially important parasite pathogens. In order to assess the levels of infection with these organisms, we initiated a system to collect random or individual fecal samples from animals in both herds. The samples were collected and examined for these parasites at least monthly for the past seven years. Figures 24-3 and 24-4 are a comparison of the fluctuations in the parasite loads as determined by random and individual fecal samples. At no time have we detected outbreaks of parasitic disease associated with either of these groups of parasites. In examinations of 160 cattle that have been necropsied to date, no tissue parasites (outside of the gastrointestinal tracts) have been found. One-hundred of these have been cattle variously exposed naturally to anaerobically digested sludge.

We have not conducted specific studies to isolate bacterial, viral, or fungal parasites. No recognizable disease conditions have appeared in the cattle herds that could be specifically related to these kinds of pathogens. However, semi-annual serologic examinations for *Leptospira* sp. and *Brucella* sp. organisms have been conducted with negative results.

Parasites in Swine

Two studies were completed in which 17 to 20 Specific Pathogen Free (SPF) "weaner" pigs were placed in confinement pens of approximately 2 acres. The equivalent of about 200 MT/H of dry ADS had been applied to the soil of the pens during the previous 5 years. The pigs were allowed to live "naturally" in the enclosure for a period of 4 months then were necropsied. In the first experiment, 10 of the 20 contained *Ascaris* sp. worms in the gastrointestinal tracts. In the second experiment, 2 of 17 contained worms in the gastrointestinal tracts. This suggests that viable *Ascaris* sp. ova were present in the soil in the pens which had been treated with the ADS and some of the pigs became infected. The presence of the worms appeared to have little or no detectable effect upon the pigs, however, because only a few worms (4-5) were present in any single pig. No other parasites were recovered from either the gastrointestinal tracts or tissues.

Heavy Metals in Animal Tissues

Cattle

One of the major problems associated with the utilization of ADS as a soil conditioner or fertilizer has been concern for the potential transmission of heavy metals, organic compounds or pathogens into the environment. Our direct grazing study was concerned with the potential transmission of heavy metals into the food chain as well as transmission of pathogens. As indicated,

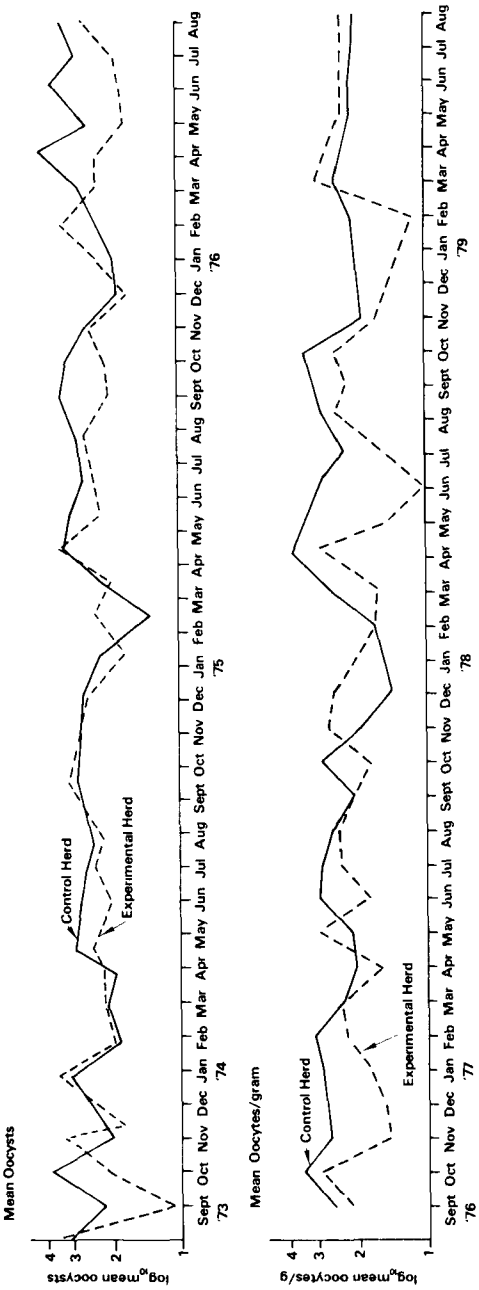

Figure 24-3. Comparison of the Average Levels of Coccidial Oocysts in Fecal Samples from Cattle Grazing Pastures Treated (Experimental) or Not Treated (Control) with Anaerobically Digested Sludge; 1973-1979.

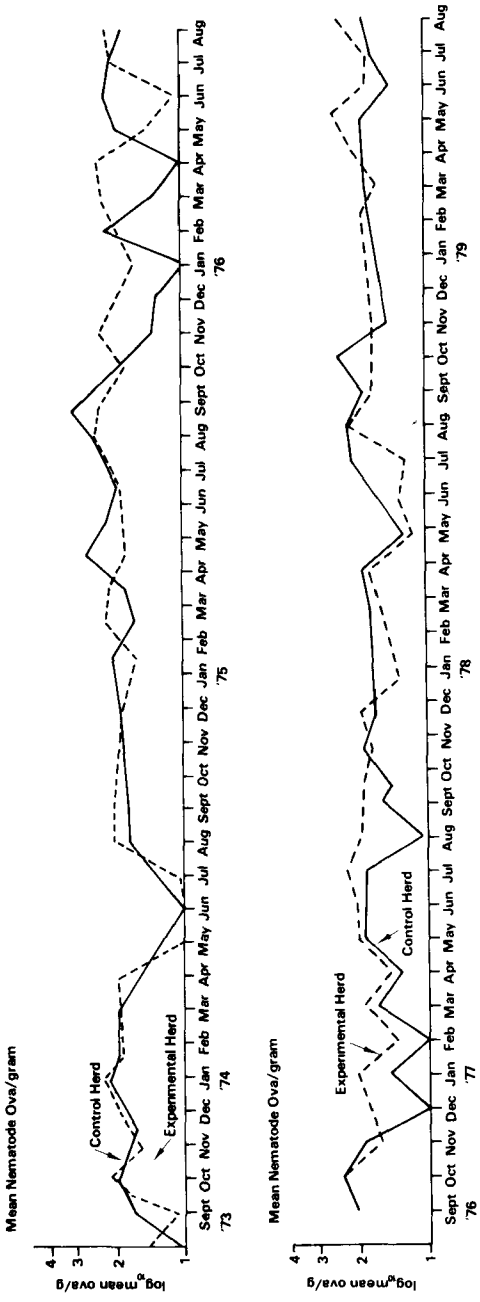

Figure 24-4. Comparison of the Average Levels of Trichostrongylinate Nematodes in Fecal Samples from Cattle Grazing Pastures Treated (Experimental) or Not Treated (Control) with Anaerobically Digested Sludge; 1973-1979.

each year a number of animals from the experimental and control herds were slaughtered with the intent of examining specific tissues for the presence of heavy metals, organic chemicals, or disease. Slaughtered cattle were grouped into two age groups consisting of calves less than 12 months of age born in the project, and of mature cattle, usually 5-15 years old. Some of the latter were born in the project. Most of the mature cattle had been in the control or experimental groups since the inception of the study (7 years). In addition, fetal fluids and tissues were secured from fetuses from a number of cows necropsied.

Tables 24-2 and 24-3 show the average levels of some heavy metals in vital tissues of cows or calves in the experimental and control groups. The figures shown represent the average ppm of heavy metals for the number of animals shown in parenthesis. These results are based upon freeze-dried tissues, a process which extracts essentially all of the water from the tissues. For example, lyophilization for 48 hours removes water so that kidney tissue is reduced to 21-23% of its original wet weight. Bone weight is reduced by 55%. Therefore, the ppm shown in the tables needs to be decreased

Table 24-2. Summary of Heavy Metals in Tissues of Adult Cows (8-15 years old) Ingesting Forage Irrigated with Sludge (ex) Compared to Tissues from Cows Ingesting Forage not Irrigated with Sludge (con). 1975-1979. Dry weight basis.

	µg/g						
	Zn	Cu	Cd	Cr	Ni	Pb	Fe
Diaphragm							
$\bar{x}$ Ex (39)	134	5	0.076	0.120	0.270	<1	120
$\bar{x}$ Con (14)	151	7	0.045	0.164	0.198	<1	136
Heart							
$\bar{x}$ Ex (39)	68	16	0.193	0.086	0.238	<1	242
$\bar{x}$ Con (14)	64	16	0.068	0.611	0.288	<1	216
Liver							
$\bar{x}$ Ex (39)	192	164	7.061	0.084	0.240	1.109	210
$\bar{x}$ Con (14)	117	60	1.800	0.472	0.415	<1	189
Kidney							
$\bar{x}$ Ex (39)	114	21	40.690	0.150	0.328	<1	306
$\bar{x}$ Con (14)	93	22	14.370	0.522	0.471	<1	315
Brain							
$\bar{x}$ Ex (39)	51	13	0.052	0.116	0.411	<1	93
$\bar{x}$ Con (9)	47	11	0.060	0.165	1.330	<1	137
Bone							
$\bar{x}$ Ex (40)	58	2	0.092	0.400	0.803	.736	2.413
$\bar{x}$ Con (14)	68	8	0.441	0.990	3.300	.940	14
Blood (wet wt.)							
$\bar{x}$ Ex (78)	3.1	.99	0.002	0.025	0.007	.084	NA
$\bar{x}$ Con (18)	3.1	.63	0.007	0.010	0.009	.026	NA
Milk (wet wt.)							
1974							
$\bar{x}$ Ex	2.1	.17	0.003	0.012	0.005	0.001	NA
$\bar{x}$ Con	2.3	0.19	0.003	0.009	0.008	0.001	NA
1976							
$\bar{x}$ Ex	3.7	0.10	0.002	0.483	0.166	0.016	NA
$\bar{x}$ Con	2.8	0.06	0.000	0.311	0.091	0.008	NA

Table 24-3. Summary of Heavy Metals in Tissues of Calves (less than 10 months old) Ingesting Forage Irrigated with Sludge (ex) Compared to Tissues from Calves Investing Forage not Irrigated with Sludge (con). 1975-1979. Dry weight basis.

	µg/g						
	Zn	Cu	Cd	Cr	Ni	Pb	Fe
Diaphragm							
x̄ Ex (43)	131	6	0.094	0.309	0.296	<1	87
x̄ Con (20)	141	6	0.067	0.618	0.385	0	NA
Heart							
x Ex (43)	71	17	0.111	0.220	0.428	<1	242
x̄ Con (20)	65	16	0.119	1.215	0.931	<1	NA
Liver							
x̄ Ex (43)	114	117	2.301	0.205	6.052	<1	193
x̄ Con (20)	118	113	0.688	0.360	0.606	<1	NA
Kidney							
x̄ Ex (43)	88	20	12.302	0.188	1.566	<1	351
x̄ Con (20)	81	20	3.875	0.357	2.376	<1	NA
Brain							
x̄ Ex (3)	47	10	0.062	0.121	0.290	<1	66
x̄ Con (20)	51	11	0.032	0.088	0.418	<1	NA
Bone							
x̄ Ex (43)	48	3	0.416	0.574	1.670	1.530	19
x̄ Con (20)	49	6	0.731	0.907	2.249	1.286	NA

by nearly 5 times (kidney and other soft tissues) and 2 times (bone) to ascertain the approximate live wet weight values in the tissues.

Table 24-2 also shows the quantity of heavy metals present in milk and blood from cows near the beginning of the study in 1974 and two years later after they had been on pastures treated with ADS.

In a somewhat similar grazing study, Kienholz et al. (10) reported significant increases in Zn and Cd in kidneys and livers of old range cows grazing forages grown in soils in which sludge from the Denver Metropolitan Sanitary District had been incorporated. None of the animals showed any gross or histopathological abnormalities at necropsy. The levels of Zn and Cd were lower in both liver and kidney than those shown in Table 24-2 of the present report. This may be partly due to their use of fewer animals, but it may also reflect differences in sludges, soil conditions, kinds of forage or lack thereof, etc.

Swine

Table 24-4 shows the average levels of heavy metals from tissues of swine exposed to ADS in confined pens. Weaner pigs (35 lbs) were confined to pens 9 m x 14 m and the soil was treated with sludge equivalent to applications of 12, 26, or 50 dry metric tons per hectare. They were fed standard, commercially prepared rations for approximately 4 months and

Table 24-4. Mean Levels of Heavy Metals in Selected Tissues Taken from Pigs Exposed to Different Levels of Anaerobically Digested Sludge (Dry Equivalents in Metric Tons/Hectare) in Soil During a 4-Month Feeding Period. Dry Weight Basis.

		μg/g					
	Animals	Cd	Cr	Cu	Ni	Pb	Zn
			Diaphragm				
Control	8	0.027	0.217	4	NA	< 1	93
12 MT/H*	4	0.047	0.235	4	NA	< 1	79
26 MT/H	8	0.368	0.425	6	NA	< 1	82
50 MT/H	2	0.026	0.469	4	0.100	< 1	59
			Heart				
Control	8	0.040	0.697	18	NA	< 1	74
12 MT/H	4	0.057	0.472	15	NA	< 1	66
26 MT/H	8	0.032	0.288	15	NA	< 1	74
50 MT/H	2	0.050	1.269	14	0.388	< 1	52
			Liver				
Control	8	0.074	0.111	17	NA	< 1	234
12 MT/H	4	0.369	0.160	38	NA	< 1	367
26 MT/H	8	0.822	0.583	18	NA	< 1	247
50 MT/H	2	0.451	0.463	9	0.087	< 1	108
			Kidney				
Control	7	0.544	0.442	45	NA	< 1	100
12 MT/H	4	1.322	0.194	45	NA	< 1	128
26 MT/H	8	4.375	0.322	32	0.125	< 1	116
50 MT/H	2	4.488	0.088	22	NA	< 1	66
			Bone				
Control	8	0.059	0.442	1	NA	< 1	112
12 MT/H	4	0.035	0.797	1	NA	< 1	121
26 MT/H	8	0.039	1.427	1.6	0.132	1.9	116
50 MT/H	2	0.051	0.594	3	0.188	1.25	95

*H = hectare.

then were necropsied. Their exposure to ADS was by ingestion of plants growing naturally in the pens and by contact with treated soil in the pens. In general, there were linear increases in some heavy metals in some tissues, depending upon the rates of application of sludge to the soil in the pens. Cadmium, for example, varied from 0.54 ppm in the kidneys of unexposed control pigs to 1.32, 4.38 and 4.49 ppm in the kidneys of experiemtnal pigs exposed to soils treated with 12, 26 or 50 dry metric tons of ADS per hectare. Cadmium appears lower than expected in kidneys of pigs exposed to the maximum levels of sludge, but the analysis is based on tissues from two animals and may not be a valid comparison.

Health Effects

In all of our studies, as well as those cited, there has been no indication of disease in experimental animals variously exposed to ADS. As far as we have been able to ascertain, the transmission of pathogens has not been a problem. Disease could have occurred as a result of the presence of some organics or heavy metals translocated to vital tissues such as kidneys and

livers where some heavy metals accumulate, but these tissues have not shown significant histopathology alterations. No pathogenic disease organisms have appeared in the cattle or swine; therefore, there has been no reason to believe that pathogens affecting cattle or swine were present in the sludge. Parasitic organisms such as *Ascaris lumbricoides suum* of swine have been shown to be transmitted through ADS to swine (9) but no similar infections have occurred in cattle.

Serological examinations of the blood of all animals, twice yearly, have failed to detect the presence of pathogens such as *Leptospira* sp. and *Brucella* sp. No attempts have been made to isolate specific viruses because no disease suggesting virus origin has appeared.

Performance

There have been no reports of morbidity or mortality in animals consuming sludge-fertilized (SF) products in a natural environment. Although performance data for growth of adult cattle discussed earlier are not available, weights of 10-month-old calves from control and experimental herds are presented. The average dressed weight of necropsied calves was 155 kg; the average live weight was 282 kg. There were no significant weight differences between control and experimental calves. Projected calculations to a yearling basis indicate that calves foraging on the ADS treated pastures would be near 350 kg (770 lbs).

Two feeding trials, designed to ascertain whether heavy metals in tissues of cattle could be reduced during a typical "feeding-fattening" period, were conducted. Twenty calves, originating from pastures treated with sludge and 10 calves originating from pastures not exposed to sludge, were taken from the experimental or control herds and were placed in a typical "feed yard" environment. Both groups were housed in concrete corrals and were given a prepared feed that was known to have been free of any exposure to ADS. The calves were approximately 9 months of age at the beginning of the experiment, and all were selected from the calves born in the project at the experimental sites during the spring. After 150 days in the feed yard, all were necropsied and kidney, liver, heart, diaphragm, muscle, brain, and bone were taken for chemical analysis. The results of the analysis of tissues from each "feeder" group are being compared to the results of analysis of tissues taken from herd calves necropsied 150 days earlier; peers of those necropsied after the feeding trial. The results of all the analyses are not yet available, but preliminary indications are that there was a reduction in the concentration of heavy metals in most tissues. Presently, we are not able to determine whether the reductions were due to dilution by growth or were due to physiologic activities.

Reproduction

Ingestion of forages and grains grown in soils treated with ADS does not appear to adversely affect reproduction in cattle. The presence of heavy metals in tissues of cows at the levels indicated in Table 24-2 did not appear to interfere with reproduction. Cows foraging on ADS fertilized pastures have performed as well as those foraging on control pastures. The rates of reproduction in the control and experimental herds have fluctuated between 85% and 90% during each of the 7 years of the study and there has been no significant difference in the rates of the two herds. Calves born to cows in the experimental group, grazing sludge treated pastures, have been equal to or superior in quality to control calves.

Detailed information on levels of heavy metals in fetal fluids and tissues is not yet available, but is presently being evaluated and should supply valuable information about the potential transfer of heavy metals from dam to foetus in the bovine.

Conclusions

Accumulation of heavy metals in soil, plants and animal tissues is of concern to those responsible for the safe and proper disposal of sewage wastes. Not all heavy metals are of equal concern. Currently, cadmium has received the greatest attention. Whether it justifiably deserves this attention has not yet been confirmed. Cadmium is accumulative in body tissues and is said to be a cause of failure of some organs. In warm-blooded animals, it accumulates in greatest concentrations in kidneys and livers. In our studies Cd concentrations were always highest in these organs. Kidney and liver normally could be expected to have higher levels of metals like Cd because it is their function to remove excess or harmful materials that may be excessive to the needs of the body. However, Cd is not known to be a required element and therefore any Cd is excessive to body needs. Other organs and tissues do not accumulate quantities of Cd at the levels found in the kidney and liver tissue. It has been suggested that accumulation of Cd in excess of 200 ppm in human kidney interferes with normal activity. The level at which pathology begins to occur in the ruminant kidney has not been specifically determined. In our studies, individual animals have had as high as 106 ppm but have shown no evidence of disease.

Other tissues such as somatic muscle, heart, brain and blood have been shown to acquire comparatively small quantities of heavy metals. Bone tends to accumulate lead, but it may bc metabolized and pass out of the body of some animals rather quickly. With the exceptions of Cd and Pb, none of the other heavy metals were significantly increased in various tissues and organs examined in our studies. Under the conditions of exposure herein

described copper, chromium, iron, nickel and zinc did not appear to be a threat to the animals well-being and the quantities of lead and cadmium accumulated appeared to be well below toxic levels in both cattle and swine.

Physiologically, swine are closest to the human body in many respects. Because of this, one may reasonably consider the results obtained in our studies to be applicable to humans.

No evidence of disease attributable to association with ADS has appeared in cattle in our seven-year study. Similarly, no evidence of disease appearing in swine living in close association with ADS has appeared.

The effect of ADS upon strip-mined, reclaimed soils has been one of improving the soil condition. The real value of ADS addition to soil is dependent upon the initial condition of the soil. In high quality agricultural soils, such as those found in Central Illinois, the addition of ADS is likely to be unproductive. In some instances, the presence or addition of ADS may be valuable in helping to control disease causing organisms such as plant parasitic nematodes.

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25
RESTORATION OF A WOODY ECOSYSTEM ON A SLUDGE-AMENDED DEVASTATED MINE-SITE

Paul L. Roth, George T. Weaver, and Michael Morin

Anaerobically digested sewage sludge was applied to an abandoned surface-mined tract in southern Illinois. Target application rates ranged from 400 to 1000 metric tons per hectare. The site is characterized by extensive amounts of pyritic materials leading to barrenness, highly acid runoff, and the most polluted waterway in Illinois. Third-year leaf, stem, and root tissue of *Acer saccharinum* L., *Fraxinus pennsylvanica* Marsh, *Pinus virginiana* Mill, *Betula nigra* L., and *Populus deltoides* Bartr. var. *deltoides* were analyzed for concentrations of Cd, Cu, Fe, Mn, Ni, and Zn in μg/g. Sludge-amended spoil samples from the rhizosphere of *A. saccharinum* were tested for pHw, H^+ ion content and metal elements Cd, Cu, Fe, Mn, Ni, and Zn.

General component part concentrations (μg/g dry weight), for third-year samples, indicated that roots and foliage consistently have higher metal contents than stems, but the overall trend indicates concentrations in third year tissues are lower than first-year tissues. For example, third-year stem and root tissues of *Betula nigra* exhibited Zn ratios of 11.15 and 11.33 respectively, while first-year ratios for stem and root were 17.90 and 20.40 respectively. The overall ranges in concentrations for the metals tested were: Cd, 0.01-950; Cu, 0.50-292; Fe, 0.50-8590; Mn, 5-3270; Ni, 0.50-85; and Zn, 10-2960.

Extractable spoil metal concentrations exceeded those in most published reports due in part to the low pHw (4.9) and appreciable H^+ ions present in the spoil substrate. In general there were poor correlations between spoil extractable amounts and concentrations in component parts of tree species.

The 126 hectare (312 ac.) Palzo tract in Williamson County, Illinois, was surface-mined from 1959 to 1961. Coal removal severely devastated the Palzo tract, an example of some 2835 hectares (7000 ac.) of previously productive land in similar condition in southern Illinois. Not only was the vegetation removed, but the patchwork of spoil types left after surface mining, because of their geologic composition, produced mineral acids that were extremely toxic to indigenous fauna and flora. The ultimate result has been extensive non-point-source pollution and subsequent deterioration of aquatic life and water quality below a site which had remained barren for two decades.

The ultimate goal of research at the Palzo site is to develop a feasible technology for restoration of an ecosystem on devastated mine sites through the application of municipal sewage sludge. The multiple benefits of this approach include: the utilization of the nutrients, organic matter, and water

composing the sludge; elimination of erosion of toxic spoils; reduction of acid runoff; restoration of barren mine land to a productive environment; and a socially acceptable and biologically and economically feasible method of sewage sludge disposal. The initial objectives of this study were to determine tree species suitable for planting on similar sites based on species overall growth performance, to evaluate several sludge application rates to determine which, if any, is most beneficial with respect to growth and survival of selected tree species, and to monitor any changes in acid runoff and water quality. Current investigations include heavy metal cycling, organic matter cycling of both the sludge and plant species, and spoil compaction.

Municipal sewage sludge, such as that from the Metropolitan Sanitary District of Greater Chicago, usually contains several toxic heavy metals which may damage plants, animal food chains (Chaney 1973), and adjacent aquatic ecosystems. Minimizing these hazards by designing a reclamation system which retains these metals on affected sites through biotic storage, while suppressing their entry into food chains, is the focus of current research at the Palzo site. One requisite for success is identification of woody species that can tolerate and accumulate heavy metals in tissues which are not heavily grazed by herbivores.

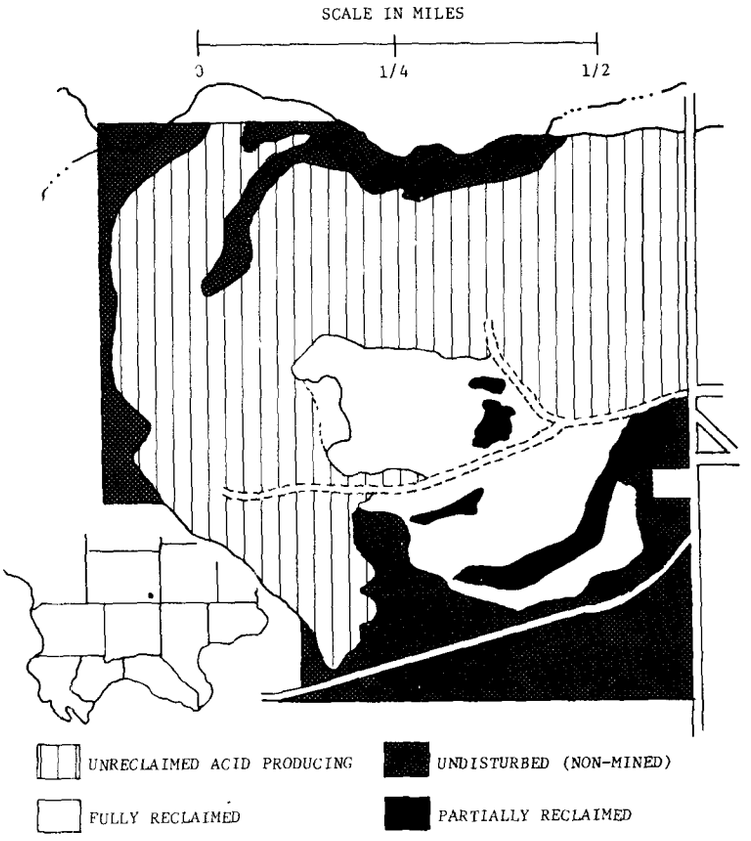
Consequently, as part of a comprehensive study for reclamation of this site, we undertook a study of accumulation of Cd, Cu, Fe, Mn, Ni, and Zn by several tree species growing on sludge treated spoils. The specific objectives concerned with this paper are: (1) To determine if the concentrations of each metal increased in these tree species when grown on sludge-treated spoils; (2) To determine if concentrations of heavy metals in these tree species were affected by rates of sludge application to spoils; (3) To determine if the metals tend to accumulate in particular plant tissues.

Study Area

The study site is located in Section 16, Township 10S, Range 4E, Williamson County, Illinois (Figure 25-1). The tract of 126 ha (312 acres) was surface-mined from 1959 to 1961 for the underlying Dekoven and Davis coal seams. During mining approximately 1.5m (5 feet) of iron pyrite containing black shale was placed on the surface to expose the Davis seam. The resulting spoil was a mixture of surface and subsurface soil, black shale, underclay, and sandstone (USDA Forest Service 1972). Upon subsequent oxidative weathering spoil pH decreased to a range of 1.8 to 4.6. The high acidity was the result of mineral acids formed from the oxidation of sulfides from iron pyrites (Peterson and Nielson 1973). Under this condition of low pH, several metals become soluble in amounts sufficient to cause toxicity to plants (Berg and Vogel 1973).

Other hazards, known to be detrimental to the establishment and

Figure 25-1. The Location of the Study Area.



survival of plants, which may characterize the Palzo site, include high surface temperature coupled with high surface evaporation and a low moisture-holding capacity of the spoil, low organic matter content, spoil compaction, deficiencies of macronutrients, low cation-exchange capacity, and a high susceptibility to erosion due to barren surface and coarse texture. Acidic runoff from the barren portion of the tract was causing severe off-site water pollution damage to Sugar Creek and the South Fork of the Saline River (USDA Forest Service 1972).

In order to reclaim the site to a condition capable of supporting vegetation, anaerobically digested sewage sludge was applied to the spoils in order to develop a soil medium capable of sustaining suitable vegetation and abating off-site pollution. The sludge, which contained approximately 10% solids (USDA Forest Service 1972), was pumped from a holding lagoon

through a flexible pipeline to a tractor-drawn disk. The fluid flowed down the disk blades and was incorporated to a depth of approximately 30cm. Application rates were 448, 462, 560, 619, 668, and 997 dry m tons/ha. Before this reclamation work began at Palzo, 78 of the 126 ha were absolutely devoid of vegetation.

Methods

Seven irregularly shaped experimental compartments averaging approximately 2 ha were laid out on the Palzo site (Figure 25-2). One compartment was

Figure 25-2. Palzo Compartment Design.

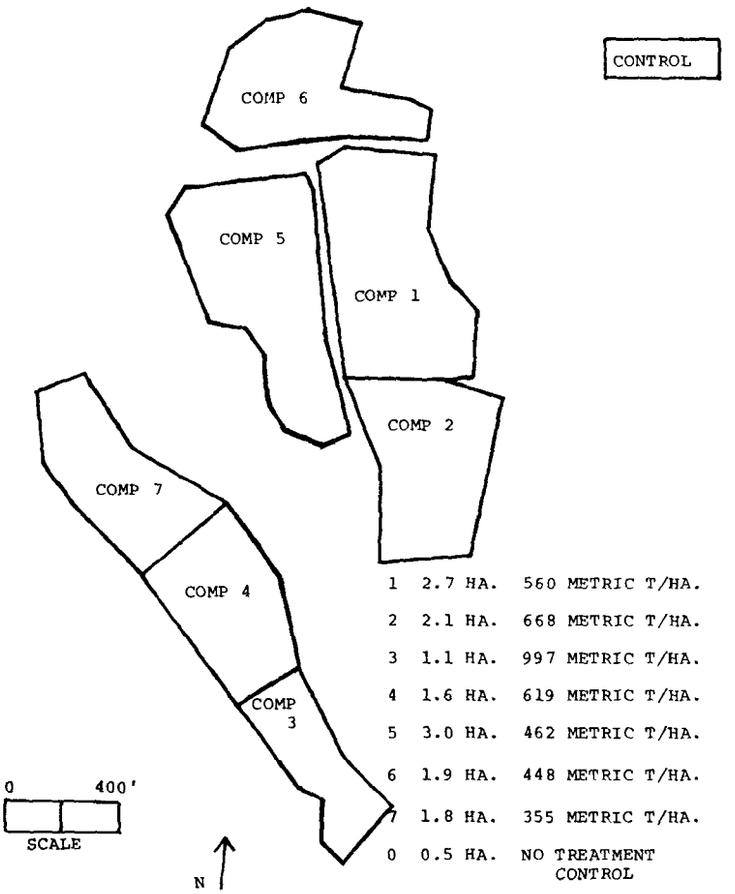
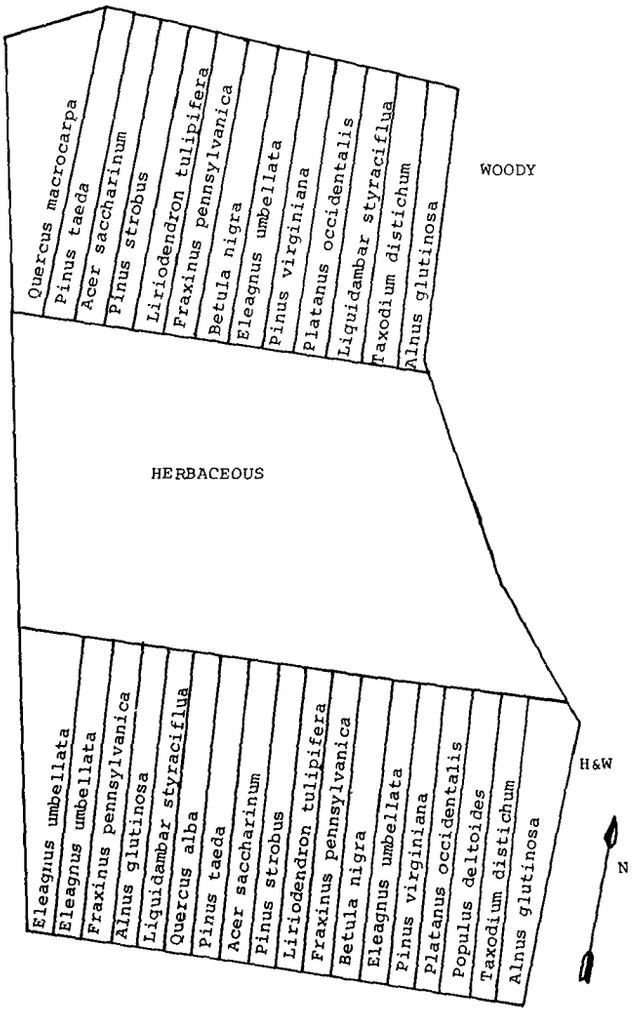


Figure 25-3. Species Planting Design.



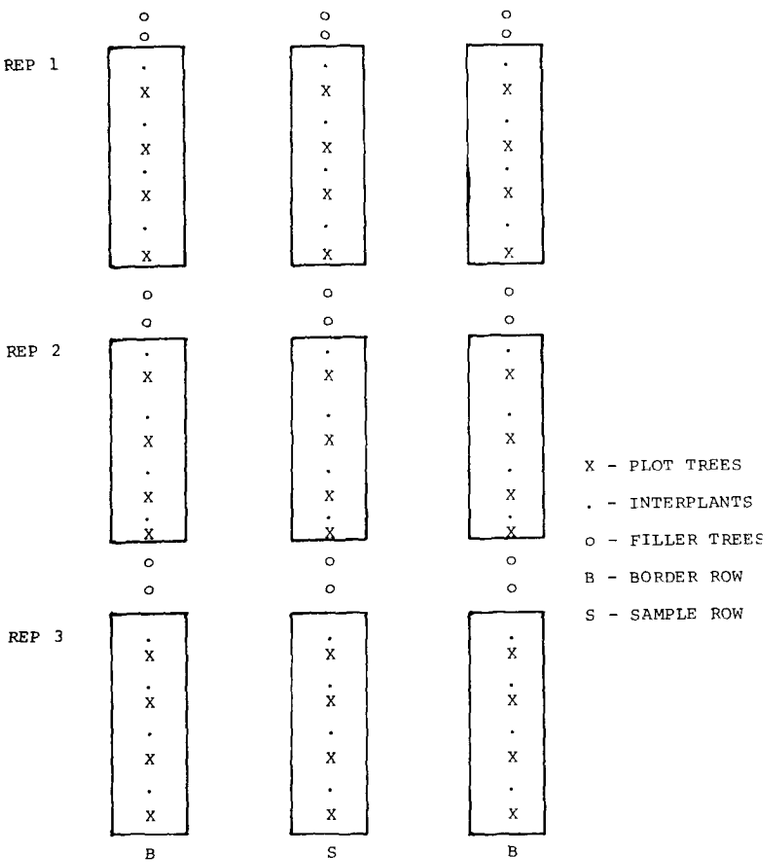
left untreated to serve as a control. Each compartment was subdivided into three equal-sized units: a woody species planting unit, a herbaceous species planting unit, and a combination unit planted in both woody and herbaceous species (Figure 25-3). Multiple rows of seventeen tree species were hand-planted in the spring of 1976. Four sample plots were randomly selected within each species for each unit containing woody plants (Figure 25-4). The five tree species selected for heavy metal analysis in this study were *Acer saccharinum* L., *Fraxinus pennsylvanica* Marsh, *Pinus virginiana*

Mill, *Betula nigra* L., and *Populus deltoides* Bartr. var. *deltoides*.

Baseline samples for laboratory heavy metal analysis were established by random selection of plants of each species from the nursery stock (Svoboda et al. 1979). The number of seedlings to be set aside for baseline samples depended on the size of the stock. The number of seedlings selected varied from 20-30 trees per species. These baseline samples were replicated 4 to 5 times. Following selection, the samples were individually bundled by species and stored at 1° to 3° C until laboratory analysis could be initiated.

First-year and third-year samples were taken from surviving trees of each species within each woody unit of each compartment. Careful harvesting of the trees helped insure collection of most of the rooting system. The

Figure 25-4. Field Plot Design with Three Replications.



number of samples varied according to the number of replicates within plots--either three or four. The selection of samples was made using a random number table. Providing sufficient survival existed, one tree per row per plot was selected for destructive sampling. Thus a maximum of three trees was taken for each species per plot.

Since cottonwood was an invader species, the harvesting of eastern cottonwood was conducted in a different manner than the planted species due to its irregular occurrence. Eastern cottonwood grew in small groups dispersed throughout the Palzo site. The groups were subdivided into two sampling units from which six trees were harvested per unit. The selection of trees from these sampling units was conducted randomly. Tree age was determined by examining the number of growth rings in a cross section of the stem just above the root collar.

In addition to the tree samples, analyses of the metal content within the spoil surrounding the roots were made. Since testing of all spoils was impractical for the allotted time of this research, spoil from the rooting zone of thirty-six silver maple trees was sampled. Silver maple occurred most frequently on the tested plots. These spoil samples were air dried and crushed to pass a 20-mesh screen. Two methods of soil metals extraction were employed. One was the 0.1 N HCl method which has been shown to extract large amounts of metals (Wear and Evans 1968, Leeper 1972). The other soil metals extraction method utilized was the DTPA chelate method (Lindsay and Norvell 1969). The soil metals extraction methods were designed to react under a fixed pH conditions. The pH for the DTPA chelate method is 7.3. These pH conditions do not typify the pH conditions at Palzo. Therefore, the pH of each of these extractants was adjusted to the average pH of Palzo spoils (4.9) by using 6N HCl for the DTPA extractant and NaOH for the 0.1N HCl extractant. Tests were completed under fixed and adjusted pH conditions for comparison of these extractants when used on sludge-treated acid surface-mine spoil.

The 0.1 HCl solution is an acid extractant which will dissolve firmly-held, exchangeable metals. However, it will dissolve metals which are tightly held to the soil colloids as well (Leeper 1972). Thus this method measures the maximum amount of mobile metals present. The DTPA chelate method has been used as an indicator of plant uptake from soils with excessive toxic metal levels (Korcak and Fanning 1978). Leeper (1972) states that the DTPA chelate method has been utilized for estimating the heavy metal supplies available to plants rather than the total amounts present in the soil (Morin 1980).

Additional soil tests were the determination of pH according to McLean (1973) using the Lab-Omatic Model 165 pH meter, with an H^+ ion indicating glass electrode and a reference saturated calomel electrode, and the determination of the H^+ ion content using the SMP Buffer Method (Shoemaker et al. 1962).

The preparation of all trees of baseline, first-year and third-year data were done in the following manner. The trees were dissected with a set of sterilized stainless steel shears into the roots, stem, and leaves. The roots were carefully washed with tap water to remove soil adherents, and rinsed several times with deionized water. Following dissection, the component parts were placed in paper sacks, labeled, and oven dried at 70°C. After a drying period of 48 to 72 hours, the samples were ground in the Wiley Mill to pass a 20-mesh stainless steel screen. Upon completion of the grinding, the samples representing the different component parts of roots, stem, or leaves were weighed to the nearest 0.001 gram. The tree samples were wet ashed using the nitric acid-perchloric acid (HNO_3-$HClO_4$) method according to Smith (1953). Following digestion, samples were diluted with deionized water to a volume of 50 ml. These samples were stored at 1° to 3°C in leached polyethylene bottles until laboratory analysis was initiated.

The laboratory analysis included the determination of the presence and concentrations of cadmium, copper, iron, manganese, nickel, and zinc, using recommended instrument settings and an air-acetylene flame (Perkin-Elmer 1973).

Statistical tests utilized to analyze the data included T-tests, one-way analysis of variance, and a correlation analysis using the Partial Correlation Coefficient.

Results and Discussion

All five tree species were combined according to component parts (roots, foliage, and stem). Mean, minimum and maximum concentrations are compiled in Table 25-1 for three-year-old plant materials. The limits of concentrations ($\mu g/g$ dry weight) for heavy metals at age three were for Fe, 0.50-8590.00; Zn, 10.0-2960.00; Mn, 5.00-3270.00; Cu, 0.50-291.50; Cd, 0.01-950.00; and Ni, 0.50-85.00 (Morin 1980). Concentrations of cadmium at 0.01 were actually below 0.01 but could not be recorded more accurately with the laboratory procedure and equipment utilized in this study.

General component part concentrations for third-year samples indicated that roots and foliage consistently had higher metal contents than stems, but the overall concentrations in third-year tissues were lower than first-year tissues. For example, third-year stem and root tissues of *Betula nigra* exhibited Zn ratios of 11.15 and 11.33 respectively. Concentrations in tissues of both third-year and first-year samples were significantly greater than concentrations in baseline nursery stock as reported by Svoboda et al. (1979). Also, third-year concentrations were significantly greater than concentrations reported for woody plants growing on uncontaminated sites (Guha and Mitchell 1965, Young and Carpenter 1967, Stone 1968, Woodwell et al.

Table 25-1. Mean, Minimum and Maximum Metal Concentrations (μg/g) Among Combined Component Parts of Five Tree Species Grown on Sludge-Amended Spoils.

	CD	CU	FE	MN	NI	ZN
ROOT						
Min.	a/	3.50	75.00	5.00	0.50	15.00
Max.	77.00	245.50	8590.00	1315.00	44.00	1075.00
Mean	20.94	48.05	1282.40	196.50	10.21	298.27
SE	1.20	3.24	108.50	16.41	0.64	15.54
STEM						
Min.	a/	0.50	0.50	4.00	0.50	10.00
Max.	104.50	291.50	840.00	1040.00	85.00	1080.00
Mean	22.93	12.48	81.69	164.76	5.90	358.50
SE	2.30	2.00	8.90	13.46	0.72	30.97
FOLIAGE						
Min.	a/	1.00	1.00	5.00	1.00	40.00
Max.	950.00	93.00	4090.00	3270.00	80.00	2960.00
Mean	38.94	12.05	256.70	728.38	14.28	818.94
SE	6.70	0.81	36.34	53.02	1.09	64.67

a/ Indicates concentrations are < 0.01.

Table 25-2. Significance Rank of Metal Concentrations in the Component Parts of Five Tree Species.

Metal		
CADMIUM	F>R>S	A. saccharinum
	R>S=F	F. pennsylvanica
	F>S=R	P. deltoides
	R>S=F	P. virginiana
	F>S>R	B. nigra
COPPER	R>S=F	A. saccharinum
	R>S>F	F. pennsylvanica
	R>F=S	P. deltoides, P. virginiana, B. nigra
IRON	R>F=S	A. saccharinum, F. pennsylvanica, P. deltoides, P. virginiana, B. nigra
MANGANESE	F>R=S	A. saccharinum
	R>F=S	F. pennsylvanica
	F>S=R	P. deltoides, P. virginiana, B. nigra
NICKEL	F=R=S	A. saccharinum, P. virginiana
	F>R=S	P. deltoides, B. nigra
	R>F>S	F. pennsylvanica
ZINC	F>R=S	A. saccharinum, P. deltoides
	R>F=S	F. pennsylvanica, P. virginiana
	F>S>R	B. nigra

a/ >, indicates significance at the 0.05 level; =, indicates non-significance at the 0.05 level.

1975). Heavy metal concentrations also generally exceeded levels reported for plants from sites contaminated primarily by atmospheric deposition of heavy metals (Tyler 1972, Smith 1973).

Generally significant differences were delineated between combined component parts. Foliage concentrations were significantly higher than root or stem concentrations for Cd, Mn, Ni, and Zn. The significantly lowest concentrations were found in stems for Fe, Mn, and Ni. The differences for Cd, Mn, and Zn between stem and roots were not significant. There were significant differences between two component parts for every metal except Ni. Ni showed significant differences among all three component parts. Fe exhibited the greatest difference in concentrations with the lowest concentration of 81.69 ppm in the stem while the roots recorded a high of 1292.40 ppm. Roots exhibited the highest concentrations of Cu and Fe (Morin 1980).

Metal concentrations varied by component parts for individual species. Table 25-2 shows the significance rank of concentrations (μg/g) of the six metals in the component parts for the five study species. Cadmium results exhibited the greatest differences among the species with each species demonstrating a different concentration pattern. Manganese concentrations were greatest in foliage of all species except *F. pennsylvanica*. There were no significant differences among all three component parts for Mn. Foliage and stem concentrations for Cu and Fe among species were not significantly different, except for *F. pennsylvanica*. Only *B. nigra* showed significant differences for Zn.

Overall, *A. saccharinum* is different than the other species in its concentration patterns for Cd, Cu, and Mn. *F. pennsylvanica* exhibited different concentration patterns than the other species for Cd, Cu, Mn, and Ni. No clear patterns were discernible among component parts for *P. virginiana* or *P. deltoides*.

Discussion

Lawrey (1977), Smout (1978), and Svoboda et al. 1979) have all reported that excessive concentrations of heavy metals occur in the component parts of plants grown on certain surface-mined sites. At the Palzo site, the fact that third-year and first-year tissues contained higher concentrations of heavy metals than baseline nursery plant materials was not unexpected, since the trees were grown on an abandoned acid-producing tract ameliorated with metal-contaminated municipal sewage sludge.

General component part concentrations (μg/g dry weight) for third-year samples indicated that roots and foliage consistently had higher metal concentrations than stems (Table 25-3), but the overall trend indicated that concentrations in third-year tissues were lower than those in first-year tissues.

However, the patterns of concentrations for heavy metals were similar for third-year and first-year concentrations. Third-year levels, particularly in stem and root tissues, have been sustained, indicating continued uptake of heavy metals with accompanying increases in biomass production. Sidle and Sopper (1976) reported similar dilution effects due to increased biomass for Cu and Cd in the foliage of *Picea glauca*. The third-year concentrations continue to portray higher levels than those found in natural ecosystems (Van Hook et al. 1977, Woodwell et al. 1975).

It is interesting to note that some third-year concentrations at Palzo continue to exceed levels regarded (by some scientists) as toxic. That the plant survives may be due to heavy metals being stored in plant tissues in forms not readily transported within the plant. In addition to biomass productivity and heavy metal storage within the plant in relatively non-transportable forms, two other factors appear to be taking place. A

Table 25-3. Concentrations (μg/g) of Six Metals in the Component Parts of Five Tree Species Harvested from Sludge Amended Spoils.

Species	Foliage Mean	Species	Stem Mean	Species	Root Mean
			CADMIUM		
2	0.81 a	2	1.26 a	2	16.74 a
4	5.67 a	1	9.65 b	3	18.21 a
1	25.15 a	4	15.44 b	1	19.04 a
5	94.94 b	3	38.33 c	4	21.63 a
3	107.77 b	5	73.87 d	5	33.08 b
			COPPER		
4	7.57 a	3	5.27 a	3	28.35 a
3	10.85 a b	4	6.78 a	5	46.69 a
1	12.65 a b	5	8.25 a	2	51.45 a
2	13.10 a b	1	13.53 a	4	53.67 a
5	15.56 b	2	21.77 a	1	53.92 a
			IRON		
2	84.00 a	3	50.38 a	3	697.25 a
4	123.42 a	2	54.53 a	2	808.64 a
3	123.88 a	1	67.32 a	5	1337.68 a b
5	331.19 a	5	86.52 a	1	1783.18 b
1	597.03 b	4	167.00 b	4	1879.40 b

1/Species code: 1) A. saccharinum, 2) F. pennsylvanica, 3/ P. deltoides, 4/ P. virginiana, 5/ B. nigra

2/Newman Keuls-Hartley Modification Mean Separation Technique; like letters indicate homogenous subsets at the 0.05 level; unlike letters indicate significant differences at the 0.05 level.

Table 25-3. (Continued)

Species	Foliage Mean	Species	Stem Mean	Species	Root Mean
			MANGANESE		
2	123.93 a	2	87.38 a	3	65.42 a
4	333.52 b	3	89.79 a	4	66.48 a
3	780.83 c	4	122.78 a	1	173.61 b
1	955.97 d	1	149.03 a	5	226.67 b
5	1836.46 e	5	446.04 b	2	357.38 c
			NICKEL		
2	7.61 a	2	3.43 a	3	5.29 a
4	9.33 a	3	4.42 a	5	5.71 a
5	11.95 a	4	6.19 a	1	10.25 b
1	12.81 a	5	7.50 a	4	10.67 b
3	36.04 b	1	8.47 a	2	15.25 c
			ZINC		
2	129.28 a	2	149.64 a	3	174.79 a
4	211.30 a	4	196.48 a b	2	272.38 a
1	791.39 b	1	262.08 b	1	282.00 a
3	1639.16 c	3	267.50 b	4	296.11 a
5	1930.62 d	5	1142.08 c	5	494.00 b

1/Species code: 1) A. saccharinum, 2) F. pennsylvanica, 3/ P. deltoides, 4/ P. virginiana, 5/ B. nigra

2/Newman Keuls-Hartley Modification Mean Separation Technique; like letters indicate homogenous subsets at the 0.05 level; unlike letters indicate significant differences at the 0.05 level.

decline in microbial activity, due to high levels of metals in the sludge and spoil, inhibit the reintroduction of these elements into tree component parts. Also, there appears to be an accumulation of heavy metals in the litter layer.

An important mode of ion movement at Palzo is via airborne particles. Several researchers (Tyler 1972, Jordon 1975, Jackson and Watson 1977) have reported that plants grown in air-polluted environments accumulate excessive quantities of heavy metals. Considerable evidence of airblown deposition of the metal-rich spoil-sludge substrate was observed on the Palzo site. Parker (et al. 1978) reported similar concentrations of heavy metals in plant tissues in a polluted urban area of Gary, Indiana.

The relatively high heavy metal concentrations in root tissues is probably the result of direct root contact with the spoil and sludge materials (Smout 1978, Tisdale and Nelson 1975). The root system is continuously expanding into new areas where previously unavailable ions are exposed.

Also, the non-translocation of heavy metals from the root system to other tree component parts and several nutrient-metal interactions merit consideration.

The mean extractable concentrations ($\mu g/g$) of six metals in the rooting medium using four metal extractants are given in Table 25-4. The extractants were adjusted to a mean of 4.9 in order to simulate the mean pH of Palzo spoil samples. The results appear to reject the hypothesis that no significant differences exist between two soil metal extractants under normal and adjusted pH conditions.

Significant differences occurred among all four extractants for Fe. Except for Zn, which showed no significant difference, all other metals tested exhibited significant differences between at least two extractants. Table 25-5 shows the minimum, maximum, and mean extractable metal concentrations in the rooting medium among the four extractants. The variation in concentrations would obviously affect the data interpretation and pattern definition, depending on the extraction method selected.

Table 25-6 indicates the r-values for the relationships between soil hydrogen levels meq/100g and component part concentrations of *A. saccharinum*. There were no significant relationships at the 0.05 level, though a few positive significant correlations occurred at the 0.10 level. Root and foliage concentrations had significant correlations to soil hydrogen levels only

Table 25-4. Extractable Concentrations ($\mu g/g$) of Six Metals in the Rooting Medium Using Four Metal Extractants.

Soil Test[1]	Mean	Soil Test	Mean	Soil Test	Mean
	CADMIUM		COPPER		IRON
2	44.44 a[2]	4	26.08 a	1	81.30 a
1	65.25 a	1	61.76 a	2	226.00 b
3	299.20 b	2	73.75 a	3	729.78 c
4	430.57 c	3	451.98 b	4	868.62 d
	MANGANESE		NICKEL		ZINC
2	3.38 a	1	30.00 a	4	4.69 a
4	4.39 a b	2	32.75 a	2	4.73 a
1	5.40 b	4	124.80 b	1	5.00 a
3	8.47 c	3	173.68 c	3	5.06 a

1/Soil Extractant Code: 1) DTPA - Standard pH Conditions, 2) DTPA - Adjusted pH Conditions, 3) 0.1N HCL - Standard pH Conditions, 4) 0.1N HCL - Adjusted pH Conditions.

2/Newman Keuls-Hartley Modification Mean Separation Technique; Like letters indicate homogenous subsets; unlike letters indicate significant differences at the 0.05 level.

Table 25-5. Mean, Minimum, and Maximum Extractable Metal Concentrations (μg/g) in Rooting Medium Using Four Extractions.

	CD	CU	FE	MN	NI	ZN
DTPA - Standard pH Conditions (pH 7.3)						
Min.	12.60	14.04	21.60	1.50	3.60	1.39
Max.	153.00	107.10	156.60	12.70	70.20	7.59
Mean	65.25	61.76	81.30	5.40	29.60	5.00
SE	6.05	4.21	5.57	0.49	2.80	0.24
DTPA - Adjusted pH Conditions (pH 4.9)[1/]						
Min.	7.20	15.12	57.60	0.60	3.60	2.30
Max.	120.60	176.58	370.80	9.60	171.00	6.35
Mean	44.44	73.75	226.00	3.38	32.75	4.73
SE	4.37	7.00	13.24	0.36	47.60	0.15
0.1N HCL - Standard pH Conditions (pH 1.3)						
Min.	115.20	108.80	268.80	2.40	19.20	3.06
Max.	627.20	696.32	1382.40	18.80	435.20	7.76
Mean	229.20	451.98	729.78	8.47	173.68	5.06
SE	21.64	27.26	52.31	0.02	15.07	0.19
0.1N HCL - Adjusted pH Conditions (pH 4.9)						
Min.	179.20	1.28	313.60	1.30	32.00	1.82
Max.	889.60	104.96	1798.40	8.70	307.20	6.32
Mean	430.57	26.08	868.62	4.39	124.80	4.69
SE	27.00	4.49	53.93	0.37	10.04	0.17

1/ Indicates extractant was adjusted to Palzo mean pH in order to simulate typical conditions on site.

Table 25-6. The Simple Pearson Product Moment Correlation Coefficients of Component Part Concentrations (μg/g) of Acer saccharinum to Soil Hydrogen Ion Concentration (meq/100g).

COMPONENT PART	CD	CU	FE	MN	NI	ZN
Root	0.2897**	0.2517	0.2768**	0.0519	0.0324	0.2034
Stem	0.2123	0.0095	0.0172	0.0409	-0.1849	0.3127**
Foliage	0.2749**	-0.0858	0.2714**	-0.1365	-0.1947	0.1169

** Indicates a significant correlation at the 0.10 level.

for Cd and Fe. Only Zn had a significant stem correlation. Component part concentrations of *A. saccharinum* to extractable spoil concentrations under standard and adjusted pH conditions generally showed the same wide range of variation under the four extractant methods with but few significant correlations. Significant correlations were found for Cu, Mn, and Zn, primarily in root and stem tissue (Morin 1980).

Summary and Conclusion

The data and information gathered in research upon the Palzo site provide valuable information concerning mineral cycling changes occurring over time on a drastically disturbed sludge-amended surface-mined site. Heavy metal concentrations varied by species in both combined and individual plant component parts. These concentration variations may be attributed to a wide range of influences and factors, including:

1. The nature of both the sludge and spoil materials.
2. Detrimental effects of excessive heavy metal concentrations, on the normal physiological functions of the plant's vascular system.
3. The changes in an ecosystem over time, such as the development of a litter layer, a more dense plant population, and changes within the plants themselves as biomass increases and tissues mature.
4. The introduction of herbivores to the site.
5. Interactions with varying climatic conditions.
6. The gradual breakdown of the sludge itself.
7. Differences in spoil pH.
8. The method of laboratory analysis utilized, particularly important when comparing the data and results of other researchers.

In most cases, the highest concentrations reported were in foliage components, then roots, and lastly stem tissues. An important avenue of travel for these metal elements at Palzo is via airborne particulates. The relatively dry growing seasons together with the lack of vegetative cover in some areas and the lack of soil aggregate structure in the immature spoil substrate all contributed to a conveyance of particulate matter onto leaf surfaces. With the exception of *Pinus virginiana*, high concentrations exhibited in deciduous leaf tissues represent one-year concentration levels only. *Pinus virginiana* is capable of holding needles up to three years. Therefore, metal concentrations in foliage of this species are distributed among needles of three age groups, possibly affecting concentrations. Of the five species studied, *Pinus virginiana* and *Fraxinus pennsylvanica* exhibited consistently lower concentrations in the foliage component. These lowered concentrations indicate that these species are important since they pose a lesser threat to browsing animals (Morin 1980).

The concentration results for stem and root components indicate that

Betula nigra, Pinus virginiana, and *Acer saccharinum* were maximum root and stem accumulators, meriting consideration of these species for future use on these sites due to storage of potentially toxic metals in component parts of limited access and palatability to browse species. Increases in stem concentrations over the three-year period appear to be linked to the translocation of elements from leaves to stem tissue prior to senescence. In contrast, direct contact of roots with the spoil and sludge substrate contributes appreciably to the high storage levels recorded within the roots. Also, an apparent sink for metal elements is the developing litter layer. The adverse effects metals have on microbial populations limit the cycling processes on the site.

Populus deltoides, sampled as an invader species, exhibited fewer significantly different concentrations in component parts than the planted species, with the exception of the root component. In almost every instance, except Cd, concentrations in the root component of *P. deltoides* had the lowest average recorded.

The 0.1 N HCl extraction technique gave consistently higher levels of metals on the spoil material than the other extraction techniques utilized in this study. The relatively low pHw at Palzo coupled with the acidic nature of this extraction method contributed to higher extractable concentrations. In contrast, the consistently lower extractable amounts achieved using the DTPA method indicate soluble chelated forms available for plant uptake.

The majority of correlations between hydrogen ion and component part concentrations were low, but positive, indicating that H^+ ions partially affect metal concentrations within plant component parts (Morin 1980).

When one considers the myriad hardships and handicaps facing woody plants on hostile sites such as Palzo, it is surprising perhaps that woody plants can survive at all. However, the results of our research give cause for encouragement that ultimate successful reclamation of devastated mine-sites is both possible and feasible.

The recent enactment of the federal surface-mine legislation should ensure that areas surface-mined for coal will be reclaimed using the most technologically sound methods. The abandonment of surface-mined lands in the past clearly indicates a need for reclamation in the planning of surface and underground mines. The recent development of the Rural Abandoned Mine Program (RAMP) represents a concerted effort by man to correct some of the mistakes of the past. In addition, the successful revegetation of Palzo using sludge is an example of new and developing technology for attacking the most drastically disturbed sites. Future research at Palzo will provide additional data which will further substantiate the need for sewage sludge as an amendment to these disturbed spoils.

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26
LEACHATE QUALITY IN ACID MINE-SPOIL COLUMNS AND FIELD PLOTS TREATED WITH MUNICIPAL SEWAGE SLUDGE

Dean H. Urie, Craig K. Losche, and F. D. McBride

Leachate studies conducted in the greenhouse and field plots in Southern Illinois evaluated the chemical changes following incorporation of liquid sewage sludge into the surface 15 cm of acid mine spoils. Sludge treatments of 336 and 672 metric tons/hectare (dry weight) resulted in increased calcium and sodium concentrations in leachate at the 120 cm depth in both tests. After 1 year, nitrate-N concentrations increased rapidly to over 100 and 200 ppm under the 336 and 672 mt/ha sludge rates, respectively. Iron, aluminum and trace metal concentrations were reduced under both sludge treatments during the 2 years after sludge incorporation.

Both sludge dosage levels reduced phytotoxic conditions in the surface soil adequately to permit establishment and growth of cover crops over a 3-year period. Runoff from infiltrometers was reduced on the sludge treated vegetated plots. Phosphorus and nitrogen concentrations in the runoff from sludge treated plots were also reduced below control levels.

Mixing 67 or more metric tons of sawdust into the sludge-spoil layer reduced the concentrations of nitrate-N in leachate below the 10 ppm level. However, sludge-sawdust mixtures increased drought effects on small experimental plots.

Introduction

A plot test using municipal sewage sludge was conducted in 1970-1971 on an abandoned strip-mine in southern Illinois by the U.S. Forest Service (Lejcher and Kunkle 1973). The results of this test indicated that at least 300 metric tons of sludge (dry solids) would be required to establish vegetation on the 192 acres of extremely acid spoils at the "Palzo" mine. Plans were developed for a pilot scale test involving leveling and sludge treatment of the entire tract.

The spoil at the Palzo mine is typical of about 6,000 acres of acid orphan spoils concentrated in Salem and Williamson Counties in southern Illinois (Haynes and Klimstra 1975). Traditional liming and fertilization practices have generally been unsuccessful in revegetating these acid spoil areas. Until the spoil was graded in 1974, the Palzo mine site presented a particularly hostile environment for plant growth as high pyrite mineral content spoils were continually exposed by erosion. Typical surface pH values

ranged from 2.0 to 4.6. Before grading, the spoil was 19 percent weathered and unweathered sandstone, 22 percent mixtures of sandstone and shale, 5 percent shale over weathered sandstone, 50 percent black shale surface, and 5 percent bottom "fire" clay.

Before the pilot scale study was installed on the entire Palzo mine (Cunningham et al. 1975), greenhouse research tests were begun to define the environmental impact of sludge use and to determine the effectiveness and acceptability of two levels of sludge applications, 336 and 662 mt/ha. Evaluations of the changes in leachate quality were conducted in greenhouse soil columns by the North Central Forest Experiment Station, USDA Forest Service. Concurrently with the initiation of field treatments at the Palzo mine, field plots were installed to test a range of sludge treatments similar to those tested in the greenhouse. Herbaceous and tree vegetation tests were conducted by scientists from Southern Illinois University in studies partially funded by the USDA Forest Service, and the U.S. Environmental Protection Agency.

Greenhouse Leaching Chamber Study

Thirty-six vinyl lined boxes (30 x 60 cm x 120 cm deep) were filled with mixed spoil from the Palzo mine. The boxes were constructed with two ceramic soil water samplers placed at the bottom. Spoil fragments larger than 10 cm were removed. The soil water samplers were maintained under 0.3 bar tension. The spoil filled boxes were settled and leached with 20 l distilled water before treatment with sludge and lime.

Agricultural lime ($CaCO_3$) at 0, 22, and 44 mt/ha and digested municipal sludge (10% solids) at 0, 336, and 662 mt/ha were applied in all combinations with four replications in a completely randomized design. The lime was surface applied and incorporated to 15 cm depths. Sewage sludge was applied at 11 mt/ha (dry wt) equivalent increments. After drying, each increment of sludge was incorporated to 15 cm soil depths. About two sludge applications could be made each week. The 332 mt/ha rate was completed in about 3 months, the 662 mt/ha rate in about 5 months. Distilled water was added to all boxes at a 5 cm/month rate (added in bi-weekly increments) to simulate percolating precipitation at a rate about equal to 50 percent of normal rainfall.

Leachate was measured at monthly intervals for volume and analyzed for total acidity, S, Al, Fe, Cd, Cr, Cu, Ni, Ca, Pb, Mg, Mn, P, Na, Zn, NH_4-N and NO_3-N.

Fe, Cu, Mn, Zn, Al, Cu, and Mg were measured by i.c. emission spectrophotometry; Co, Ni, Pb, and Cd by atomic absorption spectrophotometry; Na and K by flame emission spectrophotometry; S by the reduction method and potentiometric titration of the absorbed S =

(NaOH) with $AgNO_3$ and Ag/S selective ion electrode; P by a modified ascorbic acid method; NH_4-N and NO_3-N by specific ion electrode, and titratable acidity potentiometrically to pH 7.0.

Two general patterns of leachate chemical concentrations resulted during the initial 30-month period. During the sludge incorporation period, while the spoil surface was being frequently disturbed, leachate from all treatments contained high concentrations of all measured cations, presumably originating from the freshly mixed raw spoils. Concentrations of S, Fe, Al, and Mg decreased over the ensuing 2 years, with more rapid reductions in the concentration of many elements under sludge treatments and showing the additional effect of increasing sludge rates. Concentrations of Fe and Al in the leachate are shown in Figure 26-1. Significant sludge effects became evident after 9 months for Fe and after 13 months for Al.

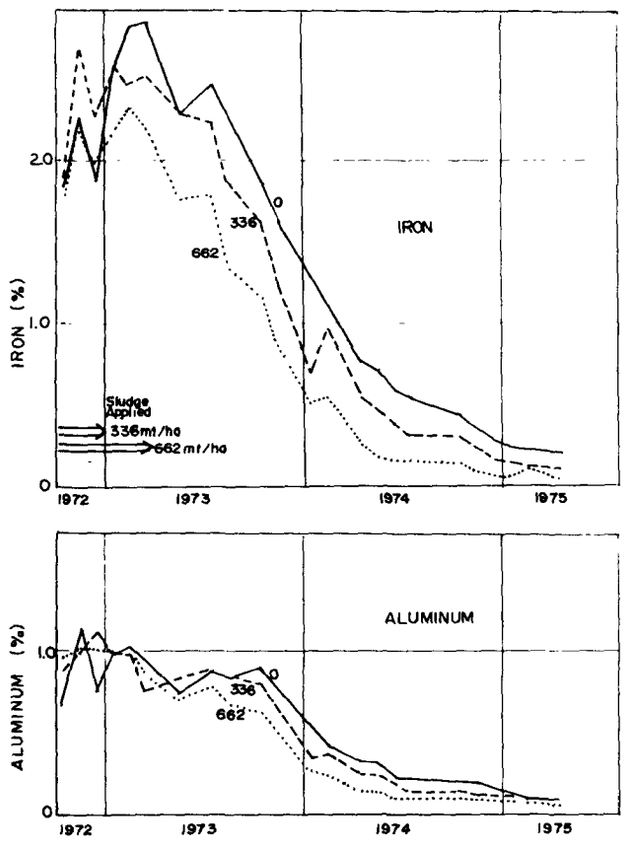

Figure 26-1. Mean Iron and Aluminum Concentrations in Leachate from Columns Treated with 0, 336, and 662 mt/ha of Sewage Sludge.

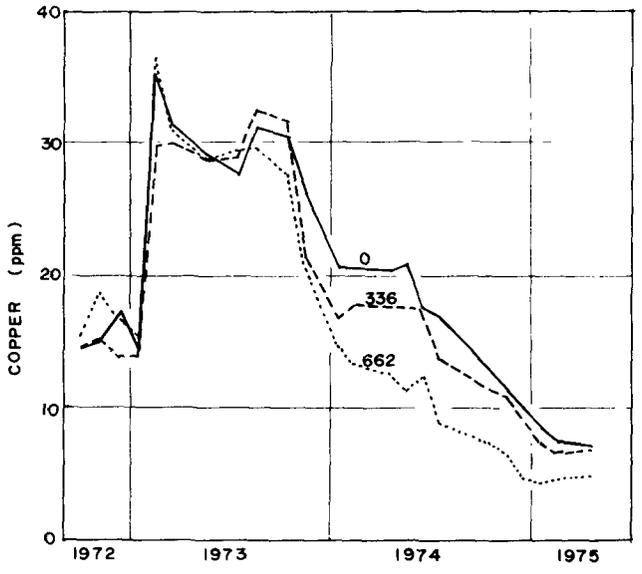

Figure 26-2. Mean Copper Concentrations in Leachate from Columns Treated with 0, 336, and 662 mt/ha of Sewage Sludge.

Trace element patterns were similarly affected by sludge treatments. The pattern for copper (Cu) in Figure 26-2, is representative of those also measured for Ni, Mn, Cr, and Pb.

Ca and Na concentrations under sludge treatments were significantly higher than controls from the 7th through the 29th month after treatments began.

Lime treatments were not significantly related to any cation or to P and S concentrations in the leachate, nor did the lime significantly alter leachate acidity.

The greatest sludge effect on leachate quality was a flush of nitrate beginning about 6 months after sludge treatments ended (Figure 26-3). Nitrate-N concentrations were directly related to sludge dosage rates, peaking about 1 year after sludge additions ended. These concentrations were well above environmentally safe levels for surface or groundwater for the remainder of the test period.

Field Leachate Study

Field trials of the sludge dosage levels used in the greenhouse were initiated in 1975 at the Palzo mine site. Twenty-four 15 x 30 m plots were established

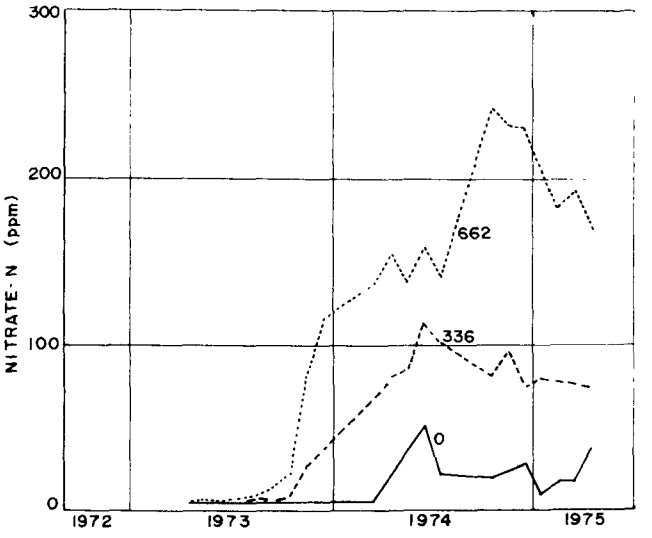

Figure 26-3. Mean Nitrate Concentrations in Leachate from Columns Treated with 0, 336, and 662 mt/ha of Sewage Sludge.

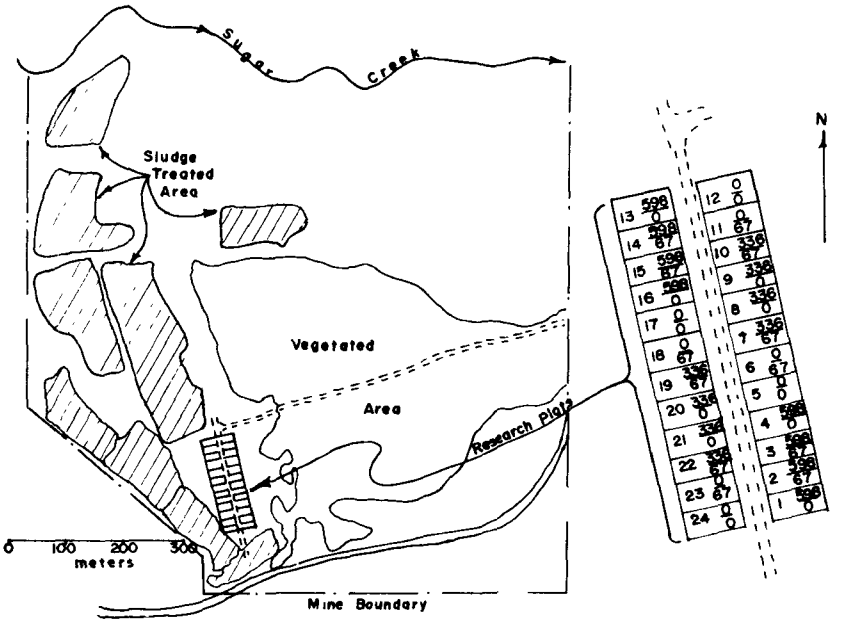

Figure 26-4. Field Study of Acid-Mine Spoil Leachate Quality Using 0, 332, and 598 mt/ha of Sewage Sludge and 0 and 67 mt/ha of Lime, Palzo Mine.

with 12 on each side of a NW-SE oriented ridgeline (Figure 26-4). Paired suction lysimeters were buried at 120 cm in the center of each plot and connected to collection bottles at the edge of each plot. The entire system was maintained at 0.3 bar tension during periods following heavy rain and during snowmelt.

Agricultural lime (0 and 67 mt/ha) and sludge at 0, 332 and 598 mt/ha (dry wt) were applied in all combinations with four replications. Plot treatment pattern was dictated by the limitations of the sludge spreading equipment. In essence, this limitation resulted in a single block of sludge treated plots at each rate, on each aspect. Thus, each sludge-treated block could be considered as a large plot with leachate sampled at four equally spaced locations. Control and lime-only treated plots were interspaced between the sludge treatment blocks.

Lime was applied before sludge treatments and disked to about 15 cm depths. Sludge was surface spread from a liquid manure tanker in 10 mt/ha increments. As soon as each application dried, the sludge solids were disked into the soil. Control plots were disked at the same frequency. Sludge applications began in August 1975. One hundred seventy-three mt/ha were applied by the end of the 1975 field season to all sludge treatment plots. Annual rye (*Secal cereale*) was seeded in October 1975 to reduce surface erosion. Sludge applications resumed in July 1976. The 332 mt/ha treatments were completed in August 1976. The 598 mt/ha rate was reached by the end of the 1976 field season. The 598 mt/ha dosage was accepted as the high rate for the field study, as sludge applications had to stop to allow for establishment of a cover crop. This second planting included annual rye (18 kg/ha), orchard grass (*Dactylis glomerata*) and tall fescue (*Festuca elatior*) (67 kg/ha). Annual rye was used to prevent erosion until the perennial grasses became established.

Seven sets of leachate samples were collected during the sludge application period. Five to seven sets of samples per year have been collected since. Leachate samples did not provide a measure of total percolate under the field conditions. Chemical analyses were similar to those utilized during the leaching chamber study except that d.c. emission spectroscopy was used for cation and P determinations. NO_3-N analysis, using a specific ion electrode, was the only nitrogen measurement. pH was determined by glass electrode in the laboratory.

Concentrations of Fe, Al, and Cu in leachate from the field study (Figure 26-5) were only 10-20 percent of those occurring at the beginning of the leaching chamber tests. This difference may be explained by the 2-year delay between grading of the field plots and the sludge applications, allowing leaching during the intervening period. Concentrations were, therefore, at about the same levels as those measured in the control leaching chambers after 2 years. Sludge treatments with attendant surface mixing resulted in slight increases in Fe and Al during the summers of 1975 and 1976. After

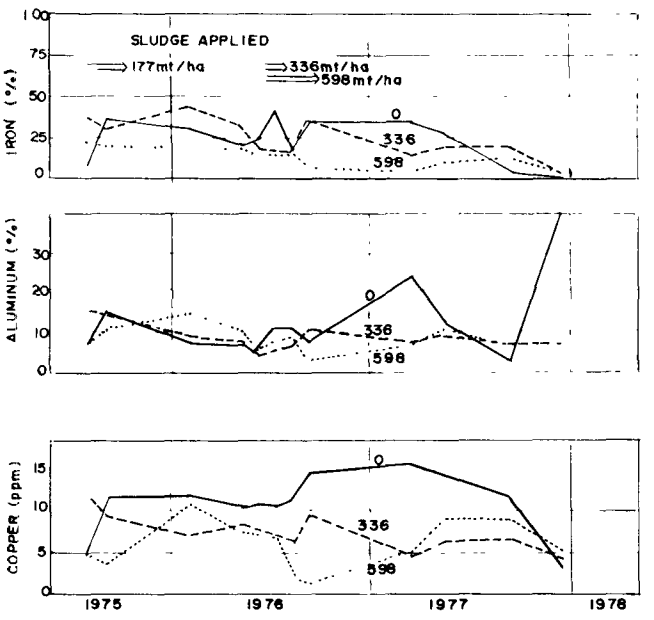

Figure 26-5. Mean Iron, Aluminum, and Copper Concentrations in Leachate from Field Plots Treated with 0, 336, and 598 mt/ha of Sewage Sludge.

sludge treatments were completed a reduction in concentrations continued over the following 2 years. Significant sludge effects were measured during the spring of 1977. No lime effects were measured during this period.

Trace element concentrations in the field leachate were also at lower levels than in the leaching chamber at the beginning of the field study. The concentrations of copper (Figure 26-5) illustrate the typical pattern. Mean concentrations of copper were consistently lower in sludge-treated spoils, although these differences were not significantly different from controls during any one sampling period. Significant reductions in Cu, Ni, Mn, Cr, Hg, and B were measured 20 months after sludge treatments began.

Nitrate-N concentrations in leachate from sludge treatments reached 50 ppm by the end of the 1976 application period (Figure 26-6). Under the 332 mt/ha treatments, NO_3-N levels varied from 30 to 70 ppm for 2 years,dropping to 20 ppm by the end of 1978. The additional sludge added to the 598 mt/ha plots produced a peak NO_3-N concentration of 180 ppm in late 1977. By the end of 1978, the concentrations under both sludge treatments were equal, although still slightly above environmentally acceptable level for potable groundwater. Control plots showed nitrate-N levels below 10 ppm by the end of 1977.

Calcium concentrations increased during the period when surface

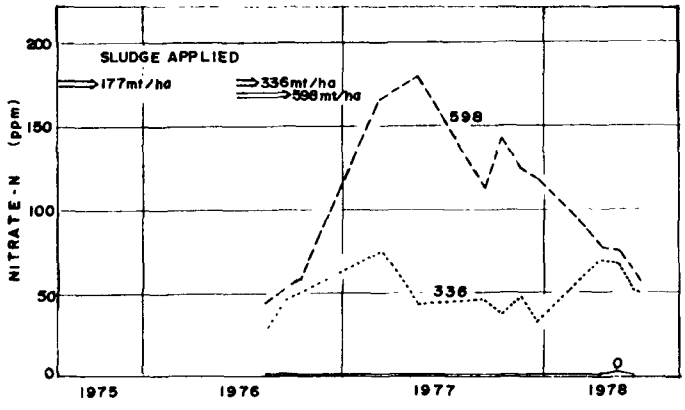

Figure 26-6. Mean Nitrate Concentrations in Leachate from Field Plots Treated with 0, 336, and 598 mt/ha of Sewage Sludge.

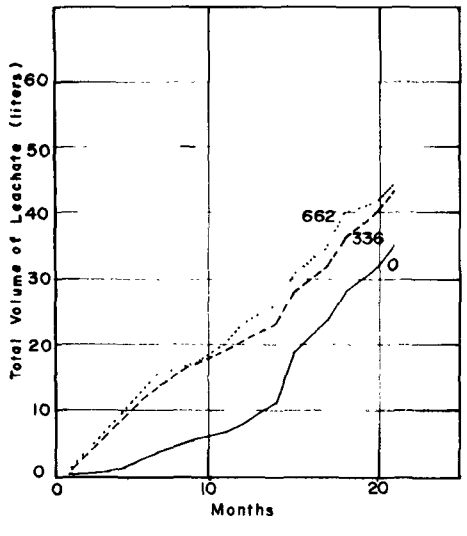

Figure 26-7. Cumulative Volume of Leachate from Leaching Chambers.

disturbance of control and treated plots were in progress. During the following 2 years, Ca concentrations remained higher under sludge treatments, although significant differences occurred between sludge and nonsludge plots only in July 1975, during sludge applications, and in September 1977.

Effects of Sludge Liquid on Chemical Concentrations

Addition of liquid sludge augmented the volume of percolate in both field and greenhouse experiments. Figure 26-7 illustrates the cumulative volumes of leachate removed in the greenhouse tests under controls and the two sludge treatments. Comparative data on leachate volume could not be collected under the field conditions. Rapid drying by greenhouse fans evidently removed most of the sludge liquid, as the cumulative curves for the 332 and 662 mt/ha treatments are similar even though twice as much liquid sludge was applied to the 662 mt/ha columns. Control volumes were lower, however, during the sludge application stages. After sludge application ceased and all columns received equal additions of water, the leachate volumes in both controls and sludge-treated columns equalized. About 5 cm of additional leaching had occurred in sludge treated columns at this stage of the study, 30 percent more than in controls. Differences in the concentrations of leachate chemicals were affected by this dilution effect.

In field studies the sludge was applied during mid-summer when surface drying conditions were good. Although infiltration of sludge liquid was not measured, field observations indicated that most of the sludge supernatant liquid was held at the surface by sludge soilds which sealed the spoil surface. No runoff of sludge was observed, although the potential soil water flux could not be related to the volumes of leachate collected by the soil-water samplers because the system was not contained, as in the greenhouse study.

Surface Runoff and Runoff Quality

Surface runoff measurements were not made on a continuing basis on the field plots. In May 1977, 1 year after sludge treatments were completed, 1.2 m x 1.2 m infiltrometers were installed on selected plots, about 10 m from the upslope edge of the plot. Thirty minute infiltrometer tests at 33 mm/hr rates produced measurable runoff from both sludge-treated and control plots (Figure 26-8). Only the sludge-treated plots supported vegetation at this time. Runoff reductions of 33 and 50 percent less than controls were measured on 332 and 662 mt/ha treatments, respectively. In July 1978 the tests were repeated with a similar response, except that runoff from the heaviest sludge dosage plots was much lower than in the earlier

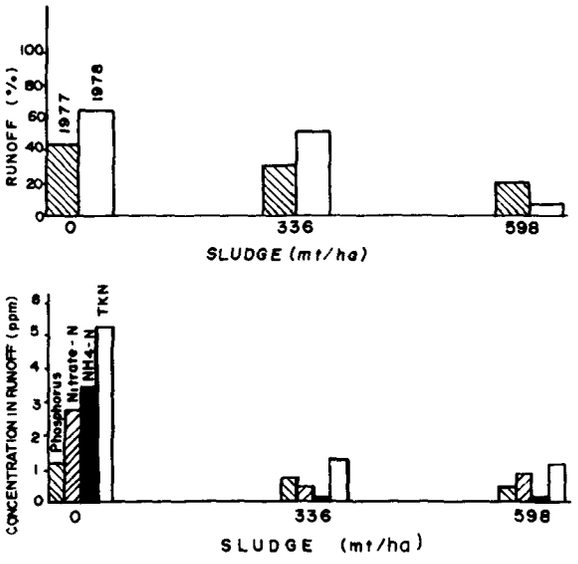

Figure 26-8. Runoff as Percent of Applied Rainfall from Infiltrometer Tests, Palzo Field Plots, 1977 and 1978; and Mean NO_3-N, NH_4-N, TKN and Phosphorus Concentrations in Runoff from Infiltrometers on Palzo Field Plots, 1977.

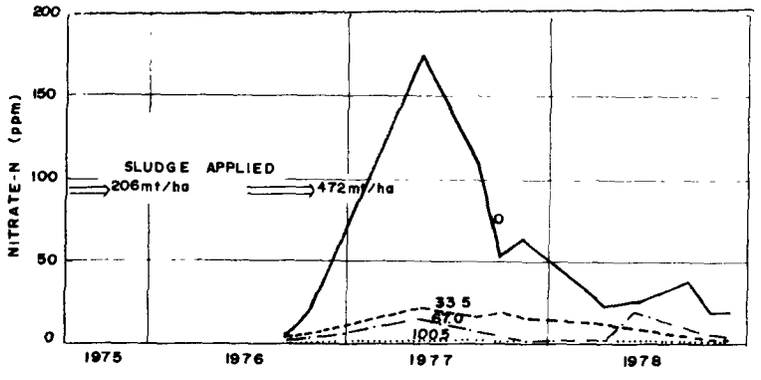

Figure 26-9. Nitrate-N Concentrations in Leachate from Field Plots Treated with 472 mt/ha of Sludge and 0, 33.5, 67.0 and 100.5 mt/ha of Sawdust.

test. The 332 mt/ha plots were less effective in reducing erosion, a reflection of a reduction in vegetation density. Vegetation near the upper slopes had been reduced to the level where its runoff limiting capability was reduced. Analysis of the runoff water from the 1977 tests showed lower concentrations of NH_4, TKN, and NO_3 on vegetated, sludge-treated plots than on controls. Nitrogen levels were about the same on both sludge treatments.

Discussion

Sewage sludge had been shown in previous studies on the Palzo site to create surface soil conditions which allow establishing a protective vegetation cover and return of the site to productive uses. The large amounts of sludge required to produce these effects result in high loadings of the potentially toxic elements characteristics of sludge from industrial cities. The greenhouse and field studies conducted with Palzo spoils have shown that nitrate is the principal pollutant which must be dealth with. Calcium and sodium are also increased in soil leachate, but not at gross pollution levels. The recognized toxic metals are not increased in the leachate at the 120 cm depth, at least during the years immediately following sludge treatments. In fact, sludge incorporation into plow depths decreases the concentrations of many of these metals in leachate from the acid spoil materials. Long-term studies will be needed to determine whether breakdown of sludge organics ultimately releases these metals to leaching.

In a comparison study at the Palzo mine, sawdust was mixed with sewage sludge at 33.6, 67.2, and 100.8 mt/ha rates. The nitrate concentrations in leachate, which was sampled at 61 cm, were reduced to environmentally acceptable levels (Figure 26-9). However, introduction of the sawdust apparently increased the drought stress on plants, as vegetation did not survive through the third growing season on the small (3 x 3 m) plots. Larger scale tests would be required to determine how serious this might be over an extended period.

These results indicate that sludge may be used for ameliorating highly acid spoil materials if the enrichment of groundwater with nitrate is not a critical concern. It may be possible to combine lower rates of sludge treatment with lime and organic residues to obtain the soil condition needed for revegetation, thus reducing the nitrate leaching hazard.

A concern for the future, as the sludge solids decompose, may be a lessened capability for retaining potentially toxic elements in the surface spoil horizons. If so, leaching to groundwater could become a problem. Maintaining a viable vegetative cover may replace organic matter adequately to make up for the loss from sludge mineralization.

Monitoring the surface water and groundwater on the Palzo mine in

compliance with the State of Illinois environmental protection regulations is continuing. Chlorides in runoff from the sludge-treated areas have increased (Jones and Cunningham 1979). Reductions in the concentrations of Cu, Cr, Cd, Al, Fe, Zn, and Mn in this runoff were of the same magnitude as those found in the leachate studies reported here. The nitrate flush measured at the 120 cm level has not yet impacted groundwater quality at 12 m depths nor elevated levels in Sugar Creek which drains the Palzo mine site. Presumably, the time required for vertical percolation through the unsaturated zone has not yet passed. Movement of nitrate enriched groundwater to surface water may be so slow that dilution will lessen the impact of this nitrate flush.

Cost of Palzo Demonstration Project

Exclusive of research expenditures, the operational-scale portion of the Palzo reclamation project provided a realistic estimate of total costs for similar operations. Total rehabilitation costs for the entire strip-mined area are not available because about 25 ha (60 acres) of the site have not yet received sludge. Some grading costs were covered by training programs for Job Corps equipment operators. The grading costs listed below are based on contract grading accomplished in 1972, prior to the Job Corps program.

Estimated total costs by area and per ton of dry sludge are listed below:

Cost component	Costs/unit area		Costs/dry ton sludge	
	($/ha)	($/ac)	($/mt)	($/ton)
Grading	4,900	2,000	8	7
Sludge transportation and application	56,800	23,200	85	77
Monitoring	2,520	950	3	3
Total	$64,220	$26,150	$96	$87

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VIII / VEGETATION ESTABLISHMENT

OVERVIEW

Edward H. Bryan

Conceptually, there is something appealing about the possibility of dealing constructively with societal residuals, such as recognizing their potential values as resources and then learning how to take advantage of those potential values. However, what must be kept clearly in mind is that residuals such as sludges from wastewater treatment plants contain many if not all of the original constituents of the wastewater that posed a threat to public health and represented a potential nuisance.

As an inevitable consequence of their origin, sludges derived from human wastewater must be presumed to be infected with pathogenic organisms and contaminated with organic and inorganic toxic substances. After their production, wastewater treatment plant sludges may be treated to change their composition and form by processes such as thickening, digestion, elutriation, chemical and/or thermal conditioning, irradiation with gamma rays or electons, mechanical dewatering and composting. Each unit operation or process contributes to a change (usually reduction) in the risk to human or environmental health that is associated with further processing or management of the sludge.

The ideal concept for final disposition of sludges would be one that reduces subsequent risk to human or ecosystem health associated with further contacts with them to zero. More realistically, an acceptable concept would be one that results in equal or less risk than is already associated with the environment into which the sludge is placed. Use of sludges to reclaim land that has been removed from otherwise productive use or which, in its existing condition, poses a threat to human health or environmental quality is an example of such a concept. The papers presented in this session deal with case histories of places where this concept is now under active evaluation. The use of sludges to revegetate land areas that have been degraded by accumulations of spoils from mining operations may prove to be the most appropriate, cost effective and otherwise productive way of managing both problems. It may also prove to be the concept that minimizes any further threat to the ecosystem posed by either the degraded land, the sludges or both.

27
USE OF SEWAGE SLUDGE TO IMPROVE TACONITE TAILINGS AS A MEDIUM FOR PLANT GROWTH

Justin V. Cavey and James A. Bowles

The potential for use of sewage sludge to improve taconite tailings for the growth of cover plants was investigated in this study. The tailings were alkaline in reaction and low in available phosphorus and nitrogen. Partially dewatered municipal sewage sludge was incorporated into the tailings at three different rates. The establishment and growth of annual nurse plants and perennial cover plants were compared to both untreated tailings and those treated with three levels of commercial fertilizers during two growing seasons. The yield on sludge-treated plots was significantly greater than on fertilizer-treated and control plots during the second year of growth. Sludge-treated plots also produced dense cover during the initial year, but results were more variable due to growth of annual plants. Untreated taconite tailings produced inadequate cover during both seasons of growth.

Introduction

Increasing demand for iron and depletion of iron-rich Lake Superior ranges have made it economically feasible to mine low-grade taconite deposits. Beneficiation processes magnetically separate the iron and concentrate it into pellets, leaving a slurry of waste tailings to be deposited in diked basins which cover extensive areas at many mine sites (Davis, 1964).

A cyclone separates the tailings into coarse and fine fractions. Coarse tailings are utilized to construct a dike which encircles the basin while the fine fraction materials are released into the basin interior to settle out of suspension. Clear water is returned to the processing plant for reuse.

Most mine spoil materials are deficient in many plant nutrients, and have low clay and humus contents and, therefore, low cation exchange capacities (Berry and Marx, 1977; Wong and Tam, 1977).

Tailings also lack stable structural development and are susceptible to wind and water erosion (Shetron and Duffek, 1970). These limitations make the required reclamation difficult and expensive.

Early stabilization of tailing basins with cover crops minimizes erosion and improves these materials for the establishment of perpetuating plant communities (Jones et al., 1975). Once these communities are established, the potential for a land use compatible with adjacent lands is enhanced.

Municipal wastewater treatment plants convert the human wastes into sewage sludge. In many locations land application of sludge is an acceptable means of disposal (Keeney et al., 1975). Sewage sludge contains significant

amounts of plant nutrients and organic matter (Sommers, 1977). Mineralization releases available plant nutrients in the sludge over a period of time. Pomares-Garcia and Pratt (1978) estimated 35 to 45 percent mineralization in the first ten months after application. Sewage sludge has been utilized successfully as an amendment to facilitate revegetation of various mine spoils (Stucky and Newman, 1977; Hunt et al., 1971).

The objectives of this study were: (1) to compare sewage sludge to commercial fertilizer in revegetation of alkaline taconite tailings; and (2) to evaluate the establishment and growth of three grass species and three legume species on the treated and untreated taconite tailings.

Methods and Materials

The tailings basin of the Jackson County Iron Company mine located near Black River Falls, Wisconsin, was the site of this study. Ores generating the tailings are from the iron formation which consists mainly of magnetite, quartzite and lenses of schist containing quartz, chlorite, muscovite, and biotite. Removal of the high iron components yields a gray-colored, alkaline, calcareous, moderately coarse textured tailing.

Periodic flooding and deposition of new wastes precluded use of the basin interior as a study site. A nearly level site was selected on the berm of the tailings dike where the basin tailings could be placed for the experimental plots. Earthmovers and graders were utilized to cover an area of approximately 0.33 ha with 30 cm of tailings.

Physical and chemical properties of these tailings that were considered important in the selection of treatments and plant species were determined or provided by either the Jackson County Iron Company or UW-Extension Plant and Soil Testing Laboratory.

The content of selected macronutrients is shown in Table 27-1. The free carbonate content of the tailings would limit the availability of phosphorus and micronutrients, i.e., molybdenum and zinc. Soil reaction

Table 27-1. Analysis of Selected Macronutrients in Taconite Tailings.[+]

Nutrient Analysis (88 samples)		
Nutrient	Content in kg/ha	
	Range	Mean
P	0-8.8	3.5
K	99-165	138.6
Ca	2,220-3,300	2,779.7
Mg	110-220	183.7

[+]Analyses provided by UW-Extension Soil and Plant Testing Lab in Madison, Wisconsin.

was measured with a pH meter. Values ranged from 8.2 to 8.7 and the mean for all sample plots was 8.5.

Bulk density determinations were made on all plots using the excavation method. Samples were taken at the same time for particle size analysis using the hydrometer method (Black, 1965). Bulk densities ranged from 1.2 to 1.8 g/cm^3 with a mean of 1.6. Textures varied from heavy loamy sands to fine sandy loams but were predominantly sandy loams. Sand content ranged from 52 to 86 percent and had a mean value of 72 percent. (Fine and very fine sands dominate.) Silt and clay contents varied from 12 to 56 percent and 2 to 13 percent respectively with mean values of 25 percent silt and 3 percent clay.

A split plot design was used to divide the site into three blocks. Within each block six treatments and a control were randomly assigned to 4.3 m x 18.3 m plots. Treatments consisted of three commercial fertilizer and three sludge rates (see Table 27-2). Each plot was then subdivided into three 4.3 m x 6.1 m split plots which were randomly assigned one of three plant mixtures. Plant mixtures are listed in Table 27-3.

Sewage sludge was obtained from the Wisconsin Rapids sewage treatment plant. The chemical composition of the sludge is shown in Table 27-4. After anaerobic digestion, the sludge was dewatered in concrete drying beds producing a solids content of 42 percent.

Sludge was weighed in a five gallon pail and applied using a wheel barrow and shovel. Following application, the sludge was incorporated to a depth of 15 cm with a rototiller. Plots receiving commercial fertilizer were rototilled prior to fertilization. Seeds were sown by hand and incorporated with a rake. Planting was completed on June 16, 1979.

Plant growth was monitored biweekly throughout the 1979 and 1980 growing seasons. Yields were determined by clipping a representative .84 m^2 circular sample from each subplot in early September, 1979 and late July, 1980. Data were analyzed using analysis of variance and the means were compared by Duncan's Multiple Range test.

Results and Discussion

First Growing Season

Establishment of ground cover, mainly through the use of annual grasses, was the main objective of the initial growing season. Barley seedlings had emerged on all plots two weeks after planting and attained heights which ranged from 7 cm in control plots to 9 cm in plots receiving the high rate of sludge. Plants in the control plot grew very little in comparison with the plots treated with fertilizer and sludge, but matured and produced seed in all plots.

Japanese millet required a longer period of time to germinate. Millet

Table 27-2. Sludge and Fertilizer Rates Used on Taconite Tailings.

Treatment	Rate (Available N-P-K)+
Control	No sludge or fertilizer
Low Sludge	12.5 Mt/ha (50-160-10 kg/ha)
Medium Sludge	25 Mt/ha (100-320-20 kg/ha)
High Sludge	50 Mt/ha (200-640-40 kg/ha)
Low Fertilizer	55-33-49.5 kg/ha
Medium Fertilizer	82.5-55-49.5 kg/ha
High Fertilizer	110-77-49.5 kg/ha

+Available N in sludge based on 2 percent N content and a 20 percent mineralization rate for initial growing season. P and K analysis of sludge provide by UW-Extension Soil and Plant Testing Lab in Madison, Wisconsin.

Table 27-3. Plant Mixtures Used on Taconite Tailings.

Plant Mixture	Species	Rate(kg/ha)
Bluegrass-Clover	Canada Bluegrass (*Poa compressa*)	11
	Red Clover (*Trifolium pratense*)	9.7
Brome-Alfalfa	Smooth Brome (*Bromus inermis*)	15.2
	Alfalfa (*Medicago sativa*)	11
Wheatgrass-Clover	Western Wheatgrass (*Agropyron smithii*)	9.7
	Alsike Clover (*Trifolium hybridum*)	11
All Mixtures	Barley (*Hordeum vulgare*)	16.5
	Japanese Millet (*Echinochola frumentacea*)	8.6

Table 27-4. Chemical Composition+ of Wisconsin Rapids Municipal Sludge.

Element	ppm (Dry Matter Basis)	
	Sample 1	Sample 2
P	14,211.0	11,545.0
K	863.7	696.2
As	106.6	93.4
Cd	61.8	57.5
Cr	1,607.0	1,337.0
Cu	199.3	172.0
Pb	277.5	242.9
Hg	5.5	5.0
Ni	448.5	392.2
Zn	506.5	444.9

+Analyses provided by UW-Extension Soil and Plant Testing Lab in Madison, Wisconsin.

seedlings were first observed four weeks after planting. The germination percentage of millet was also quite variable. In some plots it flourished and became the dominant plant in 1979, while in others it did not germinate. Millet matured and produced seed in all plots in which it was present.

Two volunteer annual grasses, witchgrass (*Panicum capillare*) and hairy crabgrass (*Digitaria sanguinalis*), were present in all plots receiving sewage sludge and were included in annual grass production values. Annual grasses and nurse crops dominated 1979 production and comprised an average of 96.6 percent (19,848 kg/ha), 81.7 percent (15,086 kg/ha) and 96.1 percent (20,193 kg/ha) of the yield of bluegrass-red clover, brome-alfalfa, and wheatgrass-alsike clover plant mixtures respectively.

The three legume species germinated in all plots two weeks after planting. Little growth occurred in the control plots in which mean maximum heights were 4 cm, 6 cm, and 3 cm for red clover, alfalfa, and alsike clover respectively.

The mean height of red clover ranged from 7 cm on plots receiving the low sludge rate to 16 cm on plots receiving the high sludge rate with a mean maximum height on all treatments of 11 cm. The average yield was 555.6 kg/ha which was 2.7 percent of the total production of this plant mix.

The mean height of alfalfa ranged from 8 cm in plots receiving the low fertilizer rate to 23 cm in plots receiving the medium sludge ratio, and had a mean of 13 cm for all treatments. Alfalfa was the most productive of the legumes yielding 2,187.8 kg/ha (11.8 percent of this mixture).

Alsike clover yielded 545.6 kg/ha comprising 2.6 percent of the biomass produced by plots planted to this mixture. Maximum plant height ranged from 6 cm in low sludge rate plots to 11 cm in high fertilizer plots and had a mean height of 6 cm in all plots.

Smooth brome exhibited better growth in 1979 than either Canada bluegrass or western wheatgrass. It ranged in maximum height from 6 cm on control plots to 26 cm in plots treated with medium sludge rates and had an overall mean of 19 cm. Production was 1,201 kg/ha (6.5 percent of plant mix).

Canada bluegrass and western wheatgrass produced 147.0 kg/ha (0.7 percent of plant mix) and 269 kg/ha (1.3 percent of mix) respectively. Maximum height of Canada bluegrass ranged from 3 cm on plots treated with low sludge to 8 cm on high commercial fertilizer plots (overall mean 5 cm). Western wheatgrass had a maximum height of 4 cm in plots treated with low sludge rates to 10 cm in high sludge plots (overall mean 8 cm).

The statistical analysis of plant mixture yields within the same soil treatment showed no significant differences. Production values (see Table 27-5) were quite variable within a soil treatment. A major cause of this was the inconsistent germination of Japanese millet.

The production of plant biomass varied greatly among the different

Table 27-5. Effect of Soil Treatment and Seed Mixture on Yield of Plants Grown on Taconite Tailings.

		Mean Biomass Production (kg/ha)	
Soil Treatment	Seed Mixture	1979	1980
Control	Blue Grass-Clover	132	86
	Brome-Alfalfa	252	139
	Wheat Grass-Clover	179	80
	Mean*	188a	102A
Low Sludge	Blue Grass-Clover	2,931	2,741
	Brome-Alfalfa	2,356	3,100
	Wheat Grass-Clover	2,509	2,181
	Mean*	2,589ab	2,674C
Medium Sludge	Blue Grass-Clover	4,666	4,532
	Brome-Alfalfa	3,427	3,371
	Wheat Grass-Clover	3,520	2,882
	Mean*	4,094bc	3,595C
High Sludge	Blue Grass-Clover	6,408	3,865
	Brome-Alfalfa	4,703	4,177
	Wheat Grass-Clover	5,439	1,991
	Mean*	5,517c	3,344C
Low Fertilizer	Blue Grass-Clover	1,547	284
	Brome-Alfalfa	2,436	957
	Wheat Grass-Clover	1,459	998
	Mean*	1,804ab	746AB
Medium Fertilizer	Blue Grass-Clover	2,384	999
	Brome-Alfalfa	2,043	1,518
	Wheat Grass-Clover	3,878	1,671
	Mean*	2,769abc	1,396B
High Fertilizer	Blue Grass-Clover	3,107	823
	Brome-Alfalfa	2,819	2,223
	Wheat Grass-Clover	3,930	731
	Mean*	3,285bc	1,259B

*Treatment means followed by different letters are significantly different at the 1% level. Each year treated separately.

soil treatments (see Table 27-5). The mean production ranged from 188 kg/ha on the control plots to 5,517 kg/ha on those with high sludge rates. Statistical analysis showed that yields were significantly different at the one percent level. However, the results of Duncan's Multiple Range test did not show significant differences at the one percent level between the control and low sludge and low and medium fertilizer rates even though yields and ground cover were strikingly different (see Table 27-5). This was due to the great variability between individual plots within a treatment. This variability was mainly caused by different germination rates of Japanese millet. Variations in texture and compaction of the taconite tailings may also be involved in these variations. The relationship of soil treatment means to the control are shown in Figure 27-1.

Second Growing Season

There was very little regeneration of nurse crops in 1980. Although barley produced seed in 1979, it was virtually absent in 1980. Millet plants were present in 15 plots, but were a minor component. Two annual grass invaders occurred in many plots. Cheatgrass (*Bromus tectorum*) was common in many parts of the study area; and Japanese brome (*Bromus japonicus*) grew only in plots that were seeded with the wheatgrass-alsike clover plant mixture. It may have been introduced from the western wheatgrass seed. Annual grasses comprised 13.0 percent (521 kg/ha) of the bluegrass-red clover yield, 1 percent (47.5 kg/ha) of the brome-alfalfa yield, and 12.1 percent (383.2 kg/ha) of the wheatgrass-alsike clover yield.

The legumes made the greatest increase in production, and were dominants in all treatments except the control, in which perennial grasses were dominant. Alsike clover increased more than either alfalfa or red clover, and was slightly higher than alfalfa in overall production. The high production of legumes should have a very beneficial effect on continued plant production in materials like taconite because of their low nitrogen

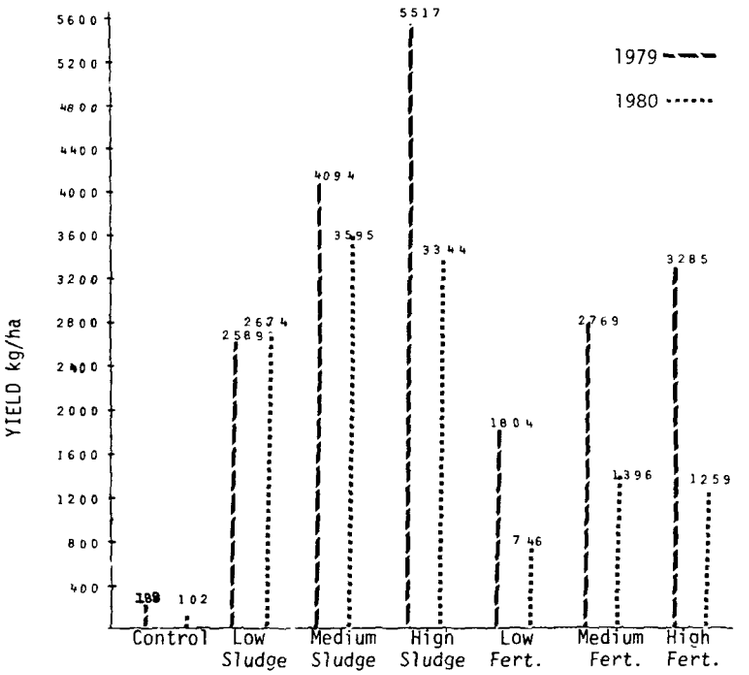

Figure 27-1. Comparison of Mean Yields of Sludge and Fertilizer Treatments with Control.

and humus content.

The perennial grasses all made large increases in production and made up a significant percentage of the total yield and plant cover in most all plots. Smooth brome was the largest producer and western wheatgrass the lowest. Since both smooth brome and western wheatgrass are characterized by high rhizome growth, these grasses should continue to increase in production and percent cover.

Statistical analysis of plant mix production within soil treatments showed significant differences at the 0.5 percent level. Duncan's Multiple Range test indicated that brome-alfalfa plant mix was significantly different than the wheatgrass-alsike mix. Based on mean yields of the plants tested, brome grass and either alsike clover or alfalfa will make the best legume-grass mix.

The production of total biomass again showed large differences among the different soil treatments (see Table 27-5). The mean yields ranged from 102 kg/ha on control plots to 3,595 kg/ha on those receiving the medium sludge rate. Statistical analysis showed that yields were significantly different at the 0.5 percent level. Duncan's Multiple Range test indicated that all treatments except the low fertilizer rate were significantly different at the 1 percent level from the control. Also, the three sludge treatments were all significantly different from the fertilizer treatments but not from each other (see Table 27-5). The relationship of sludge and fertilizer treatment means with the control are shown in Figure 27-1.

There were some individual plots that showed great variation from the mean treatment yield. Differences in taconite properties undoubtedly had influence but it is believed that very high production of Japanese millet and barley in 1979 may have greatly reduced the seedling survival of the perennial plants. For example, the plot with the highest overall production in 1979 was a wheatgrass-alsike clover plant mix on a high sludge rate treatment. The following year this same plot produced less than all 27 sludge-treated plots except one. This change in relative yield from 1979 to 1980 was most evident in alsike clover-western wheatgrass plots that had high Japanese millet production.

Summary and Conclusions

1. A split plot experimental design was utilized to test the effect of both sewage sludge or commercial fertilizer applications and different plant species on the establishment and growth of vegetation in taconite tailings. Both sludge and fertilizer treatments resulted in yields that were appreciably greater than those on untreated taconite. These differences were significant at the one percent level during the initial growing season; however, variation among individual plots within treatments caused only the high and medium

sludge and high fertilizer treatments to be significant from the control. A major factor contributing to individual plot variations was the different germination rates of Japanese millet, one of the annual plants used in all plots.

2. Plant growth and cover during the initial year were dominated by the annuals, barley and Japanese millet. Both annuals matured and produced considerable seed in all treatments except the control. Barley germinated earlier and more consistently and appeared to have less impact on the establishment and growth of perennial plants. The perennial grasses and legumes became established in all treatments but this was appreciably influenced by use of sludge, rate of fertilization, and extent of dominance of annual grasses. The differences in mean yields during the initial year between plant groups were not statistically significant.

3. Mean yields of plant biomass produced during the second growing season were significantly different at the 0.5 percent level. A comparison of means showed that all treatments were significantly different from the control except the low fertilizer treatment. All sludge treatments were also significantly different than the fertilizer treatments. None of the fertilizer or sludge treatments were significantly different from each other. Field observations and an analysis of the 1979 growing season data indicate that this was mainly due to variability among individual plots within a treatment. A major factor contributing to this variability was the complete dominance in some plots of Japanese millet during the initial growing season.

4. Plant growth was dominated by legumes during the second year in all treatments except the control, in which perennial grasses dominated. Yield differences between plant groups were significant at the 0.5 percent level. Brome and alfalfa produced the highest yield and was significantly greater than wheatgrass and alsike clover. The annual grasses planted produced low populations of seedlings during the second growing season.

5. Results of this study indicate that either use of commercial fertilizers or high organic matter amendments, i.e., sewage sludge, are essential to the establishment and growth of vegetation in taconite tailing basins.

Results also indicate that municipal sewage sludge is more effective than commercial fertilizers in preparing taconite tailings for plant growth. Comparisons of the plant species used in this study indicate that either alsike clover or alfalfa were the best legumes, smooth brome grass the best perennial grass, and barley the best annual nurse crop.

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28
THE RESPONSE OF NATIVE HERBACEOUS PRAIRIE SPECIES ON IRON-ORE TAILINGS UNDER DIFFERENT RATES OF FERTILIZER AND SLUDGE APPLICATION

Darrel G. Morrison and Julie Hardell

Native prairie species were planted in test plots on iron ore tailing deposits at the Jackson County Iron Company site near Black River Falls, Wisconsin, in early June of 1979. Three levels of nitrogen and phosphorus were added in various combinations and sewage sludge was applied at two rates. Primary objectives of the study were to (1) determine whether fertilization made a significant difference in the response of the ten species selected, and if so, (2) evaluate the performance of these species at the different levels of fertilization.

Species utilized in the study included five native grasses (big and little bluestem, sideoats grama, Canada wild rye, and switchgrass) and four prairie forbs (leadplant, prairie bush-clover, beebalm, and black-eyed susan). In addition, foxtail, a non-native annual, was planted at 10% of the seed mix as a cover.

A total of eleven treatments were tested, including eight chemical fertilizer combinations, two rates of sewage sludge application, and a control with no additives. Four replications of each were plotted with the seed mix at a rate of 22 kg/hectare (20 pounds/acre), in one-square-meter plots for harvest, and four-square-meter plots for continued monitoring.

First-year results showed native grasses performing much better than the forbs under all treatments. Sideoats grama was the best performer overall, with many plants flowering the first season. Canada wild rye showed good germination and survival, but slow growth. The native species showed little significant response to fertilizer treatment. On the other hand, foxtail, the cover species, performed best under the highest chemical fertilizer and sewage sludge treatments

Introduction

Iron ore tailings deposits, in the absence of a vegetational cover, are subject to water and wind erosion, creating a potential hazard to the surrounding area. Revegetation of such deposits by natural invasion is typically a very slow process (Dickinson, 1975). Therefore, selection of plant species and techniques which will accelerate this process are important in overcoming this hazard and in returning tailings deposit sites to a productive and visually-attractive state.

Tailings result from the mineral extraction process, and are finely

ground rock and minerals that have been processed to remove the desirable ore. Tailings are highly variable in physical and chemical properties, influenced by both the nature of the ore body and the type of mining and processing operation.

Among the problems associated with tailings revegetation are the following: (1) adverse physical properties affecting structure, density, and water penetration; (2) extreme deficiencies of some major nutrients; (3) presence of toxic compounds or high salt concentrations; (4) wind blasting; and (5) high temperatures and limited water (Hunter and Whiteman, 1974).

Basically, two approaches to the establishment of vegetation on mine wastes such as tailings have been tried historically. One is to greatly modify the environment through various amelioration techniques, e.g., application of a layer of topsoil, fertilization, mulching or watering; then planting introduced agronomic species or trees and shrubs on the more amenable site. A second approach is to utilize plant species which can tolerate the difficult environmental conditions on the site, and which by their presence modify conditions sufficiently for other species to invade over time.

The approach utilized in this experiment contains elements of both of these; i.e., utilizing predominantly native species which are considered tolerant of many of the existing environmental factors on the site, but providing nutrients at different levels in order to increase the likelihood of success of the plantings. It is expected that the species composition will change over time.

Use of Native Species in Reclamation

Current Wisconsin and federal reclamation legislation stresses the importance of promoting a natural succession of plants that will eventually lead to a vegetational cover similar to that originally on the site (Public Law 95-87, Sec. 515 (b)(19); Wisconsin State Statutes, Chapter 421, Sec. 144-83 (2)(c)).

Prairie species were selected for this study for several reasons. They are tolerant of sun and wind exposure, limited water supply, and high temperatures, as well as being tolerant of soils that are low in nutrients and relatively high in alkalinity. Also, most of the species that were selected are indigenous to the local area, but will not necessarily preclude invasion by tree and shrub species whose propagules are introduced.

The use of colonizing grasses followed by the introduction of persistent trees and shrubs was advocated by Miller (1978). Wali and Kollman (1977), Riley (1974), and Coates (1973). All discuss the advantages of encouraging a natural succession of species.

Fertilization Studies on Tailings

Chemical fertilization. Native species have been reported by Dickinson (1975) to invade iron ore tailings deposits in Minnesota after fertilization. Little work has been done to evaluate the effects of different rates of fertilizer

application on sites that have been seeded to native species. The original character of the tailings and the desired plant growth, of course, affects the amount of nutrients needed, as noted by Nielson and Peterson (1978).

Dean and Havens (1972) found all tailings to require the addition of nitrogen and phosphorus for plant growth. They found rates of 30 lbs/a N and 33 lbs/a P to achieve satisfactory results.

Sewage sludge. Sludge improves the physical properties of soil and supplies nutrients long enough to establish plant growth (Walsh, 1976). Types of organic compounds in digested sewage sludge were found to be similar to those of soil organic matter by Shammas (1978). Like other organic matter, sewage sludge is potentially of benefit in tailings revegetation by improving texture, increasing water-holding capacity, and protecting aginst erosion (Dinsmoor, 1977). Further, organic matter content of the soil is instrumental in reducing loss of nitrogen and other nutrients through leaching (Tisdale and Nelson, 1975).

Gordon (1969) used sewage sludge for covering gold tailings to prevent erosion. Dean et al. (1974) obtained satisfactory results by mixing sludge with tailings and also layering it at various depths.

Field Study

Objectives of the Study

The field study initiated in 1979 evaluates the performance of prairie species grown on iron ore tailings under different rates of fertilizer and sewage sludge application. Specific objectives were (1) to determine if fertilization made a significant difference in the response of the ten species selected and if so, (2) to evaluate the performance of these species at the different levels of fertilization. Observations are continuing during the present (1980) growing season, and will continue for three more years.

The Site

Location. The field study was conducted at the Jackson County Iron Company open pit mine located 11.27 km east of Black River Falls, Wisconsin. Presettlement vegetation in this area was predominantly oak savanna.

Climate. Precipitation averages 76.28 cm (30.03") per year with record ranges between 47.12 cm (18.55") and 102.21 cm (40.24"). June is typically the wettest month of the year, averaging 12.67 cm (4.99"). Seventy percent of all precipitation falls from April through September. The average annual temperature ranges from 4.9°C to 9.3°C (40.9°F to 48.8°F), with an absolute range between -46.1°C to 42.2°C (-51°F to 108°F). The average frost-free period is 116 days between May 23 and September 17.

Description of the mine and mining operation. The Jackson County Iron

Company mine is the only operating mine in Wisconsin, and the smallest iron ore mine in the United States in terms of tonnage extracted. Production started in December 1969 and is scheduled to shut down in 1990, by which time it will have produced 17 million tons of taconite pellets (Vase, 1980).

The operation is an open-pit mine. The pit presently covers 125 acres and is 270 feet deep. On completion, it will cover 136 acres and be 725 feet deep.

There are two types of waste materials resulting from the mining and extraction process--spoils and tailings. The spoils are non-ore-bearing rock and soil lying above the ore body, and are deposited in a number of spoils dumps near the open pit.

The tailings are a waste by-product of the magnetic extraction process. On this site, they consist primarily of silica with trace amounts of hematite and magnetite. The tailings are piped in a water slurry to a circular tailings disposal pond, 3600 feet in diameter. At the edge of the pond, a cyclone separator sorts the coarse fraction from the fine. The coarse tailings are used to build the dike of the pond, which covers 319 acres. The fine fraction is released into the pond where it is kept wet.

Materials and Methods

Plot layout. Experimental plots were set up on the western side of the tailings dike. Road building equipment was used to grade and prepare a bed which was level and quite compact. Plots of two different sizes were alternately staked out with one meter between plots. The size of the larger permanent plots was four square meters; plots scheduled for first-year harvest were one square meter. Treatments were set up in a completely randomized design. There were four replications of each treatment for a total of 44 large plots and 44 small plots. A border containing the test species was planted around the periphery.

Tailings analysis. The tailings are sandy loam in texture with an average pH of 8.5. Analysis of them showed a low phosphorus content, marginal potassium and magnesium, and sufficient calcium. From previous studies it was known that there was virtually no nitrogen present and that the organic matter content was very low (Dinsmoor, 1977; JCIC, 1977).

Species selection and planting techniques. Each plot was planted with a mix of ten species in June 1979 at the rate of 22 kg/ha (20 lbs/a).

Five of the species in the mix are native prairie grasses. All five had been previously tested at the same mine site without any fertilizer application by Dinsmoor (1977) and seemed to warrant further consideration. The five native grasses utilized in the 1979 field study included big bluestem (*Andropogon gerardi*), little bluestem (*Andropogon scoparius*), sideoats grama (*Bouteloua curtipendula*), Canada wild rye (*Elymus canadensis*) and switchgrass (*Panicum virgatum*), each planted at 10 percent by number of seeds.

Two legumes were included in the mix at a rate of 15% by number: leadplant (*Amorpha canescens*) and roundhead bush clover (*Lespedeza capitata*), both of which grow in dry prairies in Wisconsin, but which had not been widely tried for revegetation of tailings. Two other prairie forbs were included at a rate of 5% by number. These were beebalm or bergamot (*Monarda fistulosa*) and black-eyed Susan (*Rudbeckia hirta*). Both have been observed to invade disturbed sites readily, without persisting over long periods; and both had earlier been seen as natural invaders on spoils deposits at the Jackson County Iron Company site.

The tenth species utilized in the study was foxtail (*Setaria* spp.), planted at 10% of the mix, by number. The foxtail seed, hand-collected for the project, included four species, *S. lutescens, S. saberii, S. verticillata,* and *S. viridus*, and no attempt was made to separate them. While not native, they are annuals which provide initial cover, and a degree of protection to first-year seedlings of the native species. Cornelius (1946) found that weedy annual grasses, including *Setaria viridus*, provided about four times as much basal cover as prairie grasses in a prairie restoration at the end of the first growing season. He believed they were beneficial because their cover helped control erosion and protected the young perennial grasses, but became almost negligible after the third growing season.

The seed mix was hand-broadcast in the plots and raked in. A pelletized mulch of grass hulls, was applied to a thickness of 2.2 cm (1 inch). No supplementary watering or weeding was done during the growing season.

Fertilizer Treatments

Chemical fertilizer. Phosphorus, applied as triple super phosphate, was rototilled into the tailings at rates of 0 kg/ha, 28 kg/ha, and 112 kg/ha, hereafter referred to as P_0, P_1, and P_2 respectively. Nitrogen in the form of ammonium nitrate was applied to the tailings surface and raked in at rates of 0 kg/ha, 88 kg/ha, and 175 kg/ha, referred to as N_0, N_1, and N_2 respectively. The various combinations resulted in nine different chemical fertilizer treatments, referred to as: N_0P_0, N_0P_1, N_0P_2, N_1P_0, N_1P_1, N_1P_2, N_2P_0, N_2P_1, and N_2P_2. (see Table 28-1.)

Sewage sludge. Two levels of sewage sludge, obtained from Wisconsin Rapids, were applied as separate treatments (Table 28-1). The sludge was applied at application rates of 85 mt/ha and 42 mt/ha (dry-weight basis). The sludge was rototilled into the tailings plots ten days prior to planting. Plot surfaces were raked smooth. See Table 28-2 for analysis of samples of sludge used in the experiment.

Above-ground parts of plants in the 44 one-square-meter plots were harvested in September following the first growing season. Dry weight was of primary importance in evaluating the fertilizer and sludge treatments. Total dry weight of all species was analyzed. Then total dry weight of *Setaria* spp. and the total dry weight of all native species combined were separately

Table 28-1. Fertilizer Rates Applied.

Fertilizer	Symbol	Rate kg/ha	lbs/A
Ammonium nitrate (NH_4NO_3)	N_2	175	156
	N_1	88	79
	N_0	--	--
Triple super phosphate ($Ca(H_2PO_4)_2$)	P_2	112	100
	P_1	28	25
	P_0	--	--
Sewage sludge	SS_2	85 mt/ha	38 t/a
	SS_1	42 mt/ha	19 t/a

Table 28-2. Analyses of Two Samples of Wisconsin Rapids Sewage Sludge Used in the Experiment.

Analysis	Sample 1	Sample 2
Total N, %	0.62	0.73
NH_4-N, ppm	8.0	10.5
NO_3-N, ppm	360.0	700.0
P, ppm	14,211.0	11,545.0
K, ppm	863.7	696.2
As, ppm	106.6	93.4
Cd, ppm	61.8	57.7
Cr, ppm	1,607.0	1,337.0
Cu, ppm	199.3	172.3
Pb, ppm	277.5	242.9
Hg, ppm	5.5	5.0
Ni, ppm	448.5	392.4
Zn, ppm	506.5	440.9
Dry matter, %	64.5	67.6

analyzed. For selected species, the average dry weight per plot was also analyzed.

Percent cover, plant height, and the number of plants per plot were also collected.

Results and Discussion

Number of plants. The number of plants established at the end of the 1979 growing season was generally encouraging. The number ranged from 33 to 161 per meter-square plot with the average number over all treatments being 84. Of these 84, 20 were *Setaria* spp. Total number of plants in harvested plots was 3652, of which 3542 were grasses.

Elymus canadensis gave the best results in terms of number of plants, making up 39.8% of the total plant count. *Setaria* spp., the annual cover crop made up 23.9% of the total. *Bouteloua curtipendula* made up 18% of the total. The two bluestems (*Andropogon gerardi* and *A. scoparius*) together comprised 13.8% of the total number of plants. *Panicum virgatum* accounted for only 1.5% of the total number of plants.

All of the forbs were low in numbers, totalling only 110 plants over the 44 meter-square plots. See Table 28-3 for number of seedlings produced, by species.

The average number of plants per plot under different treatments is shown in Table 28-4.

Table 28-3. The Number of Seedlings Produced in 44 One Square Meter Plots.

Species	Seedlings produced	Seedlings as % of viable seed	Seedlings as % of total no. established
Grasses			
Andropogon spp.	504	22.9	13.8*
Bouteloua curtipendula	658	59.8	18.0*
Elymus canadensis	1452	132.0	39.8*
Panicum virgatum	54	4.9	1.5*
Setaria spp.	874	79.4	23.9*
Forbs			
Amorpha canescens	28	1.7	0.77
Lespedeza capitata	34	2.0	0.93
Monarda fistulosa	12	2.3	0.33
Rudbeckia hirta	36	6.8	0.98

*Species statistically analyzed

Table 28-4. Average Number of Plants Per Plot for Each Treatment.

Treatment	Number of Plants/Plot
N_0P_0	83
N_0P_1	116
N_0P_2	97
N_1P_0	74
N_1P_1	72
N_1P_2	96
N_2P_0	63
N_2P_1	63
N_2P_2	56
SS_1	112
SS_2	85

Response to fertilizer treatments. Based on dry weight of the harvested above-ground biomass, the native prairie species showed very little response to fertilizer treatments, while foxtail (*Setaria* spp.) gave the best response with high rates of chemical fertilizer and sewage sludge application.

Possible explanations of the similar response of native prairie species under different fertilizer treatments include the following: (1) these species have low nutrient requirements; (2) they are very efficient at extracting available nutrients due to their extensive network of roots; and (3) *Setaria* spp. may have utilized the nutrients to the disadvantage of the slower-growing native species.

Overall, there were significant differences in mean total dry weight per plot under the different chemical fertilizer and sludge treatments. The largest increase in dry weight, as shown in Table 28-5 occurs when the phosphorus application is increased from P_1 to P_2 level, in combination with N_1 or N_2. Note that the mean total dry weight per plot treated with sewage sludge increased from 309 grams at the 18.7 mt/ha application rate to 424 grams at the 42 mt/ha rate.

Individual species responses. *Bouteloua curtipendula* gave the best results overall, among the prairie species. It germinated well and grew quickly, achieving the greatest average dry weight per plant for each treatment. Some individuals flowered with no correlation to fertilizer treatment.

Elymus canadensis germinated exceptionally well in the field, but did not grow as rapidly as expected, possibly because of the relatively late planting date.

Table 28-5. Total Dry Weight Per Plot; Treatment Means and Standard Deviations (grams).

Treatment	Mean	Standard Deviation
N_0P_0	158	22
N_0P_1	177	24
N_0P_2	209	46
N_1P_0	237	78
N_1P_1	291	102
N_1P_2	496	110
N_2P_0	321	39
N_2P_1	275	100
N_2P_2	529	87
SS_1	309	46
SS_2	424	67

Andropogon gerardi and *A. scoparius* were grouped together because they could not be separately identified at harvest time due to their very small size.

The other prairie species germinated poorly in this study; i.e., *Panicum virgatum* and the forbs, *Amorpha canescens, Espendeza capitata, Monarda fistulosa* and *Rudbeckia hirta.*

Setaria spp. performed well as a cover crop on the tailings. Germination was high and growth was rapid, with virtually all plants flowering by the end of the season. It provided good cover for the slower-growing native perennials as well as for erosion control. It protected the prairie species from dessication and sand-blasting. At the same time, it may have competed for nutrients and moisture. The total dry weight for *Setaria* spp. was greatest under the N_2P_2, N_1P_2, and SS_2 treatments.

Second-year Observations

No harvesting has occurred in 1980, the second growing season of this planting. Hence, no quantitative data are available. Visual observations indicate that *Setaria spp.* has performed as expected, being greatly reduced in number and visual dominance during the second growing season. It has been replaced in apparent importance by *Elymus canadensis*, which was approximately 1 meter tall in most plots by midsummer and appears to have flowered under all treatments. *Bouteloua curtipendula* clumps have increased in size and appear to be the second-most important species. *Monarda fistulosa* and *Rudbeckia hirta*, while not great in number, have been visually significant because of their conspicuous flowering during the second growing season. Generally speaking, plant vigor appears to be correlated with higher application of fertilizer. The significance of these differences will be determined only with analyses of this year's harvest. Seedlings of *Populus tremuloides* have invaded in many of the plots during the 1980 growing season.

Conclusions

Certain prairie species seem to have been established successfully on iron ore tailings in this experiment. After one growing season, the necessity of fertilization was not verified. After two seasons, it appears that the fertilizer at least facilitates growth and development. The use of *Setaria* spp. as a cover appears useful, although it responded best to high rates of fertilization. It has diminished in importance during the second growing season, as predicted. Invasion of woody species from the surrounding area has also begun to occur.

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29
USE OF MUNICIPAL SLUDGE IN THE RECLAMATION OF ABANDONED PYRITE MINES IN VIRGINIA

Kenneth R. Hinkle

Two abandoned pyrite mine sites consisting of approximately 8 ha along Contrary Creek in Louisa County, Virginia have been reclaimed using municipal sludge as a soil conditioner. A reclamation program partially funded by an Environmental Protection Agency (EPA) demonstration grant began in 1976. After the mine waste areas were regraded to approximate natural contours, municipal sludge along with lime and fertilizer were applied as soil amendments followed by seeding. All sludge used in the project was trucked from the Blue Plains Sewage Treatment Plant in Washington, D.C., free of charge. The extreme toxicity of mine wastes including heavy metals along with two very dry years in 1976 and 1977 seriously hampered efforts to establish vegetation on the reclaimed sites. To overcome this problem a maintenance program including the application of additional sludge, lime, and fertilizer and reseeding has been in progress since 1976. By the summer of 1980 about 90 percent of the reclaimed areas supported a fair to good growth of vegetation, but some extremely toxic areas remain barren and continue to pose problems.

Although there have been insignificant gains made in the primary objective of this project, the improvement of water quality in Contrary Creek, it is felt that insufficient time has elapsed to allow the hydrologic system and mine waste chemistry to react to the reclamation effort. It has been demonstrated that by using municipal sludge as a soil amendment, vegetation can be grown on highly toxic mine wastes. It is probable that not a fraction of the success in promoting vegetative growth would have been realized without the use of sludge. No harmful effects are known to have resulted from the use of sludge in this project, and no public opposition has been voiced.

Introduction

The Contrary Creek project is located in Louisa County, Virginia approximately 65 km northwest of Richmond and approximately 120 km southwest of Washington, D.C. Contrary Creek is a small stream approximately 8 km in length and has an average annual flow of 207 l/s (7.3 cfs) at its mouth where it flows into Lake Anna, an impoundment completed in 1972 as a source of cooling water for a nuclear power plant. In the nineteenth century extensive mining activity took place in this part of the Virginia Piedmont, and between 1880 and 1920 three deep-shaft pyrite

mines were operated adjacent to Contrary Creek. During this period large volumes of pyritic wastes were dumped along Contrary Creek disturbing about 18 ha at the three mine sites and resulted in a severe acid mine drainage (AMD) problem in the stream leaving it practically devoid of aquatic life. The area remained essentially in this condition for over 50 years after the mines closed. In the early 1970s after the Virginia Electric Power Company decided to build a nuclear power plant downstream from the mine sites, the Virginia State Water Control Board (SWCB) assumed responsibility for developing a program to abate the AMD in Contrary Creek and Lake Anna. It was feared that the continual influx of AMD which included heavy metals would eventually result in a buildup of contaminants in the reservoir.

Project Development

In 1973 the SWCB decided to apply for an EPA demonstration grant under Section 107 of PL 92-500 to be used in constructing abatement measures. As part of a feasibility study done by a consultant to support the grant request, the SWCB began a water quality monitoring program to define the magnitude of the AMD problem in Contrary Creek. Average concentrations of approximately 20 water samples collected at the mouth of Contrary Creek in 1974 are shown in Table 29-1.

In 1975 the SWCB was awarded a grant to be used in reclaiming two of the mine sites which are known as the Boyd Smith and Sulphur. The provisions of the grant were that the EPA would provide funds for contractual services which included construction work, and the SWCB would match the Federal funds with 40 percent of the total project cost through in-kind services consisting of project administration, monitoring and report preparation. The Soil Conservation Service (SCS) has provided the SWCB with engineering and technical assistance throughout the project. Prior to initiating reclamation, easements were secured with each property owner involved. A private mining firm assumed responsibility for reclaiming the third mine site along Contrary Creek known as the Arminius.

Reclamation of the Sulphur and Boyd Smith Sites began in 1976 and consisted essentially of (1) regrading and smoothing the mine wastes; (2)

Table 29-1. Average Composition of Water at Mouth of Contrary Creek (mg/l).*

pH	Acidity as $CaCO_3$	SO_4	Fe	Cu	Zn	Pb	Mn
3.3	169	267	23.1	1.20	3.5	0.05	1.5

*Average of approximately 20 samples collected in 1974.

constructing diversions; (3) excavating mine wastes from stream channels and stabilizing banks with riprap; (4) applying municipal sludge, lime and fertilizer; and (5) seeding and mulching.

Source and Transportation of Sludge

The source of the sludge used in the project was the Blue Plains STP in Washington, D.C. The Blue Plains STP generated approximately 275 t of anaerobically digested sludge daily which is concentrated by vacuum filtration to about 20% solids. The District of Columbia agreed to deliver all of the sludge needed free of charge, which substantially lessened the cost of the project. A cost of about $10/t for hauling had been estimated in the feasibility study and if this had actually been billed to the project, an additional expense of about $99,000 would have been incurred to date.

Sludge was transported in 18-t capacity trucks which were routed to minimize travel through populated areas, and hauling was done in compliance with Virginia Department of Highways and Transportation regulations. Trucks were carefully cleaned after each dumping to prevent spillage on public highways. The Virginia State Department of Health (SDH) provided the SWCB with guidelines for sludge disposal.

Application of Sludge

Approximately 400 truckloads of sludge amounting to about 7250 wet t were delivered in the project over a two-month period in the spring of 1976. Since the sludge was delivered concurrently with the regrading and smoothing work, it was possible to dump most of the sludge directly upon the application areas after lime and fertilizer had been spread. Sludge was normally allowed to dry a few days and then spread to a thickness of about 10 cm with a bulldozer followed by incorporation with a heavy duty disc. The longer sludge dries, the easier it handles, but it was not practical to let the sludge lie for long periods due to risk of heavy rains and the overall construction time frame. It was found that spreading could be done more efficiently by backdragging with a bulldozer rather than by pushing. Sludge was usually incorporated to a depth of 8 to 16 cm. Where the ground was too soft to support heavy equipment, a small disc drawn by a farm tractor was used for incorporation.

The 1976 seeding work was performed during the month of June which was not the most favorable time, but since the regrading and smoothing had progressed considerably faster than expected, it was not feasible to delay the seeding until fall. The late seeding coupled with meager rainfall during the remainder of the summer resulted in sparse seed germination. It was

obvious by late summer that a complete reseeding would be necessary. Reseeding with additional liming and fertilizing was done in the spring of 1977, but 1977 proved to be one of the driest years of the century making the spring seeding almost a complete failure.

The two dry years of 1976 and 1977 combined with the extreme toxicity of the mine wastes led to development of an annual maintenance program. Maintenance each spring and fall beginning in 1977 has consisted of applying soil amendments, reseeding, erosion control work, and irrigation of a small portion of the Sulphur Site. Additional sludge was applied each fall of 1977 thru 1979. The first real success in the vegetative work did not occur until 1978 when nearly normal seasonal rainfall returned, but short dry periods in 1978 and 1979 necessitated pumping irrigation water from a nearby beaver pond to maintain new and established growth on critical portions of the Sulphur Site.

As more of the reclaimed areas began to support vegetation and as maintenance work concentrated on isolated problem spots, sludge was stockpiled near application areas rather than dumped directly on them and was usually allowed to dry for two to three weeks. Various means were used to move sludge to application areas including an earthmoving pan, and end loader, and a small dump truck. When a pan was used, the sludge was partially spread as it was released from the pan, and further smoothed with a bulldozer. Where the ground was relatively level a limited amount of sludge was incorporated to very shallow depth of a few cm by light discing, and on one occasion approximately 0.2 ha of the Sulphur Site was treated with a second layer of sludge after the first application had been incorporated. After smoothing and incorporating to a few cm with a small disc, seed was sown directly on the second sludge layer. A similar procedure was used for a small amount of sludge used in 1979 when application with very little incorporation was done with an end loader. While this degree of incorporation is less than normally desired for aesthetic reasons and leaves a rougher surface, no problems resulted. Seed sown directly in the sludge generally had better germination rates than elsewhere, and the rougher surface retained more moisture. Of course, there is always some risk of heavy rains washing sludge into nearby streams, but it was found that sludge became more cohesive when wet and did not flow appreciably even when it was dumped directly on moderate slopes. All sludge dumping, spreading and incorporation was done in a manner to minimize the possibility of sludge reaching any streams. A summary of sludge application at the Sulphur and Boyd Smith Sites is shown in Table 29-2. Sludge was also trucked from the Blue Plains STP to the third upstream mine site where similar reclamation methods were used by the mining firm having an interest in that site.

Composition of Sludge

During the main phase of reclamation in 1976 when 1596 dry t of sludge were applied to the Boyd Smith and Sulphur Sites, samples were collected from each truckload of sludge and composited into one daily sample for analyses of pH, metals, and nutrients. Composite monthly analyses of the

Table 29-2. Summary of Sludge Application.

Year	Total t (wet)	Avg. % Solids	Total t (dry)	Total ha Sludged	t/ha (dry)	tons/ac (dry)
1976	7257	22	1596	6.6	200-260	90-116
1977	1769	19.9	352	1.6	220	99
1978	544	20.3	110	0.8	138	62
1979	308	19.5	60	0.7	82	37
TOTAL	9878		2118			

Table 29-3. Composition of Sludge Used at Contrary Creek (ppm - dry weight).

	pH	Cu	Zn	Pb	Hg	Cd	Cr	Ni
SWCB Data(1) 1976	6.5	785	2529	550	5.1	17.0	659	29
Blue Plains(2) STP Data 1976-79	6.1	678	1604	477	3.8	14.9	717	42

(1)Average of 40 daily composite samples.
(2)Average of monthly composite samples

Table 29-4. Average Percentage of Nutrients on Dry Weight Basis in Sludge Used at Contrary Creek in 1976.

Nutrient	Percent*
N	3.23
P_2O_5	7.32
K_2O	0.32

*Average of 40 daily composite samples

sludge were also provided by the Blue Plains STP for each month that sludge was delivered from 1976 to 1979. Table 29-3 shows average pH and metal analyses of sludge used in this project, and nutrient content of the 1976 sludge is shown in Table 29-4. The heavy metals content of the Blue Plains sludge is within the range of that reported from other municipal STP's and is generally lower than that from highly industrialized cities.

Lime and Fertilizer Application

Lime application rates were determined on the basis of pH and lime titration analyses of composite soil samples from various parts of the reclamation sites. Initially, 10-10-10 fertilizer was used supplemented by 38-0-0 (ureaform) on areas that could not be sludged, but continued soil analyses indicated that the more difficult areas to vegetate were deficient in potash. Consequently, a high potash fertilizer was used beginning in 1979. Lime and fertilizer rates used in the project are shown in Tables 29-5 and 29-6, respectively.

Soil Analyses

As part of an extensive monitoring program, composite soil samples have been collected by the SCS and SWCB periodically from various areas of the project sites for analyses of pH, nutrient availability, and heavy metals content. All soil samples were taken with a soil auger at depths of about 5 cm in the root zone with the exception of one set collected in the fall of 1979 below the viable soil layer. Table 29-7 compares pH and nutrient availability before and after reclamation on the west and east sides of the Sulphur Site. Prior to reclamation the west side was characterized by massive heaps of fine tailings while the east side consisted primarily of coarser reject material. The west side has been one of the more difficult areas to vegetate in the entire project and continues to be one of the major sources of AMD in Contrary Creek. As can be seen in Table 29-7 there was significant improvement in pH and phosphate (P_2O_5) availability in the top layer of soil on both the west and east sides between 1975 and 1979. The samples collected below the root zone in what is essentially the same type of material as covered the surface prior to reclamation showed slight improvement over pre-reclamation conditions. The potash (K_2O) availability remained extremely low on the west side of the Sulphur Site until 1979 despite repeated applications of sludge, lime, and fertilizer. Note that there was a dramatic increase in pH and potash availability on the west side in the summer of 1980 but phosphate decreased slightly. On the east side where vegetation has been more successful, there was a pronounced increase in

Table 29-5. Summary of Lime Application Rates[1] (t/ha)[2].

1976	1977	1978		1979		1980
		Spring	Fall	Spring	Fall	Spring
8.9	13.4-31.2	22.3	11.1-33.4	4.5-17.8	8.9-22.3	8.9

(1) A range of application rates indicates that the lower rate was applied to all areas and the upper rate was the maximum applied to difficult areas.
(2) To convert t/ha to tons/ac multiply by 0.449.

Table 29-6. Summary of Fertilizer Application Rates (Kg/ha)*.

1976		1977		1979		1980
				Spring	Fall	Spring
10-10-10	38-0-0	10-10-10	38-0-0	6-6-12	6-0-12	6-0-12
1121	448	561	448	1121	1121	1121

*To convert Kg/ha to lbs/ac multiply by 0.892.

Table 29-7. Comparison of pH and Nutrient Availability in Soils at Sulphur Site - 1975-1980.

Area and Date	Depth (cm)	pH	lbs/ac P_2O_5	lbs/ac K_2O
Sulphur West				
11-75	5	2.4	0 - 7	0 - 18
10-79	5	3.6	252+	0 - 18
10-79	60	2.5	28 - 46	0 - 18
8-80	5	6.1	14	103
Sulphur East				
11-75	5	2.2	0 - 7	0 - 18
10-79	5	5.0	48 - 69	212 - 253
10-79	30	3.2	9 - 18	68 - 90
8-80	5	6.6	14	103

potash availability in the surface horizon soon after reclamation began. As stated above, this pattern generally emerges over all of the reclaimed areas.

Soil samples were also analyzed regularly for heavy metals. Metals data and pH values from composite samples collected from 1976 to 1980 on both sides of the Sulphur Site are shown in Table 29-8. All of these samples were collected at depths of about 5 cm. It can be seen that there has been a dramatic drop in metal concentrations as reclamation progressed and that concentrations remain considerably higher on the more toxic west side of the Sulphur Site. Obviously, a very thin soil layer supports the vegetation covering much of the reclaimed areas, and very toxic mine wastes still underlie some of the now vegetated areas. An indication of the composition of the mine wastes is presented in Table 29-9. These analyses were conducted by EPA in the summer of 1980 on samples collected from some of the most concentrated and relatively unweathered metal-laden mine wastes along the stream bank of the Sulphur Site.

Table 29-8. pH and Metals Content in Soil at Sulphur Site (mg/kg - dry weight basis).

Area and Date*	pH	Cu	Fe	Mn	Zn
Sulphur West					
11-76	4.1	50	30	74	262
6-77	3.1	62	34	17	82
3-78	5.1	0.1	7.8	6.8	6.6
6-78	5.9	1.0	24	3.6	1.5
3-79	4.5	3.2	7.6	6.4	28
2-80	4.9	0.2	0.4	2.6	3.4
Sulphur East					
11-76	5.5	8.6	4.2	31	18.8
3-78	7.3	0.3	6.2	0.5	0.1
3-79	5.9	0.3	3.6	1.9	1.2
2-80	5.2	0.2	0.8	1.7	3.4

*Each analysis is for one composite sample collection.

Table 29-9. Analysis of Mine Wastes at Sulphur Site (mg/g).

Al	Cu	Fe	Mg	Mn	Mo	P	Pb	Pt	Zn
27.7	6.6	238.7	26.0	0.3	0.08	1.4	5.2	2.4	2.4

Seeding and Vegetation

The most successful planting has been Ky-31 fescue grass. This cool weather grass tends to go dormant during the hot dry months, but usually revives quite readily when rain comes and when irrigated. Weeping lovegrass has been the second most successful and has demonstrated a high tolerance for drought in this harsh environment. It has proven most invaluable in surviving through dry periods and reducing erosion when no other vegetation germinated and has been used in the seed formula since 1977. Both Korean and Serecia lespedeza have been included in the seeding, but neither of these legumes has shown appreciable success and they have never matured enough during any growing season to achieve reseeding. Various nurse crops including wheat, rye and oats have been sown along with each seeding and have significantly aided in promoting vegetative growth. Typical seeding rates are shown in Table 29-10.

In the fall of 1978 samples of vegetation from established and new growth were collected and analyzed for metals uptake by a private firm contracted by EPA. The results from selected areas of the project site are shown in Table 29-11. As can be seen, most metals tended to be higher in the reclaimed areas than from the control sample, but there seemed to be no pronounced pattern between areas of established and new growth.

In the spring of 1977 the Glatfelter Pulpwood Company, owner of the Sulphur Site, planted loblolly pine seedlings over the entire Sulphur Site, but virtually none survived the dry summer that followed. The same was true for a planting of Virginia pine seedlings at the Boyd Smith Site which was part of the SWCB reclamation. No blanket planting of trees has been tried since 1977. However, the Glatfelter Pulpwood Company has continued to plant experimental plots at the Sulphur Site, but with little success.

In 1978 numerous varieties of weeds including foxtail, fall panicum, and smartweed began to invade some of the less toxic areas reclaimed, and at least two species of trees began to appear in significant numbers during 1979. The most abundant species is a variety of poplar that attained heights of 0.6 m the first year. By the late summer of 1980 about 90 percent

Table 29-10. Typical Seeding Formula Used at Contrary Creek.

Species	Kg/ha*
Tall Fescue (Ky-31)	67.3
Weeping Lovegrass	2.2
Korean Lespedeza	11.2

*To convert Kg/ha to lbs/ac multiply by 0.892

Table 29-11. Metals Uptake of Vegetation Determined in Fall of 1978 (μg/g).

Area	Cd	Cr	Cu	Fe	Hg	Mn	Ni	P	Pb	Se	Zn
ontrol	<0.1	<0.1	6.7	220	<0.1	155	1.0	50	0.1	< 0.1	60
ulphur West											
Established growth	0.03	1.3	26.0	500	<0.1	340	4.6	60	0.6	< 0.1	80
New growth	<0.1	<0.1	9.0	1300	<0.1	120	6.6	300	4.8	< 0.1	60
ılphur East											
New growth	0.4	1.8	17.6	330	< 0.1	240	2.1	345	0.8	0.6	40
Established growth	0.2	0.09	3.6	86	< 0.1	320	1.2	170	0.1	0.4	40
yd Smith											
Established growth	2.5	0.7	18.8	70	0.1	470	2.1	240	0.1	1.2	360

of the reclaimed areas supported a fair to good growth of vegetation. All of the Boyd Smith Site and over half of the Sulphur Site appeared on the way to reverting back to the natural wildlife habitat of the surrounding environs, but the sparsely covered stream banks and thin soil cover of the Sulphur Site remained highly vulnerable to drought. Irrigation had to be resumed in the summer of 1980 when hot, dry weather again threatened the project. The early difficulties in establishing vegetation necessitated extending the original three-year project period, 1975-78, to 1980. Due to the continued need for maintenance and repair work, the SWCB has now requested another two-year extension from EPA. However, the level of maintenance work required is continually decreasing. Average cost of reclamation including all maintenance work to date has been approximately $15,000 per ha.

Effects of Sludge on Environment and Public Reaction

No health hazards or adverse effects on the environment are known to have resulted from the use of large volumes of sludge in this project. As part of a comprehensive water monitoring program still in progress to assess the overall results of the project, fecal coliform and BOD analyses were conducted on water samples collected semi-monthly, and nutrients were analyzed annually. No significant effects of the sludge have been detected in the water studies. The remoteness of the project from populated areas had undoubtedly minimized the potential for nuisance and odor complaints and no major odor problem ever occurred. No public opposition to the use of sludge in this project was voiced despite the fact that environmental groups have been very active in the county. The project has been well publicized in area newspapers, and a public meeting setting forth details of the proposed reclamation was held in the county before the project began.

Conclusions

While there has been insignificant achievement in the principal objective of this project, the abatement of AMD in Contrary Creek and Lake Anna, considerable progress has been made in revegetating the formerly denuded mine sites and erosion has been reduced substantially. There is little doubt that not a fraction of the vegetative growth would have been realized without the use of sludge. The utilization of municipal sludge is very beneficial in the reclamation of areas severely devastated by mine wastes, but restoration to the natural environment is by no means a short-term process. In a project of this type, regular maintenance will be required for at least five years because of the difficulty in creating a soil layer of sufficient thickness to

maintain vegetative cover and withstand drought.

The continued lack of significant improvement in water quality can be attributed to seepage from the stream banks, runoff from barren banks during heavy rainstorms after soluble sulfate minerals have formed during a dry period, and toxic mine wastes remaining in the stream bed. It will take some time for the reduced infiltration and chemical changes caused by addition of sludge and lime to reduce the AMD emanating into the stream.

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30
VEGETATION ESTABLISHMENT ON ACIDIC MINE SPOILS AS INFLUENCED BY SLUDGE APPLICATION

Faz Haghiri and Paul Sutton

Greenhouse and field experiments were conducted to determine the optimum rate of sewage sludge amendment for vegetation establishment on acidic mine spoil and to determine the effect of sludge on the quality of leachate and metal content of the established vegetation. Another field experiment has been initiated to evaluate the use of composted papermill sludge as a substitute for topsoil in establishing vegetation on acidic mine spoil.

The optimum rates of single application of sewage sludges for establishment of vegetation on acidic mine spoil under greenhouse conditions were determined. Based on the greenhouse results, field plots (lysimeters) containing mine spoil were treated with two sludges at different rates ranging from 179 to 716 metric tons/ha. Application of sludge markedly increased the pH of the spoil and dry weight of plants grown. As the rate of sludge amendment was increased both pH and dry matter yield increased. Sludge type and rate of application significantly influenced the concentrations of several heavy metals in Kentucky 31 tall fescue. Nitrate - N concentration in the leachate increased with increasing rate of application and decreasee significantly with time after application of the amendment. Irrespective of loading rate, NO_3-N concentration in the leachate peaked during the late winter and early spring.

Based on a greenhouse experiment, composted papermill sludge (67, 90 and 112 metric tons/ha) was applied to field plots of acidic mine spoil. The sludge significantly increased the pH of the spoil but there were only small increases in pH as the rate of sludge application was increased. Persistence and growth of vegetation with and without additional applications of plant nutrients (nutrient maintenance) will be evaluated.

Introduction

In the eastern United States there are over 400,000 hectares of land, which have been disturbed by surface mining for coal, that is too acid to support vegetation. These unreclaimed areas can contribute to aquifer and stream pollution with acid mine drainage, and result in damage to roads, water reservoirs, bottom lands and stream channels by sediment erosion and subsequent silting.

Earlier stripmining removed the overburden and disposed of it without regard to its chemical and physical properties. In many cases this resulted in materials, that were not suitable for plant growth (Bennett et al. 1976,

and Tyner and Smith, 1945), being placed on the surface of spoilbanks. In stripmine areas in the Appalachian Region many of the failures to establish vegetation were associated with high acidity caused by the exposure of pyritic materials during mining.

Vegetation can be established on acid mine spoils by applying soil amendments such as municipal waste or by covering the spoil with topsoil (Lejcher and Kunkle, 1973; Peterson and Gschwind, 1973; Sopper and Kardos, 1972; Sutton and Vimmerstedt, 1973). In many areas surrounding unreclaimed mined lands the topsoil is very thin or nonexistent. Also, when topsoil is removed one area is disturbed in order to reclaim another.

Although municipal wastes contain all nutrient elements required for plant growth, they also contain, depending on the source, other elements such as Cd, Ni, Cr, Hg, Se, As, etc., which may be considered as contaminants in the food chain (Melsted, 1973). A major concern with regard to the application of sewage sludge and sewage effluent on stripmine spoil is the availability of heavy metals to plants. Another concern is the effect the heavy metals will have on the quality of subsurface waters.

Materials and Methods

Sewage Sludge

Greenhouse Experiment. Greenhouse experiments were conducted to determine the optimum rate of digested sewage sludge amendment for vegetation establishment on acidic mine spoil. Vacuum filtered sewage sludges were obtained from four different cities in Ohio (Newark, Bellaire, Cleveland, and Canton) and their chemical composition and moisture contents were determined (Table 30-1). The sludges were incorporated into the top 15 cm layer of acidic spoil (pH 2.9) in 7-liter capacity pots with drainage holes. The application rates ranged from 11 to 358 metric tons per hectare, in geometric progression, for Cleveland, Newark, and Canton sludges, while Bellaire sludge was applied at 90, 358, and 716 dry metric tons per hectare. After the incorporation of sludges, samples from the sludge-spoil mixtures were obtained for pH determinations. The sludge-spoil mixtures were seeded

Table 30-1. Chemical Composition of Digested Sewage Sludges (Dry Basis) Used in Greenhouse Investigation.

Source (City)	pH	Ni	Cu	Zn	Cd	Mn	Al	Solid	P	Total N
				µg/g				%		
Newark	12.1	121	194	3150	22	253	1.42	25.6	0.1	1.20
Bellaire	6.2	137	358	10790	92	618	1.70	20.0	1.3	1.14
Cleveland	8.5	700	1015	5650	475	955	0.71	19.6	2.5	2.27
Canton	7.3	700	1003	5275	81	534	1.03	51.5	4.0	1.15

to Kentucky 31 tall fescue.

Tall fescue did not grow under the Cleveland and Canton sludge treatments while plants responded well to Newark (45-358 metric tons/hectare) and Bellaire (358-716 metric tons/hectare) sludge amendments. Because the selection of the optimum rate of sludges for field application was based on the plant response and chemical composition of the test crop to sludge loading rates under greenhouse conditions, the sludge loading rates of 179 and 358 metric tons per hectare for Newark and 358 and 716 dry metric tons per hectare for Bellaire were chosen.

Field Lysimeter Experiment. In order to evaluate the vegetation establishment and growth on acidic mine spoil, and to determine the heavy metal content of the established vegetation and the quality of leachate water as affected by sewage sludge application under field conditions, fourteen precast tanks (120 cm X 240 cm X 97 cm) coated with "Thoroseal" were placed on 2 percent sloped platforms on a spoilbank at the experimental site on the Eastern Ohio Resource Development Center (Fig. 30-1).

At the lower end of each plot (tank) a leachate-sampling facility was installed. In September of 1976, the field plots (tanks) were filled with acidic mine spoil from the number 9 coal seam (Meigs Creek). The spoil materials were allowed to settle. Newark sludge at 179 and 358 dry metric tons per hectare and Bellaire sludge at the rates of 358 and 716 tons per hectare were surface applied. The experimental treatments consisted of two rates of sewage sludge, two types of sludges with three replications plus two untreated plots (tanks) to serve as controls. After 1 month the applied sludges were incorporated into the top 15 cm layer with a rototiller and the plots were seeded to Kentucky 31 tall fescue. However, the seeds failed to germinate because of severe cold weather that fall. During April 1977, the plots were lightly raked and reseeded with fescue.

Leachates from each plot were collected in a 113-liter (30 gal.) fiber glass container located in a 10.5 m X 3 m X 2.1 m cellar. After each leachate event the total volume of percolates from each plot was determined. A representative leachate sample (1 liter) was obtained from each container and frozen for analysis of Mg, Al, Fe, Mn, Ni, Cu, Cd, Zn by atomic absorption and ICP methods; of P and $SO_4^{=}$ (Standard Methods for Examination of Water and Wastewater, 1975); of total N and NH_3-N (Bremner, 1975); of total acidity and soluble salts (Brown, 1970); and of pH by glass and reference electrodes on a pH meter.

To determine the percent organic carbon decomposition, immediately after the application of sewage sludge and annually from then on, core samples 0-15 cm in depth were obtained and total organic carbon determined by the Walkley and Black Procedure.

Plant materials were harvested twice yearly, dried, weighed, ground and digested with $HClO_4$ and HNO_3 for metal analyses.

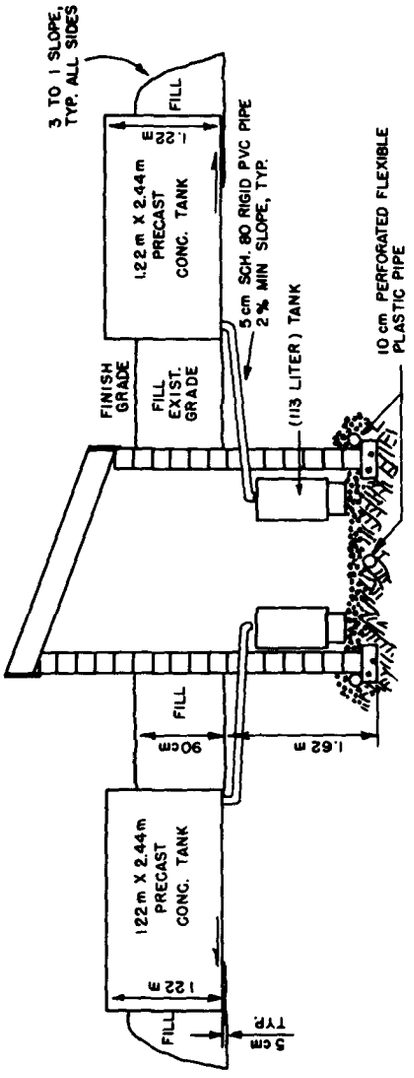

Figure 30-1. Field Plots (lysimeters) and Leachate Collection Facility.

Composted Papermill Sludge

Based on a greenhouse experiment, loading rates of 67, 90 and 112 t/ha of dry composted papermill sludge were selected for a field experiment on acidic spoil resulting from the stripmining of the number 9 coal seam. The papermill sludge, consisting of 50% cellulose fiber and 50% Kaolin clay, was mixed with ground bark (fine and coarse) on a one to one part (by volume) basis. Nitrogen and phosphorus (P_2O_5) were added at the rate of 1 and 0.3 kg/cubic meter, respectively. The mixture was composted 21 days using the aerated pile method at a temperature ranging from 55 to 75°C during the last 19 days of composting. In the spring of 1979, the composted papermill sludge with fine and coarse bark was applied in three replications to plots 6.1 m X 18.3 m and incorporated to a depth of 15 cm with a rototiller. Nitrogen, P and K were applied at the rates of 6.7, 20 and 112 kg/ha, respectively.

During June 1979, the plots were seeded to a mixture of alsike clover, birdsfoot trefoil, ladino clover, orchardgrass and Kentucky 31 fescue. The plots were mulched with 4.5 metric tons/ha of straw and topdressed with an additional 34 kg/ha of N in July 1979.

Soil samples were obtained during October 1979 from the composted papermill sludge spoil mixed zone. During July 1980, samples of the vegetation were obtained for yield determination.

Results and Discussion

Sewage Sludge

Greenhouse experiment. The chemical composition of digested sewage sludges, on dry basis, from four different cities in Ohio is shown in Table 30-1. The high concentration of toxic heavy metals in the Cleveland and Canton sludges resulted in a failure of Kentucky 31 tall fescue to grow where the acidic spoil materials were treated with these sludges. However, tall fescue responded well to Newark sludge (45-358 metric tons/ha) and Bellaire sludge (358-716 metric tons/ha) amendments. The application of these sludges significantly increased the pH of the spoil. The pH of spoil increased from 2.9 to 6.7 and 7.1 by adding 179 and 358 metric tons/ha of Newark sludge, respectively, while the addition of Bellaire sludge at the rates of 358 and 716 metric tons/ha raised the pH values of the spoil to 6.2 and 6.4, respectively.

The average dry weight of tall fescue grown in the greenhouse as affected by an initial application of different rates and types of sludge over a three-year period is shown in Table 30-2. The yield of tall fescue increased with increasing rate of sludge for all years. However, with the exception of the 716 tons/ha Bellaire sludge treatment, there was a significant yield reduction for the third year as compared to the first year's harvest.

Table 30-2. Dry Weight of Tall Fescue Grown in Sludge-Treated Acidic Mine Spoil Under Greenhouse Conditions.

	Newark Sludge (MT/ha)				Bellaire Sludge (MT/ha)	
Year	44	90	179	358	358	716
	..... g					
1976	2.74	5.40	6.77	8.70	5.34	6.47
1977	1.53	2.70	3.62	6.28	3.01	5.19
1978	1.14	2.21	2.80	4.31	2.35	8.17

The concentrations of different metals in the plants obtained from the first and final cuttings of tall fescue which were grown in sludge-treated spoil are shown in Table 30-3. In all samples the metal concentrations were considerably lower for the final cutting (1978) as compared with the first cutting (1976). These decreases in yield and metal concentration with time occurred as the readily mineralized portion of the organic nitrogen and as the heavy metals became depleted and the residual organic nitrogen and heavy metals were stabilized or fixed in the humic fraction of the spoil-sludge mixture.

Generally, the concentration of heavy metals in plant tissue decreased with the increasing loading rates. This was partially due to the increase in the pH of the sludge-acidic spoil mixture which in turn rendered the metals less available to plants.

Field Lysimeter Experiment. *Yield and chemical composition of tall fescue.* Tall fescue was well established for both sludges and the applied loading rate treatments. The chemical composition of digested sludges used in the field study is shown in Table 30-4. The dry matter yield harvested over a three-year period (1977-79) from the 179, 358 and 716 metric tons/ha rate of the sludge are shown in Table 30-5. For the Bellaire and Newark sludges the yields from the higher loading rate treatments were significantly higher than the lower rate treatments. Total N concentration of plant tissue was significantly higher from the 716 than the 358 metric ton/ha Bellaire sludge treatment, while for Newark sludge total N concentration in plant tissue was significantly greater at the higher rate only for the first crop year (Table 30-5).

At the 358 metric ton/ha rate, in general, dry matter yield and total N concentration in plants from the Newark and Bellaire sludge treated lysimeters were not significantly different even though total N (Table 30-4) in Bellaire sludge (1.35%) was higher than in the Newark sludge (1.13%). Yield decreases for the 1979 crop as compared to 1978 occurred as the readily mineralized portion of the sewage sludge organic N became depleted and the residual organic N was stabilized in the spoil humic fraction. The decrease of available N with time is evident by noting the total N content of tall fescue plant tissue from different sewage sludge treatments (Table 30-5).

Table 30-3. Concentrations of Metals in Tall Fescue Grown in Sludge-Treated Mine Spoil in the Greenhouse from the 1st (1976) and Final (1978) Cutting Harvests.

	Newark Sludge (MT/ha)				Bellaire Sludge (MT/ha)	
Year	44	90	179	358	358	716
			µg/g			
			Cd			
1976	1.57	1.37	1.48	1.33	3.01	1.20
1978	0.44	0.31	0.17	0.18	1.17	0.90
			Cu			
1976	10.02	12.37	12.66	13.03	25.61	21.61
1978	4.13	3.41	3.99	5.84	9.93	10.37
			Ni			
1976	54.77	16.78	11.23	*	6.13	5.71
1978	4.19	1.97	1.30	2.08	2.17	2.50
			Mn			
1976	353	316	324	*	427	380
1978	182	80	30	31	23	14
			Zn			
1976	154	88	88	111	417	401
1978	48	32	28	35	353	200

*Not determined

Table 30-4. Chemical Composition of Digested Sewage Sludge (Dry Basis) Used in Field Investigation.

Source	Cu	Zn	Cd	Mn	Ni	Pb	Mg	Na	Ca	Al	P	Total N
				µg/g						%		
Newark	250	2990	28	279	153	382	5730	952	11.4	1.37	0.92	1.13
Bellaire	341	16100	63	629	110	584	5120	709	7.6	1.77	1.53	1.35

Table 30-5. Dry Matter Yield and Total N Concentration of Tall Fescue as Affected by Sludge Type, Loading Rate and Time.

Sludge Loading Rate	Dry Weight*			Total N**		
	1977	1978	1979	1977	1978	1979
MT/ha	g			%		
179 (Newark	320	499	418	1.51	1.67	0.94
358 (Newark)	728	1009	857	1.88	1.41	1.00
358 (Bellaire)	601	900	734	2.12	1.41	1.00
716 (Bellaire)	905	1029	861	2.57	1.91	1.17

*LSD at 5% for sludge treatment: 123 g; for year: 137 g; and for treatment x year: 256 g.

**LSD at 5% for sludge treatment: 0.09%; for year: 0.10%; and for treatment x year: 0.19%.

The statistical analyses of the concentrations of various elements in plant tissue (Table 30-6) showed that for the Newark sludge the concentrations of Mg, Cu, Ni, Mn, and Zn in plant tissues for the 1977 crop were significantly higher at the 358 than the 179 metric ton/ha rate. The higher rate of the Bellaire sludge (716 metric ton/ha) increased the plant concentrations of Mg, Cu, Fe, Ni, and Zn. A comparison of the effect of the two sludges at the same amended rate (358 metric ton/ha) on the metal concentration in plant tissue showed that for the 1977 crop year the concentrations of Cu, Mn, Zn, and Cd were significantly higher while Mg and Al were lower from the Bellaire sludge. This would be expected since the Bellaire sludge contained considerably higher amounts of metals, with the exception of Al, than the Newark sludge (Table 30-4).

With few exceptions, the concentrations of all the metals analyzed in the 1979 plant samples were significantly lower than the 1977 tissue samples. Analysis of the tall fescue indicated that the concentrations of elements found in the sludge were not too high to have any adverse effect on plants. The increases in the pH (Table 30-7) and percent organic matter (Table 30-8) of mine spoil by sewage sludge application aided the fixation or immobilization of heavy metals.

Leachate analyses. The volume of water that leached through the lysimeters from November 1976 to April 1979 was considerably higher from the control than from any sludge-treated lysimeters. The higher leachate volume from the control was due to the absence of vegetation. The volume of percolate from the lysimeters was affected inversely with the loading rate of sludge amendment. The quantity of percolates from the control, Newark 179 and 358 metric ton/ha, and Bellaire 358 and 716 metric ton/ha were 636, 564, 520, 540, and 512 liters, respectively. Leachate volume and NO_3-N concentration of the leachates from various leaching events throughout the

Table 30-6. Concentration of Different Metals in Tall Fescue Samples (1st and 3rd-Year Crops) from Sludge-Treated Mine Spoil.

Sludge Treatment	Metal Concentration								
	Mg	P	Al	Cu	Fe	Ni	Mn	Zn	Cd
MT/ha	... %		....	.....	.....	µg/g	.....	.....	µg/kg
179 (Newark)									
1977	0 41	0.37	173	10.5	156	5.9	61	61	218
1979	0.17	0.40	73	2.2	109	0.6	32	18	173
358 (Newark)									
1977	0.51	0.36	197	14.7	157	3.8	20	83	198
1979	0.17	0.18	120	2.1	182	0.8	29	21	172
358 (Bellaire)									
1977	0.28	0.36	157	16.8	193	4.5	199	420	966
1979	0.13	0.16	102	3.4	142	1.9	40	215	751
716 (Bellaire)									
1977	0 37	0.25	190	18.7	291	5 5	204	537	785
1979	0.09	0.06	195	3.8	281	1.7	44	230	626
LSD (5%)									
Treatment	0.02	0.04	33	1.3	35	0.9	9	47	103
Year:	0.02	0.05	37	0.8	39	1.1	10	53	115

Table 30-7. Mine Spoil pH Over a Three-Year Period at 0-15 cm Depth as Affected by Sludge Amendment.

Amendment				
Sludge Loading Rate	Year 1976	1977	1978	1979
MT/ha	..... pH			
179 (Newark)	5.8	6.4	6.4	6.2
358 (Newark)	7.0	7.4	6.3	6.9
358 (Bellaire)	6.4	6.7	5.9	6.3
716 (Bellaire)	6.8	6.8	5.5	6.3
Control	2.6	3.3	3.3	3.4

LSD at 5% for sludge treatment: 0.6; for year: 0.1; and for treatment x year: 0.2.

Table 30-8. Organic Carbon Content of Mine Spoil at Different Depths at the Conclusion of Study as Affected by Sludge Amendment.

Sludge Loading Rate	Depth (cm) 0-15	15-30	30-45	45-60	60-80
MT/ha	..... %				
179 (Newark)	6.10	4.81	4.87	4.81	4.54
358 (Newark)	7.39	5.13	5.24	5.01	5.00
358 (Bellaire)	8.26	5.24	4.48	4.84	4.87
716 (Bellaire)	11.94	5.99	5.16	4.71	5.44
Control	4.00	4.04	4.74	5.01	4.60

LSD at 5% for sludge treatment: 0.64%; and for depth: 0.44%

study period (November 1976-April 1979) at the highest rate of the two sludges (Newark 358 and Bellaire 716 metric ton/ha) and the control are shown in Fig. 30-2. Generally the peak concentration of NO_3-N in the leachate samples during the sampling period occurred during the late winter and early spring. These peaks correspond to those periods when plants are largely dormant, and subsequently, reduced evapotranspiration increased leachate volume.

The concentration of NO_3-N in the percolate from sludge treated mine spoil was influenced by the rate of sludge amendment and the length of time after application. As expected, NO_3-N increased with increasing rate of incorporated sludge and decreased with time after the amendment. The monthly average concentration of NO_3-N in the leachate from lysimeters treated with 358 metric ton/ha of Newark sludge was significantly higher than from those lysimeters which received the same rate of Bellaire sludge. The maximum concentration (monthly average) of NO_3-N in the leachates for all treatments was found during the early spring of 1977 and the peak values were 17.0, 12.2, 3.5, and 1.5 mg/liter for the Newark 358, Bellaire 716, Bellaire 358, control, and Newark 179 level treatments, respectively. As far as NH_3-N was concerned, the concentration of this form of N in the leachate was not affected by sludge treatment or time after application.

Although the pH of the leachate during the 2.5 year period increased slightly with time for all the treatments, the magnitude of change was not

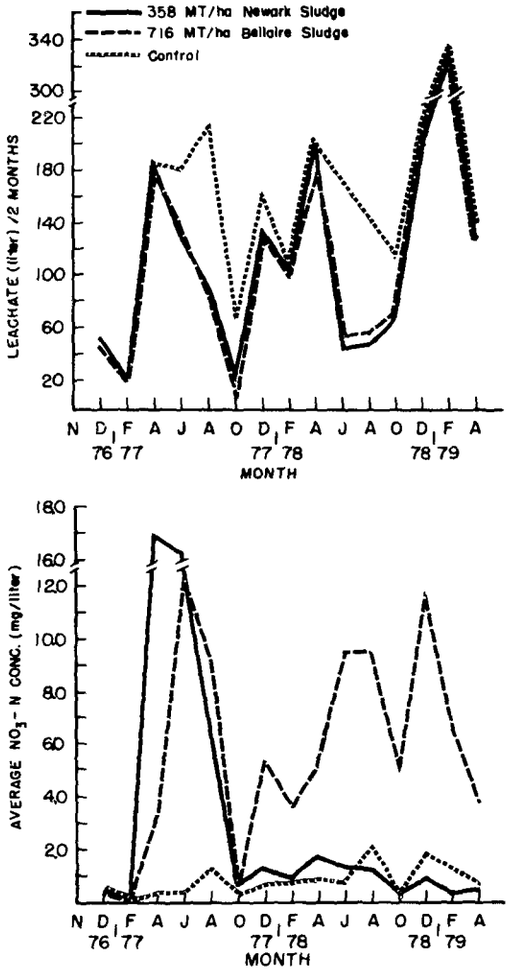

Figure 30-2. Quantity and NO_3-N Concentration of Leachate from Field Lysimeters Containing Acidic Mine Spoil Treated with Sewage Sludge.

large enough to be significant. The average pH values ranged from 2.7 (in 1976) to 3.2 (in 1979) for the 716 mt/ha Bellaire treatment while the average pH of the leachate samples from the control was approximately 3.0. The total acidity concentration of leachates was not influenced by sewage sludge rates. However, the concentration of acidity decreased appreciably with time as more water percolated through the spoil profile. For example, the Bellaire sludge at the 716 metric ton/ha treatment, the total acidity concentration

decreased from 5997 to 564 (mg/liter as $CaCO_3$). The concentration of $SO_4^{=}$ in the leachates to a large extent followed the same pattern as the total acidity. The sulfate ion concentration decreased from 18069 to 1494 mg/liter for the Bellaire 716 metric ton/ha treatment.

The concentration of Al in the leachate was affected significantly by sludge application. The maximum concentration was found in the leachate sample obtained from the 716 metric ton/ha of Bellaire sludge (1876 mg/liter) in 1976 but this value decreased significantly with time, to a concentration of 64 mg/liter in the spring of 1979. At a comparable level of sludge amendment, the average concentration of Al in the leachate was significantly higher from the 358 metric ton/ha Bellaire than from the Newark sludge. The concentration of Cu, Ni, Fe, and Mn in the percolate was not significantly influenced by the sludge treatments. However, there was a significant decrease in the concentration of these elements in the leachate with time. The maximum concentrations of Cu (7.3 mg/l), Fe (1257 mg/l), Mn (39 mg/l), and Ni (13.8 mg/l) in the leachate were found at the 716 metric ton/ha Bellaire sludge in 1976 but the concentrations of these metals were reduced in 1979 to 0.4, 9.0, 1.9, and 0.3 mg/l for Cu, Fe, Mn, and Ni, respectively. Zinc concentration (20.2 mg/l) was measured in leachate from the 716 metric ton/ha Bellaire treatment shortly after the application. Approximately two years later Zn concentration declined to 8.3 mg/l. At the 358 metric ton/ha, significantly more Zn was measured through the 2.5 year period from the Bellaire than Newark sludge. This is to be expected since Bellaire sludge contained five times as much Zn as the Newark sludge. Although Cd concentration was influenced by sludge treatments, the concentration levels of this metal in the leachates through the collection period were so low (<0.1 μg/l) that they could be considered negligible. Since P concentration of the majority of leachate samples was below the detection limit, P concentration in the leachate water from sludge treated mine spoil could be considered negligible.

Composted Papermill Sludge

The chemical composition of the composted sludge (papermill sludge + fine bark) and the raw papermill sludge is shown in Table 30-9. Figure 30-3 shows the effect of raw papermill sludge amendments at varying loading rates on the pH of acidic mine spoil under the laboratory conditions. The pH of the mine spoil increased from 2.8 to 5.8 by the amendment of 112 mt/ha of composted sludge. Higher rates of application of composted sludge did not influence the pH of the mine spoil. At the comparable loading rate (112 mt/ha) the application of raw sludge increased the pH of the spoil from 2.8 to 4.5. Figure 30-3 shows that in order to increase the pH of the acidic spoil (from 2.8 to 5.8), it required only half as much composted papermill sludge (112 mt/ha) as that for the raw sludge (224 mt/ha).

The effects of varying loading rates of composted papermill sludge on

Table 30-9. Chemical Composition of Raw and Composted Sludge (Dry Basis).

	N	P	K	Ca	Mg	Al	Fe
				%			
Composted (Sludge & Bark)	.003	.0063	0.18	8.5	0.31	0.63	0.33
Raw Sludge	.008	.0125	.004	14.4	0.57	1.22	0.67

	Cd	Cu	Mn	Ni	Pb	Zn	B
				ug/g			
Composted (Sludge & Bark)	17	18	729	14	33	685	34
Raw Sludge	23	36	537	22	47	319	33

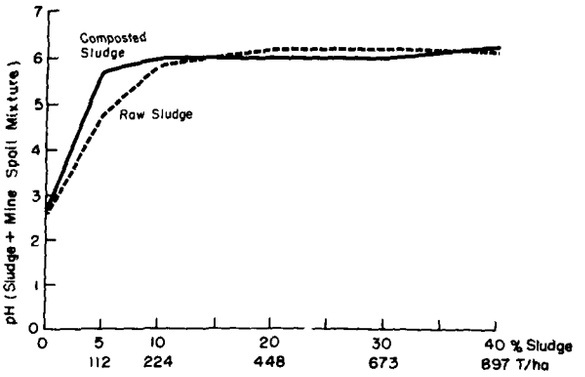

Figure 30-3. pH of Mine Spoil as Affected by Raw and Composted Papermill Sludge Amendments.

Table 30-10. Dry Matter Yield and pH of Acidic Mine Spoil as Influenced by Rates of Composted Papermill Sludges.

Comp Sludge Rate (dry ton/ha)	pH	Yield (kg/ha)
Composted with fine bark		
67	4.6	2987
90	5.3	1906
112	5.7	2554
Composted with coarse bark		
67	5.2	2669
90	5.1	2269
112	5.2	2754
Control	3.4	--
Topsoil (20 cm) + lime (18 T/ha)	7.2	3048
$LSD_{.05}$		1221

the pH of acidic mine spoil and the dry matter yield of vegetation grown under field conditions are shown in Table 30-10. Although composted sludge amendment significantly increased the pH of mine spoil as compared to the control, there were no significant differences in the pH values with increasing rates of sludge application. The dry matter yield data shows that there were no significant differences among the treatments which indicate that for vegetation establishment on acidic mine spoils the application of composted papermill sludge was just as effective as topsoiling the mine spoil with a 20 cm layer of limed soil.

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IX / ENGINEERING ASSESSMENT

OVERVIEW

Robert K. Bastian

Utilizing municipal wastewater and sludge in land reclamation and biomass production projects has been clearly demonstrated to be an effective means of treating and beneficially recycling these materials. Systems studied to date have included the use of municipal wastewater or sludge in reclaiming, stabilizing and revegetating such areas as surface mine spoils, mine tailings, borrow pits, quarries, cleared forests, dredged spoils, fly ash and construction sites. However, there has been considerably more experience in the use of sewage sludge than wastewater for such projects.

In conjunction with this symposium, an effort was undertaken to define the current status of using municipal wastewater and sludge in land reclamation and biomass production, and to determine if these practices are ready for routine use in municipal wastewater and sludge management. If they are not ready for such use the assessment was to recommend procedures such as further research, demonstrations, or construction of full scale "innovative and alternative" systems at selected locations.

A team of three internationally recognized engineers was retained to help conduct the engineering assessment. They represent a broad range of expertise and include both practicing consultants and a university professor. All were experienced in both research and design of land application systems. The team included: Mr. L. Gene Suhr, CH_2M - Hill; Dr. H. G. Schwartz, Sverdrup & Parcel and Assoc., Inc.; Dr. William J. Jewell, Cornell University.

The overall engineering assessment involved individual efforts by the team members to evaluate the current status of utilizing municipal wastewater and sludge in land reclamation and biomass production activities in various areas. Team members met with the research scientists, operating system personnel and others who presented papers on the results of various projects and relative concepts at this symposium. Each member of the engineering assessment team then prepared his own assessment report based upon the symposium presentations and discussions, supplemented by information made available from other sources.

31
USE AND TREATMENT OF MUNICIPAL WASTEWATER AND SLUDGE IN LAND RECLAMATION AND BIOMASS PRODUCTION PROJECTS—AN ENGINEERING ASSESSMENT

William J. Jewell

Introduction

Continued desire for improved environmental quality while energy demands increase and urban development consumes valuable farmland is a major concern of modern society. Historically, municipal wastes were considered plant nutrients on loan to consumers, and after use they were returned to the farmer for production of more food. Today there are extensive efforts ongoing to control municipal wastes by using them for reclamation of poor quality or spoiled land and for the production of food and biomass. This overview was prepared to estimate the technical and economic feasibility of using municipal wastewater and sludges for land reclamation and biomass production.

Drastically disturbed land results from surface mining, highway construction, and dredging of rivers and harbors. Surface mining has disturbed 1.76×10^6 ha (6,700 miles^2) in the U.S., with half of this caused by coal mining (Schaller and Sutton, 1978). Each year an additional 40,470 ha are disturbed by coal mining, and much of this will occur in the populated eastern half of the U.S. If this land could be reclaimed with the concomitant purification of waste materials, two serious problems would be eliminated. Comparison of the sludge application rates used in land reclamation show that all of the U.S. sludge production could result in recovery of all the disturbed land resulting from strip mining of coal. The potential of using wasted resources in wastewaters and sludges to accomplish land reclamation offers substantial benefits.

The goal of this assessment is to determine the capability of this technology to adequately treat municipal wastewater or sludge as innovative/alternative wastewater treatment and sludge management technologies while utilizing these materials for land reclamation and biomass production purposes. Specific objectives are to:

1. summarize applicable engineering criteria and special factors or conditions applicable (physical characteristics, pollutant removals, system by-products, loading rates, monitoring and other engineering conditions); and
2. outline future research needs.

Since valuable components of wastes as well as the potential problems are

contained in the sludge resulting from wastewater treatment, this will be the main focus of the study. Wastewaters will be considered only briefly.

Background and Literature Survey

Regulatory Considerations

Pollution control regulations have increasingly focused on beneficial use of wastes since passage of the Water Quality Act Amendments of 1972 (PL92-500), and this has implied increased use of land application of wastewaters and sludges. Relatively little progress was made in adopting land application since most of the technology was poorly defined; and incentives to consider recycling programs were, in large part, nonexistent. In 1978, this deficiency was recognized and incentives were added for the consideration of innovative and/or alternative waste treatment systems that were cost- and energy-effective. Today there is a significant increase in new approaches to waste treatment that include land application. A brief summary of the Federal regulations as they apply to sludge management will be given prior to consideration of land reclamation.

Extensive regulatory and legislative activity has focused on land application of sludge (National Archives of the United States 1979, U.S. Congress 1977, USEPA 1980a; 1980b, Plehn and Dietrich 1980, New York DEC 1980). Because of numerous regulatory activities for sludge application to land, recent attempts have been made to develop a more coordinated regulation (USEPA, USFDA, and USDA 1981).

After many years of discussions among the federal agencies with overlapping authorities relating to sewage sludge management (USEPA, USFDA, and USDA, 1981), it is highly significant that they now state that ". . . the federal agencies believe that the use of high quality sludges, coupled with proper management procedures, should safeguard the consumer from contaminated crops and minimize any potential adverse effect on the environment." Coordinated regulatory action has made efforts to define the conditions under which sewage sludge can be incorporated into productive agriculture (USEPA 1980b), whereby risks are minimized and continuing production of high quality food is assured. The federal policy based on the requirements of the Resource Conservation and Recovery Act and the Clean Water Act, ". . . sets forth the use of high quality sludges and proper management practices that growers, processors and consumers can be assured that the current high standards of food quality in this nation will not be compromised (USEPA 1980b)." Areas that have received attention include a definition of "high quality" sludge, maximum soil contaminant levels, pathogen reduction, physical contamination, and soil monitoring.

One noteworthy development is the definition of a "high quality sludge," which will become known as a "good sludge." It is a sludge that

contains no more than the following concentrations of contaminants, on a dry weight basis (mg/kg):

Cadmium	-	25
Lead	-	1000
PCB	-	10

Gradual phase-in of federal regulations will limit the annual application rate of good sludges to achieve less than 0.5 kg cadmium per ha-year. Total cumulative lifetime loadings shall not exceed between 5 and 20 kg cadmium per ha, depending on the soil pH and cation exchange capacity. Cumulative lead application should not exceed 800 kg per ha.

The above limitations are not considered to be highly restrictive for "good sludges" since application at a rate equal to nitrogen or phosphorus fertilizer needs will not cause a metal accumulation problem (Lo et al. 1980, Naylor and Loehr 1981). For example, a typical sludge would supply crop phosphorus and nitrogen requirements at application rates of 1 and 4 dry tons per acre, respectively. At the nitrogen application rate the cumulative metal loading restriction for cadmium and lead would occur after annual applications for 125 years and 500 years, respectively.

Federal regulations for non-food chain landspreading have not been developed for the control of substances at concentrations above those defined earlier for a "good sludge." One option for use of heavily contaminated cadmium sludges allows unlimited sludge application provided that: (1) the crops grown are limited to animal feed; (2) pH is controlled, (3) a facility operating plan prevents human ingestion of crops, and (4) future owners of the land are provided notice that food chain crops should not be grown. This latter requirement raises questions about the value of the land if such a restriction remains in a deed.

Of course, the preceding limitations with food chain relations have limited applications to land reclamation. There are several important implications. If a "bad" sludge is used for non-food chain purposes, such as land reclamation, the regulations suggest that the land would have to be sold for non-food chain uses in all cases.

The possible use of wastes to reclaim strip-mine lands is attractive. The Surface Mining Control and Reclamation Act was signed on August 3, 1977, after a long battle in Congress to enact Federal legislation regulating surface coal mining (Harvey, 1978). The general goal of the performance standards in the Reclamation Act is to develop a permanent vegetative cover of the same seasonal variety native to the area of land to be affected. The vegetation must be capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area.

According to Maneval (1980), the OSM is not highly supportive of sludge use for land reclamation, especially as part of the abandoned mine land reclamation projects. Since most lands are privately owned, there is no guarantee that after reclamation they could be restricted from use in

food chain application that USEPA would require, if a "bad sludge" were used. The OSM would have ". . . no objection to the use of the 'unrestricted sludges' or sludge derived products in either active or abandoned mine reclamation projects." However, successful revegetation efforts most often include application of topsoil, use of soil amendments, lime and mulch. Finally, restricted or contaminated sludges are not recommended by OSM for use in active or abandoned coal mines due to the potential of solubilization of heavy metals or toxic organic materials. This appears to be a highly conservative position and may not be warranted according to the data relating to pollutant movement in soils, as will be discussed in later sections.

Recent studies have examined the legal, institutional, technical and economic constraints to transporting and reclaiming land with sewage sludge (Deese, et al., 1980, Nye et al., 1980). These two studies outline methods of responding to public concerns with full scale demonstrations and other public information programs.

Land Application of Wastewater and Sludges

A comprehensive review of the recent papers on beneficial uses of municipal wastewaters and sludges indicates a rapid increase in activity. The number of papers published in each area for the past four years is summarized in Table 31-1. The majority of these 289 papers report favorable influences of wastewater and sludges on agricultural systems.

A large amount of information on sludge application to land can be gained from the decades of European experience (Water Research Center, United Kingdom, 1979). Since the mid-1930s, sludge disposal on farms has been practiced in many facilities surrounding London. The general impression that one receives from the farmer is stated as, ". . . reaction of user has been consistently favorable--even enthusiastic--for over 40 years." Many of these European studies are somewhat different than the question of reclamation, since sludge is often used in active agriculture on the better soils.

Table 31-1. Summary of Number of Publications on Land Application of Wastewaters and Sewage Sludges from 1976 to 1979.

	Number of Articles		
Year	Wastewater	Sludges	Total
1976	10	16	26
1977	7	15	22
1978	18	47	65
1979	40	136	176
Totals	75	214	289

Table 31-2. Land Reclamation with Wastewater and Sludges. (Application rates in dry metric tons per hectare unless otherwise noted).

Land Treated or Reclaimed (Location(s))	Application Rate		Plants Seeded	References (all 1980)
	Sludge	Fertilizer		
Iron Ore Tailings, (Wisconsin)	42185	P 0 to 112 ktg/ha N 0 to 175 kg/ha	Succession Prairie Grasses (10 species in all)	Morrison and Hardell
Surface Coal Mining - Acid Soils, (Ohio)	11 to 796		Kentucky Tall Fescue	"
Bituminous Strip Mine, (Pennsylvania)	Liquid Ana. Dig. 7 to 11 Dewatered, 90 to 184 Liquid Ana. Dig. 202	Small Demo. Projects	-----	Sopper & Kerr
Anthracite Refuse	0 to 148	----	Planted Tree Species, 5 grasses, 5 legumes	Sopper & Kerr
Stripped Coal Mine (Pennsylvania)	Liquid Dig. Composted with Wood Chips, 203	----	Grass Mixtures	Kerr & Sopper
Acid Spoil Site, (Illinois)	336 to 672	----	Small Plots	Urie, et al.
Acid Mine Spoil	Paper Mill Composted Sludge, 67 to 112	----	Small Experiments	Haghiri & Sutton
Strip Mine Spoil	Ana. Dig. Sludge 0 to 896	----	Corn and Rye	Hinesly, et al.
Abandoned Pyrite Mine	Composted, 82 to 260	Inorg. Controls	----	Hinkle
Acid Spoil	Paper Mill Primary and activated sludge	----	Greenhouse	Hoitink & Watson

Table 31-2. (Continued)

Land Treated or Reclaimed (Location[s])	Application Rate		Plants Seeded	References (all 1980)
	Sludge	Fertilizer		
Acid Minespoil	Composted	----	Blueberries	Hoitink & Watson
Taconite Tailings	Ana. Dig. and Dewatered	----	Grasses and Legumes	Cavey & Bowles
Calcareous Strip Mine Spoil	Ana. Dig., 0 to 453	----	Corn	Peterson, et al.
Gravel Spoils	Compost, 0 to 160	----	----	Hornick
Zinc Smelter Surroundings	Ana. Dig. Sludge Plus Fertilizer	----	Small Plot, Grasses	Franks, et al.
Bituminous Strip Mine, Anthracite Refuse	Compost, 170	----	4 ha Demo. Sites	Sopper & Kerr
Acid Mine Spoil	Ana. Dig.	----	Woody Ecosystem	Roth, et al.
Southeast Strip Mine	Dried Sludge, 0 to 275	----	Pine Tree	Berry
Normal Soil	Lime Stabilized Filter Cake Sludge, 0 to 180	----	Christmas Tree	Lambert & Weidensaul
Iron Ore Tailings	Ana. Dig., 42, 85	----	Grassed & Native Vegetation	Morrison & Hardell
Marginal	Wastewater & Sludge 0 to 150	----	Poplar	Kerr & Sopper
Forest Soils	Wastewater & Sludges	----	Douglas Fir & Other Species	Cole
Iron Ore Overburden	Wastewater Effluent 5 to 10 cm/wk	----	Ash, Larch, Pine & Others	Borovsky & Brooks

Land Reclamation with Municipal Wastes. The 1980 Pittsburgh symposium reported in these proceedings summarized the state of the art of the feasibility of municipal wastes use for reclamation of land. Table 31-2 summarizes the type of land reclaimed and the amount of waste used as reported at this meeting. Out of all the studies listed in Table 31-2, only one did not result in rapid and successful vegetation of strip mine lands (Hinkle, 1980). In this study, a severe drought prevented vegetation from growing. After irrigation for several years, this site was also successfully reclaimed.

After having a large program rejected by public opposition in 1977, Sopper and Kerr (1980a) and 1980b) developed several four-ha demonstration projects in Pennsylvania. An example of the metal loading rates applied as compared to the Federal and State recommendations are shown in Table 31-3. All sites were rapidly and successfully reclaimed with healthy vegetation.

Sopper and Kerr concluded that the demonstration sites reclaimed with treated sewage sludge ". . . indicate that stabilized municipal sludges, if applied properly, can be used to revegetate mined lands in an environmentally safe manner with no adverse effects on the vegetation, soil or groundwater quality." Unfortunately, it is possible that the potential impact of the sludge on the groundwater may not have occurred within the period of the study.

A general review of the data in literature show several noteworthy trends:

1. Even the most drastically disturbed land can be successfully reclaimed using sewage sludge with a minimum adverse effect on the environment.
2. There is no consistent information regarding sludge characteristics and amount required to reclaim the disturbed land. In several cases,

Table 31-3. Comparison of Recommended Soil Loading Rates for Application of Metals in Sewage Sludges and Typical Loading Rates Used for One Study in Pennsylvania (from Sopper and Kerr, 1980a).

Metal	Sludge Application Rate, dry MT/ha		Recommended Metal Total Applications	
	11	184	U.S. E.P.A.	Pennsylvania
	Metal loading, kg/ha			
Cu	21	129	280	112
Zn	21	147	560	224
Cd	0.1	0.6	11	3
Pb	10	55	1120	112
Ni	1	12	280	22
Cr	16	74	-	112
Hg	0.01	0.09	-	0.6

the type of sludge (treated or raw, primary or secondary, liquid, dewatered, or composted, etc.) was not mentioned.

3. The majority of studies were completed without the use of controls that would enable the evaluation of the usefulness of sewage sludge. Without the use of inorganic fertilizers, lime and mulches at rates that provide good vegetation, it is difficult to make economic comparisons.

The Metropolitan Sanitary District of Chicago's sludge utilization program has contributed a great deal to the understanding of this topic (Peterson, et al. 1980) on a large scale. Between 1970 and 1975, 6,284 ha of calcareous strip mine land was purchased for reclamation with sludge. Careful monitoring of sites over a seven-year period have been conducted. Yearly application of sludge has varied from 0 to 129 MT/ha, and accumulated additions of sludge have ranged from 235 to 453 MT/ha. Changes in soil include some of the following:

Soil Parameters	Initial	After 7 years of Sludge Application
pH	7.4	6.5
Bulk Density, gm/cc	1.61	1.10 to 1.19
Organic Matter, %	0.61	2.83 to 4.72
Available Nitrogen, μg/g	9	220

At 280 μg/g the Chicago sludge contained about 10 times the median concentration of cadmium, and has provided an excellent opportunity to determine the effectiveness of high application rates. Although current federal regulations limit maximum cadmium accumulation loading rates of 9 kg/ha for sites growing human consumed crops, some fields have received cumulative cadmium loadings of 135 kg/ha. Corn grain grown on controls had 0.04 to 0.46 μg/g cadmium, whereas the grain grown on all sludge amended sites had a cadmium concentration in 1979 ranging from 0.46 to 0.81 μg/g. Even though the cumulative cadmium addition is high, the increased cadmium in the corn grain after seven years of use is only 50 percent higher than the higher control values. Hinesly has shown that certain varieties of crops such as corn have been identified that will have little or no increased metal uptake when exposed to high soil metal levels.

Hinesly, et al. 1980 have studied extensively the impacts of land application of the Chicago sludge. They reported beneficial aspects of sludge application, and they also emphasized the plant uptake of metals. Protein content increased more than 25 percent at the massive sludge loadings, but cadmium accumulation, although increased by seven- to tenfold, remained below levels observed in grain grown on non-sludge amended sites.

In one of the few studies of the effects of land application on animal health, Fitzgerald (1980) reported that massive exposures of cattle and swine to the Chicago sludge had little or no effects. After consuming a considerable

amount of the sludge through direct consumption, or indirectly by consuming contaminated crops, some heavy metals were accumulated in kidneys in proportion to the time and amount of exposure that the animals had had to the anaerobically digested sludge. All concentrations were well below the concentration at which one would expect to detect clinical evidence of disease, and muscle tissue was not affected. After seven years of exposure to the Chicago sludge, no clinical or histopathological evidence was detected.

These positive studies on little health effects on animals in the Chicago studies contrast with a number of European studies (Williams 1979) clearly linking disease transmission with agricultural use of sludge. It would appear that the major reason for the difference may relate to the degree of treatment and resultant pathogen reduction achieved prior to land application.

Acid strip mine sites that resisted all revegetation efforts with conventional methods (fertilization, pH control, and mulching) were successfully reclaimed with sludge by Corey, et al. (1980). Typical pH values were 2 to 4.6 at the surface. Sludge applications of greater than 300 metric tons per ha were found to be necessary. Plot studies (15 x 30 meters) showed that nitrate-nitrogen concentrations at 120 cm depth peaked at 170 mg/ℓ (as N) two years after application at 598 MT/ha (applied over a period of about 1.5 years). This illustrates a potential problem that may occur with large applications of liquid sludges.

Forest Applications

A summary of several studies involving the use of woody ecosystems for strip mine or poor soil utilization is shown in Table 31-2. Extensive studies have been conducted by researchers at Pennsylvania State University, and the large scale efforts in this area have been completed at the University of Washington by Cole (1980). Cole reported on a technique for applying liquid sludge to mature and established forests. The application of 200 tons/acre of sludge resulted in minimum movement of the metals in a gravelly soil (at a pH of 6). A large increase (greater than 900%) in biomass productivity was observed using either treated effluent (5 cm/week) or sludge. The largest problem faced by the University of Washington workers related to site management. Weeds showed a great response to waste applications and could out-compete tree seedlings. The protein content of vegetation at waste applied sites was two to three times higher than controls, thus resulting in preferential browsing by wildlife. Clearly, special precautions need to be taken early in life of a site using trees as part of the revegetation plan. Economic analysis showed that the forest application of Seattle, Washington, sludge was the most cost-effective final disposal method. Additional economic discussion will be presented later.

Wastewater and sludges were successfully used to reclaim marginal and strip mine lands in Pennsylvania (Kerr and Sopper, 1980b; Kardos, et al.,

1980). These studies also experience competition from weed growth and wildlife browsing, resulting in 57 to 79% survival in trees over a five year period. Potential tree biomass production on reclaimed strip mine land was estimated to average 11 tons/ha-yr (control was 1 ton/ha-yr) using sludge application. The potential of increasing tree biomass productivity on poor soils with sewage sludge without adverse environmental effects seems to be well established by these studies.

In summary, reclamation of strip mine lands or other adverse soils with sludges and wastewater is technically and practically feasible. Previous and on going demonstrations varying in size up to the massive Chicago program now nearly a decade old with 6,000 ha emphasize significant benefits achieved by using waste as a resource to fertilize soils to enable them to be attractively revegetated or to be used for wood production. Applications of sludges varying from 30 MT/ha to greater than 300 MT/ha were found to be necessary for long-term reclamation. Several studies that have focused on the environmental impacts report minimal effects on the environment. Some studies reported on the possibility of excessive nitrogen leaching to the groundwater at higher sludge application rates. Sufficient data are available to clearly establish that wastewater and sludges can be used to effectively place disturbed land into crop production while purifying the wastes that are used for this purpose.

Unfortunately, it must also be concluded that the engineering design criteria and the economic feasibility of the use of wastes for strip mine reclamation is much less clear. Comparisons of waste management technologies and costs and the limitations of soil to serve as a waste treatment system will be used to clarify these two areas in subsequent sections.

Designing Land Application Systems

General Conditions

There are two major concerns that emerge when the ultimate sludge disposal option of recycling by land application is considered. The first is the pathogen/disease transmission concerns, and the second is concern over the toxic contaminants that may be in sludge as a result of industrial contamination. Examination of the literature and existing full scale experiences with the use of sewage sludge provide little data to support the arguments that these concerns should be considered to be major barriers to the utilization of sewage sludge by land application, including its use in agricultural crop production. The overall conclusions which appear to represent the state of the art are: 1) incorporation of sewage sludge in crop production is often the most cost-effective sludge management option; 2) the hazardous materials can be managed and monitored so that any serious problems resulting from land application practices can be avoided; and 3)

land application alternative represents the recycling, low resource utilizing technology representative of the type of solutions being sought by the general public now and for the foreseeable future.

Two aspects of the wastewater and sludge problems need to be understood by those seeking solutions to ultimate sludge disposal. First, there are three media for final disposal of sewage sludge--the air, land or water. Except for the problems of several large cities, disposal on land appears to be the favored alternative. Second, even if all sludge were used in agriculture at rates proportional to the amount of nutrients required by the crops, the amount of cropland that would be utilized would be less than 1 percent, on a nationwide basis. Thus, on a national scale, it is difficult to envision that this technology for reusing sewage sludge while effectively controlling the sludge pollutants would result in large scale problems. Of course, any sludge utilization scheme should be accompanied by a comprehensive management program.

The following paragraphs discuss the historical background, present composition and variation of toxic elements in sludge, and examine the design problems and long-term considerations that should be included in a land reclamation sludge management plan.

Potential Problems

There are several potential problems that need to be carefully managed when sewage sludge is applied to the land. The hazardous materials such as the toxic elements are perhaps of greatest concern. A number of studies have examined the composition of toxic heavy metals in sludge from a large number of U.S. cities, whereas few studies have been completed on the toxic organics. There are several important general observations to make in regards to the composition of sewage sludge. First, it is a low quality fertilizer since the N content is 1/3 to 1/4 the concentration of inorganic fertilizers, and the organic nitrogen in stabilized sludge is probably largely unavailable to plants. Thus the sludge is probably more valuable for its organic carbon content (i.e., for soil conditioning) than for its fertilizer value. Secondly, application of median quality sludge at a common crop use nitrogen application rate of 200 pounds per acre per year adds about 0.1 lbs per acre of Cd for each application and about 6 lbs. per acre of lead. If this is mixed uniformly through the top 12 inches of soil, the cadmium concentration in the soil will increase by about 0.025 ppm per application and the lead concentration will increase by 1.5 ppm.

Industrial Contaminants: Short- and Long-Term Effects. One of the obvious problems with the use of sewage sludge involves the potential impact of unexpected toxic contaminants. Since any material used in homes and industry may be found in sewage sludge, it would probably be appropriate to establish some type of continuous bioassay monitoring system to evaluate unexpected or unmeasurable plant inhibitory substances in sludges. Such a

bioassay could involve relatively short-term (one month) response tests using common plants (such as tomatoes or chrysanthemums). An experienced botanist could detect minor inhibitory effects such as heavy metal toxicity, nutrient deficiency, etc. This bioassay approach would assist in avoiding serious short-term consequences in most cases. It would also provide assurance to the public that a maximum effort is being taken to protect them from unexpected situations. Such a bioassay approach is not included in existing regulations.

Another consideration is the potential long-term effects of the toxic materials in the soils. Because of their strong electrical charge, most heavy metal ions are bound tightly to the soil complex and, therefore, remain in the top few inches of soil. Annual applications of sewage sludges will result in increased organic matter, increasing the soil's cation exchange capacity and, in general, improving the soil's basic properties. After terminating sludge applications, especially in cases where the maximum quantities of metals have been applied, some concern has been expressed regarding the long-term mobility of these elements.

There are a number of factors which appear to indicate that no serious long term effects will be encountered. First, no data exist to indicate such will be the case, even though historical studies have been completed. Even at sites that are several decades old, metals have not become mobile. On the contrary, the metals seem to enter into aging or reversion reactions which make them less available with time.

Finally, as indicated earlier, the total quantity of material added to soil over a 10- to 20-year period does not add toxic elements in sufficient quantities to make them capable of significantly changing the characteristics of the soil.

Soils as Sludge Treatment Systems

The application of sludges to soils can be a highly effective alternative to minimize treatment cost, maximize pollution control, and recycle a useful by-product. Soils have the capability of storing the major fertilizer nutrients, precipitating most toxic metals into chemical forms unavailable to plants, providing continuing stabilization of the organics, and, under proper management, providing pathogen control. The favored type of soil for sludge utilization would be a medium-drained, fine-textured soil with a medium to high cation exchange capacity (>20 meq. per 100 grams of soil), high organic content, and a neutral to alkaline pH. Modification of strip mined areas to conform with these general considerations needs to be considered.

Sludge Quantities and Characteristics. The more than five million dry tons of municipal sewage sludge generated each year in the U.S. is expected to nearly double as soon as secondary treatment of domestic wastewater is fully implemented. The total costs (capital, operation, and maintenance) of treating and disposing of this material approaches a billion dollars per year,

and represents more than half the cost of wastewater treatment, in many instances. It is essential that effective and low cost alternatives for utilization and final disposal of this material be made available.

Of the nearly 16,000 municipal treatment plants in the U.S., about 5,000 are pond treatment systems with little or no sludge facilities. Of the remaining 11,000 plants, fewer than 350 treat wastewater flows greater than 10 million gallons per day. More than two-thirds of the nation's sewage treatment plants have design flows less than 1 MGD (USEPA 1976, 1978). This size distribution makes it necessary to consider sludge processing and disposal technologies that can be utilized by small communities.

Although the characteristics of sludge are highly variable, some generalizations are possible. A population of 10,000 will produce about one million gallons per day of domestic wastewater from which 1,000 pounds of dry solids at 8 percent will be separated by the primary clarifier, and400 pounds of secondary biological solids at a concentration of 3 percent solids would be produced by a thickener following activated sludge treatment and secondary clarification. After two-stage anaerobic digestion, the quantity of sludge would be about 900 pounds of dry solids in a 4 percent total solids concentration. Composition characteristics of municipal sewage sludge, as reported in numerous studies, are shown in Table 31-4.

Table 31-4. Composition of Sewage Sludge (USEPA, 1976).

Characteristics	Range	Typical Value/Mean	Median Values
Total Solids, % wet wt.	1 to 10	4.0	
Volatile Solids, % dry wt.	30 to 60	40 (digested sludges)	
Nutrients			
Nitrogen, % TS	1.6 to 6.0	3.0	
Phosphorous	0.5 to 4.0	3.0	
Potash, K_2O, %TS	0 to 3.0	0.5	
Energy, Btu/lb	1700-6800	4000	
Heavy Metals, ppm dry	*		
Ag, Silver	nd-960	225	90
As, Arsenic	1-50	9	8
B, Boron	200-1430	430	350
Ba, Barium	nd-3000	1460	1300
Be, Beryllium	nd	nd	nd
Cd, Cadmium	nd-1100	87	20
Co, Cobalt	nd-800	350	100
Cr, Chromium	22-30,000	1800	600
Cu, Copper	45-16,030	1250	700
Hg, Mercury	0.1-89	7	4
Mn, Manganese	100-8800	1190	400
Ni, Nickel	nd-2800	410	100
Pb, Lead	80-26,000	1940	600
Sr, Strontium	nd-2230	440	150
Se, Selenium	10-180	26	20
V, Vanadium	nd-2100	510	400
Zn, Zinc	51-28,360	3483	1800

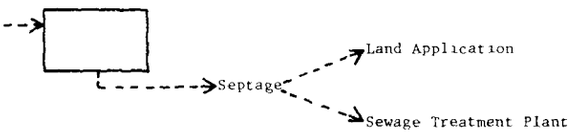
* not detectable

Although it may be thought that source control of toxic materials such as heavy metals might be feasible, this is not necessarily the situation. Because of the ubiquitous nature of some substances, such as cadmium and mercury, even pure domestic sewage will contain some of these substances. Since biological processes tend to separate soluble and particulate heavy metals, they can be concentrated in the sludge.

The major options for sludge generation, treatment and disposal are given in Table 31-5. In general, the sludge that is generated is a stabilized liquid or a solid containing a wide range of materials. For most land application purposes (including reclamation), the fate and characteristics of nitrogen will be the most important factor.

Table 31-5. List of Options for Sludge Treatment, Disposal, and Utilization.

I. On-site Wastewater Treatment

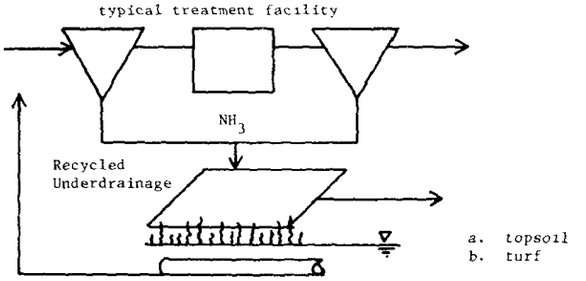


II. Centralized Sewage Treatment

A. On-site Control

1. → Incineration → Ash to Landfill

2. Soil assimilation with dedicated land as shown with a typical treatment facility



B. Off-site Utilization/Disposal

1. Raw Sludge to Sanitary Landfill

2. Water Disposal

3. Treatment and Land Spreading

a. Use in crop production--fruits and vegetables

b. Non-food crops

c. Reclamation

d. Recycled in commercial products

A considerable amount of research has been conducted on the conditions responsible for translocation of heavy metals from sludge into various plants and animals (Loehr et al. 1979, Sommer et al. 1976, USEPA 1977, Page 1974) and no attempt will be made to review this extensive material. However, after considering various approaches, the USEPA has suggested limiting sludge applications as a function of specific metal content and soil cation exchange capacity (CEC).

There is little general agreement on the disease organism content criteria which should be followed when applying sludge to land. In general, the use of sludge in agriculture is generally recommended only for crops that are not consumed raw by humans. Well digested sludge is commonly surface applied to cropland; undigested raw sludge has been successfully injected beneath the soil surface used for non-food crop production.

In summary, it would appear that information is now available to minimize any potential negative impact of heavy metals in sludges as used in agriculture. The Council for Agricultural Science and Technology concluded that, "most metals are susceptible to control through choice of appropriate application sites, limiting the sludge application rate to that required to meet nutrient demands, and applying the sludge to well-aerated soils with pH controlled by sound management practices (CAST, 1976)."

Land Application Designs to Minimize Leachate Formation. By relating the soil assimilation rates and quantities to application rates, it should be possible to insure control of leachate and/or predict pollutant movement and eventual breakthrough to groundwater. This approach was developed in a land treatment training program (Loehr et al. 1979), and is useful for sludges and wastewater. In this method, the most restrictive pollutant loading controls the sludge application rates.

There are two major options for beneficial reuse of sludge by land application for land reclamation purposes. The application of sludge as a fertilizer source is the more common use of sewage sludge. The use of sludge on dedicated land has been practiced on a limited scale for land reclamation. It is based on the premise that soil can be used to effectively convert large quantities of sludge to safe residues at a minimum cost while providing effective control over all sludge components, and land reclamation possibilities at a low cost.

Use as a Fertilizer. Recent U.S. Environmental Protection Agency guidance can assist in evaluating the feasibility of using sludge as a fertilizer replacement. Calculation of the quantity of sewage sludge that can be safely added to provide a plant fertilizer source on agricultural land used to produce food chain crops is as follows:

1. Estimate the fertilizer requirements based on crop needs, soil condition, and climate.
2. Estimate the plant available nitrogen in the sludge, and compare the sludge application rate necessary to provide the crop's nitrogen

requirement to the cadmium limitations.

3. Compare acceptable loading rates for all five metals of major concern: lead, zinc, copper, nickel, and cadmium.
4. Calculate the phosphorus and potassium crop requirements as compared to that supplied from the limiting application rate of sludge.

When available nitrogen limits the sludge application rate, the total amount of sewage sludge applied will usually vary between 5 and 10 dry tons per acre per year. When one of the metals limits the application rate, the amount of sludge is often less than 5 dry tons per acre per year. At a median cadmium sludge concentration of 10 ppm (dry matter basis) and a total nitrogen content of 3 percent of the total solids, the fertilizer nitrogen requirement for corn silage production is the limiting criteria at a loading of 5.6 dry tons of sludge per acre per year. A 20-year total application of 112 tons is significantly less than the safe application rate for cadmium. A total land area of about 30 acres would be needed to make good agricultural use of the sludge from a one million gallon per day wastewater flow for a 20 year design life.

Sludge Application to Land Dedicated to Sludge Disposal and Reuse. The lowest cost option for disposing and reusing sludge would involve minimum pretreatment and direct application of raw sludge to land at maximum assimilation rates. In order to oxidize all of the available nitrogen, the application of sludge would be limited to about 1.7 tons per acre per day. If the application was limited due to cold weather, the amount of land required would be about 0.8 acres per million gallons of flow. The application of sludge at the maximum soil assimilation capacities in a dedicated land site has a number of advantages, as illustrated in Figure 31-1. These are:

1. Rapidly available salts and pathogens are controlled at the treatment site and will be of little concern in the land reclamation scheme.
2. Highly contaminated return streams will not occur since the underdrainage should be relatively pollutant free.
3. The volume of underdrainage is insignificant in most areas, and what is most important is the impact of the return flow to the treatment plant is insignificant.
4. The volume and weight of material is relatively unchanged, but the material to be transported to a reclamation site has characteristics and appearance of topsoil.

A dedicated, underdrained land application site for sludge disposal and reuse essentially becomes a topsoil or turf generation site. It is assumed that most of the organics are stabilized when the sludge is mixed into the top 7 to 15 cm of soil over a two-year period. The volume of topsoil that can and should be harvested relates to the concentration of organic matter

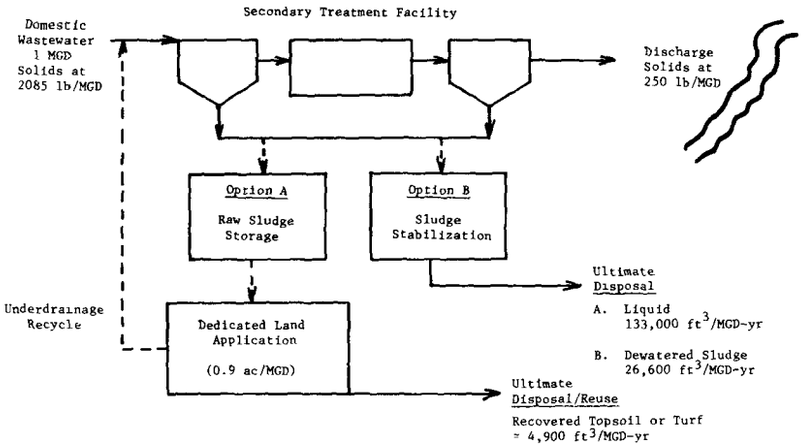


Figure 31-1. Comparison of liquid sludge management and dedicated land management of sludge for recovery of topsoil or turf for land reclamation and other purposes. Various assumptions used in calculating the masses and volumes are: bulk densities of liquid sludge assumed to be 62.4 lbs/ft^3, soil bulk density 91 lb/ft^3, the dedicated land site is harvested every two years, half the stabilized volatile organics are degraded in the top 3 inches of the soil in two years, the nitrogen remains constant at 7 percent of the sludge volatile organics, and the dewatered sludge cake is 20 percent dry matter.

that will be required upon final application of the material. McGinnies and Nicholas (1980) studied the relationship of topsoil depth to plant root development on acid strip mine land with wheatgrass. He noted that normal root development occurred with about 7.5 to 10 cm of topsoil. If it is assumed that this depth is required to reclaim soil and that the organic matter content must initially be 20 percent, harvesting about 8 cm depth from a dedicated land site every two years would result in the production of reclamation cover material for 0.25 ha per 4,000 m^3/d of flow capacity.

The fate of domestic sewage solids in a secondary treatment facility shown in Figure 31-1 contrasts the fate of sludge in several alternative management systems–with and without stabilization prior to land application–and the mass and characteristics of materials handled. Without intermediate thickening or dewatering, the volume of sludge is not affected by stabilization. It is assumed that the dedicated land is harvested every two years (see figure for other assumptions). A comparison of the volume and mass of materials generated each year from the secondary treatment of one million gallons per day are as given in Table 31-6.

Clearly, the dedicated land system described here offers significant advantages over sludge disposal plans using liquid or dewatered sludge as reclamation materials. Even though 82 percent of the material that would

Table 31-6. Comparison of Volumes and Masses of Sludge Material Generated from Domestic Sewage Treated to Secondary Standards with the Major Treatment Options. All Volumes Expressed on an Annual Basis of Amount Per MGD of Capacity.

	Weight (Tons/MGD-yr)	Volume (ft^3/MGD-yr)
Liquid Sludge (raw and digested)	4150	133,000
Dewatered Sludge	830	26,600
Recovered Solids from Dedicated Land Sites	223	4,900

be harvested from the top 3 inches of the dedicated land site would be soil, the total weight and mass to be handled would only be about 5 percent of a comparable liquid system. Not only is this material much less objectionable to handle and transport, it should be much less costly. Since it has been shown that 7.5 cm of topsoil can be used for reclamation, the dedicated land sites would vary from 0.25 to 3 acres per year per MGD of flow capacity.

There are relatively few instances where sludge has been applied at rates designed to test the soil assimilation rate and leachate control capability as outlined in the dedicated land treatment option. Lewis (1977) reported successful "sludge farming" of refinery wastes on a full scale where the application rates equalled 150 tons per acre per year of dry solids and oils. Due to the presence of an impermeable clay layer beneath the soil horizon, no leachate occurred in this arid climate application. Lewis estimated the cost of this land treatment of oily sludge to be $3 per ton of refinery sludge.

The most extensive test with high rate application of sludges using the dedicated site method has been accomplished by the Springfield, Illinois, Sanitary District (Troemper 1974, Andrew and Troemper 1975). This system is identical to the alternative proposed here. In a development effort which covered a period of six years, from 1965 to 1970, an 8-acre plot was used to apply an average of 56.8 dry tons of stabilized sludge per acre per year. At this rate, more than 10 times the fertilizer rate, corn production rates averaged 42 percent higher than control values. The estimated sludge disposal costs were about $1 per dry ton of solids. They considered this to be the most desirable sludge disposal option of those available.

Land Reclamation Practices--Nitrogen Limitations

A review of the vast amount of information describing the potential for

converting poor soils into ones that support vegetative growth appear to include one significant deficiency--there is no goal or definition of the minimum characteristics of a "productive soil." Generalizations are difficult due to widely varying site-specific characteristics. However, there must be a minimum set of conditions that would maximize the chances of establishing a perennial vegetative cover, under normal conditions.

Aspects of these minimum conditions that could be addressed are: nutrients available for continuous recycling; topsoil humus content, or refractory organic content to establish nutrient holding capacity and possible recycling of biomass; characteristics to achieve water holding capability; and secondary topsoil requirements such as pH, trace elements, etc. It is likely that for any given location there are a set of limiting values relating to the above aspects that would enable artificially planted combinations of grasses, nitrogen fixing plants, trees and bushes to eventually establish a permanent vegetative cover.

The conditions that may be required to establish a permanent vegetative cover using sewage may not be either economically or environmentally attractive. For example, too much sludge may be required to establish a minimum level of refractory organic matter in the soil, or the sludge may result in contamination of the groundwater. Until the minimum conditions for successful reclamation projects are established, it will be difficult to justify differing sludge utilization practices for land reclamation.

Modeling Sludge Nitrogen Interactions

Some of the basic information exists to provide minimum goals for permanent vegetation establishment on poor soils, but it appears that many of the specific needs relating to sludge application are missing. One approach for addressing the complex interactions relating to sludge use for soil reclamation purposes is to develop a system overview using a modeling approach. A review of this area or development of a model of the sludge-soil-ground-water interaction is beyond the scope of this report. However, many studies have considered aspects of this problem Particularly intensive efforts have been made by several Cornell University researchers to develop simple and useful models in this area. Steenhuis (1981) has adapted several currently available models to illustrate several major limitations of the use of sludge application to soil by focusing on the nitrogen cycle.

The data used for validation of the Steenhuis models were obtained from literature for the unique full scale land application site used at Springfield, Illinois, where aerobically and anaerobically digested sludges are applied (Andrew and Troemper, 1975). Examination of a wide variety of land application of sludge alternatives led to the following observations.

Influence of Pretreatment on Sludge Environmental Impacts. The form of nitrogen in the sludge will have a major influence on its interaction in soil

and the pollution potential. Untreated primary sludges will have most of the nitrogen in a combined organic form that becomes rapidly available when placed in soil, whereas well composted sludge will have a lower amount of organic nitrogen that will be made available to plants much more slowly. The application of a treated sludge in liquid form provides a large amount of available nitrogen to the plants, and if in the nitrate form may result in rapid movement to the groundwater.

Examples of Sludge Application Possibilities. It is reasonable to assume that a minimum soil organic matter content will have to be established in inorganic soils to support the sustained growth of vegetation. The fate of sludge solids in soils showed that when one large application of anaerobically digested sludge (200 dry tons/ha) was added, most of the organic matter was oxidized, leaving the topsoil with an organic nitrogen content similar to poor soils after seven years. Conversely, the application of 200 kg N/ha of primary, anaerobically digested sludge and compost showed that only composted sludge is useful in building topsoil organic matter for permanent soil reclamation.

A high rate one-time application of aerobically digested sludge will result in flushing of nitrates to the groundwater in excess of the drinking water standard.

Comparison of Sludge Pretreatment Effects. In land reclamation, one large addition of soil conditioning materials to enable permanent vegetative cover would represent the lower cost option. No vegetation would be harvested from the site. The model was used to illustrate the fate of nitrogen at a low application rate (300 kg/ha) and a high application rate (3000 kg/ha) for liquid anaerobically digested sludge and composted sludge (see Table 31-7). The liquid sludge loading results in relatively small additions of dry

Table 31-7. Summary of Nitrogen and Organic Solids Loading Rates Examined with the Cornell University Soil Water-Nitrogen Models.

	Type of Sludge			
	Anaerobically Digested		Composted	
Sludge Nitrogen Content				
Total gm/ℓ	3		-	
gm/kg dry solids,	-		10	
Ammonia, % Total	50		0	
Organic, % Total	50		100	
Nitrogen Loading Rates, kg/ha (One Application)	300	3000	300	3000
Solids Loading Rate, MT/ha	3	30	40	400

solid matter (3 to 30 MT/ha), whereas the compost adds ten times this amount (40 to 400 MT/ha).

At a loading rate of 3000 kg N/ha with composted sludge (equivalent to 400 metric tons/ha dry sludge) with a one-time application, the nitrogen in the groundwater remains close to, but below, the drinking water standard concentration. Thus, this sludge loading rate represents the maximum that should be considered for permanent vegetation cover stimulation, where groundwater protection is essential. A large amount of nitrogen reaches the groundwater when the liquid sludge is applied.

The single loading of the two different forms of sludge raise interesting policy-risk questions for land reclamation. The minimum sludge loading rate with compost at 40 MT/ha appears to release nutrients at a low rate that may limit vegetative growth. High applications of compost provide the amount of organic matter and available nutrients to support a vigorous vegetative cover for a period greater than ten years.

With large liquid sludge applications to soil that provides a larger amount of available nutrients at lower solids application, after three years of plant growth, most available nutrients will begin to limit plant growth. If sufficient legumes are established three to four years after the low liquid sludge application, it is likely that establishment of a permanent vegetative cover will be successful. The concentration of the nitrate lost to the groundwater will not violate the drinking water standards at the lower application of liquid sludge, although they are much greater than the losses predicted with composted sludge.

Relatively high application rates of liquid sludge are necessary to create a significant amount of organic topsoil. However, the nutrients move rapidly out of the topsoil, and the time over which a significant amount of solids remain available is not much longer than that for lower liquid sludge application (three to four years). Groundwater effects due to nitrate leaching can be serious with large amounts of liquid sludge application. The drinking water concentrations may be exceeded by as much as ten times the 10 mg/ℓ nitrate standard, and this can last for four years in constantly drained areas.

Economic Considerations

The economics of incorporating waste treatment and recycling into land reclamation efforts are complex, and it is difficult to justify one activity against another solely on an economic basis. According to coal industry sources, strip mine reclamation costs are now approaching 25 percent of the FOB mine price of coal. Thus any savings in land reclamation costs could have a beneficial impact on the price of coal. The following is a brief discussion of the various costs involved in waste treatment and land reclamation.

Waste treatment costs. Land application as a wastewater treatment method involving land reclamation and biomass production is not a major

consideration. Land treatment can be a cost- and energy-effective mode of treatment for municipal wastewater. Wherever land is available this represents a viable alternative. However, large land areas are required (frequently greater than 200 acres per million gallons per day of capacity), and the biomass value does not represent a major return in this waste management system. It is difficult to envision wastewater usage for many land reclamation projects, primarily because the sites are usually quite distant from the wastewater generation sources.

Sludges contain 100 to 10,000 times the concentrations of plant nutrients and other useful materials than the wastewater. Therefore where treatment and transportation costs are acceptable, sludge incorporation in reclamation schemes may be attractive. Typical sewage sludge treatment costs vary as follows (USEPA 1980b):

Disposition Method	$/dry ton
Incineration	80 - 240
Composting	70 - 200
Surface Disposal	25
Landfills	73 - 226
Ocean Dumping	30 - 50
Ocean Disposal	20
Land Spreading	40 - 210
Distribution & Marketing	2 - 12

The dedicated land total treatment cost would vary from $10 to $30 per ton.

Transportation costs are highly variable and depend on haul distances and transport method. Approximate costs may vary from $6 to $20 per ton for a 100 mile transportation distance (Nye et al. 1980, Peterson et al. 1980). Potential reclamation sites are located at distances varying from 30 to 450 miles for 18 of the larger Eastern cities (Nye et al. 1980).

Sludge as a Fertilizer. Land application of sewage sludge as a fertilizer raises a number of concerns which are difficult to offset with the benefits gained from the material. Extensive use of inorganic fertilizers has been possible because of their low costs. Custom-applied fertilizers used on row crops and forage seldom cost more than $150 per acre. Gross income from such crops may vary from $100 to $500 per acre. Thus sludge use in these situations has a maximum fertilizer value of $100 (but additional fertilizer in the form of potassium generally are necessary). If 10 tons per acre of dry sludge are applied each year, the value of this material averages about $10 per ton. Although this is a highly simplistic analysis, it illustrates the difficulty in recovering the cost of sludge processing, since the total cost of sewage sludge stabilization, handling, and disposal often exceeds $100 per dry ton, as shown earlier.

In cases where land reclamation is an objective, sewage sludge can

represent a high value material. The application of 50 tons per acre to disturbed areas would result in conversion of the land to cropland. This application or the upgrading of marginal land results in a usage of the sewage sludge which has a value equal to or exceeding its processing cost. The total cost of sludge treatment and transportation to reclamation sites for the city of Chicago was estimated to be $339 per MT (capital = $38 per MT, operation and maintenance $301 per MT; and 43% of the total was transportation costs) (Peterson et al. 1980). Cost for the sludge disposal in land reclamation for Philadelphia was similar. A detailed review of sludge disposal options for Seattle showed costs varying from $280/ton (ocean dumping) to $857 per ton (agricultural application with purchase of all land). The lowest cost option (other than ocean disposal) was for use in silviculture at $453 per ton (Cole 1980). Addition of sludge to established forests resulted in a 62% increase in board feet in the Washington study, or the value of timber increased from $140 to $150 per acre. At the sludge application rates studied, this results in a sludge value of less than $3 per ton. Kerr and Sopper (1980a) noted a five year increase in wood yield equal to 7 to 16 MT/ha. The energy value of such an increase over a five-year period could equal as much as $25/ton of sludge.

Land Reclamation Costs. One important aspect of the economic considerations is the cost of reclamation practices without the use of sludge. Reported values show that the reclamation costs can be extremely large. Urie et al. (1980) gave estimated costs as follows:

Cost Component	Costs per unit area, $/ha	Costs per ton sludge, $/MT
Grading	4,900	8
Sludge transportation and application	56,200	85
Monitoring	2,520	3
	$63,620	$96

The most important economic area in favor of sludge use may be where it qualifies as a topsoil substitute. According to the Surface Mining and Reclamation Act regulations, substitute materials can qualify for this purpose. In some cases an exemption from removing, storing and reusing the topsoil could be obtained. A large part of the total costs of strip mine reclamation will be committed to topsoil removal (and possibly separate removal of other soil horizons), storage, grading, and redisposition of the stored material after the coal is removed. Extensive data reported here shows that the addition of sludge to any soil can result in a satisfactory plant environment, thus indicating that it should be considered a topsoil replacement.

Minimum Cost Sludge Treatment and Disposal/Reuse with Land Reclamation. The lowest cost option for using sludge for reclamation of

inferior soils would appear to include the use of the dedicated land system near the treatment plant, followed by harvesting a mixture of stabilized sludge and soil. If this mixture were applied to a depth of 10 cm and this was sufficient to reclaim the site, the following estimated cost would be incurred:

Cost Component		$/dry ton
Sludge treatment		
(with stabilization-anaerobic digestion)		150
(without stabilization)		5
Sludge application on dedicated land		31
Topsoil harvesting at 10 percent organic matter		5
Transportation - 100 miles and land application		35
Total Costs	without pre-stabilization	$ 76
	with pre-stabilization	$221

These estimates are given for two major alternatives--one where the sludge is stabilized prior to land application as is the practice at Springfield, Illinois; and another where it is not, i.e., where raw sludge is applied. In the design criteria the limiting loading rate factor in a dedicated land site is the soil nitrification rate, not the organic carbon oxidation rate. It is well within the capability of the soil biomass system to stabilize the sludge at the suggested loading rates. However, if the dedicated land is not well isolated and well managed, odor generation may occur with the application of raw sludge. There should be incentive to consider options that enable land application of raw sludge, since the pretreatment does little except provide odor control while increasing the cost by 500 percent over the simpler dedicated land option.

The above considerations lead to a highly cost-effective method of treating and disposing of sludge with minimum impact while recovering spoiled land. If the sludge loading equivalent requires 100 MT/ha (dry organic matter) to reestablish permanent vegetative cover, a total cost of $4,500 (topsoil harvesting and transportation) per acre plus grading costs should be the minimum cost goal. This cost should be compared to that incurred for soil removal and storage, pH adjustment, mulching and potentially extensive irrigation that may be required without an organic soil amendment. Also, proper management will result in good vegetative growth and permanent land reclamation. Other options are more complex and involve higher costs and risk of failure. The sharing of appropriate portions of costs using this option can result in minimum cost to the municipalities and a savings of as much as 70 percent of strip mine reclamation costs.

Summary and Conclusions

Land application of wastewaters is a cost-effective and minimum energy

consuming treatment alternative. Where land is available, this is often the optimum alternative, and adequate engineering design information is available to develop these systems. In most instances, the contaminant level and nutrient concentrations in municipal wastewaters are so dilute as to cause few concerns. However, land reclamation with wastewaters is difficult because of their low organic and nutrient concentrations, and because poor soils and sites requiring reclamation are remote from the larger cities. Conversely, the sludges contain large quantities of nutrients as well as some hazardous materials at concentrations between 100 and 10,000 times that of the wastewater. Thus, of the two, municipal sludges are much more useful materials, and are the focus of this assessment. These materials must be carefully treated and disposed of in order to minimize costs and environmental impact. Using the soil as a treatment system and final disposal/reuse site for sewage sludge while encouraging biomass production or recovery of disturbed land solves two problems at the same time.

Problems with Wastewater and Sludge Use in Land Reclamation

Surface mining has disturbed 1.76 million ha of land in the U.S., with half of this caused by coal strip mining. Each year an additional 40,000+ ha of land is disturbed by coal mining, and this rate will increase in the future.

The quantities of municipal sewage sludge presently produced at 5 million tons per year have been projected to increase to 9 million tons per year when secondary treatment is completely implemented. The annual total cost will approach $900 million and be more than half the total sewage treatment costs in many cases.

There are fewer than 350 municipal treatment plants, out of a total of nearly 16,000, with flows greater than 10 million gallons per day (MGD). Greater than 65 percent of all U.S. municipal treatment plants have flows less than 1 MGD. For this reason, sludge handling and treatment need to be simple and efficient, even at low flows.

Present practices indicate that more than half of the sewage sludge presently produced is applied to land, and this may increase to 75 percent when ocean dumping ceases. About 20 percent is currently used in crop production.

A comparison of typical sewage sludge loading rates used in land reclamation of several disturbed strip mine lands indicates that all the sewage sludge could be used to reclaim the land disturbed by coal mining. If the use of sewage sludge in land reclamation could be economically attractive, this management method should receive major attention in the immediate future.

The goal of this assessment was to determine the capability of this technology to adequately treat municipal wastewater or sludge as innovative/alternative wastewater treatment and sludge management technologies while utilizing these materials for land reclamation and biomass

production purposes. This review shows that land reclamation with sludges should receive a high priority. If widely implemented the ultimate sludge disposal problems could be eliminated, all drastically disturbed lands could be permanently revegetated, with significant resulting cost savings to municipalities and strip mining interests.

Regulatory Considerations

There has been a great deal of regulatory activity directed at sludge treatment and management at local, state, and federal levels. A large amount of research and development data have become available as various regulations have been formulated. Several critical factors in the regulations relate to the cessation of ocean disposal, as well as the generally accepted position that many sewage sludges can be managed so that their use in agriculture can be considered safe.

Coordinated regulatory activity has addressed the most immediate concerns related to sludge application to land, i.e., use in food chain applications. Federal guidelines have now defined a "good" sludge that is safe to be used in fruit and vegetable production (one that has limited concentrations of cadmium, lead, and PCBs). Examination of the concentration of these elements in municipal sludges indicates that this definition eliminates nearly half of the sludge generated from consideration for use in fruit and vegetable production.

In general, a review of the extensive amount of data produced on land application of sludge in Europe and the U.S. shows that the recent guidelines are overly conservative. Even highly contaminated sludges and poor soils can be managed to result in food production unchanged from that without sludge benefits. The state of the art of the technology is far more advanced than the regulations. However, the regulations will be useful in development of key public information programs as long as the risks and benefits from such programs are clearly defined. Hopefully, exceptions to these conservative limitations will be granted in areas where management can document the control necessary to protect the food chain and the environment.

Few regulations for non-food chain uses of sludge have been promulgated. The most significant regulation that affects land reclamation relates to the future status of the land where a "bad" sludge is used, or where application rates exceed the acceptable cumulative loadings stated as being acceptable with "good" sludge. The regulations suggest that the land receiving excessive metals loading never be used for food chain crop production and that the property deed must state this restriction. There is a growing body of information indicating that this restriction is not necessary. Because of the conservative nature of regulations and definitions, this restriction will likely limit the potential use of sewage sludge in reclamation programs.

Passage of the Surface Mining Control and Reclamation Act of 1977 was intended to internalize the costs of coal surface mining, which are being borne by society in the form of ravaged land, polluted water and other adverse effects, without significant losses in coal production. In the wetter climates, this Act requires that a permanent vegetation (with contours and plant species similar to the natural area) be established for a five-year period, and that the period be extended for ten years in the dryer areas. Industry sources have complained that these restrictions now account for as much as 25 percent of the cost of coal and vary from $10,000 to $60,000 per ha. As is shown in this overview, the option for using sludge can result in decreasing this cost to perhaps less than $5,000 per ha, while returning spoiled land to a healthy native self-regenerating plant cover.

Experience with Wastewater and Sludge Use in Land Reclamation

Where properly managed, the use of wastewater and sludges has been successful and has often resulted in cost-effective pollution control/biomass production systems. This symposium showed that the reclamation of severely disturbed lands, such as zinc smelter areas or acid strip mines, were immediately reclaimed using sludge applications varying from less than 10 MT/ha up to nearly 1,000 MT/ha, with application sites varying from several square meters to 6,900 ha. In general, experience shows that demonstration sites within a region are a key to obtaining public acceptance of sludge reclamation programs.

Minimum soil conditions required to support perennial vegetative cover on adverse soils such as those associated with strip mining of coal are poorly defined, especially for use of sludge. Limiting factors, such as organic or humic matter content, nutrient mobilization rate, cation exchange capacity, and moisture holding capacity cannot be specified. This requires that empirical results obtained from successful reclamation sites be used as practice guidelines.

Some of the basic questions relating to land reclamation with sludge have been examined in a simple but comprehensive model. This model combines the interactions of nitrogen in soils and was validated using an intensive and well documented sludge application system. The results show several important considerations relating to type of sludge considered for land reclamation, influence of application rate on vegetative cover, groundwater influences, and the duration of adverse effects and benefits that can be expected from sludge applications. The model results emphasize that in some cases researchers have concluded that land application of sludge will have no severe effect on the groundwater before such an effect can be measured.

There is a vast but predictable difference between the use of liquid stabilized sludge and composted sludge. Single applications of 400 MT/ha of composted sludge will support a vigorous vegetative cover in central

Pennsylvania for more than ten years, and the loss of nitrogen to the groundwater will result in a concentration less than 10 mg/ℓ of NO_3-N. The addition of liquid stabilized sludge supports active vegetation for a short period (three or four years) but can result in significant nitrate leaching to the groundwater if not properly managed.

This review emphasizes that the state of the art of modeling sludge-soil-groundwater interactions is sufficiently advanced as to allow extensive review of policy and specific site evaluations.

Design of Land Application Systems for Sludges

Consideration of the capability of soils to assimilate (convert and control) pollutants in sludge provides a rational basis for the design of land application systems. Two options are considered here: (1) use as a fertilizer in conventional agriculture; and (2) application to soil at maximum rate as a final disposal/reuse method in a unique dedicated land area. The use of most stabilized sewage sludge as a fertilizer source is a practical and manageable option.

A four-step procedure is outlined which enables sewage sludge loadings to maximize its fertilizer value and to control major toxic material at a safe level. This usually results in the application of sludge at rates of 5 to 10 dry tons per acre per year. Land area requirements of about 30 acres per million gallons per day of wastewater flow are controlled by the available nitrogen.

The second unique system of dedicated land application of sludge gives good control over all sludge interactions and represents a simple and low cost option for sludge management. The site is located near the wastewater treatment site, the area is underdrained, and a topsoil substitute is harvested from the site every few years. This harvested material can be used as a topsoil substitute in land reclamation programs. Maximum sludge application rates may result in leachate formation, particularly nitrate-nitrogen forms. For this reason this option is only viable where an effective underdrainage system can be installed to capture the leachate and recycle it to the treatment site.

The soil pollutant assimilation capacities indicate that the nitrification reaction rate controls the sludge application rate in a dedicated land facility. Maximum sludge assimilation rates would be approximately 300 tons (dry) per acre per year in colder areas where application could only be practiced for about six months of the year. This is equivalent to an underdrained land area requirement of slightly less than one acre per million gallons of domestic wastewater flow. It may be possible to use raw sludge in this alternative where odor is not a concern since the limiting design consideration should generally be the nitrification rate. In warm climates where a sludge can be applied year-round, the area required may be as low as 0.44 acres per million gallons per day of wastewater flow.

Economic Considerations

There is some difficulty in evaluating the economics of using sewage sludge in agriculture, for biomass production, or for land reclamation. For example, as a fertilizer in crop production sludge has a value varying from $10 to $30 per ton (dry) depending on the acceptable loading rate. It may have as high a value as this in intensive forest operations for biomass production, but its value decreases to less than $2 per ton when used to stimulate lumber production in older forests. Most treatment systems (anaerobic digestion, aerobic digestion, composting) cost $100 to $300 per ton (dry) processed. Thus, recovery of sludge treatment costs from agricultural benefits with conventional systems is unlikely.

The use of a rational sludge management system incorporated into a land reclamation program would appear to lead to highly cost effective alternatives. Total sludge handling and stabilization costs for a dedicated land system are estimated to be less than $30 per ton, and transportation costs of a topsoil replacement would be around $45 per ton. Thus, reclamation at applications of 100 MT organic matter per ha would cost between $2,000 to $5,000 per acre, or less if the municipality shared in sludge transportation costs. These costs contrast with the limited ability of substitute material to reclaim strip mine lands at more than 10 times the cost. This system also eliminates most concerns that relate to sludge use since the material has the appearance and characteristics of a rich topsoil. Thus, a land reclamation program using sludge treatment systems based on known soil assimilation capacities (and demonstrated in full scale) can lead to highly effective pollution control systems that reclaim land at a small fraction of the costs of alternative practices.

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32
UTILIZATION OF MUNICIPAL WASTEWATER AND SLUDGE FOR LAND RECLAMATION AND BIOMASS PRODUCTION--AN ENGINEERING ASSESSMENT OF ITS POTENTIAL IN THE WESTERN UNITED STATES

L. Gene Suhr

Introduction

"It is safe to say that despite many years of research and operational experience the most difficult problem facing municipal wastewater treatment agencies today is disposal of the sludge generated" (18). Regardless of the methodology employed to treat wastewater, a residue (sludge) will remain. This sludge residue poses both a problem difficult to solve, and an opportunity offering significant reclamation potential.

As a problem, sludge is certainly significant: Current annual U.S. municipal sludge production is variously estimated to range between 3.3 and 4.5 million metric tons (17,29) (tonnes, dry basis). This volume will inevitably increase as more municipalities must provide secondary levels of treatment in accordance with Federal law. Sludge disposal is also an expensive undertaking. Conservatively estimated, nearly $1 billion is spent annually to handle the 4 million dry tonnes of sludge, when all costs and credits involved in sludge processing, transportation, and disposal are considered.

Municipal sludge is also a significant resource. Aside from the value of its organic matter content, the N, P, and K contained in 4 million dry tonnes per year of digested sludge (approximately 160,000, 120,000, 12,400 tonnes, respectively) would provide sufficient fertilizer to meet the average requirements for nearly 2 million acres of cropland per year.

Unfortunately, the application of sludge to lands which are, or may be used for agricultural purposes (particularly growing food chain crops), has been and will likely remain highly controversial. Realistically, the ultimate repository for sludge must be the land. Federal legislation calls for ending dumping of harmful sludges by December 31, 1981. Although some sludge will undoubtedly continue to be incinerated or otherwise burned, it seems logical to conclude that a large portion of current and future municipal sludge will ultimately wind up on the land. Basically, this suggests that there is an increasing need to plan environmentally sound, cost-effective, land-based systems for sludge disposition. Such systems will include landfills, agricultural/silvicultural use, and perhaps increasingly land reclamation.

Revegetation of disturbed lands is a current area of active sludge application testing. The new Surface Mining Control and Reclamation Act of 1977 (Section 515 of Public Law 95-87) states that a permanent vegetative

cover of the same seasonal variety native to the area of land to be affected must be established and must be capable of self-regeneration and plant succession to at least equal the extent of cover of the natural vegetation of the area. The Office of Surface Mining Reclamation and Enforcement (OSM), established under the law, has recommended performance standards for meeting the revegetation requirements. The OSM recommendations, which follow, can provide significant guidance for future reclamation/revegetation testing:

1. Ground cover and productivity of living plants on the revegetated area shall be equal to that of an approved reference area.
2. The period of responsibility initiates when ground cover equals the approved standard after the last year of augmented seeding, fertilizing, irrigation or other work which ensures success.
3. In areas of more than 26.0 inches of average annual precipitation, the period of extended responsibility will continue for not less than 5 years. In areas with 26.0 inches of precipitation or less, the period of responsibility will continue for not less than 10 years.
4. In both cases, the ground cover and productivity shall equal the approved standard for the last 2 consecutive years of the responsibility period.
5. The ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of that of the approved reference area.

The purpose of this paper is to present an engineering assessment of the feasibility of reclamation and revegetation of disturbed lands or enhancing forest productivity/biomass production while beneficially disposing of municipal sludge. The assessment is presented in four sections: Environmental, Social, and Engineering Concerns; Research Results; Research Needs; and Conclusions. This assessment is intended to be directed at the western United States, although it must (because of the available research) draw heavily on the results of work carried out in eastern states.

The basis for this engineering assessment is in part information presented in the technical papers presented at a 3-day symposium: "Utilization of Municipal Wastewater and Sludge for Land Reclamation and Biomass Production" held in Pittsburgh, Pennsylvania, on September 16-18, 1980. Additional information was also gathered from visits to reclamation sites and from the literature.

Environmental, Social, and Engineering Concerns

Municipal sewage sludge, even though treated by a variety of processes to reduce pathogens, is not a sterile material. In addition, it may contain significant amounts of deleterious materials including certain heavy metals,

chlorinated hydrocarbons, pesticides, and the like. Its organic nitrogen content (often about 50 percent of total nitrogen) mineralizes in soils to form ammonia nitrogen and nitrate nitrogen, which may lead to ground water contamination by nitrates. Ova of parasitic worms and bacterial spores resist inactivation (except by heat or radiation) and may persist for relatively long times in sludge-amended soils. These potential problems need to be addressed carefully by the professionals responsible for feasibility studies and any subsequent planning of potential land-based sludge application projects.

The general public probably prefers not to think much about sludge. From their viewpoint, sludge may well be a waste material of questionable value that is potentially dangerous and is best placed somewhere, anywhere, but a long way from their "front door." The general public will agree that "something" needs to be done with sludge, and will usually agree that a properly designed land application system is acceptable, as long as it is not too close to "them." On the other hand, certain special interest groups tend to be more specific with their concerns. They tend towards a "quasi-scientific" approach, demanding absolute answers to a seemingly endless list of "what if" questions. Termed a "core opposition group" by one author (7), such groups are often formed specifically to oppose a project. However, traditional environmental groups, such as the National Wildlife Federation, Sierra Club, National Resource Defense Council, and others with similar names, have typically not mobilized their membership against well-conceived and planned projects (8).

Regulations

The institutional framework of agencies having (or desiring to have) jurisdiction over land application projects is often complex, and review and approval processes can be lengthy, as illustrated on Figure 32-1 (7).

Regulatory aspects of sludge disposal are carried out principally by the United States Environmental Protection Agency (EPA) and its counterpart state organizations. Strict regulation of sludge disposal is relatively recent; but, in spite of its short history, is complex and is becoming increasingly more so. Beginning in about 1975, the EPA adopted a series of regulations that have placed restrictions on incineration, ocean dumping, land disposal, and land spreading of sludges. Under the authority provided in both the Clean Water Act and the Resource Conservation and Recovery Act, the EPA has promulgated a set of interim final regulations for land disposal of sludges from publicly owned treatment works. As of this writing final regulations to supplant the interim final regulations have not been published. In addition, many states have adopted similar regulations that in some cases (e.g., Pennsylvania) are more stringent than the interim Federal standards.

In some rare instances, municipal sewage sludge may be classified as a hazardous waste under the terms of the Resource Conservation and

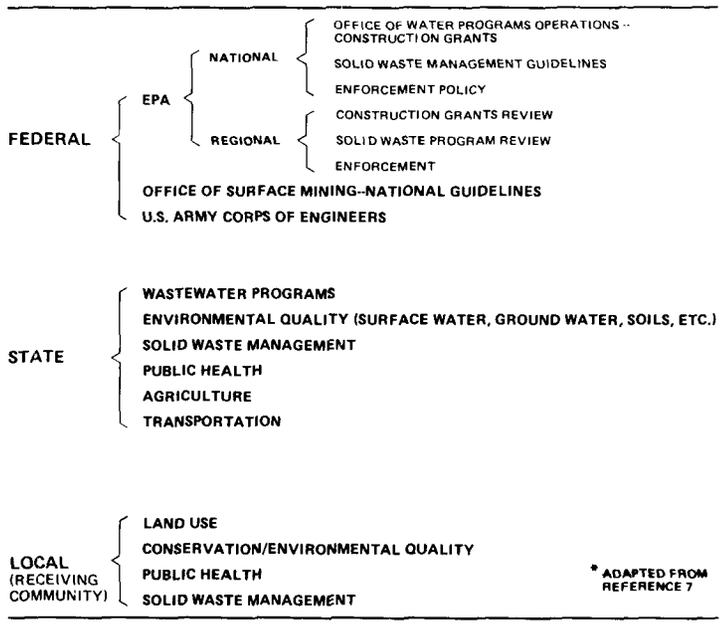

Figure 32-1. Types of Agencies Having Jurisdiction Over Land Application*.

Recovery Act. For example, the sludge must be considered a hazardous waste if the appropriate extraction procedure testing of a specific sludge sample results in a leachate with concentrations of any chemicals equal to or exceeding 100 times the EPA's drinking water standard. If a particular sewage sludge is found to be a hazardous waste, then any land application project using such a sludge would have to be classified as a hazardous waste disposal facility and hence would be subject to very strict safeguards.

Regulations concerning sewage sludge disposal in land application projects are in a rapid state of change. Here again, the professionals responsible for potential or actual projects must keep themselves apprised of the current regulations, and attempt to predict the probable future content or revision of such regulations.

From an engineering viewpoint, designers of land application sludge disposal systems seek four major elements in a successful project. The system should be: implementable; environmentally sound; as economical as possible; and adequately long-lived, predictable, flexible, and reliable. This is not to say that there must be 100 percent "iron-clad" assurance that there will be no problems, but rather that there be a high degree of probable success associated with a project. Failing this, the engineer's "comfort level" may be drastically lowered and his response, firmly rooted in engineering ethics,

may well be to turn to more proven, albeit less innovative and more costly, techniques.

Research Results

A series of technical papers generally concerned with land application of municipal sewage sludge was presented at this symposium. The full texts of these papers are presented elsewhere in this publication. For the sake of brevity, these papers are neither abstracted nor extensively quoted in this assessment. It is of interest, however, to attempt to summarize and to paraphrase the general consensus of the various researchers' findings as presented at this conference.

Of the technical papers presented, 22 were based on actual in-situ research. A variety of forms of sewage sludges were tested by these researchers, including liquid digested sludge, dewatered digested sludge, heat-dried digested sludge, composted digested sludge with amendments, mixtures of composted digested sludge with amendments, and dewatered digested sludge and kraft paper mill sludges. Application rates tested ranged from less than 10 dry tonnes per hectare to more than 900 dry tonnes per hectare. In most cases, the various treatments were replicated, and control plots were extensively employed. Nine papers reported the results of leachate quality tests and 13 papers reported on the results of plant tissue analyses. Nineteen papers reported quantitative growth response data, while only seven papers presented even sketchy cost information.

A variety of site conditions (many of them sites devastated by surface mining activities) were investigated. In many instances these sites represented what could be considered to be totally hostile environments for revegetation; yet in nearly all cases, the researchers demonstrated that vegetation could be successfully reestablished through the use of a regime including the extensive use of municipal sewage sludge. Sites in 14 states were represented by the 22 research papers presented. Of these 14 states, only 3, New Mexico, Oklahoma, and Washington, are western states. One paper (19) presented the results of extensive research dealing with the potential uptake of parasites and heavy metals by swine and cattle as a result of contact with either ground or forage subjected to municipal sewage sludge application. Table 32-1 presents a classification of these papers (1-29).

Symposium participants agreed nearly unanimously that potential ground water pollution, either by migrating heavy metals or nitrate contamination, did not pose a serious problem as long as appropriate loadings and agronomic practices were followed. There was less unanimity of opinion as to the uptake of heavy metals by plant tissue. As reported elsewhere in the literature, such uptake is related to the type of crop, soil type, and soil pH. Researchers tended to agree that noncomposted sewage sludges

Table 32-1. Classification of Papers Presented at the "Utilization of Municipal Wastewater and Sludge for Land Reclamation and Biomass Production" Symposium.

Reference No.	In-Situ Research	Research Location	Material Tested	Growth Response Tests	Leachate Quality Tests	Plant Tissue Analyses	Cost Information	Remarks
1	No	--	--	--	--	--	No	Regulations of Surface Mining Act
2	Yes	PA	C, A_1	Yes	Yes	No	No	Biomass Production
3	Yes	PA	A, B, C, D, E	Yes	Yes	Yes	No	Research continuing
4	No	--	--	--	--	--	Yes	Philadelphia Program
5	No	--	--	--	--	--	No	
6	No	--	--	--	--	--	No	Pennsylvania Regulations
7	No	--	--	--	--	--	No	Institute of Research
8	No	--	--	--	--	--	Yes	Sludge transportation
9	Yes	WV	D	Yes	No	Yes	No	Greenhouse studies
10	Yes	OK	A	Yes	No	Yes	No	
11	Yes	MN	Effluent	Yes	No	No	No	
12	Yes	SC	B_1	Yes	Yes	Yes	No	Research continuing
13	Yes	WA	B, A_1	Yes	Yes	Yes	Yes	Research continuing
14	Yes	OH	B	Yes	No	No	No	
15	Yes	TN, GA	B	Yes	No	No	No	
16	Yes	NM	G, B	Yes	No	No	No	Sludge data forthcoming
17	Yes	IL	A	Yes	Yes	Yes	Yes	Excellent reference
18	Yes	IL	A	Yes	No	Yes	No	
19	Yes	IL	A	Yes-animal	No	Yes-animal	No	Excellent reference
20	Yes	IL	A	No	No	Yes	No	
21	Yes	IL	A (10%)	No	Yes	No	Yes	
22	Yes	WI	B	Yes	No	No	No	
23	Yes	WI	B	Yes	No	No	No	
24	Yes	WA	B	Yes	No	Yes	Yes	$15,000 per hectare
25	Yes	OH	F	Yes	No	Yes	No	
26	Yes	OH	B, F	Yes	Yes	Yes	No	Greenhouse export, field lysimeter
27	Yes	MD	D	Yes	Yes	Yes	No	
28	No	--	--	--	--	--	Yes	Overview paper
29	Yes	PA	D, E	Yes	Yes	Yes	No	Describes Philadelphia program

A = Liquid digested sludge, A_1 = sec. effluent

B = Dewatered digested sludge, B_1 = Dewatered heat treated sludge

C = Heat dried sludge

D = Composted digested sludge with amendment

E = D + B

F = Dewatered kraft mill sludge

G = Straw or other mulch

tended to promote competition by weeds, but this does not seem to be an insurmountable problem. Some researchers (13,33) pointed out that animal browsing of trees planted in sewage-sludge-amended soils seemed to be more prevalent than that which occurred in nonamended similar stands nearby. Foliar uptake of heavy metals by tree species was found to be greater in sludge-amended soils than nonamended soils (13,31,33). The long-term impact of browsing wildlife as a result of such increased heavy metals concentrations is now being studied (33); the testing on swine and cattle mentioned earlier may provide some insight and guidance.

Revegetation of Disturbed Lands

A variety of sludge application methods have been studied; however, most of the work to date concerned with reclamation of drastically disturbed lands has utilized dewatered sludge cakes dried so that conventional land-spreading techniques could be used. Incorporation into the soil on such projects has tended to be through the use of chisel plow techniques, which produces enough furrowing to leave an irregular land surface. Such techniques not only minimize potential erosion, but are substantially less costly than deep plowing or tilling techniques, which may often not be feasible due to the rocky nature of the surface to which sludge is to be applied. Seeding techniques studied have almost invariably employed seed mixtures containing both grasses and legumes. The grasses establish themselves rapidly, and act as a nurse crop for the slower growing legumes that begin to predominate in later years.

Beginning in 1973, the University of Washington, College of Forest Resources, began studies to investigate the feasibility of applying both municipal wastewater and sludge to forest ecosystems. The results of their extensive research were reported at a symposium: "Municipal Sewage Waste Application to Lands in the Pacific Northwest" (July 8-10, 1980--Seattle, Washington; the proceedings of this symposium were published in early 1981, and may be obtained by contacting Professor Caroline Bledsoe, College of Forest Resources, University of Washington, Seattle, Washington 98195).

In the University of Washington research, two distinctly different methods of sludge application were tested. One method involved the use of dewatered sludge spread directly on sites cleared for the establishment of new tree plantations. On some sites the sludge was spread by truck and was incorporated into the soil layer using a construction disk. On other sites, the sludge was left on the surface and sowed with a grain crop. In either case, it proved necessary to age the applied sludge for a period of about 1 year before tree seedlings could be successfully established.

The second system of sludge application involved the hydraulic spraying of liquid sludge containing approximately 10 percent solids. This system proved advantageous for application of sludge to existing tree stands, and for use in reaching off-road areas that could not be traversed by trucks.

The Washington research has included a number of public health studies. These included heavy metals analyses, coliform analyses, limited virus and other pathogenic organism analyses, and studies to determine the fate of nitrogen.

In general, the movement of cadmium and lead into the soil was found to be very limited. Nickel, on the other hand, was found to move more rapidly into the underlying soil, progressing about 10 centimeters in a year's time. Extensive ground water monitoring at a depth of 10 meters did not indicate any adverse change in ground water heavy metal concentrations, even at the relatively high sludge dosages (200 dry tonnes per hectare) tested.

Although heavy metals remained relatively immobile in the soil, research has indicated selective uptake, particularly by the understory species prevalent in mature forests. For example, thistle occurring in sludge-amended soils accumulated 15 times as much cadmium as it did on control plots, while blackberry and salal (Gaultheria shallon) accumulated only 5 to 6 times as much. In no event, however, did heavy metal uptakes approach phytotoxic levels. The studies indicated that less than 1/10 of 1 percent of the heavy metal content of sludge will be assimilated by plant cover during the first year following application.

As is the case with other research, little evidence was found of downward migration of coliform into the soil, and no evidence was found of fecal coliform contamination in the ground water table directly beneath sludge-treated areas. Coliform residence time in the sludge itself was found to be less than 2 years after application.

The fate of nitrogen in sludge-treated forest sites is not yet fully clear. The Washington research has indicated that within 2 months after application up to 40 percent of the nitrogen content of the sludge had disappeared. The loss was determined to be principally in the form of gaseous ammonia losses; however, on cleared sites where sludge was mixed with soil, as much as 9.1 percent of the applied nitrogen was lost as leachable nitrates. In general, however, leachable nitrate losses were more commonly in the range of 1 to 2 percent of total applied nitrogen.

Nitrogen in sludge may be biologically converted to either the ammonia or nitrate forms. That these are the two forms in which nitrogen may most easily be lost from the soil is supported by numerous researchers. Since the conversion of nitrogen to the leachable nitrate form can create potential water pollution problems, ways to minimize microbial activity should be helpful in preventing nitrate problems. Vogt (34) and her co-workers have postulated that high carbon content admixtures, when blended with sludge, could accomplish this. Their research indicates that admixtures that produce higher carbon-to-nitrogen ratios (sawdust for example) are helpful in reducing the amount of nitrogen microbiologically converted to leachable nitrates.

The use of sludge in the forest ecosystem promotes the growth of an extensive weed cover, which will compete directly with trees for both space

and moisture. This weed cover can be particularly troublesome in cases where new plantations are being established. In addition to competing for space, moisture, and nutrients, weed cover provides an excellent habitat for rodents. In turn, the increased rodent population is quite harmful to the tree seedlings, since the gnawing activities of the rodents results in tree girdling and subsequent mortality. Washington research indicates that the weed problem may be expensive (perhaps $200 per hectare) to control, and that cultivation is a superior control method over the use of herbicides.

All of the small trees established in sludge-amended plantations exhibit more luxurious growth with higher protein content than do seedlings grown in control plots. The Washington research has indicated that browsing animals such as deer will preferentially seek such seedlings for browsing. The extensive browsing is injurious to the trees, and appears to be difficult to control by means other than fencing. In addition to the potential damage to plantations caused by rodents and browsing animals, the question remains as to the possible impact of toxic substances in the sludge on wildlife. Research has indicated that foliar heavy metal uptake does occur, but the impact on mammals is not known. This is the subject of ongoing research being undertaken by Professors West and Taber at the University of Washington. Studies underway include patterns of habitat use by blacktail deer, analysis of deer foraging patterns, determination of heavy metal concentrations in deer and small animals, changes in small mammals species composition on sludge deposition sites, and documentation of heavy metal uptake rates in the small mammals.

Applying sludge directly to existing timber stands can avoid many of the difficulties associated with weed and animal control on younger stands. Professor Cole (13) at the University of Washington believes that typical Northwest forest stands up to 50 years in age can benefit significantly from the application of liquid sludge applied by spraying from a tanker. Application on the older stands can be done at any time; however, spraying of the younger stands of timber would necessitate washing the sludge off the foilage in order to prevent interference with photosynthesis, unless the spraying were done during the rainy season. The growth response of timber is, not surprisingly, much greater for sites established in low productivity soils. Tillman and Schreuder (30) have investigated the economics of sludge utilization as a forest soils amendment. Their work has resulted in the establishment of methods for projecting the potential economic return, which may be achieved through the use of cost/benefit projections.

In summary, sludge loadings ranging from 10 to 900 tonnes per hectare have been studied in conjunction with revegetation of disturbed lands. The higher loadings tended to produce poor vegetative response and promoted undesirable concentrations of contaminants in the leachate and foilage. Application rates in the range of 100 to 200 tonnes per hectare showed excellent vegetative response and little or no tendency to cause significant contamination of ground water or foilage.

Large-Scale Reclamation Projects

The most recent large-scale reclamation projects are located in western Pennsylvania and have been extremely well monitored. In these projects (36) a mixture of about one-half dewatered, digested sludge from Philadelphia and one-half composted dewatered, digested sludge (with wood chips added in the ratio of 2 to 1) has been used. Loading rates of 132 tonnes per hectare were applied, resulting in additions of 1.05, 1.11, and 0.17 tonnes per hectare of N, P, and K respectively. Table 32-2 shows concentrations of constituents in the sludge mixture applied and compares the loadings applied according to Pennsylvania Department of Environmental Resources (PDER) and EPA recommendations. These projects have shown no evidence of ground water contamination, plant toxicity, or other undesirable side effects, while still providing excellent revegetation response.

Other Pennsylvania reclamation projects have been carried out, using a sludge amendment composed solely of composted dewatered digested sludge (with a 2 to 1 ratio of wood chips) from Philadelphia applied at a rate of 200 tonnes per hectare. These have been equally as successful as the mixed compost/dewatered sludge; however, current PDER regulations for zinc, copper, lead, nickel, and cadmium residues would have been exceeded by this material and dosage. The added nutrient levels of N, P, and K respectively were 0.73, 0.46, and 0.18 tonnes per hectare. This illustrates one of the significant impacts of composting, i.e., loss of volatile nutrients and carbon, resulting in a concentration of fixed matter including heavy metals.

An earlier large-scale example of reclamation began in April 1974 at the AMAX, Inc. Urad Mine near Empire, Colorado. This project which used

Table 32-2. Comparison of Recent PA Experience (36) in Sludge Application in Stripmine Reclamation with PDER and EPA Regulations Concerning Trace Metals.

		MAXIMUM ALLOWED BY		
TRACE METAL	ACTUALLY APPLIED kg/Ha	EPA (AGRICULTURAL LANDS)* kg/Ha	PDER AGRICULTURAL LANDS kg/Ha	NON-AGRICULTURAL RECLAMATION kg/Ha
Zn	197	280-1200	134	224
Cu	80	140-560	67	112
Cr	53	N/A	67	112
Pb	60	560-2240	67	112
Ni	13	140-560	13	22
Cd	0 6	6-22	3	3
Hg	0 07	N/A	0 2	0 6

*Depends on Soil CEC - minimum-maximum range shown

over 3,800 dry tonnes of dewatered, digested sewage sludge (from the Metropolitan Denver Sewage Disposal District No. 1) has been very successful, and in 1981 received the National Environmental Industry Award from the President's Council on Environmental Quality (39,40).

Three major waste products were used to reclaim the tailing areas: waste rock from a nearby mine; dewatered, digested sewage sludge; and waste wood chips from a sawmill in the area. The waste rock was generated during the development of another AMAX mining operation, the nearby Henderson Mine. The source of the rock was 4,000 to 5,000 feet underground where it was being excavated as mine tunnels were being created. The granite rock was a sterile growth medium and would require the addition of organic matter.

One source of organic matter was sewage sludge obtained from the Metropolitan Denver Sewage Disposal District No. 1, located 87 miles away from the Urad tailing area. Additional organic matter was provided by waste wood chips from a sawmill pole-peeling operation in Frazer, Colorado, located 23 miles away from the reclamation project. The objective of the approach was to initiate a rapid development of a mature soil under highly adverse conditions. The tailing areas then were seeded with a carefully researched mixture of grasses and herbs. Trees and shrubs were also planted.

The tailing areas were first seeded with various grasses. The areas were irrigated only during the first growing season to ensure germination and establishing of growth. The mixture of grass seeds--developed from previous company-sponsored research--included smooth brome, timothy, meadow foxtail, creeping foxtail, orchard grass, red top, red fescue, hard fescue, Kentucky bluegrass, cicer milkvetch, white clover and an annual ryegrass.

A year after the initial seeding--when grass growth was high enough to protect seedlings from the sun and freezing winds--trees and shrubs were planted. To date, the company has planted a total of 39,000 tree and shrub seedlings at Urad. The trees were planted in the protection of shingle slats and consisted of evergreens, including Engelmann spruce, lodgepole pine, bristlecone pine, subalpine fir and limber pine. Other plantings included aspen, willows and other vegetation native to the area. Approximately 20 different species of shrubs have been planted. In general, vegetation has surpassed expectations for the initial 6-year growth period. Tree seedlings and shrubs are still protected from the sun and wind by shingle slats, but grass planted on tailing sites during the early stage of reclamation now stands waist-high in areas.

Tree seedlings and shrubs planted on the tailing sites have experienced a 50 to 60 percent survival rate. The rate was not expected to be higher due to the nature of the climate and excessive exposure to freezing winter winds. Reforestation in the more protected areas of the valley, such as road cuts, has shown a plus-90 percent survival.

The valley today is green and stable. A vigorous, productive and diverse

stand of vegetation now exists. The diversity is increasing yearly with the invasion of native species from the surrounding area. It is anticipated that the vegetation will be self-sustaining within 5 years, far sooner than originally anticipated.

Research Needs

The use of municipal sewage sludges as an adjunct to reclamation and revegetation of disturbed lands as well as improving biomass yields is becoming increasingly well documented. A need does, however, exist for additional information. Specifically recommended additional research is needed in the following areas:

1. Effects of sludge-amended vegetation on wild animals.
2. Growth response of vegetation grown in sludge-amended soils in areas of sparse precipitation.
3. Effects of uncomposted sludge on seed germination.
4. Economics of land reclamation and revegetation using sludge-amendments, with emphasis on transportation, application, and monitoring costs.

In particular, the use of sludge-amendments to soils in areas of sparse precipitation has not been as well studied as similar uses in areas of more generous precipitation. For example, all but one of the actual field research studies reported at this symposium was conducted in areas having mean annual precipitation rates in excess of 66 centimeters. Except for the Pacific Northwest west of the Cascade Mountains and the other western mountainous areas, this is a far greater annual precipitation than found in most of the western United States. The mean annual precipitation in those areas in which significant field studies have occurred is graphically shown on Figure 32-2.

Insufficient information currently exists concerning determination of the costs associated with initial surface preparation and necessary follow-up monitoring activities for land reclamation projects. Such information as is available suggests that monitoring costs may be relatively high, particularly where a relatively large number of separate small reclamation projects are involved. It is probable that a data base already exists to allow the computation of these costs; however, the current literature is notably lacking in such information.

The current literature also lacks recommendations as to what may be an appropriate amount of monitoring activity to ensure environmentally sound projects. In this respect, the state of Pennsylvania seems to lead the way with the passage on September 5, 1980 of their Act 97, which imposes guidelines for sewage sludge use for land reclamation. These guidelines are based on extensive research and include not only loading factors (both for

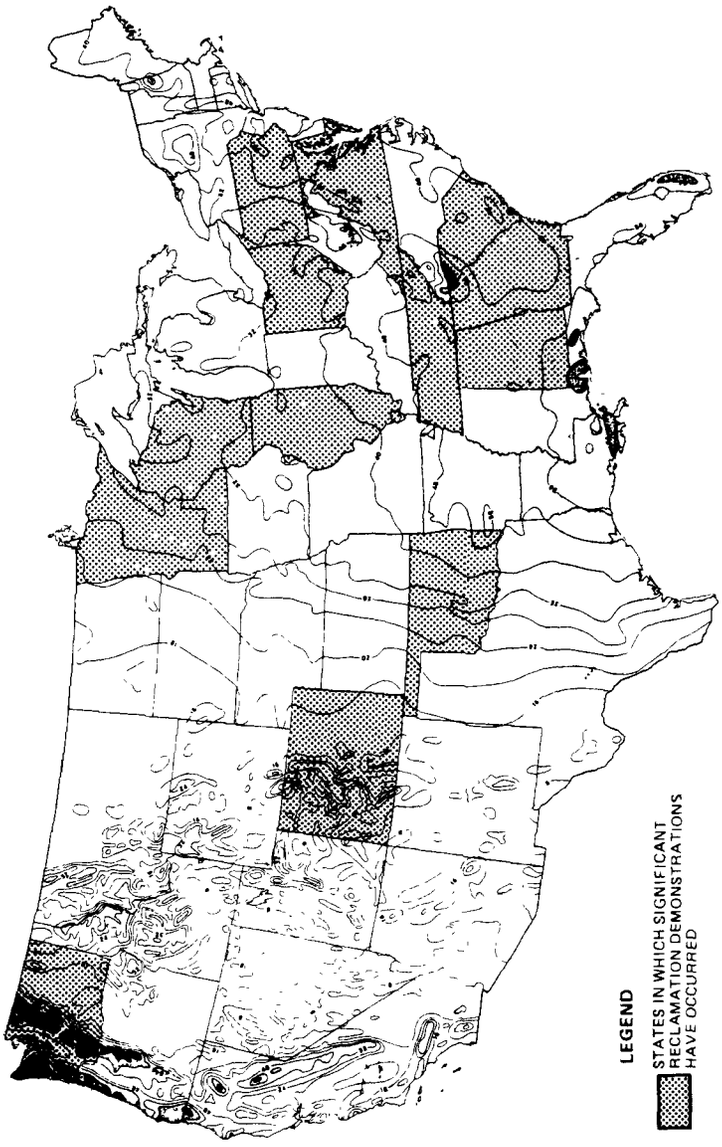

Figure 32-2. Mean Annual Precipitation in the Conterminous United States

nitrogen and trace metals) but site suitability, site preparation, and monitoring activities. Two onsite investigations of the site are required before any spreading of sludge. The initial investigation includes review by soil scientists and hydrogeologists. The second investigation is made after all proposed erosion and sedimentation control and monitoring devices are in place.

As a part of Pennsylvania's permitting process, soils are analyzed for metal content and pH and, if necessary, lime is added to adjust the pH prior to sludge application. The regulations require that the soil pH at land reclamation sites be adjusted to 6.0 or greater within the first year of initial sludge application, and to 6.5 within the second year. A further requirement is that a pH of 6.5 be maintained for 2 years after final sludge application. Chemical and bacteriological analyses are required. At least three samples must be collected from monitoring wells and lysimeters before sludge application, and the sample points are checked monthly for a period of 1 year after sludge application. Samples collected before the sludge is applied and for the first 3 months following application must be analyzed for pH, chlorides, nitrate nitrogen, ammonia nitrogen, organic nitrogen, iron, aluminum, manganese, copper, zinc, chromium, cobalt, lead, cadmium, nickel, and total and fecal coliform. Samples collected during the fourth through the eleventh months following sludge application must be analyzed for pH, ammonia nitrogen, nitrate nitrogen, zinc, copper, lead, cobalt, nickel, cadmium, chromium, and total coliform. Initial soil samples taken prior to sludge application must be analyzed for pH and cation exchange capacity. In addition, soil samples covering the entire soil profile (obtained from pits used to install the lysimeters) are to be analyzed both before sludge application and 1 year after sludge application for pH, Bray phosphorus, calcium, magnesium, potassium, sodium, iron, aluminum, manganese, copper, zinc, chromium, cobalt, lead, cadmium, nickel, and Kjeldahl nitrogen. In addition, vegetation samples taken after the first growing season are to be analyzed for nitrogen, potassium, magnesium, aluminum, copper, chromium, lead, nickel, phosphorus, calcium, iron, manganese, zinc, cobalt, and cadmium.

Conclusions

The use of municipal sewage sludge in the reclamation and revegetation of devastated lands has been quite extensively investigated. The results to date have been encouraging and environmentally beneficial, especially from test applications on lands disturbed by mining activities. Many mining activities bring to the ground surface spoils that weather to cause extremely low pH conditions but have essentially no organic content. This type of condition apparently can be ameliorated more successfully through the incorporation

of municipal sewage sludge than by conventional reclamation techniques, which essentially involve only the addition of pH control, commercial fertilizers, and mulching. The recent passage of the Surface Mining, Control, and Reclamation Act requires restoration of lands disturbed by mining activities and will undoubtedly provide considerable opportunity for utilization of sludge for this purpose. When properly carried out, restoration projects in areas of abundant rainfall have proven to be extremely satisfactory, and these projects provide a sound design basis for additional projects. However, the potential for accomplishing revegetation in the semi-arid regions of the Western states is not as well documented. A need exists to attempt demonstration projects in such areas.

The use of municipal sewage sludge to enhance forest productivity has been quite extensively studied in the Pacific Northwest and this research is continuing. Results are encouraging enough to make investigation at the facilities planning level reasonable. Additional work, particularly in the area of sludge delivery and application, is necessary to develop a more definitive overall cost estimate. Research to date in the Pacific Northwest forests seems to indicate that application of sludge to existing forest stands may be more economical and perhaps more environmentally trouble free than the use of sludge to establish new plantations. Undoubtedly, the forest ecosystem benefits from increased productivity as a result of sludge application, and initial attempts have been made to quantify this increased productivity in economic terms; however, the work to date is probably not definitive enough to form a rational basis for computing or guaranteeing an economic return on projects based on hypothetical productivity increases alone.

Design teams associated with potential reclamation/biomass projects must be cognizant of the need for a multiple discipline approach in their activities. In addition to engineers, teams must include soil scientists, hydrogeologists, agronomists, forestry specialists, chemists, biologists, and economists. Thorough investigation must be made of the amount and characteristics of the sludge to be applied, and projects must include a definitive program for monitoring, before and after application. Given appropriate attention to these types of details, it would appear that a relatively sound basis for large scale planning of sludge application/reclamation projects is possible.

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33
UTILIZATION OF MUNICIPAL WASTEWATER AND SLUDGE FOR LAND RECLAMATION AND BIOMASS PRODUCTION—AN ENGINEERING ASSESSMENT OF ITS POTENTIAL IN THE EASTERN UNITED STATES

Henry G. Schwartz, Jr., and Walter D. Lehman

Introduction

The problem of sludge disposal, exacerbated by the upgrading of existing wastewater treatment plants, the construction of new treatment plants, the phasing out of ocean dumping, and the increasing energy costs for incineration, is placing greater demands on landfilling and landspreading as ultimate disposal methods. In an effort to meet these demands, along with the added incentive provided by the Surface Mining Control and Reclamation Act, continued research is being performed on land utilization and disposal of sludge. Sludge utilization for the revegetation of non-productive land and sludge disposal on forested land to increase biomass production have received considerable attention. Incorporation of various forms of sludge into barren soils coupled with the utilization of grasses, legumes, food crops, or trees has been found to enhance revegetation efforts. Disposing of sludge on land presently sustaining plant life has greatly increased the productivity of the site. Sludge disposal on food-chain crops, however, has been the subject of much controversy. Lack of conclusive technical information on health effects and concern about aesthetic matters has affected public and regulatory agency acceptance and resulted in extensive regulation.

In a closely related area, the use of raw and treated municipal wastewaters to enhance land reclamation is being examined. The treatment and disposal of wastewater by land application is an accepted practice, but the use of similar techniques for land reclamation is limited.

The purpose of this paper is to assess the current status of municipal wastewater and sludge utilization in the reclamation of disturbed and non-vegetated land and the disposal or use of sludge on forested land in the eastern U.S., and to determine if these systems can adequately and routinely be used as sludge disposal alternatives. This assessment is based principally on papers presented at the Symposium on Utilization of Municipal Wastewater and Sludge for Land Reclamation and Biomass Production in Pittsburgh, Pennsylvania in September, 1980.

Performance of Wastewater Utilization and Disposal Systems

Land application of municipal wastewater has been practiced for many years. Design criteria and regulations are well-established. However, use of wastewater for increased biomass production or revegetation of disturbed and non-productive land has recently been given more attention.

Borovsky and Brooks (1980) examined irrigating iron-ore overburden with secondary effluent. Numerous woody species were planted, irrigated, and monitored. Application rates of 0, 5, and 10 cm/wk (0, 2, and 4 in/wk) were used for 12 weeks. Irrigation did not substantially affect plant growth in this study, but other research has shown more promise.

Cole (1980) performed studies on biomass production of woody and grass species by application of secondary wastewater. Wastewater and river water (as a control) were applied at 5 cm/wk (2 in/wk) throughout the entire year. It was found that all species exhibited significant increases in growth through irrigation with wastewater as compared to the controls. Ammonia nitrogen in the wastewater showed less leaching than nitrate nitrogen. However, those plots possessing a vegetative cover typically kept the nitrate from reaching concentrations greater than 10 mg/l at soil depths of 180 cm.

Franks, et al. (1980) examined the revegetation of soil rendered non-productive by fumes from a zinc smelter. Ten species of grass and one of legumes were studied using combinations of sludge, secondary effluent, fertilizer, urea, lime, mulch and water. Irrigation with the treated effluent was not effective for adequate revegetation, whereas the sludge additive significantly enhanced plant growth.

Sopper and Kerr (1979C) examined applying secondary effluent to various types of soils on which different species of trees existed. At loadings of 5 cm/wk (2 in/wk), some systems were adequate in protecting ground water quality. However, most of the sites examined exhibited problems in controlling ground water nitrate concentrations. One of the sites examined had all its pine trees blown down by a snow storm. The following year a herbaceous vegetative cover developed and subsequent analysis revealed that ground water nitrate concentrations could be kept below 10 mg/l.

Nutter, et al. (1979) utilized an oxidation pond effluent to spray irrigate a steep forest slope that possessed an established understory vegetation in addition to trees. A definite increase in biomass production was observed on the irrigated sites over the non-irrigated site. Maintaining acceptable ground water nitrate concentrations depended upon the loading rate and

form of nitrogen applied to the site. The total nitrogen applied to the site by the pond effluent varied from 525 kg/ha/yr when the pond was aerated to 928 kg/ha/yr when the pond was not aerated. In addition, there was a marked increase in the organic nitrogen loading for non-aerated effluents over aerated effluents. It was found that ground water nitrate concentrations could be kept below 10 mg/l by using aerated effluent, but the concentrations reached 16.8 mg/l when non-aerated effluent was used for irrigation.

Kerr and Sopper (1980) applied secondary effluent to an abandoned agricultural field on which poplars were planted. Herbaceous growth was not controlled and, therefore, became well-established throughout the poplar stand. An application rate of 5 cm/wk (2 in/wk) was used from April to October. The effluent application was effective in increasing the poplar growth without violating ground water quality standards. The average nitrate concentration at a 120 cm depth was 7.0 mg/l the first year and only 8.5 mg/l in the seventh year.

Performance of Sludge Utilization and Disposal Systems

Numerous forms of non-productive land have been studied and researched in an attempt to develop viable methods for revegetation using sludge. These studies have examined various types and application rates of soil amendments along with different species of grasses, legumes, and crops.

Hornick (1980) examined revegetation of gravel spoils with corn and beans. A control was utilized that received 179-112-112 kg/ha (160-100-100 lb/acre) N,P,K commercial fertilizer. Sewage sludge compost and feed lot manure were added at 0, 40, 80, and 160 mt/ha (0, 17, 36, and 71 tons/acre) to selected sample plots. The 40 and 80 mt/ha plots also received inorganic nitrogen fertilizer to equal the 179 kg/ha added to the control. It was found that the soil amendments reduced soil temperature and increased soil moisture, resulting in increased seed germination over the control. Results also showed an increase in biomass production for crops grown on the amended plots with no substantial differences in the heavy metal uptake occurring between the control and the amended plots. Leachate samples taken at a depth of four feet revealed rapid movement of nitrates and chlorides for the compost amended plots. The feedlot manure amended plots showed less chloride movement than the compost plots and less nitrate movement than the control plot.

Hinesly, et al. (1980) applied 0, 224, 448, and 896 mt/ha (0, 100, 200, and 400 tons/acre) (dry weight equivalent) of digested sewage sludge (55% solids) to a strip mine spoil. The sludge was applied on level-ridge terraces with manure spreaders. Disk plows were not used, however, for incorporation of the sludge into the spoil. This prevented the development

of a subsurface compaction layer. Eleven species of grasses were grown, and later strips of wheat and rye were killed with paraquat, and corn was planted in the dead residues. The best grain yields were observed at the intermediate loadings. The 896 mt/ha loading of sludge containing 4,230 mg Zn/kg, 276 mg Cd/kg, and 1,380 mg Cu/kg gave grain yields similar to those of the control. Results showed that concentrations of zinc and cadmium in the corn leaves grown on the 896 mt/ha were 297 and 15.4 mg/kg, respectively.

Sutton and Haghiri (1980) conducted studies on coal stripmine spoil using both vacuum filtered sludge from four cities and a composted sludge from a papermill. Greenhouse studies utilizing 11-716 mt/ha (5-320 tons/acre) of digested, vacuum filtered sludge incorporated into the top 15 cm of spoil (pH = 2.9) resulted in no response of fescue grown on two of the sludges which contained high concentrations of heavy metals. The plant growth response to the other sludges increased as the loading rates increased. Additional tests, conducted on the leachate, determined that nitrate leaching reached a peak during the late winter and early spring when the plants are inactive, resulting in reduced evapotranspiration and consequently increased leachate volume. Concentrations as high as 17 mg/l of nitrate (monthly average) were obtained.

Based on the greenhouse study results, Sutton applied 0, 67, 90, and 112 mt/ha (0, 30, 40, and 50 tons/acre) of dry composted papermill sludge on an acid mine spoil resulting from the stripmining of coal. From the greenhouse study, it was found that applying the city sludge at 112 and 224 mt/ha (50 and 100 tons/acre) increased the spoil pH from 2.8 to 4.5 and 5.8, respectively. Subsequent application of the papermill composted sludge at 112 mt/ha (50 tons/acre) increased the spoil pH from 2.8 to 5.8 with no further effect on spoil pH with increased application rates. The papermill sludge contained 50% cellulose fiber and 50% kaolin clay and was mixed in equal volume parts with bark. Nitrogen at 1 kg/m^3 and phosphorus at 0.3 kg/m^3 were added to the mixture, which was then composted. A rototiller was used to incorporate the compost into the top 15 cm of the spoil and 6.7, 20, and 112 kg/ha (6, 18, and 100 lb/acre) N, P, and K were also applied. The plots were seeded with grasses and legumes and then mulched with 4.5 mt/ha (2 ton/acre) of straw. An additional 34 kg/ha (30 lb/acre) N was added later. No significant differences resulted between biomass production for the different loading rates and applying 20 cm of topsoil and 18 mt/ha (8 tons/acre) lime.

Bowles and Cavey (1980) examined the revegetation of taconite tailings using fertilizer and sludge. A level site was obtained and tailings were adjusted to a depth of 30 cm. A control, three fertilizer loadings of 55-33-49.5 kg/ha N,P,K, 82.5-55-49.5 kg/ha N,P,K, and 110-77-49.5 kg/ha N,P,K, and three sludge loadings of 28.75, 57.5 and 115 mt/ha (12.8, 25.7, and 51.3 tons/acre) were used. The sludge, anaerobically digested and dried in concrete beds, contained 42% solids, and approximately 1500 ppm Cr, 500 ppm Zn, and

60 ppm Cd. The sludge was applied to the plots using a shovel and wheelbarrow and incorporated into the top 15 cm using a rototiller. Grasses dominated the sites the first year, and legumes dominated the second year. Both the fertilizer and sludge treatments produced increased vegetation growth over the control, with the sludge treatment being more effective than the fertilizer treatment. Smooth brome grass, barley, alsike clover, and alfalfa provided the best results.

In a related study by Morrison and Hardell (1980), the same site discussed above was used. The tailings consisted mainly of silica, with small amounts of hematite and magnetite. Phosphorus, as triple super phosphate, was rototilled into the tailings at 0, 28, and 112 kg/ha (0, 25, and 100 lb/acre) and was used with 0, 88, and 175 kg/ha (0, 79, and 156 lb/acre) of ammonium nitrate to produce nine amendment combinations. Sludge, containing 65% solids, and approximately 500 ppm Zn, 1,500 ppm Cr, and 60 ppm Cd, was applied at 42 and 85 mt/ha (18.7 and 37.9 tons/acre). Plant growth increased with increasing fertilizer and sludge loadings. The highest fertilizer loadings, however, produced better results than the highest sludge loadings. Foxtail, Canadian rye, and side oats grama performed well the first year with the rye diminishing the second year. Bergamot and black-eyed Susan were more apparent the second year.

Hoitink and Watson (1980) examined revegetating stripmine spoil in greenhouse and field tests. A sludge mixture of primary and secondary activated sludge was obtained from a paper plant. The sludge contained 25-35% solids which consisted of 50% kaolinite clay and 50% organic matter. Sludge incorporation rates of 0, 56, 112, 168, 224, and 336 mt/ha (0, 25, 50, 75, 100, and 150 tons/acre) were accomplished in the greenhouse study by use of a concrete mixer. Potassium and phosphorus were added at 200 and 85 kg/ha (178 and 76 lb/acre), respectively. Nitrogen, ammonium nitrate, and a slow release fertilizer were also added at various loading rates. Kentucky-31 tall fescue was sown at 55 kg/ha (49 lb/acre). It was found that yields improved with increasing sludge loading rates and also with increasing nitrogen. However, the rate of increase was greatest when nitrogen was not applied, possibly indicating that the sludge nitrogen was not as readily utilized when other forms of nitrogen were available. It was also concluded that the maximum vegetative yield was not attained. Based on the greenhouse study, 0, 168, 224, and 336 mt/ha (0, 75, 100, and 150 tons/acre) were added to a spoil containing 0.81% S and having a pH = 2.5. A mixture of grasses and red clover along with 20 kg/ha (17.9 lb/acre) of nitrogen, phosphorus, and potassium were added to the field spoil. No vegetation was established on the nontreated areas. Vegetation grown on the amended areas contained no abnormal levels of heavy metals.

Hinkle (1980) examined the revegetation of two abandoned pyrite mine sites. Anaerobically digested sludge vacuum filtered to 20% solids along with lime were added to the site. A bulldozer and disks were used for

incorporation into the top 8-16 cm. Lime additions were based on pH and lime titration analyses of various samples taken throughout the site. In many cases, this calculated rate proved to be insufficient and, along with abnormally low rainfall periods, resulted in poor vegetative responses. Kentucky-31 tall fescue, weeping love grass, and Korean lespedeza were planted. The fescue exhibited the best response, with the legumes never obtaining sufficient maturity to reseed. Wheat, rye, and oats added as nurse crops helped to establish vegetative growth. Heavy metal concentrations in the mine wastes were significantly higher than in the overlying soil. These highly toxic wastes were also present along the stream banks and other areas resulting in no vegetative growth. In areas where vegetation was established, the heavy metal concentrations in the plants were normally below accepted tolerance levels.

In earlier work performed by Sopper and Kerr (1979B, 1980A) various sludge loading rates were examined for revegetating coal stripmine spoils. At each site soil samples were taken and analyzed. Lime and sludge application rates were determined. The various sludge application rates were compared to the EPA (Table 33-1) and Pennsylvania Department of Environmental Resources (PDER) recommendations (Table 33-2). In all cases, the EPA recommendations were met for metal loadings, but the PDER recommendations were sometimes exceeded. Whenever the PDER recommendations were met, the heavy metal concentrations found in the vegetation were below recommended tolerance levels (Table 33-3). On occasion, when the PDER limits were not achieved, however, certain heavy metal tolerance levels were exceeded. In no instance did any of the vegetation exhibit the effects of toxic contamination.

In a more recent study, Sopper and Kerr (1980B) applied composted sludge to a bituminous coal stripmine spoil. The spoil exhibited a pH of 3.5-4.8 and a cation exchange capacity of 14.5-16.3. It was determined that

Table 33-1. EPA Recommended Total Trace Metal Loadings for Agricultural Land.[1]

Metal	Soil Cation Exchange Capacity (meq/100 g)		
	0-5	5-15	15
	Amount of metal (lbs/acre)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	125	250	500
Cd	5	10	20

[1] U.S. EPA (1978)

Table 33-2. PDER Recommended Maximum Trace Element Loading Rates for Land Reclamation.[1]

Metal	Maximum Loading Rate for Land Reclamation (lb/acre)	Maximum Loading Rate Land Reclamation for Farming (lb/acre)
Cd	3	3
Cu	100	60
Cr	100	60
Pb	100	60
Hg	0.5	0.2
Ni	20	12
Zn	200	120

[1] Sopper and Kerr (1979A)

Table 33-3. Suggested Tolerance Levels of Heavy Metals in Agronomic Crops.

Metal	Concentration in Vegetation (ppm)
Cu[1]	150
Zn[1]	300
Cr[1]	2
Pb[1]	10
Co[1]	5
Cd[1,2]	3
Ni[2]	50

[1] Melsted, S. W., 1973. "Soil-Plant Relationships," Recycling Municipal Sludges and Effluents on Land, National Association of State Universities and Land-Grant Colleges, Washington, D. C., pp. 121-128.

[2] Council for Agricultural Science and Technology, 1976. "Application of Sewage Sludge to Cropland: Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals," Office of Water Programs, U.S. EPA, EPA-430/9-76-013, 63 pp.

11.2 mt/ha (5 tons/acre) of lime would be required to obtain the desired pH for revegetation. One part anaerobically digested municipal sludge centrifuged to 25% solids was mixed with two parts wood chips and composted. The final amendment product containing 50% solids was obtained by mixing equal parts of the compost and the centrifuged anaerobically digested sludge (25% solids). Daily samples were taken of the

final product and calculations along with comparisons to the PDER recommended guidelines resulted in an application rate of 132 mt/ha (59 dry tons/acre). At this loading rate, the compost-cake mixture had an applied nutrient equivalent of 1,060, 925, 130 kg/ha (944, 826, 118 lb/acre) N, P, K, which is equivalent to 9,000 lb of 10-21-2 commercial fertilizer per acre. The amendment was incorporated into the top 10 cm of spoil by a chisel plow and then 67 kg/ha (60 lb/acre) of seed (1/3 Kentucky-31 tall fescue, 1/3 Pennlate orchard grass, 1/6 Iroquois alfalfa, and 1/6 birdsfoot trefoil) was applied. Analysis of metal concentrations in the vegetation one year later showed that all were well below the recommended tolerance levels. Analysis of heavy metal concentrations in the soil after one year showed all to be within the normal range for soils. Soil percolate and ground water samples showed that nitrate, copper, and zinc concentrations were consistently within the USEPA drinking water standards. On one occasion, the three-foot percolate concentration for cadmium exceeded the USEPA drinking water standards. Even though lead concentrations in the three-foot leachate and ground water samples exceeded the USEPA standards, they also exceeded the standards prior to the application of the soil amendment mixture.

In another recent study by Sopper and Kerr (1980C), a compost sludge mixture from the same source as discussed above was applied to a bituminous spoil having a pH of 4.0 to 6.7 and a cation exchange capacity of 9.5-12.3. It was again determined that 11.2 mt/ha (5 tons/acre) of lime would be required. Based on calculations and comparisons to the PDER guidelines, the same application rate and application technique as the previously mentioned study were used. Four sites were developed for study of this spoil. One was seeded at 56 kg/ha (50 lb/acre) with 40% Kentucky-31 tall fescue, 40% Pennlate orchard grass, and 20% birdsfoot trefoil. The other three sites were seeded at 91 kg/ha (81 lb/acre) with 25% Kentucky-31 tall fescue, 6% birdsfoot trefoil, and 69% winter rye. Analysis of metal concentrations in vegetation, metal concentrations in the soil, and ground water pollutant concentrations found all to be within their respective recommended limits.

In addition to applying sludge to land for revegetation, a number of related studies have been performed to examine the feasibility of utilizing sludge on forested land to increase biomass production. Studies initiated by Corey, et al. (1980) are presently examining the effects of sludge disposal on loblolly pines. The study is being conducted on a 41,000 ha (101,000 acres) pine plantation possessing a wide variety of soil types. The sludge will be applied at 275-550 kg/ha (245-490 lb/acre) on pine stands that are 0, 12, 18, and 20 years old. The sludge will be obtained from a waste treatement plant processing a waste consisting of 25% municipal and 75% industrial (primarily textile industry) waste. The sludge is aerobically digested, thermally conditioned, and dewatered. Conventional farm

equipment will be used to apply the sludge. The studies on this site will investigate the effects of soil amendments on biomass production and associated effects on soil characteristics, nutrient availability and mobility, and contamination of groundwater.

One of the studies performed by Berry (1980) consisted of evaluating the effect on biomass production in shortleaf and loblolly pines from the application of sludge. The site had its top soil eroded as a result of poor soil management. Consequently, shortleaf pines exhibited symptoms of nitrogen deficiency, and loblolly pines displayed slow growth rates. The sludge, a product of a secondary treatment plant utilizing anaerobic digestion and sand drying beds, contained approximately 2% N, 1% P, 0.5% K, 1.9 ppm Cd, and 251 ppm Zn. Sludge was applied at 0, 17, 34, and 68 mt/ha (0, 7.6, 15, and 30 tons/acre). Loblolly pines grew best at 68 mt/ha (exhibiting an 18% increase in height and a 19% increase in diameter over the control after five years of growth), and shortleaf pines grew best at 17 mt/ha (exhibiting a 33% increase in height and a 15% increase in diameter over the control after five years of growth). The survival rate decreased as the application rate increased. Competition from weed growth stimulated by the sludge application had a noticeable effect on tree growth.

Sludge obtained from a secondary wastewater treatment plant utilizing anaerobic digestion and sand bed drying was used by Berry (1980) in a study to revegetate a kaolin clay strip mine spoil with loblolly pines. Application rates of 0, 34, 69, 148, and 275 mt/ha (0, 15, 31, 62, and 123 tons/acre) were used, and the sludge was incorporated into the top 15 cm of the site by disking. The plots were also subsoiled to a depth of 60 to 90 cm. The sludge contained approximately 2% N, 1% P, 0.5% K, 1.9 ppm Cd, and 251 ppm Zn. The first six months' survival rates for the pines were lowest on the 138 and 275 mt/ha plots, and the first year biomass productions on the 34, 69, and 138 mt/ha plots were double that of the control, while the 275 mt/ha plot biomass production was comparable to the control.

Other studies performed by Berry (1980), using the same sludge on various types of spoils, utilized loblolly, shortleaf, and Virginia pines along with sweetgum for revegetation. The maximum loading rate used in these studies was 68 mt/ha. The largest biomass productions were usually obtained at the 17 and 34 mt/ha sludge loadings and were significantly greater than the productions on the control plots. The sludge amendments also produced significant weed growth, which led to competition with the pines. The 34 mt/ha was determined to be an adequate loading rate for any site.

Kerr and Sopper (1980) examined reforestation of a burned anthracite coal refuse bank. Dewatered and heat dried sludge was applied at 0, 40, 75, and 150 mt/ha (0, 18, 33, and 67 tons/acre). Ten species of seedlings were planted. The hardwoods exhibited better survival and growth than the conifers, due mainly to competition between the stimulated herbaceous

vegetation and the slower growing conifers. Hybrid poplar, black locust, and European alder possessed the best survival and growth. The poplars grown on the 150 mt/ha were found to have a biomass of over ten times more than the control after five years of growth.

Extensive work has been performed by Cole (1980), some of which includes applying dewatered sludge (approximately 18% solids, 1,170 ppm Cu, and 62 ppm Cd) to a clear cut site for use in establishing new tree growth. Due to the high moisture content of the sludge, it was usually left to dry for a year before seedlings were planted. Application rates of 45 to 450 mt/ha (20 to 200 dry tons/acre) were used. The sludge was dumped from trucks and either left on the surface and sowed with oats or rye, or incorporated into the soil using an 80 cm (32 inch) construction disk. There were no toxic effects by heavy metals on the vegetation, but substantial nitrate leaching did occur beneath the plot incorporated with 450 mt/ha. The various species of trees responded differently to the applied sludge. Weeds responded extremely well, and their competition with the trees along with the subsequent arrival of voles created a problem for establishing tree growth. An additional problem that developed after establishing tree growth was that deer were selectively grazing on the trees grown on the sludge, again hindering their growth.

Other work performed by Cole (1980), consisted of applying sludge to established forest sites. A dewatered sludge, containing approximately 18% solids, 1,170 ppm Cu, and 62 ppm Cd, was sprayed on the land by means of a pressurizing pump and directional nozzle system, after transfer from transport trucks to a forest application vehicle. An application range of 40 meters was achieved using this system. The sludge was applied at 45 to 450 mt/ha (20 to 200 dry tons/acre) on stands ranging from 5 to 50 years of age. In order to prevent a reduction in photosynthesis, the younger trees had to be washed to remove sewage from the foliage. The larger, established trees did not need to be washed. A significant increase in the basal area of Douglas Fir existed on all sludge-amended stands over the controls. It was also found that 1-2% of the applied nitrogen in the sludge was being leached past the root zone.

Related work performed by Riekerk and Zasoski (1979) examined the effects of sludge application to forest soils on leachate and ground water. Suction lysimeters were installed at the lower boundary of the A, B, and C horizons. The dewatered sludge was applied in 10 and 25 cm depths on forested sites. Results showed that there was very little leaching of phosphorus and heavy metals below the surface soil. Nitrates, however, reached concentrations as high as 20 ppm in the ground water, and almost 30 ppm in the spring receiving some of its source water from percolate through the sludge applied site.

Hornbeck, et al. (1979) applied a municipal dewatered sludge (20% solids) to a 60-year-old plot of hardwoods at 25 and 125 wet tons/ha (11

and 56 wet tons/acre, or 2 and 11 dry tons/acre). The predominant tree species are beech, sugar maple, yellow birch, and white ash. Hand tools were used to apply the sludge. Analysis of soil water collected by lysimeter at 20 and 45 cm showed minor changes in water chemistry for the 25 t/ha application. Chloride concentrations were found to reach 11.3 mg/l at the 45 cm depth beneath the 125 t/ha sludge application. Nitrates, however, reach only 3 mg/l at the same sample point. There was no significant difference in tree growth between the two sludge plots and the control. At these loading rates, which are substantially lower than the previous mentioned loadings, the total basal area increases for two years were 0.9 m^2/ha, 1.3 m^2/ha, and 0.8 m^2/ha for the control, 25 ton/ha, and 125 ton/ha sites, respectively.

Lambert and Weidensaul (1980) examined biomass production by utilizing sludge at a nursery and two Christmas tree plantations. A digested dewatered sludge and an anaerobically digested liquid sludge (10% solids) mixture were applied by a manure spreader at 0, 35, 80, and 120 mt/ha (0, 16, 36, and 56 tons/acre). One plot was amended with 120 kg/ha ammonium nitrate-N. It was found that the poplars and black locust responded well to the sludge amendments with increased growth occurring with increased sludge loadings. The hardwoods (red oak) were not affected by the sludge, and the growth of the conifers was adversely affected at the 80 mt/ha loadings.

The Christmas tree plantations, one a fertile, well drained silt loam and the other an infertile, poorly drained silty clay, were amended with a lime stabilized dewatered sludge at 0, 11, 22, 45, 90, and 180 mt/ha (0, 5, 10, 20, 40, and 80 tons/acre). The plots were rototilled, and two-year old pine seedlings were planted. The survival rate was similar at all loadings except the 180 mt/ha at which the survival rate dropped substantially for a great majority of the species planted. Growth rates decreased at loading rates above 22 mt/ha with the greatest decreases occurring in the poorer soil. Again, weed growth became a problem especially at the higher loading rates.

Engineering Assessment

Wastewater Utilization

In the previously examined performance of wastewater utilization, it was observed that an increase in biomass production usually could be achieved by irrigating with wastewater. While woody species exhibited increased growth when irrigated with wastewater, they did not effectively prevent nitrates from contaminating ground water. Those studies utilizing herbaceous growth as well as trees were much more effective in accomplishing plant uptake of nitrates and, therefore, maintaining acceptable ground water nitrate

concentrations. Revegetation of disturbed and non-productive land through the use of wastewater was not found to be as effective as other methods of revegetation. As discussed in the following section, application of sludge to disturbed and non-productive land provides a superior method for establishing the basis of topsoil formation which is essential if permanent revegetation is to occur.

Sludge Utilization

Previously, the performance of methods used to apply sludge to revegetate disturbed and non-productive or forested land was reviewed. Initial studies examined the effects of several types and application rates of sludge to various forms of disturbed and non-productive land (Table 33-4). Generally, the highest loadings of sludge, especially those containing high levels of heavy metals, resulted in poor vegetative responses. In addition, contaminant levels in the soil leachate (principally nitrates) and in the vegetation (metals) reached undesirably high levels. Application rates of 80 to 202 dry mt/ha were found to provide good vegetative response without contaminating the ground water or the vegetation. The application rates were found to depend on the makeup of the sludge used as a soil amendment, the condition of the non-productive land, and the type of vegetation to be grown. Application rates for optimum revegetation have been found in some studies to exceed 200 dry mt/ha. However, in the most recent studies by Sopper and Kerr (1980B, 1980C), it was shown that if the EPA and PDER guidelines were followed, successful revegetation can be accomplished without contaminating the ground water, exceeding the tolerance limits of plants for toxic elements, and altering the soil composition to where it no longer represents a typical soil. The procedure developed and utilized by Sopper and Kerr (1980B, 1980C, 1980) for revegetating bituminous coal mine spoil along with the appropriate guidelines, appears to provide a feasible means of effectively utilizing sludge for revegetation.

Conventional land reclamation practice consists of recontouring the land, liming, fertilizing, and seeding. In many cases, years will pass, frequently involving annual fertilizer applications, before any sufficient positive response is achieved. The advantages of revegetating with a sludge amendment as opposed to a conventional soil amendment (lime and fertilizer application), and the reasons that vegetation responds more readily, are twofold. First, the use of stabilized sludge provides the nutrients required by vegetation in a form in which they are released gradually for plant uptake. This avoids excessive leaching of nutrients that are not used, and eliminates the necessity of adding a new supply of nutrients every year. Moreover, as found by the numerous studies using sludge, it is much more desirable from an odor standpoint to use a stabilized sludge, especially a digested one than an unstabilized one. Secondly, the sludge contains high amounts of organic matter, whereas commercial fertilizer does not. The presence of the organic

Table 33-4. Sludge Application for Land Reclamation Summary of Selected Field Studies.

Sludge Type	% Solids	Loading Rates* (mt/ha)	Optimum Loading (Mt/ha)	Application	Vegetation	Site	Reference
Composted		40-160			Corn Beans	Gravel Spoils	12
Digested	55	224-896	448	Manure Spreaders	Grasses Corn	Stripmine Spoil	8
Vacuum Filtered		11-716	112-224		Fescue	Coal Stripmine Spoil	25
Composted Papermill		67-112	112	Rototiller	Grasses Legumes	Coal Stripmine Spoil	25
Digested & Bed Dried	42	28-115		Shovel Wheelbarrow Rototiller	Grasses Legumes	Taconite Tailings	3
Sewage Sludge	65	42-85		Rototiller	Grasses	Taconite Tailings	16
Primary & Secondary Papermill	25-35	56-336			Fescue	Stripmine Spoil	10
Digested & Vacuum Filtered	20	82-260		Bulldozer Disks	Grasses Legumes	Pyrite Mine	9
Composted	74	202			Grasses Legumes	Coal Stripmine Spoil	22

Table 33-4. (Continued)

Sludge Type	% Solids	Loading Rates* (mt/ha)	Optimum Loading (mt/ha)	Application	Vegetation	Site	Reference
Liquid, Dewatered		90-184			Grasses Legumes	Coal Stripmine Spoil	20
Dewatered	29	80-108			Grasses Legumes	Coal Stripmine Spoil	20
Composted	50	134			Grasses	Coal Stripmine Spoil	20
Composted	50	132		Chisel Plow	Grasses Legumes	Coal Stripmine Spoil	23
Composted	50	132		Chisel Plow	Grasses Legumes	Coal Stripmine Spoil	24

* Actual sludge content and loading will vary according to the specific sludge conditioning process used (e.g., Bark addition in composting process to achieve 50% moisture content).

matter accelerates the formation of a top soil which can be instrumental in retaining moisture and affecting the temperature of the soil, both of which benefit revegetation.

Disadvantages to revegetating a particular site depend upon the sludge characteristics and the site conditions. Some sludges contain relatively high levels of heavy metals and, if applied to the land in sufficient quantities, can hinder plant growth or enter the food chain through plant uptake. In addition to obtaining a sludge that has contaminant levels low enough so as not to present a public health concern, the sludge source needs to be within a reasonable haul distance of the application site in order to be economically attractive for use in revegetation efforts.

Conventional sludge management practices include ocean dumping, incineration, landfilling, and landspreading. Ocean dumping of sludge is a subject of continuing regulatory debate and, in any event, is restricted to coastal communities. Landfilling and incineration are the most prevalent sludge disposal practices in this country. But landspreading on disturbed or non-productive land with the intent to revegetate it or applied to cropland, is unique in that the sludge is serving a useful function. In spite of this inherent attractiveness, however, one must assess many factors when considering a landspreading approach to sludge disposal.

Relatively rigorous or standard design practices have been developed for incinerators and landfills. In contrast, landspreading with the intent to revegetate is a more recently accepted form of sludge disposal and reuse and, therefore, the least developed from an engineering point of view. Furthermore, designing an adequate and viable sludge revegetation system requires more than standard engineering practices. Soil scientists, hydrologists, and agronomists or foresters along with the engineers are needed to produce sound designs. Current guidelines, knowledge obtained through recent studies and demonstration projects, soil characteristics (e.g., pH, texture, gradation, CEC, extractable nutrients, organic content, etc.) and the type of vegetation and its characteristics (e.g., moisture requirements, toxic metal tolerance levels, nutrient uptake, etc.) are all required for a sludge utilization for revegetation project design.

In any sludge management system, pollutant mobility is a concern. Incineration of sludge results in pollutants entering the air and the ash produced by incineration contains pollutants that may leach out in landfills. Landfilling without incineration still presents the problem of leaching and contaminating ground water. Landspreading of sludge also must deal with this problem. The EPA and state guidelines for applying sludge to land have addressed this problem. Many studies have demonstrated that if the sludge is applied correctly, contaminants will be fixed in the soil and/or taken up by vegetation resulting in acceptable and or allowable levels of pollutants in ground water. In addition, these guidelines and studies have provided for limiting the amount of toxics taken up by plants, thereby preventing or

adequately controlling toxic effects to plants or their consumers within currently applicable standards.

Economic constraints play a dominant role in sludge management systems. Incineration systems require a large capital investment for dewatering equipment, the incinerator, and air pollution control devices. Operating and maintenance costs are also high due to the energy requirements of the incinerator. Landfilling non-incinerated sludge requires a substantial investment for land, involves higher transportation costs than incineration for increased volumes, but requires considerably less energy costs. Investments for landspreading may or may not include the cost of land since the land is often owned by some individual desiring to utilize the sludge as a soil amendment or fertilizer for revegetation or crop production. Transportation cost will vary greatly depending on the proximity of the application site to the sludge source. Each sludge management system will need to be carefully analyzed to determine which sludge management method is most cost effective and environmentally acceptable.

A final constraint for consideration in a sludge management system is public acceptance. Landfill sites are subject to public scrutiny primarily for aesthetic reasons, but also for public health considerations. A sludge utilization system for agricultural crop production or revegetation purposes may also be subject to public concern based on aesthetic reasons. However, the initial opposition to landspreading of sludge for revegetation or reclamation purposes often can be overcome by the obvious advantages of revegetating non-productive or disturbed land. Of greater concern is the public health aspect of potentially introducing toxics into the food chain. EPA and state guidelines set limits restricting the amounts of toxic contaminants from sludge that can be applied to the land in order to adequately protect water, soil, and vegetative quality. It is imperative that these guidelines be adhered to in the design of landspreading systems and that monitoring programs be established to insure compliance during actual project operation.

In addition to existing guidelines, criteria have since been issued by the U.S. EPA that encompass landspreading as well as landfilling of municipal wastewater sludges and other types of non-hazardous solid wastes under the joint authority of the Resource Conservation and Recovery Act and the Clean Water Act. Interim criteria were included for cadmium and PCB loadings from such wastes applied to land used for the production of food-chain crops as defined in 40 CFR Part 257.

The performance of applying sludge to forested land for disposal and to increase biomass production was also previously reviewed. The effects of various loadings of sludge (Table 33-5) on numerous species of trees, on the soil, and on the ground water were examined. Extensive research has been carried out on sludge application to increase biomass production in the state of Washington, but relatively little work has been done elsewhere.

Table 33-5. Summary of Sludge Application Rates on Forested Land for Disposal and Increased Biomass Production.

Sludge Type	% Solids	Applied Loading Rates (mt/ha)	Age of Stand (Yrs.)	Pollutant Leaching	Reference
Digested, Thermal Conditioned and Dewatered	--	275-550	0-20	*	4
Digested & Bed Dried	--	0-68	NEW	+	1
Digested & Bed Dried	--	0-275	NEW	+	1
Digested & Bed Dried	--	0-68	NEW	+	1
Digested & Heat Dried	--	0-150	NEW	+	11
Dewatered	18	45-450	NEW	NO_3	3
Dewatered	18	45-450	5-50	NO_3	3
Dewatered	--	--	0	NO_3	15
Dewatered	20	5-25	60	Cl_2	9
Lime Stabilized & Dewatered	--	0-180	2	+	12

* - New project, results not yet available.

+ - Leachate not sampled.

Much of the work that has been done outside Washington has not addressed pollutant leaching or runoff from areas receiving sludge. From the material reviewed, there appears to be a broad range of application rates, but these are apparently not based on the constraints for groundwater quality, soil characteristics, or plant uptake.

The physical size of such land application sites for sludge to increase biomass production will be similar to that for revegetation with sludge. Compared to the conventional sludge management practices of incineration and landfilling, the land application of sludge to forest sites will require larger areas of land. In order to determine the actual land requirements, however, more detailed studies with increased focus on design factors will be necessary. To develop a design procedure for sludge application to forest sites to increase biomass production, a number of parameters must be considered. Regulations limiting the amount of nitrates and heavy metals that are applied to the soil are one constraint that may be required. Pollutant mobility, as discussed with sludge utilization for revegetation, is a primary concern for any land application sludge management program.

Research by Cole (1980), and Riekerk and Zasoski (1979) found that the amount of pollutants leached to ground water is reduced if the sludge is spread on the land and not incorporated into the soil. More work is presently being performed to examine methods of reducing the pollutant concentrations in the leachate. Heavy metals, even though applied to the acid soils used in these two studies, exhibited relatively little leaching. These studies indicated that metal immobility can be expected for the specific soil used, but the amount of metal uptake by vegetation still remains a question, along with mobility of heavy metals in other types of soils. Unlike the development of research on uses of sludge for revegetation, work on application of sludge in forests to increase biomass production is still being performed to obtain optimum application rates and techniques to minimize the potential detrimental effects on ground water.

The nutrient requirements, most importantly nitrogen, for various species of trees will have an effect on the sludge application rate and, therefore, the amount of the nutrient leached past the root zone. The toxic effects of heavy metals on trees may also be a constraint on the amount of sludge applied. Differences in tolerance levels for various species of trees as well as the age of trees on an application site must be considered. The initial indication from the research performed to date is that hardwoods are more tolerant of heavy metals than pines and that older mature trees are more tolerant than seedlings. These early findings indicate that older stands may be able to receive larger application rates than younger stands and hardwoods more than pines, but no conclusive results have been presented as yet. Engineering design procedures depend on and are related to groundwater quality constraints and plant tolerance level, as well as the sludge and soil characteristics.

Economic constraints for land application of sludge are similar to any other sludge management system already discussed. Land requirements and transportation costs will most likely be the controlling factors, and a cost effective analysis will be needed to adequately assess all the alternatives available to any program. Public acceptance of a sludge application to forest land system to increase biomass production may be greater than for a sludge utilization system for revegetation. Sludge application to forests usually would not be considered to directly involve the human food chain. In some studies, however, it was found that deer preferred to feed on trees grown on sludge amended soils over trees grown on unamended soils. This does not seem to present a significant potential contamination risk compared with applying the same sludge to crop land.

Conclusions and Recommendations

Wastewater Utilization

Irrigating with wastewater has been shown through numerous studies to be an effective means of increasing biomass production. Contamination of ground water supplies, primarily through nitrate leaching, appears to be a problem associated with this type of wastewater treatment or disposal system. It has been shown, however, that herbaceous growth is more effective in nitrogen uptake than is woody growth. A major deficiency in utilizing wastewater for revegetation of disturbed and non-productive land is its inability to provide a sufficient source of material needed for topsoil formation.

Procedures or methodologies have not been adequately developed for applying wastewater for biomass production. Determination of optimum loading rates that result in an adequate increase in biomass growth while still protecting soil, water, and public health quality is needed. Research examining the relationships between woody and herbaceous growth is needed so that optimum biomass production can occur along with acceptable renovation of applied wastewater.

Land application of wastewater for treatment and disposal purposes is well established. However, land application of wastewater to revegetate non-productive land appears to be of limited value, while land application of wastewater to increase biomass production has not been adequately researched to be utilized as an engineering practice.

Sludge Utilization

The utilization of sludge to revegetate non-productive or disturbed land has been extensively examined in numerous studies, some of which are cited herein. Revegetation of coal stripmine spoils, gravel spoils, clay stripmine spoils, iron-ore tailings, abandoned pyrite mine sites, and sites devastated by toxic fumes has been demonstrated in studies with various sludges and

soil amendments. These research studies clearly demonstrate the technical feasibility of reclaiming or revegetating non-productive or disturbed land with municipal wastewater sludge. The most recent work of Sopper and Kerr provides a consistent methodology for examining the sludge and soil to determine preliminary site conditioning requirements. Federal and state guidelines for sludge application to land are substantiated by many studies, and result in application rates that successfully assist in the revegetation of sites while producing currently acceptable conditions in ground water, soil, and vegetation.

Even though the application rates and type of vegetation used are highly site specific, enough research has been performed and sufficient guidelines exist to develop a sound design for revegetation by sludge utilization. Continuing research on the toxic effects of heavy metals and other pollutants is needed to ensure the present guidelines are adequate or, if not, to provide information for their needed refinement.

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