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Preliminary Investigation Of Sewage Sludge Utilization In Roadside Development

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16. Abstract

Problems with existing sludge disposal practices, combined with new information about its nutritive and soil-conditioning qualities, have led to accepted practices of land applicaction of sludge. Both the Department of Transportation, as an agency with large land holdings and landscaping needs, and municipalities in Washington state may benefit from land application of sludge on roadsides.

The use of sewage sludge on roadsides can potentially improve the growth of erosion control grasses, shrubs and trees while minimizing the costs for subsequent reseeding, replanting, or refertilization. Proper site selection and management techniques can potentially minimize public health and environmental impacts from heavy metals, nitrates, pathogens and organic toxicants. Steep roadside slopes, where erosion control is most needed, present a challenge to existing sludge application techniques, but one that is not insurmountable.

A review of current national and local research, and a cost comparison analysis, have shown that roadside utilization of sludge may be a feasible practice without infringing on the health, safety and welfare of the public. Tasks are outlined for a demonstration study to investigate application techniques, vegetation types, public health and environmental impacts, and public acceptance and education.

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PRELIMINARY INVESTIGATION OF SEWAGE SLUDGE UTILIZATION IN ROADSIDE DEVELOPMENT

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DRAFT REPORT

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EXECUTIVE SUMMARY

Roadside Sludge Utilization

The concept of municipal "sludge disposal" has begun to evolve into "sludge utilization" in recent years. Problems with existing disposal practices combined with new information about the nutritive and soil conditioning qualities of sludge have led to accepted practices of land application. Both the Department of Transportation, as an agency with large land holdings and landscaping needs, and municipalities in Washington may benefit from land application of sludge on roadsides. This study looks at the obstacles and potentials for the incorporation of sludge land application into Department of Transportation landscaping practices.

Opportunities

The most dramatic characteristic of vegetation grown in sludge is the immediate and lush growth that occurs after planting, a characteristic necessary for good erosion control.

Continuation of grass growth, in preference to other plants, is beneficial to long-range erosion control and has been shown to be an advantage of sludge application. Heavy plant growth may also improve the visual impact of roadsides, often a major criterion in roadside landscaping. In addition, the opportunity exists for wildlife enhancement, often a desired goal of roadside plantings, due to increased food and cover. Increased removal of pollutants from roadside runoff may also be a benefit of heavy vegetation growth.

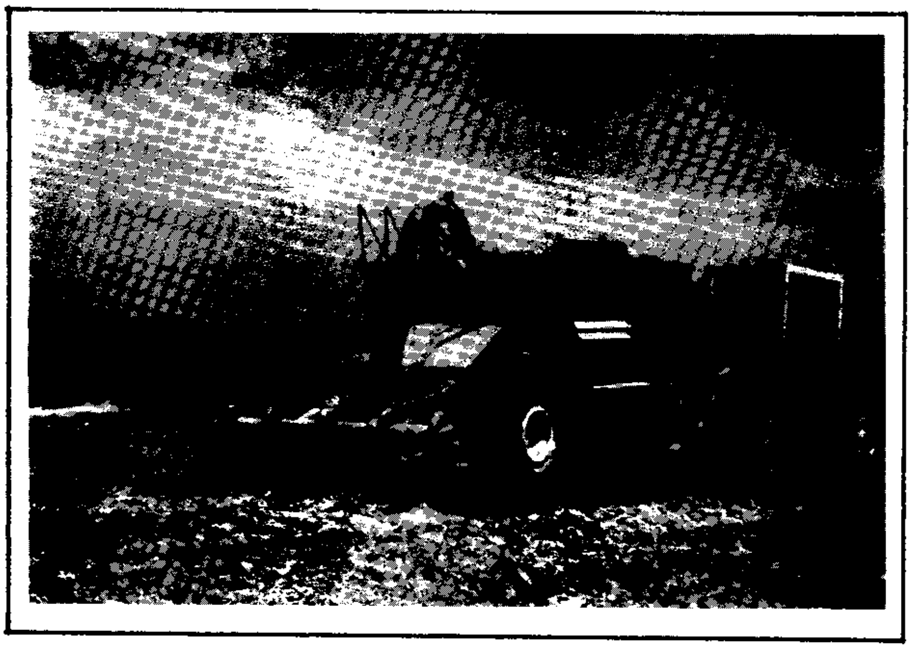
A cost comparison between existing erosion control technologies and possible sludge utilization practices shows a potential reduction in long-term maintenance and erosion control costs with the use of sludge as a mulch/fertilizer/soil amendment. In some cases, capital costs may be cut as well.

Constraints

Research on land application of sludge in agriculture, forestry, and reclamation projects has brought potential health and environmental impacts to the foreground. Proper management and site selection can mitigate many of the problems that have arisen; other questions are as yet unanswered. Since roadsides do

This cross section of a Douglas-fir bole shows the increase in ring width due to effects of sludge application three years prior to harvest. This growth response represents a dramatic increase over untreated trees. The stand was thirty-one years old when sludge was applied in 1977 at a rate of 80 tons/ha (5 cm depth).

College of Forest Resources, University of Washington



not grow food or food chain crops, several potential health impacts are eliminated.

Public exposure to pathogens that remain in sludge after treatment can be minimized by restriction of public access, application away from groundwater recharge areas and in soils of restricted permeability, and by choice of application method. Mobility of excess nitrates and heavy metals that can contaminate surface water and groundwater can be controlled by calculation of proper loading rates, application away from recharge areas and in soils of restricted permeability, choice of application methodology, and controlled drainage from the site. Questions about heavy metals are complicated by the fact that roadsides "trap" heavy metal emissions from cars. Exposure to PCB's, the only organic toxicant detected above trace levels in Seattle and Olympia sludge, is minimized by the fact that only landscaping plants and no food crops will be grown. Preventing contamination of ground and surface water systems will further minimize PCB exposure.

Agency willingness to respond to public concerns and questions, and an understanding of the potential problems and benefits, is essential to cultivating public acceptance of a land application project. Choice of application methods can serve to minimize public nuisances such as odor and visual impact.

An additional constraint is the frequent steepness of roadside cut slopes. Existing application technologies may be useful, or new technologies may need to be developed.

Demonstration Study

A demonstration study is an important next step for determining the extent of benefits involved, the actual costs, and the health and environmental impacts that may occur. Results from a demonstration study should:

- show which application technologies are feasible and appropriate,
- indicate appropriate grass and plant species,
- reveal impacts to surface water and groundwater and whether changes are necessary in drainage system design, including vegetating drainage ditches,[1]
- provide better criteria for site selection, and
- provide an educational tool for both the public and Department of Transportation personnel.

Conclusion

From this study it has been determined that utilization of sludge in roadside development can be a feasible, cost-effective and even desirable practice.

INTRODUCTION

Roadway construction techniques often result in a roadside devoid of topsoil, nutrients, and healthy vegetation. A variety of erosion control and planting techniques have been used in an attempt to mitigate this problem, but they are not always successful. Opportunistic plants such as Scotch broom are able to take over large sections of roadsides, outcompeting struggling grasses and shrubs. The need to herbicide, reseed and fertilize in many of these areas raises the cost of roadside landscaping.

Addition of sewage sludge, which can contain up to 50% organic matter, has been shown to improve soil texture and increase fertility, both of which can produce short term as well as lasting effects on plant growth and soil stability (Zazoski, 1981; Municipality of Metropolitan Seattle, 1981; U.S. Environmental Protection Agency, 1978). Reclamation of landfills and strip mines, as well as growth of agricultural and forestry products, has been greatly enhanced by the addition of sludge (Jewell, 1982; Hornick, 1982; Phillips, 1978). Sludge as a soil amendment can improve the structure of heavy soils, minimize leaching of commercial fertilizers and water loss in infertile sandy or gravelly soils, and provide a wider variety of nutrients and trace minerals than commercial N-P-K fertilizers (Municipality of Metropolitan Seattle, 1981; Zazoski, 1981).

PURPOSE

The variety of conditions that occur on roadside right-of-ways offer several opportunities for sludge utilization in planting enhancement. Many municipalities would welcome the opportunity for utilization disposal of sludge, as well as improved visual aesthetics, along the highway. Many of these roadside conditions, however, may not be compatible with current methods of sludge application. Furthermore, the potential exists for negative public health and environmental side effects to accompany roadside sludge application. The purpose of this report is to explore current practices in roadside revegetation and in sludge application, and to assess the overall feasibility of sludge utilization in highway right-of-ways. Though wastewater irrigation and use of composted sludge are also potentially feasible alternatives, the scope of this study will only include digested municipal sludge.

BENEFITS

The potential benefits of sludge utilization on highway right-of-ways determined through this investigation include:

1. Reduction in maintenance costs: With a well established vegetation cover, invasion of unwanted plants can be minimized, thereby eliminating costs for herbicides and mechanical removal. The long-term

effectiveness of sludge can eliminate costs for repeat fertilization. If sludge application could be incorporated into final grading, costs for fertilization could be cut down considerably.

2. Reduction in erosion control costs: Immediate establishment of a grass cover for erosion control can minimize excess runoff and siltation in drainage ditches, reducing costs for cleaning and/or replacement of ditches, culverts, catch basins, etc. Costs for reseeding and repeat fertilization can be minimized by the establishment of a stable, self-sustaining grass cover. Other costs and problems related to erosion, such as roadway obstruction, reconstruction of banks, public nuisances, etc., can be reduced.

3. Improved public relations: The opportunity to work cooperatively with municipalities could improve local public relations. Local communities would be provided with many more options for sludge disposal as road construction projects develop, or as the need/desire for roadside enhancement arises. The cost of transporting sludge could be reduced for many communities, such as Olympia and Seattle, that are presently hauling long distances for disposal. The control of Scotch broom and other weed species along the roadside would reduce the number of complaints from local landowners who have

had to battle an increase in weeds, and improved aesthetics would be welcomed by the general public and travelers.

4. Enhancement of functional plantings: Trees and/or shrubs planted in the median for headlight glare reduction, vegetative buffers along the roadside, vegetation for delineation, wildlife plantings, etc., are examples of functional vegetation that could be enhanced without additional fertilization or replanting.

5. Improved runoff water quality: Established grass stands on roadsides could expedite pollutant removal from highway runoff before it drains into receiving waters.

BACKGROUND

History

The idea of returning the nutrients present in sewage to the land is not new. Land application of raw sewage was used for centuries in Europe and Asia until modern treatment practices were developed (Tarr, 1981). "Sewage farming" started about 1800 in large cities in Great Britain, including Edinburgh. By 1850, land-spreading techniques had reached the U.S. as well as other large European cities, such as Paris and Berlin. Sewage farming in the U.S. was used mainly for crop irrigation, especially in water-depleted areas of the West, but also served as a means of sewage disposal. By the 20th century, however, sanitary engineers began arguing that there existed public health problems from sewage in open waterways; that labor/cost/benefit imbalances made sewage farming less feasible; and that as cities grew, land for application was either too far from the city center or too expensive if it was more centrally located (Tarr, 1981). Modern sewage treatment technology began evolving at about the same time sewage farming declined.

Current Practices

The current state of sewage treatment technology involves primary, secondary and sometimes tertiary treatment. Primary treatment involves physical separation of liquid (effluent) and solids (sludge). Secondary treatment consists of bacterial conversion of organic matter in primary effluent to a biological by-product, secondary sludge. Primary and secondary sludges are mixed together to be treated, usually digested and dewatered, and ultimately disposed (Figure 1).

Various sludge disposal methods have evolved in the last half century. Ocean dumping of raw sludge was a common practice for coastal and near-coastal cities, but has been banned by the U.S. Environmental Protection Agency (EPA) since 1981 (Soil Conservation Society, 1982). Landfilling, incineration and air

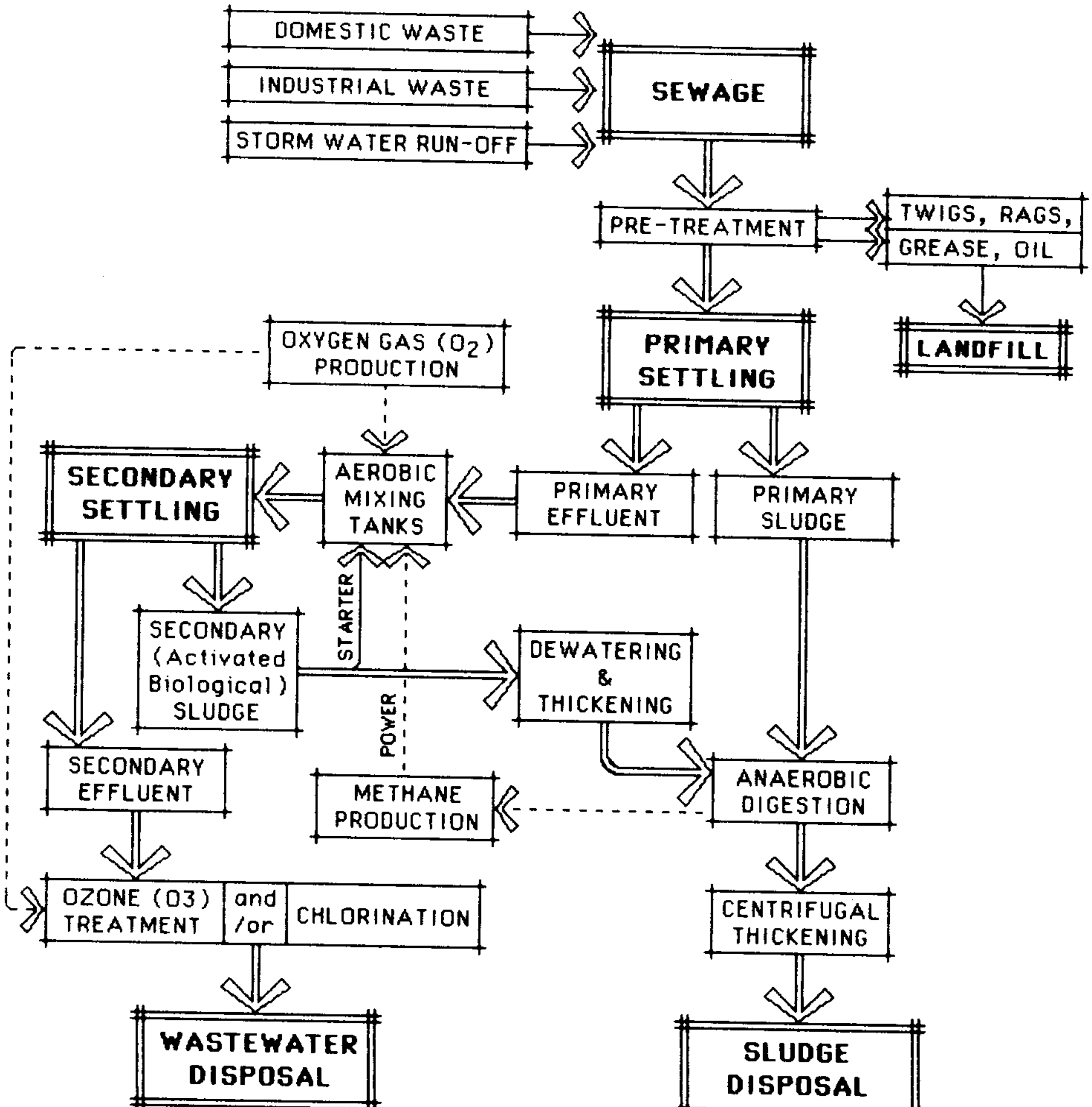


Figure 1. Plan for Secondary Wastewater Treatment Process - Modeled After the Olympia, WA Treatment Plant.

drying in open lagoons are currently the most commonly accepted options for disposal (Sverdrup et al., 1977). Land application has become a more viable alternative, especially for agricultural lands (Philips, 1978). Composting, and subsequent sale, has become a very attractive alternative to communities that have an appropriate market for the product (Environmental Protection Agency, 1983). Table 1 shows a comparison of disposal methods.

As environmental constraints have increased on conventional sludge disposal methods, and as the potential uses of sludge have been recognized, many municipalities have tried to identify needs and opportunities for land application. Increasing work in this area continues to show that the benefits of sludge application are numerous and that health and environmental impacts can be minimized by proper application methods and monitoring (Henry and Cole, 1983; Turner and Braven, 1983; Huddleston, 1984; Rimkus, et al., 1978; Sopper and Kerr, 1980). Much of the research in land application has occurred in agriculture. There has been more recent work in land reclamation, due somewhat to the 1977 Surface Mining Control and Reclamation Act, and in forestry.

Previous Work in Land Application

As the cost of commercial fertilizer has risen in recent years, agricultural use of sludge has gained acceptance (Washington State Department of Ecology, 1982). The most widely used method of application is land-spreading followed by disking

Table 1. Comparison of Problems & Benefits Associated with Available Sludge Disposal Methods.

DISPOSAL ALTERNATIVE	POTENTIAL PROBLEMS	ASSOCIATED BENEFITS
LANDFILLING	• Soil Contamination • Groundwater Pollution • Visually Unaesthetic • Land Use Impact • Decline of Usable Land	• Provides Permanent Storage Site
INCINERATION	• Air Pollution • Ash Disposal (to Landfill) • Soil Contamination • Groundwater Pollution • High Energy Usage	• Eliminates Sludge
EVAPORATION/ DRYING LAGOONS	• Soil Contamination • Groundwater Pollution • Visually Unaesthetic • Air Pollution • Land Use Impact	• Reduces Volume
LAND APPLICATION	• Soil Contamination • Groundwater Pollution • Surface Water Pollution • Impact on Food Crops	• Enhances marginal/ unusable lands • Reclaims mining/ construction sites • Increases forest productivity • Substitutes for high-cost, petroleum-based fertilizers • Low processing cost/ possible financial return
COMPOSTING (for commercial sale)	• Surface Water Pollution • Groundwater Pollution • Soil Contamination • Impact on Food Crops	• Can be used as fertilizer/ mulch on large or small scale • Substitutes for high-cost, petroleum-based fertilizers • Provides financial return

into the soil. The nutrients present in sludge in both organic and inorganic forms provide immediate and long-term sources of fertilization, often reducing the need to fertilize repeatedly throughout the growing season (Washington State Department of Ecology, 1982). The range of macro- and micro-nutrients provide more of the trace minerals needed by plants than most commercial N-P-K fertilizer, sometimes resulting in higher yields from sludge grown crops (Cunningham et al., 1980; Boone, 1984). The main limitation in agricultural use is the potential for uptake of heavy metals that are often present in sludge. Because of this possibility, the U.S. Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) have set tolerance levels for amounts of metals in agricultural crops (Washington State Department of Ecology, 1982). The problems with heavy metals will be discussed later in this paper as they apply to roadside utilization of sludge.

Sludge has been used in reclamation of strip mines, landfills, construction sites, and other seriously disturbed areas as a soil conditioner. Reclamation is aided by the retention of moisture and nutrients in otherwise infertile soils, which helps to encourage plant growth (Hornick, 1982; Murray, 1981). The use of sludge can improve erosion control, as well as potentially decrease the number of steps involved to attain complete reclamation (Washington State Department of Ecology, 1982; Hickey, personal communication).

The Centralia Coal Mine in Centralia, Washington (Figure 2), operated by the Washington Irrigation and Development Company (WIDCO), has been using municipal sludge in its reclamation program for several years. Sludge has been transported to Centralia from Olympia and Seattle. The exposed subsoils at the Centralia mine are easily saturated and therefore have high runoff during periods of rain. Because of this characteristic, the Office of Surface Mining (OSM) required that the sludge be injected under the soil surface, instead of applied on the surface, to minimize potential runoff pollution (Taylor, personal communication). The equipment used allows the sludge to be injected up to three feet deep, after which trees are planted (Figure 3). This practice bypasses several stages of plant succession by introducing most of the organic matter and nutrients that would be accumulated through natural succession (Figure 4). The objective is to shorten the process by which the land is returned to its original state, in accordance with the Surface Mining Control and Reclamation Act (Taylor, Hickey, personal communications). The greatest limitation on subsurface injection for roadside application is that the equipment generally cannot be used on a slope greater than 12-15 percent (Keating, personal communication).

The use of sludge in forestry has been studied in depth at the University of Washington's Pack Forest Research Center near

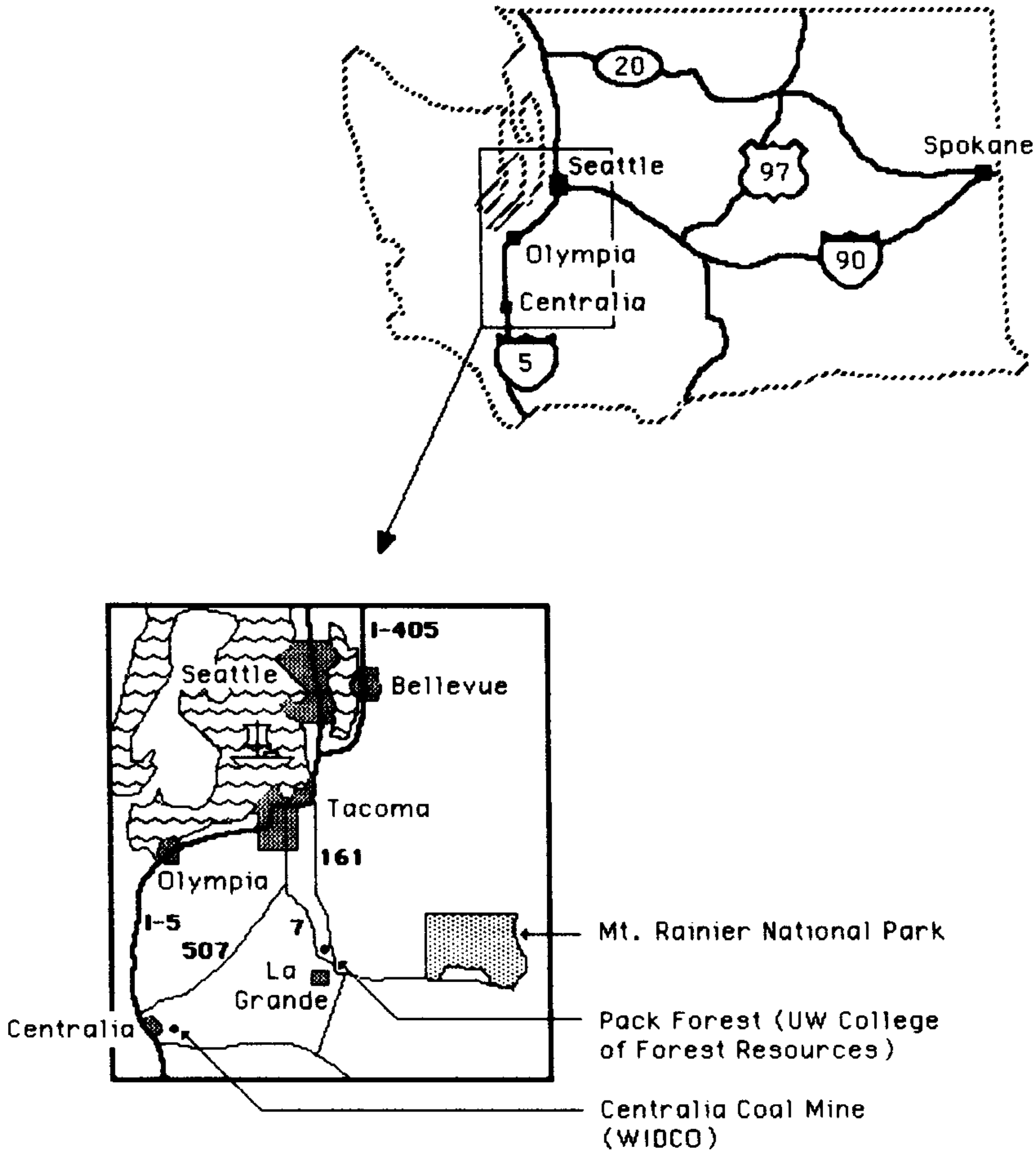
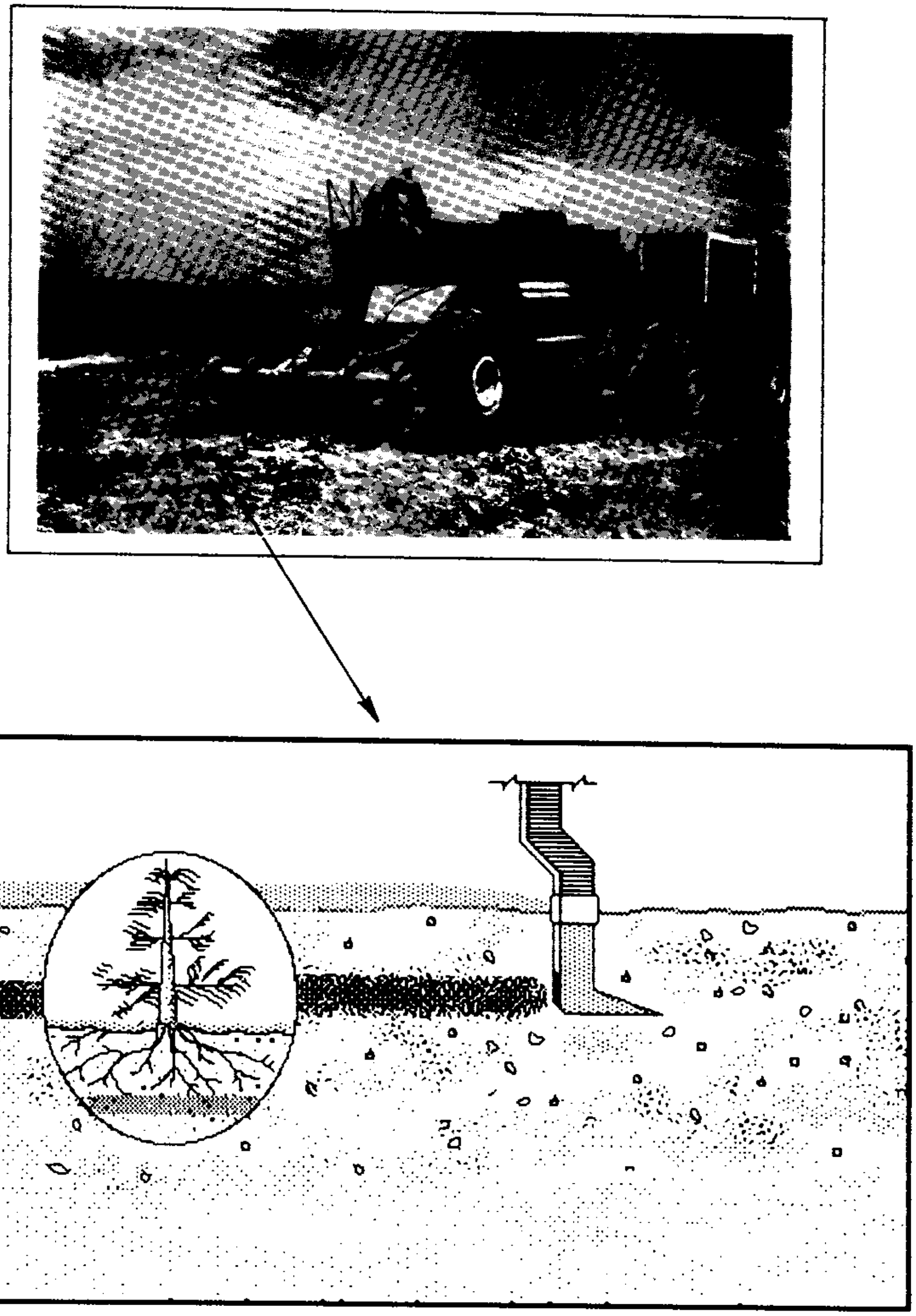
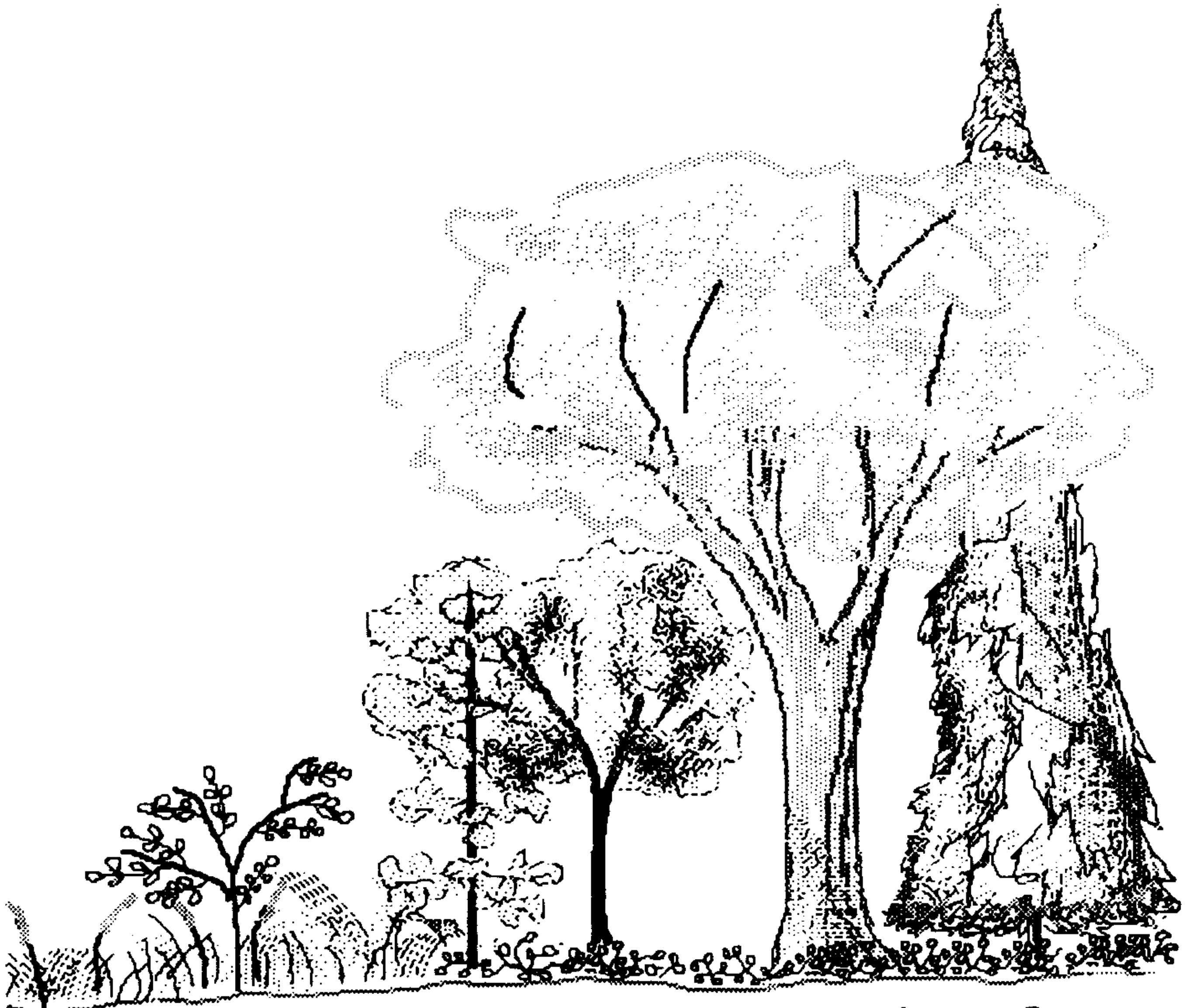


Figure 2. Location Map.



Sludge provides nutrients and holds water in upper soil layers.

Figure 3. Subsurface Injection of Sludge.



In drastically disturbed conditions, succession may take place over a longer time frame, and may not always follow a "typical" pattern.

Figure 4. General Pattern of Natural Plant Succession.

La Grande, Washington (Figure 2), in conjunction with the Municipality of Metropolitan Seattle (Metro). Experimentation with slope, sludge application methods, loading rates, timing, tree age, and tree species has led to the evolution of many of the "best management practices" for forestry, and an understanding of many of the natural processes in a forest ecosystem that are affected by sludge application. Application by pressurized spraying over the canopy of seedlings that are a minimum of seven years old and under the canopy of mature trees has been found to produce many desirable results with few undesirable side effects (Henry, personal communication). Sludge application in this manner has been found to accelerate growth and biomass production in both seedlings and mature trees (Henry, personal communication) (Figure 5). Trial and error has also shown that grasses grown in sludge-applied areas can outcompete very young tree seedlings and many weed species, including Scotch broom, a common nuisance species in open right-of-way areas (Henry, personal communication) (Figure 6). This principle has been incorporated into a powerline right-of-way test study started at Pack Forest in the summer of 1984. The results of this study should be useful to the highway right-of-way investigation. A demonstration study on the effects of sludge within an entire watershed, to be initiated at Pack Forest in the summer of 1984, should also produce useful information on drainage patterns and problems.

Though both trees are the same age, the tree on the left was treated with sludge seven years ago.

Figure 5. Seedlings from Sludge Applied and Non-applied Stands, Pack Forest.

Grass was seeded into sludge-treated ground nine years ago.

Figure 6. Nine Year Old Grass Stand, Pack Forest.

Metro has included land application projects in its long-range sludge management plan, along with forestry and composting practices, and has been seeking appropriate lands for application projects (U.S. Environmental Protection Agency, 1983; Sasser, personal communication). Through these projects it has been found that sludge application with subsequent grass seeding promotes a uniform grass cover that outcompetes weeds, including Scotch broom and Canadian thistle. The sod cover that is formed from this practice may also support trees without competition (Lucas, personal communication). This premise also may be very useful as applied to highway right-of-way plantings.

Roadside vegetation research by the University of Rhode Island has included the use of sludge and sludge compost as mulch, top dressing, and soil amendments. While it was found that sludge slurries were effective as fertilizers, research centered on the use of sludge compost because of the lack of odor and visual impact (Wakefield et al., 1981).

The cost of each of the above-mentioned practices varies, to a great degree, depending on equipment used for application, whether on-site or off-site storage is used, transportation, loading rates, previous cost of fertilization, and return on investment (Hickey, Henry, Colby, Sasser, personal communications). These factors will be evaluated in relation to application on highway right-of-ways. The Pack Forest, Centralia, and Metro experiences will be drawn upon heavily through the rest of this discussion, because they all deal directly with: 1) the young glacial soils and climatic conditions of Western Washington; 2) sludge quality produced in the large metropolitan areas of the Northwest; 3) the current costs of transportation, labor, energy, etc. in the Northwest; 4) public attitudes of local communities; and 5) the problems encountered with application to non-food and/or non-food chain crops.

ISSUES

Composition of domestic and industrial wastes, stormwater flow, agricul-tural runoff, and differences in sewage treatment systems all contribute to the range of biological and chemical properties of municipal sludges. Some of these characteristics can potentially create public health or environmental problems in land application systems. These problems will be presented here to the extent that they are currently understood; the findings from most recent research and the implications of these findings will also be reviewed. An assessment will be made of obstacles that would potentially be encountered in a roadside application program. It should be kept in mind that similar problems exist with most, if not all, other sludge disposal/utilization methods.

Public Health

In a survey of professionals in fields related to land application of sludge, public health was identified as one of the areas most in need of further research (Kelley et al., 1983). Of greatest concern was public exposure to pathogens, ground-water and drinking water pollution, and heavy metal contamination of soils and food.

PATHOGENS:

Some disease-causing microbes and viruses can remain viable in sludge through treatment (Sorber, 1981). Public exposure to pathogens after sludge application can come from surface runoff, leaching into the groundwater, trans-mission of aerosols from spray application and from surface-emissions, consumption of soil (many adults and children are afflicted with pica, a disease that results in consumption of unnatural, and sometimes inedible, foods), transference by animal or insect vectors, physical contact (e.g., public grass areas), or consumption of edibles grown in sludge-amended soils (Municipality of Metropolitan Seattle, 1983).

Anaerobic digestion kills most, but not all, pathogens. Ovas and cysts (the reproductive organisms of microbes) can withstand the digestion process, and even the heat of composting (Sorber, 1981). The length of the time the sludge is digested affects the numbers of microorganisms present; therefore, all sludges are different, even from day-to-day in the same treatment plant (Allen, personal communication). The amounts of pathogens present in the sludge before application can have an effect on how public exposure is to be mitigated. Method of application also has an effect; for example, subsurface injection of sludge eliminates many pathways of exposure, whereas pressurized spray application increases potential contact from aerosols. As a general rule, however, the Washington State Department of Ecology (DOE) recommends that public access to applied areas be restricted for one year (Washington State Department of Ecology, 1982). This restriction has been achieved through signing and fencing in other projects (Henry, personal communication; Lucas, personal communication). Since limited-access highway roadsides are already considered to be restricted areas, signing of the boundaries of applied areas, and possibly a minimal barrier such as a string barrier should be sufficient (Everson, personal communication; Henry, personal communication). The local health agency issuing the application permit has final jurisdiction on adequate restriction measures.

Factors affecting the survival of microorganisms in the soil are solar radiation, temperature, moisture content, soil pH, soil texture, competitive microflora (Sorber, 1981), age and health of organism population, and season of the year (Edmonds and Mayer, 1981). In general, bacteria and virus survival is reduced by hot temperatures, alternative periods of freezing and thawing, acid pH, low organic matter, and low soil moisture (Edmonds and Mayer, 1981). Edmonds and Mayer (1981) found that few viable fecal coliform bacteria penetrated to depths greater than 5 cm (2 inches) beneath the sludge, and virtually none reached the groundwater when sludge was applied to a forest clearcut. They showed that, in general, most bacteria are removed after passage through the first meter of soil and have little to no effect on groundwater. Fecal coliforms tended to survive longer in forest soils than in the clearcut (Edmonds and Mayer, 1981).

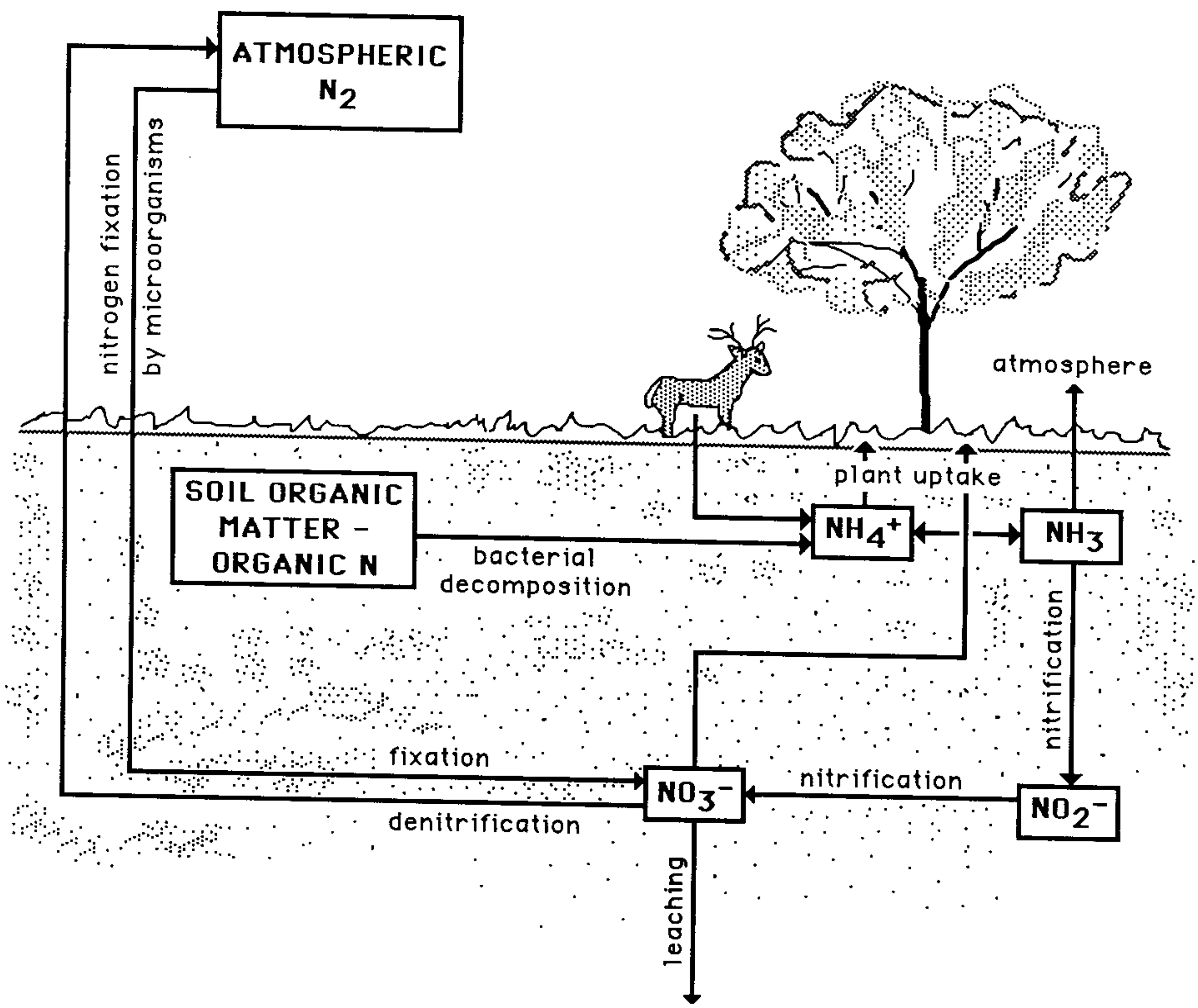
Most documented cases of disease caused by sewage sludge irrigation have resulted from drinking contaminated water and eating contaminated vegetables (Edmonds and Mayer, 1981). The impact to groundwater can be minimized by proper site selection to ensure that application occurs in soils with restricted permeability and away from groundwater recharge areas. Since highway roadsides are not used for the production of food or food-chain crops, there would be no direct impact on human food. Proper restriction of public access, maintenance of conditions that discourage bacteria and virus survival, and choice of application method can further ensure no impact to public health.

The potential for exposure of WSDOT workers to pathogens exists in a roadside application program. The regulations and precautions that apply to sewage treatment plant workers have been used in previous land application projects (Henry, personal communication), and should be utilized by WSDOT personnel coming into direct contact with a sludge-treated area.

NITRATES:

While large amounts of nitrogen (N) present in sludge serve to fertilize plants, there are potential problems with excess nitrogen leaching through the soil and into the groundwater. Nitrogen is present as organic N, tied up in organic matter and unavailable to plants, and as inorganic N decomposed into a mobile form. Inorganic forms of N are ammonia gas (NH_3) and ammonium ion (NH_4+), the relative concentrations of which are controlled by pH and which are usable by plants; nitrate (NO_3-), which is the form most usable by plants and is more mobile in the soil than ammonium; and nitrite (NO_2-), which can be oxidized into nitrate. In aerobic soils ammonium tends to be oxidized to nitrite and then nitrate in the bacterially mediated process known as nitrification. In anaerobic conditions, dentrification, also bacterially mediated, converts nitrate to nitrogen gas (Figure 7).

Nitrogen applied in excess of the plants requirements can lead to formation of excess nitrates, which can readily leach through the soil profile. Studies at Pack Forest have found that leaching does not tend to be a problem beyond the first year



Plant uptake of nitrogen varies with plant species and with time of year.

Figure 7. Schematic of Nitrogen Cycle.

after application, although the fertilizing effects of the nitrogen in sludge can last 5-10 years due to continuous conversion of organic N (Henry, personal communication). In the first year after application, mobile nitrogen consisted of already available ammonium and nitrate plus 20 percent of organic N converted into NH_4^+ and NO_3^-. Plant uptake and leaching accounted for 100 percent of these mobile forms. In the second year, available N consisted of approximately 8 percent of the remaining organic N, most or all of which was used by the plants. Availability was approximately the same in subsequent years (Henry, 1983).

The rate of sludge application depends heavily on the first-year leaching level. The amount and form of N present in the sludge used and the N requirements of the plants to be grown in the amended soils determine the loading rates (Washington State Department of Ecology, 1982; Cole and Henry, 1983). Appendix C presents methods of calculating sludge loading rates recommended by the DOE. According to the DOE, there should be no nitrate leaching problems, and therefore no groundwater monitoring requirement, if sludge is applied at or below the level of plant N-uptake (Betts, personal communication).

Concern about nitrates has arisen with the discovery that ingestion of excess nitrates by humans has been found to cause methemoglobinemia, or "blue baby" syndrome (Wagner, 1971). For this reason, the EPA has set a limit of 10 ppm on nitrates in drinking water. Since drinking water is the only pathway to human exposure related to sludge application, drinking water contamination must be avoided. Correct loading rates and proper selection of sites with soils having somewhat restricted permeability, away from groundwater recharge areas, and well above the groundwater table, will minimize the impact of nitrates on drinking water.

ORGANICS:

EPA-regulated organic toxicants that can occur in sludge include pesticides (usually chlorinated hydrocarbons such as DDT, endrin, and dieldrin; or organophosphates such as 2-4 D and 2-4-5 T) and polychlorinated biphenyls (PCB's) (Municipality of Metropolitan Seattle, 1983). After application of sludge, organics can be transmitted through ground and surface water, aerosols, soil, and by biomagnification up the food chain in edible plants, fish, and animals (Municipality of Metropolitan Seattle, 1983).

Both the Metro (Seattle) and Lacey-Olympia-Tumwater-Thurston County (L.O.T.T.) sewage treatment agencies report very low to trace amounts of organic pollutants in their sludge (Municipality of Metropolitan Seattle, 1983; Allen, personal communication). The only organic reported above trace amounts was the PCB level in Metro's sludge. After projecting potential PCB concentrations after application, Metro found that the PCB levels in their sludge probably do not approach FDA tolerance limits (Table 2).

PCB's have been demonstrated to cause cancer in laboratory animals, while various pesticides have been linked to acute and chronic health effects and some are regarded as carcinogens. As PCB's can bioaccumulate up the food chain, the FDA has set limits for PCB levels in soil, water, fish, poultry, red meat, animal byproducts, and feed for food-producing animals that reflect this magnifying effect. However, there are still unanswered questions relating to the health effects of many organic pollutants, especially at low levels. Many pesticides and industrial organics have been restricted or banned by the EPA and FDA on suspicion of being detrimental to human health, without direct cause/effect evidence. Compared to the concentrations of potentially toxic organics in the human food chain through agricultural and industrial use, the concentrations of these compounds in most sludges are relatively low. There are few absolute conclusions that can be drawn regarding the presence of organics in sludge aside from a comparison with existing standards.

Sludge in highly agricultural areas such as Eastern Washington may tend to show different ranges of organic toxicants due to heavier pesticide use. This is a factor to take into account when considering using sludge from different municipalities.

Table 2. Comparison of PCB Levels & Standards (concentrations in parts per million). (from Municipality of Metropolitan Seattle, 1983)

A. West Point (Metro) Sludge PCB Levels.

DATE	DIGESTED	DEWATERED
6/23/81	1.1 ppm	0.8 ppm
7/ 7/81	6.7	0.1
7/22/81	0.3	1.9
8/ 4/81	5.9	1.6
8/18/81	1.1	1.7

B. PCB Concentrations Estimated as a Result of Sludge Forest Application.

LOCATION	CONCENTRATION
Sludge - Soil - Litter	.05 - 1.0 ppm
Surface Water	< .0005
Edible Plants	< .2
Groundwater	< .0005

C. FDA Limits for PCB Concentrations in Food

FOOD	CONCENTRATION
Milk & Dairy	1.5 ppm
Poultry	3.0
Red Meat	3.0
Eggs	0.3
Fish & Shell Fish	5.0
Feed for Food-Producing Animals	0.2
Infant Foods	0.2

HEAVY METALS:

There are several concerns about public exposure to heavy metals through drinking water, farm crops, and meat. Metals in sludge generally originate from industrial waste, transfer pipe corrosion, street and parking lot runoff, household wastes, or plumbing (Municipality of Metropolitan Seattle, 1982). Many heavy metals are naturally present in most soils, and some micro-nutrients such as copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) are essential to good plant growth in small amounts (Table 3) Like most environmental problems, metals are a resource that can become toxic in large quantities.

Heavy metals tend to be relatively immobile; that is, they attach to soil particles and usually do not become detached. However, as soil pH decreases, the ability of soil particles to adsorb and hold metals decreases, and metals are released into the subsurface water system (Zazoski, 1981). Additionally, if the soil becomes saturated with metals, the excess will become mobile (Bledsoe, personal communication). These metals can subsequently move into the plant uptake zone and be assimilated along with water and other nutrients or enter the groundwater. Some metals, such as nickel (Ni) and zinc (Zn) are more soluble and are transported in soils more readily than others (Zazoski, 1981).

When metals move into groundwater and plants in large quantities, they can begin to pose a problem to public health.

Table 3. Essentiality of Trace Elements.
(from Phillips, 1978)

TRACE ELEMENT	ESSENTIAL		NON-ESSENTIAL	
	Plants	Animals	Plants	Animals
Antimony			X	X
Arsenic			X	X
Beryllium			X	X
Boron	X	X		
Cadmium			X	X
Chlorine	X	X		
Chromium		X		
Cobalt		X		
Copper	X	X		
Fluorine		X		
Iodine		X		
Iron	X	X		
Lead			X	X
Manganese	X	X		
Mercury			X	X
Molybdenum	X	X		
Nickel		X		
Selenium		X		
Sodium (macro)		X		
Vanadium		X		
Zinc	X	X		

Toxicity to plants can be caused by actual metal poisoning, or by excess metals competing with needed nutrients and causing plants to "starve" (Bledsoe, personal communication). Toxic levels are different for each metal and for each plant species. Toxic metals can also be transmitted through plants up the food chain, causing health effects in herbivores and carnivores (Municipality of Metropolitan Seattle, 1983). High levels of metals in drinking water also have the potential to cause health problems in humans (Municipality of Metropolitan Seattle, 1983).

Cadmium (Cd) and lead (Pb) are known to be potential toxicants and are the cause for the majority of concern in sludge application (Zazoski, 1981; Washington State Department of Ecology, 1982). Because Cd is relatively more mobile in soil, it usually serves as a more restrictive parameter for determining intake limits (Municipality of Metropolitan Seattle, 1983; Zazoski, 1983). The drinking water limit for Cd is 10 micrograms per liter (Municipality of Metropolitan Seattle, 1983). While Cd and Pb have not been shown to have a direct toxic effect on herbivorous animals such as deer that consume plants grown in sludge-amended soils (West et al., 1981), daily human ingestion of deer liver or kidney, the organs where toxins accumulate, could potentially produce a toxic effect over time (Municipality of Metropolitan Seattle, 1983). A recent study investigated the results of three sludge application strategies: (1) sludge is applied according to the nutrient needs of plants and EPA Cd application limits are not exceeded; (2) application exceeds nutrient requirements and equals or exceeds Cd limits; and (3) application greatly exceeds nutrient needs and exceeds Cd limits (Abron-Robinson and Weinberger, 1985). The second strategy caused no significant Cd accumulation in soil or groundwater quality change. In the third case soil metal content increased, but no groundwater deterioration occurred. Detention of runoff prevented surface water quality change.

The Washington State Department of Ecology (1982) has set more stringent Cd levels for sludge used in agriculture that affect not only current land use but also future land use through resale restrictions. Appendix C presents the DOE's suggested calculations for maximum cadmium loading. If the maximum application rate is not exceeded, then there are no restrictions on the resale of land for agricultural use (Department of Ecology, 1982; Taylor, personal communication).

The potential problems from heavy metals on roadsides are mainly from the movement of metals either in water percolating through the soil or in surface water runoff. Movement of metals in even acidic soils at Pack Forest was localized near the surface (Zazoski, 1983), and the levels of Cd and Pb deeper than 5 feet in land reclamation projects are expected to be below detection limits (Municipality of Metropolitan Seattle, 1983). The University of Rhode Island study found that there was little downslope movement of heavy metals in runoff from a 14% slope treated with sludge. Where any movement occurred, grass buffer areas not treated with sludge were effective in reducing contaminants in the runoff water (Wakefield et al., 1981).

Permissible sludge loading rates can be determined according to the metal levels in sludge and the existing levels in soils. Background levels of metals in soils along heavily traveled highways can be high due to automotive emissions and storm runoff (Wang et al., 1982). Existing levels may substantially affect acceptable sludge loading rates on roadsides (Table 4).

Since roadside plants are not grown as human food crops, potential infiltration to drinking water is the prime concern about metals in roadside sludge application. Mobility of metals can be controlled by regulating the depth of sludge applied, maintaining soil pH at a minimum of 6.5 (very slightly acidic), applying on sites that are away from aquifer recharge areas and well above the groundwater table, and directing surface drainage through vegetated channels or across vegetated slopes. Since it is conceivable that some roadside plants, such as blackberries or rosehips, may be gathered for edible use, sludge application is probably most appropriate in limited-access, high-speed corridors where such activity is unlikely. Discouraging any public access for the first year after application would also be a good policy.

Much is unknown about links between ingestion of heavy metals and human health. There are many sources of metals in a

Table 4. Comparison of Metal Levels in Roadside Soils and Sludge Concentrations (mg/kg).

SOURCE		CONCENTRATION (mg/kg)					REFERENCE
	METAL	Lead (Pb)	Copper (Cu)	Cadmium (Cd)	Iron (Fe)	Zinc (Zn)	
Top 1cm soil surface; I-5 @ NE 185, Seattle							(Wang et al., 1982)
Distance from Road Edge (M)	0	3,640	120	34.1	42,300	522	
	1	4,460	115	70.5	60,200	526	
	2	1,680	80.8	61.2	18,500	251	
	3	1,360	90.5	72.6	34,400	265	
	4	646	43.8	27.6	25,000	226	
	6	617	35.4	26.7	26,500	201	
	8	486	36.4	15.9	21,400	145	
	10	313	27.0	18.6	21,300	141	
	12	288	25.7	24.1	23,000	180	
	13	354	29.2	24.9	24,600	135	
	18	201	30.2	23.1	23,400	178	
Soil Core; I-5 @ NE 185, Seattle							(Wang et al., 1982)
Depth (cm)	0	1,630	50.0	16.0	17,000	201	
	1	607	36.4	26.0	21,800	295	
	3	128	33.9	22.3	21,400	69.5	
	5	185	25.3	25.5	24,300	67.5	
	7	139	22.2	25.0	24,900	38.2	
	9	168	21.2	23.0	23,800	26.9	
	11	66.8	36.3	28.5	27,500	25.7	
Metro (Seattle) Sludge							(Metro, 1983)
	5/27/81 to 9/27/81	680	1,300	44	NA	1,800	
L.O.T.T. (Olympia) Sludge							Allen (personal communication)
	7/20/83	270	590	4	11,000	950	
	6/ 1/84	340	720	6	13,000	1,200	

typical human diet that represent a much greater risk of exposure than does the application of sludge to roadside soils. The above-mentioned precautions should minimize the impact of sludge-amended soils even further.

Environmental Problems

Several potential environmental problems that are associated with sludge application include pollution of surface and groundwater systems, soil contamination, and disruption of ecosystem dynamics. Many of the mechanisms associated with these problems have been explained in the public health section of this report.

SURFACE WATER POLLUTION:

Pollutants in stormwater runoff ultimately end up in open receiving waters (i.e. lakes or streams), unless pollution is mitigated between the source and the receiving waters. Existing pollution in highway runoff consists mainly of petroleum products, sediments, heavy metals and nutrients that come from motor vehicle emissions or wear of vehicle parts or are transported to highways from the surroundings (Mar et al., 1982) Contaminant concentrations and total loadings depend on the highway's traffic volume and other conditions (Mar, et al., 1982). Highways having the greatest potential to affect aquatic ecosystems significantly during routine operations are those having the highest traffic volumes and direct drainage of runoff to receiving waters. Accidental spills of toxic materials and certain intermittent maintenance practices represent other potential threats to aquatic systems. The various pollutants primarily exist as solids and tend to settle in bottom sediments that are feeding grounds for many invertebrates, which in turn are food sources for fish, mollusks, birds and other larger animals.

Use of sludge on roadsides could potentially contribute to an increase in metals and nutrients in runoff. In addition to the health hazards previously mentioned, discharge of nitrates and phosphates into receiving waters could cause eutrophication of lakes and streams. The various harmful side effects potentially accompanying that condition include increased algal blooms, reduced dissolved oxygen due to decomposition of larger algal biomasses, and changes in the composition of aquatic organisms (Dunne and Leopold, 1978).

Potential runoff water pollution problems due to sludge application can be alleviated by applying sludge at the level of nutrient uptake of plants, selecting a site that is well away from open waters, and timing applications to occur during the dry season. Pollutants in runoff from sludge-treated areas could also be reduced by using retention/detention facilities and/or vegetated drainage courses. There are indications that R/D facilities can settle out 20-60 percent of metal and nutrient pollutants, depending on the design of the facility and the length of time water is held in the pond (Horner, 1985). Vegetated surfaces and grassed ditches have been shown to be effective in removing various pollutants from a number of different waste streams (Horner, 1985). Research on the treatment of routine runoff from Washington State highways by vegetated channels determined that a length of 200 feet is capable of removing 80 percent of relatively insoluble metals like lead and 60 percent of more soluble metals such as copper and zinc (Wang et al., 1982) (Figure 8). In general, sludge would be expected to contain different proportions of the various metals than routine highway runoff and would have different fractions in the particulate and soluble fractions. Therefore, study would be required to determine the degree of treatment that vegetation could provide runoff from sludge-treated areas. Based on the general experience with overland flow treatment, relatively effective removal of both particulate and dissolved metals would be expected (Horner, 1985). Nutrient removals have been less consistent in past cases and appear to decline in the winter (Horner, 1985). Study of nutrient transport from sludge-treated areas will be necessary.

A related issue is whether to apply sludge to vegetated plots devoted to treating routine highway runoff. Sludge application would enhance growth on such plots, to the benefit of treatment, but may introduce additional contamination. Although

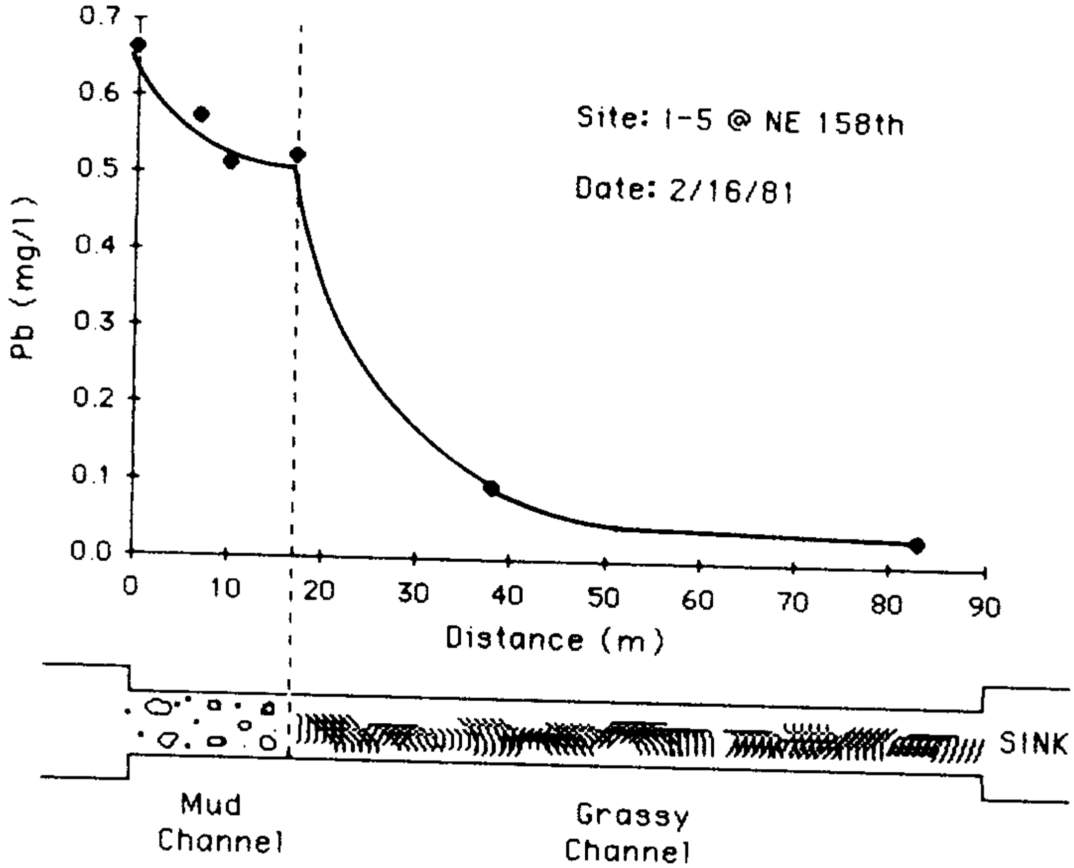


Figure 8. Typical Pattern of Reduction in Runoff Lead Concentration with Distance Traveled in Mud and Grass Channel. (from Wang et al., 1982)

further study of the point is again needed, the best policy may be to apply sludge to such plots during their construction only and allow a period for assimilation of pollutants before the plot is placed in overland flow treatment service. Further applications then would not be made during the period of service.

GROUNDWATER POLLUTION:

Many groundwater flows serve to recharge lakes and streams. The same pollution sources that can contaminate underground drinking water supplies can ultimately be detrimental to many forms of aquatic life. Good water quality can be maintained through proper selection of sites that are away from aquifer recharge areas, are well above the groundwater table, and contain soils of somewhat restricted permeability.

SOIL CONTAMINATION:

Roadside soils serve as a trap for heavy metals and other motor vehicle emissions (Wang et al., 1982). Additions of sludge to these soils may raise the existing level of metals. Since roadway construction often calls for disposal or alternative uses of roadside soils, plans for new construction in areas where sludge has been applied should take into account soil metal levels, the destination of the soils, and whether or not agricultural restrictions should apply.

ECOSYSTEM DISRUPTION:

While water and/or soil pollution may not contribute directly to the death of plants, fish, or wildlife, low levels of pollutants can cause subtle changes that result in a shift in the balance of affected ecosystems. Both terrestrial and aquatic systems that interact with roadways could be affected by pollutants introduced in sludge application. Examples are detrimental species shifts as a result of eutrophication and biomagnification of toxicants in food chains.

It should be noted that, through the vegetation enhancement sought in considering highway right-of-way sludge application there is a potential for a positive effect on birds and, possibly, other wildlife forms that are supported by roadside vegetation. This change could be particularly beneficial in urban areas where no other food or cover sources exist.

Public Acceptance

One of the largest hurdles to overcome for many sludge application projects has been public resistance. A well planned program of public education and publicity is invaluable in setting the stage for public acceptance of new projects (Ettlich and Lewis, 1977; Boone, 1984; Huddleston, 1984). Political commitment from local officials can also serve to boost public opinion (Scaramelli, 1984).

Of greatest concern to the public are the potential health risks, which are the focus of current and future research and regulation. Proper site selection and good project management can minimize these risks. Odor problems, another major concern, can be minimized by using well digested sludge containing a low volatile solids count; by injecting sludge under the soil surface so there is no contact with the air; by applying very thinly on the surface during the summer so that sludge dries as quickly as possible; and by adding lime to raise pH and stop volatilization, thereby eliminating odor. (Taylor, personal communication; Henry, personal communication). Choice of application methodology can also minimize visual impacts. Either sub-surface injection or disked-in surface application can reduce most visual evidence of sludge application. Plans by Metro for a pilot project to dry sludge into pelletized form may provide another technology that would have minimal visual and odor impacts in land application (Sasser, personal communication). This project will not be in operation until 1986.

Good public relations and good planning and management of a sludge utilization program can help to overcome public objection. Boone (1984) found that people's objections are often related to negative word associations. By changing "municipal sludge" to "municipal fertilizer," the public responded much more positively to a utilization program. Demonstration projects were also found to be very important in gaining public approval (Murray et al., 1981). A survey of many people in fields able to utilize sludge or sludge compost, such as nurseries, landfills, strip mines, wastewater treatment facilities, parks and golf courses, forestry, and landscaping, showed a high interest in the use of such products. However, it was not determined if this favorable attitude was due to rising costs of commercial fertilizers, a growing awareness of the value of organic material to soils, or a combination of both (Ettlich and Lewis, 1977).

Much of the concern about the impacts of land application of sludge is due to the fact that it is a relatively new technology and has been evolving throughout the last 15-20 years at the same time that environmental awareness has been growing. Older disposal technologies, such as incineration, landfilling, and ocean dumping (now discontinued), were well in place and accepted practices when environmental legislation and regulations began to affect development and technology and they were not subjected to the same kind of scrutiny as land application. The fact that the impacts of land application projects have been evaluated more closely implies that many of the impacts have been assessed, analyzed, and mitigated better than in the case of older technologies. The public needs to be aware of the impacts and benefits of all sludge disposal technologies in order to evaluate land application within a broader context.

PERMIT PROCESS

Because sludge is defined as a solid waste, land application projects require permits from jurisdictional agencies (Washington State Department of Ecology, 1982). The permit process is a way for agencies to control potential effects on public health and on the environment. The Washington State Department of Ecology reviews all permits for land application of sludge, but it is ultimately up to county health departments in whose jurisdiction the project occurs to approve and enforce all permits. In order to answer questions that come up during the permit process, information on sludge characteristics, site characteristics, storage methods (if applicable), and rates and seasons of application should be known.

Since sludges can contain a variety of potentially hazardous substances (e.g., heavy metals and nitrates), it is necessary to have a complete analysis of the sludge before applying for a permit, in compliance with the Resource Conservation and Recovery Act of 1977 (RCRA). Nutrient requirements of plants must be known, along with sludge quality, in order to calculate loading rates. Hydrology, geology, soils, climate, and context of the site must be understood in order to evaluate the effects of sludge application on the site and its surroundings. Application methodology can then be determined by site and sludge characteristics, plant requirements, and steps needed to minimize public nuisance, public health, and environmental impacts. Rates and seasons of application can be determined after a methodology has been chosen.

It may be necessary to set up soil and water monitoring systems to determine the effects of application in order to satisfy the permit process. This determination would be a necessary part of any field trials to test equipment and verify methodologies. Any on-site storage facilities must be approved by the DOE.

COMPARATIVE COSTS

With data from Washington State Department of Transportation personnel (Barnes, personal communication) and from "Cost Data for Landscape Construction" (Kerr, 1984), the capital and operating costs over a nine-year period of existing erosion control practices are compared with the potential costs of using sludge. All costs are calculated on a per acre basis. The nine-year time length was adopted because of the availability of data from a study at Pack Forest, where a grass stand grown in sludge-amended soil continues to be self-sustaining after nine years.

Since municipalities are currently paying disposal and/or hauling costs, it is assumed that they will continue to pay for sludge transportation to disposal/utilization sites. Metro reports that the agency expects to be paying hauling costs for their sludge into the foreseeable future (Lucas, personal communication). Capital requirements are itemized in actual costs, and the total is also expressed in cost to the state on a federal project (i.e., interstate), where the state pays 10 percent of initial erosion control costs. On the advice of WSDOT (Barnes, personal communication), overhead differences among alternatives were considered to be negligible. Mowing in the WSDOT highway system is designated on a location basis regardless of the characteristics of the grass stand. Therefore, mowing costs were also considered to be equal among alternatives.

Hydroseeding

Hydroseeding is the most commonly used practice for erosion control on new highway construction. A slurry of wood fiber mulch, commercial fertilizer and grass seed is sprayed on exposed areas, with a tackifier added on occasion to promote adhesion on steep slopes. The effects of commercial fertilizer are short-lived, and refertilization is recommended every few years to maintain a healthy ground cover. The costs of hydroseeding are estimated at:

	Capital Costs	Operating Costs
a. Hydroseed materials & labor	$1200/ac	
b. 3-time refertilization @ $800/ac each		$2400/ac
Total	$1200/ac (or $120/ac federal projects)	$2400/ac

Due to variable conditions, hydroseeding may not be completely successful, resulting in poor grass growth and incomplete ground coverage. In such circumstances, undesirable plant species, such as Scotch broom, may invade. Removal of undesirables and subsequent reseeding is often necessary. Costs in this situation are approximately:

		Capital Costs	Operating Costs
a.	Hydroseed materials & labor	$1200/ac	
b.	Mechanical removal of plants - labor & equipment		$100/ac
c.	1-time rehydroseeding		$1200/ac
d.	2-time refertilization		$1600/ac
	Total	$1200/ac (or $120/ac federal projects)	$2900/ac

In an extreme case of hydroseeding failure, maximum erosion and bank collapse may occur. This event would necessitate regrading of the bank and subsequent rehydroseeding or other means of vegetative bank stabilization. Costs of possible side effects of bank collapse (e.g. damage to cars, roadway, or drainage system) are not included in the following estimate:

	Capital Costs	Operating Costs
a. Hydroseed materials & labor	$1200/ac	
b. Regrade of bank at .70/sq yd		$3,300/ac
c. 1-time rehydroseeding		$1200/ac
d. 2-time refertilization		$1600/ac
Total	$1200/ac (or $120/ac federal projects)	$6100/ac

Burlap

A fiber mat such as burlap is sometimes used to stabilize slopes before vegetation gets established. The fiber eventually degrades, leaving vegetation for erosion control.

	Capital Costs	Operating Costs
a. Burlap	$3500/ac	
b. Hydroseed	$1200/ac	
c. 3-time refertilization		$2400/ac
Total	$4700/ac (or $470/ac federal projects)	$2400/ac

Topsoil (Type B)

Topsoil is often removed at the start of construction, stockpiled on site, and replaced at the end of construction in order to encourage better grass growth, usually with subsequent establishment of shrubs and trees. Topsoil is a valuable on-site commodity when it can be used. Costs are approximately:

		Capital Costs	Operating Costs
a.	Removal, stockpile, and replacement of 6" of topsoil @ $4/cu yd	$3230/ac	
b.	Hydroseeding	$1200/ac	
c.	2-time refertilization		$1600/ac
	Total	$4430/ac (or $443/ac federal projects)	$1600/ac

Topsoil that is transported from off the site (Type A) is approximately twice the above cost.

Sludge with Hydroseeding

Sludge could be substituted for mulch and fertilizer in a hydroseeding operation. This practice may be useful on steep slopes. The assumptions in the cost estimate below are that hydroseed trucks could be filled directly at the treatment plant and that sludge would be provided at the times of year that hydroseeding takes place (approximately March 1 - May 15 and August 15 - October 1 in Western Washington), so that the state would not have to provide storage facilities for sludge. The cost estimate is:

	Capital Costs	Operating Costs
a. Labor and seed	$800/ac	$0
Total	$800/ac (or $80/ac federal projects)	$0/ac

If the hydroseeding technique could be used for spray application of sludge to existing vegetation, seed costs would be eliminated. In this event costs would be approximately:

	Capital Costs	Operating Costs
a. Labor	$600/ac	$0
Total	$600/ac (or $60/ac federal projects)	$0/ac

While hydroseeding with sludge appears to be inexpensive, it may not provide as much of an increase in soil organic matter and nutrients as the following methods.

Subsurface Sludge Injection

The cost of this alternative is based on WIDCO's approximate per acre cost for its entire operation, including on-site sludge storage, equipment, maintenance, monitoring systems, etc. The assumption in the estimate is that WIDCO's equipment maintenance and depreciation costs would be similar to the cost to WSDOT to rent that equipment.

	Capital Costs	Operating Costs
a. WIDCO total cost	\$2000/ac	
b. Labor and seed	\$400/ac	\$0
Total	\$2400/ac (or \$240/ac federal projects)	\$0

Spread and Disked Sludge

Using existing WSDOT equipment, sludge could be spread and disked with a D-6 cat having a grader and disker.

	Capital Costs	Operating Costs
a. D-6 cat to spread and pull disk at \$1/sq yd	\$4840/ac	
b. Labor and seed	\$400/ac	\$0
Total	\$5240/ac (or \$524/ac federal projects)	\$0

Sludge/Soil Mix Final Grading

Application to steep slopes may be possible with a sludge/soil mixed "topsoil" applied during final grading. One successful technique for creating a mix has been spreading and disking of sludge into subsoil, with subsequent removal of the top foot of mixture and applying it where necessary. This operation could be performed on-site at construction, if a site is available, at the cost estimated above for spreading and disking plus subsequent transportation to the site of final topsoil placement. Another means would be to remove soil to an on-site stockpile, windrow and mix with sludge, and replace by grading with on-site equipment. The cost of this method is outlined below.

		Capital Costs	Operating Costs
a.	Removal of 6" soil, mixing, and replacement of 1' of "topsoil" at $5/cu yd	$6050/ac	
b.	Labor and seed	$400/ac	$0
	Total	$6450/ac (or $645/ac federal projects)	$0

A variation of this technique would be to apply and grade a layer of sludge and top it with a layer of onsite soil for final grading. This method would achieve the same type of stratification of sludge and soil as subsurface injection. The cost for this application would be similar to spread and disked sludge.

The L.O.T.T. treatment plant estimates a cost of $1.86/mile hauling charge. This cost is estimated at 1984 levels and includes equipment depreciation. This is an approximate cost that would have to be paid for hauling if sludge is not obtainable free-of-charge.

DISCUSSION

Further Research in Roadside Application

The major obstacles to land application of sludge have been public health considerations associated with food or food-chain crops, public exposure to pathogens and toxins, environmental impacts, and the availability of appropriate application techniques. Since roadsides are not used for edible crop plants, several of these concerns are not obstacles to a roadside application program.

The constraints that would be encountered in roadside use are application to steep slopes, impacts to groundwater and surface water quality, restriction of public access, and public acceptance of a program. Roadside slopes are sometimes much steeper (maximum 2:1 or 50 percent) than the areas where sludge application has previously been successful. Existing application techniques may be successful on these slopes, or new techniques may need to be developed. Surface runoff from roadsides is generally controlled by the use of drainage ditches, sometimes in conjunction with retention/detention facilities. Both vegetated drainage ditches and R/D facilities can reduce the level of pollutants in runoff water, although the existing techniques may need modification to accommodate runoff from an area with sludge amended soils. Public resistance to alternative technologies is usually caused by misperceptions. Public acceptance can be garnered through the use of educational materials, public meetings, open access to agency personnel, and test studies that can demonstrate actual problems and benefits. Means of restricting access would depend on the characteristics of the site selected and its proximity to heavily or lightly traveled roadways. It is recommended that the next step in seeking solutions to the above questions be a demonstration study.

Demonstration Study

The following questions could provide an organizational framework for a demonstration study:

1) Can desired vegetation be established/enhanced through the use of sludge?

   IF NO - - what kind(s) of vegetation would respond better?

   IF YES - -

   2) Can existing application methodologies work on desired slopes?

      IF NO - - can new methods be developed?

      IF YES - -

3) Does chosen application method adversely affect the quality of surface and groundwater?

IF YES - - can this be mitigated?

IF NO - -

4) Does public react adversely to desired use?

IF YES - - can reaction be minimized through education, public meetings, or use of different application techniques?

IF NO - -

5) Can this be incorporated into current WSDOT practices?

IF NO - - what is (are) the limiting factor(s)?

IF YES - - PROJECT RESULTS CAN BE IMPLEMENTED.

Sludge could potentially be used in roadside development to help vegetate soils exposed by new construction, or to replace or enhance existing vegetation. Vegetation projects may include the establishment of the following: 1) temporary grass cover for erosion control; 2) permanent grass and/or shrub cover for "clear zone" areas; 3) large shrubs or trees for barrier plantings; 4) non-native ornamental plantings for urbanized areas; 5) native plantings for rural areas; and 6) healthier and more productive vegetation in existing plantings. Based on the findings of this study and discussions with Department of Transportation personnel, it is recommended that a demonstration study focus on the following: 1) the use of sludge to establish erosion control grass that will prevent "invader" species such as Scotch broom from becoming established, and/or 2) the use of sludge to enhance existing vegetation. The findings from a demonstration study would provide information for choosing appropriate plant varieties, and might also show that the use of sludge for other projects is appropriate.

Areas of new construction typically need immediate revegetation for erosion control and offer the most opportunities for sludge utilization. Steeply cut slopes created by new construction may be able to receive sludge application by: 1) liquid (non-dewatered) sludge added to hydroseed mixture, 2) final grading of a sludge-soil mixture instead of topsoil, or 3) dry (pelletized) sludge spray (will not be available from Metro for several years). Spreading and disking, or sub-surface injection, would be appropriate on slopes less than 15-25 percent, depending on soil condition, season, and other factors (Washington State Dept. of Ecology, 1982).

Sludge consistency is as important a variable as application technique on steep slopes. While under and overstory spray application to existing tree stands has been successful at Pack Forest on slopes of up to 30 percent, a demonstration on a variable tilt table showed that a 1" application of 17 percent solids sludge was stable on sand at a slope of 42 percent (Henry, 1983). However, an injection of 8 percent sludge on a slope of 12-15 percent at the Centralia Coal mine was unstable and had to be retreated with sludge of a thicker consistency (Keating, personal communication). Solids in the range of 14-20 percent seem to be appropriate for most applications using dewatered sludge. Spray application of up to 18 percent solids is possible at Pack Forest because of high pressure spray equipment. A disadvantage of using sludge in hydroseeding may be that sludge consistency of less than 10 percent would be needed, depending on the abilities of the equipment. Sludge with a low percentage of solids may not be stable on steep slopes. However, testing of different aged sludges may alleviate this problem.

Different mixes of grass seed may produce variable results on sludge-amended soils. A mix of clover, fescue, and three kinds of ryegrass was applied to the powerline right-of-way sludge demonstration study in progress at Pack Forest. The mixture offered a combination of quick growth, winter hardiness, and appeal to wildlife (Henry, personal communication). Variable grass mixtures should be tested for growth rate and productivity in order to ensure optimum results.

Existing vegetation to be evaluated may include poorly growing erosion control grasses or struggling trees and shrubs (Figure 9). A project by Metro at the King County Airport improved

Figure 9. Poorly Established Erosion Control Grass Stand Along I-5, Olympia.

turf growth by spreading a thin layer of sludge on an existing grass stand of less than 5 percent slope. The work at Pack Forest on trees from 7 to 200 years old provides a model for over- and understory spray application to trees. Both of these techniques, however, have high visual impact and may be unacceptable on public roadways. While subsurface injection is the least visually impacting technology, it has only been used on unvegetated areas. A test project of subsurface injection on an existing, poorly-growing grass stand may show improved productivity from sludge injection with minimal vegetation losses during application.

Replacement of undesirable species such as Scotch broom may require one of two actions: 1) mechanical removal of broom plants, with subsequent sludge application and grass seeding; or 2) sludge application and grass seeding over existing broom plants. Being a nitrogen-fixing plant, Scotch broom is typically out-competed on bare sites by other species when nitrogen-rich sludge has been applied. It remains to be seen in a test study whether broom plants would die off substantially after sludge application to an existing stand and how much mechanical removal would be required.

A demonstration study should take place in a community that is interested in exploring alternatives to sludge disposal and where public officials are willing to support and encourage alternative technologies. With proper steps taken to restrict public access and to prevent public health and environmental impacts, public support could be encouraged through existing political structures and political figures. Such support is essential in making a demonstration study, and an eventual full-scale application, successful

Site Selection

In order to select a site for sludge application, background data on soil characteristics, geology, topography, hydrology, and water quality must be gathered. An investigation of the soil profile will allow for an understanding of the potential for heavy metal and nitrogen leaching and the surface and subsurface drainage patterns. The soil drainage patterns will subsequently give information on necessary distance to groundwater recharge zones and distance to receiving waters. The type of surface water drainage system associated with the site (e.g. vegetated drainage channel, overland surface runoff, etc.) will also help determine the necessary distance from receiving waters. Maximum slopes depend on management practices or application techniques that minimize erosion hazards.

Results of a demonstration study should give information on methods of application to variable slopes, any problems with surface water and groundwater, and changes in vegetative growth patterns. Careful site selection is essential in optimizing the benefits of a sludge application, while minimizing or eliminating any negative impacts. Since each potential application site has a unique set of characteristics, it is essential to develop a thorough set of selection criteria. The results of an appropriate demonstrate project, along with the information presented in this report, should be a sufficient basis for formulating these criteria.

CONCLUSIONS

The utilization of sludge as a resource, instead of its disposal as a waste, opens up many opportunities for municipalities and for land managers. Active research in the Northwest and other areas of the country has shown that the benefits of sludge application are numerous, and that the problems are not unmanageable.

The use of sludge in roadside revegetation appears to be a feasible and cost-effective project. Several tests with grass plantations in sludge-applied areas have produced homogeneous, stable grass stands with no weed invasion. This outcome is consistent with WSDOT goals for many roadside areas, either for permanent or temporary grass stands. Enhancement of existing vegetation, shown to be possible with sludge land application, is also a desired feature on many WSDOT right-of-ways. Several existing application technologies appear to be usable on inter-changes and relatively shallow slopes along roadways. Since roadsides are not used to grow food or food-chain crops, many of the problems encountered in sludge land application that are related to edible crops are eliminated.

A cost comparison demonstrated that sludge can be effective in reducing maintenance costs, as well as providing slope stabilization through self-sustaining erosion control vegetation. Sludge used in hydroseeding, spreading and disking operations, and sub-surface injection, may prove to be the most cost-effective application methods, depending on the conditions in which they are applied.

The questions remaining about roadside application revolve around public exposure, application to steep cut banks, changes in surface water and groundwater quality, changes in grass (vegetation) productivity, selection of appropriate plant varieties, community acceptance, and specific direct and indirect costs of sludge application. Many of these questions can be answered or refined through a demonstration study.

A demonstration study would not only answer some of the remaining questions, but would provide a tool for education of both the public and WSDOT personnel. Not only do the physical constraints of sludge application need to be overcome, but also misconceptions about the use of sludge and the choices that are presently available for waste disposal and waste utilization.

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APPENDICES

APPENDIX A

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APPENDIX B

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APPENDIX C

WASHINGTON STATE DEPARTMENT OF ECOLOGY
RECOMMENDED METHODS FOR CALCULATING SLUDGE APPLICATION RATES
BASED ON NITROGEN AND CADMIUM LOADINGS

GENERAL INFORMATION

A. Assumptions:

1. The methods below assume the density of sludge is the same as water, i.e., 1.0; but in actuality, the density of sludge can be slightly greater.

2. The formulas and examples below assume that nitrite (NO_2) nitrogen and nitrate (NO_3) nitrogen levels in wet and dry sludges are negligible. These nitrogen levels may be significant in aerobically digested sludge.

   When analyzing sludge for nitrogen levels, always analyze for nitrite, nitrate, ammonia, and organic nitrogen.

3. The calculations below assume 100 percent availability of ammonia nitrogen (NH_3-N) and 20 percent availability of organic nitrogen (Org-N) in the first year. Organic nitrogen availability to plants can actually range from 20 percent to 35 percent, depending on environmental conditions, e.g., soil moisture content, soil temperature, aerobic/anaerobic nature of soil.

B. Chemistry/Math - Rules and Tips

1. When wet or dry sludge is analyzed for nitrogen levels, volumetric chemistry is generally used. Therefore, results are initially obtained as a volumetric or wet weight concentration, i.e.,

$$\frac{mg}{liter}$$

   Volumetric or wet weight concentrations $\frac{mg}{liter}$ can easily be expressed as a gravimetric or dry weight concentration $\frac{mg}{kg}$.

   The WDOE recommends that sludge analyses be reported as dry weight results.

B.1.a. To convert concentrations expressed as $\frac{mg}{l}$ (wet weight) to $\frac{mg}{kg}$ (dry weight), divide the wet weight by the percent (%) solids.

$$\frac{mg}{kg}\text{ (dry weight)} = \frac{\frac{mg}{l}\text{ (wet weight)}}{\text{\% solids (as decimal fraction)}}$$

B.1.b. To convert concentrations expressed as $\frac{mg}{kg}$ (dry weight) to $\frac{mg}{l}$ (wet weight), multiply the dry weight by the percent (%) solids. $\frac{mg}{l}$ (wet weight) = $\frac{mg}{kg}$ (dry weight) X % solids (as decimal fraction)

2. <u>Units</u>

$1000 = 1 \times 10^3 = \text{kilo}$

$.001 = \frac{1}{1,000} = 1 \times 10^{-3} = \text{milli}$

$.000001 = \frac{1}{1,000,000} = 1 \times 10^{-6} = \text{micro}$

THEREFORE: 1 kg = 1 kilogram = 1,000 grams

1 mg = 1 milligram = 1×10^{-3} grams = .001 g

1 ug = 1 microgram = 1×10^{-6} grams = .000001 g

<u>Gravimetric Units</u>: (How to relate dry weight concentrations to parts per million)

$$1\ \frac{\text{mg}}{\text{kg}} = \frac{1\ \text{milligram}}{1\ \text{kilogram}} = \frac{1 \times 10^{-3}\ \text{g}}{1 \times 10^{3}\ \text{g}} = \frac{.001\ \text{g}}{1,000\ \text{g}}$$

$$\frac{.001\ \text{g}}{1,000\ \text{g}} \times \frac{1,000}{1,000} = \frac{1\ \text{g}}{1,000,000\ \text{g}} = 1 \text{ part per million (ppm)}$$

<u>Volumetric Units</u>: (How to relate wet weight concentrations to parts per million)

1 liter = 1,000 milliliters = 1,000 grams

THEREFORE:

$$1\ \frac{\text{milligram}}{\text{liter}} = \frac{.001\ \text{g}}{1,000\ \text{ml}} = \frac{.001\ \text{ml}}{1,000\ \text{ml}}$$

$$\frac{.001\ \text{ml}}{1,000\ \text{ml}} \times \frac{1,000}{1,000} = \frac{1\ \text{ml}}{1,000,000\ \text{ml}} = 1 \text{ part per million (ppm)}$$

3. <u>Percent</u>

To express a number as a percent, you multiply by 100.

To express a percent as a decimal fraction, you divide by 100.

<u>Example</u>:

Express $\frac{15,000\ \text{mg}}{\text{kg}}$ NH_3-N as a.) a percent; and b.) a decimal fraction:

a.) $\frac{15,000\ \text{mg}}{\text{kg}} = 15,000$ parts per million (ppm)

$$\frac{15,000}{1,000,000} \times 100 = \frac{15}{10} = 1.5\%$$

b.) $\frac{1.5\%}{100} = .015$

CALCULATIONS

A. To Calculate Sludge Application Rates Using Sludge Nitrogen Analyses on a Dry Weight Basis:

A.1.

To calculate sludge nitrogen application rates, the sludge available nitrogen content must first be calculated:

$$\frac{\text{lbs. N Available}}{\text{Ton Sludge}} = \left(\%\ NH_3\text{-N} \times 100\% \times \frac{2{,}000\ \text{lbs.}}{\text{ton}}\right) + \left(\%\ \text{Org-N} \times 20\% \times \frac{2{,}000\ \text{lbs.}}{\text{ton}}\right)$$

$$= \left(\frac{\%\ NH_3\text{-N}}{100} \times \frac{100\%}{100} \times \frac{2{,}000\ \text{lbs.}}{\text{ton}}\right) + \left(\frac{\%\ \text{Org-N}}{100} \times \frac{20\%}{100} \times \frac{2{,}000\ \text{lbs.}}{\text{ton}}\right)$$

The simplified form would be:

$$= (\%\ NH_3\text{-N} \times 20) + (\%\ \text{Org-N} \times 4)$$

Example:

Data

Analysis of Dried Sludge yields

NH_3-N = 10,000 mg/kg

Total-N = 30,000 mg/kg

Calculations

NH_3-N = 10,000 mg/kg

= 10,000 ppm

$= \frac{10{,}000}{1{,}000{,}000} \times 100$

= 1%

Similarly, Total-N = 3%

Organic-N = Total-N minus NH_3-N

= 3% minus 1%

= 2%

From above: $\frac{\text{lbs. N Available}}{\text{Tons Sludge}} = (\%NH_3\text{-N} \times 20) + (\%\ \text{Org-N} \times 4)$

Therefore: $\frac{\text{lbs. N Available}}{\text{Tons Sludge}} = (1 \times 20) + (2 \times 4)$

$= 20 + 8$

$= \underline{\underline{28}}$ lbs.

A.2.a.

To calculate sludge application rate as tons sludge/acre/year, divide the crop nitrogen requirement by the sludge nitrogen content.

$$\frac{\frac{\text{Ton Sludge}}{\text{Acre}}}{\text{Year}} = \frac{\text{Crop N uptake as } \frac{\text{lbs./acre}}{\text{year}}}{\text{Sludge N as } \frac{\text{lbs}}{\text{ton sludge}}}$$

$$= \frac{\text{lbs. N/acre/year}}{\text{lbs. N/ton sludge}}$$

$$= \frac{\frac{\text{ton sludge}}{\text{acre}}}{\text{year}}$$

Example:

Data

Crop N uptake for corn = $\frac{\text{170 lb. N/acre}}{\text{year}}$

Sludge N as lbs./tons sludge = $\frac{\text{28 lbs. N}}{\text{ton sludge}}$ (From A.1.)

Calculation

$$\frac{\frac{\text{Ton Sludge}}{\text{Acre}}}{\text{Year}} = \frac{\frac{\frac{\text{170 lbs.}}{\text{acre}}}{\text{year}}}{\frac{\text{28 lbs. N}}{\text{ton sludge}}}$$

$$= \frac{\frac{\text{6.1 tons}}{\text{acre}}}{\text{year}}$$

As you can see $\frac{\text{6.1 tons sludge}}{\text{acre}}$ were needed for the first year and only $\frac{\text{5.7 tons sludge}}{\text{acre}}$ were needed for the second year. In the third year even less $\frac{\text{tons sludge}}{\text{acre}}$ would be needed because of the residual mineralization of both year 1 and year 2 sludges combined with the initial nitrogen availability of the year 3 sludge. The important thing to understand is that continually applying at $\frac{\text{6.1 tons sludge}}{\text{acre}}$ every year for four years would be over applying and could pollute surface or ground water.

A.2.b. For repeated applications, once per year, you may assume that Organic-N continues to become available (mineralize) at a rate of 5% per year for the next three years. The 5% Org-N mineralization rate for the three years after application must be multiplied times the continually decreasing pounds per acre Org-N left from the first year application. So if there are yearly sludge applications, the net additional effect of the available organic nitrogen from the first year's sludge gets smaller every year. By the fifth year the contribution of organic nitrogen is so small it can be disregarded. The resultant Org-N number is then subtracted from the crop requirement when computing application rates. For year 1 it can generally be assumed there is no residual nitrogen. For years 2, 3, and 4 the general equation is:

$$\frac{\text{Tons sludge}}{\text{acre}} = \frac{\text{Crop N requirement - residual N from previous year(s) sludge}}{\frac{\text{lbs. available N}}{\text{ton sludge to be applied}}}$$

Example:

Data: 1. 2% Org-N in 1st year sludge (see A.1.)

2. 6.1 tons/acre/year was 1st year application rate (see A.2.a.)

3. 28 lbs. N/ton sludge for year 2 sludge (see A.1.)

4. Crop N uptake for corn 170 lb. N/acre/year

Calculation:

For year 1 applied:

$$\frac{\text{lbs. Org-N}}{\text{acre}} = \frac{\text{6.1 ton sludge}}{\text{acre}} \times 2\%\ \text{Org-N} \times \frac{\text{2,000 lbs}}{\text{ton sludge}} = \frac{\text{240 lbs. Org-N}}{\text{acre}}$$

For year 2 residual:

$$\frac{\text{lbs. Org-N}}{\text{acre}} = \left[\frac{\text{240 lbs. Org-N}}{\text{acre}} - \frac{\text{240 lbs Org-N}}{\text{acre}} \times 20\%\right] \times 5\%$$

$$= [240 - 48] \times .05$$

$$= \frac{\text{9.6 lbs}}{\text{acre}}\ \text{residual N}$$

For year 2 application rate:

$$\frac{\text{Tons sludge}}{\text{acre}} = \frac{\text{Crop N requirement - year 1 residual N}}{\frac{\text{lbs. available N}}{\text{ton year 2 sludge}}}$$

$$= \frac{\frac{170 \text{ lb. N}}{\text{acre}} - \frac{9.6 \text{ lb. N}}{\text{acre}}}{\frac{28 \text{ lb. N}}{\text{ton year 2 sludge}}}$$

$$= \frac{5.7 \text{ tons year 2 sludge}}{\text{acre}}$$

A.3.

Calculate sludge application rate as cubic yards/acre/year as follows:

$$\frac{\text{Cubic yards sludge}}{\frac{\text{Acre}}{\text{Year}}} = \frac{\text{ton sludge}}{\frac{\text{acre}}{\text{year}}} \times \frac{2{,}000 \text{ lbs.}}{\text{ton}} \times \frac{1 \text{ cubic yard}}{1684 \text{ lbs.}}$$

$$= \frac{\text{ton sludge}}{\frac{\text{acre}}{\text{year}}} \times 1.2$$

Example

To convert 6.1 $\frac{\text{tons/acre}}{\text{year}}$ to $\frac{\text{cubic yards/acre}}{\text{year}}$

$$\frac{\text{Cubic yards/acre}}{\text{year}} = 6.1 \times 1.2$$

$$= 7.3 \ \frac{\text{cubic yards/acre}}{\text{year}}$$

B. <u>To Calculate Nitrogen Loading for Wet Sludge, e.g., Digester Sludge, Using Sludge Analyses on a Wet Weight Basis:</u>

It is important to remember when surface applying liquid sludge that approximately 50% of the ammonia nitrogen NH_3-N volatilizes. When doing the calculations, expression of results on a wet weight basis, i.e., mg/l, <u>must</u> be used (see General Information Section, B.1.b.).

1. To obtain:

$$\frac{\text{lbs. N. Available}}{\text{gallons sludge}} = \left(\%\ NH_3\text{-N} \times 50\% \times \frac{8.3\ \text{lbs.}}{\text{gal.}}\right) + \left(\%\ \text{Org-N} \times 20\% \times \frac{8.3\ \text{lbs.}}{\text{gal.}}\right)$$

$$= \left(\frac{\%\ NH_3\text{-N}}{100} \times \frac{50\%}{100} \times \frac{8.3\ \text{lbs.}}{\text{gal.}}\right) + \left(\frac{\%\ \text{Org-N}}{100} \times \frac{20\%}{100} \times \frac{8.3\ \text{lbs.}}{\text{gal.}}\right)$$

$$= (\%\ NH_3\text{-N} \times .04) + (\%\ \text{Org-N} \times .02)$$

Example:

<u>Data</u>

Sludge Analysis Dry Weight Basis yields:

NH_3-N = 10,000 mg/kg   % Solids = 3%

Total-N = 30,000 mg/kg

Organic-N = 20,000 mg/kg   (i.e., Total-N minus Inorganic-N)

<u>Calculations</u>

$$\text{Organic N} = \frac{20{,}000\ \text{mg}}{\text{kg}} \times .03 \qquad NH_3\text{-N} = \frac{10{,}000\ \text{mg}}{\text{kg}} \times .03$$

$$= 600\ \text{mg/l} = 600\ \text{ppm} \qquad = 300\ \text{mg/l} = 300\ \text{ppm}$$

$$= \frac{600}{1{,}000{,}000} \times 100 \qquad = \frac{300}{1{,}000{,}000} \times 100$$

$$= .06\%\ \text{(wet weight)} \qquad = .03\%\ \text{(wet weight)}$$

From above: $$\frac{\text{lbs. N Available}}{\text{gallons sludge}} = (\%\ NH_3 \times .04) + (\%\ \text{Org-N} \times .02)$$

$$= (.03 \times .04) + (.06 \times .02)$$

$$= \frac{.0024\ \text{lbs. N}}{\text{gallons sludge}}$$

$$= \frac{2.4 \times 10^{-3}\ \text{lbs. N}}{\text{gallons sludge}}$$

2. Use crop nitrogen requirement to calculate sludge application rate as gallons per acre per year:

$$\text{gallons/acre/year} = \frac{\text{Crop N uptake as lbs./acre/year}}{\text{Sludge N as lbs./gallon}}$$

$$= \frac{\text{lbs. N/acre/year}}{\text{lbs. N/gallons}}$$

$$= \text{gallon sludge/acre/year}$$

Example:

Data

Crop N uptake for corn = 170 lb./acre/year

Sludge N as lbs./gallon - .0024 lbs. N/gallon sludge (From previous example)

Calculations

$$\frac{\text{gallons sludge}}{\text{acre}} = \frac{\text{Crop N uptake lb./acre/year}}{\text{Sludge N lb./gal.}}$$

$$= \frac{170}{.0024} = 70{,}833 \text{ gallons sludge/acre/year}$$

C. To Calculate Cadmium Loading for Dry and Wet Sludge Applications

Using Cadmium Analysis on a Dry Weight Basis:

The federal Resource Conservation and Recovery Act (RCRA) 40 CFR, Part 257, prescribes the cadmium loading allowed annually from sewage sludge applied to food crops. The following chart converts the metric system kg/ha (used in RCRA), to the avoirdupois lb./acre system.

Time Period	Maximum Annual Cadmium Application Rate	
	kg/ha	lb./acre
Present to June 30, 1984	2.0	1.8
July 1, 1984 to December 31, 1986	1.25	1.1
January 1, 1987 and after	0.5	.45

The following calculations will demonstrate methods to determine sludge cadmium loading rates expressed as: 1) $\frac{\text{kg}}{\text{ha}}$ 2) $\frac{\text{lb.}}{\text{acre}}$ 3) $\frac{\text{tons}}{\text{acre}}$ 4) $\frac{\text{cu. yds.}}{\text{acre}}$ 5) $\frac{\text{gals}}{\text{acre}}$

These methods are based on cadmium laboratory results being reported as mg/kg dry weight. Methods 1-4 are to be used for applying dried sludges. Method 5 should be used for applying wet (digester) sludges:

METHOD 1: kg sludge/ha (application rate) $= \frac{\text{kg Cd/ha allowed}}{\text{sample result (dry weight)}} \times 10^6$

Example:

Data

kg Cd/ha allowed = 2.0 kg Cd/ha;

sample result = 4.0 mg Cd/kg dry weight.

Calculation

kg sludge/ha (application rate) $= \frac{2.0}{4.0} \times 10^6 = .5 \times 10^6$

$= \frac{500{,}000 \text{ kg sludge}}{\text{ha}}$

<u>METHOD 2</u>: lb. sludge/acre (application rate) = $\frac{\text{lb. Cd/acre allowed}}{\text{sample result (dry weight)}} \times 10^6$

<u>Example</u>:

<u>Data</u>

lb. Cd/acre allowed = 1.8 lb. Cd/acre;

sample result = 4.0 mg Cd/kg dry weight.

<u>Calculation</u>

lb. sludge/acre (application rate) = $\frac{1.8}{4} \times 10^6 = .45 \times 10^6$

= 450,000 lb. sludge/acre

<u>METHOD 3</u>: tons sludge/acre (application rate) =

$$= \frac{\text{lb. Cd/acre allowed}}{\text{sample result (dry weight)}} \times 10^6 \times \frac{\text{ton}}{\text{2000 lbs.}}$$

$$= \frac{\text{lb. Cd/acre allowed}}{\text{sample result (dry weight)}} \times 500$$

<u>Example</u>:

<u>Data</u>

lb. Cd/acre allowed = 1.8 lb. Cd/ acre;

sample result = 4.0 mg Cd/kg dry weight.

<u>Calculation</u>

tons sludge/acre (application rate) = $\frac{1.8}{4} \times 500$

= 225 tons sludge/acre

METHOD 4: cubic yards sludge/acre (application rate) =

$$= \frac{\text{lb. Cd/acre allowed}}{\text{sample result (dry weight)}} \times 10^6 \times \frac{\text{1 cubic yard}}{\text{1684 lbs.}}$$

$$= \frac{\text{lb. Cd/acre allowed}}{\text{sample result (dry weight)}} \times 594$$

Example:

Data

lb. Cd/acre allowed = 1.8 lb. Cd/acre;

sample result = 4.0 mg Cd/kg dry weight.

Calculation

cubic yards sludge/acre (application rate) = $\frac{1.8}{4} \times 594$

= 267 cubic yards sludge/acre

METHOD 5: To obtain gallons/acre sludge application rate for cadmium loading, it is necessary to convert mg/kg Cd dry weight analysis back to a wet weight: $\frac{mg}{l}$ Cd (liter)

$$\frac{mg}{l}\text{ Cd} = \frac{mg}{kg}\text{ Cd} \times \frac{\%\text{Solids}}{100}$$

Using the mg/l Cd number, gallons/acre application rate can be determined as follows:

$$\frac{\text{gallons sludge}}{\text{acre}}\text{ (application rate)} = \frac{\text{lb. Cd/acre allowed}}{\frac{mg}{l}\text{ Cd}} \times 10^6 \times \frac{\text{1 gallon}}{\text{8.3 lbs.}}$$

$$= \frac{\text{lb. Cd/acre allowed}}{\frac{mg}{l}\text{ Cd}} \times 12 \times 10^4$$

Example:

Data

lb. Cd/acre allowed = 1.8 lb./acre;

sample result = 4.0 mg Cd/kg dry weight.

%Solids = 5%

Calculations

First, convert dry weight to weight:

$$\frac{mg\ Cd}{l} = \frac{mg\ Cd}{kg} \times \frac{\%Solids}{100}$$

$$= 4\ mg/kg \times \frac{5}{100}$$

$$= 4 \times .05$$

$$= .2\ mg/l$$

From above gallons sludge/acre (application rate) =

$$= \frac{lb.\ Cd/acre\ allowed}{\frac{mg\ Cd}{l}} \times 12 \times 10^4$$

$$= \frac{1.8}{.2} \times 12 \times 10^4$$

$$= 1{,}080{,}000\ gallons$$

APPENDIX D

GLOSSARY

AEROBIC - an organism or process requiring oxygen.

ANAEROBIC - an organism or process that does not require oxygen.

AQUIFER - permeable layer of underground gravel or sand that contains, or serves as conduit for, groundwater.

BIOLOGICAL MAGNIFICATION - buildup in concentration of same substance, such as DDT, in successively higher trophic levels of the food chain or web.

COMPOSTING - breakdown of organic matter in solid waste in the presence of aerobic bacteria to produce a humus-like end product, which can be used as a soil conditioner.

ECOSYSTEM - self-sustaining and self-regulating community of organisms interacting with one another and with their environment.

EFFLUENT - the liquid release from wastewater.

EUTROPHICATION - an excess of nutrients in an aquatic ecosystem, supporting a large amount of aquatic plant life that can eventually deplete the oxygen supply.

FOOD CHAIN - transfer of energy in the form of food from one organism to another when green plants (producers) are consumed by plant-eaters (herbivores), which in turn may be consumed by meat-eaters (carnivores).

GROUNDWATER - water beneath the surface of the ground in a saturated zone.

HEAVY METALS - group of metallic elements with relatively high atomic weights, such as mercury, iron, cobalt, cadmium, lead, nickel, zinc, copper, and others.

INORGANIC - composed of matter other than plant or animal origin (e.g. mineral fertilizer).

LEACHING - extraction or flushing out of dissolved or suspended materials from soil, solid waste, or another medium by water or other liquids as they percolate downward through the medium to groundwater.

NUTRIENT - element or compound that is an essential raw material for organism growth and development. MACRONUTRIENTS are those needed in relatively large quantities to sustain growth (e.g., carbon, hydrogen, oxygen, nitrogen). MICRONUTRIENTS are those needed only in small quantities (e.g. copper, nickel, zinc).

ORGANIC - a substance of plant or animal origin (e.g., petroleum-based fertilizer).

PATHOGEN - any organism that produces disease.

pH - numeric value that indicates relative acidity or alkalinity of a substance on a scale of 0 to 14, where 7.0 is neutral, values less than 7 indicate acidity and values greater than 7 indicate alkalinity. pH equals the negative of the base 10 logarithm of the hydrogen ion concentration.

RUNOFF - overland movement of water to surface water, sometimes containing solid particles, nutrients, metals, and other contaminants.

SLUDGE - solid matter settling to the bottom of sedimentation tanks in a sewage treatment plant that must be treated further by digestion, possibly dried, and disposed of or recycled on the land.

SOIL TEXTURE - the consistency of soil exhibited by relative proportions of particles of varying size (e.g. clay, silt, sand), and the resulting pore space between particles for air and water storage.

SUBSOIL - the soil underlying top layers of humus, organic matter, and topsoil in an undisturbed soil profile. Usually of poor quality for growing vegetation.