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Land Cultivation of Industrial Wastes and Municipal Solid Wastes

State-of-the Art Study

Volume I Technical Summary and Literature Review

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LAND CULTIVATION OF INDUSTRIAL WASTES AND MUNICIPAL SOLID WASTES: STATE-OF-THE-ART STUDY

Volume I

Technical Summary and Literature Review

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Soil has an enormous capability to assimilate waste materials. If managed properly, soil can often serve as a sink for a wide range of waste materials. Thus, land cultivation is truly a final disposal method whereby the waste is recycled on land.

Francis T. Mayo
Director
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ABSTRACT

A literature review of published and unpublished data was conducted to evaluate land cultivation of municipal refuse and industrial wastes. Land cultivation is a process whereby waste is spread and incorporated into the surface soil. This process is viable only where soil, geology, waste characteristics, climate, and other environmental conditions permit. Depending on waste characteristics, land cultivation can be either coupled with crop production or used solely as a disposal practice. After incorporation into the soil, the waste is decomposed by microbial metabolism and chemical processes, or is lost through volatilization.

Land cultivation of municipal refuse has been limited due to the large land area required, possible unsightliness, and the lack of significant amounts of operational information. Land cultivation of industrial wastes has been more widely practiced. For instance, land treatment of wastewaters has been used by the food processing industry. Three treatment systems are commonly employed: slow infiltration, overland flow, and rapid infiltration. Grasses are grown to remove nutrients and water and to facilitate infiltration. Land cultivation of sludges has also been practiced by the food processing industry, and by refinery, paper and pulp, pharmaceutical, and a few organic chemical industries. Unless the waste to be deposited on land is considered either harmless or a nutrient source and soil amendment, the disposal area is generally devoid of any purposely seeded food crop. Most farm equipment may be suitable for use in the land cultivation of industrial wastes.

Approximately 3 percent of all industrial wastes can be disposed of by land cultivation. The waste loading rate is generally limited by the soil physical properties (texture, drainage, and permeability) and waste characteristics (pH, bulk density, soluble salt and heavy metal contents, nitrogen and phosphorus contents, etc.). Land cultivation costs range from \$2 to \$18/m^3 of industrial waste, excluding transport cost. Existing state regulations generally call for consideration of planned land cultivation projects on a case-by-case basis.

Documented environmental impacts of land cultivation concern soil accumulation and plant uptake of heavy metals and other waste constituents, surface and groundwater contamination, and emanation of odors. These and other potential impacts are

ABSTRACT (continued)

controllable by improved operating techniques and effective monitoring programs. In particular, routine monitoring of surface soil can provide an early warning of fugitive contamination. Also included are a site conceptual design and case study summaries (detailed in Volume 2).

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SECTION 1

INTRODUCTION

The United States, with its large population and highly industrialized economy, generates vast volumes of waste annually. During the 4-yr period from 1970 to 1974, an estimated 122 million t/yr (135 million tons/yr) wet weight of municipal solid waste was produced. Industrial wastes were estimated at an additional 237 million t/yr (260 million tons/yr) dry weight during this same period (1).

Disposal of these wastes has become a major problem. Many disposal techniques have been utilized or proposed, none of which is problem free. Problem areas encountered have included adverse environmental impacts, excessively high costs, and a scarcity of acceptable sites. Existence of these problems has led to a continuing search for new techniques to dispose of specific waste types.

Land cultivation of municipal solid waste and industrial sludges is a relatively new disposal method. It has been practiced with several industrial sludges and wastewaters in several locations in the nation, and with municipal solid waste (refuse) in at least three locations. Relatively little data is available on land cultivation, as compared to many other disposal methods, due primarily to its recent origin and limited practice. This report describes a study to compile available data from diverse sources and to develop new information about the practice of land cultivation.

AVAILABLE DISPOSAL METHODS AND PRACTICES

Refuse and industrial wastes are primarily disposed of in sanitary landfills, because landfilling usually has been the least costly method of disposal acceptable to state and federal environmental health agencies (2). However, there are currently mounting tonnages of waste being produced, decreasing land availability, higher land costs, and increasing public concern over environmental issues.

Table 1 lists disposal methods and associated drawbacks for municipal solid waste and industrial waste. It should be noted that some of the disposal methods are used for temporary storage or volume reduction; the residues left after such processing are

TABLE 1. DISPOSAL METHODS FOR MUNICIPAL SOLID WASTE AND INDUSTRIAL WASTE AND ASSOCIATED DRAWBACKS

Disposal Method	Significant Drawbacks
Sanitary landfill	Leachate and methane gas production; local lack of acceptable sites; long-term commitment of land to disposal purposes.
Incineration	Costs and air pollution.
Pyrolysis	Unproven and costs.
Composting	Costs and low demand.
Discharge to sewers	Treatment plant operational problems and water pollution.
Ocean dumping	Potential adverse effects on marine life.
Deep well injection	Highly dependent on favorable geologic conditions; water pollution.
Evaporation and infiltration	Air and water pollution.
Recycling	New market development.
Cropland application	Limited wastes.
Land cultivation or biodegradation	Water pollution; high land requirement.

generally buried in sanitary landfills. It is not unusual to find combinations of these methods practiced in a disposal process. For example, industrial sludges are often disposed with refuse in a sanitary landfill. The selection of a specific disposal method for any specific waste would be based upon the characteristics of the waste, land availability, and economic and environmental considerations.

DEFINITION OF LAND CULTIVATION

The term "land cultivation" as used throughout this report is defined as a process whereby waste is mixed with or incorporated into the surface soil at a land disposal site. Other terms which sometimes are used to describe the same basic practice are land farming, garbage farming, landspreading, land application, land disposal, soil farming, and soil incorporation. The land cultivation process differs from other solid waste disposal methods in that it is designed as a form of ultimate disposal.

HISTORY OF LAND CULTIVATION

Spreading of organic wastes on agricultural land to supply nutrients to crops is a practice dating far back in history. In the Orient, "night soil" has been applied to cropland for centuries. Farmers throughout the world have long utilized livestock manure to fertilize fields. In addition, many nations have been landspreading sewage for many years. These practices are considered to be a form of land cultivation. However, in these situations, the wastes commonly applied have been of animal or human origin, not of industrial origin.

Evidence indicates that the oil industry was one of the earliest practitioners of land cultivation of industrial sludges. For example, land cultivation of oily wastes at one site in California began in the 1950s.* Several major oil companies are currently conducting full-scale or experimental land cultivation operations. A major motivation for interest in this disposal method is the high rate of microbial decomposition of the oil under aerobic conditions. This allows relatively large quantities of oily waste to be applied to a given plot of land over time. The same land can be reused for disposal of additional waste. Thus, land cultivation often appears to be the most economical disposal method available.

The food processing industry was another early user of land cultivation. Organic wastes produced by this industry are readily decomposed in the soil. Also, the wastes applied can serve as a nutrient source and soil conditioner.

In recent years, several private firms - both manufacturers and commercial waste disposal operations - have begun practicing land cultivation. Cultivation of industrial sludges is often initiated with a small-scale pilot project when the cost and/or availability of alternative disposal methods force a reevaluation of disposal methodology. If the pilot project proves successful, the effort is generally expanded to cultivate all, or much, of the generated waste. There has been a recent expansion of the number of locations practicing land cultivation and the types of industrial sludges involved. However, the growth

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*SCS Engineers. Land Cultivation of Industrial Wastes and Municipal Solid Wastes: State-of-the-Art Study, Vol. 2. EPA 68-03-2435. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.

rate of land cultivation sites is relatively low, so that the number of sites is still not large. Further, the types of sludges cultivated continue to be primarily organic and non-hazardous.

Land cultivation of municipal refuse is not widely practiced. The earliest large-scale operation was conducted in Oregon (3) and has since been terminated. Field trials of land cultivating waste paper were recently completed by the U.S. Navy at Port Hueneme, California (4). Also, a small-scale demonstration project sponsored by EPA is being conducted near Houston (5). Only one large operation is being conducted - at Odessa, Texas. The goal of the Odessa project, which began in 1975, is to combine refuse disposal with soil enrichment objectives through application of the organic materials in the refuse. In general, cultivation of refuse will probably be limited in use due to a combination of factors: to be economically feasible, land cultivation demands a large tract of marginal land, which can be leased or puchased at low cost; the land must be close to the refuse source; and the climate must allow nearly year-round cultivation. Few localities offer such conditions.

PROJECT OBJECTIVES AND SCOPE

This project was conceived by the EPA as a state-of-the-art review and assessment of land cultivation as a disposal method for refuse and industrial wastewaters and sludges. A total of nine major objectives were established:

- Gather and assess all available information relating to past, existing, and planned land cultivation activities
- Identify sites where land cultivation is being practiced, and determine pertinent technical, operational, economic, and environmental factors of five to six selected sites
- Collect and analyze soil and vegetation samples at seven operating sites
- Evaluate the compatibility, feasibility, and environmental safety of land cultivation for various waste types
- Characterize and quantify waste types potentially suitable for land cultivation
- Review state regulations governing land cultivation
- Prepare a site conceptual design
- Investigate the environmental effects of nonstandard disposal of hazardous wastes

- Recommend needed future research and demonstration projects.

Waste Types Evaluated

Specifically excluded from consideration during this study are sewage sludge and all radioactive wastes. Little, if any, industrial wastewater is land cultivated per se; therefore, major emphasis was placed on industrial sludges and refuse. Both organic and inorganic sludges were evaluated. Information on the wastes studied is summarized in Table 2.

TABLE 2. MATRIX OF WASTES EVALUATED

Waste Type	No. of Sites Studied	Organic	Inorganic
Oily	3	X	
Organic chemicals	1	X	
Tannery	1	X	X
Sulfuric acid	1		X
Soap and detergent	1	X	
Pulp and paper	1	X	
Mixed industrial	1	X	X
Municipal refuse	1	X	X

Data Sources

A variety of sources were utilized to obtain information for this study. Much significant information was obtained from papers published in the proceedings of conferences or symposia on disposal of residues on land or land application of waste materials. Computer search for published data from various abstracts failed to provide sufficient information. A number of technical journals provided a valuable source of information. These included: Compost Science, Environmental Science and

Technology, Journal of Environmental Quality, Residue Review, Journal of Agricultural and Food Chemistry, Advances in Agronomy, and Agronomy Journal. Other significant sources included published books and governmental reports, and personal interviews with state regulatory agency representatives, university researchers, and site operators.

Project Duration

Activities were initiated in July 1976 and extended over an 18-mo period. Early effort was devoted to reviewing all available literature and contacting knowledgeable persons. Later, site visits were conducted to obtain necessary information and, in many cases, soil and vegetation samples.

SECTION 2

SUMMARY AND RECOMMENDATIONS

A review of the available literature pertaining to the disposal of industrial wastewater and sludge and municipal solid waste (refuse) by land cultivation has been conducted. This literature review was supplemented by field investigations at ten operating sites in nine states across the nation. Samples of soils and vegetation were collected at seven of the sites to provide further insight into the effects of land cultivating a variety of wastes.

Land cultivation is based on the aerobic microbial decomposition of organic wastes in the surface soil. This disposal practice may upgrade drastically disturbed lands and eliminate gas and leachate problems generally associated with anaerobiosis in sanitary landfills.

Nonstandard disposal of hazardous wastes was also investigated, but in less detail than land cultivation. The thrust of this effort was to identify nonstandard disposal techniques currently in use and the associated hazardous wastes.

This section summarizes the work which is reported in detail in later sections.

PROJECT FINDINGS AND CONCLUSIONS

Information obtained through the literature review, field interviews with operating personnel, on-site observations, and sampling and analysis allows several conclusions to be drawn concerning land cultivation as a disposal technique. Briefly summarized, these conclusions are:

1. Information about the operational, economic, and environmental aspects of land cultivation of municipal refuse and industrial sludge is limited. Published literature primarily deals with the land application of municipal sewage sludge and wastewater, and animal manures, as well as the landfilling of municipal refuse and hazardous wastes.

2. Major waste types currently being land cultivated are sludge from oil refineries and wastewaters from the

food processing and paper and pulp industries. The chemical composition of these wastes may vary considerably within the same industry. Waste characteristics often are not adequately characterized with respect to their environmental acceptability to be disposed by this method before being cultivated.

3. Existing land application is, in many respects, similar to farming operations. Experience and equipment used in farming are often applicable to, but not necessarily designed for, land cultivation.

4. The quantity of municipal solid waste cultivated is not expected to increase significantly in the future due to the sorting and shredding costs, and the scarcity and cost of large tracts of land in close proximity of major cities.

5. The quantity of cultivated industrial wastes should increase with time due to stringent regulations on air and water pollution control. The estimated quantities of industrial wastewater and sludge suitable for land cultivation in 1975, 1980, and 1985 are:

	1975	1980	1985
Wastewater (10^6 m^3/yr)	735	840-920	940-1,160
Sludge (10^6 t/yr, dry wt.)	7.2-7.5	8.8-9.1	10.8-11.1

6. Only a limited number of industrial wastes are amenable to land cultivation without treatment. With the advancement of processes that remove or detoxify the hazardous constituents of the waste products, the waste types potentially suitable for land cultivation will be increased.

7. Currently there are no official federal guidelines that suggest the suitability of certain waste types for land cultivation. The waste to be land cultivated is usually evaluated based on the concentrations of soluble salts (including sodium), heavy metals, and toxic organics and elements. Application rates vary with waste type, land availability, and climatic conditions.

8. There have been no incidents of water pollution reported at any of the studied sites. Heavy metals and trace elements appear to be retained in the zone of incorporation. Surface soils and plants collected from sites receiving refinery wastes showed elevated

concentrations of heavy metals (particularly lead, zinc, manganese, and nickel).

9. The effect of land cultivation on the food chain is not known, since those land cultivation sites studied that receive wastes containing high concentrations of hazardous constituents do not have agronomic or food crops.

10. Improvements in equipment design are needed. The cultivator used at Odessa, Texas, is subject to frequent mechanical breakdown. Users of conventional agricultural tank wagons for applying industrial sludge also report repeated failures. One such operator indicates that the tank wagons are his highest maintenance item.

11. Both capital and operating costs are dependent on local conditions. The most significant causes of these cost variations are labor rates and land costs.

12. Annual operating costs, which include amortized capital costs, are subject to economies of scale. This is most clearly indicated in the costs developed for the site conceptual design (Section 13). The costs obtained for five case study sites (Section 14) show a similar trend, even with local, site specific, differences. This data shows a range from $1.7/$m^3$ to $17.6/$m^3$, with input waste quantities of from 3,400 m^3/yr to 94,400 m^3/yr.

13. Only Texas was found to have regulations specifically formulated to apply to land cultivation of industrial wastes. Most states deal with each application on a case-by-case basis.

OPERATIONAL RECOMMENDATIONS

Four factors concerned with the operation and management of a land cultivation site are recommended. These are:

1. Before cultivation activities are initiated, the waste should be thoroughly characterized. The variability in its chemical and physical properties should also be determined.

2. Next, the suitability of the proposed site for receiving wastes should be determined. Various guides are available for rating soils for receiving many kinds of wastes. Groundwater quality and depth should be evaluated, as should site topography and drainage patterns and the proximity of surface water.

3. An operational site must be properly managed. This normally entails soil pH control (generally above 6.5 for most wastes), nutrient addition to promote microbial decomposition, rational selection of waste loading rates and tilling operations to maximize waste degradation, and installation and maintenance of surface and groundwater protection facilities.

4. The site must also be properly monitored to ensure that waste constituents are retained in the layer of incorporation. This can be accomplished by collecting soil samples at three depths (0 to 30, 30 to 60, and 60 to 90 cm) prior to site activation and at 3- to 6-mo intervals thereafter. Soil samples collected should be analyzed for those constituents present in the waste which may result in water pollution problems. Groundwater and nearby surface water should also be monitored to determine effects of the disposal operation. Depending on waste and site characteristics, it may be desirable to establish a program to monitor local air quality and runoff.

RECOMMENDED ADDITIONAL RESEARCH

Further research is recommended in several areas to more adequately understand the processes involved in land cultivation. Particularly recommended is research into the following subjects:

1. Techniques to promote waste decomposition such as addition of nutrients and amendments; microbial seeding; co-disposal of two or more waste types.

2. Characterization of the intermediate and final degradation products from most industrial wastes to determine the acceptability of a waste for land cultivation and the related monitoring requirements.

3. Retention mechanisms and factors influencing the form and long-term behavior of metals in soils. This is essential to development of better recommendations and management techniques for application of high metal wastes to soils.

4. Waste quality improvement by modifications of industrial processes and other techniques such that the properties that make some wastes unsuitable for land cultivation can be removed.

5. Limits of soil loading of heavy metals, toxic organics, and hazardous constituents on cropland and noncropland.

6. Utilization of waste products as feeds, fertilizers (macro- and micronutrients), soil amendments, construction materials, etc., and techniques to recover elements and other constituents in the wastes.

7. Air quality at the land cultivation sites receiving refinery wastes and mixed industrial waste, and in areas where dust is often a problem.

8. Public attitudes toward land cultivation. This may be improved through detailed and carefully organized educational and information programs.

SECTION 3

LAND CULTIVATION PRACTICES

LAND CULTIVATION OF MUNICIPAL SOLID WASTES

The average person in the United States discards wastes amounting to 2.27 kg/day (5 lb/day) (6). Hortenstine and Rothwell (7) have estimated that 450 million t (495 million tons) of municipal solid wastes must be handled yearly. For the most part, paper is the major waste component, followed by metals, glass, food, and garden and yard materials (Table 3).

In recent years, the paper content of municipal solid waste has increased, largely because of more product packaging in the prepared food industry (6).

Soil Incorporation of Municipal Solid Waste

Few research or demonstration projects have been concerned with the application of municipal solid waste directly to soil without prior sorting or shredding. The initial research study by Hart et al. (11) incorporated coarsely ground, unsorted municipal refuse into surface soil at Davis, California, at rates of 112 to 896 t/ha (50 to 400 tons/ac) dry weight. Nitrogen fertilizer was added to balance the C/N ratio of the refuse, and the plots were kept moist. After 1 yr, an unidentifiable organic residue remained in addition to glass, metal, and plastic. No odor, insect, or rodent problems were reported, but some blowing of plastic occurred. The second year, it was somewhat difficult to incorporate an additional 896 t/ha (400 tons/ac) of waste material into the soil, since the surface layer consisted primarily of residue from the previous year's waste application.

Municipal waste has been found to be most easily handled in a land application system if it has first been finely shredded (12). The shredded waste should be distributed evenly over the land surface at rates that allow incorporation into the soil.

Data from a study conducted near Boardman, Oregon, suggest that with conventional field tillage equipment, an application rate of 448 t/ha (200 tons/ac) should not be exceeded (13, 14). In this study, the unconsolidated refuse was approximately 60 cm (24 in) thick at an application rate of 896 t/ha (400

TABLE 3. BULK COMPOSITION OF REFUSE (IN PERCENT)

Component	Cambridge, Mass. *	Middleburg, Vermont *	California†	U.S. #
Paper	35.8	48.9	43.0	36.8
Newsprint	(7.8)	(3.0)	--	(7.2)
Metals	9.2	9.1	7.0	8.8
Ferrous	(8.3)	(8.8)	(6.0)	(7.8)
Nonferrous	(0.9)	(0.3)	(1.0)	(1.0)
Glass	18.6	16.6	9.0	9.4
Plastics	4.1	2.4	2.0	3.5
Cloth, rubber, leather	5.2	2.5	4.0	3.9
Wood	1.1	0.4	4.0	3.4
Food waste	5.9	4.7	6.0	15.6
Yard and garden	0.5	0.3	19.0	17.3
Misc. and uncategorized	19.6	15.1	6.0	1.3
TOTAL	100.0	100.0	100.0	100.0

*From Winkler and Wilson (8).

†From California State Solid Waste Management Board (9).

#From U.S. Environmental Protection Agency (13).

tons/ac). After mechanical compaction and irrigation, the refuse was reduced to a thickness of 20 cm (7.9 in). Little of the sandy soil was mixed with the refuse when the refuse depth exceeded 15 cm (6 in). During mixing, rags wound around the rotovator, a problem that may be corrected by using other types of mixing devices. All the studies indicate that the application rates for shredded municipal waste depend upon waste composition and plans for final land use.

King et al. (15) applied unsorted, shredded municipal refuse and anaerobically digested sewage sludge to a Guelph loam soil in Ontario, Canada, at rates of 188 and 376 t/ha (207 and 414 tons/ac) and 2.3 and 4.6 cm (0.9 and 1.8 in), respectively. The refuse was first spread on the soil surface. A furrow was then plowed about 30 cm deep into which most of the refuse adjacent to the furrow was raked by hand. The next furrow was then plowed to cover the refuse. This technique resulted in good refuse coverage but concentrated a large part of the refuse in the 15- to 30-cm depth. Refuse in the 0- to 10-cm layer was well mixed with the soil by subsequent diskings, but there was little mixing of refuse at lower depths. Following this initial refuse application, sludge was applied, allowed to dry, and then disked into the soil to a depth of 10 cm. It was not possible to physically mix the sludge with the refuse to achieve an optimal C/N ratio. However, the application technique did place the sludge in an area of high root uptake and the refuse at a low level, where nitrates from the sludge moving downward could be immobilized or denitrified.

Stanford (5), under contract with EPA (OSW), has initiated a 3-yr study near Houston on a multivariate trial. For the study, shredded municipal refuse, dry sewage sludge, and chemical fertilizer were added separately and together on the soil surface. The effects of these additions on crop yield and quality, soil quality, and water quality will be assessed over time. The shredded municipal refuse (80 percent $\leq$ 20 cm in size) and dry sludge were applied to a sandy clay (pH 5.37) at rates up to 560 t/ha (250 tons/ac) and 336 t/ha (150 tons/ac), respectively. The wastes were incorporated into the soil by rototilling with a heavy-duty soil stabilizer. Clover and grasses were seeded. Initial observations showed marked differences in growth due to waste application; high waste application rates produced only sparse vegetation (Stanford, personal communication).

The city of Odessa, Texas, is evaluating a program utilizing sewage sludge, septics, and shredded municipal refuse to stimulate the growth of vegetation in the city's semi-arid environment (Schnatterly, personal communication). Under this soil enrichment program, shredded residential solid wastes were spread at rates up to 278 t/ha (120 tons/ac) and were tilled into a sandy loam soil with a soil stabilizer. Septics and sewage sludge were added to some plots prior to seeding with grass. Preliminary observations indicate some equipment operating problems. In addition, blowing of paper occurs occasionally; however, odor is minimal.

During a Tri Service Project at the Navy Construction Battalion headquarters, Pt. Hueneme, California (4), waste paper consisting mostly of cardboard was shredded to three size categories (0.6 to 3.81, 10.2 to 15.2, and 31 cm) and applied at rates of 44.8 to 448 t/ha (20 to 200 tons/ac) to two soils (sandy and clayey). The waste was incorporated into the surface 0 to 46 cm (0 to 18 in) by a soil stabilizer. Usually one pass was sufficient. Researchers concluded that land cultivation of the waste paper was not cost effective. This disposal method was, therefore, not recommended for use by the Armed Services.

Soil Incorporation of Composted Municipal Solid Waste

Composted municipal refuse can be used to reclaim soil material and to enhance plant growth in strip mine spoils, mine tailings, various industrial deposits, and on agricultural lands. Composting lowers the C/N ratio of the refuse, stabilizes the organic materials, and eliminates most of the health hazards possibly associated with fresh refuse. If the compost includes sewage sludge, it usually contains small but significant amounts of nitrogen and phosphorus, which serve as nutrients for soil microorganisms and higher plants. On the other hand, it is speculated that plant uptake of heavy metals may reach phytotoxic levels after continuous high rates of sludge application (Duggan and Wiles, unpublished data). Concentrations of heavy metals in sewage sludge are dependent on the type and number of local industries and the quantities of their wastewaters discharged into the sewers (16).

Refuse compost was applied at 35 to 70 t/ha (16 to 31 tons/ac) to sand tailings from phosphate mining at Bartow, Florida. The compost added organic matter and plant nutrients to the tailings, as shown by the growth of sorghum and oat crops on the treated tailings (17). In another study, the growth of young slash pine trees was neither positively nor negatively affected by the application of Gainesville, Florida, refuse compost at rates of up to 44 t/ha (19.6 tons/ac) (18). However, aesthetics of the site were somewhat spoiled by the residue of nondegradable particulates that persisted on the soil surface.

Researchers have applied refuse compost from Johnson City, Tennessee, to reclaim strip mine spoils (19), an abandoned alkaline ash pond (20), and an eroded acid copper basin soil material (21). Revegetation with grasses was possible in all these trials.

In summary, land cultivation of shredded municipal refuse has received little attention, probably due to the lack of data on economics and associated agricultural production. There has been a similar lack of data on land application of other municipal solid wastes, such as lime and alum sludges.

Incorporation of refuse compost into barren lands makes revegetation possible, particularly with the use of chemical fertilizers. Refuse incorporation, resulting in soil stabilization and organic matter enrichment, permits the establishment of a cover vegetation where fertilization alone fails. On productive agricultural land, equivalent yield increases can be obtained more economically with inorganic fertilizers than with solid wastes or refuse compost. Thus, municipal refuse or compost application appears more attractive and feasible for marginal lands than for productive agricultural lands.

LAND CULTIVATION OF INDUSTRIAL WASTEWATERS AND SLUDGES

Industrial hazardous wastes are generally disposed of in secured chemical landfills or deep wells, or are incinerated. Some hazardous wastes are recycled, stockpiled, stored, or disposed into the ocean, if permitted. Formal, routine application of industrial hazardous wastes onto land and incorporation into the surface soil are not widely practiced, except for oil refinery wastes, and little published data is available.

A number of national conferences are held annually to discuss the various aspects of treatment and land disposal of industrial wastes. Recent ones are listed in Table 4.

Land Treatment of Industrial Wastewaters

Land application of nonhazardous organic wastes from food processing, pulp and paper, textile, tannery, and pharmaceutical industries has been practiced on a limited scale at several locations (22). Land disposal of nonhazardous industrial wastewaters has been well documented (7, 22, 23, 24). Land application at most locations is used primarily as a biological treatment of wastewater and disposal method with little or no regard to agricultural production. Three application methods are generally used: slow infiltration, overland flow, and rapid infiltration (23, 25). These methods depend, in various degrees, on three components: soil organic matter, cover crop, and microorganisms. Each method is maintained and operated so that these components can be used in association with the method's hydraulic conditions, as described below.

Overland flow, or surface flooding, is suitable for fine-textured soils and generally has a low hydraulic loading. Slow infiltration, or crop irrigation, is used on soils that have extensive reaction surfaces and sufficient structure to remove

TABLE 4. A LIST OF SELECTED RECENT CONFERENCES PERTINENT TO LAND CULTIVATION OF INDUSTRIAL WASTES

Conferences	Place	Date
Annual Cornell University Conference	Ithaca, NY	Annually
Annual Purdue Industrial Waste Conference	West Lafayette, IN	Annually
Soils for Management of Organic Wastes and Wastewaters	Muscle Shoals, AL	March 11-13, 1975
Residual Management by Land Disposal	Tucson, AZ	February 2-4, 1976
Disposal of Residues on Land	St. Louis, MO	September 13-15, 1976
Land Application of Waste Materials	Des Moines, IA	March 15-18, 1976
Treatment and Disposal of Industrial Wastewaters and Residues	Houston, TX	April 26-28, 1977
Management of Gas and Leachate in Landfills	St. Louis, MO	March 14-16, 1977
Disposal of Industrial Wastes and Oily Sludges by Land Cultivation	Houston, TX	January 18-19, 1978
Acceptable Sludge Disposal Techniques	Orlando, FL	January 31-February 2, 1978
Land Disposal of Hazardous Waste	San Antonio, TX	March 6-8, 1978

BOD, nitrogen, and phosphorus. Rapid infiltration, known as aquifer recharge, is used to remove considerable amounts of water through limited soil surface area. This method is suitable to coarse-textured soils, because its BOD and nutrient removal capacities are lower than those of the overland flow and slow infiltration methods. A good cover crop, preferably forage species, is essential in the slow infiltration and overland flow methods; it is not nearly as important in the rapid infiltration method.

Land Cultivation of Industrial Sludges

Among the industrial sludges, oily wastes have been widely disposed of by land cultivation, also called land farming by the oil industry (26, 27, 28). Ongoing experiments by several major oil companies are concerned with waste degradation rates, heavy metal movement in soil, runoff, as well as the potential for groundwater contamination, and uptake of trace elements and salts by vegetation grown on the oil-treated soil.

Probably the most extensive study of oily waste application to soil was that reported by Kincannon at a Texas oil refinery (27). In the 18-mo field study, three waste oil types - crude oil tank bottoms, a fuel oil (Bunker C), and a waxy raffinate - were applied to a sandy clay loam at approximately 10 percent oil (soil basis). Mixing of the viscous oily matter into the soil was not successful until the air temperature reached about 27^{o}C (80^{o}F). Reported rates of degradation were on the order of 27,600 l/ha (70 bbl/ac) per month for the oily matter. Bacteria assimilation was assumed to be responsible for the oil degradation, but the increased number of microbial populations observed was not shown to be hydrocarbon-utilizing bacteria.

Another study of oily waste application was conducted at a New Jersey refinery. The types of oily sludges cultivated at this refinery include crude oil cleanings, slop emulsion, distillate, additives tanks, and API separator bottoms, as well as other cleaning residues (28). The average composition of cultivated sludges is approximately 25 percent oil, 40 percent solids, and 35 percent water. The application rate is approximately 1,000 t/ha (450 tons/ac) per year. Sludges are spread to a final depth of about 6.7 cm (3 in) by a track dozer and are harrowed into the soil.

In another study, Dotson et al. (26) discussed land cultivation operations for oily waste disposal at three refineries: two in Texas, and one in Illinois. Based on the results, they concluded that:

- Soil microorganisms can oxidize and decompose a large quantity of petroleum hydrocarbons under a wide range of soil and environmental conditions.

- Land cultivation of oily wastes improves soil physical and chemical properties.

- Decomposition of the wastes may be accelerated by judicious use of lime and fertilizer, artificial drainage, and tillage.

- Land cultivation is an economical and comparatively foolproof method to dispose of oily wastes.

Many private firms now practice land cultivation of industrial sludges on a trial basis. However, very little data has been published on these activities. In California, 4 of the 11 Class I disposal sites that receive industrial hazardous wastes practice land cultivation, but only on a small scale. Land cultivation is not recommended by California regulatory agencies for disposal of wastes containing significant amounts of heavy metals and organic substances that are highly toxic in dust form (29).

Table 5 summarizes some representative research projects on industrial sludge application to agricultural lands. Except for the research at Michigan and Texas, other projects have been completed.

Available data indicate that industrial sludges most well suited for land cultivation have been either organic (e.g., oil refinery, paper and pulp, cannery, nylon, and fermentation residues) or treated inorganic wastes (e.g., steel mill sludge) containing insignificant levels of extractable heavy metals. When the waste material is applied to an agricultural land, it is generally used as a soil amendment and/or low-analysis nitrogen fertilizer. The suitability of an industrial waste for land cultivation will depend on many characteristics, including: concentrations of chemical elements in the soluble and insoluble forms, concentrations of soluble salts and hazardous organic compounds, bulk densities of waste solids, pH, BOD, and flammability and volatility.

Soil, if properly managed (i.e., pH adjustment, waste loading, cultivation, runoff control, among others), can often serve as an effective disposal sink for industrial organic wastewater and sludge. However, if a specific soil cannot assimilate the applied quantity of these wastes, the soil will become anaerobic, resulting in nuisances and potential water pollution and, possibly, failure of the system. Moreover, unless the waste materials are detoxified or decomposed to nondeleterious products by the soil or weather, repeated waste application will eventually load the upper soil zone to its ultimate capacity. As a result, waste disposal by land cultivation at the site would have to be terminated. A possible solution to

TABLE 5. SELECTED RESEARCH PROJECTS ON APPLICATION OF INDUSTRIAL SLUDGES TO AGRICULTURAL LANDS

Investigator(s)/location	Waste type	Crops grown
Jacobs/Alpena, Michigan	Hardboard	Wheat
Jacobs/Manistee County, Michigan	Paperboard	Corn
Jacobs/Kalamazoo County, Michigan	Paper mill	Corn, beans
Cotnoir/Seaford, Delaware	Nylon	Corn
De Roo/Conn. Agr. Expt. Sta.	Mycelium (fermentation)	Tomatoes, oats, tobacco, corn
Nelson/W. Lafayette, Indiana	Steel mill	Corn, soybeans, wheat
Polson/Halsey, Oregon	Refractory metals processing	Ryegrass
Noodharmcho and Flocker/ Davis, California	Cannery (tomato)	Wheat, barley
Brown/College Station, Texas	Refinery (API pit)	Burmuda grass

the problem would be to strip the surface 60 cm (12 in) of soil and replace it with topsoil that has previously received no waste, a very costly endeavor.

SECTION 4

WASTE CHARACTERISTICS AND QUANTITIES RELATED TO LAND CULTIVATION

Tables 6 through 8 present available information on the waste types, characteristics, quantities, and special disposal considerations for industrial wastewaters/sludges suitable for land cultivation. The information presented is a synthesis of data obtained from published and unpublished data and from industry representatives, trade associations, and individuals currently involved in related research (30-42).

Industrial wastes are normally considered suitable for land cultivation if they comply with the following criteria:

- The organic portion biologically decomposes at a reasonable rate.
- Does not contain material at concentrations toxic to soil microorganisms, plants, or animals. In addition, there must be reasonable assurance that long-term toxic effects resulting from accumulation through absorption or ion exchange can either be prevented or mitigated.
- Does not contain substances in sufficient concentration to adversely affect the quality of the groundwater.
- Does not contain substances in sufficient concentration to adversely affect soil structure, especially the infiltration, percolation, and aeration characteristics.

Industrial wastes most suitable for land cultivation are generated primarily by industries that process organic materials. Some of these industries involve the following:

- Food processing (as in canneries and dairies)
- Textile finishing
- Wood preserving
- Pump and paper production
- Organic chemicals production
- Petroleum refining
- Leather tanning and finishing.

TABLE 6. INDUSTRIAL WASTEWATER/SLUDGE CHARACTERISTICS

SIC *	Industry	Waste Type	Characteristics (1): BOD	COD	SS	TDS	O&G	pH	TKN-N	P	Cl
20	Food & kindred products										
203	Fruits & vegetables	Raw wastewater	200-4,000	300-10,000	200-3,000	500-2,000	---	4-12	10-400	---	---
202	Dairy products	Raw wastewater	1,000-4,000	---	400-2,000	---	---	4-11	1-13	10-200	46-1,930
2011	Meatpacking	Raw wastewater	800-2,100	---	400-1,300	---	300-1,200	---	70-170	7-50	350-2,100
2061	Cane sugar	Raw wastewater	100-2,000	500-4,000	300-3,000	700-4,000	---	---	1-15	0-13	---
2082	Malt beverages	Raw wastewater	300-1,300	---	500-1,000	---	---	5-7	---	---	---
2016	Poultry dressing plants	Raw wastewater	1,100	---	560	---	43	---	---	---	---
	All of the above	Secondary wastewater treatment sludges & screenings	See Note #2								
223, 225, 226	Textile finishing	Secondary wastewater treatment sludge	See Note #2								

SIC *	Industry	Waste Type	BOD	COD	SS	TS	pH	Phenols	TKN-N	NH_3-N	P	OrgN-N
2491	Wood preserving	Raw wastewater	2,800-5,000	11,500-19,600	1,400	6,340	4-5.5	20-300	89	32	<5	57

SIC *	Industry	Waste Type	Elemental Composition (% of ash)	>10%	1-10%	0.1-1%	0.01-01%	0.001-0.01%
26	Paper & allied products (pulp & paper, paperboard & fiberboard mills)	Primary(3) wastewater treatment plant sludge & cellulosic fiber fines		Si	Al, Fe, Na, K, Ti	Mg, Mu	Pb, Ba, Sr	Zn, Su, Cu, Cr, Ni, B

Ash Content ≅ 25% (oven-dried basis)

Dewatered sludge - 18-22% solids

Fiber fractionation - ~50% less than 150 mesh

SIC *	Industry	Waste Type	Characteristics
2824	Organic fibers, non-cellulosic	Secondary wastewater treatment	See Note #2

SIC *	Industry	Waste Type	Moisture	pH	Sulfur	Ca	N	Zn	P	Na	k	Fe	Bulk density (dry wt)	Porosity
283	Pharmaceuticals	Waste mycelium	65%	8	7.1%	8.2%	1.9%	0.18%	0.11%	0.34%	0.06%	0.21%	0.45 g/cc	78 (vol %)

SIC *	Industry	Waste Type	BOD	COD	O&G	Boron	P	pH	SS
284	Soap & other detergent	Raw wastewater	100-3,000	120-7,000	0-3,400	< 1	25-1,000	2-7	25-800

TABLE 6 (continued)

SIC	Industry	Waste Type	Characteristics[1]
286	Organic chemicals	Secondary wastewater treatment sludge	See Note #2

SIC	Industry	Waste Type	Oil (wt %)	Phenols	Cyanide	Selenium	Arsenic	Mercury
291	Petroleum refining	Non-leaded product tank bottoms	45-83	1.7-1.8	0.005-14.7	1.5-22.4	0.005-0.08	0.41-0.44
		Waste bio sludge	0.01-0.53	1.7-10.2	0.001-19.5	0.01-5.4	1.0-6.0	0.004-1.28
		API separator sludge	3.0-51.3	3.8-157	0.00006-43.8	0.005-7.6	0.1-32	0.04-7.2
		Dissolved air flotation float	2.4-16.9	3.0-210	0.01-1.1	0.1-4.2	0.1-10.5	0.07-0.89
		Slop oil emulsion solids	23-62	5.7-68	ND-4.6	0.1-6.7	2.5-23.5	0.005-12.2
		Crude tank sludge	21-83.6	6.1-37.8	0.01-0.04	5.8-53	---	0.07-1.53

SIC	Industry	Waste Type	Beryllium	Vanadium	Chromium	Cobalt	Nickel	Copper	Zinc	Silver
291	Petroleum refining (con't)	Non-leaded product tank bottoms	0.025-0.49	9.1-34.6	12.7-13.11	5.9-8.2	12.4-41	6.2-164	29.7-541	0.49-0.7
		Water bio sludge	0.0013-0.0014	0.012-5.0	0.05-475	0.05-1.4	0.013-11.3	1.5-11.5	3.3-225	0.1-0.5
		API separator sludge	0.0012-0.43	0.5-48.5	0.1-6,790	0.1-26	0.25-150	2.5-550	25-6,595	0.05-3
		Dissovled air flotation float	0.0012-0.25	0.05-0.1	2.8-260	0.13-85.2	0.025-15	0.05-21	10-1,825	0.001-2.8
		Slop oil emulsion solids	0.002-0.5	0.12-75	0.1-1,325	0.1-82.5	2.5-288	8.5-112	60-656	0.013-20
		Crude tank sludge	0.0013-0.0032	0.5-62	1.9-75	3.8-37	12.8-125	18.5-194	22.8-425	0.03-1.3

SIC	Industry	Waste Type	Cadmium	Lead	Molybdenum
291	Petroleum refining (con't)	Non-leaded product tank bottoms	0.25-0.4	12.1-37.3	0.25-18.2
		Waste bio sludge	0.16-0.54	1.2-17	0.25-2.5
		API separator sludge	0.024-2	0.25-83	0.25-60
		Dissolved air flotation float	0.0025-0.5	2.3-1,320	0.025-2.5
		Slop oil emulsion solids	0.025-0.19	0.25-380	0.25-30
		Crude tank sludge	0.025-0.42	10.9-258	0.025-95

TABLE 6 (continued)

SIC	Industry	Waste Type	Characteristics[1]								
			BOD	COD	O&G	SS	Cr	Sulfide	TDS	TKN-N	Phenols
3111	Leather tanning & finishing (vegetable)	Raw wastewater[4]	700-1,880	2,000-6,000	2-1,200	730-3,340	1.2-50	12-192	300-12,200	240-1,500	6-24
			Solids	Cr,Cu,Pb,Zn	Na	Mg	Mn	Ca	Sulfides	Phenols	
		Secondary wastewater treatment sludge	2-8%	<10	100-1,500	100-500	10-50	1,000-4,000	20-200	<1	

Notes:

(1) Units are ppm on a "wet weight" basis, unless otherwise indicated, except pH.

(2) Adequate data is not available (in some cases, proprietary data exists, but is not available) to quantify specific components in these waste materials.

(3) Secondary treatment of pulp and paper mill wastewater is not yet common practice. Secondary wastewater treatment sludges are expected to be suitable for land cultivation disposal, but qualitative data on specific constituents is not available. The volume of raw wastewater generated by most pulp and paper mills is sufficiently large to make land requirements excessive for the use of land cultivation as a disposal method.

(4) As indicated by the range in constituent concentrations, the acceptability for land cultivation depends on the specific source of this waste material.

TABLE 7. WASTE-SPECIFIC LAND CULTIVATION DISPOSAL CONSIDERATIONS

SIC	Industry	Waste Type	Specific Potential Hazards	Recommended Precautions
20	Food and kindred products	Wastewater, sludge, and screenings	High sodium and TDS content and resulting detrimental effects on soil properties and plant growth	Gypsum addition; segregation of high sodium and TDS waste streams
2231	Textile finishing	Secondary wastewater treatment sludge	Heavy metal content	Plant and water monitoring; appropriate loading rate
2491	Wood preserving	Wastewater	Pentachlorophenol creosote and possible contamination of waste supplies	Appropriate loading rate about 28 to 37 m^3/ha (3,000 to 4,000 gal/ac)
26	Paper and allied products	Primary wastewater treatment sludge	Contamination with toxic materials may occur at some plants reprocessing secondary materials	Sludge analysis and subsequent appropriate site design and operating precautions
2824	Organic fibers, noncellulosic	Secondary wastewater treatment sludge	High zinc and nitrate content	Appropriate application rate and cover crop
283	Pharmaceuticals	Waste mycelium	High zinc and TDS content	Appropriate application rate and cover crop
2841	Soap and other detergents	Wastewater	Possible water supply degradation from excess nutrients	Use cover crop with good nutrient uptake characteristics
286	Organic chemicals	Wastewater treatment sludges	Potential hazards are dependent on the specific chemicals produced	Chemical analysis of sludge to detect potentially hazardous constituents
291	Petroleum refining	Nonleaded tank bottoms	High nickel, copper, vanadium, and lead content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended

TABLE 7 (continued)

SIC	Industry	Waste Type	Specific Potential Hazards	Recommended Precautions
291	Petroleum refining	Waste biosludge	High chromium and zinc content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended
		API separator sludge	High chromium, zinc, nickel, and copper content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended
		Dissolved air flotation float	High chromium and zinc content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended
		Slop oil emulsion solids	High chromium and zinc content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended
		Crude tank sludge	High chromium, zinc, and copper content	Monitoring of soil and groundwater concentrations to determine when disposal site life is expended
3111	Leather tanning and finishing	Vegetable tannery wastewater	High chloride and TDS and associated detrimental effects on plant growth	Dilution, addition of gypsum

TABLE 8 . ESTIMATED QUANTITIES OF INDUSTRIAL WASTEWATERS AND SLUDGES SUITABLE FOR LAND CULTIVATION

SIC	Industry	Waste type	Waste quantities* 1975	1980	1985
20	Food and kindred products				
2011	Meatpacking	Wastewater†	150	170-190	190-230
2016	Poultry dressing plants	Wastewater†	87	98-110	110-140
202	Dairy products	Wastewater†	45	51- 57	58- 70
203	Fruits and vegetables	Wastewater†	280	320-350	360-440
2061, 2062	Cane sugar	Wastewater†	68	79- 87	89-110
2082	Malt beverages	Wastewater†	87	98-110	110-140
22	Textile mill products				
2231, 226	Textile finishing	Secondary waste-water treatment sludge#	3.9×10^4	8.5×10^4	1.8×10^5
24	Lumber and wood products				
2491	Wood preserving	Wastewater†	1.9	2.2-2.3	2.5-2.9

TABLE 8 (continued)

SIC	Industry	Waste type	Waste quantities 1975	1980	1985
26	Paper and allied products	Primary wastewater treatment sludge#	1.4×10^6- 1.7×10^6	1.6×10^6- 1.9×10^6	1.8×10^6- 2.1×10^6
28	Chemicals and allied products				
2824	Organic fibers, noncellulosic	Secondary wastewater treatment sludge#	4,800	7,300	9,800
283	Pharmaceuticals	Waste mycelium#	6.3×10^4	8.1×10^4	1.0×10^5
2841	Soap and other detergents	Wastewater†	12-14	17-18	20-22
286	Organic chemicals	Wastewater treatment sludges#	5.5×10^6	6.8×10^6	8.5×10^6
29	Petroleum refining and related industries				
291	Petroleum refining	Non-leaded product tank bottoms#	4.1×10^4	5.1×10^4	6.2×10^4
		Waste bio sludge#	4.0×10^4	5.0×10^4	6.2×10^4

TABLE 8 (continued)

SIC	Industry	Waste type	Waste quantities 1975	1980	1985
291	Petroleum refining (continued)	API separator sludge#	3.4×10^4	4.2×10^4	5.2×10^4
		Dissolved air flotation float#	2.9×10^4	3.7×10^4	4.5×10^4
		Slop oil emulsion solids#	1.7×10^4	2.1×10^4	2.6×10^4
		Crude tank sludge#	390	490	610
31	Leather and leather products				
3111	Leather tanning and finishing (vegetable)	Wastewater†	2.5	2.3	2.2
		Secondary waste-water treatment sludge#	820	740	680
	Total wastewater†		735	840-920	940-1,160
	Total sludge#		$7.2\text{-}7.5 \times 10^6$	$8.8\text{-}9.1 \times 10^6$	$10.8\text{-}11.1 \times 10^6$

*Waste quantities for 1975 based on ref. 1-15 and contacts with industry representatives and current researchers. Values for 1980 and 1985 assume the 1975 relationship between production and waste generation, and are based on industry-specific production projections (if available).

†Wastewater quantities are given in units of millions of cubic meters per year.

#Sludge quantities are given in units of metric tons per year on a dry weight basis.

WASTE CHARACTERISTICS

Information on the characteristics of wastes disposed by land cultivation is often very limited or unavailable. The scope of this project did not include a sampling program to improve the available information. Thus, a general description of wastes suitable for land cultivation follows. Available specific waste characteristics information is summarized in Table 6.

Food Processing

Food processing facilities that directly discharge their wastewater normally utilize secondary wastewater treatment. In addition, most such facilities screen their wastewater to remove large suspended materials. Thus, food-related industrial wastewaters normally consist primarily of organic material that is readily biodegradable in the soil environment if appropriate application rates and operating procedures are utilized. Application rates are typically limited by the hydraulic loading rate that is compatible with site-specific soil conditions. High sodium concentration in wastes from caustic peeling may limit the application rate or may prevent land cultivation of certain wastewaters due to sodium induced deterioration of the soil structure.

Textile Finishing

The textile finishing industry utilizes thousands of organic chemicals in various production processes. The chemicals fall into a number of general classifications, including fiber reactive dyes, dispersed dyes and pigments, flame retardant and water repellent finishes, and pigments. Wastewaters containing these chemicals usually receive secondary biological treatment. Generated sludges are composed principally of waste cellular material and organic compounds which were passed through the treatment system. Detailed information is not available on the suitability of these sludges for disposal by land cultivation, but preliminary information indicates that land cultivation may be an appropriate disposal practice. At least three sites are currently under construction for disposal of textile-finishing wastewater treatment sludges by land cultivation (39, 41).

Wood Preserving

The wood preserving industry utilizes a variety of chemicals to inhibit the deterioration of wood products. Several of the chemicals, such as chromated copper arsenate and flour chrome arsenate phenol (FCAP), are highly toxic. Consequently, discharge of wastewaters containing these materials is being phased out in favor of recycling systems for using the wastes (31, 38) (Harrison, personal communication).

Most preserved wood products are treated with pentachlorophenol and/or petroleum- and coal tar-based materials. Despite the potential toxicity of these compounds, wastewaters from wood preserving plants have been shown to be suitable for land cultivation. At loading rates of 28 to 37 m^3/ha (3,000 to 4,000 gal/ac) per day, bacteria in the soil environment effectively decomposed these preservative compounds (33).

Approximately 10 to 15 percent of all wood preserving plants are direct dischargers of secondary treated wastewater. Recent investigations indicate that sludges resulting from this wastewater treatment may also be suitable for land application. Reports detailing the relevant investigations are considered proprietary and were not available for review.

Pulp and Paper Production

Investigations conducted to date indicate that most segments of the pulp and paper industry generate wastewater treatment sludges suitable for land cultivation (30, 38, 40) (Ruppersberger, personal communication). These segments manufacture products such as:

- Sulphite
- Kraft (sulphate)
- Semi-chemical
- Strawboard
- Groundwood
- Cardboard
- Boxed board and paper board.

To analyze the acceptability of pulp and paper industry sludges for land cultivation disposal, it is helpful to divide them into three cateogries:

- Primary sludges composed of about 50 percent or more calcium carbonate solids (or lime sludges)
- Primary sludges composed principally of cellulosic fibers
- Biological sludges resulting from biological wastewater treatment.

Lime Sludges--

In areas where soil acidity is a problem, lime sludges that are land cultivated can serve as a substitute for ground limestone. The appropriate sludge application rate normally depends on:

- Calcium carbonate content of the sludge
- Soil pH and texture

- Type of crop grown
- Rate of nitrogen application
- Particle size of the sludge solids.

Primary Sludges Composed of Cellulosic Fibers--

Primary wastewater treatment sludges (composed principally of cellulosic fibers) do not possess the utilization capabilities of lime sludges. However, the sludges do contain from 3 to 6 kg nitrogen per metric ton (12 lb/ton) of solids on a wet weight basis (in addition to other nutrients). The release of available nitrogen depends upon particle surface area, aeration, temperature, moisture, and the availability of other nutrients.

Biological Sludges Resulting from Biological Wastewater Treatment--

Sludges resulting from biological wastewater treatment are also normally acceptable for disposal by land cultivation. However, application rates may be limited by the nitrogen requirement of the crop. If these sludges are applied to fine textured soils, particular attention must be paid to maintaining aerobic conditions during the decomposition process.

Organic Chemicals Production

Various categories of organic chemical products include:

- Synthetic noncellulosic organic fibers
- Pharmaceuticals
- Soap and other detergents
- Miscellaneous organic chemicals.

Synthetic Noncellulosic Organic Fibers--

Manufacturing facilities producing synthetic noncellulosic organic fibers (such as nylon or polyester) and that are direct dischargers of their wastewater typically employ secondary wastewater treatment prior to discharge. The sludges are composed principally of waste cellular material and are usually not contaminated by constituents that would be detrimental to soil productivity. After land cultivation, the sludges decompose to provide a low-grade source of plant nutrients, particularly nitrogen. Characteristics of these sludges are similar to those of domestic wastewater treatment sludges (37).

Pharmaceuticals--

Microbial pharmaceutical production of various organic acids (such as citric acids) and antibiotics (such as tetracycline and terramycin) generates a fermentation residue, which consists primarily of spent fungal mycelial tissue and lime. The lime is added to the residue to raise the pH to the neutral-to-slightly-alkaline range.

Zinc is often added to the residue to control microbial growth during the fermentation process, in which case it is present in the waste mycelium. The concentration of zinc in the residue ranges from approximately 10 to 10,000 ppm, depending on the exact control procedures utilized. Some mycelial residues may not be suitable for land cultivation because of high zinc concentrations. In addition, land cultivation of this waste may be limited by its soluble salt concentration, which interferes with water adsorption and nutrient uptake by the plants.

Soap and Other Detergents--

Wastewaters generated in the manufacture of soap and other detergents are contaminated with organic materials and inorganic nutrients, particularly phosphorus. Land cultivation of these wastewaters provides for decomposition of the organic wastes and utilization of the inorganic nutrients if a cover crop is grown. Particular attention must be paid to nitrate and soluble salt accumulation in the soil since high nitrate levels may result in groundwater contamination. Salt accumulation may deteriorate soil structure, reducing permeability (32).

Miscellaneous Organic Chemicals--

Biological treatment of wastewater from the production of miscellaneous organic chemicals generates sludges that may be suitable for land cultivation. These sludges are composed primarily of waste cellular material that is readily biodegradable under aerobic conditions. However, these sludges may be contaminated with toxic organic chemicals and/or heavy metals, depending on the product mix at the particular manufacturing facility.

The product mix varies widely from plant to plant, and even varies from day to day within many plants. Thus, the suitability of the resulting sludge for disposal by land cultivation may vary, and must be assessed on an individual basis. If land cultivation is used for sludge disposal, the accumulation of nondegradable constituents (e.g., heavy metals) in the soil must be monitored to determine when the site life has been expended. The useful life of the disposal site can be extended by pretreatment of individual process wastewater streams, which contribute the contaminants of concern to the overall wastewater flow from the plant. An alternative approach is to adjust waste application rates to control total toxic contaminant input to any portion of the site.

Petroleum Refining

Six sludges suitable for land cultivation without pretreatment are generated by the petroleum refining industry:

- Nonleaded tank bottoms
- API separator sludge

- Dissolved air flotation float
- Soil oil emulsions solids
- Crude tank sludge
- Waste biosludge.

These sludges vary from 3 to 83 percent oil by weight and contain up to 7,000 ppm of various heavy metals (e.g., zinc, copper, nickel, chromium). The oil and heavy metal concentration depends on the particular waste type, the source of crude oil being processed, and the types of refining processes utilized. Currently, land cultivation of these sludges serves principally as a disposal methodology for the inorganic fraction and as a treatment method for the organic fraction. Microbial action decomposes the organic fraction of the sludge when aerobic conditions are maintained. Inorganic components of the waste will not degrade and consequently accumulate in surface and subsurface soil horizons. Many of these waste sludges contain substantial quantities of heavy metals; thus, use of oily waste land cultivation sites for crop production needs to be carefully investigated. Information currently available indicates that these sites are not suitable for production of crops for direct human consumption.

Leather Tanning and Finishing

It has not yet been determined whether wastewater/sludge generated by chrome leather tanning and finishing plants is suitable for land cultivation (34). The suitability of vegetable leather tanning and finishing wastes for land cultivation varies from plant to plant, and depends on factors such as total dissolved solids (TDS) concentration. A high TDS concentration in the wastewater results from salt used to preserve the hides before tanning. The level of TDS concentration depends on the housekeeping practices in each plant and on the particular method of hide preservation. Wastewaters with TDS concentrations in excess of 3,000 mg/l are not suitable for application to most soils since the high sodium content is detrimental to the soil, causing a structural breakdown and decreased permeability.

Sludge from secondary wastewater treatment at vegetable leather tanning plants is normally suitable for land cultivation. This sludge is composed mainly of waste cellular material produced in the treatment process and is typically not contaminated by constituents that would be detrimental to soil productivity (43). The TDS concentration of the sludge is affected by the same variables as is the wastewater, e.g., plant housekeeping practices and the method of hide preservation. In addition, the percent solids concentration of the cultivated sludge is a factor, since increasing the solids concentration has the effect of decreasing the TDS concentration. Sludge application rates must be decreased for the higher TDS concentrations. Further, a high TDS concentration in a sludge may make it unsuitable for land cultivation. In general, a sludge with a high solids content will be acceptable for land cultivation at a reasonable application rate with little risk of soil damage due to sodium.

Other Industries

Information from all industrial sources on the suitability of wastes for land cultivation is not currently available. Data are particularly lacking for industries that generate principally inorganic wastes. However, some inorganic wastes (e.g., gypsum) could likely be disposed by land cultivation. Since the wastes are inorganic, they would not be significantly affected by microbial decomposition and would accumulate in the soil environment. Thus, land cultivation of inorganic wastes would serve as a disposal option and normally would not be associated with crop production. A potential exception is lime sludges generated as a result of water treatment. In areas where soil acidity is a problem, lime sludges might be used to neutralize soil acidity in fields used for crop production. Lime sludges might also be cultivated in conjunction with wastes to maintain soil pH at, or above, 6.5 to immobilize most heavy metals.

WASTE-SPECIFIC DISPOSAL CONSIDERATIONS

Generalized considerations for disposal of industrial wastewaters/sludges by land cultivation are discussed in detail in Sections 10 and 13. Any wastes to be land cultivated should first be chemically characterized to identify specific problems that might arise. After a waste has been adequately characterized, appropriate disposal sites can be identified. In addition, the appropriate hydraulic and organic loading rates that are compatible with specific waste and site characteristics can be determined. Necessary soil, crop, and groundwater monitoring programs can also be developed.

Waste-specific land cultivation disposal considerations are summarized in Table 7. The constituents of concern in a specific waste depend on the industry and particular manufacturing facility that generate the waste.

WASTE QUANTITIES

The estimated quantities of industrial wastewaters/sludges suitable for land cultivation in 1975, 1980, and 1985 are presented in Table 8. Estimates of the waste quantities generated in 1975 were obtained from various published and unpublished reports, and contacts with industry representatives and trade associations (30, 35, 36) (Tanners' Council of America, personal communication; Harrison, personal communication). Projections of the waste quantities generated in 1980 and 1985 assume the 1975 relationship between production and waste generation and are based on industry-specific production projections (if available) for the overall increase of solid waste generation. Although increased attention to in-process modifications to enhance resource recovery is anticipated, increased pollution control residuals due to implementation of regulations are also anticipated.

The detailed information presented in Table 8 is summarized below:

Waste Type	Year 1975	1980	1985
Wastewater (10^6 m^3/yr)	735	840-920	940-1,160
Sludge (10^6 metric tons dry weight basis)	7.2-7.5	8.8-9.1	10.8-11.1

Recent reports estimate the total quantity of generated sludge on a dry weight basis to be 237 x 10^6 t/yr (44), which indicates that only about 3 percent of all industrial sludge is likely to be suitable for land cultivation. Similarly, the total quantity of industrial wastewater suitable for land cultivation is only about 1 percent of the total.

SECTION 5

MECHANISMS OF WASTE DEGRADATION AND VOLUME REDUCTION

If properly managed, soil may serve as an effective disposal sink for many wastes. In land cultivation, it is preferred that the chemical constituents in the waste be retained in the surface layer and/or decomposed by the various soil processes. In particular, the organic fraction must be biologically degradable at reasonable rates. Current information on the relative persistence of various chemical constituents in soils is substantial; however, information on the kinetics of the individual degradation processes is fragmentary and inadequate. The important processes that contribute to waste volume reduction include microbial degradation, nonbiological (chemical and photochemical) degradation, and evaporation and volatilization (Figure 1).

MICROBIAL DEGRADATION

Biological processes are greatly affected by many wastes commonly applied to soils. These processes, in turn, decompose, utilize, or alter the added wastes. The soil microbial population constitutes a biochemically complex system capable of producing unique enzymes that degrade a large number of organic substances (45, 46).

Organisms Important to Waste Utilization

There are normally large numbers of diverse microorganisms in soils, consisting of several groups that are predominantly aerobic in well-drained soils. These microorganisms normally adhere to the surfaces of the soil colloids. The majority of groups is heterotrophic, deriving energy from the breakdown of organic substances. These are the dominant microorganisms responsible for the decomposition of applied wastes.

The principal groups of microorganisms present in surface soils are bacteria, actinomycetes, fungi, algae, and protozoa (48). In addition to these groups, other micro and macrofauna are often present, such as nematodes and insects.

The bacteria are the most numerous and biochemically active group of organisms, especially at low oxygen levels. Bacteria

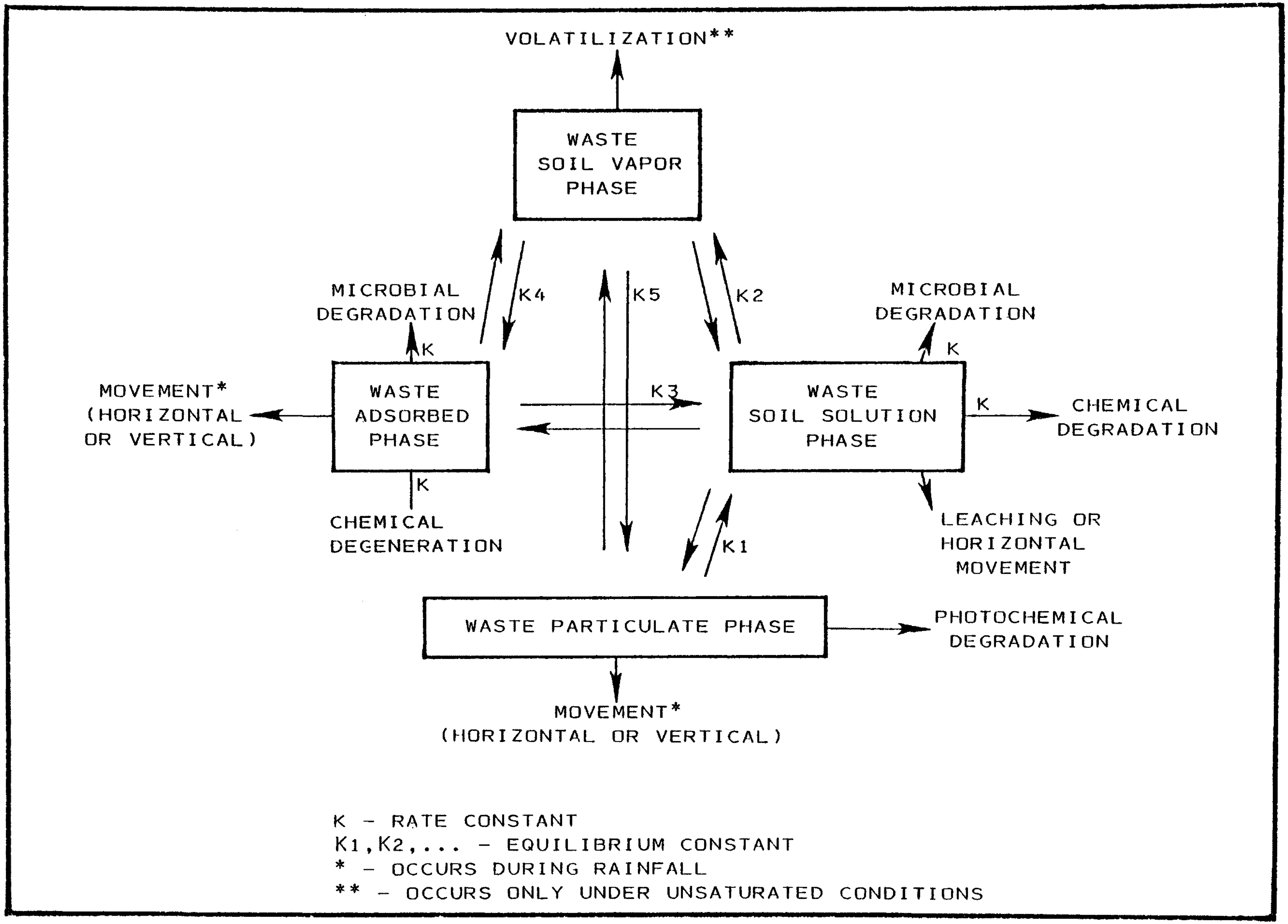

Figure 1 . Mechanisms of waste degradation.

are primarily responsible for transformations of nitrogen, sulfur, and trace elements in soils. Of the diverse species that exist, many bacteria flourish only under certain environmental conditions or carry out explicit functions, such as the oxidation of ammonium to nitrite by nitrosomonas and of nitrite to nitrate by nitrobacter (49).

Actinomycetes are less numerous than bacteria. They usually predominate in soils of low moisture content and in organic material in the later stages of decomposition. These microorganisms can decompose a variety of comparatively resistant substances.

Fungi often grow vigorously after initiating decomposition. They have extensive mycelial branching and compete effectively with bacteria for simple carbohydrates and bioproducts. Many fungi can readily attack cellulose, and a few species can utilize lignin, which is very resistent to decomposition. Fungi have much lower nitrogen demands and are more tolerant to acidity than bacteria (46).

Soil animals make up a large group of microorganisms. The more prominent ones with respect to waste utilization are the protozoa, nematodes, and earthworms. All soil animals may assist during waste decomposition. Earthworms are important in mixing organic wastes with the soil, which improves soil structure, aeration, and fertility (45). However, nematodes may impede waste degradation, feeding on bacteria, fungi, algae, protozoa, and other nematodes (46). Their ecological importance, therefore, is concerned with their effect on total microbial activity through destruction of the species they consume.

Soil Environment and Activity of Microorganisms

In general, conditions favorable for plant growth are also favorable for the activity of soil microorganisms. Environmental factors influencing plant growth have been well documented and include soil pH, air temperature, soil water content, and nutrients (45, 46, 50, 51, 52).

Soil pH--

The optimum pH for bacterial growth is near 7. Only a few species live when the pH is above 10 or below 4 (46). Actinomycetes thrive in neutral or alkaline soils with a lower pH limit of about 5. Nearly all fungi grow best at pH 7 or above, but they are far more tolerant to acidity than are other microflora; some fungi grow rapidly at pH 2 or lower. Soil animals are adversely affected by acidity, especially when the pH is below 5.

Air Temperature--

Many species can tolerate a fairly wide temperature range, but the optimum temperature is usually within a few degrees of the upper part of the range (53). As a general guideline, the activity of a species will double for each 10°C rise in temperature until the optimum level for the particular microorganism is reached.

Soil Water Content--

The decomposition process is typically not restricted by moisture if the soil water content is kept above a certain minimum (usually between 30 and 90 percent of the water holding capacity of soil). However, poor drainage or excess water reduces the available oxygen levels and can retard microbial decomposition of applied organic wastes (54). Actinomycete populations usually increase, while bacteria and fungi populations decrease at lower soil moisture levels. Soil organisms become essentially inactive when the soil water content drops below the level where plants wilt.

Nutrients--

Soil organisms require basically all nutrient elements required for the growth of higher plants (45). Consequently, in fertile soils, inorganic nutrients seldom need to be added for the nutrition of organisms decomposing plant and animal tissues. However, when a highly carbonaceous waste (with a C/N ratio >35) is added to the soil, inorganic nitrogen is rapidly used by the organisms for metabolic processes, especially for the production of cell protein (45, 46). Additional nitrogen must therefore be supplied to attain an optimal waste decomposition rate.

Deficiencies of phosphorus and sulfur also markedly affect microbial growth. These nutrients are usually present in adequate quantities in most organic wastes to satisfy the needs of the majority of soil microorganisms. However, if the waste is a comparatively pure organic compound such as cellulose, the available supply of several nutrient elements may be reduced to the extent that microbial growth is adversely affected (46).

<u>Aerobic vs. Anaerobic Decomposition</u>

The following generalized equations depict the microbial metabolism of organic compounds in soil under aerobic and anaerobic conditions (51):

Aerobic:

$$(CHO)_nNS \longrightarrow CO_2 + \text{microbial cells and storage products } (60\%^*)$$

$$+ NH_4^+ + H_2S + H_2O + \text{Energy}$$

$$\downarrow \qquad \downarrow$$

$$NO_3^- + SO_4^{2-}$$

Anaerobic:

$$(CHO)_nNS \longrightarrow CO_2 + \text{microbial cells and storage products } (20\%^*)$$

$$+ \text{organic intermediates } (70\%) + CH_4 \, (5\%) + H_2 + NH_4^+$$

$$+ H_2S + H_2O + \text{Energy}$$

The main products of aerobic metabolism are CO_2, H_2O, and microbial cells. In anaerobic metabolism, where decomposition is not complete, there is an accumulation of intermediate substances such as organic acids, alcohols, amines, and mercaptans. Because the energy yield during anaerobic fermentation is small, fewer microbial cells accumulate per unit of organic carbon degraded. Also, while NO_3^- and SO_4^{2-} are the end products of organic nitrogen and sulfur compounds under aerobic conditions, H_2S and NH_4^+ accumulate under anaerobic conditions (55). When NO_3^- is present and a soil becomes anaerobic, NO_3^- may be denitrified with the nitrogen lost as a gas.

Many types of organic substances are found in industrial sludges. Leithe (56) has listed organic components of industrial waste effluents according to their source. The biodegradability of some commonly known organic substances has been arbitrarily summarized as follows (51):

- Readily decomposable: amino sugars, carbohydrates, fatty acids, nucleic acids, and proteins
- Slowly decomposable: cellulose, detergents, fats, humic compounds, hydrocarbons, lignin, pesticides, phenols, plant and bile pigments, tannin, and waxes.

In recent years, considerable emphasis has been placed on studying the biodegradability of many organic substances that are considered potential environmental toxins (57). Some of

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*The percentage values are estimates of the carbon distribution of the original organic compound(s) after metabolism by the microbial population.

these substances are phenolic compounds, chlorinated hydrocarbon pesticides, nitrosamines, detergent residues such as alkylbenzene sulfonates (ABS) and nitrilotriacetate (NTA), and petroleum products.

The simpler phenols (i.e., mono- or disubstituted phenols) generally undergo hydroxylation. This generally results in the formation of a catechol-type product which is the precursor to ring cleavage and dissolution of aromaticity by microorganisms. Initial biochemical activity may occur with the substituent groups; however, this initial activity depends on the biochemical activity or position of the substituent group on the aromatic ring. In addition to these reactions, phenols may undergo conjugation, methylation and condensation reactions leading to more complex molecules (57).

More studies have been conducted on the biodegradation of pesticides in soils than on most other compounds. The principal biochemical reactions responsible for microbial degradation of pesticides include alkylation, dealkylation, amide or ester hydrolysis, dehalogenation, dehydrohalogenation, oxidation, reduction, dehydroxygenation, ring cleavage, ether cleavage, condensation, and conjugate formation (58).

The chemical structure, nature, and position of substituting groups of the pesticides affect the extent and rate of microbial degradation (50). This is demonstrated by the persistence of various pesticides in soils from normal rates of application and field conditions (Figure 2). In addition, the dosage, particle size, distribution in soil, and previous applications all influence the rate of decomposition of pesticides in the soil (59). A high application rate may be toxic to some species which would decompose the same chemical at lower concentrations. If the substance is banded or not well mixed with the soil, the concentration may be too high in the localized areas for growth of otherwise active organisms. Materials of relatively large particle size will decompose more slowly than those of smaller particle size because they will present less surface area for organisms capable of degrading the compound. Subsequent additions will therefore decompose more quickly.

In summary, although some of the toxic organic substances do persist in soils, microbial degradation will eventually proceed if the substances are adsorbed in the soil surface for a sufficient period of time. There is, however, limited information on environmental factors affecting degradation of these substances as well as the microorganisms and enzymatic reactions involved.

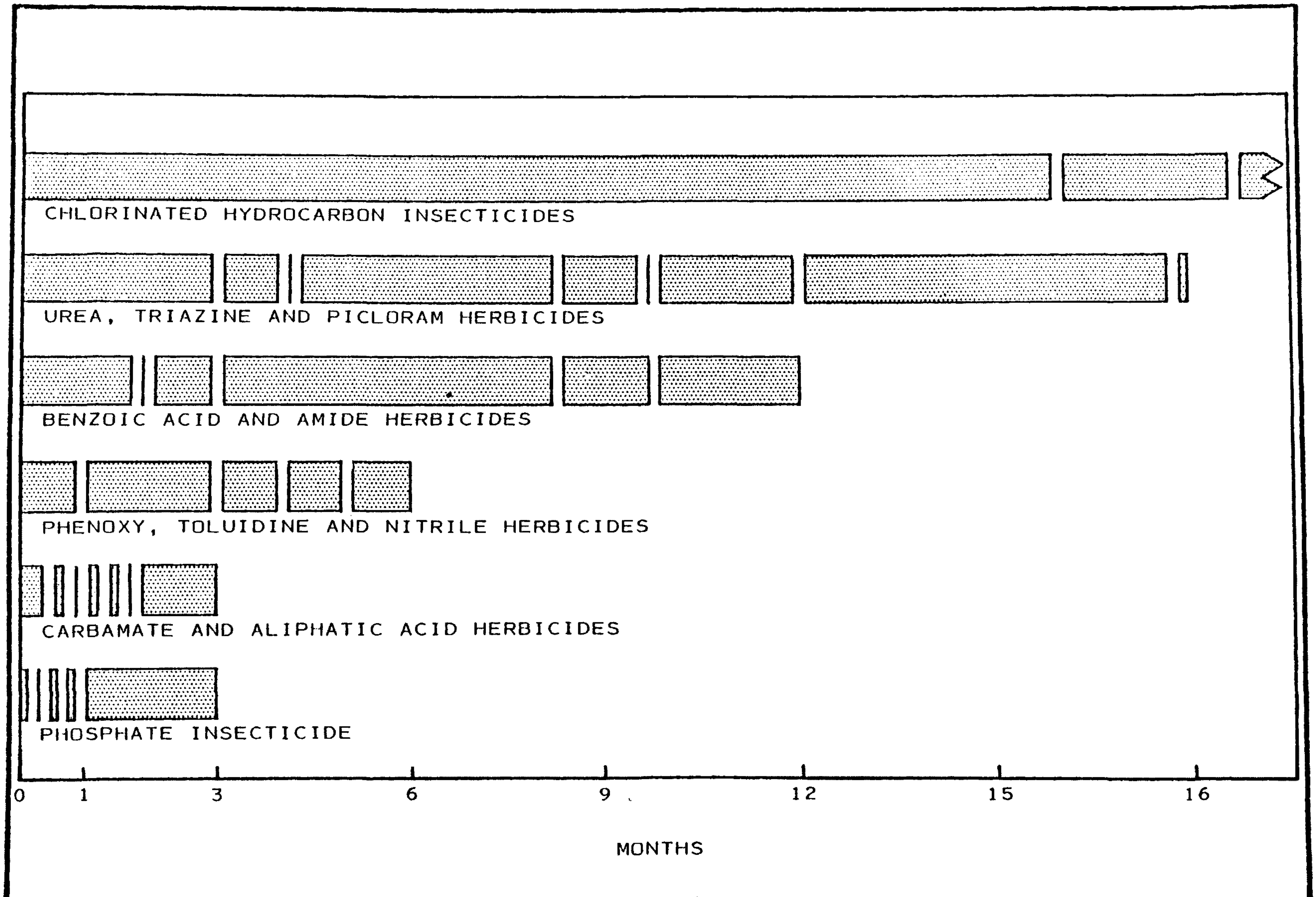


Figure 2. Persistence in soils of several classes of insecticides and herbicides (52).

NONBIOLOGICAL DEGRADATION

Nonbiological degradation processes play an important role in the dissipation of many organic substances in soils, including pesticides. In particular, considerable evidence has been reported on the importance of chemical hydrolysis and photochemical degradation (61). Other reactions, including oxidation-reduction, are important for certain compounds.

Chemical Degradation

Chemical degradation of waste materials in soil is a complex phenomenon. Various mechanisms of chemical degradation or transformation have been found or postulated, including oxidation, reduction, hydrolysis, isomerization, and polymerization. The degradation rate depends on whether the reaction occurs in solution or on an absorbent surface, and is usually a function of pH; redox potential (Eh); surface acidity; and the nature, concentration, and availability of catalytic sites (47). Hydrolysis reactions are important steps in the degradation of many organic compounds, including chloro-triazine herbicides and organophosphate insecticides. These reactions are catalyzed by clay present in the soil (62).

According to Harris (63), there is evidence that atrazine, simazine, and propazine were converted partially to their hydroxy derivatives during incubation in soils at 30°C for 8 wk. The amounts of hydroxy derivatives formed were not affected by the addition of 200 ppm sodium azide as a microbial inhibitor. Evidence for the chemical hydrolysis of diazinon was obtained by comparison of soil systems and soil-free aqueous systems containing diazinon (62). In soil systems, the rate of degradation was related to the extent of initial diazinon sorption and to the organic matter content and pH of the soil. In soil-free systems, diazinon hydrolysis was acid- or alkali-catalyzed but was slow compared to soil systems of comparable pH (2 percent per day at pH 6 compared to 11 percent in a Polygan soil). In a microbial medium inoculated with an aqueous soil extract, diazinon was stable for at least 2 wk, suggesting the absence of microbial degradation during this time period. The degradation of diazinon in soil was also reportedly enhanced by increased temperature and soil moisture content (64).

Photochemical Degradation

Chemical reactions induced by electromagnetic radiation represent a potentially important pathway for alteration and/or degradation of many organic substances applied to soil. To undergo photodecomposition, a compound must first absorb light energy. The initial phase of photochemical degradation frequently involves homolytic fission of chemical bonds to form free radicals (65). The free radicals are unstable intermediates and enter into subsequent reaction with the solvent (soil solution), with other molecules or radicals of the organic compound, or with other reactants. Thus, the overall results of the photochemical reaction may be isomerization, substitution or oxidation. The type of reaction occurring is dependent on the physical state of the waste, the solvent, and the presence of other reactants such as oxygen (65). Also important is whether the waste is in the adsorbed or unadsorbed state.

Photochemical reactions have been reported for a wide range of pesticide groups, including the chlorinated cyclodiene insecticides, chlorinated benzoic and phenylacetic acids, triazines, ureas, and dinitroaniline and picolinic acid herbicides (61). However, the role of photochemical reactions in soil pesticide degradation remains uncertain.

During a study conducted by Hatayama and Jenkins (66), a considerable amount (85 percent) of organic lead was converted to inorganic lead through air oxidation or photodegradation during the 30-day test period. A spreading or weathering method used was recommended by the American Petroleum Institute to dispose of the leaded gasoline tank wastes. There is evidence that polybrominated biphenyls (PBB's) and similarly structured toxic organic compounds also degrade photochemically (67).

Nevertheless, photochemical degradation should generally play a minor role in land cultivation since the waste is incorporated into the soil, thus reducing the amount of light received by the waste. Likewise, photochemical degradation assumes minor importance when mobile wastes are leached from the zone of photolytic influence. Storage of wastes in open lagoons will expose the material, possibly for relatively prolonged periods. Some photochemical degradation could occur under these conditions.

EVAPORATION AND VOLATILIZATION

In land cultivation of wastewaters and sludges, evaporation is a major mechanism of volume reduction. The rate of evaporation from a wet soil is controlled by the same environmental conditions that control the rate of evaporation from bulk water. Frequent mixing of the waste with soil will increase evaporation and decrease the probability of developing anaerobic conditions.

Volatilization, though intimately associated with evaporation, is concerned with the dissipation of waste constituents, rather than water, into the atmosphere. The magnitude of volatilization loss depends on the soil moisture content, chemical and physical properties of the waste and soil, atmospheric conditions (temperature, wind velocity, relative humidity, etc.), and application method (68). In land cultivation, mixing the waste with soil would significantly reduce volatilization loss due to increased adsorption of the chemical by soil organic matter and clay, and the decreased vapor pressure of the waste material.

Soil water content is one of the most important factors affecting volatilization. Chemicals vaporize faster from wet (but not saturated) soils than from dry soils, primarily because water increases the vapor pressure of the chemicals by competing for the adsorption sites (69). Also, as the water evaporates from the surface, the water-chemical solution moves toward the evaporating surface by capillary action, thus enhancing chemical loss by volatilization. Increasing the waste concentration, diffusion rate, air flow rate, or air temperature will result in an increased rate of volatilization. In land cultivation practices, the volatilization rate of soil-incorporated waste will likely be controlled by diffusion of the waste constituents in the liquid or gaseous phase, the mass flow of water to the soil surface, and the vapor pressure of the constituents.

Volatilization is one of the major pathways of pesticide loss from field soils. Willis et al. (70) measured atmospheric concentrations of dieldrin over field plots under three different regimes. In the plots designated for flooded treatment, 10 cm (3.9 in) of water were applied; for moist treatment, 1/3 to 1 bar tension; for nonflooded treatment, no water other than natural rainfall. High atmospheric concentrations of dieldrin were found over all plots immediately after water application. It was calculated that volatilization losses during a 5-mo period were approximately 2 percent from the flooded plots, 18 percent from the moist plots, and 7 percent from the nonflooded plots. In addition to the effects of soil moisture on volatilization, it was shown that air temperature influenced the volatilization rate more than any other climatic variable measured.

Some of the persistent organic chemicals can be lost from the soil surface through volatilization. In a laboratory study, Farmer et al. (71) calculated that uncovered hexachlorobenzene (HCB) volatilized at 317 kg/ha/yr (283 lb/ac/yr). The corresponding volatilization losses when the chemical was covered with 1.9 cm (0.75 in) of soil and 1.43 cm (0.56 in) of water were 4.56 and 0.38 kg/ha/yr (4.07 and 0.34 lb/ac/yr), respectively. When the soil water content or bulk density (through compaction) was increased, HCB flux through soil decreased, thereby reducing volatilization of the chemical.

SECTION 6

EFFECTS OF WASTE APPLICATION ON SOIL PROPERTIES

Chemical, physical, and microbiological properties of soil are known to be affected, to some degree, by land cultivation of municipal refuse or industrial wastes. However, little information is available on the persistence or duration of these effects on the surface soil or subsoil.

PHYSICAL PROPERTIES

In a study of land cultivation, Hart et al. (11) applied both prestabilized composted and fresh refuse to a soil to evaluate the capability of the land to accept waste. Although no physical properties of the soil were measured, improved soil tilth was observed.

Additions of shredded municipal refuse to a Sagehill loamy sand resulted in improved moisture retention, especially prior to significant decomposition of the carbonaceous refuse (1). The bulk density of the waste-amended soil decreased initially due to the low density of the carbonaceous additive and increased soil pore space, but bulk density gradually increased as the waste decomposed. The infiltration rate was not affected by applications of shredded waste up to 448 t/ha (200 tons/ac).

Improvements in soil physical properties resulting from waste additions can appreciably reduce surface runoff and erosion. In a laboratory study, wind erosion was reduced by 88 percent when a Sagehill loamy fine sand treated with 896 t/ha (400 tons/ac) of shredded municipal waste was subjected to a 48 km/hr (30 mph) wind at the soil surface for 5 min (3). The waste products must be well mixed with the surface soil to accomplish this degree of erosion control.

According to Volk (12), the effect of municipal refuse applications on physical properties of soil may endure only until the easily decomposable paper products have disappeared. He suggests that addition of organic matter to the soil through refuse or compost decomposition may improve soil structure, water holding capacity, and friability. However, to increase the quantity of stable soil organic matter would require large and frequent refuse applications.

Applications of compost generally would: 1) increase the water holding capacity, while decreasing the bulk density and compression strength of coarse and medium-textured soils (72, 73); 2) increase aeration of heavy textured soils and allow easier tillage (74). Bengtson and Cornette (18) presented data on application of municipal compost at 44 t /ha (19.6 tons/ac) to a sandy soil planted to slash pine. The application increased the amount of moisture and extended the period of moisture availability to the trees during a drought occurring soon after treatment.

The effect of industrial organic sludge on soil physical properties is, in many ways, similar to the effect of sewage sludge application. Epstein (75) reported that incorporation of 5 percent (dry weight) sewage sludge into a Beltsville silt loam soil initially increased the saturated hydraulic conductivity. However, after 50 to 80 days the hydraulic conductivity decreased to that of the original soil due to clogging of soil pores by microbial decomposition and biomass. Water stable aggregates averaged 28 to 35 percent for the sludge-amended soil, as compared to 17 percent for the original soil. The increase in aggregate stability should result in a more stable soil structure, since aggregates are more resistant to disintegration by water and the disintegrated material is less apt to fill in the pore space. Epstein et al. (76) suggested that continual application of organic matter (waste) would be necessary to maintain this structure as the cementing agents are decomposed.

Industrial wastewater and sludge often contain significant amounts of soluble salts. Wastewaters from fruit and vegetable peeling processes contain high concentrations of sodium (25). These concentrations (with sodium adsorption ratios greater than 10) are known to deteriorate soil structure by causing swelling of the soil and subsequent reduction in permeability (77).

In summary, land cultivation of municipal solid waste or organic industrial wastes generally results in increased water holding capacity and improved soil structure (except for wastes containing high levels of sodium). It also results in some degree of erosion control. The effects of waste application on soil physical properties appear short lived; large and frequent applications may be necessary to maintain these effects.

CHEMICAL PROPERTIES

When municipal compost was applied at rates of 164 and 325 t/ha (73 to 145 tons/ac) to a Mountview silt loam soil over a 2-yr period, there was an increase in soil organic matter content, pH, and potassium, calcium, magnesium, and zinc levels (73). In a greenhouse study, with compost applied at rates of 128 and 512 t/ha (57 to 228 tons/ac) to a Leon fine sand, there was an increase in extractable phosphorus, potassium, calcium, magnesium, soluble salts, and cation exchange capacity (72). Similar results were reported when compost was applied at a rate of 44 t/ha (19.6 tons/ac) to a sandy soil planted to slash pine (18).

When a highly carbonaceous material, such as municipal refuse or compost, is incorporated into the soil, the inorganic nitrogen (primarily ammonium and nitrate) in the waste and the soil is immobilized by the soil microorganisms. This is primarily due to the enhanced microbiological activity and the incorporation of nitrogen in microbial cells (77). As the decomposition proceeds, the C/N ratio narrows, and inorganic nitrogen may eventually be released. Addition of nitrogen fertilizer is usually necessary to accelerate waste decomposition and eliminate nitrogen deficiencies in crops (13, 73).

In one study, application of shredded refuse increased the extractable zinc, iron, manganese, copper, boron, calcium, magnesium, sodium, potassium, and electrical conductivity of a Sagehill loamy sand (14). In another study, King et al. (15) observed increases in plant-available potassium and electrical conductivity when refuse was applied to a Guelph loam.

Large applications of shredded waste materials could create anaerobic zones, resulting in greater mobility for certain elements, such as iron and manganese. Ammonia accumulations have been observed in anaerobic layers of municipal waste treated soil (15).

Epstein et al. (76) reported that sewage sludge applied at rates of up to 240 t/ha (107 tons/ac) greatly increased the CEC, salinity, chloride, and available phosphorus levels in a Woodstown silt loam. Also increased were total nitrogen levels in soil, which were significantly higher after the 160 and 240 t/ha (71 and 107 tons/ac) treatments than in the control. Nitrate-nitrogen levels were highest at the 15- to 20-cm (6- to 8-in) soil depth, but decreased sharply below this level.

In an incubation study, air-dry tomato waste was mixed with a Yolo sandy loam soil at rates up to an equivalent of 1,792 t/ha (800 tons/ac) and incubated at field capacity over 32 wk (Flocker, personal communication). Soil pH, soluble salt content, organic carbon, and total nitrogen were significantly increased as the application rate increased. Concentrations of sodium and potassium also increased with waste application. Nitrate-nitrogen, phosphate, and sulfate accumulated slowly with time.

A refractory metals processing waste was applied at rates of 11.2 to 112 t/ha (5 to 50 tons/ac) to a Dayton silty clay loam. The soil pH, soluble salts, extractable calcium, magnesium, ammonium-N, zinc, nickel, sulfur, fluoride, and the total zirconium, hafnium, and lead contents of the soil all increased (78). The extractable iron, manganese, and phosphorus levels decreased, according to an examination of percolation water from columns of waste treated soil. Polson (79) noted that fluoride from the waste might be more mobile than anticipated.

Incorporation of crude oil into soil increased the concentrations of organic carbon, total nitrogen, and exchangeable potassium, iron, and manganese, but decreased the extractable phosphorus, nitrate-N, and exchangeable calcium (80).

The redox potential (Eh) of soils saturated with natural gas was lower than that of surrounding soils (81). Adams and Ellis (82) found that natural gas-saturated soils were in a highly reduced condition as compared with adjacent soils. The effects of low Eh on the chemical properties of soil include increased availability and mobility of some trace elements. These effects, as well as related impacts on the growth of vegetation, can be significant in land cultivating oily wastes. When wastewaters from food processing industries are applied at rates that create anaerobic conditions, there is also an increase in the availability of elements such as iron and manganese.

In summary, land cultivation of municipal solid waste results in immobilization of inorganic nitrogen by soil microorganisms. Thus, addition of nitrogen fertilizer is usually necessary to prevent nitrogen deficiency in plants. The heavy metal and nutrient contents of municipal solid waste are low; therefore, incorporation of such waste into soil would generally be insignificant in terms of heavy metal enrichment and leaching of plant nutrients to groundwater. However, land cultivation of municipal refuse is significant in terms of increasing soil pH, cation exchange capacity, and the availability of some plant nutrients, as well as toxicants in the soil. These changes appear to be of short duration.

Land cultivation of industrial wastewaters and sludges alters some chemical soil properties. The extent of this alteration is dependent on the chemical composition, the C/N ratio, pH, and Eh of the waste, and on the soil type. The pH of the amended soil is a dominant factor in determining the mobility and solubility of many contaminants and plant nutrients.

MICROBIOLOGICAL PROPERTIES

Municipal solid waste, sewage sludge, and some industrial sludges (oily waste, pulping sludge, fermentation sludge, etc.) contain large quantities of readily decomposable carbonaceous material. Additions of these wastes to soil should cause large increases in microbiological activity.

Municipal refuse has a C/N ratio of about 65:1 (14, 15), and the surface soil generally has a C/N ratio of about 12:1 (77). When wastes with a large C/N ratio (>20:1) are added to a soil, there is a rapid increase in microbial activity with the evolution of carbon dioxide (Figure 3). During the initial decomposition, inorganic nitrogen is immobilized and incorporated into the new microbial cells, as shown in the left shaded area under the top curve of Figure 3. As decomposition proceeds, the C/N ratio of the amended soil narrows, and the energy supply (carbon) diminishes. Some of the microbial population dies because of the decreased food supply, and ultimately a new equilibrium is reached. The attainment of this new equilibrium is accompanied by the release of inorganic (available) nitrogen. The level of stable organic matter or humus may be increased, depending on the quantity and type of waste added. The time required for this decomposition cycle depends on the quantity of organic matter added, the supply of utilized nitrogen, the resistance of the organic waste constituents to microbial activity, temperature, and moisture levels in the soil (77).

When composted municipal refuse and sewage sludge were mixed with an Arrendondo fine sand, Rothwell and Hortenstine (78) observed an initial rapid increase in the bacterial population, which subsided rapidly after 6 days. However, the fungal population of the treated soil increased at each measurement period throughout the 26-day testing period.

Hunt et al. (83) reported that addition of refuse compost at rates of 8.1 to 32.3 t/ha (3.6 to 14.4 tons/ac) to a sandy soil decreased parasitic spiral nematodes and increased saprophagous nematodes. Parasitic ring nematodes were not affected.

Cottrell (13) and Halverson (14) observed that paper products were converted to indistinguishable brown organic materials 10 mo after application of municipal shredded refuse to a sandy soil in eastern Oregon. After one full growing season, essentially no paper products remained, and only resistant materials existed from the initial refuse application of 896 t/ha (400 tons/ac).

Climatic conditions affect microbial decomposition of wastes. King et al. (15) reported that refuse decomposition due to microbial activity was retarded by cool temperatures and by soil saturation from snow accumulation in the winter months. Soil saturation establishes anaerobic conditions, resulting in slower decomposition than would be experienced under aerobic conditions.

Municipal refuse applied to acid strip mine spoils in West Virginia decomposed rapidly even though the soil pH was from 3.7 to 4.4 (84). This decomposition was probably caused by acid-tolerant soil fungi.

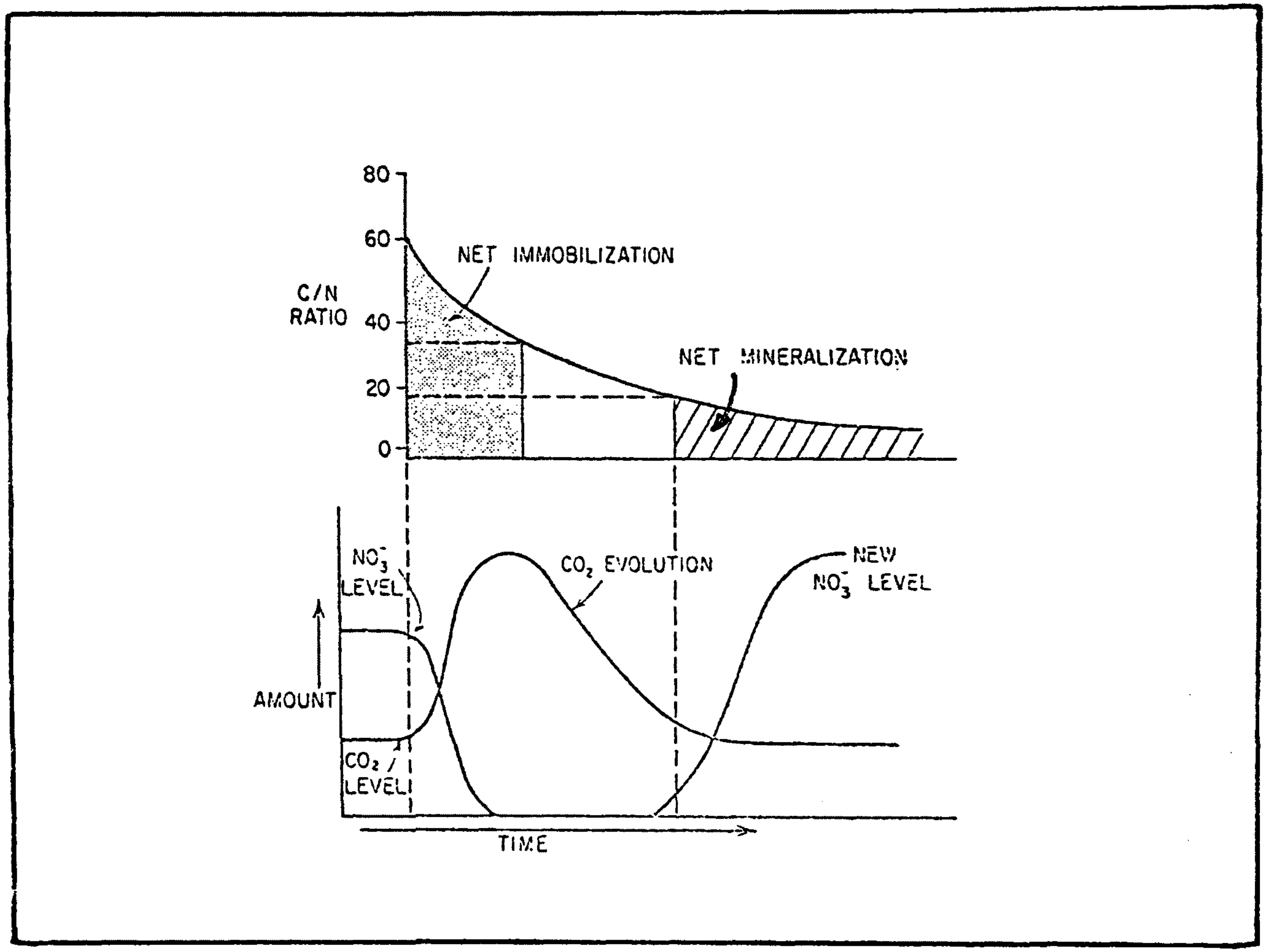


Figure 3. Changes in C/N ratio and nitrate levels of soil during microbial decomposition of a highly carbonaceous waste material (77).

Literature on the microbial assimilation of petroleum and its products is voluminous (27, 81, 82, 85, 86, 87). Over 100 species of bacteria, yeast, and fungi representing 31 genera have been reported to attack one or more types of petroleum hydrocarbons (85).

The initial effect of even minimal oil contamination is to lower microbial population and carbon dioxide production or C/N ratio (85, 86). Following this "shock" period (a few weeks to several months), there is generally a stimulation in microbial growth and shift in the relative abundance of different species of organisms. The increasing number of organisms in the contaminated soil is a good indication of a rapid breakdown of oil, which occurs if the soil is supplied with enough nitrogen and deficient minerals such as phosphorus (86).

In land cultivation, the waste may not be evenly distributed through the plow depth; therefore, zones of unusually high waste concentration may exist. Some of the contaminants or constituents in the waste can destroy soil microorganisms or suppress their activities, if present in excessive amounts. Parr (88) has reviewed the inhibiting effects of a large number of chemicals on microorganisms and their transformations in soil. Fungicides and fumigants, for example, function as partial soil sterilants, destroying pathogenic as well as saprophytic organisms, including those responsible for ammonification and nitrification.

In summary, microbial decomposition of the organic components of both municipal solid waste and industrial wastes does occur. The large soil microbial population, however, may require very specific substrate, energy sources, and environmental conditions to achieve the maximum rate of waste degradation. Waste containing high levels of certain toxic constituents (e.g., pesticides) may destroy soil microorganisms or suppress their activities.

SECTION 7

EFFECTS OF WASTE APPLICATION ON PLANT GROWTH AND ELEMENTAL UPTAKE

Various studies have been conducted on the growth and elemental uptake of crops grown on soils amended with municipal solid waste or industrial wastes. These studies, however, have been limited to greenhouse and small-scale field experiments. Published literature on vegetative impacts from land cultivation of industrial wastes is particularly scarce. Most land cultivation sites are designed for disposal only; crops are not generally grown for human or animal consumption.

MUNICIPAL SOLID WASTE

In a field study conducted to evaluate the effect of land disposal of shredded municipal waste on plant growth and nutrient uptake, the waste was applied at rates up to 896 t/ha (400 tons/ac) to a Sagehill loamy sand (13). Alfalfa and tall fescue yields of 11.2 to 13.4 t/ha (5 to 6 tons/ac) were produced during the first growing season at refuse application rates of 0 to 448 t/ha (0 to 200 tons/ac) and addition of nitrogen fertilizer at 448 to 1,120 kg/ha (400 to 1,000 lb/ac), respectively. Plant contents of nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, iron, cobalt, copper, and chromium were not affected by the addition of waste. However, manganese and zinc uptake by wheat, fescue, and alfalfa increased with waste addition and with nitrogen fertilization. At 448 t/ha (200 tons/ac), boron uptake by wheat and fescue plants exceeded phytotoxic levels. Molybdenum uptake by alfalfa grown with higher application rates reached levels potentially hazardous to livestock during the first growing season, but decreased to normal levels during the second year.

King et al. (15) reported that applications of municipal refuse at rates of 188 to 376 t/ha (85 to 170 tons/ac) and liquid sewage sludge at 2.3 to 4.6 cm (0.9 to 1.8 in) to an agricultural loam soil (pH 7.6) resulted in no significant differences in yields of rye and corn as compared to the controls. In this study, levels of zinc, copper, cadmium, and lead of rye and corn plants usually increased with waste addition but were below levels considered toxic to the crops or to animals that might consume the crops.

Steigerwald and Springer (89) conducted a 3-yr, large-scale field trial using fresh municipal solid waste, composted solid waste, and a compost of solid waste and digested sewage sludge. Climatic conditions, soil type, application rates, and plant species were not given. In the study, plant yields were strongly influenced by the type of waste added to the soil, with solid waste producing the smallest yield increases and the refuse and sludge compost the largest. For plants that thrive on solid waste (e.g., corn and tomatoes), yields were increased 20 percent or more the year refuse was applied. Plants sensitive to solid wastes (e.g., beans) reacted with reduced yields, but this impact could be somewhat alleviated by heavy watering to leach soluble salts and boron out of the root zone. However, this could result in surface or groundwater contamination. Better results were achieved with fresh solid waste applied during the fall. Solid waste compost provided higher yields than did fresh solid waste. Those plants that thirve on solid waste recorded yield increases of about 20 percent when the refuse/sludge compost was applied to the soil. All plants recorded yield increases of about 45 percent with compost application, the increases depending on the application rate. Better results were obtained with this compost when it was applied in the spring.

In a 9-yr experiment in Germany (90), ground fresh and composted refuse were applied to a silty sand (pH 5.8) at the rate of 99.7 t/ha (44.5 tons/ac) at the beginning of a 3-yr rotation, and at 89.6 t/ha (40.0 tons/ac) at the beginning of the second and third 3-yr rotations. The rotation crops were potatoes, rye, and oats. Supplemental chemical fertilizer (incremental amounts of nitrogen and constant amounts of phosphorus and potassium) was applied each year. In the first year, composted refuse increased potato yields while the fresh refuse reduced yields, probably due to nitrogen deficiency. In the succeeding 2 yr, following stabilization of the fresh refuse in the soil, however, the yields of rye and oats on the fresh refuse plots were increased over yields on both the composted refuse plots and on the control plots of equivalent chemical fertilization. For the total 9 yr of experimentation, yields were 11.1 percent higher with the composted refuse and 11.7 percent higher with fresh refuse than were the yields from the control plots receiving equivalent amounts of chemical fertilizers.

Over the past few years, numerous reports have been published on the incorporation of composted refuse into soil and its effect on crop yield and quality. Yields of Bermuda grass, sorghum, and corn increased with applications of 80, 143, and 112 t/ha (36, 64, and 50 tons/ac), respectively, of composted municipal refuse and sewage sludge (73). These yields, however, were surpassed by fertilizer application rates of 180 kg/ha (161 lb/ac) of nitrogen together with adequate phosphorus and potassium.

Hortenstine and Rothwell (72) reported that yields and the nitrogen, phosphorus, and potassium contents of oats increased greatly when compost was applied to a Leon fine sand at a rate of 521 t/ha (233 tons/ac). Radishes showed a similar response except for indications of phytotoxic effects at the 521-t/ha (233-tons/ac) compost application rate. Pelletized municipal refuse compost as a soil amendment and nutrient source increased sorghum yields even at the highest rate (64 t/ha, or 29 tons/ac) of applied compost (7).

Composted refuse increased the uptake of most plant nutrients (7, 91) except in cases where a nutrient might have already been present in adequate amounts (73). This increase was caused by changes in soil pH and water holding capacity due to compost application plus the small nutrient addition. Nitrogen was the only nutrient for which the uptake by plants was reduced by the addition of composted refuse (91). The decrease in nitrogen uptake probably resulted from an initial immobilization of nitrogen by soil microorganisms.

The sodium concentration of the newsprint component of refuse was high, but compost application had relatively little effect on sodium concentration in sorghum except at the very high rates (73). Zinc and copper concentrations were increased by both compost and nitrogen additions. Soil and plant tissue tests indicated that zinc could accumulate in potentially toxic amounts if the compost was applied at rates totaling several hundred metric tons per hectare over a few years.

Phytotoxic effects of boron in dwarf beans were observed as a result of the application of 100 t/ha (45 lb/ac) of municipal compost to light stony soil (92). Leaching the compost to decrease the boron concentration prior to application eliminated the phytotoxic effects and significantly increased the fresh weight yield of the total bean plants.

In summary, although various methods of waste disposal have been practiced for centuries, application of municipal refuse to agricultural land to improve soils and crop production as well as to dispose of the waste material is relatively new. Various investigators have applied municipal refuse or compost to marginal and agricultural lands and have found generally increased yields of many different crops. Some instances of decreased crop yields due to waste applications were also reported. In these cases, application rates were very high, and phytotoxicities were due to high concentrations of soluble salts and some elemental constituents of the waste such as boron, zinc, or copper.

The nitrogen content in the municipal refuse or compost is low and not readily available to the plant. Nitrogen deficiency usually occurs as a result of application of these waste materials to soil. Addition of nitrogen fertilizer to the waste-amended soil would increase plant growth, which should enhance plant uptake of both nutrients and toxic metals.

INDUSTRIAL SLUDGES

Baker (93) has made an extensive review of the effects of oils on plants. Oils vary in their toxicity according to the content of low-boiling compounds, unsaturated compounds, aromatics, and acids. The toxicity is in the following order: aromatics>olefins>naphthenes>paraffins. Within each series of hydrocarbons, the smaller molecules are more toxic than the larger ones. The effects of oil coating on physiological processes were summarized:

- Plant surfaces are readily wetted by petroleum oils. Cell membranes are damaged by penetration of hydrocarbon molecules, leading to leakage of cell contents; thus oil may enter the cells.

- Oils reduce transpiration rate, probably by blocking stomata and intercellular spaces. Oils also reduce photosynthetic rate by disruption of chloroplast membranes and resulting accumulation of end-products brought about by inhibition of outward translocation from the leaf.

- The effects of oils on respiration are variable, but an increase of respiration rate often occurs, possibly due to mitochondrial damage, resulting in an "uncoupling" effect.

- Oils inhibit nutrient translocation, probably through a physical interference with the transport mechanism.

- Oils inhibit germination, probably resulting from oil entering the seed and killing the embryo, or from oil coating the seed and preventing the oxygen and water uptake essential for germination.

The severity of the above effects depends on the constituents and amount of the oil, the environmental conditions, and the species of plant.

Several workers have reported that fresh oils are more toxic to plants than weathered oily waste materials (94, 95). One must assume the decrease in toxicity is a function of volatilization of the lighter molecular weight compounds present in the oily waste. Lighter weight oil also generally has more leaf penetrating capacity than do more viscous oils and thus has a higher probability of toxicity to a plant (96).

Toxicity of an oil to a plant often depends upon a particular plant characteristic. For example, increased oil retention caused by pubescence, leaf angle, and the presence of a surfactant may increase plant toxicity (93). Other plant properties which decrease oil toxicity would include heavy cuticles, low frequency of stomata, and stomata located only on the underside of a leaf. Currier and Peoples (97) have reported that barley and carrot roots were more resistant to hydrocarbons than the leaf portions of a plant. This resistance may be expected because of the existence of stomata in the plant leaf, the uptake of more polar compounds by plant roots, and the effect of a soil absorbent surface as a sink for the hydrocarbon compounds.

The stage of plant growth also affects the interaction between plants and hydrocarbons. Annual species are most damaged by summer oil applications. Oil applied during flower bud formation reduces flowering and oil treated flowers rarely produce seed (98).

Some of the initial work on interactions between plants and oily wastes were conducted by Carr, where he applied oil to soils at a rate up to 4 percent by weight (99). Carr observed that soybean growth was enhanced at approximately 1 percent oil application but the growth was markedly reduced at rates greater than 1 percent. Udo and Fayemi (80) observed marked reduction in germination of maize upon applications of oil exceeding 2 percent by weight.

Murphy (100) reported that oil applied at a rate of 23,400 l/ha (2,500 gal/ac) or more and mixed with the surface 10 cm (4 in) of soils essentially inhibited all wheat seed germination. With mixing, oil applied at a rate of 4,670 l/ha (500 gal/ac) did allow approximately 80 percent wheat seed germination. However, when crude oil was applied to the soil surface without mixing, delayed wheat seed germination was observed at the 23,400 l/ha (2,500 gal/ac) rate, but normal germination occurred with application of only 6,570 l/ha (500 gal/ac). Addition of 46,700 l or 140,100 l (5,000 or 15,000 gal) of crude oil per ha essentially eliminated germination. When oil was applied and covered with 10 cm (4 in) of soil, which would be similar to a subsurface injection of oily waste material, seedling germination was delayed at the higher application rates but no effect was seen on the percentage germination up to 46,700 l/ha (5,000 gal/ac). The wheat seed were planted at 3.8 cm (1.5 in) deep.

Although numerous studies have been completed on the effect of spray oils on plant growth, very few studies have been completed with objectives related to land application of oily waste disposal and the resultant effect on plant growth. Plice (81) studied the growth of cotton, sorghum, soybean, and field peas after application of a paraffin base, an asphalt base, and a basic sediment at rates of 0.1, 0.5, and 1 percent. He summarized his results to indicate that crop yields decreased by 14, 39, and 58 percent with applications of oil at rates of 0.1, 0.5, and 1.0 percent, respectively.

Raymond et al. (87) applied crankcase oils, crude oils, heating oil, and heavy fuel oil at 39,200 l/ha (100 bbl/ac) to soils at three locations and planted a variety of vegetables 9 mo after soil incorporation. Results, though incomplete and variable, showed that at one location, radish and garden pea seeds germinated, but very few survived to grow into normal plants. At another location, normal growth of both turnips or beans was observed in almost every treated plot. Concentrations of lead in beans and turnips were significantly higher with crankcase oil application, reaching 13 and 14 ppm, respectively, as compared to 8 and 3 ppm in the control plots.

Giddens (101) conducted field and greenhouse experiments to determine the effects of application of spent motor oil on soil properties and plant growth. At oil rates of up to 31,100 l/ha (3,320 gal/ac), peanuts, cotton, soybeans, and corn were successfully grown when amply fertilized, especially with nitrogen. Growth of sorghum and weeds was significantly reduced by high oil rates. Corn grown on recently oil-treated soil contained lower concentrations of nitrogen and manganese but the same concentrations of phosphorus, potassium, calcium, magnesium, and lead as plants grown on untreated soil. Previous oil application increased the manganese and zinc contents of corn tissue, but no toxicity symptoms were observed.

In a greenhouse experiment (80), crude oil was applied at rates of 0 to 10.6 percent by weight to a tropical soil, and three corn crops were raised in succession in the same soil. With crude oil applications at 4.2 percent (soil weight), germination and yield were reduced 50 percent and 92 percent, respectively. The poor growth was attributed to suffocation of the plants, interference with plant/soil/water relationships, and toxicity from sulfides and excess available manganese produced by anaerobic conditions during the decomposition of the hydrocarbons.

DeRoo (102) evaluated mycelial sludges produced by the pharmaceutical industry in Connecticut as a nitrogen fertilizer and an organic soil amendment. Application of the sludges at rates of 12, 36, and 108 t/ha (5.4, 16, and 48 tons/ac, wet weight) to a Windsor loamy sand in the greenhouse retarded early growth of tomato plants; corn growth was stunted only at the 108-t/ha (48-tons/ac) rate. Field studies showed that tobacco did not benefit from mycelial residues applied at rates equal to the organic nitrogen in a standard commercial tobacco fertilizer mix, and that the overall response of corn to an addition of 224 t/ha (100 tons/ac) of mycelial residues was favorable. He concluded that if those wastes were applied repeatedly at high rates to the same field, the soluble salt and high zinc content in the sludges might injure the plants.

Studies with similar objectives have been conducted using lagoon pulp sludge (Jacobs, personal communication) and nylon processing sludge (Cotnoir, personal communication). Results indicated that the sludges would have value as a low-analysis nitrogen fertilizer under proper crop management. Growth of corn and wheat was normal, and no significant uptake of heavy metals as a result of sludge treatment was noted.

In a field experiment at Santa Clara, California, cannery fruit sludge was applied to a marginal Willow clay soil at rates of 0 to 1,952 t/ha (871 tons/ac) fresh weight (103). Dry matter yields of the wheat plants increased with increased amounts of waste applied, because of plant nutrients in the waste material. A fourfold increase of forage yields over the control was noted for barley and vetch as a result of application of cannery waste to a marginal land near Gilroy, California (Flocker, personal communication).

In a field study (79), the effect of a refractory metal processing waste slurry on perennial ryegrass forage quality and seed yield was investigated. Results showed that perennial ryegrass dry matter yields were not significantly changed by waste additions up to 112 t/ha (50 tons/ac), and were similar to yields obtained in commercial farm operations. Seed yields were slightly less than normal, but seed viability was not affected by the application. In this study, of the 20 elements analyzed, 17 were not significantly affected by waste application. The remainder - sulfur, sodium, and nitrogen - showed significant increase in uptake by the ryegrass at the 112-t/ha (50-tons/ac) rate as compared to the control plots.

Nelson (personal communication) observed a distinctly stunted growth of corn, soybeans, and wheat on a soil that received heavy applications (up to 20 cm thick) of a steel mill sludge. The stunted growth was attributed to: 1) phosphorus deficiency resulting from phosphorus fixation by iron oxides in the sludge, 2) nitrogen deficiency due to microbial immobilization during decomposition of the sludge, and 3) poor root development as a result of compaction of the soil sludge mixture. However, trace elements did not accumulate in plants.

In summary, there has been some evidence of adverse effects caused by land cultivation of industrial wastes on germination, growth, and metal uptake by crops, particularly when the soil is not adequately fertilized. Nitrogen often appears to be the limiting nutrient when industrial wastes, especially carbonaceous ones, are applied. Phosphorus is also a limiting factor when metal processing or steel mill sludges that are high in iron and manganese oxides are land cultivated.

There has been relatively little research on evaluation of yield and quality of crops that are grown on soils treated with industrial sludges. Generally, unless the waste to be deposited on land is considered either harmless or a nutrient source and/or soil amendment, the disposal area is generally devoid of any purposely seeded crop. Wild grasses and weeds are relatively common at many industrial waste land cultivation sites.

SECTION 8

REGULATIONS AFFECTING LAND CULTIVATION

With the passage of the Resource Conservation and Recovery Act of 1976 (PL 94-580) on October 21, 1976, the U.S. Environmental Protection Agency (EPA) was given its first solid waste regulatory responsibility. This responsibility applies only to the management of hazardous wastes and requires that EPA develop standards applicable to generators, transporters, and disposal facilities.

The specific standards developed for hazardous waste disposal facilities will determine the impact of federal regulations on disposal of waste materials by land cultivation. Thus, land cultivation of hazardous wastes may be influenced in the future by federal regulations. For other wastes, regulatory responsibility rests with the states.

State agencies responsible for regulating wastewater/sludge and solid waste disposal in 32 selected states were contacted to provide an indication of the impact of state regulations on land cultivation of municipal solid waste and industrial wastewaters/sludges. The discussion that follows is based on the published waste disposal regulations of the 32 states and personnel. A summary of the relevant regulations in the states contacted is presented in Table 9 . As shown, 28 states do not have specific regulations or guidelines for land cultivation. In these states, land cultivation disposal is evaluated on a case-by-case basis. Evaluation procedures vary from state to state, but normally include consideration of the following factors:

- Site topography
- Depth to groundwater and adjacent surface water courses
- Soil type
- Site operating procedures and deactivation plans
- Monitoring requirements.

California is one of the 28 states that evaluates land cultivation sites on a case-by-case basis. Table 10 summarizes the requirements imposed on one site in the San Francisco Bay area. The applicants proposed to either surface spread or subsurface inject alum sludge from water treatment plants. Requirements shown in Table 10 indicate the type of constraints an

TABLE 9. SUMMARY OF STATE REGULATIONS AFFECTING LAND CULTIVATION

State	Pertinent Regulations
California	• There are no specific guidelines or regulations for land cultivation • Spray irrigation guidelines serve as one reference point in evaluating land cultivation applications • The state "Water Reclamation Law" dictates the groundwater quality must be maintained at sites utilizing land disposal of wastewater • Waste for land cultivation must be biodegradable • Group 1 wastes (hazardous materials) must be disposed of in Class I disposal sites
Connecticut	• There are no specific guidelines or regulations for land cultivation • Permits are required for all land disposal operations
Delaware	• There are no specific regulations or guidelines for land cultivation • A permit is required for disposal of waste by land cultivation, just as for any other disposal methods • Review of land cultivation permit applications concentrates on waste characteristics and site characteristics such as soil types and depth to groundwater
Florida	• There are no specific guidelines or regulations for land cultivation • Spray irrigation guidelines are used to some extent as a reference point for nutrient and hydraulic loading considerations related to land cultivation disposal sites

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Florida (Continued)	
	• Substantially different climatic conditions in different parts of the state make flexible guidelines attractive
Georgia	• There are no specific guidelines or regulations for land cultivation • Permits are not required for land disposal of wastewater if there is no surface discharge. The state reviews plans and specifications to establish the environmental adequacy of all waste disposal methods • Regulations governing spray irrigation facilities prevents the use of spraying without a cover crop
Idaho	• There are no specific regulations or guidelines for land cultivation • Specific spray irrigation regulations requiring that no groundwater mound results and that no salt intrusion be observed on neighboring property is also applied to land cultivation of wastewaters
Illinois	• There are no specific guidelines or regulations for land cultivation • Permits are required
Indiana	• There are no specific guidelines or regulations for land cultivation • Land cultivation has recently received increased emphasis due to groundwater pollution problems which showed up at several sites during the summer of 1976. These sites had operated unsuccessfully the previous years.

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Kansas	• There are no specific guidelines or regulations for land cultivation • Spray irrigation regulations are used for reference in evaluating land cultivation of wastewaters
Kentucky	• Specific land cultivation guidelines are not desired since flexibility in matching wastes and disposal sites is desired. Flexibility is particularly important due to the widely varying terrain experienced with the state • Discharge permits are not required for wastewater land cultivation systems with zero surface discharge, but construction permits are required. Provisions also exist for periodic inspection to ensure proper operation and zero discharge conditions
Maine	• There are no specific regulations or guidelines for land cultivation • Guidelines are currently being prepared for disposal of paper mill sludge by land cultivation • Guidelines have been written for disposal of municipal sewage sludge by land cultivation
Maryland	• There are no specific guidelines or regulations with the exception of certain bacteriological standards which have been set for some food processing wastes • Specific spray irrigation regulations and sludge disposal guidelines aid in the evaluation of land cultivation sites

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Massachusetts	• There are no specific guidelines or regulations for land cultivation • Certified sanitary landfill facilities must be used for disposal of hazardous waste • Land cultivation requires state approval
Michigan	• There are no specific guidelines or regulations but there are specific procedures required for site investigation prior to granting a permit for land cultivation; monitoring wells are required • Groundwater standards are in the process of being drafted which will be utilized in evaluating future land cultivation sites. All disposal sites will be required to ensure that the neighboring groundwater meets the state standards (which basically will be drinking water standards)
Minnesota	• There are no specific regulations or guidelines for land cultivation • Land cultivation is uncommon except for food processing wastes
Mississippi	• A permit is required from the state for the operation of land cultivation sites; the state must approve each type of waste being disposed at the site • Existing regulations are vague, but there are plans to write specific guidelines for various categories of waste such as oily waste, agricultural waste, etc.

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
New Hampshire	• No specific guidelines or regulations currently exist, but permission to operate a land cultivation facility is required • Permission is granted based on a view of waste composition and site soil types, topography and operating procedures. Permission is granted on a temporary basis contingent on successful test plot results. If test plot application results are successful, a more permanent permission permit would be issued
New York	• There are no specific guidelines or standards of review for land cultivation disposal • The state policy is to discourage land application of toxic waste • Guidelines for spray irrigation are used as an aid in reviewing land cultivation disposal application
North Carolina	• No specific guidelines have been written for land cultivation, but specific evaluation procedures are utilized to evaluate applications • Applications for use of land cultivation disposal requires that a soil scientist and an agronomist review and report on the site to determine appropriate design features and operating procedures • It was indicated that specific regulations are not desired, since flexibility needs to be maintained. In this way, a site appropriate for a specific type of waste can be identified and utlized

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Ohio	• There are no specific guidelines or regulations for land cultivation • Land application has received little emphasis to date since it is used only sparingly
Oklahoma	• Land cultivation disposal sites are regulated under the "Controlled Industrial Waste Disposal Act, 630S Supp. 1976." This establishes minimum site standards and other factors such as waste storage capacity. Case-by-case analysis is still required to evaluate land cultivation disposal applications • Specific regulatory guidelines were promulgated in response to the large quantities of oily waste requiring disposal (see Table 12)
Oregon	• There are no specific guidelines or regulations for land cultivation • Specific guidelines for municipal wastewater treatment, sludge disposal, and/or spray irrigation are used as a reference point in evaluating land cultivation applications
Pennsylvania	• There are no specific guidelines or regulations for land cultivation • Spray irrigation guidelines are used as a reference for evaluating land cultivation of wastewater • The general policy is to prohibit land cultivation of toxic waste which is not biodegradable

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Rhode Island	• No specific guidelines or regulations for land cultivation • Off-site disposal of waste requires a permit • Written permission is required if solid wastes are disposed in any way other than landfilling
South Carolina	• Specific guidelines apply to spray irrigation disposal facilities • Specific regulations are written for land farming of cellulosic wastes. Permits are required • Minimum site criteria have been written for hazardous waste disposal • Groundwater monitoring of land cultivation sites is normally required
Tennessee	• There are no specific regulations or guidelines for land cultivation • All types of disposal facilities are required to submit plans for approval. Each site must then obtain an operating registration from the state. Registration is not granted to a site unless the operation is determined to be satisfactory. • Hazardous waste management legislation is in preparation which may have some impact on the types of waste which may be land cultivated • As a general rule, the state does not approve disposal of toxic waste by land cultivation
Texas	• One of the few states which has specific guidelines for evaluation of land cultivation disposal applications. However, these guidelines are fairly general

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Texas (Continued)	• No permit is required for on-site disposal of waste. However, it is required that such waste disposal be recorded in the property records • The principal focus of the guidelines is to prevent the buildup of toxic materials in the soil. A safety margin is provided between the maximum allowable toxic constituent concentrations and the level at which these constituents may become detrimental to soil productivity (see Table 12).
Vermont	• There are no guidelines or regulations pertaining to land cultivation and there are no specific prohibitions against the use of this disposal method for industrial waste • It is state policy to discourage land cultivation as a disposal method for industrial waste other than food processing waste. Approximately 60 percent of Vermont residents rely on groundwater for their drinking water supply, and therefore, are very sensitive to groundwater pollution potentials arising from land disposal practices
Virginia	• There are no specific guidelines or regulations for land cultivation • Site plans are reviewed to insure that surface and groundwater standards will not be exceeded • There is a general reluctance to utilize land cultivation for disposal of toxic or hazardous waste

(continued)

TABLE 9 (continued)

State	Pertinent Regulations
Washington	• There are no specific guidelines or regulations for land cultivation • State control is exercised principally through NPDES regulatory system, even for sludges • Guidelines have been written for spray irrigation facilities, a relevant feature being that there is a five year limit on spray irrigation at any one site
West Virginia	• There are no specific regulations or guidelines for land cultivation • Land cultivation is seldom used and has received little attention
Wisconsin	• Land spreading of toxic waste is discouraged, although specific regulations have not been written • A possible exception to this general policy would be dilute solution of toxic waste which are biodegradable • A specific permit program exists governing spray irrigation. Information gained from this program can be utilized to help ensure proper design and operation of land cultivation sites

TABLE 10. SUMMARY OF REQUIREMENTS FOR A LAND CULTIVATION SITE IN CALIFORNIA*

1. Waste Disposal Specifications

- Waste disposal shall not cause pollution or a nuisance
- Only the applicant's sludges may be disposed at the site
- Waste may not be carried from the site into any waters of the state
- No waste shall be cultivated within 100 ft of the nearby creek or drainage ditch
- Discharger shall remove and relocate any wastes discharged in violation of these requirements
- Waste disposal shall not degrade the quality of any usable groundwater
- Surface spreading is prohibited when raining or when soils are saturated

2. Provisions

- Discharger must file with the Board a report of any material change or proposed change in the character, location or quantity of the waste discharge
- The Board must receive notification 90 days prior to discontinuation of site use, submitting a report of methods and controls to assure surface water quality protection during final operations and the proposed subsequent land use
- Property owner has a continuing responsibility to correct problems arising in the future
- Discharger shall permit the Board: (1) entry to premises where wastes or records are located, (2) access to copy records, (3) inspection of monitoring equipment and records, and (4) to sample any discharge

*Requirements issued by the California Regional Water Quality Control Board, San Francisco Bay Region. Waste is alum sludge from water treatment plants.

applicant might face; however, variations must be expected. In general, a case-by-case review can be anticipated to yield requirements that are site and waste specific. For example, Indiana imposed the requirement that an applicant use deep (41 cm) injection to avoid odor problems (see Indiana case study report in Volume 2).

Texas has specific land cultivation regulations that are generally applicable to all types of industrial wastewaters/ sludges. The regulations address a number of factors that must be evaluated in considering a site for land cultivation disposal, including: soils, topography, climate, surrounding land use, and groundwater conditions. Similarly, waste composition and cation exchange capacity (CEC) of the soils at the disposal site are factors that should be noted in detail to determine the appropriate waste application rate.

In Oklahoma, land cultivation guidelines are aimed at oily wastes. The suitability of other types of industrial wastewaters/sludges for disposal by land cultivation is determined on a case-by-case basis. Oklahoma's guidelines are similar to those of Texas, both of which are summarized in Table 11. Oklahoma has specifically excluded water soluble inorganic wastes, judging that such wastes are not suitable for land cultivation. A list of wastes deemed to be amenable to land cultivation is also given, as follows: API separator sludge, oil storage tank bottoms, biological waste treatment sludge, process filter clays, petroleum coke waste, process catalyst, water treatment sludge, and process water treatment sludge.

Local regulations, except for zoning restrictions, normally do not affect the use of land cultivation as a disposal technique. Occasionally, local health officials may require secondary biological treatment of industrial wastewater.

Although the vast majority of states contacted did not have specific land cultivation regulations or guidelines, indications are that several states planned to develop regulations in the future. Mississippi is currently in the process of developing specific regulations for land cultivation of different types of wastes, such as agricultural and food processing wastes, and oily materials.

On the other hand, Kentucky has no plans to write regulations and feels that specific regulations are inappropriate for a variety of reasons. In particular, the belief was expressed that it is important to have flexibility to match wastes to appropriate disposal sites, especially in a state with such widely varying terrain and soil conditions.

Two of the states that have regulations related to land cultivation are Maine and South Carolina. In both states,

TABLE 11. SUMMARY OF TEXAS AND OKLAHOMA LAND CULTIVATION GUIDELINES

Item	Guideline (Summary Statement) Texas	Oklahoma
• Soils	• Should be deep, prefer high clay and organic content and have large surface area (best soils are classed as CL, OL, MH, CH and OH under the Unified Soil Classification System)	• Should be deep, have large total surface area and have high clay and organic content (best soils are classed as CL, OL, MH, CH and OH under the Unified Soil Classification System)
• Topography	• Prefer surface slopes less than 5 percent, greater than 0 percent	• Slope should be less than 5 percent, greater than 0 percent
• Climate	• High net evaporation, median mean temperature, moderate 24-hr, 25-yr frequency maximum rainfall	• High net evaporation, median mean temperature, moderate 24-hr, 50-yr frequency maximum rainfall
• Surrounding Land Use	• Sparsely populated, or provide buffer and locate downwind from nearby residences	• Sparsely populated, or provide buffer and locate downwind from nearby residences
• Groundwater Conditions	• Avoid shallow potable groundwater. If not possible, provide vegetative cover, avoid high application rates, monitor groundwater quality	• Avoid shallow potable groundwater. If not possible, provide vegetative cover, avoid high application rates, rigidly monitor groundwater quality
• Waste Restrictions	• Not addressed	• Water soluble inorganic industrial wastes should not be land cultivated
• Application Rates	• Minimum waste composition analysis: Cl, PO_4, Total N, Zn, Cu, Ni, As, Ba, Mn, Cr, Cd, B, Pb, Hg, Se, Na, Mg, Ca	• Minimum waste composition analysis: Zn, Cu, Ni, As, Ba, Mn, Cr, Cd, B, Pb, Hg, Se, Na, Mg, Ca, Cl, PO_4, Total N

(continued)

TABLE 11 (continued)

	Guideline (Summary Statement)	
Item	Texas	Oklahoma
• Application Rates	• Determine soil cation exchange capacity (CEC)	• Determine soil CEC if any of the elements in waste composition analysis above are present
	• Total metals application over site life should be less than 50 percent of CEC of top 1 ft of site's soil	• Not addressed
	• If crop grown and harvested at site, total metal application in 30-yr period should be less than 5 percent of CEC	• Not addressed
	• Total N applied in waste, less than 125 lb /ac/yr	• Total N applied in waste, no more than 125 lb /ac/yr, or the maximum amount utilized or assimilated by vegetative cover
	• Annual free water applied in the waste should be less than annual evaporation rate	• Total free water applied should be no more than the net evaporation for time period between applications
	• Not addressed	• Oily waste application rate must be such that soil-waste mixture contains no more than 10 percent oil by weight
	• Not addressed	• Recommended application rate for oily wastes at established (over 6 mo old) sites: - 35 bbl oil/ac/mo - without fertilizer - 60 bbl oil/ac/mo - with fertilizer

(continued)

TABLE 11 (continued)

Item	Guideline (Summary Statement) — Texas	Guideline (Summary Statement) — Oklahoma
• Operational Restrictions	• All runoff must be contained (use dikes or lined control collection basin) unless discharge permit is obtained. Collection basin should contain 25-yr, 24-hr maximum rainfall	• All runoff must be contained unless discharge permit is obtained (use dikes or lined central collection basin). Collection basin must contain all site runoff from a 50-yr, 24-hr maximum rainfall.
	• Soil pH must be maintained at above 6.5 while the site is active	• Soil pH must be maintained at above 6.5 while site is active
	• Mix waste into soil as soon as possible	• Mix waste into soil as soon as possible
	• Vegetation for human or animal consumption must be analyzed for metals contained in the waste before feeding	• Vegetation for human or animal consumption must be analyzed for metals and any elements in the waste which are known to be concentrated by the plant species before use or sale
• Mixing Frequency	• Not addressed	• Dependent on rainfall. Recommended practice is to mix twice monthly for first 2 months, then once every other month
• Mixing Depth	• Not addressed	• Sludge should be mixed into soil to a depth of 6 to 12 in

regulations pertain only to land cultivation of cellulosic waste materials from the paper and allied products industry. Land cultivation of other types of waste is evaluated on a case-by-case basis.

Although specific regulations may not currently affect land cultivation in most states, state policies may have an impact on the type of wastes that can be land cultivated. In New York and Vermont, state policy is to discourage and minimize land cultivation of wastes other than those from agriculture or food processing.

SECTION 9

SITE SELECTION CONSIDERATIONS

In discussing site selection criteria, one can give only general principles that apply to wastes from many sources and to waste management systems that are in common use. Since it is rare to locate candidate sites that exhibit all the characteristics of an ideal location, the final decision as to whether a site should or should not be used for land cultivation of a specific waste almost always represents a compromise. Most sites can be modified to meet the majority, if not all, of the criteria. The site selected should be usable on a continuous basis.

GENERAL SELECTION CRITERIA

Seven categories of general site selection criteria can be developed:

- Access
- Land use status
- Perceived site conditions
- Flora and fauna
- Climate
- Economics
- Public acceptance.

These categories provide convenient reference points and are not equally important for all sites.

Access

Access is an important consideration in attempting to locate a land cultivation site. Site access routes that pass through or near residential areas, hospitals, schools, and business areas may be undesirable to citizens because of noise, traffic, and the potential for accidents and waste spills. The routes should, instead, pass through industrial and warehouse areas.

Access road alignments, and grades along the routes and within the land cultivation sites are also important considerations. Grades should not exceed 7 percent to properly accommodate loaded waste delivery truck traffic. Steeper grades place potentially damaging strain on trucks, cause significantly increased operating noise, and increase the potential for brake failure and subsequent accidents. Roads must be structured for the anticipated size and weight of waste delivery trucks.

Land Use Status

Land use status relates to the extent that development of a land cultivation site would conflict with use and value of present and future on-site and adjacent property. Potential sites located on or adjacent to areas used or proposed for parks, playgrounds, open space, and wildlife preserves may be unsuitable unless site management is very well planned and executed. Adjacent property may experience a temporary decline in property value during the period of waste disposal activities. However, land cultivation of some organic wastes in an agricultural area may renovate marginal soil for future farming, ultimately increasing its value.

Potential cultivation sites must also be compatible with county zoning and land use requirements. Areas set aside for residential use in the near future, for example, would make unlikely land cultivation sites.

Cultivation operations should be evaluated before startup to minimize odor, dust, noise, and unsightliness for nearby property owners. Screening can be provided by natural topography or vegetation, as well as by man-made barriers or planted vegetation. Use of uncultivated buffer zones around the site perimeter may also be necessary if there are nearby residential or commercial areas.

Another consideration for site selection should be the potential for historical or archaeological finds in previously undisturbed areas. Information on this potential may be readily available from local historical societies, probability maps for archaeological finds, and other sources.

Site operations in the vicinity of utilities may create problems. For instance, high voltage power lines can be subject to short circuiting and loss of power transmission efficiency in the presence of dust and high humidity. Dust will normally be a major consideration only while mixing a dried waste into the soil, or when disking a field after the applied sludge has had time to dry. Underground water, gas, petroleum, and utility pipelines may require relocation or some other protection measure to minimize corrosion and/or breakage.

Perceived Site Conditions

Potential land cultivation sites should be selected to promote an efficient, environmentally safe operation. To this end, consideration should be given to soil, dust and litter, topography, and subsurface hydrology.

Soil--

The soil should not be extremely rocky or have large boulders. These conditions would make cultivation procedures difficult and cause greater wear on the land cultivation equipment. Soil characteristics for sites that receive municipal refuse, industrial wastewaters, and industrial sludges are discussed in Section 10.

Dust and Litter--

Windblown dust and litter can have an adverse effect on inhabitants living in the vicinity of a prospective site. Blowing dust is aesthetically displeasing and may carry hazardous components of some cultivated waste to inhabited areas. Also, as mentioned earlier, dust, when combined with high humidity, can short circuit the insulating system of high voltage power lines. Potential for adverse dust conditions can be anticipated by familiarization with local prevailing wind conditions, the type of waste to be disposed, and operating techniques to be employed at the site.

Land cultivation of municipal solid waste has the greatest propensity to create dust and litter problems. Industrial sludges and wastewaters may actually prevent windblown dust, although disking of a field after applied sludge has dried may generate dust. In the case of municipal solid waste, a light application of water or wastewater may control blowing debris and prevent dust conditions. Water addition may also enhance biodegradation processes.

Litter from land cultivated municipal refuse may be unsightly if not contained. Therefore, prevailing winds should be studied and mitigating measures applied to avoid spread of litter. Litter fences, natural barriers, and treelines have been used with some success to contain refuse litter.

Topography--

Erosion of the land cultivation site due to runoff should be controlled. Prospective sites should be on relatively level ground with an average grade of 0 to 5 percent. Grades greater than 5 percent will significantly increase water velocities with a subsequent increase in erosion. It is equally important to avoid standing water on the cultivated soil. Standing water can create anaerobic conditions and/or excessive leaching of waste constituents to groundwater supplies. A 1-percent grade should be sufficient, in most cases, to ensure a noneroding runoff.

The disposal area should be protected by natural or artificial features (e.g., dikes and berms) to assure protection against washouts from a 50-yr storm. Washouts can result in the spread of eroded soils and waste pollutants to adjacent property. The probability for washouts increases significantly in areas that include stream beds, gullies, flood plains, etc. Sites located in these areas, therefore, would require costly drainage facilities. It is thus preferable to avoid these areas when considering potential sites.

In evaluating the suitability of alternative sites, it is useful to determine the various landforms that could be occupied by the sites, as shown in Figure 4 (104). The types of landforms that can be used for land cultivation sites are:

- Upland flat and terrace
- Upland crest and valley side.

Upland flat and terrace landforms are generally the most desirable locations for land cultivation sites. However, suitability of these landforms depends upon site-specific conditions, including the depth to groundwater and soil characteristics. Upland flat areas with low permeability and fine-grained soils are typically preferable. Highly permeable coarse-grained soils usually underlie terraces, sometimes at very shallow depths. Thus, if a site is to be located on a terrace landform, there should be no surface expressions of groundwater nearby. The likelihood of groundwater intersecting a terrace site increases as the site position approaches either the valley wall or the level of the modern floodplains.

Upland crests and valley side landforms are the second most desirable locations for land cultivation sites. This is because groundwater usually flows away from these landforms, and because surface water is limited to incident precipitation and controllable off-site runoff. Upland crest and valley side landforms require the diversion of surface water to reduce the amount of water entering and possibly infiltrating the site. Except in very impermeable soils or during extremely wet seasons, groundwater levels in these landforms should lie well beneath the site.

One drawback to site location in upland crests or valley sides is that these landforms are often in groundwater recharge areas. Thus, for each prospective site, the possibility of groundwater contamination should be investigated in terms of the soils and hydrology.

Subsurface Hydrology--

Data on groundwater hydrology are useful in evaluating the potential for contamination at any given site (105). The basic hydrologic data needed for evaluation are:

- Depth to groundwater
- Direction of groundwater flow
- Water quality characteristics.

The water table typically lies deeper in arid regions than in humid regions. The depth of the water table tends to change

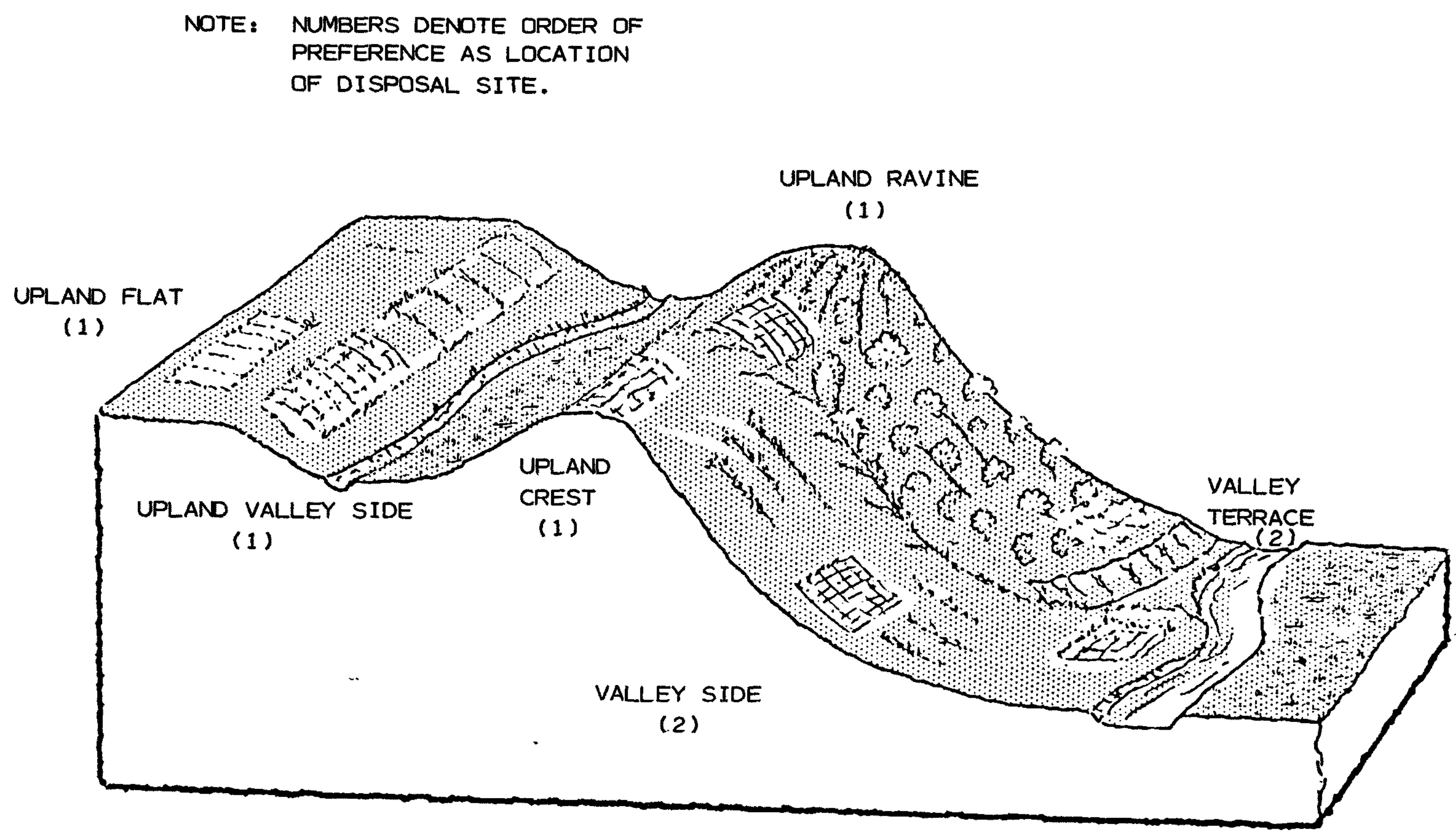


Figure 4. Relative location of various landforms (104).

with surface topography: it is deeper beneath interstream areas, shallower in lowlands, and it coincides with the surface of perennial streams. The water table is usually shallower in relatively impermeable soils, such as clays, than in relatively permeable soils, such as coarse sands. In dense, unfractured rock, the water table may be absent or discontinuous (106).

Data on the direction of groundwater flow is essential. First, this data helps determine the location of a land cultivation site, which should preferably be downstream from a water supply well. Second, the data is important for accurate installation of site monitoring wells.

Data on groundwater flow can sometimes be obtained from records kept by various local agencies. If these records are incomplete, certain rule of thumb may be used to verify the direction of flow. One rule is that groundwater moves in accordance with the hydraulic gradient, from high to low elevations. With this in mind, an accurate topographic map should be consulted that shows the site and surrounding area. All existing wells should be marked on the map. The depth to groundwater in each well should be noted, and the elevation of the groundwater surface with respect to sea level calculated. Approximate contour lines can then be drawn on the map to connect wells of equal groundwater elevation. The direction of groundwater flow will be perpendicular to these elevation contour lines.

It may be necessary to drill wells at the candidate sites to provide supplementary groundwater depth data, or to obtain subsurface soil and geological information. Any wells drilled should be cased with PVC pipe for possible future use in the site monitoring program.

It is generally preferable to locate a land cultivation site over a brackish or otherwise unusable groundwater than over a potable water source. Thus, basic information should be gathered concerning the water quality of underlying site aquifers. This information establishes baseline quality conditions and is subsequently useful for determining water quality impacts based on monitoring data. Information on water quality can usually be obtained from local health departments and water companies.

Flora and Fauna

A balanced ecology contains a large variety of diverse flora and fauna, known as a high species diversity. It is best to locate land cultivation sites in areas with a low species diversity which do not contain rare or endangered species, or in areas previously disturbed by man. Thus, operations will not pose hazards to environmentally significant flora and fauna, such as unique or endangered species.

Climate

Climatic conditions may have a strong impact on the microbial decomposition of cultivated wastes. The biodegradation rate tends to increase under warm, humid conditions and decrease under cold, arid conditions. Since the biodegradation rate strongly affects the allowable waste application rate, land area requirements are directly affected by the climate. Under warm, humid conditions, less land is required for a given waste quantity than under cold, arid conditions.

Economics

Capital and operation and maintenance costs for land cultivation sites can vary significantly. These costs are affected by land availability, soil conditions, topography, waste type, utility relocations, screening devices, labor rates, and other factors. For instance, land might be leased at little or no cost in a case where land cultivation will condition the soil for future use.

In addition, costs can be affected by the distance required to transport the waste between the source and the disposal area. Most municipal and industrial wastes are generated near centers of population, which can be far from open, low population density areas where land cultivation might be favorable. The economic success of land cultivation may hinge on minimizing waste transport distances.

Public Acceptance

Public acceptance is of vital importance when selecting a land cultivation site. If significant public or pressure group protest is encountered, the selected cultivation area may not be a practical choice, even though all technical aspects of the site are ideal. Public attitudes toward land cultivation can be improved through detailed and carefully organized information programs.

Public acceptance is determined, in part, by proximity of the prospective site to residential areas and/or to areas frequented by the public. When disposal sites are located close to inhabited areas, common complaints are dust, odor, vectors, unsightliness, and traffic. In some cases, public opposition may exist in spite of effective mitigating measures. Therefore, to ensure success in locating land cultivation sites, it is best to avoid inhabited areas as much as possible and to design effective mitigation measures into the site at the project inception.

SPECIFIC SELECTION CRITERIA

Some site selection criteria differ significantly depending on the characteristics of the waste. In the following subsections, specific criteria will be discussed as they apply to the three general waste categories addressed. Also discussed will be sites receiving combinations of waste.

Municipal Solid Waste

Land cultivation of municipal solid waste should most logically be practiced in areas where waste application improves soil characteristics. In such areas, refuse may act as a soil conditioner for cropland or may be used in land reclamation programs. Cultivation of refuse may increase the cation exchange capacity and water holding capacity of a sandy soil, increase the permeability of a clay soil, reduce wind and water erosion, and provide some micronutrients. Most soil types are amenable to land cultivation of refuse. Marginal or disturbed land are especially good candidates for land cultivation of municipal solid waste. Table 12 is a summary of a few soil limitations for accepting nontoxic biodegradable sludges and solids.

Industrial Wastewater

Land cultivation and spray irrigation practices for application of industrial wastewater are similar. The major difference is the higher degree of homogeneous mixing and gaseous exchange in land cultivation, often allowing the wastewater application rate and quantity applied to be slightly increased.

Specific criteria for selecting land cultivation sites for industrial wastewater vary, depending on a number of physical and geochemical parameters. Such parameters include wastewater characteristics, wastewater loading, duration of application, acreage required, local water quality standards, climate, ultimate land use, and seasons of application. The specific site selection criteria include the following:

- Infiltration
- Soil thickness
- Ion exchange capacity of the soil.

Infiltration--

Wastewater components should remain in the soil's biologically active zone long enough to be decomposed aerobically. The time required for aerobic decomposition is largely a function of waste composition and application rate, and soil characteristics.

At land cultivation sites, fine-textured, unconsolidated soils are preferred to mechanically weathered bedrock, quarry wastes, or artificial fills containing diverse waste materials

TABLE 12. SOIL LIMITATIONS FOR ACCEPTING NONTOXIC BIODEGRADABLE SLUDGES AND SOLIDS*

Item†	Degree of Soil Limitations: Slight	Moderate	Severe
Permeability of the most restricting layer above 152 cm	Moderately rapid and moderate 1.5 to 15 cm/hr	Rapid and moderately slow 15 to 51 and 0.5 to 1.5 cm/hr	Very rapid, and very slow, >51 and <0.5 cm/hr
Soil drainage	Well drained and moderately well drained	Somewhat excessively drained and somewhat poorly drained	Excessively drained, poorly drained, and very poorly drained
Runoff	None, very slow, and slow	Medium	Rapid and very rapid
Flooding	Soil not flooded during any part of the year		Soil flooded during some part of the year
Available water capacity from 0 to 152 cm or to a limiting layer	>20 cm	7.6 to 20 cm	<7.6 cm

*Modified from a draft guide for use in the Soil Cons. SErv., U.S. Dept. Agr. (107)
†For definitions see the *Soil Survey Manual*, U.S. Dept. Agr. Handbook No. 18, 1951.

and particle sizes (108). Moderately well-drained to well-drained soils are preferred because they meet both infiltration and drainage requirements. However, even less well-drained soils can be considered, provided that wastewater is not being applied during periods of prolonged rain, heavy rainfall, or freezing weather.

Hydraulic conductivity values, summarized in Table 13, have been reported in various sources (104). Soil limitations for accepting liquid waste are summarized in Table 14.

Soils classified as extremely slow to very slow create waterlogging and runoff problems at cultivation sites. Soils classified as slow may require drainage facilities to improve aeration conditions and prevent erosion. These slowly drained soils may prove to afford better nutrient and heavy metal removal than moderate to very rapid soils (108). However, the wastewater application rates must be considerably lowered with such soils.

Soils in the moderate to rapid class should be ideal for land cultivation sites. For soils in the very rapid class, flow rates may be excessive, thus precluding a high degree of waste renovation. Wastewater must be retained within the soil profile for a sufficient period of time to allow the degradation processes to be effective.

Highly permeable layers of sand and gravel beneath the soil, which might include fractured bedrock, weathered bedrock, or cavity systems, allow for little if any additional waste degradation. Once the wastewater enters a porous media, only dilution and dispersion should be anticipated. Therefore, the overlying layer of soil should be deep enough to achieve the desired degree of biodegradation.

Soil Thickness--

It is generally agreed that a 0.9- to 1.2-m (3- to 4-ft)-thick soil column should be adequate to provide the degree of wastewater stabilization required for spray irrigation sites (108). Since very little is known about soil thickness requirements at land cultivation sites, and since there are similarities between the two techniques, it appears that the 0.9- to 1.2-m soil thickness might apply equally well for land cultivation sites. This soil thickness estimate assumes that toxic substances do not exist in the waste or are in such low concentrations that groundwater quality will not be impaired if migration from the surface ultimately occurs.

Ion Exhange Capacity of the Soil--

A high cation exchange capacity (CEC) is a desirable soil characteristic which is related to the levels of organic matter and clay, as well as types of clay minerals in the soil. CEC

TABLE 13. CLASSES OF PERMEABILITY OR PERCOLATION RATES FOR SATURATED SUBSOILS (104)

Class	Hydraulic Conductivity or Percolation Rate cm/hr	Comments
Extremely slow	<0.003	So nearly impervious that leaching process is insignificant. Unsiutable for wastewater renovation under most circumstances.
Very slow	0.003 to 0.025	Poor drainage results in staining; too slow for artificial drainage. Wastewater renovation possible under restricted conditions.
Slow	0.025 to 0.25	Too slow for favorable air-water relations and for deep root development. Usable under controlled conditions; drainage facilities may be required; runoff likely to be a problem. Good nitrate removal possible.
Moderate	0.25 to 2.5	Adequate permeability (conductivity). Ideal for most irrigation systems.
Rapid	2.5 to 25.4	Excellent water-holding relations and permeability (conductivity). Ideal for most irrigation systems. Application rates may have to be reduced to ensure renovation.
Very rapid	>25.4	Associated with poor water-holding conditions. Infiltration and drainage may be too rapid to achieve complete renovation. Extreme caution required.

TABLE 14. SOIL LIMITATIONS FOR ACCEPTING NONTOXIC BIODEGRADABLE LIQUID WASTE*

Item†	Degree of Soil Limitation		
	Slight	Moderate	Severe
Permeability of the most restricting subsoil horizon to 152 cm	Moderately rapid and moderate 1.5 to 15 cm/hr	Rapid and moderately slow 15 to 51 and 0.5 to 1.5 cm/hr	Very rapid, slow, and very slow >51 and <0.5 cm/hr
Infiltration	Very rapid, rapid, moderately rapid, and moderate 0.6 in/hr	Moderately slow 0.5 to 1.5 cm/hr	Slow and very slow <0.5 cm/hr
Soil drainage	Well drained and moderately well drained	Somewhat excessively drained and somewhat poorly drained	Excessively drained, poorly drained, and very poorly drained
Runoff	None, very slow, and slow	Medium	Rapid and very rapid
Flooding	Soil not flooded during any part of the year	Soil flooded only during nongrowing season	Soil flooded during growing season
Available water capacity to 152 cm or to a limiting layer			
T#	20 cm		8 cm
P**	8 cm	8-20 cm	8 cm

*Modified from a draft guide for use in the Soil Cons. Serv., U.S. Dept. Agr. (107).
†For definitions see the *Soil Survey Manual*, U.S. Dept. Agr. Handbook No. 18, 1951.
#Temporary installation.
**Permanent installation.

determines the amount of exchangeable waste constituents that can be retained and stored until assimilated by the biologic system at a later date. This is particularly important during periods of peak precipitation in the late fall, winter, and early spring when the excessively wet soil and cold weather retard microbial decomposition of the constituents in the wastewater.

Industrial Sludges--

Land cultivation of industrial sludges is usually performed primarily as a waste disposal technique. However, depending on the waste composition, the soils might derive certain benefits from application of such materials.

In general, the solids content of most industrial sludges is on the order of 5 percent, meaning that the waste is about 95 percent water. Because of this high water content, the previously discussed criteria for industrial wastewater are also applicable to most industrial sludges. Further, these sludges are often the product of secondary wastewater treatment facilities that deal solely with industrial effluent. These industrial sludges are similar to municipal sewage sludges, although the industrial sludges are normally low in pathogens. Because of the similarities, existing local criteria and regulations dealing with the land cultivation of sewage sludges should be consulted and applied, when appropriate, to site selection for industrial sludges.

Application of nontoxic biodegradable sludges, such as cannery waste, requires the same basic site selection criteria that were previously discussed for municipal solid waste. Table 13 summarized some of the soil limitations for sludges. Depth to groundwater for industrial sludge disposal sites should be in excess of 1.5 m (5 ft), depending on the soil porosity.

When applying sludges as a nutrient soil conditioner to agricultural land, soil texture is an important consideration. For disposal of relatively dry wastes, finer textured soils may be more desirable than sands. There is more available moisture storage in these soils, which usually contributes to higher crop yields and higher nutrient removal. In both coarse- and fine-textured soils, more efficient nutrient utilization is obtained if the soils are deep and well drained, with no compact layers to interfere with deep root penetration (109).

Oily wastes and hazardous sludges should be isolated as much as possible from the surrounding environment. The potential site, therefore, should have either an impermeable layer protecting the groundwater, or a deep groundwater table. Oily wastes are not as great a concern as most hazardous sludges. No instances have been reported where land cultivated oil debris has caused groundwater contamination (110). However, a program of soil and groundwater monitoring should be planned and implemented.

Surface drainage of sites that accept industrial sludges should be carefully controlled to include:

- Drainage diversion of runoff from adjacent property
- Control of on-site erosion by level grades or terracing
- Prevention of on-site materials passing to adjacent property.

Sites Receiving Combinations of Waste

When selecting potential land cultivation sites, it is important to anticipate receipt of various waste combinations; the compatibility of different waste types must be thoroughly evaluated. A site that appears unsuitable for disposal of a particular waste might be made suitable by combining various wastes. For example, a prospective site to be used for municipal refuse might seem unsuitable because of blowing dust and proximity to an inhabited area. The potential problem could be solved by application of a compatible wastewater in conjunction with the refuse. Another example is a prospective wastewater disposal site with an excessively drained soil. Land cultivation of a sludge or refuse before wastewater application might condition the soil by increasing its water-holding capacity. The wastewater could then be applied after the soil is conditioned to retain more water.

Land cultivation of an industrial sludge containing a significant heavy metal concentration requires a soil ph $\geq$ 6.5. If local soils are acidic, land cultivation of this waste is unacceptable. But if a lime sludge from a water treatment plant is available, it may be cultivated in conjunction with the industrial sludge since the lime sludge will increase the pH.

In summary, site selection requires the following steps:

- Determine waste type and objective of land cultivation (i.e., waste utilization or disposal).

- Assess the soil properties and select criteria to determine the suitability of the soil for receiving the waste in question. Various guides are available for rating suitability of soils for receiving many types of wastes.

- Using soil surveys, determine which soils in the area are suited for receiving wastes.

- Locate the suitable soils on the soil map to determine extent of candidate sites.
- Using on-site investigations of soil, geology, and hydrology, determine the actual suitability of the candidate site for receiving wastes.

SECTION 10

SITE OPERATIONAL CONSIDERATIONS

WASTE TREATMENT

Waste pretreatment or conditioning facilitates handling, storage, and field operations and detoxifies or removes waste constituents that may persist in soil and pose environmental hazards. In some cases, the materials removed can be reused, but the recycling process may be complex and costly.

Municipal Solid Wastes

Municipal refuse should be shredded prior to land cultivation. A nominal size of 5 cm (2 in) has been suggested (Volk, personal communication) to facilitate handling and soil incorporation and to reduce breakdowns of equipment due to jamming of the mixing blades with large pieces of waste materials. The active operation in Odessa, Texas, however, shreds refuse to a nominal 10 cm (4 in) size. The magnetic separator is currently extracting only about 60 percent of the ferrous metals, which is considerably less than originally anticipated. No other significant operational problems have been reported (Schnatterly, personal communication).

Ferrous metals are magnetically separated, while non-ferrous metals may not be removed due to costs associated with their separation. The shredded refuse is compacted into transfer trucks and hauled to the site for disposal by land cultivation.

Industrial Wastewaters and Sludges

Current information indicates that industrial wastewater and sludge are land cultivated as generated, with little or no pretreatment.

Most industrial wastewaters and sludges presently land cultivated are generated by the industry's wastewater treatment plant; as a result, they are similar in many respects to municipal effluent and sewage sludge. Pathogens and viruses are usually of little concern when industrial wastes are land cultivated. However, some industries have combined waste which may contain human waste. Secondary treatment (e.g., activated sludge) is often employed by the industry, though some industries (e.g., food processing) use only primary treatment. In some instances, pH adjustment and cooling of wastewater are also used. If the waste is high in BOD, sodium and soluble salts, such as those generated by the food processing and pharmaceutical industries, low application rates or dilution may be necessary.

Lime sludge generated by a water treatment plant can be land cultivated directly, although it may require dewatering by evaporation in a storage pond or pelleting to reduce the waste volume and field operating costs.

It is speculated that many of the so-called hazardous industrial wastes may be land cultivated once they have been pretreated. For example, if a pesticide waste is treated by a biological or chemical process which alters its formulation such that it will no longer pose hazards to the environment, it may be suitable for land cultivation. Such pretreatment may not be cost effective.

EQUIPMENT AND PERSONNEL REQUIREMENTS

Selection of the proper equipment and personnel is an important consideration at prospective land cultivation sites. The quantity and types of equipment and personnel required depends on the volume and characteristics of waste to be disposed, requirements imposed by regulatory agencies, the land area of the site, and the need for other duties (e.g., direct traffic and unloading operations).

Equipment Selection

A wide variety of equipment can be utilized for land cultivation of waste. Equipment selection depends primarily on the characteristics of the waste applied and on the constraints imposed by regulations. For example, rototillers are highly adaptable to mixing municipal solid waste with soil, whereas less expensive disk plows are sufficient for mixing liquid waste and sludges. Further, tank wagons may be adequate for surface application of sludge at some locations, whereas subsurface injection equipment may be required at other locations by local regulations.

Table 15 lists possible types of equipment suitable for application of various types of waste. The most frequently used land cultivation equipment is listed. However, other related agricultural equipment may be satisfactory to some extent, especially for sites that handle small quantities of waste.

TABLE 15.* EQUIPMENT CAPABILITY MATRIX

Equipment	Waste Category Refuse	Sludge	Wastewaters
Rototillers	X		
Subsurface injection units		X	X
Tank wagons - surface spreading		X	X
Disks		X	X
Wheel tractors	X	X	X
Track tractors	X	X	X
Refuse blades	X		
Earth moving blades		X	X

*Based on greatest adaptability of equipment types according to case study experience. Many equipment types may be interchanged with those having a lower degree of suitability.

Rototiller Mixing--

Rototillers, or soil stabilizers, are suitable for mixing refuse with soil (4). They also may be used to homogenize liquid and sludge wastes with soil, although disk plows are usually sufficient for this purpose. Many types of rototillers are available that will homogenize the refuse with soil in one pass, although a greater degree of mixing can be accomplished with multiple passes. Rototillers are usually self-propelled machines with blades adjustable to a mixing depth of approximately 46 cm (18 in) in soft soil (Figure 5) and a mixing width fixed at 2.4 m (8 ft). Figures 6 through 10 show examples of a few available rototiller varieties.

Maintenance of rototillers used in land cultivating refuse may be a problem due to the severe operating environment. Personnel at Odessa, Texas, report that mechanical failures are a common occurrence with their rototiller, which operates up to 60 hr/wk. When the rototiller was first obtained, the operators determined that the front end was too light. A need was also apparent for equipment to spread the refuse before mixing with the soil. It was decided to solve both problems by adding a dozer blade to the front. However, the added weight of the large blade, plus the load placed on the equipment by requiring it to both spread and mix, has caused frequent failures of the front suspension and axle. Some failures of hydraulic pumps and valves have been caused by the very dusty conditions of operation (Dobbs, personel communication).

Figure 5. Mixing tines of Bros rototiller.

Figure 6. Bros mixing.

Figure 7. Raygo mixing.

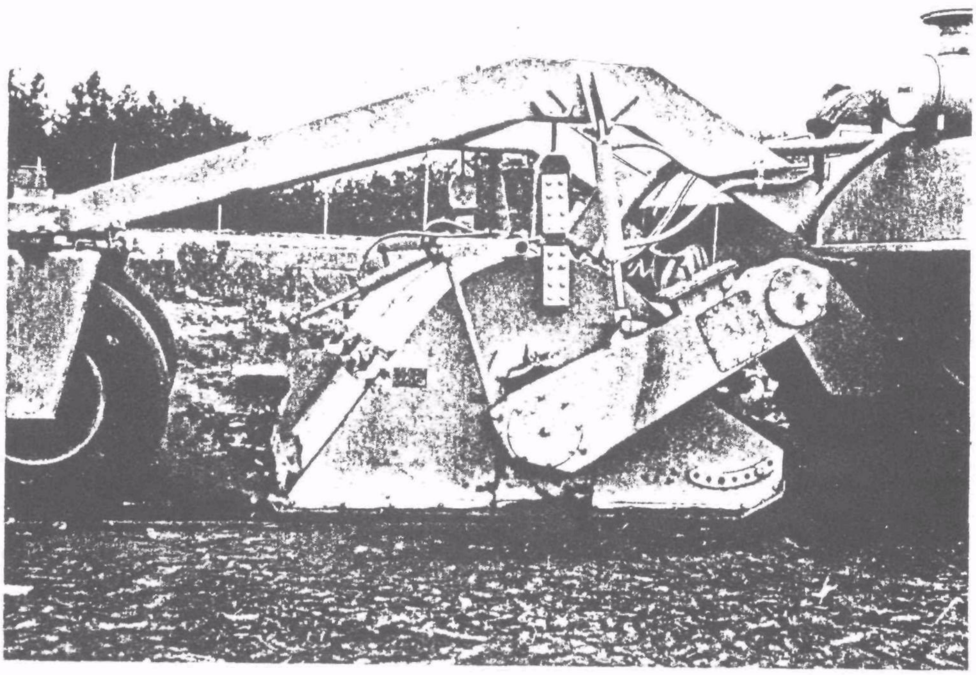


Figure 8. Raygo mixing chamber.

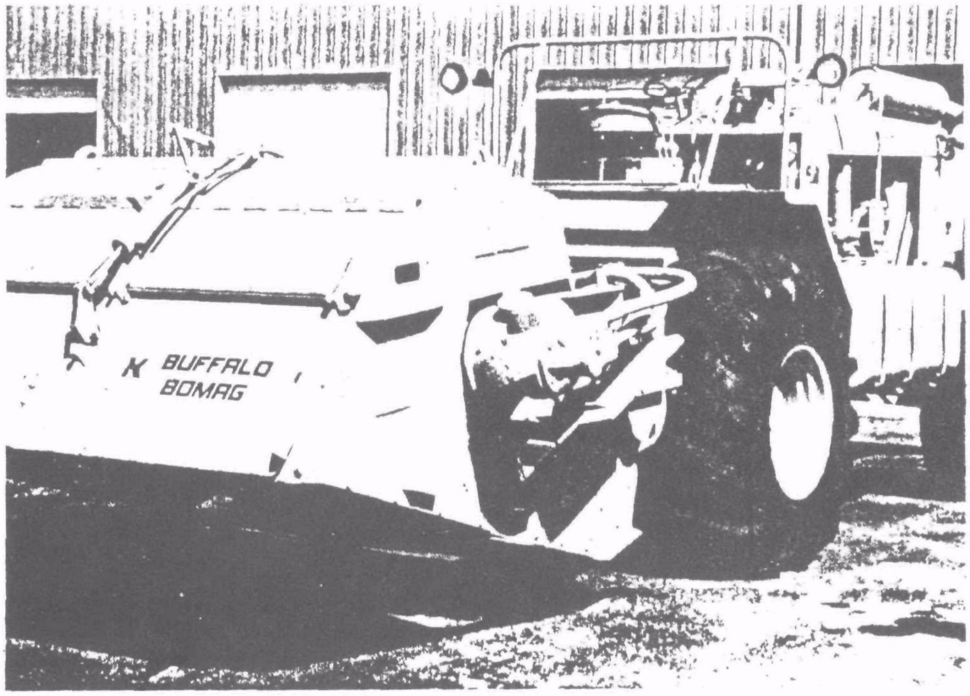


Figure 9. Koehring rototiller.

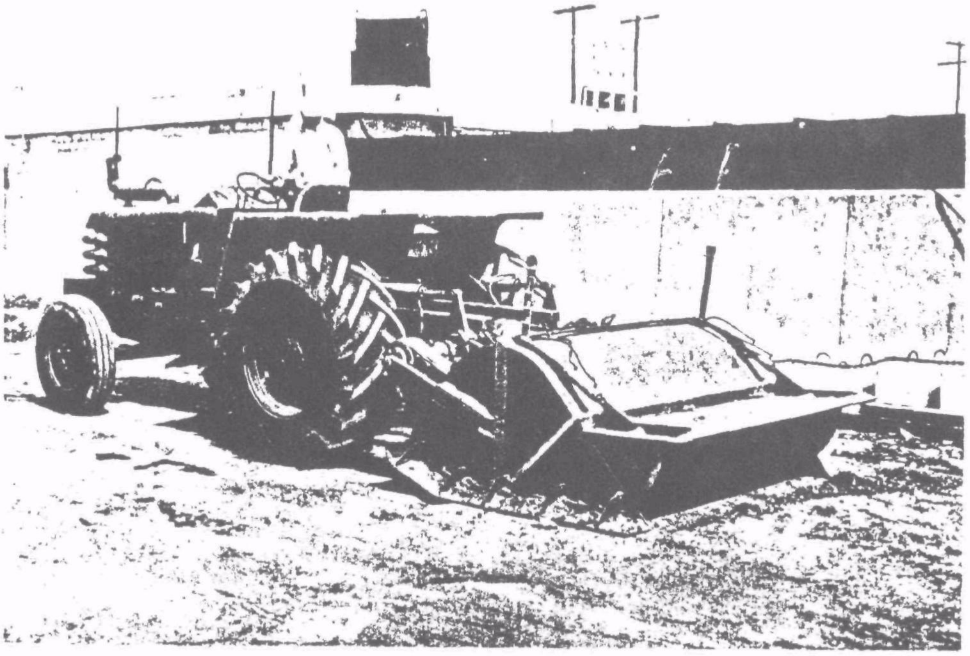


Figure 10. Pettibone rototiller.

Subsurface Injection--

Subsurface injection may be required for liquid wastes and sludges that are noxious, highly volatile, or odorous. Specialized equipment is available that allows injection of the liquid waste deep enough to minimize air pollution. Figures 11, 12, 13, and 14 illustrate equipment specifically designed for subsurface injection. This equipment includes high flotation tank trucks with special liquid injection plows attached at the rear which can transport wastes to the cultivation site over short distances. Tanks for the trucks are generally available at 6.1- and 7.6-m^3 (1,600- and 2,000-gal) capacities. Some manufacturers also produce an optional tank that will hold 13.6 m^3 (3,600 gal).

Figure 14 shows another type of unit, which incorporates a different approach to subsurface injection. The unit is a track dozer with an injector mounted on the rear. Sludge is pumped from a storage tank (usually underground) to the injector through a hose that trails the unit (shown in Figure 14). Flow capacities of 0.6 to 3.8 m^3/min (150 to 1,000 gal/min) are available. The track dozer, used as the prime mover, requires a power rating of 40 to 60 HP.

In addition to tank trucks and track dozers, a third type of unit is available. This unit is basically a tractor-drawn tank wagon with an added injector. Two such tank wagons are pictured in the case studies, the one used by the Indiana site for deep (40 cm) injection, and the one used by the Illinois site for surface spreading. The Illinois operators report that mechanical failures of the wagon chassis have been a problem. These failures are primarily due to the extensive use of the wagons, which is far greater than the average farmer uses such equipment. To rectify the problem, the operator has strengthened the chassis, but some failures still occur.

Surface Spreading--

Equipment used for surface spreading of wastes before cultivation comprises a variety of transfer vehicles, standard farm units, and specialized devices. Some of this equipment includes the following:

- Refuse collection vehicles
- Refuse transfer trailers
- Open bed trucks
- Tank trucks
- Tank wagons.

Liquid waste is usually effectively applied using spray nozzles or spray bars.

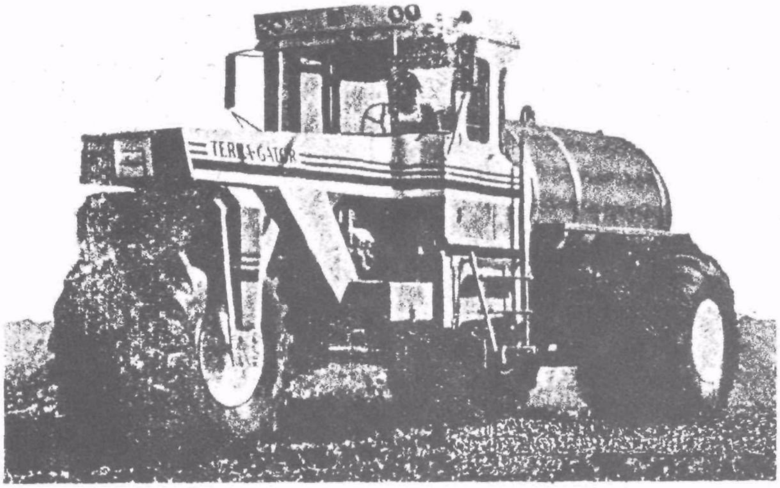


Figure 11. Terra-gator sludge injector.

Figure 12. Big Wheels sludge injector.

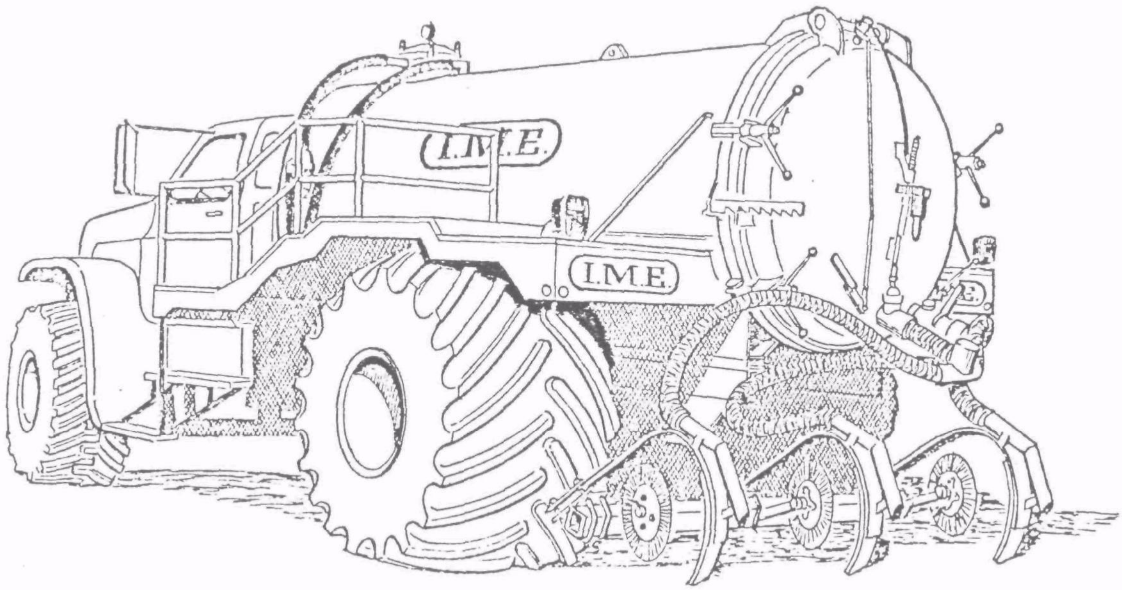


Figure 13. I.M.E. sludge injector.

Figure 14. Deep Six sludge injector.

A wide variety of equipment, produced by many manufacturers, is available for surface spreading. Equipment selection is dependent on waste type and quantity, cultivation site characteristics, and budget. Figure 15 shows shredded refuse being unloaded at Odessa, Texas. The equipment being used is a refuse transfer vehicle. For municipal solid waste, any easily unloaded vehicle can be employed.

If the waste is a high solids sludge, equipment similar in design to standard manure spreaders may be used. Figures 16 and 17 illustrate two high flotation trucks with spreader bodies, which are examples of the type of equipment available. For small quantities of high solids sludges, tractor-drawn farm manure spreaders may be adequate. All major farm implement manufacturers produce such spreaders.

For wastewaters and low solids sludges, tank trucks or tank wagons are the logical choice of equipment. Figure 18 shows a high-flotation tank truck equipped with a spray plate in operation. Figure 19 depicts a typical medium-size tank truck designed for over-the-road use, which can be used for surface spreading if the field is firm. This truck may be equipped with a spray bar, plate, or nozzle. Large tank trucks, as in Figure 20, can be used if field conditions allow. The particular vehicle shown in Figure 20 has a capacity of 15 m^3 (4,000 gal) and uses a homemade spray bar.

Conventional farm tank wagons, using a tractor as the prime mover, can also be employed for surface spreading. This type of equipment is utilized at the Illinois case study site.

Disk Mixing--

Surface spreading of waste requires a subsequent operation to mix the wastes with soil. This mixing is necessary to promote biological degradation by exposing waste to soil and to produce runoff potential and odors. For refuse, mixing can be accomplished with disks, but it is preferable to use a rototiller.

Standard agricultural disks used in conjunction with a tractor or track dozer can efficiently mix liquid waste or sludge with soil. The size of the disk is dependent on waste quantity. Large disks are required for large-scale operations to minimize the time spent mixing, thereby minimizing operating costs. There are three basic disk types: disk tillers (Figure 21), disk plows (Figure 22), and disk harrows (Figure 23). One or more disk types are produced by most farm implement manufacturers. Because of their sturdy construction, disks should perform well for a relatively long time for most land cultivation operations. However, under highly abrasive

Figure 15. Refuse spreader from transfer truck.

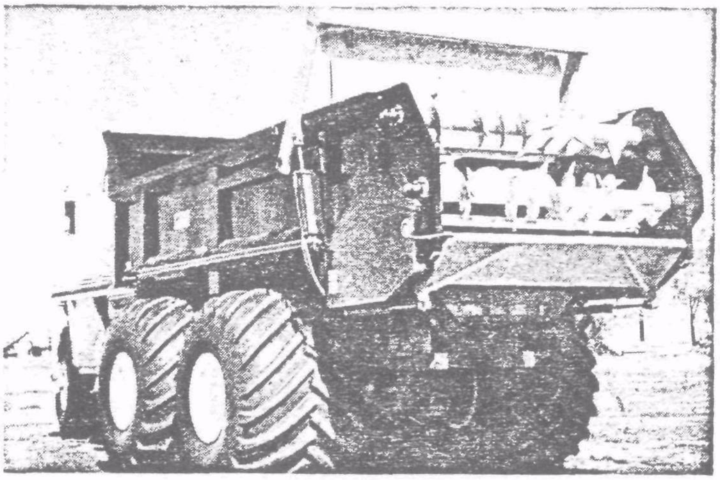


Figure 16. Terra-gator sludge spreader.

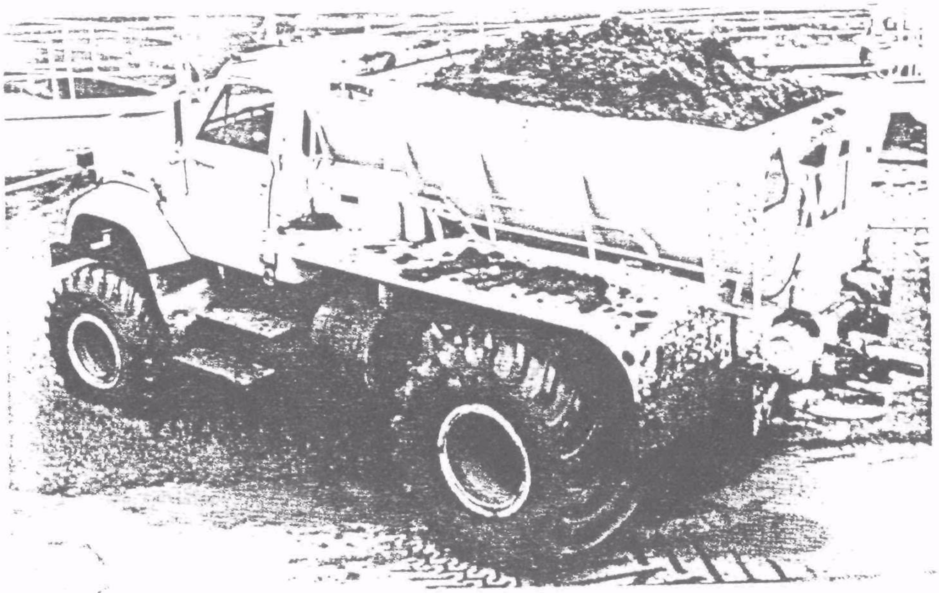


Figure 17. Big Wheels sludge spreader.

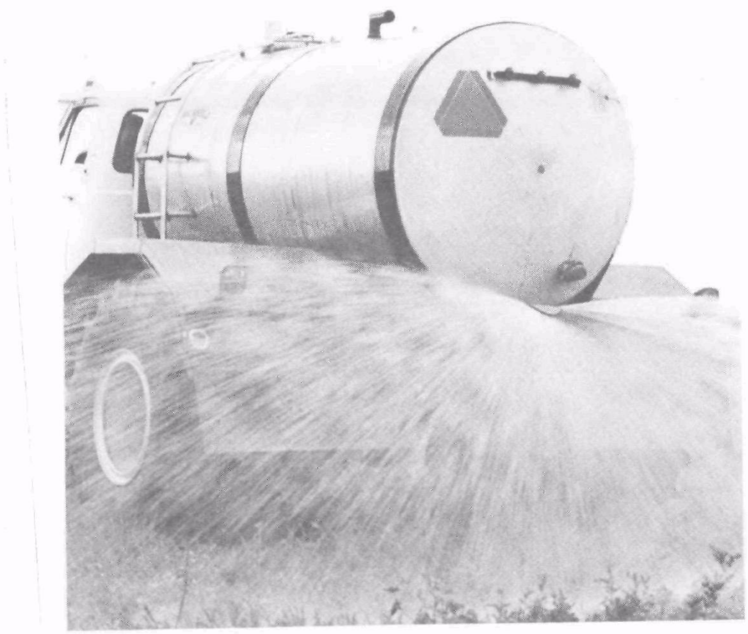


Figure 18. Big Wheels spreader with spray plate.

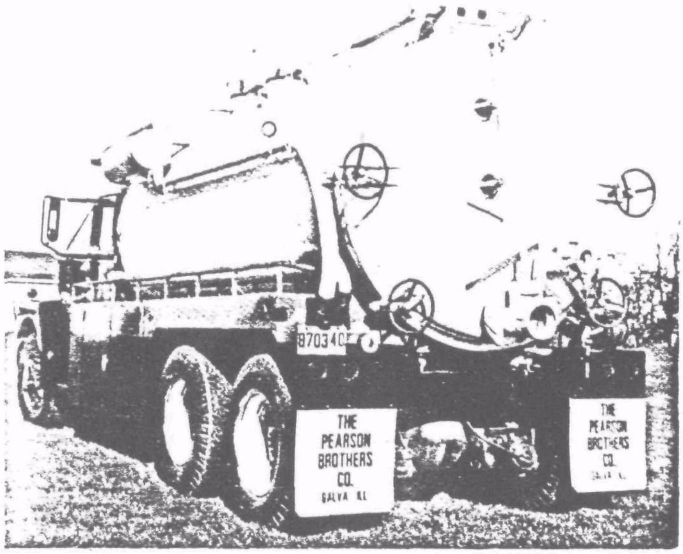


Figure 19. Medium size tank truck capable of surface spreading.

Figure 20. Large tank truck with spray bar spreading sludge on field.

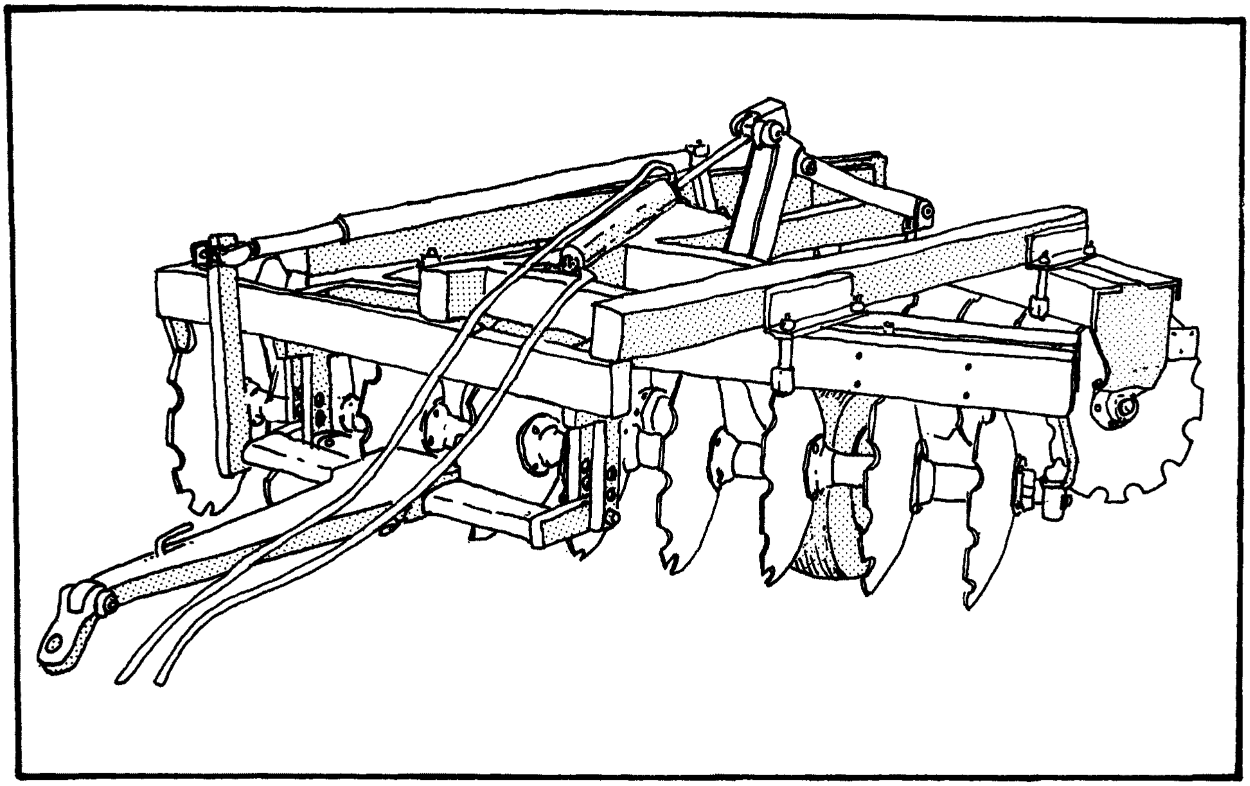


Figure 21. Example of disc tiller.

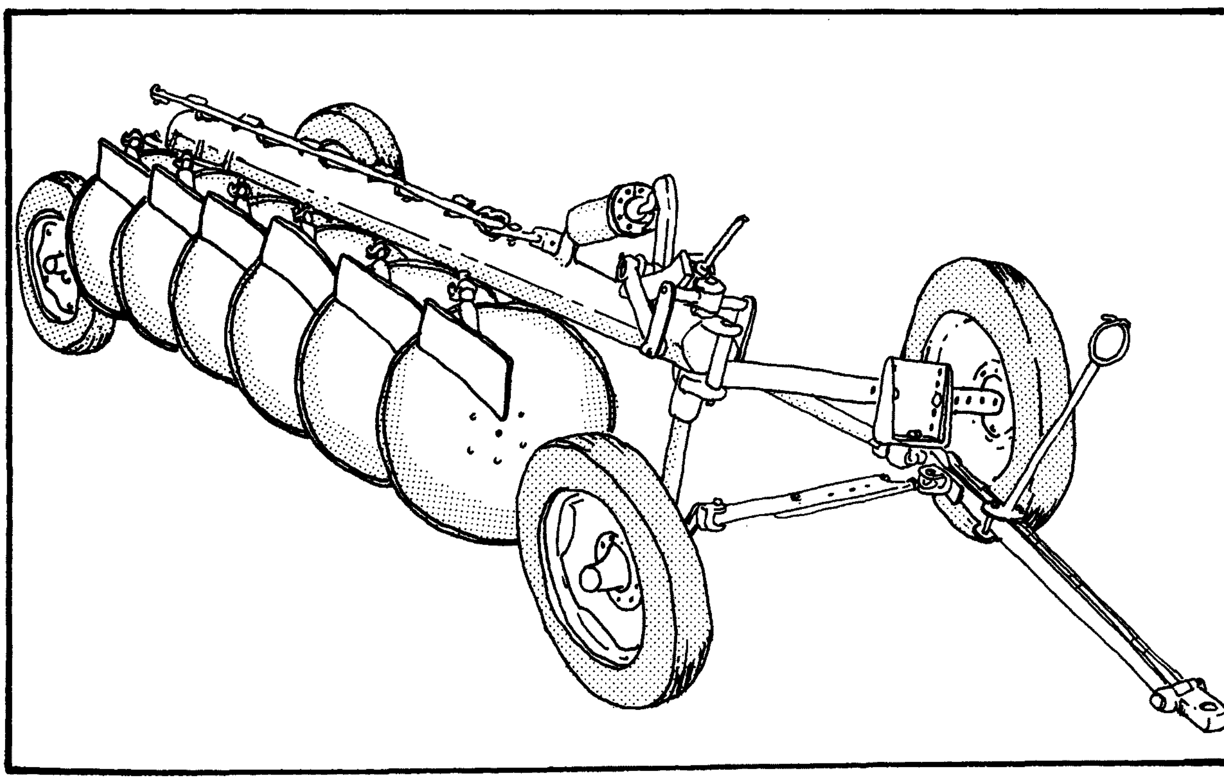


Figure 22. Example of disc plow.

Figure 23. Example of disc harrow.

conditions, such as cultivating oily wastes in sandy soil, disks may require more frequent repair and replacement.

Personnel

Numbers and types of personnel required at a land cultivation site are primarily a function of the quantity of waste input. A minimum of one skilled equipment operator is required at any site. For small-scale operations, one person may be able to perform all necessary duties. However, because of safety considerations, it is desirable to have two or more persons at the site.

As the size of operation increases, the necessary staff grows. For small-scale operations, one person may be required to weigh incoming wastes, direct unloading of wastes at the proper locations, and maintain records. For large-scale operations, two persons may be needed for these functions. If the site operates many pieces of equipment, it may be cost effective to provide an on-site maintenance staff. For larger operations, one person will be needed to manage and direct activities.

WASTE STORAGE

Land cultivation is strongly influenced by local climate. Field operations are usually curtailed during periods when the soil is excessively wet or frozen, with the waste stored for application under more favorable conditions. In addition, storage is necessary when an equipment breakdown occurs.

It is normally best to provide storage at the treatment site, so that cultivation activities will not be slowed by fluctuations in waste generation or transport scheduling. Also, there is greater public acceptance of storage tanks or lagoons at the treatment site than at the application site. Aeration tanks are used for short-term storage of industrial wastewater/sludge, while storage tanks, ponds, or lagoons are used for long-term storage. Odors can be a major problem with waste storage.

In the Odessa operation, cultivation is halted only when there is a land cultivation or refuse shredding equipment failure. When this occurs, the refuse is landfilled. Refuse should be stored after shredding with storage facilities provided at the shredder or at the land cultivation site.

WASTE LOADINGS AND REAPPLICATION

Optimum waste loadings can be defined in a number of ways depending on the purpose and frequency of application.

The purposes include erosion control, crop irrigation, groundwater recharge, nutrient supply, or simply disposal. Application frequency depends on available land area, application rate, waste characteristics, and climate.

Municipal Solid Wastes

In an experimental land cultivation project in Houston, Texas, optimum application rates are defined by two criteria: the lowest loading rate that will economically enhance crop yield; and the highest loading rate that the land can accept without evidence of environmental damage (Stanford, personal communication). From the economic point of view, optimum rate is determined by: 1) cost of soil incorporation; 2) length of time when the land is not in productive use; and 3) crop growth and sustenance of high yield (Schnatterly, personal communication).

From field and laboratory data on the environmental impacts including growth of forage crops, a maximum rate of 448 t/ha (200 tons/ac) per application of municipal refuse on a sandy soil should not be exceeded (13, 14). Conceivably, the application rate would be lower on fine-textured soils, primarily because of increased difficulty in mixing the refuse into the surface soil. In routine disposal currently practiced at Odessa, Texas, an average rate of approximately 112 t/ha (50 tons/ac) is used for the one time application.

Information on frequency of application is not available, but it can be inferred from the degradation rate reported. Generally, paper products will decompose within 1 to 2 yr, but more resistant materials such as plastic, some metals, and rubber fragments remain identifiable for many years (11, 12, 13, 15). Under well-aerated, moist, warm soil conditions and frequent mixing, it appears that a second application of shredded municipal refuse can be made in 12 to 18 mo. Rates of decomposition of subsequent waste additions, however, have not been reported. Thus, the feasibility of yearly application needs to be determined.

Industrial Wastewaters

Depending on the waste characteristics and the application system, loadings of industrial wastewater can vary considerably. Wallace (22) summarized the hydraulic and organic loading rates used at existing land application sites for industrial wastewaters (Table 16). He noted that either hydraulic or organic loading can control in a given instance. In some cases, neither will be as important as the cation loading, especially with regard to sodium. For wastewaters with BOD concentrations in the 1000 mg/l or less range, hydraulic loading will usually control.

TABLE 16. SUMMARY OF HYDRAULIC AND ORGANIC LOADING RATES USED IN EXISTING LAND APPLICATION SYSTEMS FOR INDUSTRIAL WASTES*

Type of Waste	Hydraulic Load		Organic Load (BOD)
	gal/ac/day†	in/wk	lb/ac/day#
Biological chemicals	1,500	0.39	370
Fermentation beers	1,350	0.35	170
Vegetable tanning			
Summer	54,000	13.91	360
Winter	8,100	2.09	54
Wood distillation	6,850	1.76	310
Nylon	1,700	0.44	287
Yeast water	15,100	3.89	-
Insulation board	14,800	3.81	138
Hardboard	6,000	1.55	85
Boardmill whitewater	15,100	3.89	38
Kraft mill effluent	14,000	3.61	26
RI **	350,000	90.13	120
Semichemical effluent	72,000	18.54	90-210
Paperboard	7,600	1.96	13-30
Deinking	32,400	8.34	108
Poultry	40,000	10.30	100
Peas and corn			
57 day pack	49,000	12.62	238
35 day pack	34,400	8.86	2,020
Dairy			
Low value	2,500	0.64	10
High value	30,000	7.73	1,000
Soup	6,750	1.74	48
Steam peel potato	19,000	4.89	80
Instant coffee and tea	5,800	1.49	92
Citrus	3,100	0.80	51-346
Cooling water - aluminum casting (RI)	95,000	24.46	35

* Summarized by Wallace (22)

† Multiply by 9.35×10^{-3} to convert to m^3/ha/day

Multiply by 0.89 to convert to kg/ha/day

** RI - Rapid Infiltration

Some characteristics of the application systems are presented in Table 17.

Industrial Sludges

Loading rates of industrial sludge depend on the waste composition, site characteristics, and crops to be grown, if cropping is planned. Except for oil refinery sludges, data on application rates for industrial sludges are meager.

Waste composition and percent solids generally dictate the amount of sludge to be applied at the land cultivation site. The waste loading rate can be determined according to the partial requirement of crops for nitrogen and/or phosphorus such as for paper mill and fruit cannery sludges. High concentrations of such constituents as sodium (food processing waste), soluble salts and zinc (pharmaceutical waste), and nonessential metals (tannery and refractory metal processing waste) may limit the quantity of sludge which can be safely disposed of on land with regard to crop production and/or soil accumulation.

Although the USDA has suggested heavy metal loading guidelines for agricultural disposal of municipal sewage sludge, no loadings for these heavy metals or other persistent, toxic constituents are recommended for nonagricultural soils. Most disposal site operators are aware of the potential hazards of heavy metals and other toxic constituents entering the food chain when a hazardous waste is land cultivated. However, the question arises as to the loading of various waste constituents if the land cultivation site is intended for disposal only. Only two states (Texas and Oklahoma) have regulations or guidelines on land cultivation with respect to heavy metal loading (see Section 8). It is reasonable to assume that under proper site management, if the heavy metals or other hazardous waste constituents are shown by soil analysis to remain in the plow layer (equivalent to surface 60 cm), there should be no limit on the quantity of waste that can be applied at the land cultivation site.

Research work has recently indicated that fruit cannery sludge (103) can be applied to fine-textured soil up to 250 t/ha (dry wt) and refractory metal processing waste (79) up to 112 t/ha without resulting in groundwater contamination or reduced crop yield. Frequency of applications and long-term environmental effects resulting from land cultivating these sludges have not been reported. Generally, if large acreage of land is available for sludge disposal, such as the operation in Gilroy, California, for cannery waste, the land will receive only one application (617 m^3/ha) per year (Felice, personal communication).

TABLE 17. COMPARATIVE CHARACTERISTICS OF LOW-RATE IRRIGATION OVERLAND FLOW, AND INFILTRATION-PERCOLATION SYSTEMS*

	Design Approach		
Factor	Low-rate Irrigation	Overland Flow	Infiltration-Percolation
Liquid loading rate	0.5 to 4 in/wk†	2 to 5.5 in/wk	4 to 120 in/wk
Annual application	2-8 ft/yr	8 to 24 ft/yr	18 to 500 ft/yr
Land needed per 1 mg	140 to 560 ac plus buffer zones	46 to 140 ac plus buffer zones	2 to 62 ac plus buffer zones
Soils	Moderately permeable loamy sands to clay loams	Slowly permeable silt loams to clays	Rapidly permeable sandy loams to sands
Slopes	Cultivated crops: 0-6%. Forages and forest species: 0-15%	2-6%	Less than 2%
Removal of suspended solids and BOD	90 to 99%	90 to 99%	90 to 99%
Removal of nitrogen	80 to 100% (may exceed 100%)	70 to 90%	0 to 80%
Removal of phosphorus	95 to 100% (may exceed 100%)	50 to 60%	70 to 95%
Fate of wastewater	Evapotranspiration and deep percolation for groundwater recharge, discharge into surface waters, or recovery and reuse. Runoff controlled.	Runoff maximized for recovery and reuse. Relatively little evapotranspiration or deep percolation.	Deep percolation maximized for groundwater recharge, recovery and reuse. Runoff controlled. Negligible evapotranspiration.

* Adapted from Thomas and Harlin, Jr. (111) and Pound and Crites (23).

† Irrigation at 4 in/wk would be seasonal. An 8 ft/yr application would average 2-1/2 in/wk over a 40-week irrigation period.

In the land cultivation of oil refinery sludges, the waste is usually spread to a layer between 7.6 and 15.2 cm thick. Lewis (28) reported sludge at an average of 1,008 t/ha/yr (450 tons/ac/yr) was applied at one refinery. This amounts to 112 t/ha/mo (50 tons/ac/mo) based on a 9-mo operation. Generally, when the oil content in the surface 15 cm (6 in) decreases to 2 to 4 percent, additional sludge can be applied. Under normal operating conditions this would take about 2 mo. Waste application on such a frequency precludes growth of any cover vegetation. According to the experience of the researchers at an Oklahoma refinery, the optimum application rate for refinery wastes appears to be at 5 percent oil in soil (Huddleston, personal communication). This is equivalent to 112 t oil/ha (50 tons/ac), based on surface 15 cm (6 in) of soil.

SOIL AMENDMENTS

In addition to climatic factors, it is important to provide an optimum soil environment for microbial decomposition of waste material. Nutrient and moisture requirements, liming, and microbial seeding are discussed.

Nutrients

Most of the waste applied to soil can serve as an energy source and provide some essential elements for the growth of soil microorganisms. Since most nutrients (except probably for nitrogen) are abundant in soils, they are not a limiting factor in normal degradation processes.

When a highly carbonaceous material such as municipal solid waste or an oily sludge is added to a soil, the C/N ratio of the surface soil is increased substantially. To maintain a favorable C/N ratio (10 to 20:1) and reasonable degradation rate, addition of nitrogen fertilizer during soil incorporation is necessary, particularly if vegetation is included in the waste management program.

Additions of nitrogen and phosphorus fertilizers were found to greatly enhance microbial decomposition of oils (27, 112). At one refinery, maintaining available nitrogen and phosphorus concentrations at 20 to 30 ppm is recommended (28). This recommendation is arbitrary. A fertilizer program should be made based on the evaluation of waste composition and soil fertility. It is important to determine the C/N ratio of the waste to be land cultivated as well as the fertility status of the soil. If the C/N of the waste is large and the soil fertility is low (e.g., marginal land), calculations can be made as to the quantities of fertilizer nitrogen (and/or phosphorus, calcium) that are needed to increase microbial degradation of the waste added without causing groundwater pollution due to leaching of the fertilizer added.

Moisture

Water is a universal transport medium for all biological processes. Maintaining soil moisture at field capacity would be ideal for microbial decomposition of wastes. Waterlogging is undesirable since it creates anaerobic and nuisance conditions.

In field operations, it has been suggested that water be applied to municipal solid waste through sprinklers to control blowing of debris and to reduce waste volume (79). Waste decomposition ratesmay decrease considerably under arid conditions. Additional water is seldom applied to the soil which receives industrial wastewater or sludge. In practice, high evaporative loss is preferred to enable increased frequency of sludge application.

pH Adjustment

Unless the waste is used as a soil amendment to adjust pH (e.g., application of concentrated sulfuric acid to sodic and strongly alkaline soils, or using fly ash as a liming material on strongly acidic soils), the pH of the waste is not extreme. Thus, the change in soil pH due to waste applications is a slow and reversible process.

Maintaining a soil pH near 7 is important since it is favorable for microbial activity and plant growth. However, the purpose of maintaining soil reaction near pH 7 at some land cultivation sites is primarily to retain phosphorus and heavy metals in the surface soil. In land treatment of wastewater, adjusting the soil to neutral is not a common practice.

Microbial Seeding

Since most soils have a large and diverse population of microorganisms, it is generally assumed that if optimum conditions are maintained, biodegradation of the added waste will proceed at a reasonably rapid rate.

SOIL INCORPORATION PROCESSES

Since land cultivation is designed to be an aerobic decomposition process, it is important to keep the soil-waste mixture aerated by frequent mixing. In practice, however, disking or rototilling operations vary with waste type and location.

At most land cultivation sites, soon after the waste is spread and leveled over the area, it is mixed with the soil by disking or rototilling. However, if wastewater or dilute liquid sludge is applied to a soil, especially when a cover vegetation is present, no disking is involved. Subsurface injection of industrial sludge would result in partial mixing of the waste with soil, and generally disking is not required.

The practice of land cultivation of shredded municipal refuse in Odessa has indicated that a second mixing 3 to 6 mo following waste application is beneficial since high winds have resulted in wind erosion thereby exposing the refuse initially mixed with soil. In addition, the second mixing may enhance the degradation process.

For most industrial sludges, the waste is spread or leveled to a thin layer immediately following application and allowed to dry for a few days. After initial drying, the material is incorporated into the soil by one to several diskings. Depending upon the visual appearance of the decomposition products and the general weather conditions, additional disking and drying periods are completed as necessary. This procedure has been adopted for cannery wastes in Gilroy, California.

At most land cultivation sites receiving oily sludges, initial drying generally takes from 1 to 3 wk depending on waste loading and evaporation. The waste is then mixed into the soil by a track dozer and/or disking. Subsequent mixing is done at weekly to monthly intervals. The soil is sometimes disked and leveled as part of site preparation prior to receiving additional waste.

MANAGEMENT CONSIDERATIONS

In the land application of wastes, it is generally agreed that if the site is properly managed, many adverse effects resulting from waste disposal or utilization can be mitigated.

Management of a land cultivation site consists of:

- Soil management
- Timing of operation
- Other management considerations, such as control of wind movement and snow distribution, and site monitoring.

Soil Management

The goals of soil management are to immobilize heavy metals and other toxic constituents, increase the decomposition of waste materials, control soil erosion and runoff, and prevent groundwater contamination.

Immobilizing Heavy Metals and Other Toxic Constituents--

Various studies have been performed on heavy metal movement in landfills or in soils with incorporated sewage sludge. The studies show that most heavy metals are less mobile under neutral-to-alkaline and well-aerated conditions.

Increasing the Decomposition of Waste Materials--

Organic waste decomposition depends on waste type and loading rate, as well as on aeration, nutrients (e.g., nitrogen and calcium), water content, and air temperature (see Section 5). Repeated heavy waste application may lead to anaerobiosis, which slows down waste decomposition, and to deterioration of soil structure. It is important to maintain a neutral soil reaction and good aeration, since these conditions are favorable for the microbial degradation of the added organic wastes.

Controlling Soil Erosion and Runoff--

Soil erosion is a function of rainfall, soil properties, slope length and steepness, cropping sequence, and supporting practices (113). Methods of minimizing soil erosion would likewise control on-site runoff and pollutant transport.

Although nothing can be done to change the amount, distribution, and intensity of natural rainfall, there are measures to reduce its erosiveness, i.e., to decrease impact raindrop and splash energy, as well as the amount and velocity of overland flow (114). For wastewater application by sprinklers or other means, methods should be chosen and managed that result in a low impact and splash energy.

Slope length and steepness affect pollutant transport, which can be modified by supporting practices (e.g., terraces, diversions, and drains) and cropping. Terraces restrict slope length and provide orderly disposal of runoff (115), and can be designed to meet specific needs. For example, broad-basis terraces are used to control runoff and to collect transported solids (116); level bench terraces are used to impound potential runoff in a large area and to allow for infiltration (117, 118). Overland flows that originate off-site create the same problems as on-site runoff. Diversions can be utilized to protect an area or a structure from runoff (119), to divert water out of active gullies, or to shorten the length of slope for erosion control. A diversion must have an adequate outlet and be designed for safe flow velocities expected in bare channels. Runoff and/or overland flow can also be controlled by maintaining adequate drainage. Excess water may be removed from the site by open or covered drains (120). Methods for maintaining subsurface drains have been described by the Soil Conservation Service (121). Ham (118) discussed the use of drainage wells for control of water tables.

Vegetative cover and surface mulch are other effective means of controlling runoff and erosion (122, 123). Vegetative cover protects against raindrop impact, reduces detachment, and lessens surface scaling, all of which lead to high water intake. Mulch creates barriers and obstructions, which reduce flow velocity and carrying capacity, reducing transport. Relatively modest reductions in flow velocity result in large reductions in erosion rates, since the quantity of material moved is proportional to about the fourth power of velocity (123).

Preventing Groundwater Contamination--

Groundwater contamination can be reduced by practices that promote microbial degradation of wastes, enhance heavy metal retention in the surface soil, and remove nutrients and potentially hazardous waste constituents by plants. In addition, contamination can be reduced by avoiding the overloading of waste on the land cultivation site (124).

Timing of Operation

The timing of operations must take wind, precipitation, and air temperature into account. For instance, when the direction of the wind can cause odor problems, operations should be suspended. Also, winds are often calmest in early morning, late evening, and through the night. Thus, applications of odorous wastes should proceed at these times, avoiding winds that cause waste to spread beyond the site boundaries. In addition, precipitation can influence operations, particularly in humid climates, since applications onto rain-soaked soil contribute to runoff and should therefore be avoided. Other seasonal weather factors must also be considered, such as freezing and resultant loss of microbial efficiency due to cold weather. Waste storage is required when freezing temperatures do not permit winter operation, or where regulations prohibit application on snow-covered ground. If the site is used for crop cultivation, schedules for water application must be adjusted according to rainfall to avoid over-irrigation. Hence, management personnel must have a working knowledge of farming practices as well as principles of waste disposal.

Other Management Considerations

Other management considerations include the control of wind movement, snow distribution, and site monitoring.

Control of Wind Movement and Snow Distribution--

Proper landscaping of a site reduces wind movement and, where applicable, controls snow distribution. Woodruff et al. (125) reported that a field windbreak can moderate summer wind movement. This is desirable because strong winds can move waste materials before they can be incorporated into the soil. Such windblown materials will accumulate in depressions and erosion rills; they will thus be subject to overland movement and leaching with succeeding rain and irrigation water. The design of natural, live windbreaks, and recommendations for species and their management can be obtained from the Soil Conservation Service. Live windbreaks of shrubs and trees can promote the removal of soil moisture from the disposal area by evapotranspiration. Manmade barriers can serve in the early development of a disposal area until natural, live windbreaks are established and effective.

Manmade barriers, such as snow fences, are effective for influencing snow distribution (126, 217, 128). These barriers must be properly placed to avoid unwanted drifts and excessive volumes of meltwater that are concentrated in certain parts of the disposal area. Well-distributed snowmelt minimizes transport of waste materials and eroded soil caused by overland flow.

Site Monitoring--

Any land cultivation operation must have an ongoing monitoring schedule that includes observing system performance, monitoring the quality of affected natural systems (e.g., underlying groundwater), and evaluating environmental impacts with quality changes. Details of site monitoring are discussed in Section 12.

There are no overall formulas to guide a monitoring program, since each waste and its method of disposal is unique. Monitoring should begin with assessing the chemical composition of the waste. Such information confirms, on a day-to-day basis, that the waste is acceptable for cultivation and provides a record of land loading. Monitoring should also assess soil and groundwater quality.

If crops are harvested for human or animal consumption, the extent of folian contamination and plant uptake of waste constituents must be determined. The health and welfare of workers within the site must be carefully observed if there is body contact with the material or inhalation of aerosols. Public health protection may demand adequate disinfection before application of certain wastes.

SECTION 11

ENVIRONMENTAL IMPACT ASSESSMENT

Soil, a natural acceptor of wastes, has been viewed as a physical, chemical, and biological filter that can effectively deactivate, decompose, or assimilate a wide range of waste materials. Factors affecting this assimilative capacity must be understood and considered to develop sound management systems in land cultivation.

Published information on the environmental impacts of land cultivation of municipal solid wastes and industrial wastewaters and sludges is not sufficiently well understood to make precise predictions of impacts. For this reason, studies dealing with the disposal of these wastes at landfills or of land-farmed sewage sludges have been used and the knowledge extrapolated to land cultivation conditions where appropriate.

SOIL-WASTE INTERACTIONS

It is highly desirable to predict the behavior of the proposed waste within the soil system at the outset of a land cultivation practice to predetermine the impact of the practice on the receiving environment. To predict the consequences of land disposal of any waste material, the various chemical, physical, and microbiological processes that describe the movement and fate of constituents in the soil-water environment must be understood. For precise predictions, knowledge of the local hydrogeologic environment integrated with characteristics of various waste types is also necessary.

A major difficulty in predicting soil-waste interactions is the inherent variability of the waste. To predict the interactions which occur between a waste product and the soil, the chemical and physical properties of the waste must be adequately characterized. In particular, the range or variability of the composition of the waste should be known.

When a waste is applied to soil it triggers a series of soil-waste interactions that determine the fate of various constituents present in the waste. Some of the more important interactions, which are extremely complex, are adsorption, ion exchange, complexation, precipitation, oxidation-reduction, and enzymatic degradation (47, 51, 129, 130).

Mathematical models which describe soil-waste interactions, including adsorption, storage, and consumption of chemicals in soils, have been developed and summarized (47). The basic approach is to consider generalized flow models and then integrate various component models into the general model for the prediction of movement and attenuation of contaminants through soils.

Organic Wastes

Addition of organic wastes to soil usually results in increased microbial activity. Carbon dioxide, water, and microbial cells are the main products of aerobic metabolism. The proteins, carbohydrates, nucleic and fatty acids, amino sugars, and other organic materials found within microbial cells will be readily degraded by the common biochemical pathways of glycolysis such as the tricarboxylic acid cycle, and B-oxidation (46, 51, 131).

The refractory organics in wastewaters and sludges (estimated by the difference between the values of COD and BOD) are slowly degradable. These include phenols, detergents, fats and waxes, hydrocarbons, cellulose, lignin, tannin, plant and bile pigments, pesticides, and humic compounds (51). The duration which these substances remain in soils depends on their concentration and on the soil environment. With physical entrapment and chemical sorption of these compounds in the soil matrix, effective microbial degradation should occur.

One important aspect of soil-waste interactions is the microbial methylation of trace elements. Rogers (132) reported that methylation of mercury in agricultural soils was directly proportional to clay content, moisture content, soil temperature, and mercury concentration. Methylation of inorganic and organic forms of many elements is a common microbiological metabolism which results in their mobilization through volatilization and increased toxicity (Table 18). The methylated forms of lead,

TABLE 18. MICROBIAL FORMATION OF METHYLATED COMPOUNDS*

Element	Methylated Product†
Hydrogen	$CH_4\uparrow$
Lead	$(CH_3)_4Pb\uparrow$
Mercury	$(CH_3)_2Hg\uparrow$, CH_3Hg^+
Arsenic	$(CH_3)_2AsH\uparrow$, $(CH_3)_3As\uparrow$ $CH_3AsO(OH)_2$, $(CH_3)_2AsO(OH)$
Sulfur	$(CH_3)_2S\uparrow$, CH_3SH, $(CH_3)_2S_2$
Selenium	$(CH_3)_2Se\uparrow$, CH_3SeH, $(CH_3)_2Se_2$
Tellurium	$(CH_3)_2Te\uparrow$

*Summarized by Doran et al. (135).

†↑ = volatile compounds

mercury, arsenic, and tellurium are more toxic than their inorganic precursors, and the occasional magnification of these substances in the food chain (primarily fish) creates a pollution problem requiring perennial vigilance (133). The potential health hazards associated with volatilization of methylated heavy metal at a land disposal site has not been reported in the literature.

Inorganic Wastes

Soils comprise a dynamic system in which numerous chemical reactions occur simultaneously. Equilibrium, in its true sense, is probably never attained in soils. When an inorganic waste is added to a soil, it may interact with the soil solids, liquids, and gases (Figure 24) (134); after the waste is incorporated into the soil, the soluble constituents enter the soil solution (reaction 1). The released cations can exchange with those already on exchange sites in the soil (reactions 2 and 3). When the activities (effective concentrations) of ions in solution exceed the solubility products of solid phase compounds and minerals, these compounds can precipitate (reaction 4). When the soil solution is under-saturated with respect to solid phases or minerals present, these solid phases can dissolve (reaction 5). Ions in the soil solution can be removed by plants or leached from the soil (reaction 6). Waste constituents are also assimilated by microorganisms and incorporated into soil organic matter (reactions 7 and 8). Gaseous constituents enter the soil air and may escape from the soil (reaction 10), or components of the soil air may react with the soil solution and become part of the soil matrix (reaction 9).

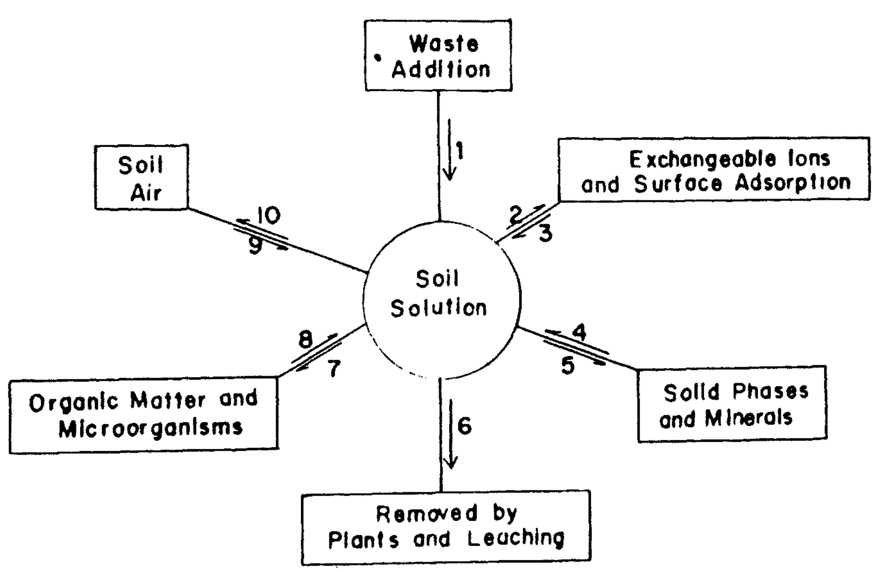


Figure 24. Reaction of wastes with soils (134).

The soil solution is affected by all the reactions that occur as constituents are added or deleted. The composition of the soil solution is ultimately controlled by the solubility of various mineral and organic phases in the soil, and the environmental factors of moisture, temperature, and aeration. In many reactions, the rates of precipitation and dissolution are sufficiently slow that kinetics, as well as thermodynamic factors, must be considered.

WATER QUALITY

Land cultivation must adequately protect the surface and subsurface waters from contamination with the potentially toxic constituents present in the waste or regulting from waste decomposition. Wastewater constituents that are not used by plants, degraded by microorganisms, or fixed in the soil may leach to the groundwater. Runoff resulting from excess waste application or heavy rains may carry the constituents and sediments to nearby streams and lakes.

Migration to Groundwater

Incorporation of wastes into the surface soil may result in soluble contaminants moving downward by infiltration and leaching, or percolation. Many factors are involved in determining whether the contaminants are reduced to harmless proportions before they reach the groundwater. These factors include hydraulic conductivity, soil structure, soil texture, evapotranspiration, rainfall intensity and duration, and soil sorption properties (47). The degree of attenuation and loss in potency or concentration of the contaminated water at a distance from the waste sites must also be considered.

The major mechanisms causing movement of chemicals in the soil are molecular diffusion in, and convection with, water as the water moves through the soil. The ion transport through the soil profile is controlled by a number of factors: 1) pore size continuity, 2) fluid dispersion, 3) cation and anion exchange capacity, 4) cation and anion exchange equilibrium, 5) rate of cation and anion exchange, and 6) soil water content (136). These factors are discussed later under Soil Attenuation.

Because anions such as HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- are soluble in water and most soils have limited anion exchange capacity, they will be the most likely to appear in the groundwater. Crop removal of potential pollutants (e.g., nitrate and orthophosphate) can play a significant role in reducing pollution hazards to the groundwater (137).

Based on information on the chemical composition and application rates reported in laboratory and field studies, incorporation of municipal solid wastes into the surface soil at agriculturally possible rates probably would not contaminant groundwater supplies with heavy metals, toxic chemicals, or pathogens. If groundwater rose such that it came in contact with the applied waste, the possibilities of groundwater contamination would rise considerably. This suggests that land cultivation of wastes in shallow groundwater areas would not be allowed.

In a study on the movement of elemental constituents in a Sagehill loamy sand (pH 7.5) treated with shredded municipal refuse, nitrate was the only ion studied which posed a threat to groundwater quality problems (14). This nitrate was from the nitrogen fertilizer which had been added to the soil to help alleviate the high C/N ratio of the carbonaceous refuse. Boron and total dissolved salts may be present at elevated concentrations in the groundwater if soils have high percolation rates and the municipal solid wastes are added in a long-term program.

The potential for groundwater contamination with industrial wastewaters and sludges is greater because the wastes are in liquid form and because the contaminants are present at greater concentrations in comparison to municipal solid wastes. Instances have been recorded of groundwater contamination by industrial wastes containing hazardous constituents (heavy metals, toxic organics, radioactive materials, cyanide, etc.) (138). These instances appear to be the result of wastewater impoundments and improper burial or open dumping of solid wastes.

Considering the extent of land cultivation practices and the types of industrial wastewaters and sludges suitable for soil incorporation, the constituents that would most commonly pose a pollution potential to the groundwater would be nitrate, salinity, and possibly BOD (resulting from hydraulic or organic overloading of the wastewaters and sludges). Certain wastes that contain high concentrations of various elements could contaminate waters with these elements. For example, from a laboratory experiment, Polson (79) suggested that fluoride may present a problem to groundwater when a refractory metal processing waste was applied at a rate of 2 percent or more to a Dayton silty clay loam. However, when the same waste was applied in the field at rates of up to 224 t/ha (100 tons/ac), no increase in fluoride content in the soil profile was observed.

Adriano et al. (137) presented data on the effect of long-term land disposal by spray irrigation of food processing wastes on the nitrate and phosphate levels of the subsurface waters. The two study sites had coarse-textured soils and shallow subsurface waters. During seasons of major irrigation, nitrate appeared in subsurface waters in concentrations exceeding public health standards; phosphate concentrations exceeded environmental guidelines at all times. Annual additions to subsurface waters were estimated at 76 and 65 percent of input nitrogen, respectively, at the two study sites. The corresponding figures for phosphate were 27 and 2 percent. Data presented suggests that the rates of accumulation of excess nitrogen and phosphorus in the soil profile could have been reduced materially if vegetation at these sites had been cut periodically and harvested. However, in the case of nitrogen, it appears that long-term protection of groundwater supplies through nutrient cycling in land disposal systems cannot be achieved if levels of input nitrogen are much greater than the quantities which can be removed in harvested crops.

Carbaryl, a nonpersistent insecticide, was applied at 25.4 kg/ha to a Congaree sandy loam field plot containing a shallow (about 1.1-m) water table (139). Within 2 mo after soil application, carbaryl appeared in the underlying groundwater where it persisted at least 8 mo. Maximum groundwater concentration (at the end of the second month) was about 0.3 mole/l. This concentration may be safe for animal consumption.

Considerable information is becoming available on the movement of trace elements and toxic chemicals in soils under laboratory conditions. However, there is only limited field data available on the contamination of groundwater by metals and toxic chemicals in the industrial wastewaters and sludges that are disposed of by land cultivation. The potential for groundwater pollution always exists, and waste overloading occurs, particularly when irrigation or rainfall is heavy and under extreme soil conditions such as prolonged water-logging, low pH (<5), and in sandy soils with a shallow water table.

Soil Attenuation

Consideration of the role of soils for management and utilization of wastes must take into account the chemical reactions that may occur with the waste constituents. The reactions can be grouped conveniently into: 1) ion exchange, 2) adsorption and precipitation, and 3) complexation. The mechanisms and rates of most, if not all, of these reactions are dependent upon the type and amounts of clay, hydrous oxide, and organic matter, as well as upon more dynamic properties, including solute composition and concentration, exchangeable cations, pH, and oxidation-reduction status.

Ion Exchange

The ion exchange capacity of soils varies primarily with:

- Kind of clay mineral present
- Quantity of clay mineral and/or amorphous materials
- Amount of organic matter present
- pH of the soil.

The dominant exchangeable cations are Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Al^{3+}, and H^{+}. Under waterlogged conditions, Mn^{2+} and Fe^{2+} may occupy a significant portion of the exchange complex. Because of their low solubility and low concentration in the soil solution, heavy metals such as Pb^{2+} and Cd^{2+} are not competitive with common divalent cations (such as Ca^{2+}) for clay adsorption sites (140). The precipitation of heavy metals, as well as iron and aluminum, may block exchange sites. Although the cation exchange capacity of a soil is considered in the application rate of sewage sludges (or heavy metal loading) to agricultural soils, it serves more as an indicator of overall soil properties rather than being the specific mechanism by which heavy metals are fixed in soils.

The extent of metal participation in true exchange reactions varies, depending on the metal, metal concentrations, soil constituents and their corresponding properties, pH, and presence of chelating agents (130).

While cation exchange is the dominant exchange process occurring in soils, some soils do retain anions such as NO_3^- and SO_4^{2-} on exchange sites. Anion exchange is especially important in acid-weathered soils high in hydrous oxides and kaolinite. Singh and Kanehiro (141) reported that two Hawaiian soils sorbed from 1.3 to 2.6 meq NO_3/100g soil at pH 5.0, with the amount decreasing as pH increased. It is unlikely, however, that this type of sorption would be significant, except in areas where soils are acid and contain considerable amounts of amorphous materials, hydrous oxides, and kaolinite.

Sorption and Precipitation Reactions--

These two reactions are often in competition, with precipitation dominating at relatively high concentrations of reactants. Several types of mechanisms have been postulated for the process of removing an ion from solution and bonding it to a solid surface, including physical sorption, chemisorption, and penetration into the solid mineral phase (130).

Retention of phosphate, arsenic, sulfur, selenium, molybdenium, boron, and trace metals has been discussed (129, 130, 142). Several mechanisms for the retention of metals in soils have been proposed. Hodgson (143) listed these reactions as: 1) association with soil surfaces, 2) precipitates, 3) occluded in other precipitates, 4) native constituents of soil minerals, 5) solid-state diffusion into soil minerals, 6) incorporation into biological systems or residues. While all of these reactions undoubtedly operate to some extent in surface soils, differences in the relative importance and rates of these mechanisms exist, depending on the metal, soil properties, and environmental conditions.

The factors controlling the relative dominance of precipitation over surface sorption in the retention reactions of metals are solution metal concentration, pH, ion pair formation, and possibly existence of organo-metal complexes (144, 145, 146). High concentrations of metals favor precipitation, forming oxides, hydroxides, and other solid phases (carbonates, sulfides, etc.) of low solubility, particularly at higher pH values (124). This concept is simplified by the following equation:

$$Zn^{2+} + 2\ OH^- \longrightarrow Zn(OH)_{2(s)}$$

Precipitation occurs when $[Zn^{2+}]\ [OH^-]^2$ exceeds the solubility product (K_{sp}). Conversely, when $[Zn^{2+}]\ [OH^-]^2$ drops below the K_{sp}, the solid phase $Zn(OH)_2$ begins to dissolve.

It is commonly found that with the exception of selenium, arsenic, molybdenum, and some valency states of chromium, the availability of metals decreases or sorption increases with an increase in soil pH (16, 129).

Organic matter is often regarded as a major factor in the sorption of metals. Humic and fulvic acids have relatively high stability constants for metals (146). The organic link to the trace metals, however, is limited not only by its chemical stability, but by its susceptibility to microbial attack, which can release the element for chemical reaction with soil constituents and/or further microbial incorporation (46).

Considerable evidence has accumulated indicating that hydrous metal oxides play a major role in the attenuation of heavy metals in mineral soils (142). These oxides, particularly those of iron, manganese, and aluminum are common in soils. They have high surface areas in relation to their weight, are highly reactive, and are of indefinite structure and composition.

Reducing conditions in soil have been reported to promote mobility of some trace metals (Cr, Ni, Cu, Zn, and Co), and noticeably of Fe and Mn (147). This would suggest that where drainage is poor in soils, these metals become more soluble and mobile through soil. However, it is generally true that the sulfide system controls the mobility of trace metals under anaerobic conditions (147, 148). Sulfide (formed under highly reduced conditions) reacts with trace metals to form very slightly soluble precipitates. Attenuation of trace metals in reduced soil conditions, thus, depends on a number of chemical and microbiological transformations.

Complexation--

Waste streams may contain many organic substances which can react with trace metals. Classes of organic compounds which have the greatest potential for serving as electron donors in metal complexes include enolates, alkoxides, carboxylates, phenoxides, alkyl amino, heterocyclic nitrogen compounds, mercaptides, phosphates, and phosphonates (149). Stabilities of complexes are normally measured by the equilibrium constants for complex formation and expressed by stability constants. In soils, the metal-organo complexes may be degraded biologically, releasing the trace metals at varying rates (46).

High molecular-weight humic substances (e.g., humates and fulvates) containing condensed aromatic nuclei in complex polymers have a high affinity for metals. This complexation contributes to the retention of trace metals in soil (146).

Low molecular-weight biochemicals of recent origin (e.g., organic acids and bases) demonstrate relatively high solubility in association with metals. These substances, while present only in small quantities in soil, are present in sufficient quantities in water-soluble forms to play a significant role in solubilization of trace metals in soil.

Physical Properties Attributable to Soil Attenuation--

In addition to the chemical properties discussed previously, some physical properties of soil also directly or indirectly affect the attenuation mechanisms. Among these physical properties are soil texture (or particle size distribution) and pore size distribution.

Many attenuation mechanisms involve physical and chemical reactions on surfaces. The greater the surface area available, the greater is the potential for attenuation of these mechanisms. Because of greater surface area per unit weight, finer soil materials (silt, clay, and colloids) have greater attenuating characteristics than coarser soil materials. In general, the finer the soil texture, the less the migration of trace metals.

Colloidal hydrous oxides and oxides of Fe, Mn, and Al react strongly with most of the trace metals and are reported to retain them against exchange much more tenaciously than do the clay minerals (142, 143). Also, these hydrous oxides coat particles such that a small amount of the oxides can have a profound effect on attenuation.

Because soluble constituents move through water in soil pore spaces and because soil water travels more rapidly through larger than through smaller pore spaces, the pore size distribution of a soil has a profound influence on migration of trace metals. Fine-textured soils with small diameter pores will restrict the migration of trace metals by slowing the rate of water movement through the soil, which in turn, allows more time for the metals to react physically or chemically with the soil particles.

Soil aeration and drainage, which are closely related to soil texture and pore size distribution, affect attenutaiton mainly through oxidation-reduction (redox) reactions. The changes in redox potentials following flooding and their relationships with the availability or mobility of nutrients and metals have been reviewed (147, 148). Under aerobic conditions, the solubility of most metals is low, and their toxicity and mobility are correspondingly reduced.

Published Information on Soil Attenuation--

Based on information in the literature, Fuller (129) grouped qualitatively 12 constituents studied with respect to mobility in soil under aerobic conditions:

- Relatively mobile - cyanide (CN^-), selenium ($HSeO_4^-$ and SeO_3^{2-}), and Cr(VI). The mobility is similar to almost uninhibited movement of Cl^-, moving at the same rate as soil solution.

- Moderately mobile - iron, zinc, lead, copper, and beryllium. The mobility is between "relatively mobile" and "slowly mobile."

- Slowly mobile - arsenic ($H_2AsO_4^-$.), cadmium, chromium (III), mercury, and asbestos (<2 μ). The mobility is between "slowly mobile" and "immobile."

- Immobile - asbestos (>2 μ). The mobility is similar to the rate of movement of clay-sized particles in soil.

The mobility classes defined by Fuller (129) are arbitrary generalizations from the 250 references cited in his report. While it is somewhat misleading to generalize about the mobility of ions without specifying the conditions, the generalization has some value in identifying ions requiring greater care upon disposal.

In a laboratory study, Fuller and Korte (150) evaluated the attenuation of 11 trace metals by leaching acidified landfill leachate (pH 5, spiked with 70 to 120 ppm of the element of interest) through 11 soil types under anaerobic conditions. They cited the important factors in attenuation as clay and free iron oxide content, soil pH, and solution flux through soil. Trace metals were placed into three categories, according to relative mobility under anaerobic conditions: 1) most generally mobile - chromium, mercury, and nickel; 2) least generally mobile - lead and copper; and 3) mobility varies with conditions - arsenic, beryllium, cadmium, selenium, vanadium, and zinc. Although the criteria used to group these elements into three mobility classes are not given, the groupings may be generally inferred from the data, given in the paper, on time to first appearance of an element in the soil column effluent.

Alesii and Fuller (144) reported that cyanide - as KCN and $K_3Fe(CN)_6$ - in water was very mobile in soils, while KCN in landfill leachate was complexed and less mobile. Soil properties such as low pH, the presence of free iron oxide, kaolin, chlorite and gibbsite-type clay tended to increase attenuation of cyanide. High pH, the presence of free $CaCO_3$, and montmorillonite-type clay tended to increase the mobility of these cyanide forms.

The effect of pH on removal of heavy metal is demonstrated by the work of Griffin and Shimp (145). These data show that adsorption by clays of cationic heavy metals - lead, cadmium, zinc, copper, and chromium (III) increased with increasing pH, while adsorption of anionic species - chromium (VI), arsenic, and selenium decreased as the pH increased. In another study (151), leachates collected from a sanitary landfill were run through columns of clay, and effluents were periodically collected and analyzed for 16 chemical constituents. The results show that chloride, sodium, and water-soluble organic compounds (COD) were relatively unattenuated by passage through the columns; potassium, ammonium, magnesium, silicon, and iron were moderately attenuated; and lead, cadmium, mercury, and zinc were strongly attenuated. Concentrations of calcium, boron, and manganese were markedly higher in the effluents than in the original leachate. Of the three clays tested in this study, montmorillonite had the highest attenuation capacity, followed by illite and then kaolinite.

Field observations (16) have indicated some movement of trace elements in soil following sewage sludge applications over long periods (decades). In most instances, however, except for boron, the movement into lower soil depth (below 3m (10 ft)) of trace elements applied in the waste was restricted. Even though all toxic metals are largely fixed in the surface layers of soil, rather small increases in trace element solubility combined with subsequent movement to the water table could result in deterioration of groundwater supplies.

An investigation was conducted of possible contamination of groundwater with lead and zinc in the "new lead belt" mining region of southeast Missouri. Jennett and Linnemann (152) leached two soils collected in the area with solutions of lead and zinc acetate and fluoroborate containing 100 and 250 ppm zinc or lead. Although no data on zinc and lead concentrations in the leachate were shown, they concluded from the study that heavy-metal contaminated soils in this region did not contribute to heavy metal contamination of the groundwater supplies. However, based on the acidic nature of the soils (pH 5.2 and 5.6) and leaching solutions (pH 3) and the quantity of solution (equivalent of 20 yr of annual rainfall) percolated through the soil, more work is needed to substantiate this conclusion.

The attenuation and persistence of pesticides in soils depend on the chemical formulation and water solubility of the compounds and their absorbtivity in soil colloids. Mobility of some selected pesticides of Hagerstown silty clay loam is presented in Table 19 (153).

Filonow et al. (154) found insignificant movement of 2,2',4,4',5,5'-hexabromobiphenyl (HBB), a mixture of polybrominated biphenyls (PBB's), through four Michigan soils amended with 100 ppm HBB (soil basis). Only traces (2-3 ppb) of HBB were detected in the leachates even after collecting 1,592 cm (769 in) of leachate. The results suggest that PBB's, which are present in some Michigan farm soils due to applications of PBB-contaminated manure, should not leach below the depth of incorporation.

Burnside et al. (155) studied, under field conditions in Nebraska, the dissipation and leaching of monuron, simazine, and atrazine in a silty clay loam and two loam soils. They found that monuron was leached to the 30- to 46-cm (12- to 18-in) depth in 4 mo, but that no monuron was detected in this soil layer after 16 mo. The herbicide might have been leached further, adsorbed, or degraded. Simazine was leached minimally in the 4 mo after its application, but there was considerable leaching after 6 mo. In contrast, atrazine was leached to the 30- to 46-cm (12- to 18-in) depth after 4 mo and to the 46- to 61-cm (18- to 24-in) depth or greater after 16 mo.

The leachability of a series of herbicides in soil columns packed with a Pullman silty clay loam was determined by Wiese and Davis (156). Upon addition of sufficient water to wet the soil column to 56 cm (22-in), 2-,3-,6-TBA and PBA were leached to about 51 cm (20-in). In contrast, esters of silvex, 2-,4-,5-T and 2-,4-D remained in the top 7.6 cm (3-in) of soil. Other herbicides used were leached to depths between these extremes.

Field studies of pesticide residues in soils subjected to natural climatic conditions commonly show that the highest pesticide concentration is in the surface layer (157, 158). Once the pesticides are leached to zones of lower organic matter content, they move at very low concentrations with percolating waters and do not accumulate. This is because the rate at which a chemical degrades often limits the extent of actual movement. Generally, the rapid degradation of many chemicals at their normal field application rate often is the dominant attenuating factor. However, this does not imply that the potential transport of pesticides to groundwater, particularly disposal of large volumes of concentrated solution on land, is of no concern. It does imply that soil and hydrogeologic conditions must be considered to evaluate the transport potential.

TABLE 19. MOBILITY OF SELECTED PESTICIDES IN HAGERSTOWN SILTY CLAY LOAM SOIL(153)

Pesticide	Mobility Class*
Amiben	5
Atrazine	3
Azinphosmethyl	2
Bromacil	4
Chloroxuron	1
Dalapon	5
Dicamba	5
Dichlobenil	2
DDT	1
Dieldrin	1
Diquat	1
Diuron	2
Endrin	1
Fluometuron	3
MCPA	4
Paraquat	1
Propachlor	3
Propanil	2
Propazine	3
Picloram	4
TCA	5
Trifluralin	1
2,4,5-T	3
2,4-D	4

*Based on soil thin-layer chromatography R_f values in increasing order of mobility: Class 1, 0-0.09; Class 2, 0.10-0.34; Class 3, 0.35-0.64; Class 4, 0.65-0.89; Class 5, 0.90-1.00. Mobility is measured as "Rf" relative to the wetting front, so that an R_f of 0.5 means that over the measured distance the pesticide only moved half as far as the water. An R_f approaching 0 indicates the pesticide was immobile.

Surface Water Runoff

Movement of agricultural chemicals in runoff has been a major source of surface water contamination in downstream areas. Chemicals may be transported as particulate, dissolved, or bound on eroded soil particles. General factors that influence runoff and erosion and, thus, influence contaminant transport in overland flow include rainfall characteristics (intensity, duration, and seasonal effect) and land characteristics (area, shape, slope gradient, type of drainage network, soil erodibility, and land usage, management and conservation practices).

The concentrations of contaminants in runoff have been shown to be related to application rates. In studies conducted by Barnett et al. (159), concentrations were greatest early in each storm and decreased with storm duration (159). Runoff losses of most pesticides in farmland are greatest immediately after application (159, 160).

Antecedent soil moisture content has a major effect on surface runoff resulting from rainfall. When the soil moisture is high, the infiltration capacity is low and surface runoff is much higher than if the soil moisture content were low.

In a land cultivation operation, the wastes are concentrated in the soil surface. Thus, the concentration of contaminants in the runoff water may be sufficiently high to have deleterious effects on certain trophic levels in the aquatic ecosystem.

Concentrations of trace elements in water considered to be toxic to aquatic organisms are, in many cases, less than those considered to be toxic to animals, man, and higher plants. Concentrations of arsenic, cadmium, chromium, copper, mercury, nickel, lead, and silver as low as 0.01 μg/ml may have serious deleterious effects on certain species of aquatic life (161). Since these tolerances are low, surface runoff of either sediment or solution into surface water should be controlled.

Surface runoff from wastewater and sludge application sites must be managed to protect nearby landowners, as well as surface water quality. Commonly, berms and dikes should be used to eliminate surface runoff from waste disposal sites.

AIR EMISSIONS

Malodorous emissions from organic wastes can have detrimental esthetic and economic effects on a community, as well as on its residents' mental and physical health (162). Public opinion surveys frequently identify malodors as the air pollutant of great concern. Air quality at a land cultivation site can be impaired by the odors, dust, volatile substances, and aerosols emitted from waste spreading and incorporation processes. There is no apparent relationship between odors and a specific organic disease, or toxicity of a gas.

Odor problems from land cultivation of municipal solid waste are minimal and can be less offensive than the odors emitted at an active landfill (11), since the waste is incorporated into the surface soil and undergoes aerobic decomposition. The gases evolved during aerobic decomposition are primarily CO_2, HN_3, and volatile products of the waste. During spreading, however, the putrescible fraction may create odors, particularly if the waste is left exposed on the surface.

Industrial wastewaters and sludges, in particular those with high concentrations of organic solids and BOD, may pose a serious potential for offensive odor nuisances if not properly managed. Odor problems can begin at the point of initial sludge handling, and the odor potential can extend for a significant period of time after actual incorporation of the sludge into the soil. During spreading and drying, the wastes may undergo anaerobic decomposition resulting in production of foul smell from compounds such as alcohols, ammonia, organic amines, mercaptans, and organic acids (162). The situation is especially serious with heavy waste applications on poorly drained soils during the wet season. Subsurface injection and thorough mixing of the liquid waste with the soil helps to control odors (Maphis, personal communication). A number of the commercially available chemicals for odor treatment are listed by Miner (163). These chemicals (hydrogen peroxide, hydrated lime, aromatic oils, etc.) are used to treat the wastes or mask the odors until they diminish with time, or are sufficiently dispersed. However, once the wastes are mixed into the soil, the odors are likely to diminish with time.

Aerosols are microscopic droplets that can be inhaled into the throat and lungs. Aerosol travel and pathogen survival are dependent on factors such as wind, temperature, humidity, vegetative screens, distance, etc. Little is actually known about the survival of pathogens in aerosols. Tarquin and Dowdy (164) detected a significant number of pathogenic bacteria colonies located 122 m (400 ft) downwind of a spray irrigation nozzle emitting meat-packing wastewater. They also reported a significant increase in aerosol travel with nozzle pressures. No form of land treatment of wastewater will completely eliminate the possibility of a pathogenic transfer, but no evidence suggests that such transfer has been a significant problem in the numerous operating land treatment systems for food-processing wastewater (25).

If disposed of by land cultivation operation, industrial wastes containing heavy metals and organic substances that are highly toxic, in dust or volatile form, can deteriorate the air quality. The level of volatile compounds present in the air is not necessarily related to severity of the odor problems. There is not sufficient data to assess the potential adverse effect on air quality due to land cultivation practices.

HEALTH AND SAFETY

Harmful effects associated with land cultivation of wastes can be of a biological, chemical, physical, mechanical, or psychological nature. It is not easy to distinguish clearly the effects of waste in general from those of more toxic or otherwise hazardous waste. For example, human pathogens in feces provide a biological threat; some industrial wastes pose chemical hazards; flammable materials involve physical danger of fires and explosions; and broken glass causes mechanical hazards. Many other effects, such as psychological and behavioral disturbances and repercussions, also merit consideration.

In this section, health and safety in land cultivation practices are discussed with respect to spreading and mixing of waste, carcinogenic potential from the waste and its degradation product(s), aesthetics, heavy metals in the food chain, and disease transmission.

Field Operations

Injuries that occur during handling, spreading, and incorporation of waste are potential hazards associated with land cultivation. Specifically, these hazards include equipment operations, fires and explosions, dust and aerosols, and odor problems. Safety precautions and emergency procedures used at a landfill and farming operations should be applicable to land cultivation disposal operations.

During land cultivation, fires and explosions could occur, injuring site personnel. After soil incorporation, some of the waste materials that are partially exposed can cause fire hazards resulting from spontaneous or accidental combustion of flammable materials. Explosions could occur, in part, due to mixing of incompatible waste materials.

Dust is another problem at municipal refuse disposal sites, particularly in dry and windy climates. Dust is a potential health hazard to personnel on the sites and may be a nuisance to residences or nearby businesses.

Gases and odors generated increase initially during spreading operations and subside as microbial decomposition occurs. However, in the weathering (spreading) method of disposing of leaded-gasoline storage tank wastes, the vapors can be inhaled or absorbed through the skin. At the levels of organically bound lead (20 to 200 ppm) encountered in the storage tank sludge, potential lead-in-air hazard could occur during the weathering process, and as an absorptive hazard through the skin during handling of the material (66). In general, the effect of air pollution on the health or frequency of illness of site personnel is not known. At sites where hazardous wastes are land applied, equipment operators usually wear a dust mask that minimizes health hazards associated with dust, volatile substances, and aerosols.

Aesthetics

If not properly managed, application of municipal refuse to land may result in aesthetic problems from blowing paper and plastic film, and exposure of residual cans, glass, and plastic. Unless the waste is shredded finely and thoroughly incorporated into the soil, the area is unsightly. If the final use of the land is for pasture, potential hazards to grazing cattle, such as accidental ingestion of the waste material (plastic, leather, metals, and rubber), should be determined.

Since waste is not usually cultivated during inclement weather conditions, it must sometimes be stored at the site for later disposal. This may create aesthetic problems if the storage facility and its surroundings are unsightly.

Trace Metals in the Food Chain

Trace metals in the waste which are added to an agricultural soil are not a direct hazard to the food chain until they have entered or contaminated an edible part of a plant. Some direct ingestion of recently applied metals or soil containing large amounts of heavy metals is a special hazard to cattle grazing waste-treated sites. Application of wastes to fresh market crops is particularly discouraged.

The roles of a number of micronutrients and trace metals in plant and animal nutritition have been reviewed (165, 166, 167, 168, 169). Animal diets are often deficient in the essential trace metals (e.g., chromium, copper, cobalt, manganese, nickel, zinc, selenium, tin, vanadium, and molybdenum). Therefore, if wastes containing slightly elevated contents of some of these nutrients are applied to soils deficient in these trace metals, the nutritive value of grains and forages used for animal consumption may be improved.

Trace elements in the waste materials applied to land that could pose a potentially serious hazard to the food chain through plant accumulation are cadmium in man and animals, and selenium and molybdenum in animals. Under proper site management, other trace metals generally pose relatively little hazard because of the low solubility of metals in a neutral, well-aerated soil, rendering them unavailable to plants and because of limited metal translocation to the edible parts of plants. Also, concentrations of some metals (e.g., zinc and copper) in plants will exceed phytotoxic limits prior to reaching toxic levels for most animal life. Considerable information is available on the effects on human and animal health of crops containing elevated levels of the trace metals, particularly of cadmium (166, 168, 170, 171, 172).

A wide variety of crop species accumulate cadmium in response to Cd concentration of the substrate. Plant content varies according to species and tissue (173). Cereals and legumes accumulate less cadmium than do leafy plants such as lettuce and spinach. Lower cadmium concentrations are generally found in tubers, seeds, and fruit than in other plant parts. Plants with cadmium concentrations of 1 ppm or greater in the edible portion are considered less desirable and unsuitable for human or animal consumption. The tissues of most crops may contain undesirable concentrations of cadmium without showing visible symptoms of cadmium toxicity.

Although selenium is an essential element for certain animals, the range between deficiency and toxicity is fairly narrow (168). At levels of 0.05 ppm selenium in the diet, degeneration of muscle tissue results due to selenium deficiency. When the diet contains more than 4 ppm, selenium toxicity may occur. Normal plants contain 0.02 to 2.0 ppm selenium and would exhibit phytotoxicity at concentrations greater than 50 ppm (165).

Molybdenum is an essential element to plants and animals. Normal plant concentrations of molybdenum are a few ppm; however, plants appear to be tolerant to high levels (a few hundred ppm in tissues). The tolerance of animals to molybdenum varies with species and age and is dependent upon the status and intake of copper, zinc, and iron by the animal (172). Cattle are considered the most susceptible of the farm animals to molybdenum toxicity. Forages containing molybdenum concentrations exceeding 10 to 20 ppm may produce molybdenosis in ruminants. The symptoms of molybdenosis are essentially those of copper deficienty, since the accumulation of copper diminishes as the intake of molybdenum increases (168). The effect of relatively high concentrations of molybdenum on copper metabolism is offset by small concentrations of sulfate in pasture.

Limiting the discussion to cadmium, selenium, and molybdenum does not imply that other trace metals are not significant in the food chain. Cunningham et al. (174) presented data showing that plants would absorb more metals (zinc, nickel, copper, and chromium) if they were applied as inorganic salts rather than in sewage sludge. The concentration of heavy metals in the plant tissues, therefore, depends upon: 1) form and level in the waste material, 2) application rate, and 3) land management, e.g., proper tilling and control of soil pH. If the soil receives more waste than it can assimilate and/or a waste cultivation site is poorly managed, some of the elements that are considered to be less hazardous could become a serious hazard in the food chain.

Pesticide and Toxic Organic Residues in the Food Chain

Industrial wastes are usually a mixture of several waste sources and may contain toxic organic compounds in varying concentrations, depending on the type of industry and pretreatment (see Section 4). When these wastes are land cultivated, it is conceivable that vegetation grown on the site can be contaminated with the toxic constituents in the wastes through surface sorption and uptake by the plant roots.

Plant surface contamination results from dust, aerosols, and volatile substances during the application and incorporation of the waste materials. Sorption by root crops and forage contamination of pasture crops could pose serious hazards to humans and animals (175, 176). Persistent potent chemicals such as hexachlorobenzene (HCB) and polychlorinated biphenyls (PCB's) are chemically and biologically very stable; thus, they are particularly significant.

Plant uptake of insecticides, fungicides, fumigants, and herbicides from soils has been reviewed extensively (176). Summarized in Table 20 is the knowledge of plant uptake of selected pesticides from soils. Also indicated on Table 20 is information on translocation of pesticides from root to different plant parts, and identification of whether the translocated compound is the parent pesticide or a metabolite.

Factors controlling uptake (in probable order of importance) are water solubility and quantity of pesticide in soil, and organic matter content of the soil. Plant roots are not very discriminating toward small (molecular weight <500) organic molecules, except on the basis of polarity. The more polar the molecule of a insecticide, the more readily it will reach the root, be absorbed by the root, and be translocated to other parts of the plant. The contaminated plant may become a potential hazard itself, depending on the ability of the plant to metabolize or eliminate the chemical before it is harvested and whether or not the chemical is translocated to the harvested portion of the plant.

Beetsman et al. (177) reported that not more than 3 percent of dieldrin from the soil passed into foliage of corn. Concentrations in root tissue were 20 to 80 times the concentrations in the aerial portions of corn, and the concentration in the corn shoots was quite constant throughout the growing season. The organophosphorus insecticides, however, are readily absorbed by plants growing in soil containing these compounds (176). Some of these insecticides (e.g., disulfoton, phorate, etc.) are systemic; they are absorbed by the roots and translocated to the

TABLE 20. PLANT UPTAKE AND TRANSLOCATION OF PESTICIDES FROM SOILS (176)

Insecticide	Absorbed by root	Translocated from root	Compounds found after translocation	
			Parent	Metabolites
Aldrin	Yes	Yes	Yes	Yes
Dieldrin	Yes	Yes	Yes	Probable
Isodrin	Yes	Probable	Improbable	Yes
Endrin	Yes	Yes	Yes	Yes
Heptachlor	Yes	Yes	Yes	Yes
Heptachlor epoxide	Yes	Yes	Yes	Unknown
Chlordane	Yes	Improbable	Unknown*	Unknown
Endosulfan	Yes	Yes	Yes	Unknown
Toxaphene	Probable	Improbable	Unknown	Unknown
BHC	Yes	Yes	Yes	Yes
Lindane	Yes	Yes	Yes	Yes
DDT	Yes	Probable	Probable	Yes
Diazinon	Yes	Yes	Yes	Probable
Dimethoate	Yes	Probable	Unknown	Probable
Disulfoton	Yes	Yes	Yes	Yes
Phorate	Yes	Yes	Yes	Yes
Parathion	Yes	Probable	Probable	Unknown
Chloroneb	Yes	Yes	Yes	Yes
Arsenic	Yes	Yes	Yes	---
Lead	Yes	Yes	Yes	---

*None, or has never been investigated.

plant top in amounts lethal to certain insects. Kansouh and Hopkins (178) presented evidence of translocation of diazinon in bean plants. Concentrations of diazinon in terminal and primary leaves of the plants increased with time, while root concentration slowly decreased,

Little is known about the relative plant uptake and accumulation in plants of hydrocarbons, surfactants, synthetic polymers, phenols, and persistent organic contaminants; however, the factors that affect the plant uptake of pesticides and herbicides in soils should also govern the absorption of these compounds by plant roots.

Moza et al. (179) investigated the uptake of 2,2'-dichlorobiphenyl (DCB) - an isomer of polychlorinated biphenyls (PCB's) by carrot and sugar beet roots in a loamy sand (pH 5.7) that received 1 ppm (soil basis) of the chemical. Carrots that were planted the first year contained 0.240 ppm of DCB and 0.012 ppm of metabolites. Sugar beets that were planted the following year contained <0.001 ppm of DCB and 0.004 of metabolites. The current FDA tolerance level of PCB for infant foods is 0.2 ppm. Since carrots are outstanding in their ability to absorb pesticidal residues from soils, growth of carrots and possibly other root crops on soils which receive waste containing toxic organic contaminants does not appear advisable.

Jacobs et al. (180) studied the uptake of polybrominated biphenyls (PBB's) by orchard grass and carrots grown in a loamy sand contaminated with 100 ppm (soil basis) of the chemical. The results showed no uptake or a very low uptake (20 to 40 ppb) of PBB's by orchard grass and carrots, respectively. Even with the use of radioactive techniques, no measurable uptake and translocation of PCB's by soybeans were detected (Fries, personal communication).

Boxes of sand treated with PCB to achieve 100 ppm concentration resulted in soybean uptake of 0.15 ppm (wet weight basis) in sprouts after 2 wk growth (181).

Carrots grown on a sandy loam, treated with 100 ppm of PCB Aroclor 1254 (soil basis), absorbed considerable amounts of the chemical (up to 42 ppm, wet weight basis) (182). The carrot peel, comprising 14 percent of the carrot weight, contained 97 percent of the PCB residues. Very little translocation of PCB occurred in the plant tissue. The translocation of PCB isomers from soil into carrots under similar circumstances is in the same order of magnitude as that of the more persistent organochlorine pesticides (182).

In summary, limited data tend to indicate that foliar contamination through application or volatilization, rather than uptake of pesticides and persistent compounds (e.g., PCB's and similar fat-soluble organic compounds), would be the mechanism by which these potentially harmful compounds enter the food chain. The danger of contamination of vegetable and grain crops by these chemicals and their degradation products would probably exist only for heavily contaminated soils. Cattle grazing on land contaminated with these chemicals, however, can take up considerable amounts of the chemicals through ingestion of contaminated soil particles, rather than through the foliages.

Carcinogenic Compounds

Regulations proposed by the Occupational Safety and Health Administration (OSHA) would preclude any human contact with carcinogenic (cancer-causing) compounds in the work place. Such compounds include not only those proven to be carcinogenic to man, but also those which at present are only known to be carcinogenic to laboratory animals.

Laboratory analyses and epidemiological studies of various occupational groups have identified over 1,500 potentially carcinogenic chemical compounds (183). Most of these compounds are of industrial origin or use; a few are used in medicine. A chemical produces a carcinogenic effect in a human or animal via inhalation, oral ingestion, or absorption through the skin. The effect produced or site of the cancer depends upon the particular chemical and, to a lesser extent, on the pathway of body entry.

Carcinogens in Man--

Some compounds known to be or suspected of being carcinogenic to humans are included in Table 21. These compounds are divided into five classes (polynuclear aromatic hydrocarbons, aromatic amines, alkylating agents, chromate salts, and inorganic arsenicals) and three specific chemicals (nickel carbonyl, asbestos, and benzene). Benzene, although not a proven carcinogen, is highly suspect. Evidence for the carcinogenic effect of these compounds in man is, in all cases, based on epidemiological studies of selected populations and industrial occupation groups. Cancer thus detected in humans is generally chronic, occurring only after relatively long-term exposure to these compounds.

Carcinogens in Animals--

A large number of chemicals have been found to produce cancer in laboratory animals. A list of selected chemicals are given in Table 22. Although no proof exists that man is similarly affected, the utmost caution should be taken in exposing humans who are working with and disposing of these chemicals.

Also presented are the effects of the chemicals; laboratory animals demonstrating the carcinogenic impact, pathway (method of administration of the chemical); and industrial uses of the

TABLE 21. POSSIBLE CARCINOGENS IN MAN (183)

Compound	Areas Affected	Uses	Form
1. Polynuclear aromatic hydrocarbons			
. Soots	skin, lungs		Powder
. Pitch, coal tar and products, creosote	skin, lips, lungs		Viscous liquids
. Mineral, petroleum and cutting oils	skin		Viscous liquids
. Benzo (a) pyrene	lungs		Insoluble crystals
2. Aromatic amines			
. 2-nephylamine	bladder	Dyes intermediate, industrial anti-oxidants	Powder, liquid, gas
. Benzidine, 4-aminobiphenyl, 4-nitrobiphenyl	bladder		Crystals or powder Liquid or crystal
. auramine, magenta	bladder	Dyes, fungicides	Soluble dyes
3. Alkylating agents			
. Melphalon, busulfan	leukemia, lymphomas	Chemotherapeutic agents	
. Chlornaphthazine	bladder	Chemotherapeutic agents	
. Mustard gas	lungs	War gas	Gas
. Bis (chloromethyl) ether	lungs	Ion exchange resins intermediate	Volatile liquid
. Dimethyl sulfate	lungs	Methylating agents	Liquid
. Methyl chloromethyl ether	lungs		Liquid, decomposes in H_2O
. Vinyl chloride	lungs		Liquid or gas
4. Nickel carbonyl	lungs, nasal sinuses	Products from nickel refining	Volatile liquid
5. Chromate salts	lungs, nasal sinuses		
6. Inorganic arsenicals	skin	Medical preparations, pesticides	
7. Asbestos	lungs		Fibers
8. Benzene (?)	leukemia		Liquid

TABLE 22. CARCINOGENS IN ANIMALS (183)

Compound	Areas Affected	Animal[†]	Pathway[#]	Uses
Acetamide	liver	R	O	Solvent, textile treating and dyeing, plasticizers
Aminotriazole	liver and thyroid	R, M	O	Herbicide, photographic reagent
O-Tolidine	bladder	R, M	O	Dye industry intermediate
Dianisidine	skin, bladder, lower intestine	R	O&I	Dyestuff and polyurethane intermediate
3, 3'-dichloro-benzidine		R, M	O&I	Dyestuff and polyurethane intermediate
Methylene dianiline	liver	R		Epoxy resin hardness, polyurethane intermediate
3, 3'-dichloro-4, 4' diaminodiphenyl methane	liver and lungs	R	O	Epoxy resin and isocyanate Polymer curing agent
Meridine	liver and lungs	R, M	O	Dyestuffs
2, 4-Toluenediamine	liver	R	O	Dye ingredient, polyurethane foam ingredient
4-Chloro-o-toluidine	liver	M		Dyestuff intermediate, bird control agent
Carbon tetrachloride	liver	M	O	Solvent, degreasing agent
Chloroform		M	O	Solvent, cleansing agent, intermediate
Dimethylcarbamyl chloride	skin and lungs	M	S&I	Synthesis of herbicides, pesticides and anthelmintic drugs
1, 1-Dimethylhydrazine	lung, blood vessels	M		Rocket fuel, synthetic intermediate
Dioxane	liver, nasal areas	R	W	Solvent
Ethyl carbonate	lungs	M		Stain solvent, dye intermediate

(Continued)

TABLE 22 (continued)

Compound	Areas Affected	Animal†	Pathway #	Uses
Ethylene imine	liver and lungs	M	0	Resin intermediate, textile and paper finishes
Propylene imine	breast, brain, ear duct, leukemia	R	0	
Ethylene thiourea	thyroid, liver	R, M	0	Rubber processing
Glycidalehyde	skin	M	S	Glycerol intermediate
Hydrazine	liver, lung, lymphomac	M		Agricultural and medical intermediate, reducing agent
Accellerene	esophagus, stomach	R	W	Dye intermediate, rubber chemical
N,4-Dinitrozo-N-methylaniline		R	0	Rubber and plastic additive
beta-Propiolactone		M	S	Sterilizing agent in labs and hospitals
Propane sultone	brain	R	0	Several proposed
Thioacetamide	liver		0	
Thiouracil	thyroid		0	Photography, rubber accelerators, metal polish
Thiouracil	thyroid		0	

*No evidence has been established that these compounds are carcinogenic in man.
†R = Rats, M = Mice.
#0 = Oral, in food, I = Injection.
S = Skin application.
W = Oral in drinking water.

chemical. The various chemicals produce leukemia and tumors in the liver, lungs, thyroid, bladder, lower intestinal tract, skin, breast, brain, ear duct, blood vessels, esophagus, and stomach.

Industrial Uses of Carcinogenic Chemicals--

Chemicals known to be carcinogenic have a wide range of industrial uses. Dyes are the most common carcinogenic chemicals listed. The rubber and plastic industries are users of six of the animal carcinogenic chemicals. Auramine and some inorganic arsenicals, as well as three animal carcinogens, are also used in the production of certain pesticides.

Carcinogenic chemicals are used by several other industries and processes, such as those that manufacture ion exchange and epoxy resins, photographic chemicals, rocket fuel, and drugs, and those involved in nickel refining, textile treating, metal working, degreasing, paper finishing, glycerol manufacturing, and wood preserving.

Disposal Precautions--

Personnel dealing with the collection, transport, or disposal of industrial wastes should be protected to the same extent as personnel working directly with the chemicals. This protection required that industrial waste containing significant quantities of any known carcinogen not be disposed by land cultivation. If land cultivation of such an industrial waste is planned, pretreatment to remove the carcinogen or to alter the chemical to a noncarcinogenic form will be necessary.

Placing human health and safety restrictions on the land cultivation of industrial wastes is complicated by the phenomenon known as cocarcinogenesis. A cocarcinogen is a material that has minimal or no cancer-inducing ability by itself, but can increase the effectiveness of a carcinogen when the two are administered together. There is also a danger that the mixture of two chemicals can be carcinogenic, while the two individual chemicals by themselves have no carcinogenic effects. Because of these possibilities, it is extremely important to avoid indiscriminate human exposure to substances with unknown biological effects.

Pathogens

From a public health aspect, one of the most immediate and serious questions raised in land cultivation practice for waste materials is the potential for the transmission of pathogens, including bacteria and viruses. Transmission can potentially occur via: 1) groundwater, 2) aerosols, 3) physical contact with the waste or contaminated crop, or 4) the food chain. The disease-producing organisms do not have to be present in the host material because the environment contains spores, bacteria, viruses, insects, vermin, and other vectors awaiting a favorable growth condition.

In a field experiment in which tomato cannery waste was spread on soil, excessive fly infestation led to a temporary shutdown of the project (Ayers, personal communication). Hart et al (11) encountered similar problems in their study of land spreading of municipal raw refuse; however, mixing the waste materials with the surface soil alleviated the problem.

Municipal raw refuse has been shown to contain viable pathogens that may pose a health hazard to animals and humans (51, 184). Included are the bacterial pathogens (salmonella, shigella, mycobacterium, and *Vibrio sp.*), the infectious hepatitis virus, enteroviruses and adenoviruses, protozoans such as *Endamoeba histolytica*, and certain pathogenic fungi and fungal allergens.

Because survival time in soils is limited, pathogens generally do not pose a long-term threat to the soil as a resource. Many of the pathogenic microorganisms can survive in soils for a few days, although some may survive for several months (185). Survival time in the soil for a given microorganism is generally prolonged by low temperature, high water content, and neutral pH, and may also be affected by the organic matter content of the soil. It has been reported that fecal coliform organisms rarely penetrate as deep as 1.2 m (4-ft) of an unsaturated soil, and horizontal movement through uniform soils is generally limited to 30.5 m (100-ft). Application of wastes on soil generally decreases pathogen survival and virulence with time (186). The threat to groundwater is therefore minimized.

It has been established that fruits and vegetables, especially root crops, can become surface contaminated by pathogens and may pose a threat to human health if consumed raw (185, 186). Research is needed in the general areas of survival, movement, and possible inactivation of viruses through adsorption or microbial antagonism. This research should clearly establish the extent of a potential pathogen hazard, including long-term health effects, in relation to waste application to different soils.

SECTION 12

SITE MONITORING

Land used for waste renovation or disposal must be monitored so that the environment is adequately protected. Monitoring, in the broad context, includes observing operation performance, checking the quality of potentially affected natural systems, and observing and recording environmental impacts as quality changes occur. It is a tool for developing preventive maintainance procedures. In land cultivation, monitoring should be used to confirm the predictions and judgments made during project development and design with respect to the natural systems. Monitoring should be employed to expand understanding of operation performance; it should not be used as a substitute for understanding the many interrelated physical, chemical, microbiological, and hydrologic factors within any project prior to implementation.

The elements and/or constituents in industrial wastes which are considered as pollutants are listed in Table 23; however, no single waste would likely contain all these pollutants. The constituents or parameters to be monitored will depend, to a large extent, on their concentrations and waste properties and on the purposes of land cultivation, i.e., utilization or disposal of the waste.

Soil, groundwater, surface runoff, vegetation, and air quality are specific areas which should be considered for monitoring at the land cultivation site.

SOIL MONITORING

The soil at the land cultivation site should be physically and chemically characterized during project design. The monitoring program developed should identify changes in these characteristics to avoid permanent or irreversible soil damage.

Recent studies show that chemical analysis of core samples from waste disposal sites permits positive identification of any chemical constituent within the soil profile (188). This is true regardless of whether the chemicals are present in precipitated form in the zone of soil incorporation, are retained on soil particles in the semi-saturated fringe, or are dissolved in groundwater within the zone of saturation. Chemical analyses of soil core samples are usually faster, easier, and more

TABLE 23. SELECTED POLLUTANTS WHICH MAY BE PRESENT IN INDUSTRIAL WASTE STREAMS AND RESIDUES (187)

Alkalinity	Aluminum
BOD	Boron
COD	Cadmium
TS	Chromium
TDS	Cobalt
TSS	Copper
Ammonia	Iron
Nitrate	Lead
Phosphorus	Magnesium
Turbidity	Manganese
Fecal Coliform	Mercury
Acidity	Nickel
Hardness, Total	Selenium
Sulfate	Sodium
Sulfite	Vanadium
Bromide	Zinc
Chloride	Oil and Grease
Fluoride	Phenols
	Polychlorinated biphenyls
	Surfactants
	Algicides
	Chlorine
	Organics specific to organic synthesis

economical than analyses of groundwater samples collected from observation wells.

By determining distribution of a chemical constituent or contaminant in soil (concentration vs. soil depth), it is possible to discover whether the pollutant is retained in the surface soil or moving slowly to lower soil depths (189). This information can be used as an early warning of pending groundwater contamination.

Core Sampling

The number of core samples and sampling depths selected will depend on the variability of the soil, allocated budget, the degree of accuracy desired, particular constituents to be determined, waste management, and the general overall purpose of investigation. Cultivated soils are generally more variable than virgin soils, and saline and alkali soils are extremely variable. There is no set standard for soil sampling suitable for all studies. The movement of most waste constituents in soil is a slow process, except in very sandy soil with high rainfall. Thus, for most land cultivation sites, yearly sampling of surface (0 to 30 cm) and subsurface (30 to 60 cm, 60 to 100 cm) soils will suffice. Petersen and Calvin (190) have discussed field sampling with respect to statistical validity. The following points are well established:

- A series of cores of equal diameter and comparable depth taken according to some systematic grid layout of the area should be composited.
- Separate soil cores should be analyzed, or replicate sets of composites should be made to determine statistical significance of results on the final composite.
- Separate composite samples representing different segments of the soil profile or root zone should be taken.
- Contamination from soil surface materials (crop residues, sludges, fertilizers, etc.) should be avoided as well as contamination of one soil depth with that of another.
- In an area to be sampled at successive intervals, a map should be made that shows initial sampling points. Subsequent samples should be taken at short, but definite distances away from the preceding sampling point.

- Composite samples provide only an estimate of the mean of the population from which the samples forming the composite are drawn.

Samples taken prior to waste application from the disposal area or from a control area where no waste has been applied should be used to establish baseline date for comparison. Soil characteristics for the control should be similar to those in the disposal area. Samples should be air dried (at temperatures less than 40^{o}C), ground, and passed through a 2-mm sieve as soon as possible after collection. Chemical analysis is generally performed on the air-dry samples, and the concentration is expressed on an oven-dry (110^{o}C) basis (191). However, some analyses such as Cr and nitrogen should be refrigerated and analyzed as soon as possible.

Soil Analyses

The physical properties of the soil are seldom evaluated in the monitoring program at most land cultivation sites once the field operation has been implemented. This is based on the assumption that these properties will not be adversely affected if proper site management practices are followed.

The primary objective of soil analysis is to monitor the accumulation as well as the vertical and horizontal movement of potential contaminants applied in the waste. A list of the parameters to be monitored prior to and following waste application is presented in Table 24. Such factors as soil pH, CEC, organic matter content, and soluble salts (EC), which affect the migration of contaminants are also included. Monitoring of soluble salts is also important when the site is planted to grasses or agronomic crops. A generalized index of crop sensitivity to soil salinity is presented in Table 25.

Field measurements of aeration status (oxygen tension and oxidation-reduction potential or Eh) are useful in deciding if favorable conditions exist for aerobic decomposition of the waste applied. However, these measurements are not included in site monitoring since collection of reliable data from field installations is difficult. Based on the chemistry of waterlogged soils, the aeration status can be predicted by various chemical species present in wet soil. Poor aeration is indicated by disappearance of NO_3^--N and the accumulation of NH_4^+-N, Fe^{2+}, and Mn^{2+}. Odorous gases such as CH_4 and H_2S also indicate extremely reduced conditions.

Generally, total analysis of the constituents of concern by extraction with concentrated acids is sufficient to determine the extent of movement in soil. As yet, no standard extraction procedures have been established to measure total concentration of various elements or constituents in soils treated with waste

TABLE 24. PARAMETERS TO BE MONITORED IN SOIL PRIOR TO AND AFTER WASTE APPLICATION

Parameter	Prior to Application	After Application
pH	Yes	Yes
CEC	Yes	---
Organic matter	Yes	Yes
Soluble salts (TDS or EC)	Yes	Yes
Total N	Yes*	Yes*
NO_3^--N	Yes	Yes
NH_4^+-N	Yes	Yes
Water-soluble or acid extractable ortho-P	Yes†	Yes†
Water-soluble Ca, Mg, Na, K	Yes	Yes#
Heavy metals (Zn, Cu, Pb, Cd, Ni)	Yes	Yes
B, Se, Mo, Hg, As, Cr	---	If suspected to be high in waste
Pesticides	---	If suspected present
Toxic, carcinogenic compounds	---	If suspected present
Pathogens	---	If suspected present

*If total N is low, omit inorganic N.
†If total P in waste is low, omit soil P.
#If EC or Na content in the waste is high, determine sodium adsorption ratio (SAR).

products. In soil analysis, various forms of metals have been proposed by use of different extractants (191). These include: 1) DTPA, 2) water-soluble or dilute acid-soluble, 3) NH_4OAc (exchangeable), and 4) easily reducible (189, 191). The concentrations present in these forms are used to establish the availability or potential for plant uptake and migration.

TABLE 25. RESPONSE OF CROPS GROWN IN SOILS OF VARYING SALINITY LEVELS*

Salinity, EC	Crop Responses
mmhos/cm at 25°C	
0-2	Salinity effects mostly negligible.
2-4	Yields of very sensitive crops may be restricted (most fruit crops, radish, green beans).
4-8	Yields of many crops restricted.
8-16	Only tolerant crops yield satisfactorily (e.g., spinach, barley, cotton, sugar beets, most forage crops).
>16	Only a few very tolerant crops yield satisfactorily (e.g., saltgrass, alkali sacaton, Bermuda grass).

*Adapted from Richards (192).

GROUNDWATER MONITORING

A major concern of land disposal of wastes is the possible contamination of groundwater (193). This is a significant concern for landfills, but is of lesser concern for land cultivation. This concern is due to the elusive nature and the long duration of groundwater contamination. In addition, it may take decades or centuries and large financial expenditures to remedy the damages. Groundwater monitoring is, therefore, widely practiced by site operators.

Monitoring Wells

Monitoring wells must be designed and located to meet the specific geologic and hydrologic conditions at the site. Consideration must be given to the following (194):

- Geological soil and rock formations existing at the specific site

- Depth to an impervious layer
- Direction of groundwater flow and anticipated rate of movement
- Depth of seasonal high water table and an indication of seasonal variations in groundwater depth and direction of movement
- Nature, extent, and consequences of mounding of groundwater, which can be anticipated to occur above the naturally occurring water table
- Potable and nonpotable water supply wells
- Other data as appropriate to the specific system design.

It may be necessary to establish baseline site groundwater conditions through installation of simple observation wells prior to the actual selection of locations and depths for permanent monitoring wells. No "rules of thumb" exist to determine the degree of monitoring intensity. Therefore, the best procedure to determine the number of wells to be installed is to develop a joint agreement with the responsible regulatory agency after a complete review of the site geology has been made.

Various aspects of geologic evaluations, layout of monitoring wells, well design, installation, and groundwater sampling have been discussed by Diefendorf and Ausburn (195).

Groundwater quality should be monitored immediately below the water table surface near the application site, as polluted materials entering the groundwater system may remain in the upper few feet of the water table (195). With increased distance from the site, the depth of sample withdrawal from within the groundwater system may need to be increased, or sampling at multiple depths may be required to assure interception of the potentially affected groundwater. The need for sampling at more than one depth will depend upon geologic conditions and distance from the source of pollution. Definition of the flow system with depth will be necessary to properly determine the depth to be monitored, especially when mounding is superimposed on the existing system.

Groundwater monitoring wells must be located to detect any influence of waste application on the groundwater resource. A minimum of one groundwater monitoring well must be provided in each direction of groundwater movement near the source of pollution, with adequate consideration given to possible changes in groundwater flow due to mounding effects. The orientation and spacing of multiple wells should be determined by hydrogeologic conditions at the site. All monitoring wells should be securely capped and locked when not in use, to avoid contamination.

Water level measurements should be made with reference to a permanent reference point, using U.S. Geological Survey data. Measurements should be made under static water level conditions prior to any pumping for sample collection.

Sample Collection--

To establish a suitable data base for reference to background conditions, under normal climatic conditions, one composite sample should be collected monthly from each monitoring well. In certain cases, background water quality adjacent to the site may be influenced by prior waste applications. In these cases, water quality should be analyzed by new monitoring wells or by existing wells in the same aquifer beyond the area of influence.

Blakeslee (194) recommended that samples be collected monthly during the first 2 yr of operation. After the accumulation of at least 2 yr of groundwater monitoring information, sampling frequency may be modified. He also recommended the following sampling procedures:

- A measured amount of water equal to or greater than three times the amount of water in the well and/or gravel pack should be exhausted from the well before sample collection. In the case of very low permeability soils, the well may have to be exhausted and allowed to refill before a sample is collected.

- Pumping equipment should be thoroughly rinsed before use in each monitoring well.

- Water pumped from each monitoring well should be discharged to the ground surface away from the wells to avoid recycling of flow in high permeability soil areas.

- Samples must be collected, stored, and transported to the laboratory in a manner to avoid contamination or interference with subsequent analyses.

Sample Analysis--

Preservation of samples without some change in the chemical and biological activity is almost impossible. Consequently, analyses should be completed as soon as possible after the sample is obtained. To keep changes in the sample to a minimum during storage, the guidelines by the U.S. EPA (196) or the American Public Health Association (197) should be followed. It is important to note that a single method of preserving samples is not adequate for all analyses.

Water samples collected for background water quality at a land cultivation site should be analyzed for the following:

- Chloride
- Soluble salts (electrical conductivity or total dissolved solids)
- pH
- Total hardness (if used as drinking water)
- Alkalinity (if used as drinking water)
- Nitrate nitrogen (if waste is high in total nitrogen)
- Any trace elements, pathogens, or toxic substances found in the applied wastes at elevated concentrations.

After adequate background water quality and initial site operation information has been obtained, a minimum of two composite samples per year, obtained between waste applications, should be collected from each well and analyzed for the above constituents. It is recommended that all water samples should be analyzed for easily leached chloride (or nitrate) and electrical conductivity (EC) as indicators of changes in groundwater quality resulting from the waste applied. If significant changes are noted in chloride and EC levels, samples should immediately be analyzed for other parameters to determine the extent of water quality deviation from background levels. Meanwhile, waste application should be halted until the source of buildup is identified.

RUNOFF MONITORING

Runoff is usually controlled at a land cultivation site by disking frequently, contouring to the slope of the land, and providing dikes at the low points of the site to pond the water. However, if runoff occurs often and in appreciable amounts, monitoring facilities must be provided to obtain representative water samples and corresponding flow measurements for quantitative evaluation. Sampling should be done throughout the entire period when runoff is occurring.

The sediment and water fractions of runoff samples should be analyzed for nitrogen, phosphorus, and any heavy metals, pathogens, or toxic substances that are present in significant concentrations in the applied waste. Total loss of any constituent analyzed can be computed using the following equation (198):

$$RL = \sum_{i=1}^{n} (R_i \times C_i) \times K$$

where RL is the total runoff loss (g/ha);

R_i is the volume (m^3) of runoff for any segment i of the storm and is positively related to rainfall;

C_i is the concentration (mg/l) of the constituent measured in each runoff segment;

n is the number of segments; and

K is a constant (ha^{-1}) for the land cultivation site, with size in ha

A typical example is given below:

During the month of July, runoff occurred 3 times at a 5-ha land cultivation site, and the following information was collected:

$R_1 = 1{,}000\ m^3$ $\quad R_2 = 1{,}500\ m^3$ $\quad R_3 = 500\ m^3$

$C_1 = 3.0$ mg/l $\quad C_2 = 2.0$ mg/l $\quad C_3 = 1.5$ mg/l

Where C_1, C_2, and C_3 are nitrate-N concentrations in samples collected from 85 to 90 percent of the 3 total runoffs with volumes R_1, R_2, and R_3, respectively.

Total nitrate-N losses in the runoff can be computed as follows:

$$NO_3^--N = (R_1.C_1 + R_2C_2 + R_3.C_3)\ K$$
$$= (10^3 \times 3.0 + 1.5 \times 10^3 \times 1.5) \div 5$$
$$= 1{,}350 \text{ g/ha}$$
$$= 1.35 \text{ kg/ha.}$$

VEGETATION MONITORING

The vegetation produced on the land cultivation site may be the most sensitive and meaningful indicator of the impact of waste applied to the site. Monitoring during the growing season would signal an accumulation of heavy metals or other toxic constituents in soil (199). The warning provided by timely monitoring would enable the operator to introduce corrective measures or, if necessary, to discontinue waste application.

The purpose of vegetation monitoring can be one or all of the following, depending on waste management practice and the vegetation present:

- Determine the nutrient or metal removal capability of the vegetation.

- Determine if certain nutrients or metals have reached phytotoxic concentration and if the harvested portions are suitable for consumption by animals or humans.

- Ascertain the quantity of nutrients or metals leaving the field in harvested portions of crops, or being left on the field as unharvested plant residue.

If and when agricultural monitoring is necessary, plants can be regarded as an appropriate indicator of harmful levels for certain but not all constituents. Plants may not give accurate information on carcinogens, viruses, and other pathogens, all of which may affect human health but would possibly have little effect on plant nutrition. Periodic analysis of the harvested portions of plants will, in most instances, indicate the rate and increase of metal availability to the plants; it will also signal the approach of harmful levels well in advance of permanent damage to either soil or crop. Interpretations of such an analysis must recognize normal seasonal differences in plant composition and possible sampling errors. As further toxicological information is obtained, the plant analysis can be interpreted with increasing precision in terms of potential toxicity of the plants to animals and humans.

Jones and Steyn (200) have discussed the specific portion of the plant and the number of plants to be sampled at certain stages of growth for plant nutrition studies. In general, mature leaves which are found just below the growing tip on main branches and stems are usually preferred for sampling. Sampling is normally recommended just prior to or at the time the plants begin their reproductive stage of growth. A plant portion that is soil or dust covered, damaged by insects, mechanically injured, or diseased should not be sampled. Collection of root samples which do not have a contamination problem is extremely difficult and is not warranted, except for a few root crops. In monitoring for a land cultivation site, plant accumulation of the concerned elements or toxic constituents is of greater significance than the plant nutrient status. As a result, the harvested or edible portions are generally analyzed to determine the suitability of the vegetation for consumption.

Plant analyses have three limitations where monitoring of heavy metals and other toxic constituents is concerned. First, although the analyses indicate the approach of a hazardous level for the crop analyzed, the level attained may already be toxic to more sensitive crops. Second, analyses of tops and roots are generally required to adequately diagnose all toxicities. (Note that collection of uncontaminated roots is extremely difficult.) Third, plant analyses usually cannot be used to indicate the level of soil nitrogen that may lead to groundwater contamination.

The plant processing procedure typically includes (190, 200): 1) washing the tissues in a 0.1- to 0.3-percent detergent solution followed by rinsing them thoroughly in de-ionized water; 2) drying in a forced-draft oven at 65°C for several days; 3) grinding by hand or in mills; and 4) storing in sealed polyethylene bags, preferably under refrigeration. Total elemental analyses on plants rather than selective extraction procedures are conducted. If trace elements are assayed, the washing solutions, sample processing equipment, and reagents used must be checked periodically for contamination problems.

AIR MONITORING

The air quality of most land cultivation sites is seldom monitored, unless the waste contains putrescible material that is likely to create odor problems. Since wastes containing highly toxic substances in gaseous or dust form are not suitable for land cultivation, and wastes that are land cultivated are either mixed with soil material or subsurface injected, air monitoring may not be mandatory at existing land cultivation sites.

In summary, it is recognized that land cultivation sites must be monitored to adequately protect the environment. The constituents or contaminants to be analyzed in a monitoring program are highly waste specific. The waste material applied at a site is like the raw material in a manufacturing process: to be assured of an acceptable "product," the raw material must be of known and "acceptable" quality. This requires periodic monitoring of the waste.

For visited sites with a monitoring program, groundwater receives a great deal more attention than soil, crop, or air emission. This is because groundwater monitoring is mandated by regulatory agencies for operating a land cultivation site. Monitoring of heavy metal buildup in soil or of crop quality is practiced at a few sites, while monitoring of air quality is usually not practiced. As a result, very little is known about the air quality at and around the land cultivation sites.

The problems of adequate well placements, sample collection procedures, and data interpretation seriously hamper the effectiveness of groundwater monitoring. In monitoring a land cultivation site, more emphasis should be placed on the collection and analyses of soil samples taken at incremental depths.

SECTION 13

SITE CONCEPTUAL DESIGN

The site conceptual design presented below is a synthesis of the data obtained from six case study site investigations an(related background information. The conceptual design is intended to be used as a planning tool and information vehicle for persons concerned with consideration of land cultivation as a disposal alternative. It is not intended to provide all information necessary to totally design and manage a land cultivation facility.

There is no one "typical" land cultivation facility. Therefore, a hypothetical example site is used as a basis for the conceptual design. Pertinent characteristics of the example site are described so that users of the conceptual design can identify differences between the example site and corresponding characteristics of their actual site. This enables the user to adjust the technical and economic factors in the conceptual design to reflect his site-specific conditions.

BASIS FOR DESIGN

For the conceptual design presented, the basic management objective is assumed to be the application of waste materials to the soil so that the soil can assimilate the wastes and to contain the wastes and potentially harmful by-products on the site.

It is assumed that the site is operated commercially, and not by the waste producer. Wastes from more than one source can be expected. It is important that the chemical composition of all input waste streams be analyzed and evaluated to ensure that they may be safely mixed, both in storage lagoons and in the soi An additional assumption is that transport of sludge to the site is not part of site costs; rather, it is an expense item borne by the waste generator. As is generally the case, the state in which the hypothetical disposal site is located does not have specific regulations pertaining to land cultivation disposal. Application of industrial waste to the site is evaluated by the appropriate state agency on a case-by-case basis. State agencies generally prefer land cultivation sites to have a maximum slope of 5 percent. The minimum desirable depth to groundwater is typically considered to be 4.6 m (15 ft), although this criterion may be modified depending on the quality and uses of groundwater and the types of overlying soils. It is also preferred that the soils be deep - greater than 1.2 m (4 ft) - and moderately permeable.

Waste and site characteristics assumed for the conceptual design are summarized in Table 26. The developed design is based on land cultivation of a potentially hazardous organic waste (201). The waste is a sludge resulting from treatment of industrial wastewater. To provide cost comparisons for different rates of land cultivation disposal, the conceptual design considers three annual disposal rates: 1,000, 2,000, and 4,000 dry t (1,100, 2,200, and 4,400 tons).

A sketch of the hypothetical land cultivation site is shown in Figure 25. The topography of the site is such that slopes range from 1 to 3 percent, with an average slope of approximately 2 percent. The site is part of an open drainage system, which is typical of most humid and sub-humid regions. As a result, the movement of sediments and soluble materials from the site to neighboring water courses is possible. However, the site can be modified to control runoff.

Soils at the hypothetical site are medium textured, such as silt loam, with a clay content ranging from 10 to 25 percent, varying with depth. The soils are moderately well drained and have an available moisture holding capacity of approximately 15 percent. The site is assumed to have been cleared and used for pasture for several years.

Land area required depends on the waste application rate. Waste application rates normally must be determined on a case-by-case basis, depending primarily on the soil type, waste decomposition rate, and the concentration of degradable and non-degradable toxic constituents. The assumed waste characteristics are such that an application rate of 113 dry t/ha (50 dry tons/ac) is appropriate for a useful site life of 20 yr. At this application rate, the productivity of the site for agricultural crops after 20 yr of land cultivation may not be irreversibly impaired. It is preferable, however, that the site be used solely for disposal purposes; no crop is grown during or after completion of disposal operations to prevent introduction of toxic substances into the food chain.

A surface and groundwater monitoring program is a necessary part of any land cultivation design. To adequately monitor surface water near or adjacent to the site, two samples should be taken at quarterly intervals. One sample point should be located upstream from the site and the other downstream.

The number of wells required to adequately monitor groundwater at the site depends on the complexity of the subsurface hydrology. For this hypothetical site, four wells are specified. Two wells are located at the upstream boundary of the site to

TABLE 26. BASIS FOR DESIGN

Waste characteristics:

- Potentially hazardous industrial wastewater treatment sludge.
- Five percent solids as disposed.
- Does not include domestic sewage.
- Generation rates of 1,000, 2,000, and 4,000 dry t (1,100, 2,200, and 4,400 tons) per year at 5 percent solids.

Site characteristics:

- Scope from 1 to 3 percent, averaging 2 percent.
- Silty loam soil at least 1.2 m (4 ft) deep.
- Soils are moderately well drained, with a moisture holding capacity of approximately 15 percent.
- Average precipitation of approximately 100 cm (40 in) per year.
- At least 4.5 m (15 ft) to groundwater.

Application rate:

- 113 dry t/ha (50 tons/ac) per year.

Site monitoring:

- Six water samples taken quarterly
    - Two surface water samples
    - Four groundwater samples
- Two soil samples taken quarterly
    - One surface 0 to 30 cm (0 to 12 in) depth or within plow layer.
    - One subsurface 30 to 60 cm (12 to 24 in) depth.
- Ten water quality parameters measured in each sample.

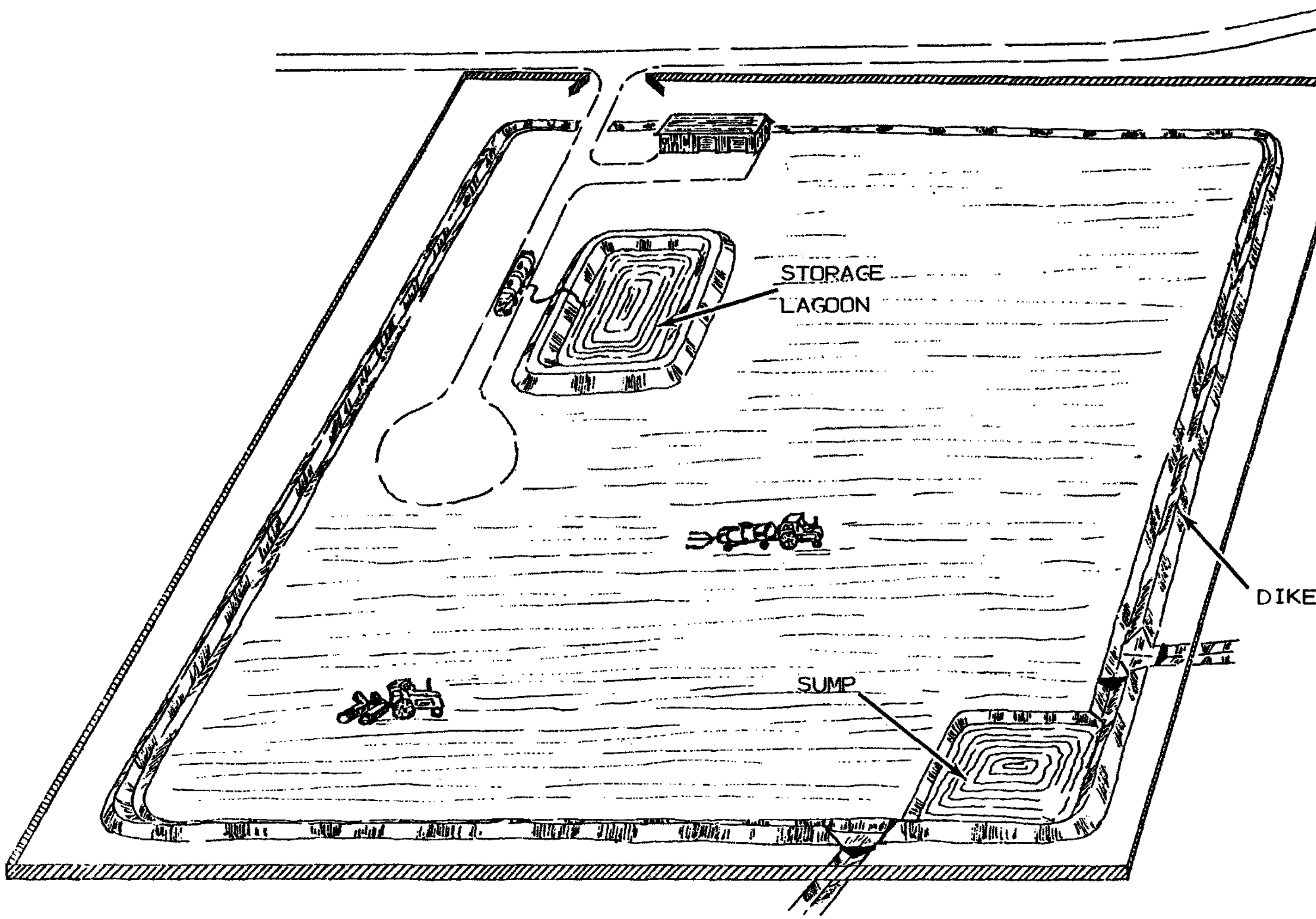


Figure 25. Artist's conception of land cultivation site.

establish background water quality. Two wells are located downstream from the site to establish the distribution and impact of localized contamination (if any) on water quality in the aquifer. More wells would be desirable, but cost considerations will usually indicate that a plan be developed to ensure most effective coverage with the least number of wells.

The suggested soil monitoring program entails taking 10 soil samples each at the 0 to 30 cm (0 to 12 in) and 30 to 60 cm (12 to 24 in) depths prior to the first waste application and at quarterly intervals thereafter. The samples at each depth are composited, processed, and analyzed. Data obtained for the soils which have received waste can be compared with the results for the controls (samples obtained prior to first waste application). This comparison will indicate any accumulation and the extent of vertical migration of waste constituents (e.g., heavy metals) beyond the plow layer.

The specific analytical requirements of the water monitoring program depend on the composition of the waste being disposed. It is recommended that the following parameters be monitored for all waste types:

- Total dissolved solids (TDS) or soluble salts (EC)
- TOC
- pH
- Sulfates
- Chlorides
- Nitrate-nitrogen
- Iron.

Other parameters of concern such as sodium, boron, selenium, molybdenum, heavy metals, and toxic organic compounds should be included in the water and soil monitoring programs if these elements are present in significant concentrations in the incoming waste. All analytical determinations can be performed by a contract laboratory.

Quarterly water sampling should be adequate for monitoring site performance. Such a sampling frequently has been typically employed by numerous land cultivation site operators and state regulatory agencies.

SITE DESIGN

Since the site's topography is gently sloping and relatively flat, substantial grading is not required to facilitate land cultivation operations. The site has been used previously for pasture, so substantial clearing is unnecessary. Uncontrolled sheet runoff from the site's surface during periods of intensive rainfall could result in contamination of adjacent surface waters.

For this reason, construction of a system of berms and runoff collection ditches around the site perimeter prior to initiating land cultivation activities is specified. These ditches will divert the first 2.5 cm (1 in) of runoff to a containment basin for later application to the site during dry weather. This surface drainage system will eliminate standing water in the cultivated area, thereby ensuring that aerobic processes necessary for waste decomposition are maintained. Additional runoff (after the first 2.5 cm) will be diverted through a coarse gravel filter for sediment control before discharge to surface waters, if analyses indicate the quality of the discharge meets appropriate regulations.

Liming the soil to a pH range between 6.5 and 7.5 is necessary if the soil is strongly acid. Nitrogen fertilizer should be applied if the waste is highly carbonaceous (carbon and nitrogen ratio >30) to speed waste decomposition.

An access control fence is placed outside the disposal area's ditch/berm and within 30 m (100 ft) of the site perimeter. A 9-m (30-ft) gate is located where the access road enters the site.

The site includes a paved access road to a sludge storage lagoon and an office/equipment storage building. The building is prefabricated aluminum on a cement slab, with plumbing and utility connections. The 3 x 6 m (10 x 20 ft) office area is insulated and furnished for the attendant and includes restroom facilities. The remainder of this structure garages the cultivation equipment and is closed to the weather on three sides.

The conceptual design includes a lagoon for the interim storage of sludge. Sludge delivery vehicles discharge into the lagoon, from which waste is taken by site equipment for subsequent cultivation, to keep delivery trucks off unpaved areas of the site.

The storage lagoon has an installed liner (clay or membrane) and is constructed at the same time as the ditch/berm and runoff containment pond. Lagoon storage volume ensures that the orderly cultivation of sludge need not depend on its time of arrival at the site. Moreover, it is assumed that inclement weather conditions prevent land cultivation during approximately 3 months of the year. Thus, the waste storage facilities should be of sufficient capacity to contain 4 mo volume of incoming sludge and have an additional foot of freeboard. This capacity not only provides storage for three winter months, but also allows for a 1-mo-long wet period in the spring, when cultivation activities are difficult or impossible.

Table 27 shows the cultivation areas and lagoon sizes required for each of the three assumed amounts of delivered sludge. Site area requirements are determined by dividing the waste application rate by the waste generation rate; adding the area required for the access road, perimeter berm, buildings, waste storage, and runoff control facilities; and adding a 30-m (100-ft) buffer on all sides.

Figure 26 presents a representative profile of the site, indicating several of the key features previously discussed.

TABLE 27. CONCEPTUAL DESIGN WASTE AND SITE PARAMETERS

Factor	Waste Quantity (dry t/yr) 1,000	2,000	4,000
Wet weight (metric tons) volume (5% solids by weight)	20,000	40,000	80,000
Total volume, m^3	20,000	40,000	80,000
Total volume, 10^6 gal ($267.16\ gal/m^3$)	5.3	10.7	21.4
Land area required (ha) (0.405 ha/ac/yr):			
• Waste spreading only	8.8	17.7	35.4
• Total (includes roads, berms, etc.)	14.2	25.5	46.2
Land area required (acres) (9 ac-in/ac/yr):			
• For waste spreading only (36.83 ac-in/10^6 gal)	21.9	43.7	87.4
• Total (including area for road, building, lagoon, berms, and 100 to 150 ft buffer zone)	35	63	114
Storage lagoon volume (sized to provide sufficient storage for 4 mo/yr):			
• In m^3	6,667	13,333	26,667
• In 10^6 gal	1.781	3.562	7.124

WASTE APPLICATION PROCEDURES

The waste to be cultivated is stored and later applied (spread) on land at an assumed concentration of 5 percent solids. Sludge spreading is accomplished using a pressurized 9.7-m^3 (2,600-gal) tank wagon equipped with a power take-off (PTO) attachment to the same tractor used for subsequent cultivation. The PTO unit is used to pump sludge from lagoon to tank wagon

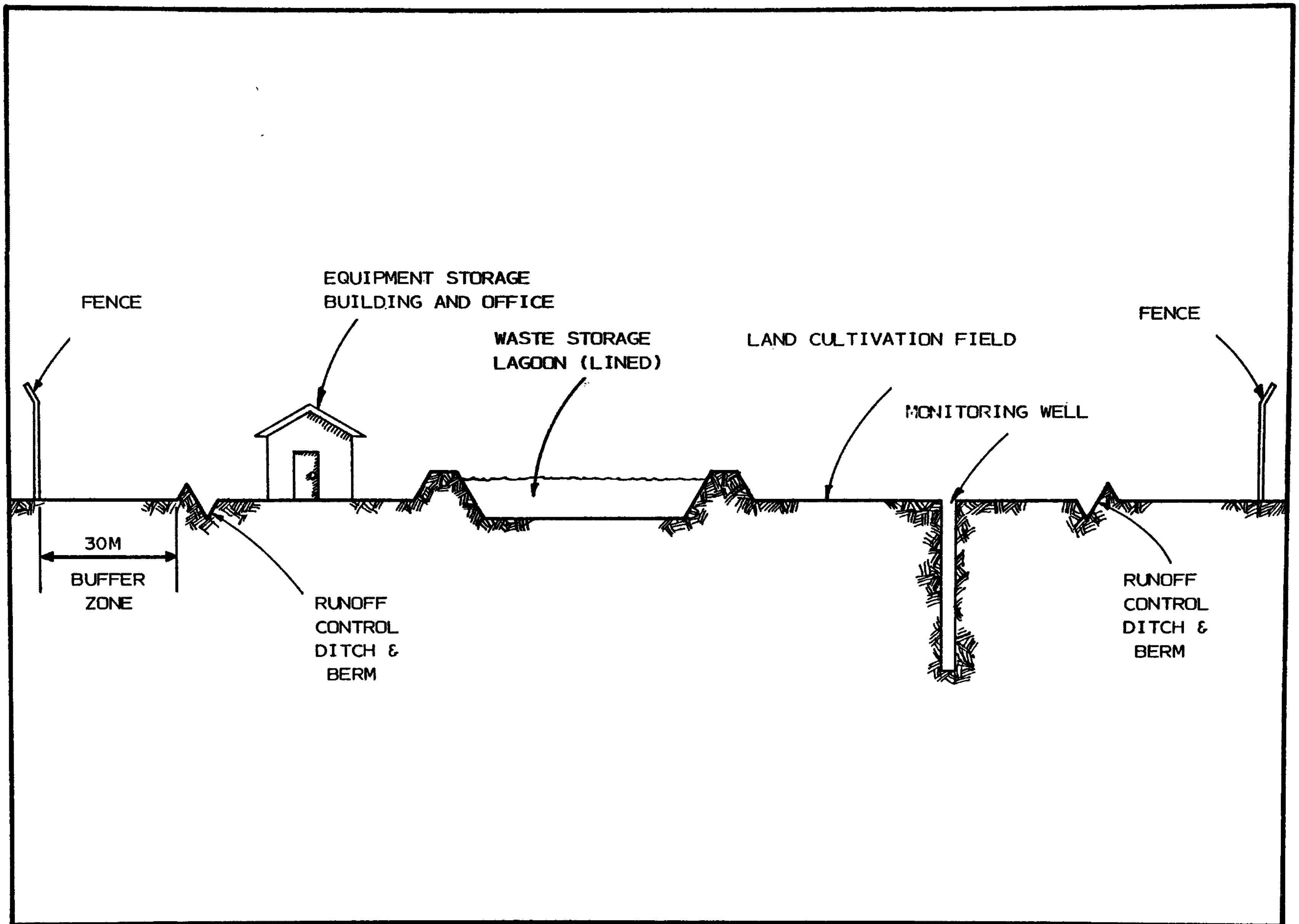


Figure 26. Representative site profile.

via an induced vacuum. The same equipment can be used to remove standing water from the runoff containment basin during periods of low spreading activity.

Waste is spread monthly (9/mo/yr) over the entire disposal area. Each application consists of 1 cm-ha (1 ac-in) of liquid waste or, in terms of dry weight, 12.5 t/ha (5 tons/ac). When spreading, the tank wagon and tractor are assumed to cover a 2.4-m (8-ft) strip at an average speed of 0.8 kmph (0.5 mph) (approximately 5.2 hr/ha or 2.1 hr/ac). Time to refill the 9.7-m^3 (2,600-gal) tank wagon, including round-trip travel time to the storage lagoon, is approximately 10, 12, or 14 min, depending on the site size.

Waste delivered to the disposal site is sampled (analysis cost borne by generator), and unloaded into the storage lagoon. Site personnel record arriving deliveries when they return to the lagoon for tank wagon refill. An average of 10 min is estimated for recording each delivery. It is assumed that the smallest site receives an average of five deliveries per day, each delivery containing an average volume of 15.7 m^3 (4,200 gal).

During winter when no cultivation is in progress, the site will be open and accepting deliveries only 4 hr/day. Thus, only one part-time employee will be required during the three inactive winter months, primarily to receive incoming waste deliveries. This employee may also perform minor site or equipment maintenance.

Following waste application, the soil-waste mixture is allowed to dry for a few days prior to cultivation. One wk or more may be required for sufficient drying in humid climates or during the rainy periods in all climates. The soil is then cultivated to a depth of 20 cm (8 in) by means of a disk unit 3 m (10 ft) wide, pulled by the tractor at an average speed of 10 kmph (6 mph), or approximately 3 ha/hr (7.3 ac/hr). Disking is performed after each application of waste and at the beginning and the end of the cultivation season.

The monitoring program requires that samples be taken quarterly of surface water, groundwater, and soil. These samples are delivered to a state-certified laboratory for analysis. This activity is expected to require a maximum of 16 man-hours or 2 man-days each quarter.

Table 28 summarizes labor requirements for each of the three assumed operation sizes, based on the number of man-hours of activity which must be completed during the 9-mo cultivation season.

TABLE 28. LABOR REQUIREMENTS FOR CONCEPTUAL LAND CULTIVATION SITE

Factor	Waste Quantity (dry t/yr) 1,000	2,000	4,000
Spread time (2.4 m width at 0.8 kmph) (5.2 hr/ha) (hr/yr)	405	810	1,620
Refill loads/yr (9.7 m^3 tank)	2,055	4,110	8,220
Refill time (round trip minutes + tank fill) (min)	10	12	14
Refill time (hr/yr)	342.5	822	1,918
Disk time (3 m width @ 10 kmph) (3 ha/hr) (11 diskings/yr) (min)	33	66	132
Winter part-time (4 hr/day) (3 mo/yr) (hr/yr)	260	260	260
Number of deliveries/day (4,200 gal or 15.7 m^3/delivery) (av)	5	10	20
Non-winter delivery time (@ 10 min/delivery) (hr)	162.5	325	650
Sampling time (16 hr/quarter) (hr/yr)	64	64	64
Subtotal hours	1,267	2,347	4,644
Non-productive time (downtime, breaks, etc. @ 15% of subtotal) (hr/yr)	197	349	692
Total labor hours/year	1,464	2,696	5,336
Total labor days/year	183	337	667
Total personnel required	0.7	1.3	2.6

The following tabulation shows equipment requirements for each site size:

Equipment Type	Waste Quantity (dry t/yr) 1,000	2,000	4,000
Tractor, 105 PTO	1	2	3
Tank wagon, 9.7 m^3	1	2	3
Disk, 3 tiers, 3 m x 40 cm	1	1	1

ESTIMATED COSTS FOR CONCEPTUAL LAND CULTIVATION SITE

Both capital and operating and maintenance costs are estimated.

Capital Costs

Capital costs associated with land cultivation are presented in Table 29. The recovery period ("useful life" or "payback" period) varies according to the type of investment. All capital costs have been annualized based on a 10 percent interest rate (or internal rate of return) over their recovery period. Major capital cost categories are land, site preparation and construction, public acceptance programs and site closure costs, and equipment.

The estimated unit cost for land at $8,640/hr ($3,500/ac) is based on the assumption that the conceptual site is at the fringe of an industrialized urban center, to assure a market for its services.

Site preparation and construction cost estimates include design and survey costs, as well as profit and contingencies for the contractor. The storage lagoon is lined with a synthetic liner having an estimated 20-yr lifespan and an installed cost of $\$4/m^2$ ($\$3/yd^2$). The on-site building was previously described. Additional space is provided at the larger sites to accommodate additional equipment. Eighteen meter (60 ft) deep groundwater monitoring wells are located at each corner of the site.

The budget for obtaining regulatory agency approval for land cultivation operations includes the usual costs for state and local permits and a public education fund to encourage citizen understanding of the site's needs and goals. Costs for any litigation or unusually long time delays are not included, although the possibility of incurring such costs should be recognized. Litigation costs for establishing sanitary landfills may exceed $50,000, with as much as a 2 year delay. Such landfill site location experience may not be directly applicable to establishing land cultivation sites, however.

Table 30 describes the procedures and assumptions used to estimate costs of site preparation and closure. Both the lagoon and containment basin are assumed to be square in plan. Earth excavated in constructing the storage lagoon is formed into a 3 to 1 berm with a 2.4 m (8 ft) wide level top, whereas the runoff containment basin is a simple 2 to 1 sloped excavation with the excavated earth used to enhance the ditch/berm around the perimeter of the disposal site. The containment basin shown in Figure 27 is assumed to be located on the low corner of the site. It is 0.3 m (1 ft) wide, with 1 percent sloped runoff collection ditches emptying into it. Table 31 shows general dimensions for the storage lagoon and runoff containment basin.

TABLE 29. CAPITAL COSTS FOR CONCEPTUAL LAND CULTIVATION SITES*

Cost Element†	Recovery Period (yr)	Waste Quantity (dry t/yr) 1,000 Total	1,000 Annual	2,000 Total	2,000 Annual	4,000 Total	4,000 Annual
Urban fringe land @ $8,640/ha: 14, 26 and 46 ha, respectively	30	$122,500	$13,000	$220,500	$23,390	$399,000	$42,330
Site Preparation:							
Grading, berms, storage lagoon (lined)	20	72,120	8,470	90,020	10,020	194,840	22,890
Access Road	20	2,500	120	2,500	120	2,500	120
Fence and gate: 1.5 m within 26 m of perimeter, 4 strand barbed wire (on top of berm)	20	5,530	650	6,490	760	8,400	990
Building: office, restroom, equipment							
Storage facility (with $32/m^2$ utilities, $10.8/m^2$ fixtures and furniture) 6 x 3 m + 6 x 3, 6, 9 m	20	8,000	940	10,000	1,180	12,000	1,410
Monitoring Wells:							
4-18 cm wells: 18 m ea @ $26.25/m	20	1,920	230	1,920	230	1,920	30
Sampling pumps: 4 @ $50 ea	20	200	20	200	20	200	20
Property Tax and Insurance @ 1.5% of In-Place Capital Investments	--	--	3,190	--	4,970	--	9,280
Budget for Site Approval	20	5,000	590	5,000	590	5,000	590

(continued)

TABLE 29(continued)

Cost Element†	Recovery Period (yr)	Waste Quantity (dry t/yr) 1,000 Total	1,000 Annual	2,000 Total	2,000 Annual	4,000 Total	4,000 Annual
Site Closure Costs @ $\$2/m^3$	20	$11,020	$ 1,290	$19,360	$2,280	$23,170	$3,900
Cultivation Equipment:							
Tractor (105 P.T.O.) 1, 2, and 3 Units	10	18,000	2,930	36,000	5,860	54,000	8,790
Disk, 3 m x 41 cm, 3 tier	5	3,500	920	3,500	920	3,500	920
Tank wagon (9.73 m^3) 1, 2 and 3 units	5	9,500	2,510	19,000	5,010	28,500	7,520
Stationary Equipment: Lagoon Aerators	10	2,000	330	2,500	410	3,000	490
Total Capital Investment	--	$261,790	--	$414,990	--	$746,040	--
Annual Capital Costs	--	--	$35,190	--	$56,310	--	$99,460
Annual Capital Costs/Dry t	--	--	$ 35.19	--	$ 28.16	--	$ 24.86

* "Total" amounts are initial costs, "annual" amounts are for first 12 months of operation. All costs are in 1976 dollars.

† Annualized capital recovery (equal annual payments) at 10% interest rate.

TABLE 30. ESTIMATED COSTS FOR SITE PREPARATION AND CLOSURE*

Item	Waste Quantity (dry t/yr) 1,000	2,000	4,000
Lagoon earthwork (m^3)	$ 840	$ 1,740	$ 2,520
Lagoon earthwork cost @ $7.85/$m^3$	$ 6,560	$ 13,660	$ 19,730
Lagoon area (m^2)	5,350	8,360	12,040
Lagoon liner cost @ $3.60/$m^2$ installed	$ 19,200	$ 30,000	$ 43,200
Runoff collection ditches with berm (linear meters)	1,160	1,650	2,480
Collection ditch and berm @ $9.85/m	$ 11,370	$ 16,260	$ 24,360
Runoff containment basin (m^3)	4,460	7,670	13,710
Containment basin cost @ $7.85/$m^3$	$ 34,990	$ 60,190	$107,550
Total for lagoon and runoff containment	$ 72,120	$ 90,020	$194,840
Assumes ditch averages .3 m x .9 m			
Site closure earthwork (m^3)	5,620	9,870	16,910
Site closure costs @ $1.95/$m^3$	$ 11,020	$ 19,360	$ 33,170

* All costs are in 1976 dollars.

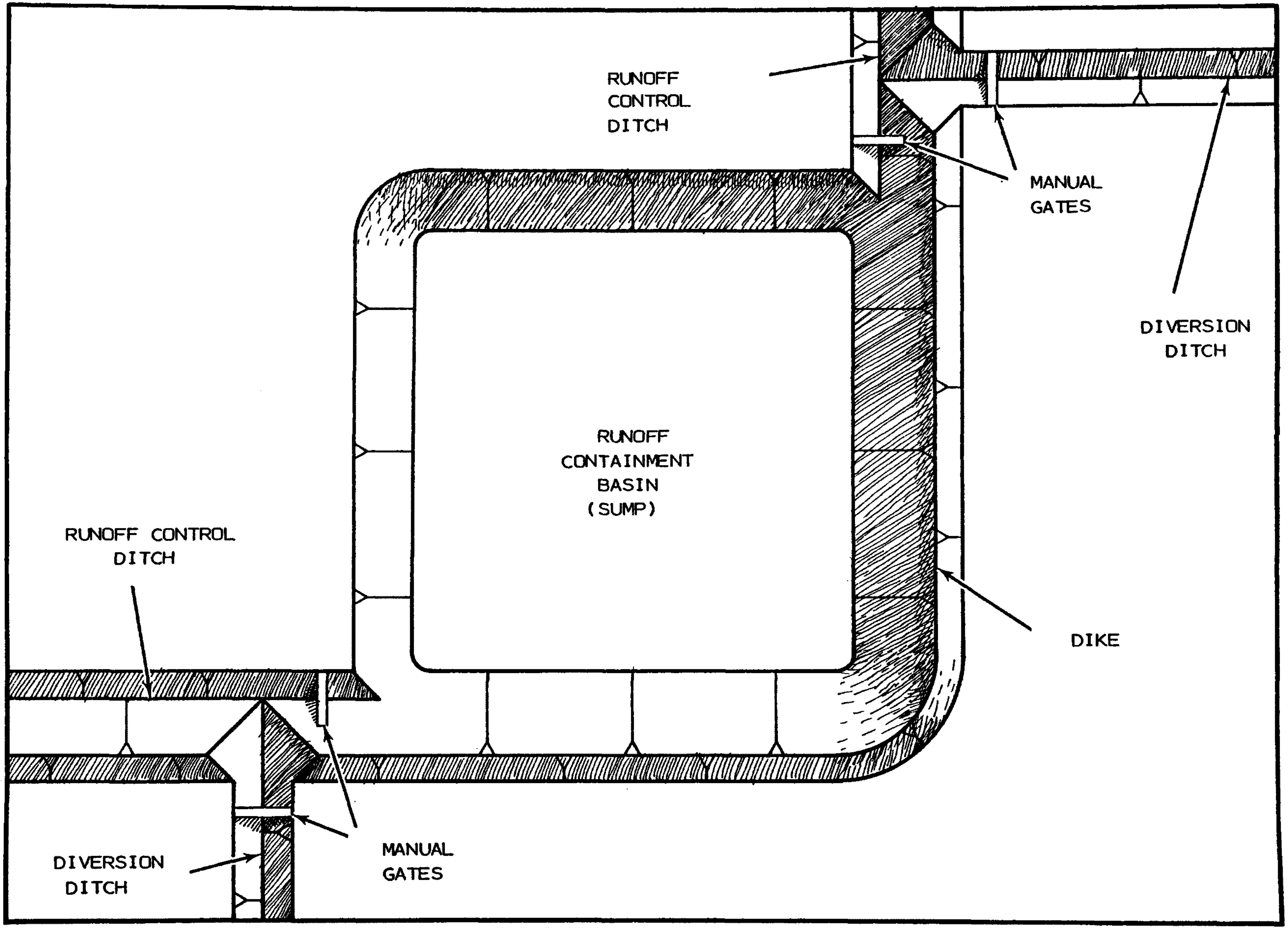


Figure 27 . Runoff containment basin.

TABLE 31. STORAGE LAGOON AND RUNOFF BASIN DIMENSIONS

	Waste Quantity (dry t/yr)		
	1,000	2,000	4,000
• Storage lagoon:			
Capacity (m^3)	6,670	13,330	26,670
Capacity (10^6 gal)	1.8	3.6	7.1
Length (m)	70	90	110
Length (ft)	238	300	360
Depth* (m)	2.1	2.7	3.86
Depth (ft)	7	9	11
Earthwork (m^3)	740	1,540	2,220
Earthwork (yd^3)	1,090	2,280	3,290
• Runoff containment basin:			
Capacity (m^3)	2,540	4,980	9,550
Capacity (10^6 gal)	0.7	1.3	2.6
Length (m)	50	60	70
Length (ft)	170	200	240
Depth* (m)	1.8	2.4	3
Depth (ft)	6	8	10
Earthwork (m^3)	4,460	7,670	13,710
Earthwork (yd^3)	5,830	10,030	17,920

*Does not include freeboard.

Operation and Maintenance Costs

In addition to capital-related annual costs, annual costs of site operation include those for labor, fuel and equipment maintenance, utilities, site maintenance and security, and monitoring, including sample analyses. Table 32 shows the basis of estimated labor costs and presents the additional data for determining operating and total annual costs.

Land cultivation is a land-intensive activity, often requiring considerable site preparation. Thus, Table 32 shows that capital costs constitute the largest portion of the total annual costs for this conceptual design.

TABLE 32. ANNUAL CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR LAND CULTIVATION*

Cost Element	Waste Quantity (dry t/yr) 1,000	2,000	4,000
Operating Costs:			
Labor @ $8/hr including fringes	$ 11,710	$ 21,570	$ 42,680
Equipment fuel and maintenance @ $10/man hr to spread, refill, and disk	7,800	1,700	3,670
Site utilities @ $100, 120, and 150/mo @ $2.96/ha/mo	500	900	1,630
Site security @ $10, 12, or 14/ night for patrol car drive-by	3,650	4,380	5,110
Sample analysis lab work (32 samples x 10 parameters ea @ $10/ parameter)	3,200	3,200	3,200
Annual Operating Costs	28,070	33,190	58,090
Annual Capital Costs	35,180	56,310	99,460
Subtotal	$ 63,250	$ 89,490	$ 157,550
Administrative Costs (15%)	9,490	13,420	23,630
Contingency Allowance (10%)	6,330	8,950	15,760
Total Annual Costs	$ 79,060	$111,870	$ 196,940
Annual Costs/dry t	$ 79.1	$ 55.9	$ 49.2

* Annual costs are for first 12 months of operations. All costs are in 1976 dollars.

All estimated costs for the conceptual designs are based on 1976 dollars. It is to be expected that those costs will rise in the future due to inflation, but no cost projections were made because of inflation rate uncertainty. For commercial sites, as presented here, disposal fees are structured to recover all costs and provide a reasonable profit. Therefore, cost increases resulting from inflation would be covered by the site operator through increased disposal fees.

As expected, the total unit costs shown at the bottom of Table 33 indicate that larger land cultivation sites are less costly to operate on a unit cost basis than are smaller sites. This situation is graphically depicted in Figure 28.

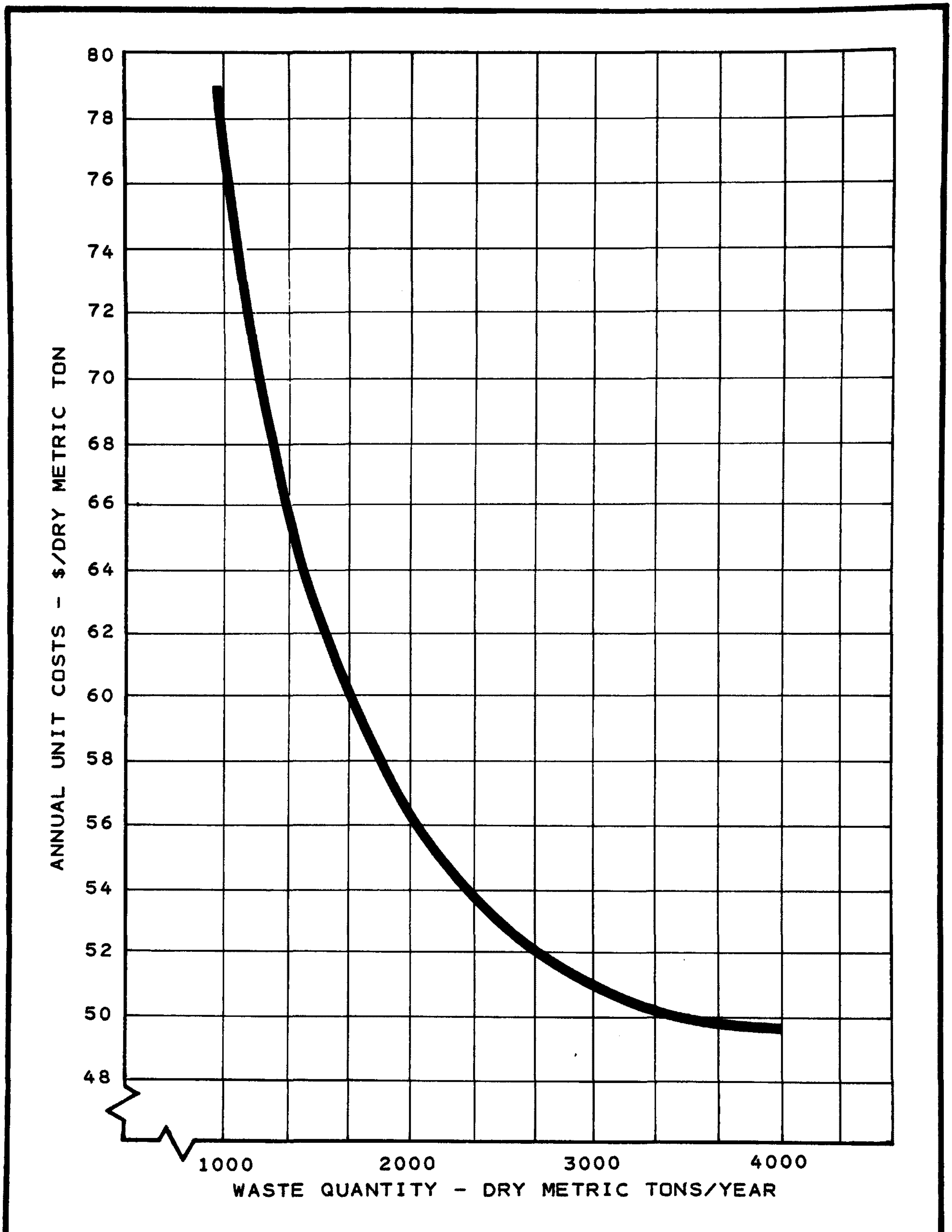


Figure 28 . Land cultivation annual unit costs.

SECTION 14

CASE STUDY SUMMARIES

Five case study sites were investigated in depth to provide technical and economic information on the disposal of industrial wastewater, sludge, and municipal refuse by land cultivation. In addition, less extensive information was obtained from a sixth site in Michigan.

The objective of each case study is to assemble and interpret available information on:

- History of land cultivation at the site
- Site characteristics
- Waste characteristics and application methods
- Costs
- Public acceptance problems encountered and solutions implemented.

Land cultivation sites were identified through contact with federal, state, and local officials responsible for regulation of wastewater and solid waste disposal, as well as private contractors who have been involved in land cultivation activities. Sites identified were contacted to fill information gaps and to determine the willingness of site owners/operators to participate in the project. Descriptions and discussions for each case study site are presented in Section 3 of Volume 2.

LAND CULTIVATION OPERATIONS

Relatively few land cultivation sites were located where a regular program of mixing waste and surface soils is practiced. Many examples of land application systems (e.g., spray irrigation) were identified. Land application systems other than land cultivation were not investigated in this study since these systems are outside the scope of this contract.

Table 33 shows that the case study sites investigated represent diverse geographical, climatological, waste, and disposal operation characteristics. Locations of the sites are given in only very general terms because the operators have requested anonymity. As Table 33 indicates, land cultivation is primarily applicable for organic wastes. Depending on variables such as waste and soil characteristics, these wastes are applied either to help fertilize and condition the soil or to use the

TABLE 3.3. SUMMARY OF CASE STUDY SITE TECHNICAL INFORMATION

Item	Southern California	Rhode Island	Indiana	Illinois	Texas	Michigan
	Case Study Site					
Type of Site	waste disposal	turf farm	agricultural land	waste disposal	disposal on pasture land	tree farm
Site Age (yrs)	22	3	1	4	3	1
Disposal area						
ha	12	24	20	45	607	1,200
ac	30	60	50	110	1,500	3,000
Climate						
Annual ppt.						
cm	37	109	104	84	36	79
in	15	43	42	33	14	31
Av. ann. temp.						
°C	15	10	15	10	18	8
°F	59	51	56	51	64	48
Topography (slope)	mostly <1%	<1%	<1% to 5%	mostly <1%	mostly <1%	0-10%
Soil type at site	sand	silt loam (glacial outwash)	loamy sand	clay	loam and sandy loam	range: sand to clay
Waste types	drilling muds and tank bottoms	secondary sludge from organic chemical mfg	lime/ferric chloride/polymer primary sludge with minor amounts of activated sludge from soap mfg	several types of industrial waste, including rendering waste, caustic water, and stack scrubber blowdown	shredded municipal refuse, sewage sludge, and septic tank pumpings	waste activated sludge from semi-chemical pulp and paper mill
Ann. waste input	82,970 m^3	3,400 m^3	6,490 m^3	37,350 m^3	17,700 MT	94,400 m^3

(continued)

TABLE 33 (continued)

	Case Study Site					
Item	Southern California	Rhode Island	Indiana	Illionis	Texas	Michigan
Haul distance						
km	varies	20	27	varies	8+	32 (maximum)
mi		12	17		5+	20 (maximum)
Application method	spread with dozer	spread from tank truck	subsurface injection	spread from tank wagon	dumped in windrows and thin spread	subsurface injection
Application rate						
cum/ha	950-1,500	228	114	59	134-278 mt/ha	190
gal/ac	40,000-63,000	24,000	12,000	6,250	60-124 5/ac	20,000
Application frequency	once/3-7 weeks	once/2 years	once/year	twice/week	one application only	once/15 years
Cultivation frequency	once/3-7 weeks	once/2 years	none*	2 times/week	initially and after 6 months	none
Additional storage facilities	none	none	none	9,840 m^3 (2.6 mg)	none	151 m^3 (40,000 gal)
Monitoring						
waste	no	solids, metals	solids, N, U^-, pH, Alk, metals	yes	sludge	Ca, metals, N, P, K
groundwater	yes	no	no	yes (4 wells)	no	on test plots
surface water	no	no	yes	no	no	no
vegetation	no	no	yes	no	in the future	yields
soils	yes	no	yes	no	in the future	no
Soil Amendments						
fertilizer	no	27-6-4	no	no	no	no

*Deep injection. Cultivate only if odors develop.

soil as a disposal sink. At the Odessa, Texas, and Michigan sites, the waste was applied to help fertilize and condition the soil. At the other four sites investigated, low-cost waste disposal without environmental degradation is the objective.

Waste application rates are determined to a large extent by the rate of waste decomposition, irrespective of the primary objective of the six land cultivation operations investigated. The waste decomposition rate is affected by many factors, expecially waste type, application procedures, and climate. Waste type is normally the principal factor controlling the decomposition rate. This is because waste nutrient, salt, metal, and/or water content may limit the total quantity of waste applied and the rate of application. For example, the high water content of wastes disposed at the Indiana site interfered with attempts at land cultivation until a sufficiently large site was acquired to handle the hydraulic loading.

Application procedures are also important. Waste application methods that can maintain aerobic conditions will maximize the waste decomposition and thereby application rate, since a change of 10°C (20°F) may affect bacterial metabolism by a factor as high as 2 (202).

Climate can also place certain constraints on specific land cultivation operations. For example, periods of heavy rains occasionally halt operations at the Indiana and Illinois sites, while freezing conditions prevent waste application approximately 3 mo each year at the Illinois, Michigan, and Rhode Island sites.

At the Rhode Island site, waste application is limited by the use of the site as a turf farm, since wastes are only applied to bare fields between turf stripping and reseeding. At the Michigan site, wastes are currently applied only to cleared lots prior to replanting. Since this results in a lapse between applications, experiments are in progress to determine the suitability of the waste for use on young trees.

Thus, land cultivation is controlled somewhat by climatic conditions and other situations. In addition, both environmental and practical considerations affect land cultivation. For operations to be environmentally acceptable, monitoring programs are being conducted or planned by five of the six case study sites. Monitoring typically consists of sampling the waste and soil four times per year. At some sites, surface water, groundwater, and vegetation are also sampled at regular intervals, depending on state and local regulatory requirements and on the apparent potential for contamination.

Practical considerations such as regulatory requirements and public acceptability were found to be similar for all six sites investigated. None of the six states involved has specific regulations for land cultivation of municipal refuse. Texas does have regulations pertaining to land cultivation, but these are designed to regulate industrial waste and not municipal refuse applications. Because of the lack of state regulations specifically written for land cultivation, each site is handled on a case-by-case basis.

Public acceptability has been good at all six sites. Odors were initially a problem at the Michigan and Indiana sites, but use of subsurface injection eliminated this problem. At five of the six sites, the owners/operators have worked closely with state regulatory agencies and local residents to facilitate public acceptance. At two of the sites, tours are periodically conducted for environmental and school groups.

LAND CULTIVATION ECONOMICS

Table 34 summarizes available information concerning the economics for the case study sites. Because of differences in site and waste characteristics, and waste application rates and methods, the costs vary for each site operation. Moreover, detailed cost information is often unavailable since it is generally considered proprietary. Also, the accounting methods used by site operators sometimes omit or lump together certain cost factors. Thus, for some sites, cost data is estimated based on best available information.

Figure 29 presents unit costs in dollars per cubic meter for the six land cultivation sites plotted against the annual waste quantity. For comparison purposes, the conceptual design (Section 13) costs are also plotted. Both the case study and conceptual design costs indicate that definite economies of scale are possible when land cultivating wastes.

Operations and costs at the Illinois and Southern California sites are similar to those of the conceptual design. However, the Michigan, Indiana, and Rhode Island costs include transportation of sludge to the site, off-site sludge storage, and pretreatment. Further, no land costs are included for Michigan and Rhode Island. To provide an equitable comparison, the Indiana, Michigan, and Rhode Island costs have been adjusted so that all six case study sites and the conceptual design have costs calculated on the same basis (Figure 29).

In adjusting costs, transportation costs for the Rhode Island and Indiana sites were estimated using data supplied by the California and Rhode Island Public Utilities Commissions and the Indiana Motor Carriers Tariff Department. This data indicated that, for the distances involved, a reasonable estimate was 9¢/km/m^3 (0.05¢/mi/gal). For those sites where land costs were not included, the implicit land value was assumed to be

TABLE 34. CASE STUDY COST SUMMARY*

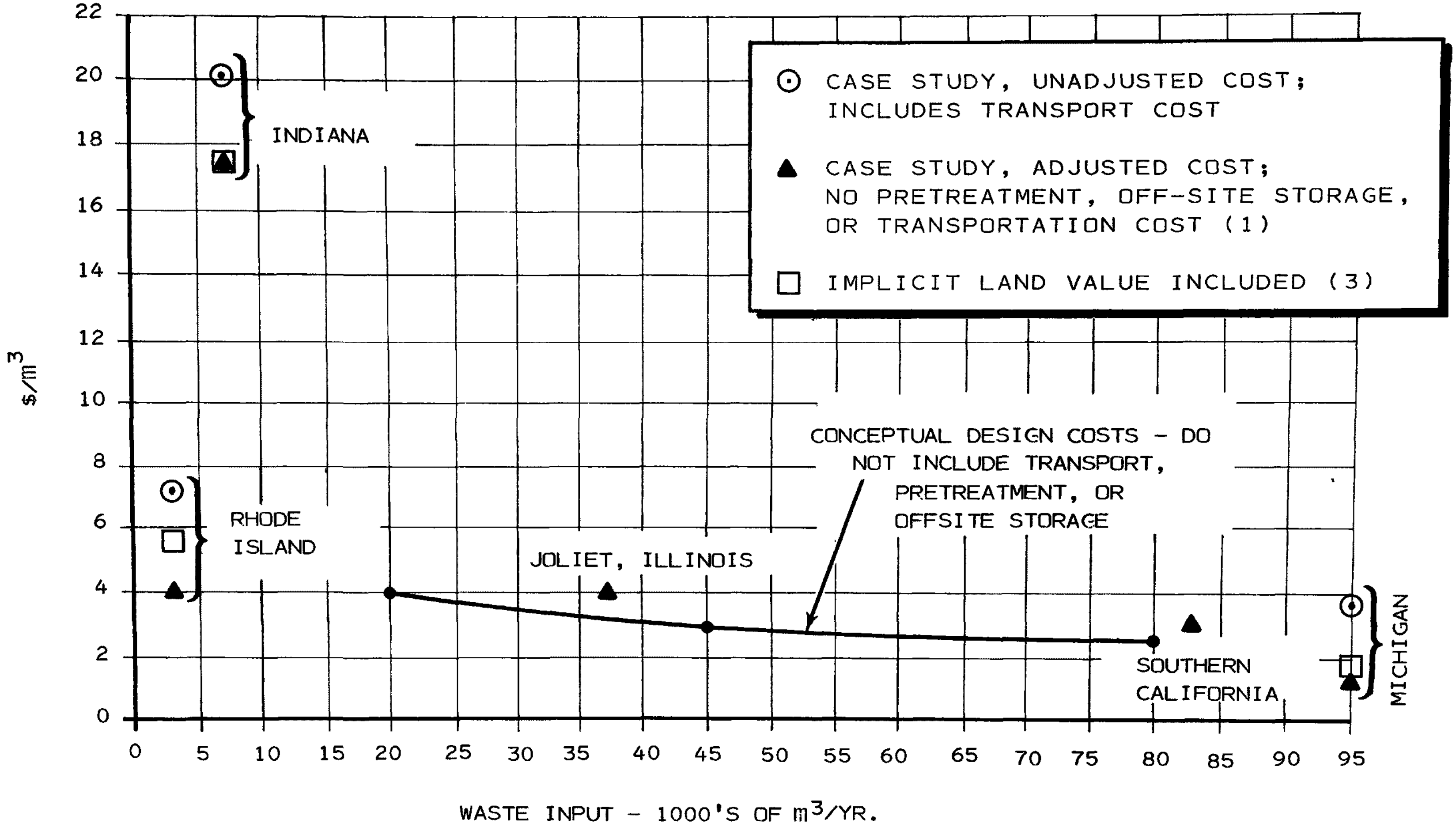
	Soil Enrichment Sites				Waste Disposal Sites	
Cost Elements	Texas	Indiana	Rhode Island	Michigan †	Illinois	Southern California
1. Amount of waste received per yr	17,700 MT	6,490 m^3	3,400 m^3	94,400 m^3	37,350 m^3	82,970 m^3
2. Pretreatment/offsite storage		N.I.**			N.I.	N.I.
Annual costs	73,700	--	4,000	140,000	--	--
Unit costs	4.16	--	1.18	1.48	--	--
3. Transport to site		See No. 5	See No. 5	See No. 4	N.I.	N.I.
Annual costs	30,420	--	--	--	--	--
Unit costs	1.72	--	--	--	--	--
4. Onsite storage	N.A.#	See No. 5	N.A.	Includes No. 3		N.A.
Annual costs	--	--	--	73,000	2,000	--
Unit costs	--	--	--	0.77	.05	--
5. Spreading/cultivation		Includes Nos. 3&4	Includes No. 3		Includes No. 8	
Annual costs	29,620	111,000	13,500	85,000	145,906	156,573
Unit costs	1.67	17.10	3.97	0.90	3.91	1.89
6. Monitoring	N.A.		N.A.		N.A.	N.I.
Annual costs	--	11,000	--	5,500	--	--
Unit costs	--	1.69	--	0.06	--	--
7. Other O&M (not included above)	N.A.	N.A.			N.A.	N.A.
Annual costs	--	--	6,630	26,500	--	--
Unit costs	--	--	1.95	0.28	--	--
8. Land costs (if not included above)					See 5	
Annual costs	1	9,000	0	0	--	52,191
Unit costs	0.00	1.39	0.00	0.00	--	0.63
9. Total costs	133,741	131,000	24,130	330,000	147,906	208,764
10. Average unit costs	7.56/MT	20.10/m^3	7.10/m^3	3.50/m^3	3.96/m^3	2.52/m^3

*All units are as indicated. Costs due to taxes, insurance, profits, etc., are included where appropriate.

†Volume and cost for this mini-case study are for 1975 only. All costs in 1976 collars except where indicated.

#Not applicable.

**Not included.



NOTES:

(1) TRANSPORT COST FOR RI AND IN ESTIMATED AT 9¢ km/m^3
TRANSPORT COSTS FOR ESTIMATED AS 50% OF CAPITAL COSTS AND 100% OF O&M AND LABOR COSTS FOR TRANSPORT EQUIPMENT.

(2) UNIT COSTS BASED ON 1976 DOLLARS EXCEPT MI WHICH IS 1975.

(3) LAND ASSUMED TO HAVE A VALUE OF 25% OF ADJUSTED OR 20% OF RE-ADJUSTED UNIT COSTS.

Figure 29. Case study and conceptual design unit costs of liquid waste cultivation.(2)

25 percent of adjusted total annual cost for that site. This percentage was based on the results of the conceptual design economic analysis reported in Section 13.

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16. ABSTRACT

A review of the available literature on land cultivation of industrial wastewater and sludge, and municipal solid waste was conducted. This review was supplemented by field investigations at 10 operating sites, including soil and vegetation analyses.

Soil is a natural environment for the inactivation and degradation of many waste materials through a variety of soil processes. Land cultivation is a disposal technique by which a waste is spread on and incorporated into the surface soil. Depending on waste characteristics, the disposal program can be either related to agriculture or solely a disposal practice.

Volume 1 is a technical summary and literature review. It contains information about land cultivation practices, waste characteristics and quantities, mechanisms of waste degradation, effects on soil properties and plants, regulations, site selection, operation, environmental impact assessment, site monitoring, site conceptual design, and case study summaries. Cited are 202 references.

Volume 2 summarizes the results of field investigations and case studies. It covers four field studies, six case studies, and a section on nonstandard disposal or utilization techniques for hazardous wastes. Field data was collected to evaluate operational procedures, costs, environmental impacts, and problems associated with land cultivation at the individual sites.

17. KEY WORDS AND DOCUMENT ANALYSIS

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