LAND TREATMENT AND DISPOSAL OF WASTEWATER IN THE POTOMAC RIVER BASIN

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CHAPTER I

INTRODUCTION

Land treatment and disposal of wastewater is far from a new idea in the United States and around the world, but it is only recently that it has received widespread interest in the United States. Use of land for wastewater treatment and disposal can recharge ground water supplies, can return nutrients to the soil, and in some cases can be a cost effective water pollution control alternative. The suitability of such a treatment system, however, depends greatly on characteristics specific to the site in the Potomac basin, or any other area. Land treatment and disposal is especially sensitive to site-specific factors such as climate, soil types, geology, topography and existing and planned land use.

The purpose of this paper is to describe alternative land treatment and disposal methods and point out some of the opportunities and problems that should be considered prior to a decision. The paper also includes information on applicable state regulations and experiences with land treatment and disposal projects in the Potomac basin area and elsewhere.

The Potomac Basin

The basin of the Potomac, embracing an area of 14,670 square miles, lies within a portion of the Atlantic slope, extending from the Allegheny Mountains to the Chesapeake Bay. The terrain varies from the flatness of the coastal plain to the mountainous country of the Appalachian highlands.

The soils of the basin range from the unconsolidated strata of sands, gravels, clays, and silts of the coastal plain to those derived from sandstone and shales typical of the eastern slope of the Allegheny Mountains. The soils of the piedmont plateau are derived from crystalline and sedimentary rocks and the soils of the Appalachian Valley are derived from limestone.

Estimated land use within the Potomac is 7,696 square miles of woodlands, 5,654 square miles of crop and pasture land, 785 square miles of urban and miscellaneous area and 534 square miles of water surface. In other terms, 52 percent of the basin is woodland, 39 percent pasture and cropland, 5 percent urban, and 4 percent water.

The present population in the basin is about four million people, but three million are clustered in the Washington Metropolitan Area and 11 other urban centers.

The Interstate Commission

The Interstate Commission on the Potomac River Basin (ICPRB) was established by a compact among the states of Maryland, Pennsylvania, Virginia, West Virginia and the District of Columbia, which initially was approved by Congress in 1940 and amended with Congressional approval in 1970. The ICPRB has long been active in advocating innovative and cost-effective systems for managing the water quality of the Potomac. Much of the concern stems from being involved in coordinating water quality related activities for the nation's river for 35 years.

At a Commission conference held in the fall of 1971, the major topic of discussion centered around spray irrigation of wastewater and the applicability of this system (The Pennsylvania experience) to other areas throughout the basin. (See reference 1.)*

The Federal Water Pollution Control Amendments of 1972

An important impetus for increased examination of land disposal as an alternative came from the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). Section 101(d)(1) of PL 92-500 states "...it is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985..." Use of land as a treatment alternative is given a substantial role in the Act. Section 201(b) of the Act stipulates that:

> (b) "Waste treatment management plans and practices shall provide for the application of the best practicable waste treatment technology before any discharge into receiving waters, including reclaiming and recycling of water, and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution and shall provide for consideration of advanced waste treatment techniques."

Land application is emphasized in Section 201(d)(1) with the stipulation that:

> (d) "The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for--
>
> > (1) The recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;"

Thus, the intent of PL 92-500 incorporates land application as a viable alternative to conventional and advanced wastewater treatment in the prevention of surface water pollution. (See reference 3.)

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*Note: References listed are the technical basis for the statement, and should be used for further research.

CHAPTER II

THE NATURE OF LAND TREATMENT AND DISPOSAL TECHNIQUES

Land treatment and disposal of wastewater utilizes unconsolidated soil and vegetation as the treatment media and ground water usually is the ultimate recipient of much of the purified water. The selection of a land disposal technique is based upon seven fundamental, but interrelated factors: (1) wastewater characteristics, (2) water quality goals, (3) soil types, (4) site conditions and availability, (5) climate, (6) economic and regulatory factors, and (7) rate and type of application. (See references 3, 4, 9.)

Wastewater Characteristics

In the Potomac basin states, the equivalent of secondary treatment is required prior to further treatment and disposal on the land. (See Chapter 6). The diversity of secondary effluent characteristics, caused by some differences in treatment efficiency and local variation of total dissolved solids in the wastewater makes it difficult to design common disposal system operating criteria. In addition to designing a system to meet local effluent criteria, it must be recognized that disposal of biological sludge, a by-product of secondary treatment, must be considered.

The requirement for secondary level pretreatment prior to land disposal is based upon a number of factors. Secondary level pretreatment reduces the risk of noxious anaerobic odors (bacterial decomposition without free oxygen) at the application site and reduces the risk of clogging and other harmful ecosystem responses to anaerobic conditions. It also is required by climatic constraints imposed on the disposal process, e.g. during periods of precipitation and frozen soil, effluent application to the soil is restricted. Long-term, large volume storage during such periods requires secondary level pretreatment for the maintenance of desirable conditions in the holding ponds.

Water Quality Goals

Specific water quality goals may vary in different locations, and prevention of harmful impact on final receiving water may be the controlling factor. These goals must be defined prior to the selection of a land treatment technique. Conventional opinion has been that the product water from land disposal operations should approach drinking water-irrigation water standards in quality. (See Appendix D--Selected Drinking and Irrigation Water Standards.) This would seem to be a reasonable and practical goal which would permit reuse and avoid harmful impacts on receiving waters.

Soil Types

Application of wastewater for land treatment and disposal would be ineffective if the soil medium could not accept the effluent, and provide the natural purification effects which contact with the soil produces. Thus, the nature of the soil and location of the ground water are important factors in determining the applicability of land disposal.

Site Condition

The site characteristic which should receive initial technical consideration is its ability to move liquid at the desired rate, on a long-term basis. It is then necessary to establish the vegetation which will provide the desired utilization and renovation of the wastewater.

The feasibility of land application will depend also on the availability of adequate acreage, composed of the proper type of soil, underlain with ground water at the proper level, located conveniently and assigned to proper zoning use regulations.

The movement of water on and through soils is a very complex and difficult subject. The local climate is a strong influence; as are the kinds of growing plants through their uptake of water and subsequent transpiration to the atmosphere.

Climate

Climate may have a great bearing on any decisions to adopt land application practices. In the Potomac basin, several climatic conditions can be noted: (1) it is an area with a comparatively long growing season and mild to moderately severe winters, thus land application can be practiced over a long time period without holding ponds as large as in areas with short growing seasons and severe winters; (2) it is in a zone of hot summers, which could create septic conditions and irrigation induced odors; (3) some areas are humid and evapotranspiration of moisture into the atmosphere will be inhibited. Thus, weather conditions in the Potomac basin will affect the rate of application of wastewater to land areas and the assimilation capabilities of soil.

Economic Factors and Regulatory Factors

The comparison of land treatment approaches with conventional treatment processes depends, in part, on the economic tradeoffs involved. One of these economic factors is the high capital costs for specific unit facilities, e.g., nitrification (oxidation of ammonia to nitrate) and tertiary treatment. Wastewater can have economic value when used or reclaimed by land application. The most efficient approach in terms of percentage recovery of water would be infiltration through the soil and recharge of ground water aquifers. If an economic return is important, crops grown using overland flow or irrigation can be sold to recover part of the cost of wastewater treatment. It should also be noted that land treatment and disposal can have adverse economic factors such as the removal of land from tax rolls and the relocation cost of families.

Other considerations include the large amounts of land required (See references 8, 12) in high growth areas, although investments in land may be beneficial to the county or community since (1) the acquisition of land for land treatment and disposal of municipal wastewater is eligible for a grant of 75 percent of the cost from the U. S. Environmental Protection Agency under provisions of PL 92-500 and (2) this might be a way to control growth on viable agricultural lands and to preserve green space.

If the available sites are underlain by aquifers used for potable water supply, public agencies may apply very stringent standards to infiltration systems. As water quality standards become increasingly stringent, irrigation with underdrains, overland flow or infiltration with recovery may be combined with other forms of wastewater treatment prior to stream discharge.

Using the above criteria as guiding factors in the development of a wastewater system, three application modes can be considered: irrigation, overland flow, and infiltration. These three methods will be summarized below, but more fully expanded in the next chapter and appendices.

<u>Irrigation (See references 3, 9.)</u>

Irrigation is the controlled discharge of effluent, by spraying or surface spreading onto land to support plant growth. The wastewater is "lost" to plant uptake, to air by evapotranspiration and to ground water by percolation. Application rates are measured either in inches per day or week, or in gallons per acre per day. The method as well as the rate of application depends upon the soil, the type of crop, the climate and the topography. Sloping land is acceptable for irrigation provided that application rates are modified to prevent excessive erosion and runoff.

Renovation of the wastewater occurs generally after passage through the first 2 to 4 feet of soil. Monitoring to determine the extent of renovation is generally not practiced. When it is practiced, however, removals are found to be on the order of 99 percent of biochemical oxygen demand (BOD) and suspended solids. Depending on soil types and the crops harvested, removals of nitrogen and phosphorus from the wastewater may also be quite high. (See Figure II-1.) Typical renovation efficiencies of this system are listed in Table II-1.

Overland Flow (See references 3, 9.)

Overland flow is the controlled discharge, by spraying or other means, of effluent onto sloping land with a large portion of the wastewater appearing as runoff. The rate of application is measured in inches per week, and the wastewater travels in a sheet flow down the grade.

Soils suited to overland flow are clays and clay loams with limited drainability. The land for an overland flow treatment site should have a moderate slope--between 2 and 6 percent. The surface should be evenly graded with essentially no mounds or depressions. The smooth grading and ground slope make possible sheet flow of water over the ground without ponding or stagnation. Grass is usually planted to provide a habitat for the biota and to prevent erosion. As the effluent flows down the slope, a portion infiltrates into the soil, a small amount evaporates and the remainder flows to collection channels. As the effluent flows through the grass, the suspended solids are filtered out and the organic matter is oxidized by the bacteria living in the vegetation. (See Figure II-2.) Typical renovation efficiencies of this system are listed in Table II-2.

Infiltration (See references 3, 9.)

Infiltration is defined as the controlled discharge of wastewater, by spreading or other means, of liquid onto the land with the flow path being high rate infiltration and percolation through the soil. The application rate is measured in feet per week or gallons per day per square foot. The major portion of the wastewater enters the groundwater although some is lost to evaporation. The spreading basins are generally closed and rested periodically to prevent clogging and to maintain high infiltration rates. Soils are usually coarse textured sands, loamy sands, or sandy loams. (See Figure II-3.) Typical renovation efficiencies of this system are listed in Table II-3.

Other Disposal Approaches

There are several other approaches to the disposal of wastewater on land, including subsurface leach fields, injection wells and evaporation ponds. Such techniques are generally limited in their range of application and are not considered as a major factor in wastewater disposal in the Potomac basin.

CHAPTER III

HYDROLOGIC ASPECTS OF WASTEWATER APPLICATION METHODS

The disposal of wastewater on land by any of the modes considered in the preceeding section of this report is intimately related to the natural hydrologic cycle. The hydrologic cycle is the multipath pattern through which water moves in the atmosphere, hydrosphere and lithosphere. It would appear, then that the approaches toward wastewater management which would be most successful would be those approaches that act in cooperation with natural hydrologic phenomena. This chapter will look at the hydrologic aspects of wastewater application modes with emphasis on methods of application. (See reference 9.)

Irrigation

Hydrologic considerations and constraints. The spray irrigation concept of wastewater disposal relies on the liquid infiltrating the soil surface and percolating through the soil, accompanied by some evapotranspiration, but ideally with no surface runoff. Natural precipitation is a factor, because wastewater applications either have to be suspended when the ground is very wet from heavy or prolonged precipitation, or the application rates have to be low enough that spraying can continue during precipitation with negligible reduction in treatment efficiency.

By far the most limiting factor in spray irrigation is the maintenance of infiltration capacity. Infiltration capacity and percolation capacity will in general be similar quantities at the beginning of operation of a system, but clogging of the soil surface during operation will reduce the infiltration capacity. The principal approach for maintaining or restoring infiltration capacity involves the intermittent application of wastewater with intervening rest periods. If wastewater were continuously applied to the soil, an equilibrium infiltration rate would eventually be established, but this rate would in almost every case be too small to be acceptable. An additional factor which preserves the infiltration rate, and which is often overlooked, is strict prohibition of mechanical stress or traffic that would compact the wet infiltrative surface.

A second constraint is the need to maintain aerobic conditions in the soil to properly renovate degradable organic wastes. In hydrologic terms, this translates into maintaining unsaturated flow conditions in the soil. Thus, it follows that application rates should be significantly less than percolation capacities, and less than infiltration capacities if unsaturated conditions are to exist in the infiltrative surface.

Groundwater recharge is a benefit of irrigation, but the potential danger of contaminating the groundwater resource cannot be over emphasized. Thus, the soil mantle between the ground surface and the water table must be thick enough to ensure renovation of the wastewater before it reaches the groundwater. Therefore a third hydrologic constraint is the depth to groundwater. In finer soils, the lower infiltration and percolation rates contribute to keeping the wastewater in contact with the soil long enough to complete the desired chemical and biological reactions. But coarser soils, with higher infiltration and percolation rates, may permit the wastewater to pass through so rapidly that optimum quality improvements in the liquid do not occur before the water table is reached.

Existing approaches and criteria. In existing systems the wastewater is applied using conventional irrigation equipment, generally aluminum irrigation pipe supporting risers and rotating nozzles. The Muskegon, Michigan (See Appendix A) municipal system uses rotating booms with spray nozzles directed downward. In most cases the irrigation sites are vegetated with grasses or cultivated crops, but a few systems apply wastewater in forested areas as well. (See reference 3.)

Application rates, and weekly application amounts, are generally selected on the basis of the capacity of the vegetation to take up nutrients (e.g., nitrogen and phosphorus). Usually this results in application rates being less than infiltration rates. But at times, such as during natural rainfall or in freezing weather, the customary application rates produce some surface runoff. At Pennsylvania State University, this occasional runoff is not retrieved, but the Muskegon municipal system includes interception ditches, from which occasional runoff is returned to aerated lagoons for recycling through the system.

Potential improvements. While the limit on application rates is likely to be based on the nutrient requirements of the vegetation covering the spray irrigation site, it seems that another supplementary approach may be useful for design analyses. This would be to select or limit application rates as percentages of infiltration or percolation capacities, for the purposes of maintaining specific levels of air within the soil and avoiding saturated flow with its attendant anaerobic conditions and odors.

Overland Flow

Hydrologic considerations and constraints. The overland flow mode of wastewater application relies on the renovation of the liquid during its passage over the ground as a thin sheet flow, and during its contact with the soil and plant roots in a surface layer of limited thickness. The surface runoff is accompanied by depletion of liquid via evaporation of spray, evapotranspiration, and infiltration However, these amounts are significantly less than the runoff volumes. As with spray irrigation, natural precipitation is a factor in overland runoff, requiring either the suspension of wastewater applications, or application rates that are sufficiently low so that waste treatment is not impaired during precipitation. However, natural precipitation may have a beneficial effect on an overland runoff site; the natural rainfall runoff can serve as a flushing or cleansing agent, removing from the surface some of the constituents originally deposited from the wastewater, and thus restoring the ability of the site to renovate the wastewater. This result is beneficial only as long as the constituents acquired by the natural runoff do not exceed acceptable concentrations for final runoff water.

The primary hydrologic factor in overland runoff is achieving and maintaining proper overland flow, that is, runoff which is neither too slow, which leads to ponding and anaerobic conditions, nor too fast, which leads to insufficient contact times of the wastewater with the soil and vegetation, and can also lead to soil erosion. In close relation with this factor is the requirement that the length of overland flow be sufficient to allow adequate contact times for treatment.

A secondary hydrologic constraint in the overland flow mode is the depth to groundwater. This is a constraint because some amount of infiltration and percolation is likely to occur. Since overland runoff of wastewater is generally practiced on soils of low permeability, the minimum acceptable depth to groundwater can be in the low end of the range quoted for the spray irrigation mode. (See references 3, 9.)

Existing approaches and criteria. Wastewater is applied to the ground in the overland flow mode in generally the same manner as it is in the spray irrigation mode. This involves conventional irrigation equipment with risers and rotating nozzles, applying water sequentially to plots within the disposal area so that continuous waste flow is maintained.

The installation at Paris, Texas, (see Appendix B), has provided the greatest amount of data and analysis in the literature. The Paris site has ground slopes that vary from less than 1 percent to about 12 percent, and experience indicates that slopes between 2 percent and 6 percent are desirable to avoid ponding or too-rapid runoff and erosion. Slope lengths at Paris are generally in the range of 200 to 300 feet, and travel time of the water mass is generally about one hour, although some seasonal conditions lead to times as long as 2 to 3 hours. As far as the water mass is concerned, most of the applied water is believed to run off during or soon after its spray period. But for the waste constituents in the water, a broad spectrum of travel times or contact time presumably exists, with the time period being a function of the particular constituent.

Potential improvements. In the overland flow application mode, the bulk of the renovated water is readily available at the site outlet. Thus, it appears that where greater treatment efficiency is desired, and where sufficient land is available, a potential improvement would be to capture the runoff and recycle it through the disposal field. (See reference 3.)

Rapid Infiltration

Hydrologic considerations and constraints. The rapid infiltration mode of wastewater disposal has much in common with spray irrigation, in that the wastewater is intended to infiltrate the soil and become renovated during percolation. The primary differences are that in this mode the infiltration rates are substantially higher and the liquid is applied by spreading or flooding rather than by spray. Precipitation is not a significant factor, since the surface area of the spreading basins would generally catch small amounts of rain compared to the volumes of wastewater. Moreover rapid infiltration sites are generally located in areas where natural precipitation is not great, although individual storms may be intense.

As with the spray irrigation mode, the most limiting factor in rapid infiltration is the maintenance of the infiltration capacity, that is, minimizing or reversing the effects of clogging of the soil surface. And again, the principal approach for controlling surface clogging is the intermittent application of wastewater with intervening rest periods.

The constraint of maintaining aerobic conditions in the soil cannot be met for rapid infiltration in the same manner that it is met for spray irrigation. In rapid infiltration, the application rate is 100 percent of the infiltration capacity, and if the infiltration and percolation capacities are identical, saturated flow will prevail with the exclusion of soil air. More commonly, however, the infiltration capacity is less than the percolation capacity, and is further reduced due to clogging. Thus, while the thin, clogged surface layer is subject to saturated flow, percolation below the surface takes place in an unsaturated condition, and some amount of air is available for aerobic decomposition of organic wastes. For the restoration of aerobic conditions at the infiltrative surface, resting or drying periods are essential.

The depth to the groundwater table is of even greater concern in rapid infiltration than in spray irrigation. This is because rapid infiltration is practical on coarser soils where infiltration and percolation capacities are high, and the liquid contact times are correspondingly small for a given soil thickness. In addition, the percolating liquid develops a mound or dome of groundwater upon the original groundwater table, directly beneath the rapid infiltration site. If the groundwater table is at shallow depth, this mound could rise to unacceptable levels--greatly impairing infiltration rates, and reducing the contact time of the wastewater with the oxygen contained in the soil air.

Existing approaches and criteria. Studies of the Flushing Meadows Project (see Appendix C) in Arizona have indicated that a grass cover on the basin floor is most favorable for maintaining infiltration capacities.

The normal operating schedule is now 12 days of flooding followed by 10 days of resting (20 days rest in winter). This amounts to 14 flooding periods per year. Initial infiltration rates are typically near 4 ft/day, and decrease during each flooding period to about 1 ft/day, with an average rate of about 2 ft/day. In the Flushing Meadows Project, depths of water of about 1/2 or 1 foot are maintained in the basins by overflow weirs. Overflow is returned to the influent stream and recycled.

Potential improvements. Any potential rapid infiltration site must be thoroughly subjected to subsurface investigation, with special attention given to permeability and the depth to the groundwater table. The depth to groundwater at Flushing Meadows is not a constraint only because of the high horizontal permeability at this site. For general planning purposes, it is concluded that for rapid infiltration, the depth of groundwater should be selected at the high end of the range which is 15 feet. (See reference 3.)

Methods of Application (See references 3, 9.)

There are a number of different ways to apply wastewater to the land. Each site will have its own physical characteristics which will influence the choice of the method of application. The three that are most commonly used are spraying, ridge and furrow, and flooding.

Spraying

In the spraying method, effluent is sprinkled above the ground surface similar to rainfall. The spray is developed by the flow of effluent under pressure through nozzles or sprinkler heads. The pressure is supplied by a pump or a source high enough above the sprinkler heads. By adjusting the pressure and size of the nozzle opening, the rate of discharge can be varied.

The elements of a spray system are the pump or source of pressure, a supply main, laterals, risers, and nozzles or sprinkler heads. Since the system operates under pressure, there is a wide variety of ground configurations suitable for this type of disposal. The spray system can be portable or permanent, moving or stationary.

The cost of a spray system is relatively high because of pump and piping costs and pump operating costs. The effluent used in a spray disposal system cannot have solids that are large enough to plug the nozzles. Sprinkling is the most efficient method of irrigation for uniform distribution of effluent.

Ridge and Furrow Flow

The ridge and furrow method is accomplished by gravity flow only. The effluent flows in the furrows and seeps into the ground. Ground that is suitable for this type of operation must be relatively flat. The ground is groomed into alternating ridges and furrows, the width and depth varying with the amount of effluent and the type of soil. The rate of infiltration into the ground will control the amount of effluent applied. If crops are to be irrigated with effluent, the width of the ridge where the crop is planted will vary with the type of crop. The furrows must be allowed to dry out after application of sewage effluent so that the soil pores do not become clogged.

Flooding

The third type of application is flooding. This type can be accomplished in different ways; border strip, contour check, or spreading basin. Flooding, as the term implies, is the covering of the land with a certain depth of effluent. The depth is determined by the choice of vegetation and the type of soil. The land has to be level or nearly level so that a uniform depth can be maintained. The land does need "drying out" so that soil clogging does not occur. The type of crop grown has to be able to withstand the periodic flooding.

The border strip method consists of sloped (2 to 6 per cent) strips of land 600 to 1,000 feet long divided by borders or dikes every 20 to 60 feet. The major difference between this method and the spreading basins is that this method uses smaller segments of a field and the ground is sloped.

Contour check is the creation of dikes or levees along the contour of a hill or slope. The dikes contain the effluent so it does not run down the slope. The dikes are generally placed at contour intervals of 0.2 to 0.3 feet.

Spreading basins are shallow ponds which are periodically flooded with effluent. The basins hold the effluent until it percolates into the ground, is used by crops, or evaporates into the air. Spreading basins are generally used for rapid infiltration.

CHAPTER IV

SUMMARY OF MAJOR ENVIRONMENTAL PROCESSES

There are numerous environmental consequences from the land disposal of wastewater. Studies have indicated that the basic ecosystem components and environmental processes are quite similar for all three application modes. This section will summarize the major environmental processes as they pertain to liquid wastes, oxygen demanding compounds, biostimulants, inorganics, other organic compounds, health and hygiene, biota and other topics. (See references 3, 9.)

Liquid Waste

The effects of pollutant overload can be more conveniently discussed in terms of hydraulic overload. A primary example is the oxygen balance in the receiving ecosystem. Long-term saturated conditions deplete the oxygen in the receiving soil. This can damage both the root systems of plants and trees and also change the character of microbial responses. Anaerobic microorganisms (bacteria and other small organisms which can live without free oxygen) generate by-products which clog the soil pores and cause foul odors. A subsequent period of aerobic conditions is required to oxidize these by-products and restore the infiltration/percolation capacity of the site. The restoration of aerobic conditions which in turn maintain long-term hydraulic capacity is the major reason for rest periods and or intermittent application schedules recommended for disposal systems.

Oxygen Demanding Compounds

These materials are generally considered to be the relatively easily degraded organic compounds. The Biochemical Oxygen Demand (BOD) is accepted as an index of their presence. The test actually measures the amount of oxygen required for decomposition of the oxidizable, organic material present.

In a similar context much of the "suspended solids" in secondary treated wastewaters is organic in character, and represents losses of biological sludge particles from the treatment system. Suspended solids are not additive to BOD when determining the total organic load on a land disposal site.

The fundamental ability of any terrestrial ecosystem to assimilate simple organic compounds is beyond question. This is the natural role of the decomposers in any balanced ecosystem. The microbial life in the system is the major responsible mechanism. Initial uptake might be through adsorption and/or filtration but the metabolic processes of micro-organisms provide for continuing assimilation.

Biostimulants

A wide range of nutrients and trace elements are required as growth factors for living organisms. The list includes many metals in addition to the commonly recognized nutrients such as nitrogen and phosphorus. A similar list, with perhaps different elements and different concentrations, exists for all living organisms. Elimination of just one of the factors can theoretically control the growth of the organism. Several, in excess, can stimulate overproduction.

At a land disposal operation, biological and soil ecosystem components have potential responses to nitrogen and phosphorus. Although both nitrogen and phosphorus can appear in a number of different forms and in many different compounds, their presence is usually expressed in terms of an equivalent amount of elemental nitrogen or phosphorus rather than the actual concentration of the particular form.

The nitrogen applied to a land disposal site can be in one or more forms: organic nitrogen, ammonia nitrogen, nitrite or nitrate. The relative abundance of a particular form will depend on the type of pretreatment applied. Effluents from primary systems and the very high rate secondary processes have essentially all the nitrogen in the ammonia and organic forms, that is, they are essentially unchanged from the raw sewage. The major forms of phosphorus in wastewaters, treated or otherwise, are inorganic compounds, primarily phosphates. There are two major sources in domestic wastes. Human wastes contribute a small percentage but the major domestic source is the inorganic phosphates in detergents.

Phosphorus. Phosphates will be taken up by the organisms on a land disposal site. Such activity is essentially identical to that prevailing in a waste treatment plant. In effect, the organisms only use the phosphorus; they do not "remove" it. This cycle is of some benefit to the site ecosystem. During the initial portion of a spray period the organisms would be in a relatively rapid growth phase. Phosphorus taken up at this stage would then be gradually released, for plant or soil uptake, during the rest periods.

The major components responsible for phosphorus removal are the plants and upper layer of soil at a particular site. Plant uptake can be very significant. Harvest of these plants assimilating phosphorus is obviously desirable. If the dead plant is left on-site the phosphorus present slowly diffuses from the plant material into the soil. This recycling then places total reliance on the soil.

Nitrogen. All of the major site components, plants, soils and microorganisms, can provide removal of nitrogen, depending on its form. A major opportunity for nitrate removal is by plant uptake. There may be some temporary immobilization by soil microorganisms but the major beneficial pathway is to the plants. In the general case any nitrate which is not removed by the plants becomes a fixed part of product water quality since soils have no capacity for fixation. The worst case therefore for either spray irrigation or overland flow is application of a wastewater whose entire nitrogen content is in the nitrate form. Once the nitrate is past the capillary root zone there is only one opportunity left. Denitrification by anaerobic organisms can reduce nitrate to gaseous nitrogen which can then escape to the atmosphere.

Ammonia nitrogen reaching the site has potential for two initial pathways. Some can be temporarily absorbex by the soil particles. Fixation in less soluble forms by clay minerals is possible. The fraction temporarily held is available to microorganisms. This microbial activity is also the second potential direct pathway. Aerobic organisms oxidize the ammonium nitrogen. The end product is still nitrate but the time lag inherent in the process is a definite benefit for overall removal efficiency. In effect the soils and organisms provide temporary storage for some of the nitrogen which is then gradually released for plant uptake during the non-spray, rest periods.

Both nitrification (oxidation of ammonia to nitrite-nitrate) and denitrification (reduction of nitrite-nitrate to nitrogen gas) are temperature-sensitive processes. The latter proceeds at progressively slower rates at temperatures less than approximately 75 degrees F and practically ceases at 35 degrees F. Nitrification, being an aerobic process, is less sensitive to temperature. The optimum reaction rates can occur at 60 degrees F with the lower limit for any response still close to 35 degrees F. These constraints might limit the effectiveness of a site during late fall and winter applications. Significant uptake by dormant plants during these periods is also unlikely.

In addition to the nitrogen present in wastewaters, the amount delivered to site by natural rainfall can be significant and must be considered. Nitrogen compounds can occur as particulate matter in the atmosphere. Electrochemical reaction during thunderstorms can convert atmospheric nitrogen to nitrate forms.

Inorganics (See references 3, 5, 6, 9.)

There are 13 major inorganic constituents present in municipal wastewaters. Because some of these are quite variable in original water sources, each wastewater effluent should be analyzed for these constituents during any land disposal feasibility study. As an example of concentrations which one might expect, however, Appendix E shows "typical" secondary effluent characteristics gleaned from the literature. (See reference 9.)

These materials can stress a land disposal site by their effect on both the plants and the soils. Very high levels could also inhibit or destroy the microbial population. The major risk for both plants and microorganisms is the gradual long-term accumulation of some of these materials in the soil.

The organic material which naturally occurs in topsoils, and the soil particles themselves, present a tremendous number of adsorptive surfaces when compared to the capacity of secondary sludges. It therefore seems that removal of heavy metals by soil should be very effective. It also seems probable that most of these metals will be retained in the surface layers.

Clean soils such as sands and gravels have little capability to fix heavy metals and other inorganics primarily because they lack organics and clay minerals. Site selection for all land disposal modes should favor those soils having these very desirable renovative components.

Other Organic Compounds (See references 3, 5, 6, 9.)

It is the purpose of this section to discuss those organic compounds not identified previously as BOD, i.e., compounds not readily oxidized and therefore not measured in the BOD test.

These can include substances such as chlorinated hydrocarbons, phenols and detergent components which will be present in varying amounts, depending to a high degree on the type of industrial contribution to the raw sewage. Chlorinated hydrocarbons may also impact directly on the site if certain types of pesticides are used for insect or other pest control.

Work at Pennsylvania State University indicated that approximately 70 percent of the detergent residues were removed within the top few inches of the forest floor. At the 4-ft depth removals had increased to 78-81 percent. Mechanisms for removal are cited as absorption and then degradation by the soil microorganisms.

Chlorinated hydrocarbon pesticides may be in wastewaters as a result of industrial operations or they may be in the soil if previous or future site utilization includes the application of pesticides. Adsorption, which is correlated with the clay content of the soil, followed by some microbiological degradation, is the removal process. In high concentrations insecticidal chemicals can inhibit the effectiveness of soil microorganisms. At the low concentrations anticipated for wastewater effluents, however, these materials should not create problems for any of the land disposal modes.

A major component could be cellulose. Both industrial and municipal wastes can contain significant fractions. Cellulose forms the structural fiber of many plants. Paper is the most familiar end product and its manufacture and use contribute cellulose to wastewater. Most of this is in the form of suspended solids and will settle out during either primary or secondary treatment. Degradation by aerobic processes is slow and the retention times in most secondary processes are not long enough to remove them. Cellulose in colloidal size particles can therefore often be included in secondary effluents.

Other organic fractions could actually be by-products of the secondary process or similar materials originally present in the raw wastewater. The organic content of the microbial cells involved in waste treatment processes is not completely degradable in short periods of time. These organics include humic substances similar to the composition of the natural organic humus found in most soils. In the general case their addition to soils is a positive benefit in that they tend to improve soil structure and to increase the adsorptive capacity of the surface layer.

Addition of cellulose is also no problem. Filtration through the soil matrix should trap most particles and the long retention will provide sufficient time for microbial degradation. For example, in the natural state dead plants return cellulose to the ground but humus does not contain cellulose.

Vegetation Components (See reference 7.)

The major concern is the ability of the vegetative component of the ecosystem to remove and survive on the nutrients supplied by the wastewater. Of the three methods being considered for wastewater disposal on land, vegetation is involved least in the infiltration method and most in the irrigation method, with the overland flow method lying in between. Rapid-infiltration ponds lacking vegetative cover do not allow the wastewater to penetrate as well as ponds covered with a vegetative cover. In the overland-flow method the primary purpose of the vegetation on the land is to provide adequate surface area for the materials suspended in the effluent to cling to and become absorbed. Uptake of nutrients then follows. The spray irrigation technique provides for more nearly complete interaction among all ecosystem components. This method most strongly emphasizes the "living filter" concept in which higher plants are used to complement the microbiological and physiochemical systems in the soil.

For plants to maintain adequate growth, the medium in which they grow must stay in an aerobic condition. Root systems of most plants grow vigorously in well aerated soils and develop a complex fibrous root system. Reduced soil aeration affects the roots by reducing the oxygen, increasing the carbon dioxide, and increasing the by-products of anaerobic decomposition in the plants. One method of destroying an adequate root medium is to supply excessive amounts of water.

Excessive amounts of water have definite effects on nutrient supply. If excessive water is present it may either percolate through the soil if internal drainage is good, or it may accumulate and waterlog the soil. Excessive percolation leaches the available nutrients away from the root zone, which is needed to avoid the build-up of salts.

With most suggested application rates for land wastewater disposal techniques, waterlogging should not be a problem. However, if water application rates are excessive and waterlogging does occur, the desired crops might not be able to grow and they might be replaced by other less desirable species. One possible solution is to establish specific requirements for the amounts of water the crops to be grown can withstand. In some regions such as the Potomac basin where high rainfall occurs, where large amounts of wastewater effluent may be applied, and where evapotranspiration is low, application rate is an important parameter to consider.

The mineral elements in the soils, whether required for normal nutrition or not, are all absorbed by the plants grown in the soils to some extent. A "law" of tolerance exists in which there is not only a minimum concentration of elements that can be tolerated by plants, but also a maximum level at which plants can grow. Plant growth occurs at the levels between the minimum and maximum. If a deficiency in the quantity of elements appears, any number of diseases may result. This does not generally seem to occur with sewage effluents, however, because sufficient or excessive amounts of most elements are generally present in municipal and industrial wastewater.

The ability of plants to tolerate excessive amounts of elements varies with species. The capabilities of plants to absorb and accumulate elements are not only inherited but depend on such factors as soil structure and acidity, with solubility and availability of the elements also important factors influencing absorption.

<u>Public Health</u> (See references 3, 9.)

Public health aspects are related to (1) the pathogenic bacteria and viruses present in municipal wastewater and their possible transmission to higher biological forms including man, (2) chemicals that can pose dangers to health, and (3) the propagation of insects that could be vectors in disease transmission.

The survival of pathogenic bacteria and viruses in sprayed aerosol droplets, on and in the soil, and on vegetation has received considerable attention. There is a relationship between wastewater and health. However, most of the detrimental health and hygiene aspects of land disposal should be significantly reduced by proper wastewater pretreatment including secondary treatment, filtration and disinfection.

The survival of pathogenic organisms in the soil can vary from days to months depending on soil moisture, soil temperature and type of organism. The survival of viruses in soil is largely unexplored. To avoid potential health problems, even treated effluents are not permitted to be used for vegetables or other crops for direct human consumption.

Propagation of mosquitoes and flies poses a health hazard as well as a nuisance condition. Mosquitoes are known vectors of several diseases. They may increase in population mainly because of the wetter environment and the availability of standing puddles for breeding, much of which can be avoided by control of application rates.

CHAPTER V

ADVANTAGES AND DISADVANTAGES

A review of the major factors regarding land treatment of wastewater indicate the following advantages and disadvantages. Land treatment advantages and disadvantages are very site-specific and thus must be evaluated on a site-specific basis. The following therefore are neither all inclusive nor always applicable.

Advantages

- Treatment is accomplished without producing chemical sludges which cannot be used on agricultural land.
- Buffering and absorption capacity of the soil provides a good system of disposing of some pollutants.
- The water provides some economic benefit through crop production.
- Nutrients are beneficial to and necessary for crop growth.
- Effective open spaces are preserved.
- Multiple uses could be:
  1. Wildlife preserve and hunting area.
  2. Power plants with storage lagoons for cooling water.
  3. Potential recreational areas.
  4. Agricultural production.
- Nutrients in one acre-foot of water are equivalent to 272 pounds of 20-10-15 fertilizer.
- Water and nutrients may provide an opportunity for land reclamation.
- A recycling potential occurs for nutrients and water.
- Some pollutants degrade faster in the soil than in water.

Disadvantages

- Large land areas may be involved.
- Excessive volumes of water may not be needed and may even be detrimental to land and/or crops.
- A water resource may be partially lost to the originating area.
- Positive control of water is lost when it is released into the air or on the soil.
- Lag time for problems to become evident may result in irreversible damage (groundwater or soil quality).
- Some industrial effluents are not beneficial to the land and may have severe pollution potential (heavy metals, biocides, phenols, etc.).
- Return flow from irrigation drainage may be unsuitable for further domestic use and may require additional treatment to meet water quality standards.
- Commitment of land use for disposal is required for many years.

-Pathogenic and nuisance contact opportunities are greater than with a conventional waste treatment facility.
-Significant disruption may occur in the agricultural community.
-A significant change in microclimate of the area may occur.
-Surface streams and drainage of the area change.
-A potential exists for outbreak of "limberneck" disease in waterfowl population that flock to the storage lagoon.

The advantages and disadvantages of the land treatment and disposal alternative and other alternatives should be carefully evaluated in planning any wastewater management project.

CHAPTER VI

POTOMAC BASIN STATE REGULATIONS AND PROJECTS

In this chapter, each Potomac basin state's regulations or guidelines concerning land treatment and disposal are briefly described, followed by summary descriptions of land treatment facilities within the Potomac basin portion of each state.

District of Columbia

The District of Columbia, being entirely a densely populated urban area, has no land treatment facilities and no regulations or guidelines on the subject.

Maryland

Guidelines or Regulations

The Maryland Department of Health and Mental Hygiene, Environmental Health Administration, expects to complete its final regulations on land application in early 1976. The Department of Natural Resources, Water Resources Administration, also is involved due to its responsibilities for protecting groundwater. Until that time, each facility is evaluated on a case-by-case basis using the following interim guidelines for spray irrigation:

*The effluent which is to be applied must have received an equivalent to U. S. Environmental Protection Agency's definition of secondary treatment, i.e., monthly averages of the five-day biochemical oxygen demand (BOD-5) and the suspended solids are not to exceed 30 milligrams per liter each in the effluent.

*The total coliform density of the effluent must not exceed 3 colonies/100 milliliters of water.

*The application rate for spray irrigation shall not exceed two inches per acre per week.

*A minimum buffer zone is required of 200 feet from the perimeter of the irrigated area to adjacent property lines, and a 500-foot buffer zone is recommended if the application is near residences.

*No runoff from the site, or ponding at the site, is allowed.

In addition to these requirements, the State of Maryland makes these recommendations:

*There should be five feet of unsaturated material between the ground surface and the groundwater or bed rock.

*The general slope of the land should be less than 10 percent.

*There should be an on-site storage capacity for 30 days of average flow.

*The quality of the applied effluent and the groundwater at the site should be monitored.

Land Treatment and Disposal Projects

Of the states in the Potomac basin, Maryland has the largest number of operating land application facilities.

The largest land application operation in the State of Maryland is the St. Charles City facility in Charles County. This operation began in 1968 and applies 500,000 gallons per day of effluent to seventy acres of forest. Pretreatment consists of three lagoons in series followed by chlorination and a holding pond. The application rate is variable, although it averages some two inches per week. This facility is soon to expand to 700,000 gallons per day. There is currently no groundwater monitoring.

The International Monetary Fund's Bretton Woods Recreation Center, located in Montgomery County near Seneca, also has a land application system, which has been in operation since 1968. The facility was designed for a flow of 10,000 gallons per day with pretreatment consisting of activated sludge using extended aeration, chlorination, and a holding pond. Current flows are approximately 5000 gallons per day. The effluent is pumped from the holding pond, where it is diluted with rainfall and runoff from the surrounding area, and sprayed onto a golf course.

The Potomac Valley County Club, located in Montgomery County near Poolesville, has a design flow of 8,000 gallons per day but currently is receiving only about 5,000 gallons per day during peak flow months. Pretreatment consists of a waste stablization pond, followed by chlorination and holding pond. The effluent is applied seasonally to a golf course. There is, at present, no monitoring of the effluent or of the groundwater.

Two other small land application facilities are currently operating in Maryland. They are Norbeck Country Club and the Brookmanor Country Club, both located in Olney, Montgomery County. There are no flow measurements taken at either of these facilities, nor ground water monitoring. Pretreatment at both facilities consists of septic tanks and subsurface filtration. The effluents are then stored in ponds and mixed with surface runoff until they flow out of the ponds or are sprayed over golf courses.

Of the land treatment facilities planned for Maryland in the Potomac River basin, the most significant is the facility to be built at Rossmoor Leisure World in Montgomery County near Silver Spring. This plant is planned to treat ultimately 750,000 gallons per day. Pretreatment is to consist of secondary treatment, filtration and chlorination before the effluent is applied to a 175 acre forested area. The project is to be phased, starting with 200,000 gallons per day and the operation is planned to begin in late 1976. Extensive groundwater monitoring will be required along with surface water monitoring.

Pennsylvania

Guidelines or Regulations

The Pennsylvania Department of Environmental Resources, Bureau of Water Quality Management published a Spray Irrigation Manual, a guide to site selection and system design for spray irrigation systems, in 1972 (Reference 14). Following are some of the important requirements included in the Manual:

*Generally, the equivalent of secondary treatment must precede spray irrigation. However, because of the variability of the earth materials, spray field use and effluent constituents, treatment requirements and performance criteria will necessarily have to be determined on a site-by-site basis.

*All wastes containing sewage or pathogenic organisms must be disinfected prior to spraying.

*Generally, maximum application rates shall be two inches per week or lower, depending upon the permeability and drainage of the soil.

*Spray irrigation should normally be carried out only one day a week on a given section of land, allowing six days for the soils to dry out and reaerated.

*Where domestic housing is one of the neighboring land uses, the project should include screen barriers in the 200 feet of buffer zone to prevent spray from blowing into residential land.

*Acceptable slopes for spray fields depend upon the kind of agriculture or silviculture practiced. Most standard agricultural practices are acceptable on slopes up to a maximum of 4 percent; sodded slopes up to 8 percent; and forested slopes up to 8 percent, or up to 14 percent for some seasonal operations.

*Storage must be provided to handle surge flows or to allow for operation during winter conditions. The required size of the storage facilities will depend on the volume of flow, temperature of the effluent, design of the disposal field and the expected low temperature in the area. A storage pond must comply with the Department regulations for wastewater lagoons.

*A minimum of one ground water quality monitoring point, i.e., a well or spring, must be established in each dominant direction of ground water movement away from the spray field. A background water quality monitoring point also must be established to monitor ground water entering the site. Certified reports of chemical analyses specified by the Department, e.g., phosphates, ammonia nitrogen, nitrate nitrogen, and methylene blue active substances (MBAS), of samples from the monitoring points are required to be submitted quarterly.

Land Treatment and Disposal Projects

The oldest project in the Potomac basin portion of Pennsylvania using land treatment is a seasonal operation of the H. J. Heinz Company near Chambersburg in Franklin County. A seasonal operation, it was started in 1928 and modified in 1963 for treatment of food processing wastewater. The volume of approximately 750,000 gallons per day receives secondary treatment and screening prior to application to the land by spray irrigation. The land treatment is by overland flow with little infiltration. The operation is characterized by the Department of Environmental Resources as well-managed with an effluent having a BOD-5 of 5 mg/l and suspended solids of 9 mg/l.

A spray irrigation project for wastewater from the Greencastle Products rendering plant near Greencastle in Franklin County, which started operation in 1956, was ordered to be closed because of many problems associated with the site.

Two small projects which spray irrigate treated sewage also are in operation near Chambersburg. The Laurich Estates project has a design population of 500 with a septic tank and an aerated lagoon for treatment prior to spray irrigation of the effluent. The Cumberland Valley Mobil Home Park has a design population of 100 with secondary treatment by extended aeration prior to spray irrigation.

Virginia

Guidelines or Regulations

The Department of Health and the Water Control Board of the Commonwealth of Virginia expect to promulgate joint final regulations for land application of wastewater in the winter of 1976. Until the final regulations are promulgated, the state is operating under a set of interim draft regulations. The following is a summation of the interim draft regulations as of October 1975.

*Secondary treatment and chlorination are required of all wastewater as pretreatment before land application by any method.

*A minimum detention capacity of 60 days is required to store all flows during periods when the ground is frozen, during rainy weather, or when the application field cannot otherwise be used.

*One and one-half feet of residual water depth shall be maintained in the holding pond to prevent complete draining of the pond and duplicate pumps shall be provided for delivery to the spray field.

*Application rates are limited to one-fourth inch per hour, one-half inch per day and two inches per week (one inch per week in forest field areas) for irrigation methods; four inches per week for infiltration percolation methods; and one-half inches per day or three and one-half inches per week for overland flow methods.

*The owner of the land application facility must reserve an application area of a minimum of 25 percent of the design area, capable of being used as a functional area within ten days of notice.

*A minimum buffer zone of 300 feet is required around a spray application area when an open site is used and 100 feet when an unbroken natural forested barrier at least twenty feet high is provided. If application is by flooding, the minimum buffer zone shall be only 200 feet for an open site.

*The owner of the facility is required to construct ground water quality monitoring wells both inside and outside the irrigation site at the discretion of the state. The quality of the applied wastewater after pretreatment must also be monitored.

*The maximum slope at an irrigation site should be no more than 8 percent.

*The irrigated soils must be well drained with percolation capacity of at least twice the proposed application rate.

*The minimum depth to the permanent ground water table shall be five feet for irrigation methods and ten feet for infiltration-percolation methods (with minimum of five feet to apex of recharge mound).

*When the depth of the water table is less than the minimum, a reduced application rate and/or under drainage are required.

Land Treatment and Disposal Projects

As of July 1975, only two sites in the Virginia portion of the Potomac basin use land application as a treatment technique, i.e., Oak Ridge Estates and Occoquan Forest Estates, both in Prince William County.

The Oak Ridge Estates facility was built in 1972 with a design capacity of 88,000 gallons per day. Pretreatment consists of a package plant using contact stabilization, lagooning, then chlorination. Currently 35,000 gallons per day are applied to twelve and one-half acres of forest with an application rate within that suggested by the Commonwealth of Virginia. Current monitoring at the site location is minimal with the only testing being that of the effluent before it is applied to the soil. This monitoring will increase because springs have developed in the area. The monitoring will likely include measurement of the depth of the water table and water quality parameters such as TKN (organic and ammonia nitrogen), nitrates, nitrites and fecal coliforms.

The Occoquan Forest Estates facility also was constructed in 1972 with a design capacity of 88,000 gallons per day. Pretreatment before spraying consists of two package plants in parallel using contact stabilization. Wastewater then flows into a lagoon where it was designed to be chlorinated before being sprayed onto a twelve and one-half acre forested area. With the present flow of 8-10,000 gallons per day, however, the lagoon has never filled due to evaporation and excessive seepage.

West Virginia

Guidelines and Regulations

West Virginia statutes give the State Department of Health responsibility for control of the disposal of human and animal wastes although the State Department of Natural Resources has the primary responsibility for water pollution control. Therefore the State Department of Health must approve any system for disposal of sewage, including both domestic and municipal wastes and wastes from agricultural operations and slaughterhouses. The State Department of Health has been using as guidelines for approval of projects, the West Virginia Guide for Sprinkler Irrigation (Reference 15) and the Agricultural Waste Management Field Manual (Reference 16) developed by the U.S. Soil Conservation Service and the Cooperative Extension Service of West Virginia University along with informal engineering standards developed cooperatively by the Department of Health with these and other agencies. At the same time the Department has been developing specific regulations for spray irrigation as a section of proposed sewage system design standards regulations. Following is a brief description of some of the major requirements in the draft spray irrigation regulations:

- Secondary treatment of the effluent (not less than 85 percent removal of BOD-5 and suspended solids) and chlorination for disinfection is required prior to spray irrigation.

*The maximum application rates are 1/4 inch per hour, 1/2 inch per day and 1 inch per week.

*The irrigated area must be enclosed by a fence at least 6 feet high to keep out children and small domestic animals. The fence shall be placed at least 50 feet beyond the normal spray area and a minimum of 400 feet must be provided as a buffer zone between the enclosed irrigated area and adjacent property lines and highways.

*Storage to hold a minimum of 60 days of wastewater flow is required to hold the wastewater during periods when the irrigation field cannot be operated.

*Soils in the irrigated area shall have a minimum thickness of 4 feet.

*Slopes on cultivated fields should be no more than 4 percent; sodded field slopes no more than 8 percent; forested slopes no more than 8 percent except that forested slopes up to 14 percent may be acceptable for some seasonal operations.

*A minimum of one groundwater monitoring well for water quality testing must be provided in each dominant direction of groundwater movement and between the project site and public wells or high capacity private wells.

Land Treatment and Disposal Projects

The Fairfield Subdivision near Martinsburg in Berkeley County installed a sewage stablization pond followed by an effluent polishing pond in early 1975 to serve a developing area east of West Virginia Highway No. 9. During 1975 the flow has been so small that the treated effluent in the polishing pond has either evaporated or infiltered into the subsoil. In the future, if the infiltration declines sufficiently so that the polishing pond overflows, it is proposed to dispose of the effluent by spray irrigation on eighteen acres of adjacent land. The site and soil conditions have been deemed suitable by State Department of Health for spray irrigation of the effluent.

The E. I. du Pont de Nemours and Company, Potomac River Works, near Martinsburg in Berkeley County, has been experimenting since 1974 with a spray irrigation method as one means of meeting its national discharge (NPDES) permit. Water is sprayed over grass seeded soil which has a slope of 5 percent. The spray serves to oxidize the ammonia to nitrates and the nitrogen in the wastewater is then removed by anaerobic denitrification as it flows over the surface of the grass. The spray irrigation system has been operated both during summer and winter with application rates of approximately 1/2 acre-inch per day and 14 lbs. of nitrogen per acre per day. During the summer months, removal rates have been 80 percent for ammonia and nitrates. Winter removal rates have been slightly greater than 50 percent. During the operation of this plant various operational difficulties have arisen including sodium build-up in the soil.

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APPENDIX A

MUSKEGON COUNTY, MICHIGAN*

This land treatment system is located in parts of Muskegon County, Michigan on sandy soils common to that area lying along Lake Michigan. Muskegon County is located approximately opposite Milwaukee, Wisconsin, roughly opposite the midpoint of Lake Michigan. The wastewater management system is physically divided into two parts. a large portion serving the more heavily urbanized area surrounding Muskegon Lake and Mona Lake; and a smaller portion serving the less urbanized area around White Lake. All of these lakes are large dune-impounded lakes with outlets to Lake Michigan. The purpose of the project is to eliminate the discharge of polluting materials into Lake Michigan from which the water supply for most of the population of Muskegon County is obtained. The population to be served is estimated to be approximately 160,000 persons when the system is fully developed. The design average flows for the fully developed system are estimated to be about 43 mgd (million gallons per day), with a peak capacity of roughly 90 mgd which can be sustained for a relatively long time without adversely affecting the final effluent quality. Of this total design flow, about 40 percent is expected to be industrial and the remainder is expected to be domestic wastewater. Initially, the industrial portion comprises more than half of the total flow, because many of the collecting sewer systems have not been constructed. The largest single industry served is a paper mill with a design average flow of 12 to 16 mgd of wastewater containing waste paper and pulp fibre, plus some waste clay filler.

The larger of the two irrigation sites is an area of about 15 square miles located about 10 miles east of the more heavily urbanized area. It is underlain by medium sand ranging in thickness from a minimum of 20 feet to a typical maximum of 60 feet. There are also areas where the sand thickness is greater than 60 feet. The sand deposits are underlain by an impermeable clay layer which effectively prevents the vertical movement of ground water. Aerated lagoons with a design average residence time of 3 days are used to provide the biological treatment. The normal procedure to be followed will result in discharging the biologically treated wastewater and associated solids into one of the two 850-acre storage lagoons. These storage lagoons provide additional treatment and winter storage of the treated wastewater by being allowed to fluctuate 9 feet in depth. A separate 8-acre settling lagoon will be provided for operating flexibility to allow the by-passing of the storage lagoons and permit the direct irrigation of clarified effluent from the aerated lagoon system.

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* Reference 7, Bauer and Matsche, page 322.

Percolation through the bottom of the storage lagoon is controlled by intercepting ditches around the lagoons from which it can be pumped either back into the storage lagoon, or to the outlet drainage system, or to the irrigation system. Pumping directly to the outlet drainage system is anticipated only during the initial operations of the system, which will occur before all of the irrigation system is ready to operate.

The flow into the major irrigation system comes from either the storage lagoons or from the ditch which intercepts leakage from the storage lagoons. In either case, it is chlorinated to provide a desired reduction in coliform count. During the flow in the long open channels leading to the two irrigation pumping stations, the excess chlorine will be dissipated to prevent adverse effects in the soil. The two irrigation pumping stations are each set up in two parts so that a total of four separate irrigation systems may be served. Together these systems utilize about 55 irrigation rigs of the pivot type, each of which irrigates a circular area. These circular areas range in size from about 40 to 160 acres. A total of approximately 6000 acres of land are thus to be irrigated. The design application of irrigation water is about 7.5 feet per year, or 2.5 million gallons per acre per year. A total of 15,000 million gallons of water are thus planned to be irrigated in the design year, or an average flow of 41.3 mgd. The remainder of the design flow (1.3 mgd) is handled at the smaller site serving the White Lake area. During the irrigation period of roughly 30 weeks per year the average rate of application would be 3 inches per week. However, maximum rates of 4 inches per week are anticipated during dry weather.

An extensive underdrainage system is provided in the Muskegon County project, comprised primarily of drainage pipe systems which discharge into drainage ditches. In addition, a smaller portion of the irrigation site is drained by wells. Both pumping wells and observation wells are provided. The purposes of the drainage system are to prevent the saturation of the agricultural soils under the most intense periods of irrigation and precipitation, and also to control the direction of movement of the ground water around the perimeter of the irrigation site. It was required by the Michigan Department of Public Health that no out-migration of ground water occur. Consequently, the design provides for a small inward migration of ground water from the surrounding areas into the irrigation site.

APPENDIX B*

CAMPBELL SOUP COMPANY, PARIS, TEXAS

The wastewater treatment system at Campbell's plant in Paris, Texas, was designed to treat all of the wastewater generated by the food processing operation. The Paris facility is also a soup plant. The only wastewater not treated by the company's spray irrigation system is the sanitary sewage. This rather small portion of the total water usage is directed to a municipal wastewater treatment system operated by the city of Paris.

The development of the Paris plant overland flow system was complicated by several factors. The land available for spray irrigation had been a victim of extremely poor farming and soil conservation practices during the cotton boom of the early 1900s, which resulted in severe soil erosion over most of the acreage. Around 1940 the land was abandoned until purchased by the company in 1960. By this time, most of the topsoil had disappeared and deep erosion gullies scarred the land.

The local soils are red clay overlaid by a gray clay loam. The infiltration capacity is very low--about 0.10 in/day--which precludes the use of the standard infiltration-type of spray application. Based on the early experience gained at Napoleon, Ohio, a plan was advanced for the development of an overland flow spray system. Unlike the Napoleon system, where gently rolling topography made it relatively easy to construct an overland flow system, the devastated land at Paris necessitated a complete overhaul. Using heavy earthmoving equipment, approximately 500 acres of land were transformed into a network of slopes and terraces. The entire area was seeded, fertilized, and irrigated with fresh water, to establish a good growth of sod prior to the application of wastewater.

Before being discharged into the spray irrigation system, the food processing wastewater is routed through a gravity grease separator complete with mechanical grease skimming and bottom sludge removal, and then through a series of rotary drum screens. The screened water is then pumped in the spray system by high pressure pumps. An asbestos cement force main system distributes the wastewater to 123 automatic valves located on each of the individual slopes, from whence it is applied to land via aluminum surface piping and sprinklers. After 10 years of experience the worn aluminum piping is being slowly replaced by buried polyvinylchloride piping. There are more than 700 sprinklers in the system with discharge varying between 14 and 30 gpm. Most of

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* Reference 3, Page 221.

the sprinklers are spaced 80 feet apart on each line, while the individual slopes are all somewhere between 200 and 300 feet wide. The pitch of the slopes varies between 1 and 12 percent, and this was more or less dictated by the existing topography and the balance of cuts and fills in the earthmoving operation. The slopes vary in length from 350 to 1,350 feet.

The entire system is automatically controlled, utilizing pneumatic valves in the field. The pumping system is controlled by a standard liquid level control system located in the pump reservoir. These controls are electrically connected to four modified golf course type clock timers. When the level control system activates an individual pump, the pump starting circuit energizes a clock timer. The timer is connected to the individual field valves by network of underground polyethylene tubing which supplies compressed air to close the valves. A plug board used for grouping and regrouping the various sprinkler lines is integrated with the clock timers. Activation of the clock timers by the pumping system results in the opening of a set of valves which had been prescheduled by the plug board arrangement. The timer keeps that particular set of valves open for a predetermined period of time and then automatically closes that set and opens another, and so on.

After the wastewater is distributed along the top of the slope, it trickles downward across each slope to the terraces at the bottom. These terraces run together to form larger waterways, and eventually all the waterways flow into a small stream which runs through and away from the plant property. The wastewater is purified in this process by several means. The major treatment mechanism is the biological activity of the microorganisms present on the soil and in the vegetative growth. These organisms convert the organic compounds contained in the waste back into the harmless basic elements. The grass also captures the nutrients contained in the water and utilizes them for growth.

Once a set of sprinkler lines is activated, it is programmed to run for 6 to 8 hours continuously. A rest period of at least twice the length of the operating cycle is also programmed into the controller. Grass cutting and harvesting cause alterations to this schedule, but only about twice a year.

Since the Paris system is built on clay soil, little infiltration occurs. In fact, only about 20 percent of the applied volume of wastewater finds its way into the soil, while an additional 20 percent is lost through evapotranspiration, and the remaining 60 percent flows into the waterways and away from the property.

The treatment efficiency of the system has continuously been extremely high. For example, the BOD removal averages greater than 98 percent. One other aspect of the system that merits comment, and that can also be seen in the same table, is the tremendous buffering capacity of the system. Although the quality of the applied wastewater varies quite widely (for example, in pH and conductivity) during a typical 24-hour period, the quality of treated effluent remains quite constant.

A by-product of the system is the grass which is grown on the fields. Reed canary grass has been found to be especially well suited to the spray application, and has yielded large quantities of high quality hay. Based on actual nutritional analyses, this hay is equal to the highest quality alfalfa, and when sold as a cash crop, returns at least 5 percent of the operating cost of the system.

APPENDIX C*

FLUSHING MEADOWS, ARIZONA

In 1967 the Flushing Meadows Project, near Phoenix, Arizonia, was begun. The objectives were to study the treatment of sewage effluent by rapid infiltration and determine infiltration rates. Specifically, the removals of BOD, suspended solids, nitrogen, fluoride, and pathogenic organisms were important. It was desired to obtain renovated water of a quality sufficiently high to permit unrestricted irrigation.

A site was located west of Phoenix within the flood plain of the Salt River. The 2-acre site was divided into 6 basins that are 20 feet wide and 700 feet long. The soil is a sandy loam made up of 2 to 3 percent clay, 50 percent silt, and 47 percent sand. Infiltration rates of 1 ft/day, or 350 ft/yr, are regularly achieved by flooding for 14 days and resting 10 to 20 days. During the 2 weeks of inundation (surcharge is about 1 foot) the infiltration rate drops from 2.5 ft/day to 1.5 ft/day, with an average of 2 ft/day. During the summer, 10 days are sufficient for drying, reaeration, and biological oxidation which restores the infiltration capacity, but winter operation requires 20 days.

Four of the beds are planted with grass. (Sudan grass, common and Giant bermuda grass, and rice have been used.) One bed is natural soil and one has been covered with 4 inches of 3/8-inch gravel overlying a 2-inch layer of coarse sand. At both ends of each bed is a critical depth flume and a liquid level recorder. The difference between the two recorders indicates the infiltration rate in the basin. At the outfall end of each basin a level control device maintains a predetermined depth of water and permits rapid drainage of the water when necessary. Numerous test wells are located within the treatment area, two are 100 feet away from the area, one is 250 feet away, and a final one is 300 feet away. Most wells are 20 feet deep, but one is 30, one is 100, and one is 250 feet deep. After 3 years of operation, treated water had not reached the well that is 300 feet away. Treated water is identified from native groundwater by its low salt content.

The permeability of the soil using well water is 4 ft/day. The groundwater table is at a depth of 10 feet. Removals were: BOD, fecal coliform, and suspended solids, essentially complete; phosphorus and fluoride, 70 percent; nitrogen, 30 percent; and boron, lead, and cadmium, essentially zero.

* Reference 3, Page 195

APPENDIX D*

SELECTED DRINKING AND IRRIGATION WATER STANDARDS

Substance	Drinking Water (mg/liter)	Irrigation Water (mg/liter)	Controling Concentration (mg/liter)
Aluminum	-	1.0	1.0
Arsenic	0.05**	1.0	0.05
Barium	1.0**	-	1.0
Beryllium	-	0.5	0.5
Boron	-	0.75	0.75
Cadmium	0.01**	0.005	0.005
Chlorides	250	-	250
Chromium	0.05**	0.005	0.005
Cobalt	-	0.2	0.2
Copper	1.0	0.2	0.2
Cyanide	0.2**	-	0.2
Iron	0.3	-	0.3
Lead	0.05**	5.0	0.05
Manganese	0.05	2.0	0.05
Mercury	0.002**	-	0.002
Nickel	-	0.5	0.5
Nitrate (as N)	10 **	-	10
Selenium	0.01**	0.05	0.01
Silver	0.05**	-	0.05
Sulfates	250	-	250
Suspended solids	-	-	5
Vanadium	-	10.0	10.0
Zinc	-	5.0	5.0

* Modified from Reference 9, page 5.

** From U.S. Environmental Protection Agency Proposed Interim Primary Drinking Water Standards, 40 CFR Part 141, March 14, 1975.

APPENDIX E*

TYPICAL SECONDARY EFFLUENT CHARACTERISTICS
(All as mg/liter unless otherwise noted.)

I. Oxygen-demanding compounds

a. BOD-5 25
b. COD 70

II. Biostimulants

a. Nitrogen Total N 20
Organic 2.0 (as N)
Ammonia 9.8 (as N)
Nitrite 0.0 (as N)
Nitrate 8.2 (as N)
b. Phosphorus Total P 10

III. Other organic compounds

a. Phenols 0.3
b. Chlorinated and other complex organics- (Concentration vary. Total concentration of these refactory organics approaches 45 mg/liter as indicated by the difference between COD-BOD results above.)

IV. Inorganic compounds

a. Metals

Cadmium	0.1
Chromium	0.2
Copper	0.1
Iron	0.1
Lead	0.1
Manganese	0.2
Mercury	0.005
Nickel	0.2
Zinc	0.2
Sodium	S.A.R. = 4.6

b. Non metals

Boron	0.7
Chlorides	100
Sulfate	125

V. Other characteristics

a. Suspended solids 25
b. pH 7.0

* Reference 9, page 3.

TABLE II-1

IRRIGATION RENOVATION EFFICIENCIES

Constituent	Percent Removal	Reference(s)
BOD_5	98-99	3,9
Suspended solids	97-99	3,9
Total nitrogen as N	85-97	3,7,9
Total phosphorus as P	99+	3,7
Metals	95-99	3
Pathogens	99+	3

FIGURE II-1

IRRIGATION

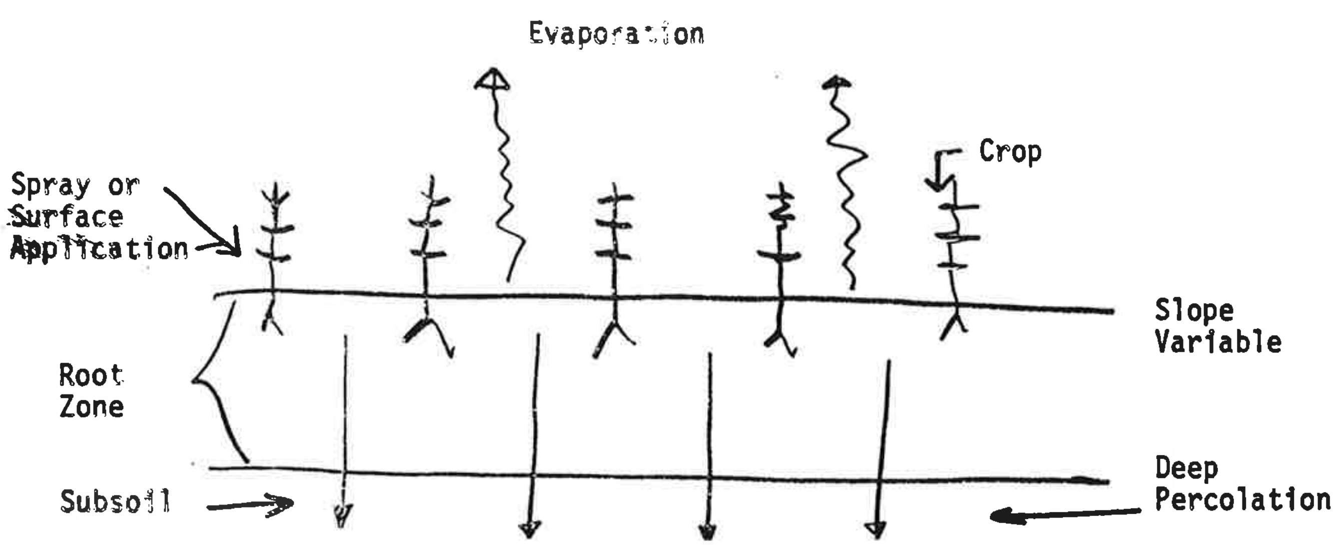

TABLE II-2

OVERLAND FLOW RENOVATION EFFICIENCIES

Constituent	Percent Removal	Reference(s)
BOD_5	98-99	3,9
Suspended solids	90-94	3,9
Total nitrogen as N	80-85	3,9
Total phosphorus as P	40-80	3,9
Metals	50	3
Pathogens	99	3

FIGURE II-2

OVERLAND FLOW

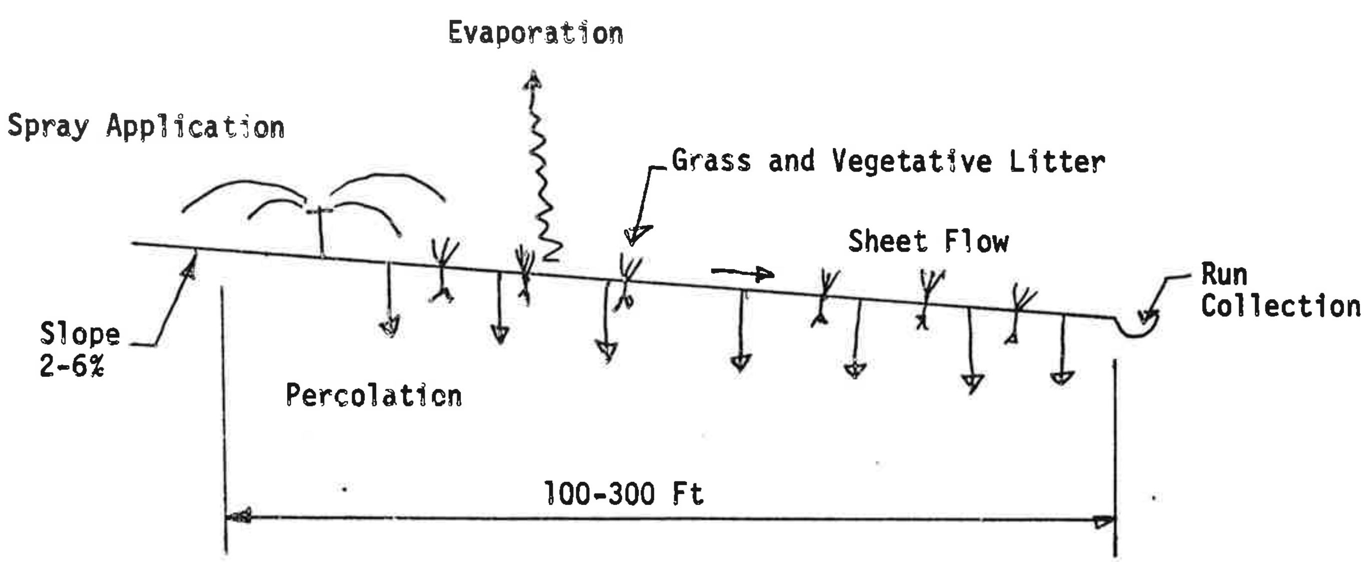

TABLE II-3

INFILTRATION RENOVATION EFFICIENCIES

Constituent	Percent Removal	Reference(s)
BOD5	88-98	3
Suspended solids	100	3
Total nitrogen as N	30-80	3,9
Total phosphorus as P	60-96	3,9
Metals	50-60	9
Pathogens	99	3,9

FIGURE II-3

INFILTRATION-PERCOLATION