using land treatment for municipal wastewater disposal

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The term "land treatment" refers to a family of wastewater disposal technologies in which the effluent is deposited onto the land rather than discharged into the surface waters. In such a system, the land itself assumes some of the treatment function, with the soil and its vegetative mat acting as a giant filter, capturing or decomposing pollutants while the water itself evaporates or percolates to groundwater.

Although land disposal methods were at one time fairly common in the United States, they fell into disuse around the turn of the century and were replaced by the treatment technology still most common today: primary treatment (screening and settling), often followed by secondary (biological) treatment, with the effluent ultimately discharged into surface waters. At this time, the use of land treatment is largely confined to the Southwest (425 or 493 land application sites in the United States).[1]

It has been recognized for some time that conventional secondary treatment may not meet the increasingly stringent limitations on the effluent discharged into receiving waters. Until recently, the usual response has been to plan for even more extensive chemical and biological ("tertiary") treatment before discharge. However, the enormous expense involved in these treatment alternatives has prompted a re-examination of land application methods, and it has been found that land treatment often enjoys a clear economic advantage over "conventional" advanced waste treatment systems. At the same time, though, other implications of land treatment methods are not so clear. This essay is a brief comparison of land treatment and conventional advanced waste treatment; it invites planners to consider the possible effects of land application on community land use.

Four steps are involved in the land treatment process:

1. Pretreatment. Pretreatment destroys pathogens and reduces the suspended solids concentration of the wastewater. Excessive solids concentrations tend to blanket the soil, reducing permeability and leading to anaerobic conditions. Also, when wastewater is applied to the land by spray irrigation, spray heads may easily become clogged. Although some states require that secondary treatment precede the application of the wastewater to the land, the pretreatment functions cited here can be fulfilled by settling followed by disinfection. "There is no justification at this time for requiring that influent to the land application system receive secondary treatment."[2]

2. Storage. A land application facility must suspend operations when the ground is frozen or wet. Accordingly, there must be a reservoir for storage during periods of inclement weather. An alternative to storage which may be applicable in some situations is to allow the discharge of effluent into receiving waters whenever it cannot be applied to the land. Since such discharges would be made only during periods of high flow or low temperatures, environmental damage would not result unless there was a potential for buildup of cumulative pollutants.

3. Land Application. The oldest and most common approach to land treatment is irrigation, the discharge of effluent onto the land to enhance plant growth. Water removal is accomplished mainly through evapotranspiration and percolation, and for this reason, a moderately permeable soil is desired. Wastewater constituents are removed in the top few inches of the soil and either accumulate there or are taken up by plants. Effluent can also be applied to the land by means of an overland flow system, which consists of a perforated pipe at the top of a moderate slope (2-6°) and a trench to collect the renovated wastewater at the bottom of the slope. Wastewater constituents are captured by the vegetative mat, not the soil matrix, so this approach is ideal for impermeable soils. Most of the water evaporates or is taken up by plants, though a small amount may run into surface waters. Overland flow is a new technique, and not much is known about the degree of renovation which can be expected. However, its performance in industrial applications has been promising.[3]

4. Crop Removal. Crop removal is important in a land treatment system because the value of the crop will provide a return which can be applied against the cost of the system. Moreover, if crops are not removed, some wastewater constituents taken up by plants would accumulate in the soil, eventually resulting in system overload.

a cost comparison

The cities of Durham and Chapel Hill, North Carolina, are currently preparing a joint "201" plan for the construction of municipal wastewater treatment facilities. When completed, these treatment works will serve Chapel Hill, Carrboro, and the southern half of Durham. One alternative being considered is the construction of a single regional plant just south of Durham, discharging into New Hope Creek. If this alternative is selected, the plant will open in 1980 with a projected flow rate of 12 mgd, increasing to 21 mgd by the year 2000. In this section, we want to compare the estimated cost of such a plant with the estimated cost of a land treatment facility of comparable size.

In making this comparison, we will assume a discount rate of 7%; this is actually being used in the Durham-Chapel Hill study and is what the Environmental Protection Agency recommends for all 201 and 208 projects.[4] Furthermore, we will assume that for discharge into surface waters, the ultimate oxygen demand of the effluent cannot exceed 15 mg/1, suspended solids cannot exceed 15 mg/1, and phosphorus concentration cannot exceed 1 mg/1. Studies indicate that such stringent discharge limitations are necessary in order to avoid a deterioration of water quality if the B. Everett Jordan Reservoir is ever filled.[5] Achievement of these discharge limitations requires secondary treatment, followed by nitrification and phosphorus removal; these processes define "secondary treatment" for the purposes of this evaluation.

For the land treatment alternative considered here, the site now being considered for the regional plant will be used for pretreatment, which will consist of settling and screening the incoming wastewater, followed by disinfection. The application site itself is located about four miles south, near the junction of Durham, Orange, and Chatham Counties. This is a rural area, sparsely populated, about half forest and half farmland; it is assumed that spray irrigation will be used on the farmland and overland flow on the forested areas of the site. The assumed application rate is two inches per week, a representative figure.[6] At two inches per week, a one-mgd flow requires about 130 acres. Therefore, to meet the 22-mgd flow requirements of the year 2000[7], about 3,150 acres will be needed for application. An additional 300 acres will be needed for a buffer zone around the site,[8] and it is assumed that for storage, 300 acres will be required. This gives a grand total of 3,150 acres necessary to handle the flow anticipated in 2000. This is a considerable amount of land and suggests that a constraint may be imposed on system size by an inability to assemble contiguous parcels of suitable land of the requisite area (on the other hand, the Muskegon, Michigan system covers 15,000 acres![9]).

The source of cost information for tertiary treatment is a 1973 study of waste treatment alternatives for Chapel Hill, prepared by Lamb *et al.*[10] In this study, detailed cost estimates for secondary treatment, plus nitrification and phosphorus removal, were given for flows of 7, 15, and 50 mgd. Interpolation was then used to get costs in the 12-21 mgd range for this comparison.

Since there are so few land application facilities in operation, estimation of land treatment costs is more guesswork than anything else. The principal source of information used here is a study done for EPA by Metcalf and Eddy, Inc., "Water Treatment and Reuse by Land Application."[11] In this report, cost estimates of transmission, pumping, site preparation, distribution equipment, and operation and maintenance were made for hypothetical one-mgd land treatment facilities of various types. With some minor changes, these cost estimates are used here by assuming constant returns to scale (for land treatment, unlike other waste disposal technologies, this is not a bad assumption).

Two other important assumptions need to be made before the cost of land treatment can be computed. First, it was observed earlier that salable crops can be grown on land application sites; the net benefits of such sale are assumed to be 5¢ per 1000 gallons of effluent applied. Actually, experiments at Penn State have shown returns often in excess of this figure.[12] The second assumption is that land prices in the disposal area are $1,000 per acre. A check with local real estate agents in 1973 showed this to be about the market price.[13]

The table below displays the cost differential between tertiary treatment and land treatment under the assumptions presented above. Evidently, implementation of a land treatment system for Durham-Chapel Hill would result in a substantial savings (about 22%) over "conventional" tertiary treatment. Furthermore, there are some economically attractive features of land treatment which are not brought out by this example. It was mentioned earlier that land treatment technology is not nearly as subject to economies of scale as are conventional technologies. Thus, for small communities, land treatment could offer an even greater economic advantage than it does in this rather large system. In fact, the saving could exceed 40¢ per 1000 gallons for systems with a flow smaller than one mgd.[14]

An important reason for the difference in scale economies is that conventional advanced waste treatment processes, unlike land treatment, require a good deal of chemical or biological expertise, regardless of size. When expertise is not available, the waste treatment plant is operated at far below design efficiencies. This has been a very common occurence in the United States and was one of the main concerns of the Congress in drafting the Federal Water Pollution Control Act Amendments of 1972.[15]

For simplicity in this example, it was assumed that all capital outlays had to be made at once, at the beginning of the planning period. This is, of course, not strictly true for either tertiary or land treatment. However, tertiary treatment systems can only be expanded in comparatively large increments, for to do otherwise would sacrifice scale economies. A land treatment system thus allows the postponement of capital expenditure, largely avoiding the construction of facilities which will never be needed if growth projections do not materialize.

There is still another advantage of land treatment whose importance is difficult to judge at this time. Surface-water discharge systems which achieve a high degree of waste removal are heavily dependent on chemical additives; the cost

Cost of Waste Treatment Alternatives

Tertiary Treatment	
Capital Cost	$12,500,000
Present Value of OMR Cost	9,750,000
Total	$22,250,000
Average Per Year	$ 2,100,000
Cost Per 1000 Gallons*	35.0¢
Land Treatment	
Capital Cost:	
Pretreatment	$ 5,000,000
Land	3,750,000
Transmission	1,180,000
Earthwork	945,000
Distribution	3,780,000
Pumping	1,350,000
Impoundment	300,000
	$16,305,000
Present Value of OMR Cost	4,860,000
	$21,165,000
Less Present Value Of	
Economic Benefits	$ 3,020,000
Land Salvage Value	760,000
Total Present Value	$17,385,000
Average Per Year	$ 1,645,000
Cost Per 1000 Gallons*	27.3¢

*Assuming a flow of 16.5 mgd.

of the chemicals is a major component of operating costs for such systems. If, as seems likely, we are entering an era of frequent material supply shortages, prices of these ancillary chemicals may increase drastically over the life of the project. If so, projections of future operating costs may be grossly underestimated.

The reliability of the comparison presented in the table is dependent on the goodness of the assumptions, some of which are highly suspect. From an economic standpoint, the most critical assumption is that of an application rate. If the rate were one inch per week instead of two, for instance, the cost advantage of land treatment over tertiary treatment in this example would entirely disappear. The reason for the importance of the rate assumption is clear enough: the application rate is inversely proportional to the amount of land required, which in turn determines the requirements for transmission equipment and site preparation.

In a well-designed system, the application rate is set as high as possible such that no constituent of the wastewater appears in quantities exceeding the assimilative capacity of the environment. Each constituent gives rise to a loading constraint, and the smallest of these is then the upper bound for the application rate of the system. Right away, then, the loading rate may depend on the characteristics of the effluent. This may mean that stiff pretreatment standards, as specified in Section 307 of the 1972 Amendments, must be imposed on industries which discharge into municipal land treatment systems. For each constituent, the constraint also depends on the approach to land treatment employed, farming practices used, crops selected, etc., as well as the natural variables of soil type, climate, and slope. The fate of materials applied to the soil is often poorly understood, and hence many of the loading constraints are only crudely known, especially with respect to long-term effects or effects on groundwater. Nonetheless, it appears as though land treatment systems in Piedmont North Carolina will be limited by the hydrologic constraints.

Whenever the hydrologic capacity of the system is exceeded, runoff or ponding will result. Runoff may transport nondegradable pollutants to receiving streams (or degradable pollutants before they are degraded), partially defeating the purpose of the land treatment system. The impact of ponding is more serious mainly because anaerobic soil conditions may be created. Not only can decomposition in an anaerobic environment cause nuisance odor problems, but the population of aerobic bacteria in the soil can be eliminated. When this happens, it may take weeks to reestablish a normal environment, during which time the waste stabilizing ability of the soil filter is severely impaired.

For a spray irrigation system, most of the water applied is removed by evapotranspiration and percolation, while for an overland flow system, the principal removal mechanisms are evapotranspiration and runoff after filtration. For both approaches, then, evapotranspiration is very important. Due to the strong seasonal component of the evapotranspiration rate (the actual rate in July exceeds that of January by about three times in this region), much higher application rates are feasible in the summer than in the winter.

To allow for this circumstance, there is a continuum of system designs: at one extreme, establishment of a constant application rate low enough to be maintained throughout the year, while on the other, impoundment of the wastewater to take full advantage of the high summer rates. In theory, the proper point on this continuum is a solvable problem but one which requires a vast amount of information: on soil, bedrock, vegetative uptake rates, potential evaporation rates, etc. Still, in view of the costs involved, one would expect that a large payoff would attend the solution.

environmental impacts

As noted, environmental damage can result when any wastewater constituent exceeds the capacity of the system. For example, accumulation of heavy metals in concentrations toxic to plants or to the animals which consume them may result upon prolonged exposure of the soil to wastewater.[16] Or leaching of nitrates into groundwater may lead to concentrations in excess of safe drinking water levels.[17] For these concerns and others, a great deal of research is needed to determine the long-term environmental impacts. To be fair, however, it must be pointed out that a correspondingly large amount of research is needed to determine the effects of prolonged discharge of effluent into receiving water, even after advanced treatment.

Besides loading considerations, land treatment has a number of other potential environmental impacts: bacteriological impacts, effects on microclimate, stormwater runoffs, and interruption of the natural water cycle. Limited space does not permit a discussion of each of these effects, but let us turn briefly to the bacteriological and water cycle impacts.

In a land application system, people may come into contact with disease organisms in two ways: wind transport of aerosols from irrigation spray and human consumption of sprayed produce. Historically, the danger from aerosols has proved to be surprisingly small. In the large Berlin and Paris sewage irrigation systems, for example, only one incidence of disease due to aerosol transport has ever been suspected since the system was instituted.[18] In Tallahassee, the incidence of disease in their land treatment system is less than that of city employees as a whole.[19] Moreover, the danger of aerosols from spray irrigation is not terribly different from the danger to people living near trickling plants, and there have been few reports of illness due to trickling filter plant aerosols.

The danger from human consumption of sprayed crops seems to be more possible. In Israel, there was evidence that a cholera epidemic was traceable to spray irrigation of crops consumed by humans, and to be safe, most authorities recommend that crops from land disposal systems be consumed by animals only. Most states which regulate land treatment systems require this, and as a result of their experience, Israel has also instituted this policy.[20]

Land treatment can also have an environmental impact if the water cycle is interrupted by diverting it from its natural destiny. Suppose a water supply for a city is formed by an impoundment on a stream. If that city discharges its wastewater back into the stream below the impoundment, then there is a comparatively small loss of volume; that which is taken from the stream is returned to it. If the city now changes over to a land treatment system, much of the water removed from the stream evaporates, and the resulting deficit could have a devastating effect on the stream ecosystem at low flow unless it is compensated for by flow augmentation.

This effect can cut both ways, depending on the water supply source. University Park, Pennsylvania, obtains its water from wells. When a land treatment system was opened there in 1964, the natural hydrologic regimen was restored instead of interrupted, with groundwater aquifers being recharged by the renovated wastewater. Officials report that the level of the water table has now stabilized, whereas previously it had been dropping rapidly.[21] The groundwater recharge potential makes land application a particularly attractive treatment option in the costal regions of North Carolina, where groundwater supplies are very common. Along the coast, land application can prevent salt water intrusion into freshwater aquifers, while further inland, land application may partially neutralize the impacts of growing urbanism and phosphate mining on the water table. The sandy coastal soils would allow high application rates, and inf act there may be a danger from soils which are *too* permeable. If infiltration is too rapid, then the wastewater could pass through the soil filter before renovation is complete, with a consequent pollution of ground water.

social impacts

Land treatment may impose real social costs on the residents of a community due to the enormous amount of land required. These costs, moreover, will be borne disproportionately by those living in the vicinity of the application site. For example, if we assume a site density of 50 people per square mile (about the average for Chatham County), the 3700-acre land requirements of the Durham-Chapel Hill example discussed earlier would require the forced relocation of abouth 300 people. In addition, those living near the site may find their property values lowered to reflect public distaste for waste treatment operations. As a result, one can visualize significant public opposition to land application, similar perhaps to the furor raised over the location of a sanitary landfill.

Both forms of opposition were evident during the land acquisition stage of the Muskegon County, Michigan, project. Residents within the site denounced the "Communist land grabbers," while elsewhere in the community a number of signs went up proclaiming "sewer city."[22] Nonetheless, these problems were overcome in spite of the project's colossal size.

The Muskegon experience suggests several avenues for overcoming public opposition. First, the public needs to be educated on the degree of health risk involved in a land treatment program. Public fears are probably greatly exaggerated. Second, the agency in charge should be very careful in relocating institutions of particular sentimental concern, such as schools, churches, or cemetaries. Third, local political leaders should be firmly committed to the project. Fourth, relocatees should at all times be treated generously and fairly. Though this may increase land costs somewhat, the land acquisition process will be speeded tremendously.

conclusion

As noted, land treatment often offers a substantial economic advantage over surface dishcarge systems in situations where advanced treatment is required. Prior to the passage of the 1972 Amendments, economic advantages were not perceived by local communities, because the cost of acquiring the land was not covered by federal grants made under the old Water Pollution Control Act. This meant that land treatment was discriminated against in favor of more capital-intensive methods. In the 1972 Amendments, the term "treatment works," for which federal grant monies could be used, was redefined to include "site acquisition of the land that will be an integral part of the treatment process or is used for ultimate disposal of residues resulting from such treatment."[24]

The 1972 Amendments also require that recipients of waste treatment construction grants consider alternative waste management techniques and apply the "best practicable waste treatment technology."[25] EPA's recently published draft guidelines for determining BPWTT[26] are quite favorably disposed to land treatment; in fact, these guidelines state that land treatment is the method of choice unless the evidence is clear that an alternative is superior in a given situation. These two aspects of federal policy should combine to make land application much more acceptable to local communities, and a rapid proliferation of land treatment sites is to be expected.

It is apparent from reading the guidelines and the 1972 Amendments that the federal decision to embrace land treatment was based entirely on cost-effectiveness criteria and on a commitment to encourage recycling as a national policy. Beyond a tacit assumption that the market value of the land would approximate social costs, the potential effects on community land use were evidently not considered. It should be clear, however, that a land treatment system may have a profound effect on land use, but not necessarily a detrimental one, especially if the community is prepared for it.

As planners, then, it would be appropriate for us to consider how land application might affect land use. For example, a land treatment site may be located in such a way as to affect the direction and intensity of growth. In addition, perhaps we should begin to investigate ways in which land treatment might be used in concert with other local objectives. Two examples will be given here. First, the land treatment site could be used as a park or public open space, as long as appropriate provisions to protect the public health were made. This is one alternative to using the site for agriculture, and in fact treated wastewater has been used to irrigate Golden Gate Park in San Francisco.[27] Secondly, a commercial airport could be surrounded by a land treatment site instead of residential development. Such social or land use criteria for location of the application site may conflict in some cases with economic or environmental considerations, but they should be part of the decision-making process.

Footnotes

[1]C.E. Young and G.A. Carlson, "Economic Analysis of Extending Land Spreading Technology to the Southeast," **Proceedings, Atlanta Workshop on Recycling Municipal Wastewater on Land**, Water Resources Research Institute, Clemson University (June,

1974).

[2]C.L. Barth, "Analysis of Findings and Priority Research Needs Related to Engineering and Management Aspects of Systems In Recycling Municipal Wastewater on Land," **Atlanta Workshop, op. cit.**

[3]"Water Treatment and Reuse by Land Application," Office of Research and Development, U.S. Environmental Protection Agency, (August, 1973). Disposal of high-BOD cannery waste by overland flow has resulted in BOD concentrations in the effluent being reduced from 800 mg/1 to 2 mg/1.

[4]"Draft Guidelines for Areawide Waste Treatment Management," U.S. Environmental Protection Agency, (May, 1974), Chap. 10.

[5]C.M. Weiss has conducted a number of water quality and preimpoundment studies on the Haw and New Hope Rivers. See for example "Water Quality Characteristics of the New Hope and Lower Haw Rivers—July 1966-February 1970," Report No. 48, Water Resources Research Institute of the University of North Carolina, Raleigh, N.C., (1971).

[6]Spray irrigation rates very between 1 and 2.5 inches per week, typically, while overland flow rates between 2 and 6 inches per week have been used. See "Water Treatment and Reuse by Land Application," **op. cit.**

[7]The 22-mgd flow allows for 1 mgd rainfall on the impoundment. Assuming that conditions are too wet to allow land application 10% of the time, or about 35 days per year, the effective rate is 1.8 inches per week.

[8]Assuming roughly a square application site, 300 acres will allow about a 100-yard buffer zone.

[9]"The Muskegon County Plan of Wastewater Reuse," **Public Works,** Vol. 45, No. 10, (October, 1973).

[10]J. Lamb **et al.,** "Preliminary Engineering Report: Chapel Hill, N.C. Wastewater Treatment Alternatives," Dept. of Environmental Sciences and Engineering, School of Public Health, University of North Carolina at Chapel Hill, (1973).

[11]"Water Treatment and Reuse by Land Applications," **op. cit.**

[12]R.R. Parizek et al., "Wastewater Renovation and Conservation," Pennsylvania State University Studies No. 23, University Park, Pa., (1967).

[13]Lamb, **op. cit.**

[14]G.A. Carlson and C.E. Young, "Economic Analysis of Adoption of Land Treatment of Municipal Wastewaters," Water Resources Research Institute of the University of North Carolina, Report No. 98, (1974), p. 5.

[15]86 Stat. 816.

[16]W.L. Lindsay, "Inorganic Reactions of Sewage Wastes with Soil," **Recycling Municipal Sludges and Effluents on Land,** Proceedings, Joint EPA-USDA Conference, Champaign, Ill., (July, 1973). See also R. L. Chaney, "Crop and Food Chain Effects of Toxic Elements in Sludges and Effluents" in the same Proceedings.

[17]"Water Treatment and Reuse by Land Application," **op. cit.** See also "Soil Microbiological Aspects of Recycling Sewage Sludges and Waste Effluents on Land," Proceedings, Joint EPA-USDA Conference, **op. cit.**

[18]"Water Treatment and Reuse by Land Application, **op. cit.**

[19]W. Leseman, "Engineering and Management Aspects of Systems Designed for the Recycling of Municipal Wastewater on Land," **Atlanta Workshop, op. cit.**

[20]"Survey of Facilities Using Land Application of Wastewater," Environmental Protection Agency, (1973).

[21]R.R. Parizek, **op. cit.**

[22]J.C. Postlewait and H.J. Knudsen, "Some Experiences in Land Acquisition for a Land Dipsosal System for Sewage Effluent," Joint EPA-USDA Conference, **op. cit.**

[23]**Ibid.**

[24]86 Stat. 844.

[25]86 Stat. 834.

[26]"Alternative Waste Management Techniques for Best Practicable Waste Treatment," Draft, EPA, Office of Water Program Operations, (March, 1974).

[27]"Survey of Facilities Using Land Applications of Wastewater," **op. cit.**