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PROCEEDINGS OF CONFERENCE ON LAND DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES

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LAND DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES

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LAND DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES

Symposium Chairman
R. W. Mason
U. S. Environmental Protection Agency, Region II

Welcoming Address
C. E. Hess
Dean of the College of Agriculture and Environmental Science
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Greetings to Conference

Land Disposal of Municipal Effluents and Sludges

Dean Charles E. Hess

March 12, 1973

It is a privilege to cooperate with the U. S. Environmental Protection Agency, Region II, in the sponsorship of this conference. The subject of Land Disposal of Municipal Effluents and Sludges has been of intense interest and study by our College for a number of years. Initially, we were concerned with disposal of animal manure. Incorporating it in the soil was one approach. Throughout the research we have tried to look at the problem from an interdisciplinary standpoint - Dr. Kaplovsky's Department of Environmental Sciences has been monitoring the quality and the fate of sewage sludge and microbial aerosols produced in the incorporation of sewage sludge in the soil. Scientists in the Soils and Crops Department have been studying the interaction between soils and the components of the sludge - nutritive components and potential heavy metal problems. They are also concerned with the use of crops to remove nitrogen that is released during the decomposition of sewage sludge. The Biological and Agricultural Engineering Department has developed a delivery system to incorporate solid wastes into the soil. We are fortunate to have General William Whipple of the Water Resources Bureau on our campus to provide support and concern for water quality in areas used for sludge disposal. The results of the initial studies indicate the concept is feasible but not without problems such as potential ground water contamination and heavy metal contamination of soil even from domestic sludge.

Although there are problems, the potential is great. We see the use of land as a disposal site and assimilator of municipal effluents and sludges as a way to help maintain open space in New Jersey and to bring together in a muturally beneficial way an urban problem with agricultural production. If the problems can be overcome and if we do not end up trading one pollution problem off for another, we will have gone a long way to solving a critical problem for municipalities in such a way that we enhance the productivity of our environment.

You have a distinguished group of speakers and they will explore all the aspects of the problem. I am sure when you leave this afternoon you will have a much greater appreciation for the complexity and the potential of Land Disposal of Municipal Effluents and Sludges.

If there is anything we at the College can do to make your stay more comfortable and rewarding, please let us know - we are here to serve you.

Sludge Characteristics of Municipal Solids

by

A. J. Kaplovsky*and E. Genetelli**

Everyone knows the practice of land disposal of human, animal and vegetable wastes has been in existence for many centuries. The practices can vary from the most primitive to the most complex. The degree of sophistication is dependent upon the local, social and economic conditions and the sludge characteristics.

Some of you may have seen and experienced as I have the land disposal procedures of the far East where waste application produce a stalk of celery 6 inches in diameter and over 2 feet long. How is it possible to maintain soil fertility year after year with natural fertilizers when they contain less than 1/3 of the important constituents present in the "so-called" complete fertilizers of today?

These farmers knew very little or cared less about how much N, H_3PO_4, or potash were in their wastes. Raw experience of trial and error told them that laddling annually a thick slurry of foul smelling natural wastes around their plantings produced a luscious looking green crop. They knew very little or cared less about the scientific explanations. They just knew it worked! They didn't choose to use human waste because its organic form of nitrogen is of longer duration and that the plant fed more continuously. They were oblivious to the countless billions of little nitrogen fixation factories found in sludge which take nitrogen from the air and convert it to the form of nitrogenous compounds easily assimilated by plant life. The importance of organic matter and its moisture retention characteristics was wasted on these farmers. Nor did they care how such sludges keep dissolved nutrients in contact with roots for a much longer time than would otherwise be possible; or how sludges may help heavy clay soils become more porous and workable. It is not known whether these farmers were forced to use these partially decomposed slurries because they had to fertilize annually. Perhaps they could not wait the two or three years for stabilized odorless organic residue to reach equilibrium under natural conditions. It is also not known whether they tried both types of fertilizers and

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found the foul smelling slurry was more effective than the stabilized solids. It is rather certain however these farmers were not aware that by permitting their wastes to "sour" the early acidification and liquefaction stages of sludge digestion were set in motion wherein growth promoting substances were being produced from indole and skatole in the form of indole acetic, indole propionic and indole butyric acids. The odorous butyric acids and mercaptans produced during initial stages of degradation did not deter them from using such material. I recall my experience in the late 30's as a laboratory assistant while looking for the presence of growth promoting by-products indole and skatole in solids wastes. The thing I most vividly recall is that the most repulsive smelling flesh scrappings from animal hides had the highest content of indole and skatole.

This practice of "night soil" application represents the extreme end of the spectrum from which we wish to escape. The parade of oxen drawn "honey carts" carrying the foul smelling slurries is something most of us who have seen this want to forget but can not forget. More importantly, we must recognize the tremendous health problem associated with such ancient practices. While in Korea, my roommate, who was a pathologist, examined hundreds of stool specimens and found 85% of the Koreans had one to three intestinal diseases. Obviously the chance of disease negates any advantages of such procedures. We must direct our attention to the problem of handling stabilized solids.

The rate of solids accumulation has reached such proportion that we can no longer depend upon the trial and error approach of the past to solve a problem which now demands a very high degree of control and perhaps reuse. As many of your are aware, restrictions on ocean dumping have increased. Further, recent stack analyses utilizing current combustion practices of plain domestic solids makes it questionable whether this direction will be acceptable for very long. The traditional trial and error approach which evolved from art to invention toward science must now be reversed wherein the science must precede the invention and art.

Thirty-five years ago, Dr. Wilhelm Rudolfs, the first Chairman of our Department of Environmental Sciences and in my opinion, a sage in the art of waste treatment, made the profound statement that waste treatment is only as effective as its solids handling capability. It was not until recent years that most professionals in the field were fully confronted with or forced to fully examine the magnitude of this phase of the problem. How often have you seen enforcement guidelines that have specific constituent limitations for the liquid effluent discharge and in another section merely state that the accumulated solids be disposed of "in an acceptable manner," without further stipulation? Perhaps the problem was so complex that they were loathe to attack it. Heretofore, the handling of the dilute solids systems has always been one of initially dewatering or further concentrating the suspended and dissolved solids phase. The ultimate disposal of such concentrated solids were given comparatively little attention or control.

If we are to avoid repeating our past mistakes we must invoke certain basic rules. (1) The conditions under which land disposal is to operate must control the characteristics and composition of municipal waste solids to be applied not vice versa. Presently, solids handling at the source produces sludge pursuant to the state of the art and then a suitable means of ultimate disposal is sought. Unfortunately, more often than not, the two are not congruent thereby forcing less than completely satisfactory solution implementations simply because sludge is a daily occurrence and something must be done in haste to overcome such accumulations. (2) In a densely populated and an industrial society, the dilution concept - out of site out of mind - has rapidly become infeasible or unacceptable. In fact, new legislation and developments have made it suspect to continue discharge of solids to the ocean and/or combustion of such solids. In effect, these turn of events have made it mandatory to reconsider land disposal as a major outlet. (3) We must be more searching and knowledgeable before we give our blessing to massive land disposal as a relatively simple technological solution. It has also become a difficult social and economic problem.

Solids in its various forms reaching municipal systems have as their origin, the water supply, bathroom, kitchen, commercial establishments, street wash, storm water, infiltration and industrial wastes. The physical state of these solids, whether they be suspended, colloidal or dissolved are largely influenced by their mode of transport, freshness or age of waste waters, temperature, pH or presence of industrial wastes. Constituent concentration and composition will vary hour to hour, day to day, season to season, year to year depending upon the habits of the people; waste collection practices; plant design and the type of contributions to the system. Solids will not only appear as suspended, dissolved or colloidal material but will occur as grit and scum. At best municipal solids may show general similarities on occasion. However to seek reproducible constituent content and concentration would be like "looking for a needle in a haystack".

Certainly, we can surmise that certain elements will be present which had as their origin our food, our water supply, street wash or grit, or our industries. Further, and to a large extent we can assume these elements originated from natural sources and by means of land disposal we would be returning these elements from whence they came. However, land disposal sites for developed communities would rarely be located where the food was grown or the chemicals withdrawn. Any concentration of people and/or development will result in a concentration of these elements thereby compounding the waste handling problem.

A basic objective is to prepare this conglomerate mass of solids for land disposal. Such preparation must be related to the land disposal management systems under consideration. Ideally, the sludge should be well digested, innocuous, readily dewaterable and "essentially" domestic. Unfortunately domestic type waste is a rarity. We must assume all such wastes are typically municipal in nature and containing heavy metals. Further, the constituent levels in the sludges now being produced and the solids handling facilities in situ will dictate or limit land disposal practices. Presently we are being forced into adopting land disposal management procedures to handle the type of waste we have on hand rather than control the waste composition at the source so that the best possible land management practices could evolve.

Except for certain coastal cities, most municipal plants have special facilities for concentrating, digestion, dewatering, stock piling and dumping which represent large investments.

Assuming ocean disposal and incineration are tentatively shelved, a number of large cities or metropolitan areas should be seeking land disposal sites. Unfortunately, suburban developments preclude such sites being close at hand. Additionally, the land will be sufficiently costly that strong efforts will be made for sludge loadings at the "disposal" level rather than at the reclamation level.

Sludge pumping will be proposed for large areas handling large single sources, whereas for small land sites and/or smaller plants dry cake transport may prove more feasible. Consequently, sludge handling and/or preparation at various waste treatment plants of necessity will differ.

Known waste-solids treatment processes usually are designed for a) reducing sludge volume and b) destruction or stabilization of such solids. Four basic processes are used: a) concentration, b) digestion, c) dewatering and d) heat drying and combustion before final disposal. The problem of disposal of a particular sludge or solids residue requires the professional to make several major decisions in arriving at the most economical solution. Once he has evaluated the available possibilities for disposal of the final residue, he must determine which combination, if any, of the four major procedures will furnish an optimum solution.

The characteristics of a specific waste residue will control in large measure the success or failure of handling of such residues. Perhaps the best example I can give is my experience with the Zimpro process while I was at the Metropolitan Sanitary District at greater Chicago. Here, we had a process that was capable of total destruction of all organic matter in the sludge solid feed. What would be better than having a capability of destroying all organic matter? The rub was we were left with waste solids and a liquid by-product that exhibited some very annoying characteristics. For example, the process itself produced as part of its residue a suspended mixture which looked and poured like coffee until a concentration as high as 42½% solids was reached. One can readily appreciate the difficulty of concentrating to this level in order to obtain separation and the costs involved. Another portion of the residue was so abrasive that our pump impellers would be completely eroded within a very short period of time. Additionally, our Utopian destruction of organic matter produced new liquid by-products with extremely high pollutional load characteristics which required recycling for further treatment.

Sludge treatment processes and methods of final disposal can be classified as follows:

A. Concentration

1) Clarifier thickening
2) Separate concentration
   (a) gravity thickening
   (b) floatation
   (c) centrifugation

B. Digestion
1) Aerobic
2) Anaerobic

C. Dewatering
1) Drying beds
2) Lagoons
3) Vacuum filtration

D. Heat drying and combustion
  1) Heat drying
  2) Incineration
    (a) multiple hearth
    (b) fluid solids
  3) Wet oxidation

E. Final sludge disposal
  1) Landfill
  2) Soil conditioning
  3) Discharge to sea

Ironically, if one is to consider only the above most widely used methods, it is possible to arrive at approximately 900 process combinations for sludge residue treatment and disposal. The success of the overall sludge disposal system depends on how well the various processes are integrated to meet economically the disposal requirements for a particular situation.

In municipal waste treatment, the raw preliminary solids and the subsequent biological flocks from the secondary system can vary considerably from plant to plant. The biological sludges are bulky and do not concentrate as well as preliminary solids. Some of the important factors which control the final solids concentration produced is the initial concentration of the sludge to be thickened, the density of the particle, their size and shape, the temperature and the age of the sludge, ratio of organic to inorganic and, for activated sludge, the design of the process itself.

The aim of solids concentration is to produce as thick a sludge as possible. However, it is not always desirable to achieve a solids concentration in excess of 10% since these sludges are difficult to pump. Experience shows that solids concentration prior to dewatering is not considered a benefit to the drying process itself, such as for drying beds. However, solids concentration may be of significant benefit to mechanical dewatering. These are just a few examples of what is being done to prepare waste solids for ultimate disposal. More importantly, we must recognize the fact that a uniform product will be the exception rather than the rule.

Let us make a more in-depth examination of composition aspect. Table I shows the constituent concentrations present in two liquid sludges from very large municipal systems having the same water supply. The wastewater entering these two plants are quite weak even though sizeable industrial loadings are involved. The resultant constituent concentrations are not considered excessive under the circumstance. However, the contributions of copper, zinc, chromium and lead are certainly worth noting. Recently, in

TABLE I

Analyses on Digested Sludge Solids*

	Plant A mg/l	Plant B mg/l
Total-N	1,512	1,542
Ammonia-N	528	608
Chloride	490	350
Sulfur	45.5	53.0
Phosphorus	677	645
Potassium	114	105
Sodium	129	78
Calcium	1,180	811
Magnesium	332	228
Boron	0.85	1.2
Manganese	14.3	4.5
Copper	32.4	46.3
Zinc	91.9	147
Molybdenum	<0.01 %	<0.01 %
Iron	1,666	662
Nickel	trace	10.2
Cadmium	1.9	10.6
Chromium	46.2	81.4
Aluminum	(227)	(173)
Silicon	(9800)	(5200)
Grease	1,477	1,469
Residue (103°C)	27,500	22,600
Sol. Salts via El. Cond.	(3800)	(3600)
pH	7.0	7.2
Total Alkalinity	55 meq/l	52 meq/l
Lead	89.9	19.2
Ash	13,200	10,200

*Derived from large municipal WWT systems receiving weak raw wastewater with appreciable industrial loads.

conjunction with our land disposal study, we examined five strictly domestic sludges and the findings are shown in Table II. Interestingly, although the constituent concentrations were lower than the municipal sludges (see Table I) they were within the same order of magnitude.

Are we to assume that background or domestic waste sludge will have appreciable amounts of heavy metals and as such reflect the habits of the people exclusive of industrial contributions?

More recently, the Interstate Sanitation Commission distributed its 1972 Annual Report which contains some very illuminating results of influent and effluent constituent concentrations at all their plants. Data (shown in Tables III and IV) was abstracted from this report and represents the 50% and 95% cummulative frequency distribution. The primary plant data (Table III) includes operations receiving heavy industrial contributions whereas the aerobic secondary systems are receptors of generally weaker waste loads. The values in parentheses indicate effluent concentrations. The reduction in constituent levels between influent and effluent should represent what is removed in the sludge phase.

A 2 Mgd plant or 14/MG week can expect a maximum 35,000 gallons of 3-5% digested solids per week. However, this normal digestion operation results in a very interesting concentration factor or roughly 40 fold. Plant influent and effluent concentration differences of as little as .05 ppm or 50 ppb as seen in Table IV will result in a concentration of 20 ppm in the final liquid sludge. Therefore, very small removals of heavy metals found in wastewater influents as shown in Table IV at 50% Cummulative Frequency Distributions should result in the following levels in the digested sludge:

Copper	=	20 ppm
Zinc	=	32 ppm
Iron	=	160 ppm
Mercury	=	.16 ppm

In Table V are shown the pounds/ton of certain constituents found in various sludges. Since these represent current composition it must be assumed these are the loadings we must contend with, and design our land disposal management practices accordingly. In the future with strong pretreatment controls in effect perhaps we will be able to maintain our municipal solids composition at levels to maximize available land use and management. However, at present we must work with what we have and the constituent composition can conceivably limit ultimate disposal applications. For example the following factors have a bearing on eventual constituent levels and whether a problem will arise or how the sludge must be prepared for transport.

TABLE II

Composition of Anaerobically Digested Liquid Wastewater Solids from Essentially Domestic Waste Systems

	Lakewood	Bernardsville	Neptune	Marlboro	Greystone
pH	6.9	7.2	7.2	7.1	7.0
T.S.	3.7 %	4.5 %	6.6 %	3.0 %	6.6 %
T.V.S.	69 %	62.6 %	43.2 %	66.5 %	41.2 %
Ash	31 %	37.4 %	56.7 %	33.5 %	58.7 %
K-N	1910 ug/g	1870 ug/g	2296 ug/g	1460 ug/g	2380 ug/g
T.Ph.	1200 "	600 "	2000 "	960 "	500 "
Fe	1535 "	430 "	2048 "	589 "	960 "
Mn	0.2 "	7 "	19 "	19 "	14 "
Mg	124 "	130 "	119 "	68 "	385 "
Ca	2020 "	1700 "	3530 "	770 "	4770 "
Na	34 "	20 "	280 "	26 "	24 "
K	23 "	40 "	36 "	91 "	74 "
Cd	2 "	0.5 "	1.25 "	0 "	0.5 "
Pb	26 "	20 "	189 "	12 "	25 "
Cr	2 "	0 "	5.6 "	2.8 "	2.5 "
Cu	32 "	49 "	54 "	21 "	68 "
Ni	2 "	1.5 "	2.7 "	4 "	1.7 "
Zn	114 "	94 "	90 "	64 "	76 "
Al	206 "	305 "	458 "	224 "	934 "
Hg	9 "	4 "	14 "	4 "	0 "

<u>Table III</u>

Municipal Treatment Works in ISD - **

Primary Plants Influent, mg/1

	Cummulative Frequency Distribution 50%	95%
B.O.D.	207	520
T.O.C.	92	273
T.S.S.	174	355
Orthophosphate	5.48	12.70
NH_3-N	16.4	36.80
Copper	0.10 (.10)	1.15 (.65)
Zinc	0.20 (.18)	1.56 (1.42)
*Chromium	<.50 (<.05)	0.5 (0.45)
*Lead	<.20 (<.20)	0.6 (0.40)
Iron	1.0 (0.8)	5.3 (4.8)
*Nickel	<0.1 (<0.1)	0.6 (0.5)
*Cadmium	<0.02 (<.02)	0.04 (.06)
Manganese	0.16 (0.16)	0.36 (0.40)
Mercury	.0012 (.0009)	0.0088 (.01)
*Silver	<.05 (<.05)	<.05 (<.05)
*Cobalt	<.05 (<.05)	<.05 (<.05)

*Most values below lower detectable limit
**1972 Annual Report
Note: ( ) effluent concentration

Table IV

Municipal Treatment Works in ISD - **
Secondary Plants Influent, mg/l

	Cummulative Frequency Distribution	
	50%	95%
B.O.D.	176	325
T.O.C.	64	162
T.S.S.	161	327
Orthophosphate	4.99	11.13
NH_3-N	18.90	39.0
Copper	.10 (.05)	0.40 (.25)
Zinc	.16 (.08)	0.54 (.26)
*Chromium	<.05 (<.05)	0.35 (.15)
*Lead	<.02 (<.02)	<.02 (<.02)
Iron	0.8 (0.4)	2.3 (1.5)
*Nickel	<.1 (<.1)	0.3 (0.2)
*Cadmium	<.02 (<.02)	0.02 (.02)
Manganese	.1 (.1)	0.38 (.38)
Mercury	.0013 (.0009)	0.008 (.0059)
*Silver	<.05 (<.05)	<.05 (<.05)
*Cobalt	<.05 (<.05)	<.05 (<.05)

*Most values below lower detectable limit
**1972 Annual Report
Note: ( ) effluent concentration

Composition of Municipal and Domestic Sludges

TABLE V. RANGES IN No/TON

	Municipal 1950	Municipal 1966 (Two Wastes)	Domestic 1973 (Five Wastes)
Total N	42	106 - 136 (121)	70 - 103 (86)
P	16	47 - 57 (52)	15 - 65 (46)
K	7	8 - 9 (8.5)	1 - 6 (2.5)
Ca	95	72 - 83 (77)	51 - 144 (97)
Mg	22	20 - 22 (21)	3.6 - 11.6 (6.4)
Hg	—	—	0 - .5
Cu	16.0	2.3 - 4.1	1.4 - 2.1
Zn	20.0	6.4 - 13.0	2.29 - 6.2
Ni	trace	trace - 0.9	.05 - .27
Cd	—	.13 - .94	0 - .11
Cr	5.0	3.2 - 7.2	0 - .19
Al	72	15 - 16	11 - 28
Pb	15	1.7 - 6.3	.8 - 5.7 (1.9)

1) Land availability - Can you obtain a parcel of land with a buffer zone to handle present and future needs?

2) Soil porosity and structure - Is the soil sufficiently porous so that a liquid sludge can lose its free water by seepage and evaporation within a reasonable time period?

3) Ground water quality - Is the ground water aquifer a prime source of water supply?

4) Reclamation - What is the maximum loading per acre and still maintain crop growth?

5) Sludge disposal - Is available land so limited that loadings must exceed maximum levels permissable for proper crop growth but not destroy drainability?

6) Site location - Is the disposal site within pumping distance economically? Are right of ways attainable for force mains and pump stations?

7) Site size - Should more than one site be needed to handle the total load, is it feasible to pump sludge to more than one location?

8) Plant size - Treatment plants vary considerably in size and sludge production. Is pumping feasible for a plant producing 25,000 gallons of 5% solids per week? 50,000 gallons per week? 100,000 gallons per week? Or should such plants produce a dry cake and transport by truck? Where is the cut-off point whether to handle a dry cake or liquid sludge.

9) Temperature and rainfall - Is site location subject to severe winter conditions and/or precipitation? Is storage or stock piling space available at the treatment plant or disposal site? Each have definite advantages.

It is readily apparent as we increase our loadings per acre the economics should improve. At the same time, however, residual constituent concentrations increase whereby land reclamation or crop growth can be effected detrimentally. Presently, Rutgers is investigating the impact which sludge application of 10, 20, and 40 tons/acre will have on soils, crops and ground water including other environmental considerations.

In Table VI are shown the effect of constituent magnification for a Domestic and Municipal sludge. Please note certain assumptions

TABLE VI. CONSTITUENT AVAILABILITY IN DOMESTIC AND MUNICIPAL SLUDGES FOR CROP GROWTH

	Domestic		Municipal	
	No/ton	No/ton	No/ton	No/10 ton
Total N[1]	103	(930)	106	(960)
P	65	(624)[2]	47.3	(447)[3]
K	1.25	12.5[2]	8.0	(47)[3]
Ca	109	1090	82.6	826
Mg	6.7	67	20	200
Hg	.49	5	—	
Cu	1.73	17.3	2.3	23
Zu	6.2	62	6.4	64
Ni	.11	1	trace	—
Cd	.11	1	0.13	1.3
Cr	.11	1	3.2	32
Al	11.2	112	15.9	159
Pb	1.4	14	6.3	63
Org. Mat.	1385	13,850	1000	10,000

(1) If we assume 10% of N available and a 10-6-4 nitrogen-P_2O_5-K_2O ratio. (2) P= 25 times too much; K= 39% of need. (3) P= 18 times too much; K= 2.4 times too much. ( ) means excess.

were made based upon present knowledge in that no more than 10% of the nitrogen would be available for plant development and that at 10/6/4 ratios for nitrogen, P_2O_5 and K_2O the nitrogen would be just adequate at a 10 ton/acre loading. However, at a ten ton loading of domestic sludge the Phosphorous would result in a 25 fold excess and in the municipal waste the excess would be 18 fold. Additionally, unanswered would be the fate of the excess nitrogen. Would it be converted to nitrate and end up as ground water contamination or released as nitrogen gas? We should concern ourselves with the phosphate levels since experimental evidence exists demonstrating that excessive phosphate can create toxicity to plant growth. The various heavy metal concentrations at the 10 ton rate are significant. At higher 20 and 40 ton/acre applications the constituent concentrations would increase proportionately and certainly must take into account a number of factors which effect the availability of constituents for plants. Some of these factors are

1) the rate of application and availability of a heavy metal such as boron, copper, zinc, chromium, cadmium, lead and nickel. 2) The total amount applied. 3) The cation exchange capacity of the soil and base saturation. 4) The soil texture. 5) The soil organic matter content. 6) The soil pH.. 7) Interaction of metals such as copper and zinc or B and Mo which interact positively. 8) The crop and even the variety of the crop. If we have to superimpose upon the above important considerations the inherent variability of composition found in municipal waste sludges, the task of crop management become exceedingly complicated and the outlook for uniform procedures is exceedingly dim. We must move on basis of fact before we include the benefits from crop growth as part of the cost benefit ratio.

In light of existing constituent composition found in waste sludges, the inherent concentration variability and the many factors which must be considered for crop management the true feasibility or economics of land disposal is largely unanswered. We must remain cognizant of the complexity of the problem as it now exists and the investigational needs before we can assess the impact of such disposal techniques. However, we mustn't lose sight of the potential of land disposal. In fact we might even consider the possibility of supplementing digested sludge with artificial fertilizers so that a more balanced application could be achieved under certain circumstances. Adding chemicals such as lime to tie-up some of the more toxic heavy metals which are now present in municipal waste solids is another possibility. In short, the practices of ultimate disposal, its management, the economics and social implications are directly or indirectly related to the composition or the character of the material requiring disposal. If a change in land disposal procedure and use is contemplated a re-evaluation of the constituent content impact and all its ramifications must be taken into consideration. Based upon current levels it is highly probable where a constituent concentration is acceptable under one set of circumstances it can become a significant problem under a different set of conditions.

DISPOSAL AND REUSE OF SLUDGE AND SEWAGE: WHAT ARE THE OPTIONS? *

by

Robert B. Dean **

A broad outline of the properties of the solids present in municipal wastewater disposal systems has been presented by Professor Kaplovsky. At the risk of a little repetition, I want to review briefly some of these properties and the quantities involved if we are to utilize the land for waste disposal. The numbers I will quote will be easy to remember approximations to the more exact figures available in textbooks and in various papers at this symposium. Table I summarizes the data in both metric and English units for your convenience.

Each person produces about 100 gallons per day or 12 cubic feet of sewage. This will cover 1,000 square feet to a thickness of just over one-sixth inch. One-sixth inch a day or nearly four feet per year is a reasonable infiltration rate for many soils. A city of 100,000 such as Trenton, New Jersey, producing 10 million gallons a day would use 100 million square feet or nearly 2,000 acres to dispose of its domestic sewage by infiltration. Higher infiltration and evaporation rates are, of course, possible in good soils and favorable climates. However, we all know areas where septic tank drain fields are ineffective because the soil will not accept even minimal quantities of water.

The solids in sewage amount to about 0.2 pounds per person each day. They can be concentrated in about one-half gallon of sludge at 5 percent

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solids which contains, of course, nearly one-half gallon of water. From the point of view of transport and disposal it is obviously easier to take care of one-half gallon of water than of 100 gallons.

The quantity of sludge solids which can be assimilated on an acre of land in a year is about 20 tons. Your city of 100,000 people produces 10 tons of dry sludge solids each day so they will need about 180 acres to take care of all their sludge. The sludge solids will be dispersed in 50,000 gallons of water each day which is only one-half of one percent of the total wastewater produced.

The Chicago Metropolitan Sanitary District treats over one billion gallons of wastewater per day. They would require about 360 square miles of land for sewage spreading or about 25 square miles for sludge spreading not including sludge from industry, according to my estimates. The total population of this country is over 200 million. We use about 20 billion gallons of water a day. If all this wastewater were to be spread on the land, it would require 7,200 square miles devoted to sewage irrigation. This is an area slightly larger than that of the state of New Jersey. Sludge from all of the people in the United States would require about 570 square miles. This area is a little less than that of Ocean County, New Jersey.

The use of the land for treatment and disposal of wastewater obviously involves substantial problems in transportation but reduces the treatment required. If good sewage treatment is practiced, our surface waters are still acceptable places to dispose of wastewater, provided that it is clean enough. However, surface waters are no longer acceptable places to put sludge solids.

Since this day's program is to be devoted to sludge disposal with sewage disposal coming tomorrow, I will say very little about the treatment and recovery of wastewaters by what has been called "The Living Filter." Treatment and recovery is one form of disposal, and a very acceptable one too, when it confers economic benefits.

The Living Filter is, of course, the soil with the living organisms, mostly microbial, which it contains. Soil microorganisms thrive on the organic matter in sludge and oxidize it to CO_2 in a relatively short period. The quantity of organic matter that can be decomposed in a year depends on many circumstances, especially climate, but it is large. We studied one example in Texas where almost one foot of waste oil, essentially 100 percent organic, was broken down by soil microorganisms each year (Dotson, Dean, Kenner, and Cooke). This is a rate of 1000 tons/acre. A fraction of the organic matter is converted to relatively inert humus but even that has a short life in a well-aerated soil as anyone who has put peat moss on his garden can testify. My six-foot high pile of dead leaves weathers down to a foot by the next summer. I dig the residue humus into my small garden and the soil takes all I can give it. For practical purposes, however, the rate of decomposition of organic matter does not limit the quantity of sludge we can apply anymore than the rate of infiltration of water limits it.

When sludge is applied to the land, water drains intp the soil, is evaporated, or is used by growing plants. Organic matter is oxidized to CO_2. Inert minerals derived from the dirt on our clothes are, of course, dirt, a synonym for soil or earth, and there is no practical limit to the quantity we can apply to the soil. We must look among the soluble pollutants to find a limiting factor. Mr. Dotson will be talking about "Constraints on Sludge Spreading," so I will not try to give his paper for him. I am indebted to him for the factor of 20 tons dry weight of sludge per acre year which I used earlier. This factor is based upon the ability of the soil, and the crops growing on it, to assimilate and degrade the nitrogen present in ordinary sludge.

Nitrogen and phosphorus, two of the three major nutrients which must be listed on every bag of fertilizer, are the two substances which are really recycled when sludge or sewage is applied to the land. None of the organic matter can be absorbed by plant roots although the humus serves a temporary function controlling the physical character of the soil. Micro-nutrients may occasionally be supplied in useful quantities but many soils have no need for them. In arid areas, of course, the irrigation value of the water supplied can be significant. Even in sludge studies the best increase in yields of corn came in dry years when the water content of the sludge served a vital role.

Nitrogen is present in many forms in our biosphere (Figure 1). Most of it is inert and nutritionally useless in the air as nitrogen gas, N_2. In sludge we find nitrogen as organic compounds and as ammonia, NH_3. Oxidation of ammonia by microorganisms produces nitrites, NO_2^-, which are quickly changed to nitrates, NO_3^-. NH_3 and NO_3^- are useful plant nutrients but growing crops have a limited capacity to use them. Any excess of nitrogen compounds over that which is taken up by the plants will leave the soil by one of two routes. Nitrates can be degraded microbially to nitrogen gas if organic matter is present and the soil is not well aerated. This destruction of combined nitrogen accounts for a significant fraction of the nitrogen applied to the soil as fertilizer. However, when an excess of combined nitrogen is applied to the soil some will show up in the ground water.

Phosphates have been blamed for many of the bad effects produced when wastewater is discharged to surface waters. If wastewater is spread on the land, the soil minerals can adsorb almost unlimited quantities of phosphates from the water that percolates down. Clean sand, however, has a very low capacity for adsorbing phosphates.

Conventional sewage treatment normally removes less than a third of the phosphates in wastewater. Many treatment processes, therefore, have been developed to remove phosphates from wastewater before it is discharged or reused. All of these schemes concentrate the phosphates in the sludge as an insoluble residue.

Phosphates in sludges, except for a small fraction bound in organic compounds, are present as calcium, iron, aluminum, or magnesium phosphate depending on the process used. Calcium and magnesium phosphates are reasonably available to plants in neutral soils, and the ratio of Nitrogen to Phosphorus applied in sludges is within the range of normal fertilizer applications. When phosphates are removed from wastewater by precipitation with iron or alum, however, the sludge contains phosphorus in a relatively unavailable form. Precipitates of iron or aluminum phosphates can persist in the soil for long periods slowly liberating their phosphorus to growing plants. These precipitates otherwise behave like inert soil minerals which can be tolerated in large amounts. An excess of iron or aluminum can tie up phosphate which might otherwise be available. Some chemical treatment of municipal wastes uses iron or alum in excess of the quantity necessary to precipitate phosphates but the absolute quantities of metal involved are small relative to the phosphate content of normal soils.

We can contrast the behavior of the fertilizer elements N, P, and K as follows: Nitrogen is used rapidly, any excess is destroyed or leached out by ground water with a small organic fraction remaining for successive seasons. Phosphorus is conserved in the soil and will eventually be used by growing plants. We can say that phosphates are bad for our waters but good for our soil. There is so little potassium in normal sewage that we can ignore it.

A large number of minor elements are needed by growing plants in quantities less than N, P, and K. Although most soils already have enough of all the essential minor elements, there are many examples of soil deficiencies which can be corrected by the minor elements contained in sewage or sludge. Unfortunately, it is possible to get too much of a good thing and an excess of an essential element above that necessary for growth can produce toxic symptoms. The exact quantity of a given element that can be tolerated in a soil depends on the plant species and strain and on the other substances present in the soil.

Zinc is a classical example of a minor element which is absolutely essential for plant growth but which produces toxic reactions when applied in excess. One of the first recorded examples of toxic effects from what was then called Sewage Farming took place at Paris, France. After several decades of applying sewage to the land, crop yields fell off because of an excess of zinc. Zinc gets into sewage from plumbing, paints, and especially from the use of zinc table tops in the French kitchens. In Nottingham, England, they apply sludge on the sewage treatment plant farm. Layers six inches thick are laid down, dried, plowed, and then farmed for six years before putting on more sludge. I was told that zinc poisoning was diagnosed on one field but was easily corrected by treating the field with lime.

Lime raises soil pH and converts most toxic metals to forms which are less soluble and hence less available to plant roots. The toxic effects of zinc, cadmium, copper, nickel, and lead can all be controlled by suitable treatment with lime. Organic matter naturally present in sludge also binds quantities of heavy metals which would otherwise be toxic.

For long term applications, the quantity of heavy metals in sewage or sludge may limit how much we can apply to a given plot of land. Unfortunately, we do not know nearly enough about plant tolerances and soil chemistry to be able to predict today just how many years we will be able to continue applying municipal wastes. We do know that we can control excess industrial discharges, such as copper from an electroplating shop, if it is economically desirable to do so.

Salts are generally unwanted in the soil or ground water. In areas of high evaporation, salts will accumulate in the soil from any form of irrigation and unless they are flushed away they will eventually kill the soil. Salts are a problem west of Kansas City but are seldom a problem in the East where rainfall exceeds evaporation and the excess moves through ground or surface waters to the sea. Salts in sewage or sludge are always greater than in the municipal water supply, usually by a factor of two in sewage from eastern communities. Some treatment processes significantly increase the salt content of wastes and may therefore be unsuitable in arid areas. Desalination is no cure except near the seacoast because the salt removed must be put somewhere.

Sludge can, of course, be stored in a landfill, preferably after most of the water has been removed. If the landfill is properly designed, it will be a form of permanent storage of no agricultural significance except for a change of land contour. If the landfill is not properly designed, toxic materials may leach out to contaminate surface and ground waters.

The soil utilizes water or passes it on to surface or ground waters. Organic matter is destroyed by soil bacteria after it has served its purpose as humus. Soluble salts remain with the water and are concentrated to toxic levels only in arid areas. Nitrogen is used at once if there are growing plants to make use of it; only a fraction is stored for later seasons and an excess may reach the ground water as nitrates. Much of the phosphorus has limited availability but it is all conserved by the soil for eventual use. Heavy metals are bound in the soil where they are available for plant use but where they may reach toxic levels. Insoluble minerals are conserved by the soil and eventually raise the salt level.

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TABLE I

REPRESENTATIVE QUANTITIES AND AREAS FOR SLUDGE AND SEWAGE

		U.S.	Metric
	WATER		
1.	One person uses per day	100 gal.	400 l
	or	12 cu.ft.	0.4 m^3
	This will cover	1000 sq.ft.	100 m^2
	and infiltrate per day	1/6 inch	4 mm
	WATER		
2.	100,000 people (Trenton, N.J.) use	10 MGD	40,000 m^3/day
	If spread	1/6 inch	4 mm
	This would cover	2000 acres	1,000 hectare
	or	3.6 sq.mi.	10 km^2
	The total water per year will be	60 inches	1,500 mm
	SLUDGE		
3.	One person produces per day	0.2 lb.	0.1 kg
	at 5% solids contained in	0.5 gal	2 l
	100,000 people produce solids per day	10 ton	9 Ton
	LAND ASSIMILATION OF SLUDGE		
4.	One acre can assimilate per year	20 ton	
	One hectare can assimilate per year		45 Ton
	100,000 people need	180 acres	70 Hectare
5.	Chicago Metropolitan Sanitary District		
	Waste water per day	1 Billion gallons	4×10^6 m^3
	Sludge per day	1000 ton	900 Ton
	For irrigation of wastewater	360 sq.mi.	1,000 km^2
	Spreading of sludge	25 sq.mi.	70 km^2
	THE USA - WATER		
6.	200,000,000 people use per day	20 Billion gallons	80 million m^3
	Irrigation would require	7200 sq.mi.	20,000 km^2
	This is a little more than the area of New Jersey		
	THE USA - SLUDGE		
7.	200,000,000 people produce per day	20,000 tons	18,000 Tons
	Spreading would require	570 sq.mi.	1,500 km^2
	This is a little less than the area of Ocean Co., N.J.		
	DECOMPOSITION OF ORGANIC MATTER (oil)		
8.	In Texas soil, per year	1 foot	30 cm
	Per acre year	1,000 tons	900 Tons
	Dotson et al., 1971		

THE NITROGEN CYCLE

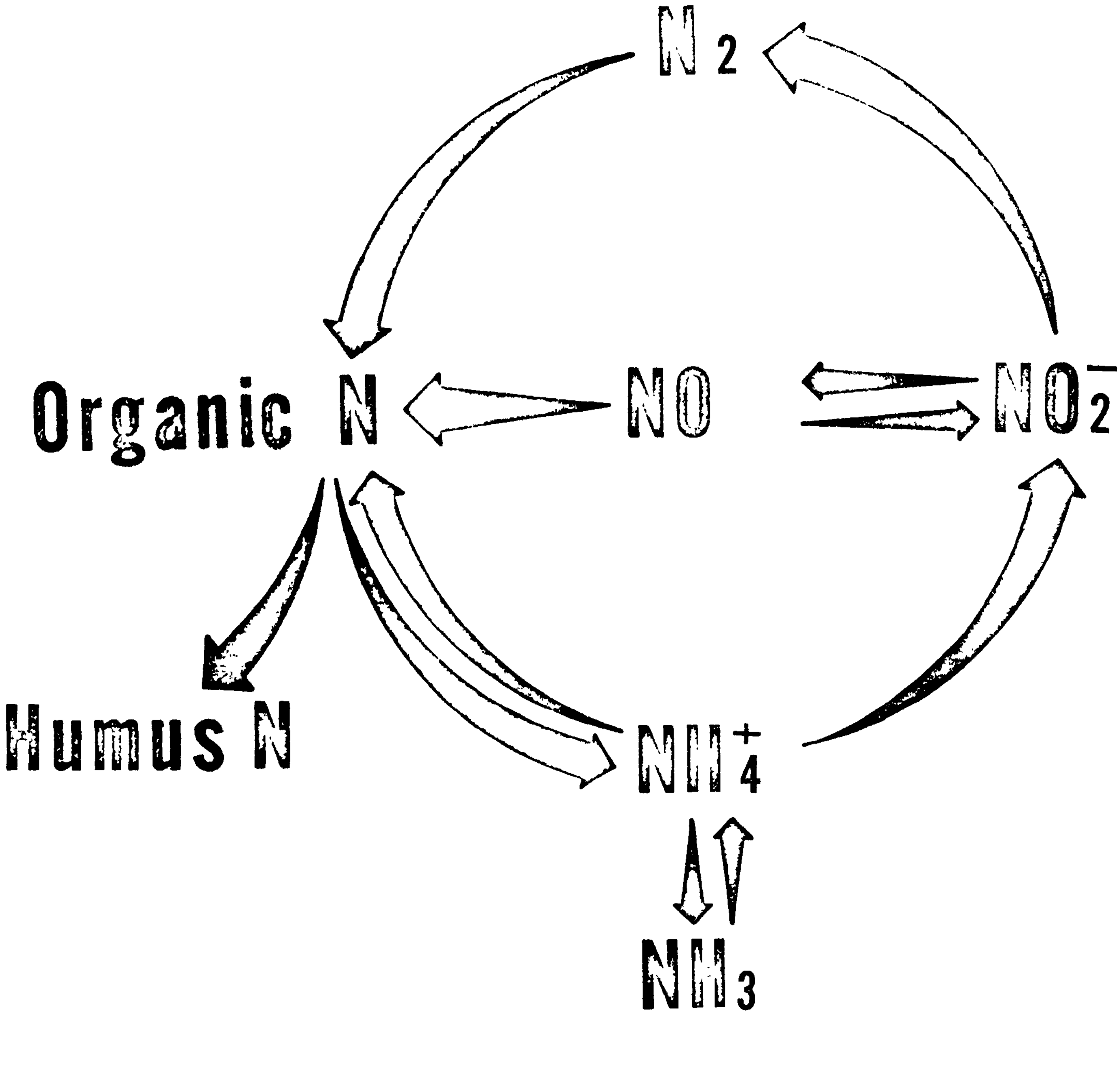

FIGURE 1

See APPENDIX for fact sheet on movie presented

"Irrigation of Liquid Digested Sludge"

SOILS AS SLUDGE ASSIMILATORS[1/]

by

James O. Evans[2/]

Introduction

In August, 1967, on my first assignment as Research Soil Scientist in Ultimate Disposal Research at the Advanced Waste Treatment Laboratory, Cincinnati, Ohio, I spent two weeks in Pennsylvania touring sewage treatment plants and studying sludge disposal methods. About 30 Pennsylvania municipalities were spreading digested sludge on rural lands.

Although I was slightly knowledgeable about a few effluent disposal operations in different parts of the country, I knew nothing about sewage sludge before going to Cincinnati. Consequently, I was not prepared for the experience I was to undergo in Pennsylvania. I went there highly skeptical of the sludge-on-land disposal practice and came away a convert. I observed sludge being spread and saw previously sludge-treated lands representing a range of soil types and topographic and land-use conditions from the Allegheny Mountains of north central Pennsylvania to the highly productive farm lands of the lower Susquehanna Valley in southeastern

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1/ Presented at the Symposium on Land Disposal of Municipal Effluents and Sludges, Rutgers University, New Brunswick, N. J., March 12, 13, 1973.

2/ Research Hydrologist, Division of Forest Environment Research, Forest Service, U. S. Department of Agriculture, Washington, D. C.

Pennsylvania. I found it difficult not to be convinced by what my eyes saw, my nose did not smell, and my ears heard from the enthusiastic farmers who were spreading sludge on their pastures and croplands. My impressions were summed up in the article, "They spread 'black gold' on their fields" which appeared in the February 10, 1968, issue of the Pennsylvania Farmer. The expression, "I call it black gold" was used by one farmer in Elk County when asked to give his opinion of the digested sludge he was receiving free of charge from the St. Marys sewage plant.

Despite my "conversion," I found it difficult to persuade others that land disposal of sludge was good and that sewage sludge really wasn't an ugly odorous waste, but instead was a valuable resource which should be recycled on land at every opportunity. Skeptics often serve a very useful purpose, and I quickly discovered I had no factual answers to many questions raised about the feasibility of disposing sewage wastes on land. So I searched the literature and initiated some studies, but today, nearly six years later, I still know few, if any, answers to the more perceptive questions posed by my skeptical colleagues. I cannot help but be pleased, however, by the current upswell of interest in land disposal, and the growing numbers of converts help to bolster my faith in the cause.

"Soils as sludge assimilators"--should you think this is a simple subject, I hasten to disagree. Since one could not adequately cover this very important topic without writing a book, I am suggesting here only a list of factors to be considered in locating and managing a site for sludge application. First I shall outline several soil properties that promote or facilitate sludge assimilation. Brief discussions on application techniques, on significant observations made by several investigators, and on the assimilation and deactivation of pathogenic organisms in sludge treated soils will follow. Then, I shall discuss the topic of soils as sludge assimilators under three main headings--physical factors, chemical factors, and biological factors.

Soil Properties that Facilitate Sludge Assimilation

Which of the soil properties relate most significantly to soil capacity for sludge assimilation? One may designate at least four soil properties as extremely important to the use of the soil as a disposal medium, (1) ion exchange capacity (or adsorption capacity), (2) buffer capacity, (3) filterability (filtration capacity), and (4) microbial transformations (1).*

Ion exchange capacity alludes to the total amount of cations and anions that are sorbable per unit of soil weight. Most soils have moderate to large cation exchange capacities (CEC) but only limited anion exchange capacities. For simplicity we will consider here only CEC. Soil CEC is the sum of both the organic and inorganic soil components. The ability of a soil to retain metals derived from a sludge source and to keep them out of ground and surface water and out of plant tissues is largely a function of its CEC.

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* Note: Underlined numerals such as (1), above, refer to citations at the end of the paper.

The buffer capacity of soils is derived from several sources. Buffering tends to restrict rapid changes in solution pH. Carbonate soils buffered to a pH of 7 or above tend to bind wastes and inhibit solubility of heavy metals.

Soil filterability refers to soil efficiency as a physical filter of suspended particles. Filtration of pathogenic organisms from sludge sources is an important element to successful use of sludge. Permeable soils of intermediate texture which have enough colloidal content to trap particulates are probably the best filters.

Microbial transformations involve utilization of soil microflora to transform certain of the major elements essential to plant growth, e.g., nitrogen, phosphorus, sulphur, and carbon.

Application Techniques

"Modes of Transporting and Applying Sludge" is the subject of another paper prepared for presentation at this symposium, so it appears prudent to say little here about application techniques. We should recognize, however, that the manner by which sludge is applied may greatly affect how it is assimilated. Spray irrigation of liquid sludge may be the best and most practical application technique in most cases. But each situation should be evaluated independently. Furrow application should work best in some cases. (For example, application between rows of trees or other vegetation planted along contours of steeply sloping land.)

Land spreading may be accomplished in several ways such as by overland gravity flow, by gravity sprinklers from a moving vehicle, and by various pressure ejection methods. The sludge may be left on the soil or soil-vegetative surface or plowed under. It may be ejected under the soil surface at various depths. In general, metabolic activity is maximized by surface sludge applications; however, dangers of contaminating surface waters and aesthetic objections are least with subsurface treatments.

This paper presents general concepts concerning factors which determine the relative ability of soils as sludge assimilators. Some readers might prefer receiving an itemized listing of facts and figures or specific detailed guidelines and work documents concerning sewage irrigation and sludge spreading on land. Certain general guidelines and documents do exist but are of limited value due to a paucity of scientific data. An application guide was developed in July 1971 by the Forest Service for north central and northeastern forest lands, and earlier, in January 1971, a problem analysis on land disposal of sewage was prepared by Forest Service Research. The Bureau of Water Quality Management, Pennsylvania Department of Environmental Resources published a sewage and industrial waste water spray irrigation manual in 1972, and USDA's Agricultural Research Service is cooperating with the Soil Conservation Service in developing a guide on land disposal of sewage and farm animal wastes. Other guides probably exist and certainly each is of some value. If a series of charts were available showing when, how, and how much of a particular kind of sludge can safely be applied to various soil types under various land, vegetative, climatic, and topographic situations, this subject would require no comment, and this symposium would not be needed. In short, there would be no unanswered question about sludge disposal on land. But, unfortunately, such is not the case, and it is imperative that we expand our knowledge rapidly in this crucial area. In order to do so, however, we must learn more about physical, chemical, and biological influences and application techniques.

Significant Observations by Several Investigators

Several opinions and statements concerning sludge assimilation have been reported which are highly instructive. E. G. Coker (2) of Great Britain has stated, "It is fair to say that almost all of the ill-effects of sludge application arise from over-heavy or excessively frequent applications." In this connection, Dr. T. D. Hinesly (3) of the University of Illinois concluded that, "Nitrogen contained in digested sludge is the most immediate limiting factor to rates of application. Our data indicates (sic) that about 2 inches of (liquid) sludge would satisfy the nitrogen needs of non-leguminous crop (sic) without producing excessive nitrate in percolated water." Concerning nitrogen loadings Mr. Coker observed that, "The response (of selected grasses and cereals) to applied nitrogen falls off above about 300 lbs/acre/year, applied at about 100 N per application."

Some investigators believe certain of the heavy metals are limiting factors to land application of sludge. The availability of these trace elements may be the key issue. Coker notes that availability depends on several factors including: (a) Soil organic content--"The higher the organic content the more firmly they (heavy metals) are held;" (b) the level of pH--a pH of 6.5 or higher tends to minimize toxic effects of excess heavy metals; (c) soil drainage--Solubility of heavy metals is enhanced by poor drainage and reduced in well-drained soils. On the other hand, Coker (2) mentioned trees flourishing on a peat swamp containing up to 7 percent copper in dry matter. He suggested that anaerobic conditions in this case might have caused precipitation of (copper) sulphide.

Consideration must be given to conditions resulting from the occurrence of two or more metals in toxic concentrations. Coker has stated that, "If a number of metals are present it is considered that the toxicity of them is additive, providing the differing toxicity of metals is taken account of during addition." One might counter that possible synergistic effects and counteractive or antagonistic effects should also be thoroughly investigated. Research concerning heavy metals has been done by Hinesly and his coworkers at the University of Illinois (4), by W. H. Allaway, U. S. Department of Agriculture (5), by J. R. Peterson of the Metropolitan Sanitary District of Greater Chicago (6), and by a number of other investigators. Available data suggests the metals problem has at times been exaggerated.

Pathogenic Organisms in Sludge-treated Soils--Are they Effectively Assimilated and Deactivated?

Since the problem of pathogens in sludge-treated soils is related primarily to sludge rather than soils, so far I have not discussed pathogens. I now briefly address this important subject. Peterson (7) stated that well stabilized sewage sludges are generally free of odors and pathogens. Perhaps his statement should be amended to read "objectionable odors." I question his assertation concerning sludge being "generally free" from pathogens. Let us hope he is right, but there are many investigators who are fearful of the pathogen spectre. In his paper, Peterson cites several studies which show that aerated soils and sunshine work together quite effectively in reducing and subsequently eliminating pathogen populations. Whatever the problem, it does not appear to be unsolvable. Lime additions seem to be effective in destroying pathogens present in sludge. Also, the use of ozone and pasteurization processes are under investigation as possible feasible means for eliminating potential pathogen hazards.

I now refer to three factors for consideration in evaluating soils as sludge assimilators.

Physical Factors Relating to Sludge Assimilation by Soils

a. Sludge characteristics

Soil infiltration and absorptive rates are altered by sludge treatments due to the nature and concentration of undissolved solids in sludge. Most unthickened liquid sludges contain no more than 5 percent solids by weight (normally between 2 and 4 percent solids), and can be spray-irrigated without difficulty. Consideration has been given by some planners to spray irrigate sludges of up to 15 percent solids content; however, a solids content of 10 percent probably should not be exceeded. In addition to difficulties encountered in pumping and spraying or ejecting thickened sludges, there may be problems in achieving acceptable infiltration and percolation rates into and through surface layers of most soils. Therefore, unless mechanical incorporation of the solids is an integral part of the treatment, the ability of the soil surface to receive and transmit liquid sludge is a controlling factor to sludge application rates. If, however, the application technique involves spreading sludge in a semi-solid state or incorporating it in soil by some other method, such as the trenching method used by Agricultural Research Service scientists at Beltsville, Maryland, sludge thickness or percent solids content may not be a limiting factor. Also, since soils must absorb less water from application of semi-dewatered liquid sludge than from that of an equal volume of thin sludge, more of the thicker sludge (dry weight basis) might be assimilated by soils of limited water absorptive capacity. There is a need for factual data on the effects of various sludge loadings on the infiltration and percolation rates and assimilative capacities of different soils.

b. Physical soil characteristics

Porosity, structure, grain-size distribution (texture), and mineralogy are important physical factors in evaluating soil capability for sludge acceptance. (Mineralogy is, of course, also a chemical characteristic.) Soils can vary drastically, and an arbitrary group of soils (each soil being of similar construction) can be expected to respond quite differently to treatments and management from that of another distinctly different group of related soils.[1/] The wide variability among certain soils indicates some can readily assimilate large amounts of certain sewage sludges while others can assimilate only small amounts. Suitable soil and crop management may compensate for or amend limiting soil properties, however. Planners have an obligation, therefore, to be knowledgeable about significant soil conditions before development plans are made. Sites may be selected where soils favorable for sludge assimilation occur. Assistance can be obtained from the U. S. Soil Conservation Service, County Agents, and State and Federal forestry soil scientists.

1/ It might help to better visualize and understand how much soils differ by considering why they differ. Soils differ because of variations in the following five "soil forming" factors: (1) The parent material (nature of rock or mineral deposit from which the soil is derived), (2) climate (temperature and precipitation amounts and extremes), (3) topography or relief (involving surface slopes and natural drainage considerations), (4) living (and dead) organisms (movements and accumulations of various vegetative and other macro- and micro-organisms on and within land surfaces), and (5) time (or age) (time is considered not just a chronological period, but a value that reflects the intensity of soil development exerted by factors 1 through 4 during the length of time they have been in operation--"old" soils showing more development than "young" soils). None of the factors act independently, of course. Each may affect or modify the other, and developed soils reflect the interrelated and interdependent influences of all of them. This paper is not a dissertation on soil genesis, but a basic understanding of the factors that produce soils--that cause them to differ so drastically from one environment to another distinctly dissimilar one (or cause them to be the same in near identical environments)--helps one to better comprehend the great variability that exists across the soil spectrum. This knowledge leads one to anticipate vastly different responses from unlike soils when they are subjected to certain land-uses and treatments.

Few soils are unsuitable for sludge disposal. Those soils most likely to be unsuitable are: (1) extremely coarse-grained soils (coarse sands and gravel), (2) extremely fine-textured soils (such as montmorillonite clays), (3) very shallow soils (to water, bedrock, impermeable layers, or gravel), (4) wet, undrained soils, (5) frozen soils, and (6) solonetz and other sodium saturated soils. The suitable soils (the vast majority of all soils) may vary greatly in relative ability to assimilate sludge, however.

c. Climatic influences

Climate plays a powerful role in determining the nature of soils, but I see no need to stress the influence of climate on sludge assimilation by soils. Briefly stated, and eliminating other variables, assimilation is aided by warm, moist to dry climates and retarded by cold, wet climates. A climate should not be too hot or dry, however. Death Valley might be an ideal spot for sludge disposal, but the local soils would make very poor sludge assimilators. Furthermore, dry climates may cause salt accumulations.

d. Land influences--relief

As a soil forming factor relief may strongly influence certain aspects of soil development such as internal makeup and soil depth. With respect to sludge application, relief involves two principal considerations. One is steepness of slope. To prevent runoff on strongly sloping lands, the rate of liquid sludge application should not exceed the soil infiltration capacity and percolation rate. Otherwise, terraces or other costly structures or land treatments involving extensive use of vegetative mulches would be required to prevent sludge runoff. (Forested hillsides with controlled runoff might be highly efficient for sludge treatment-disposal, however.) The second major consideration involves either flat land or depressional areas which are conducive to ponding if the soils either are very slowly permeable or presaturated. Relief also may strongly affect the mechanics of sludge application. Certain current application methods might range from difficult to impossible to implement on various steeply sloping or strongly dissected land areas.

e. Biotic influences

Living and dead biota (flora and fauna) influence the physical assimilation of sludge by soils. First, briefly consider vegetation with respect to: (1) Physical presence on the land. Trees or other densely growing plants will partially intercept spray applications and may act as physical barriers; (2) Physical activity within the soil. Some root systems are deep and others are shallow. Deep systems promote drainage and the development of deep soils. (Roots may exert powerful disruptive forces on subsoils.) Some root systems are large in size while others are finely divided or fiberous. (Fiberous systems promote good surface structure.) Hence, physical absorption of sludge will vary according to prevailing root systems; (3) Short term, immediate effects on soil infiltration and absorptive capacity. Infiltration can be rapid through a grass sod but slow through a bare, crusted surface of the same soil type. Percolation may cease in the frozen soils of bare lands or meadows but proceed well in the unfrozen protected soils of an adjacent forest.

Both large and small animals profoundly affect soil physical conditions which in turn may largely determine sludge absorptive capacity. Burrowing animals break up and aerate dense soils; large land animals may trample and compact soils and may destroy protective cover vegetation. Also, burrows, cracks, and root channels may facilitate direct drainage to shallow groundwater and "short circuit" the soil filter system.

f. Physical loading rates

Perhaps the key to a successful sludge disposal program is an understanding of how much of, and when, a given sludge should be applied to a particular soil or land area. Almost any soil at some time is capable of assimilating a small amount of sludge, but any soil can be overloaded. Attempts at economy are likely to lead to overloading. Overloading some aspect of the assimilation process is the cause for failure in any malfunctioning land disposal system.

Chemical Factors Relating to Sludge Assimilation by Soils

Chemical factors are as important as physical factors in respect to the assimilation of sludge by soils. The chemical nature of both sludges and soils should be considered.

a. Sludge chemical analysis

Sludges are known to greatly differ chemically; furthermore, the chemical nature of sludge from an individual treatment plant may differ considerably from day to day as determined by (1) the nature of the sewerage input and (2) treatment plant operating capabilities and conditions. Table 1 shows chemical analyses of sewage sludges from seven waste water treatment plants. Note that at the Hastings, Minnesota plant and at all of the Chicago plants, total nitrogen content in the sludges is comparatively high whereas the ammonia-nitrogen (NH_4-N) content is high at only those plants without supernatant digester drawoff. Note also that the iron content is high in the $FeCl_3$ treated West-Southwest sludge, whereas the lime treated Denver sludge is calcium enriched.

Whether a sludge is judged as "good" or "bad" may depend as much or more on its intended use as on its chemical make-up. But one should be able to identify and evaluate potential troublemakers when they occur in relatively high concentrations. Cadmium, chromium, copper, boron, zinc, mercury, nickel, and lead are commonly recognized as potential troublemakers.

What about nitrogen and phosphorous? Whether they are "good" or "bad" depends greatly on whether they are considered as needed fertilizer or as wastes requiring safe disposal. Certainly with nitrogen, and also with certain other elements and compounds, there can be too much of a good thing. We must recognize and remember that sludge analyses are quite important--they are essential to the development of ecologically sound and environmentally safe guidelines and plans for sludge disposal on land. Sludge analyses should be evaluated in light of the chemical

Table 1. Chemical Analyses of Sewage Sludges from Various Wastewater Treatment Plants.

			---M.S.D.G.C.*, Chicago, Ill.---				
Source:	Hastings, Minn.	St. Paul, Minn.	Hanover	Calumet	West-Southwest	Denver, Colorado	Athens, Ga.
Treatment Process:	Primary and waste activated: anaerobic digestion without supernatant drawoff	Primary & waste activated (1:2): undigested	Primary & waste activated: Anaerobic digestion without supernatant digester drawoff		Waste-activated: $FeCl_3$ addition: vac. filtered: Heat-dried	Primary & waste-activated: $FeCl_3$ and lime: vac. filtered: undigested	Primary: Anaerobic digestion
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Analyses	% dry wt. basis						
N-Total	5.84	4.69	5.57	5.20	6.37	4.57	3.5
NH_4-N	2.34	1.33	3.63	2.40	trace		
P	2.61	2.20	2.59	3.90	2.49	1.75	0.75
K	0.27	0.24	0.68	0.55	0.41		0.22
Ca	2.97	2.52	5.05	4.20	1.4	7.38	1.21
Mg	0.26	0.40	1.64	0.60	0.75	0.45	0.09
Zn	0.075	0.14	0.069	0.35		0.172	0.252
B	0.0013	0.002			0.002-0.04	0.00022	0.00199
Fe	0.45	0.76	2.22	3.68	5.32	1.48	
Mn	0.015	0.039	0.07	0.14	0.012	0.0253	0.0199
Al	0.65	0.74		1.21			
Cd	0.00079	0.036	0.0089	0.0125	0.028		
Cl			0.12	0.74			
Cr	0.390	0.067	0.019	0.112	0.362		
Cu	0.12	0.065	0.062	0.088	0.11	0.0324	0.046
Ni	<0.001	0.015	0.032	0.020	0.034		0.0026
Pb	0.039	0.070	0.083	0.18	0.141		

Reference: Peterson, J. R., et. al. (See Citation No. 7)

*Metropolitan Sanitary District of Greater Chicago constituency of the soils on which they are to be applied. Sludge additions could aggravate a bad condition. Conversely, sludge may act as a soil amendment. For example, sludge from sewage treatment plants serving industrial areas of Chicago has been used to reduce both acidity and the availability of heavy metals in coal mine spoils of the Palzo tract of the Shawnee National Forest in southern Illinois (8).

b. Soil chemistry

We must not overlook the importance of the chemistry of the soil. Heavy metals occur naturally in soils. They often are called trace elements within the soil matrix. (Many are essential to plant growth and are needed in appropriate amounts.) Soil chemistry alone will seldom determine whether a particular land area is a suitable sludge disposal site, but it may well often determine relative suitability. Pertinent chemical factors include soil pH and calcium reserve, percent sodium saturation, boron content, iron and aluminum content, and kind and percent of soluble salts. In brief, here are several examples of the importance of soil chemistry: (1) Sodium-saturated soils including sandy, granular soils may be virtually impermeable to water; (2) even in minute amounts in soil, boron is highly toxic to most vegetation, consequently, small amounts in sludge may be critical on marginal soils in arid and semi-arid climates; (3) a definite potential for groundwater pollution with nitrate-nitrogen (NO_3-N) exists in portions of the Northern Great Plains, dependent on management practices and on distribution of precipitation and other factors influencing the depth of soil wetting; (4) relatively large concentrations of phosphate may leach from calcium enriched soils derived from limestone-phosphate mineral (apatite) deposits, particularly if organic matter is added.

c. Climatic influences

As for climate, let us consider it here only as it modifies or influences the chemistry of sludge-soil contact and interaction. As previously mentioned in relation to sludge assimilation, warm and moist conditions promote or accelerate interaction, whereas cold, dry conditions inhibit actions and reactions.

d. Drainage influences

Drainage is intimately related to soil and climatic influences mentioned above. At this point, however, it is appropriate to project our thoughts on soil aerobic vs. anaerobic conditions as influenced by drainage and resultant chemical changes. Good drainage promotes aerobic conditions; impeded drainage leads to anaerobic conditions. In general, aerobic soil conditions are necessary for satisfactory sludge assimilation. On occasion, however, we may wish to promote anaerobic conditions within the subsoil to inhibit nitrate production or to induce denitrofication as a way of reducing nitrate pollution of groundwaters. A combination of heavy sludge loadings and impeded soil drainage may result in undesirable conditions where hydrogen sulfide gas and other offensive smelling substances are produced and in the mobilization of some metals and nutrients.

e. Biotic influences (biological actions)

Numerous biological actions directly and indirectly affect the chemistry of soils and thereby the ultimate assimilation of applied sludge. We might reflect briefly on a few of these actions. Consider vegetation for a moment. Each vegetative type tends to exert a characteristic and unique influence on the soil environment. By exerting different kinds and degrees of physical forces, various root systems differentially affect soil weathering, aeration, drainage, soil chemistry, and subsequent biological activity. Roots excrete organic acids. The litter from different tree species directly affects soil pH and nutrient accumulation vs. nutrient leaching.

Earthworms, burrowing insects, and other soil organisms mix and aerate soils, produce organic slimes and excrement, and eventually die; they are an integral part of the recycling process and directly and indirectly alter physio-chemical conditions, pH, nutrient status, and sludge assimilation.

Biological Factors Relating to Sludge Assimilation by Soils

We have just taken a brief glance at general biological influences on soils and soil chemistry. Now we should take a closer look at certain of the biological factors and how they operate.

a. Micro-organisms

The role played by micro-organisms in sludge and soil in promoting assimilation and stabilization and in creating a favorable environment for sludge utilization by higher organisms can hardly be overemphasized. It is also an area in which considerable research is sorely needed.

Although much progress has been made during the last decade, we have much to learn about the role played by micro-organisms in determining micronutrient status, about interrelations between soil humus and micro-organisms, and about chelation in soils. For example, we know that the quantity of micronutrients held in the solution phase as individual ions and as soluble metal-chelate complexes is influenced by the activities of micro-organisms and higher plants, but we need to know more concerning why, how, and how much. We also know it is important that trace metals that would ordinarily convert to insoluble precipitates at the pH values found in productive agricultural soils are maintained in soil solution by chelation (9).

Let us consider mycorrhizae organisms for a moment. Mycorrhizae are symbiotic associations in which the smallest order of secondary roots are invaded by specific fungi during periods of active root growth, and without these fungi, most plants, including important forest and horticultural species, could not survive in the dynamic, highly competitive biological communities found in natural soil habitats (10). Dr. Donald Marx, a Forest Service research soil scientist at the Southeastern Forest Experiment Station project location in Athens, Georgia, is conducting some promising studies on the use of mycorrhizae and sewage sludge to improve the physical, chemical, and biological conditions of eroded, nutrient-depleted, unproductive soils in Georgia and Tennessee.

b. Macro-organisms

Activities of certain of the larger organisms, the readily visible ones, such as earthworms, insects, burrowing animals, land animals, grass, and trees, have already been alluded to. They exert great effects on soils physically, chemically, and biologically through their physical activity, respiration, excretion, evapotranspiration (by vegetation), reproduction, and death and decay.

Concluding Statements and Recommendations

Should land application of sludge really catch on, it might become feasible to control the nitrogen content of sludge through waste treatment plant processes to make a product suitable either primarily as a source of nitrogen fertilizer or for high rates of disposal as a low-nitrogen soil conditioner.

I reiterate that overloading is the prime cause of land disposal malfunctions. Although on occasions the metals problem appears to have been exaggerated, I agree with Coker (2) that "it is of the greatest importance for the chemical engineer to develop cheap effective methods of removing heavy metal effluents before they are absorbed (and adsorbed) on the sludge organic matter . . . ."

Perhaps even more importantly toxic metals and chemicals should be removed (and reused when feasible) before discharge with sewerage into waste treatement plants. Then safer residues would result and we would be a lot less concerned about the ability of soils to assimilate sewage sludge.

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MODES OF TRANSPORTING AND APPLYING SLUDGE

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Introduction

Sludges resulting from treatment of municipal sewage are usually difficult to dewater so that transportation and application problems begin with considerations of just how much effort to expend on dewatering. The purpose of this paper is to discuss alternative methods for dewatering, transporting and applying of these sludges, with a view to stimulating the thinking of engineers concerned with the constructive use of this valuable resource. The discussion is presented from the standpoint of a practicing engineer who has been closely involved in excavating, transporting and applying to land over a half million wet tons of sludge slurry from the Metropolitan Sanitary District of Greater Chicago. The sludge was transported by unit train for distances up to 170 miles from Chicago. Application was performed by several different techniques, as will be discussed herein. Alternative transportation systems are also discussed, including truck, rails, barge, and pipeline.

Types of Sludges; Physical Characteristics

Sludges can be primary or secondary, digested or undigested, or various combinations. Although their chemical and physical characteristics vary widely, for purposes of this paper these variations will be ignored

The undigested sludges generally call for minimizing exposure of the sludge to reduce the possibility of anyone being offended or believing that he has been offended by an odor. Because of the widespread belief that all sludges do have an odor, it is also generally a good idea to handle digested sludges in the same manner. For that reason, the methods of sludge application which provide the least visibility of the sludge itself are recommended as the preferred practice.

The differences between sludges are sufficiently marked to warrant tests of both chemical and physical properties before final design of the handling facilities. The chemical characteristics are being dealt with by others at this seminar, so I shall confine my comments to the physical characteristics which affect transportation and application costs.

Costs of Dewatering

Sludges to be handled have solids contents ranging from 1% to 100%, the latter being heat dried sludges. The costs of dewatering vary widely depending upon the particular sludge and technique being used, but some generalizations will be made to illustrate basic concepts of how the desirable per cent solids for a given situation can be analyzed.

The following fundamental assumptions will be made regarding costs of dewatering:

Method	Resulting per cent solids	Dewatering Cost/dry ton
Lagoons, plus excavation	15%	$15
Vacuum filter	25%	16
Centrifuge	30%	20
Filter press	40%	30
Vacuum filter + heat drying	99%	100

The actual costs for these processes vary considerably with the particular situation which pertains to a given case, and should be specifically determined for that case. The figures given above are merely to be used in this paper in the examples given to illustrate the alternatives to be examined in designing transportation and application systems.

Hydraulic Characteristics. The hydraulic characteristics of sludges vary considerably also with the per cent solids. Fig. 1 illustrates the variation of the apparent Darcy f as a function of per cent solids for a given temperature, grease content, entrained air contents, etc., but for the sake of simplicity, we shall in this paper use the simple curves of Fig. 1 as guidelines for the illustrative examples given. Sludge (A) is a hypothetical example of a secondary sludge, and Sludge (B) is a hypothetical example of a primary sludge.

It can be noted that below a concentration of about 8% solids the sludges behave as fluids with an apparent "f" of .02 to 0.04. Sludges with 12 to 18 per cent solids can be pumped, but with substantially higher apparent friction factors, ranging up to, say, f = 0.20 as a practical upper limit, except for extremely short distances.

These hydraulic characteristics would be measured in the laboratory for any one sludge and the results used in evaluating alternative systems.

Alternative Transportation Systems

Pipeline. Pipeline costs are roughly proportional to the distance transported. Double the distance and you double the cost. This is not true with some of the alternative forms of transportation, and therefore this important difference must be kept in mind.

Pipeline costs depend a great deal on the type and permanence of the pipe used. In the work of Soil Enrichment Materials Corporation light-weight quick-coupled pipelines have been laid over the surface of the ground for contracts lasting one or two years. Such lines are low in first cost, but the entire cost of the line must be written off over the duration of the contract of which they are a part. For example, a 4-mile pipeline 12 inches in diameter was used for one such project. The capital cost of the line and pumps was approximately $200,000 installed. It was used to move sludge for the warm months of the year over a two-year period. The typical rate of flow was 1.5 MGD of 5% solids sludge, for a daily movement of 300 dry tons. With 100 operating days in each of two years, a total of 60,000 dry tons could have been moved. (The actual contract quantity was somewhat less than this amount so the full opportunity to use the pipeline did not materialize.) The capital cost would have then been about $3.33 per dry ton or, say, 83¢ per dry ton mile. To this an operating cost would be added for, say, a rough estimating total cost of $1 per dry ton mile. For a permanent pipeline written off over a period of about 20 years the capital, plus operating cost is estimated to be approximately $11.30 per dry ton for a distance of 66 miles.[1/] This works out to be about 17¢ per dry ton mile. The figure did not vary greatly with changes in per cent solids over a range of 4% to 7%. Table II summarizes the analysis.

<u>Truck Transportation.</u> For purposes of this paper, the cost of the truck transportation may be taken to be 6¢ per wet ton mile, including loading costs. The cost per dry ton mile will then depend upon the per cent solids handled. Trucks can be designed to handle any per cent solids.

<u>Barge Transportation.</u> For purposes of this paper, the cost of barge transportation will be taken as $1.50 per wet ton for distances of 100 miles, and $2.00 per wet ton for distances of 200 miles, including

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[1/] "Land Reclamation Project", Metropolitan Sanitary District of Greater Chicago, 1967, Harza Engineering Co., Bauer Engineering, Inc.

loading costs. Again the cost per dry ton depends upon the per cent solids which can be handled. The cost of unloading barges is very much a function of the ingenuity of the designer, but because covered barges would in all probability be required, it is conservative to assume that the material would be handled in the slurry form, and (with present practice) the per cent solids would probably not be greater than 8%, with 6% being a more commonly attained figure.

Rail Transportation. Tank cars are the most commonly used carriers for sludge at present. Unit trains of up to 40 cars at 85 tons each have been operated by Soil Enrichment Materials Corporation, with 24-hour turn around having been achieved as a steady practice for one-way hauls of up to 170 miles. Under these conditions, the cost of the rail transportation, including tanks cars is estimated to be, roughly, 1.2¢ per wet ton mile, including loading costs. For larger distances and larger unit trains the cost would be less; for shorter distances and smaller unit trains the cost would be more. (Note that this figure does not include excavation of sludge from lagoons, pumping from lagoons to tank cars, and application to land).

Again the cost per dry ton depends upon the per cent solids. Tank cars have been used successfully with 12% solids sludge of a digested secondary type. With primary sludges, 15% solids can be handled successfully. The cars are equipped with agitators to permit draining of these thick sludges from the cars in a reasonable period of time.

Alternative Application Systems

The following alternative application systems have been used for sludge applied to agricultural land:

1. Direct dumping of filter cake from truck, followed by spreading and plowing into the soil.
2. Direct dumping of slurry from truck, followed by plowing into the soil.

3. Flooding of prepared leveled ground from pipelines, and later plowing of the dried sludge into the soil.

4. Irrigation of slurry using high pressure nozzles.

5. Plowing in of a slurry fed continuously through a hose to a moving plow.

The latter system is the one presently preferred by SEMCO, for the following reasons:

a) It is a one step method. There is no need to return to the site to plow the sludge in later.

b) It allows the material to be handled entirely in closed containers. Lack of visibility to the general public reduces aesthetic objections, even though there may be no odor problems.

c) If there are any odor problems, even intermittent ones, this method eliminates any adverse effects on neighbors.

I have had considerable involvement with methods 4 and 5 preceding, and the preference for method 5 is based upon that experience for rather large volumes of sludge to be handled on a continuous long-term basis. I have also had experience with smaller quantities of sludge being applied with methods 1 and 2, and have found these methods acceptable for smaller quantities, such as less than 50,000 wet tons of sludge at one site for one season. For the sake of illustrating the economic significance of the various combinations of systems without getting into the benefits of particular techniques of application, we shall use the cost figure of $20 per dry ton for each of these application methods; this includes the unloading costs from the transportation system. It is beyond the scope of this paper to discuss the advantages and disadvantages of each of these methods, so that this uniform cost figure will be used even though it is of course only a hypothetical situation.

Excavation from Lagoons

The lagooning process, though it is an economical method for the concentration of sludges, involves the later step of reclaiming or excavating the sludge from the lagoon. By contrast, a method for de-watering which can be a part of a continuous flow sheet eliminates the expense of this excavation. For purposes of making cost comparisons here, the lagooning step will be assumed to require the additional expense of later excavation, and this will be taken to cost \$10 per dry ton, making a total of \$15 per dry ton for this method.

Comparison of Costs

Comparisons of the hypothetical costs of handling sludge from a large city are given in Table I. It must be remembered that these hypothetical illustrations are given simply for the purpose of furnishing examples which can be discussed here. Actual costs would depend materially on the conditions peculiar to each problem.

Alternative 1. This uses a lagooning at the site of the treatment plant, followed by later trucking at 15% solids to a site 20 miles distant, followed by dumping at this site and later plowing into the ground. The transportation cost of 6¢ per ton mile for a distance of 20 miles results in a cost of \$1.20 per wet ton. Dividing by 15% solids gives the \$8.00 per dry ton listed in the table for transportation.

Alternative 2. This is comparable to the operation of Alternative 1, except that rail haul for a distance of 100 miles is used. The material is hauled at 15% solids, with a freight cost of \$1.20 per ton for the 100 miles. Dividing by the per cent solids gives the \$8 per dry ton figure listed.

Alternative 3. Vacuum filtration is used to develop a 25% solids condition and then the material is hauled 20 miles by truck. The transportation cost of 6¢ x 20 miles $1.20 per wet ton is divided by 25% solids to obtain the $4.80 per dry ton transportation cost listed in the table.

<u>Alternative 4.</u> A portion of the sludge is concentrated by vacuum filtration and then mixed with the unconcentrated balance of the sludge to produce a 15% solids material. The cost is calculated for the filtration of 55% to be 0.55 x $16 = $8.80 per dry ton. This was rounded off to $9, allowing a small amount for mixing with the remaining 45% of the material which would be at about 3% solids. The resulting mixture is then 0.55 x 0.25 + 0.45 x 0.03 = 0.1375 + 0.0135 = 0.1510 or, roughly, 15% solids. The transportation cost of $1.20 per wet ton divided by the 15% solids gives the $8 per dry ton transportation cost listed.

<u>Alternative 5.</u> A 20-mile pipeline is used with the sludge as produced at the plant and thickened somewhat to, say, 5% solids. This can be pumped easily without high friction factors. The cost of the thickening to 5% was ignored in this comparison, as it would be small. The pipeline is written off over a period of 20 years which results in 17¢ per dry ton mile cost, or $3.40 for the 20 miles.

<u>Alternative 6.</u> This is the same as Alternative 5, except that the length of the pipeline is increased by 100 miles.

<u>Alternative 7.</u> A vacuum filtration of a portion of the sludge is used as before, followed by mixing with the unconcentrated sludge to effect an 8% dry solids content which can be handled in a barge. The corresponding cost of dewatering is of course low, but the transportation cost of $1.50 per wet ton divided by the 3% solids gives $18.75 per dry ton transportation cost, which is seen to be relatively high.

Discussion of Alternatives

One of the main points of this paper is to point up the great number of possible combinations of sludge transportation and application schemes which can be developed. This paper by no means exhausts the possibilities, but it does suggest the significance of considering the many possibilities which may be available.

First of all, the range of costs from $37 to $52 per dry ton is seen to be relatively small. They are also seen to be competitive with incineration. Unfortunately, open competition between incineration and transportation and land application as outlined in this paper is usually not permitted. Much of the reason for the lack of open competition is the present policy of the federal government to share in the capital cost of systems, but not in the operating cost. The transportation and land application systems are usually low in capital cost, and relatively more expensive in operating cost than would be the incinerators as long as the incinerators would not require repair. Once the initial incinerators require substantial repair and maintenance, and federal funds are not available for this purpose, then the transportation and land application is free to compete with the alternative of incineration.

Secondly, it is significant to note the wide range in transportation costs when viewed separately. Note that the most expensive is barge transportation, a fact at odds with most commonly held opinions. The reason is the assumption that barges would be used with 8% solids material, which is a solids content that permits the material to be removed from the barge as a fluid. The requirement that covered barges be used for sludge transportation tends to work against barging of material with a higher solids content. In the case of the railroad tank car a much higher solids content can be handled as the contents can be agitated with air and the tank car pressurized to force out the material as a thick slurry. It can then be diluted, if desired, for subsequent land application.

Although all application costs were assumed to be equal, this is of course not usually the case. For example, it is unlikely that a barge unloading site would be adjacent to the sludge application site. On the other hand, the trucks can usually go very close to the site of the application. Railroads are more likely to be closer to the application site than barges, but perhaps less close than would trucks. Mitigating against the use of trucks is the farmer's opposition to compaction of the soil by excessive truck traffic over his tillable land. All of these factors would be taken into account in any actual case.

Summary

One purpose of this paper is to illustrate some of the many possible combinations of sludge transportation and application which may be suitable to a given problem.

Another purpose is to show the competitive nature of the various alternative systems, and to demonstrate that open and competitive bidding which would permit a land application system to be considered as an alternative to incineration could result in substantial savings in cost, and also make use of the organic portion of the sludge as a resource.

The benefits to the soil from the use of sludge for enrichment have not been discussed, as these matters are the subject of other papers of this seminar.

One final comment to provide a perspective: A cost of $50 per dry ton of sludge for disposal corresponds to less than $2 per capita per year, as the sludge from roughly 30 persons amounts to about 1 dry ton per year. Possible differences in cost arising from alternative systems are even smaller. It appears that considerations other than cost should determine the best use of this resource rich in organic material.

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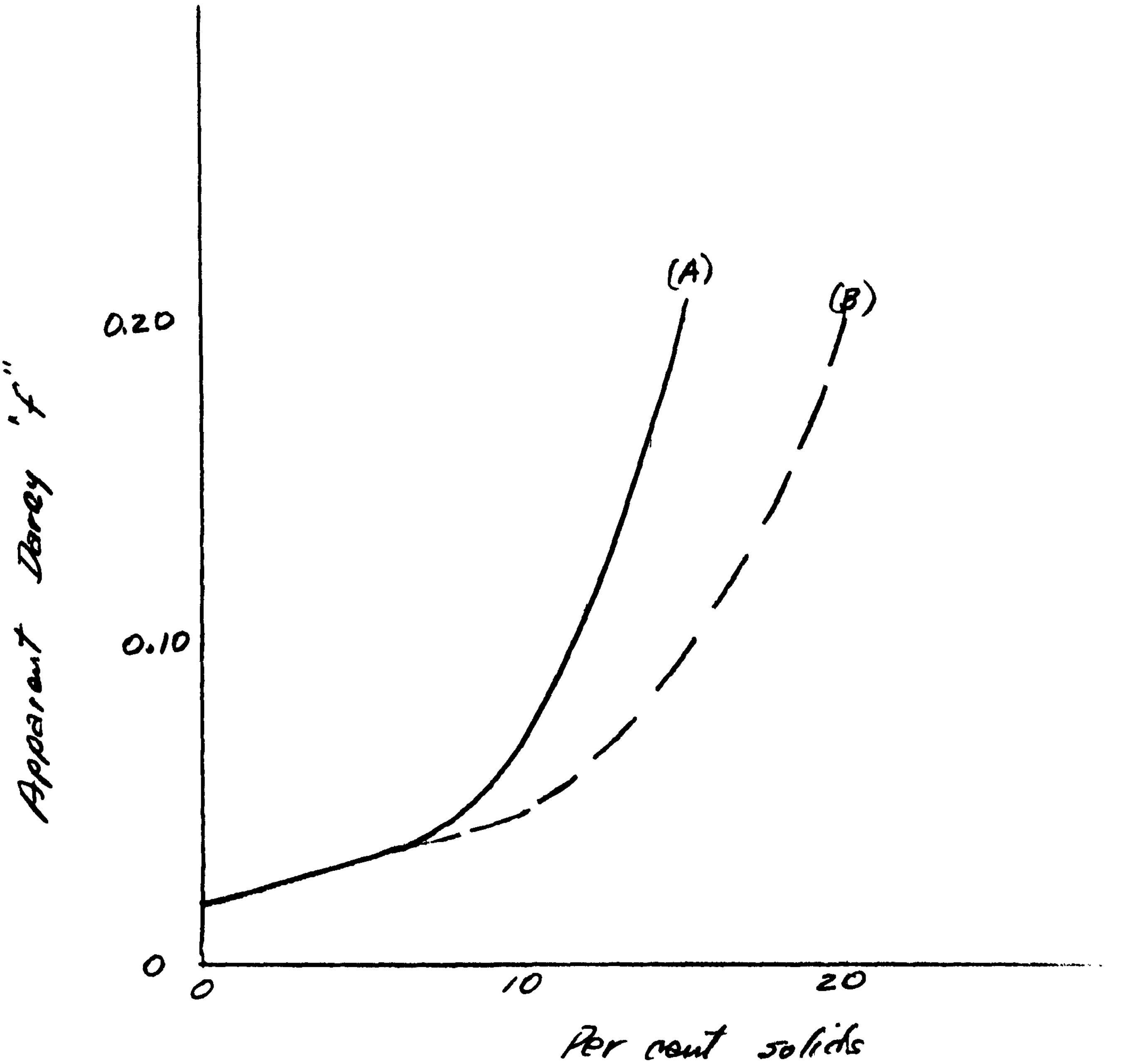

Fig. 1

Illustrative diagram for two hypothetical sludges

TABLE 1

COMPARISON OF ALTERNATIVE METHODS FOR HANDLING SECONDARY SLUDGE FROM A LARGE CITY.

DOLLARS PER DRY TON

System Description	Dewatering Cost	Transportation Cost	Application Cost	Total Cost
1. Lagooning and later excavation, then trucking to site 20 miles distant, where it is dumped and later plowed into the soil at 15% solids	$15	$8.00	$20.00	$43.00
2. Lagooning and later excavation, then 100 miles rail haul to site at 15% solids, then dilution and plowing into soil at 10% solids	15	8.00	20.00	43.00
3. Vacuum filtration to 25% solids, then truck haul to site 20 miles distant, where it is dumped and later plowed into the soil at 25% solids	16	4.80	20.00	40.80
4. Vacuum filtration of 55% to 25% solids, then mixing with remaining 45% of sludge at 3%, 100-miles rail transportation at 15% solids, then dilution and plowing in at 10% solids	9	8.00	20.00	37.00
5. Pipelining for 20 years at 5% solids for 20 miles then lagooning, later excavation and plow application at 10% solids	15	3.40	20.00	38.40

TABLE 1 (cont'd)

COMPARISON OF ALTERNATIVE METHODS FOR HANDLING SECONDARY SLUDGE FROM A LARGE CITY.

DOLLARS PER DRY TON

System Description	Dewatering Cost	Transportation Cost	Application Cost	Total Cost
6. Same as 5, except for 100 miles	$15	$17.00	$20.00	$52.00
7. 100-mile barging of 8.0% material after vacuum filtration of 20% of total and mixing with remaing 80%, followed by application to land	3.50	18.75	20.00	42.25

TABLE II

CALCULATION OF PIPELINE TRANSPORTATION COSTS

(Based on Table G-1, 1967 "Land Reclamation Project" report by Harza Engineering Co. and Bauer Engineering, Inc. to Metropolitan Sanitary District of Greater Chicago.)

Item	Site 1	Site 2	Site 3	Site 4
Pipeline length	65 miles	57 miles	66 miles	35 miles
Capital Cost(67)	$20.7 million	$18.5 million	$19.7 million	$12.7 million
Capital Cost(73)	41.4 "	37.0 "	39.4 "	25.4 "
Annual Capital Cost, 6%,20 yrs	3.73 "	3.33 "	3.53 "	2.29 "
Annual Operating Cost, energy	.08 "	0.08 "	0.08 "	.06 "
Annual Operating Cost, other	0.52 "	0.52 "	0.52 "	.52 "
Total Annual Cost	4.33 "	3.93 "	4.13 "	2.87 "
Dry tons/year	365,000	365,000	365,000	365,000
$/dry ton	$12.10	$10.80	$11.30	$ 7.90
$/dry ton mile	0.187	0.189	0.172	0.225

SOME CONSTRAINTS OF SPREADING SEWAGE SLUDGE ON CROPLAND *

by

G. K. Dotson **

Disposing of the solids removed from sewage has long been a difficult and often frustrating part of sewage treatment. Developing better methods of treating sludge and finding environmentally safe places to dispose of it are responsibilities of the National Environmental Research Center of Cincinnati, Ohio. The amount of sludge to be disposed of is increasing rapidly as cities adopt more sophisticated treatment systems. Utilizing a potential waste, sewage sludge, to fertilize and improve soils is an appealing alternative to other disposal methods.

The how sludge is applied to land is determined by the why it's applied. When the objective is disposal only, the protection of the soil is unimportant and high application rates are acceptable. Preventing water and air pollution and avoiding nuisance conditions are the main precautions. When the objective is reclamation of unproductive soils, greater leeway may be permitted in regard to application rates and accumulations. When the principal objective is the addition of fertilizer, water, and organic matter to cropland, the operating options are more limited. Protecting the productivity of the soil and the crops is necessary. The constraints discussed in this paper, unless otherwise stated, are those that apply to the use of sludge for crop production and soil improvement.

Composition

The composition of sewage sludge is variable. A 2-inch application of

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* Presented at Rutgers University Symposium on Land Disposal of Municipal Effluents and Sludges, March 12-13, 1973.

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Chicago sludge supplies 200 to 350 pounds of ammonium nitrogen and about the same amount of organic nitrogen; 250 to 450 pounds of phosphorus, of which about 80 percent is organic; and about 60 pounds of potassium per acre (Hinesly et al., 1972a). Two inches of liquid sludge, with a solids content of 3 percent, contains about 7 tons of solids.

Nitrogen

And it's the nitrogen component of sludge that usually first limits its rate of application. The nitrogen content of sludge varies from about 2 to 6 percent according to the composition of the sewage and the treatment the sewage and sludge received.

Ewing and Dick (1970) in their study of sludge disposal on land presented a hypothetical model to illustrate that 1 inch of liquid sludge would add 340 pounds of nitrogen to an acre of soil. Of this, 150 pounds would be removed by the crop; 20 percent would be evolved; mineralization would balance the added organic nitrogen; and the net immobilization would be zero. The model indicated that only a little more than 1/2 inch of digested sludge per year could be applied to the acre without contributing nitrogen to leachates. But Hinesly (1972a) suggested that about 10 to 15 tons, or about 2 to 3 inches, of an average sludge might be required to meet the nitrogen needs of a nonleguminous crop. Mixing up to 160 tons of sludge solids per acre of soil with clay subsoils did not cause nitrates to leach into ground water at Beltsville, Maryland (Menzies, 1972).

The pathways of nitrogen in soils and the degree of hazard it presents to ground water are difficult to predict. Many processes effecting changes in the form of nitrogen may occur concurrently in soils, and the rate at which they take place is determined largely by soil type and climate.

Mineralization, the conversion of organic nitrogen to ammonia, proceeds at variable rates depending on climatic and soil factors and the nature of the organic matter. Soils in the eastern part of the country naturally average about 3,000 pounds of nitrogen per acre, and about 2 percent of this is mineralized annually. Sludge nitrogen is mineralized at about 5 percent per year.

Digestion converts part of the organic nitrogen in raw sludge to ammonium. Ewing reported that Chicago sludge contains about 1,500 milligrams of nitrogen per liter, about 40 to 50 percent of which is ammonium. Some ammonium may be fixed by organic matter and silicate clays and be protected from biological attack. Volatilization of ammonia may be substantial from soils with high pH.

Denitrification, the transformation of nitrate nitrogen to nitrogen gas, takes place where free oxygen is absent or deficient and other conditions, including a supply of carbon, are favorable for biological activity. The nitrification rate is relatively fast in aerobic soils with favorable temperature.

Microbes utilize part of the available nitrogen in soils to synthesize new cells.

Plant uptake of nitrogen varies greatly, but may be 150 to 250 pounds per acre for a corn crop and more for other grasses.

The amount of nitrogen removed in runoff varies with precipitation patterns and farming practices.

Obviously, only general guidelines are possible when determining the rate that sludge can be applied to cropland without nitrate pollution of ground water. Soil type, geology, climate, crops, and farm management are important factors in determining the fate of nitrogen added in sludge. Soil management techniques may be used to prevent nitrate pollution of surface or ground water because of sludge applications. Perched water tables may be used to cause denitrification. Leachates and runoff water may be caught and treated or reused for irrigation. Soil conservation practices that prevent soil erosion and retard runoff of surface water should be applied where sludge is applied to crops.

Metals

There is much concern about the increase of metals in the environment, particularly in the food chain. Sludge applied to soil is only one source of metals and other trace elements. Other significant sources of such soil pollution include airborne emissions from factories, automobiles, and smelters; and liquid and solid waste discharges from industries, municipalities, and natural runoff including pesticides, fertilizers, mine wastes, fly ash, and animal manure. The potentially toxic metal content of sludge varies greatly. Industrial cities of all sizes tend to produce sludges with high concentrations of metals. Although sludge of domestic origin is lower in metals than industrial sludge, concentrations of zinc and copper in excess of those found in soil are present.

Some metals and other trace elements are essential nutrients for plant growth. Although essential in small quantities, they are toxic at relatively low levels to some crops. Berrow and Webber (1972) analyzed samples from 42 municipal plants treating waste from both small residential communities and large industrial cities. They found silver, bismuth, copper, lead, tin, and zinc were consistently more concentrated in sewage sludge than in agricultural soils. In a few sludges, boron, cobalt, molybdenum, chromium, and nickel were also higher. Zinc, copper, and nickel are most likely to build to toxic levels as a result of sludge spreading. The British Ministry of Agriculture, Fisheries, and Food suggested that nickel was eight times as toxic to plants as zinc, and that copper was twice as toxic to crops. They recommended that the total of copper, zinc, and nickel added to British soils should not exceed the equivalent of 500 pounds of zinc per acre. Other metals that may be present in sludge in excess include chromium, cadmium, lead, and mercury. Although sludge-borne boron is soluble and leaches from soils in humid areas, excessive concentrations of boron in the sludge or dry weather that would halt leaching could cause temporary boron toxicity to result from sludge spreading. Salts are also soluble and could be harmful under the same conditions as boron. Rohde (1962) attributed toxicity on sewage farms near Paris and Berlin to copper and zinc accumulations.

Opinions differ widely regarding the hazard of trace element toxicity caused when sewage sludge is used as a fertilizer and soil conditioner. The University of Illinois has applied 150 tons of digested sludge solids per acre to corn plots without causing toxicity. The metals added greatly exceed the suggested limit for British soils. The corn yield from these sludge-treated plots equalled that from the fertilized check plot and neither corn nor forage crops have shown any toxicity symptoms. They have not accumulated substances to lower the quality of the crop for livestock feed. Anderson (1969) from the Agricultural College of Sweden suggested that the rate of application of sewage sludge to fields should be based on the content of toxic components of the sludge. Others have expressed doubt that the prudent use of sewage sludge on farm land will cause toxicity in the soil.

Le Riche (1968) analyzed soils and crops from a market garden experiment in Woburn, England, where from 1942 to 1961, 568 tons of sludge solids were applied. Although there was some increase in metals uptake by the vegetables, crop yields were unaffected.

There is a dearth of information concerning the fate of heavy metals applied to soils. Most of the reports about toxicity have not recorded the concentrations of metals in the soils and plants. Many combinations of soil types, plant species and varieties, and climate were involved.

Only soluble trace elements, those available to the plants, cause toxicity. Several soil characteristics interact to determine the availability of trace elements to plants. Copper, nickel, and zinc can be chelated by organic matter, adsorbed on silicate clays, or precipitated near the soil surface. They are low in solubility and therefore do not leach to any appreciable degree. Oxides of iron and manganese adsorb metals, so maintaining oxidizing conditions in the soil tends to keep metals unavailable to plants. Neutral or slightly alkaline pH helps to keep metals immobilized.

There are other reasons why permissible levels of trace elements added to soils are difficult to determine. Not only do plant species vary widely in uptake and tolerance of metals, but varieties of a species differ. Much of the information concerning plant response to metals has been obtained from greenhouse pot culture. Indications of the transformations of metals in soils can be gained that way, but only by studying the effects of prolonged applications of sludge to soils in the field can the tolerable levels of trace elements be determined. The EPA-supported research project performed by the University of Illinois for Chicago is supplying some answers.

Much of the toxicity studies have involved only an excess of one or two elements. The interactions of many trace elements applied in sewage sludge are not completely understood. Greenhouse and other studies in Illinois have shown that there are both synergistic and antagonistic interactions between metals that affect the uptake and translocation within plants (Hinesly, 1972a).

The information now available on metals is inadequate to set specific guidelines for applying sludge to soil. Long-term field studies are needed for various combinations of crops, soil types, and climate.

Pending the establishment of guidelines for permissible additions of trace elements in sludge, some precautions should be observed with high rates of sludge application or with prolonged applications at lower rates. Regular testing of crops and soils should forewarn of toxic accumulations. Liming and maintaining oxidizing conditions and a high level of organic matter in the soil will help to keep metals immobilized.

Pathogens

Although no records exist of diseases having been caused by using digested sludge as a soil conditioner or fertilizer, this is still a concern of many people. A 1950 literature review by Rudolfs et al. pertained to the occurrence and survival of pathogenic organisms. The summaries of results of more than 100 experiments showed that under variable conditions of climate, soils, and plants, the viability of pathogenic organisms in soil may last for only a few hours or as long as several months. Among the most important factors influencing the survival time of intestinal pathogenic organisms were the type of organism, soil type, moisture, temperature, pH, and the presence of antagonistic organisms in the soil. A study (Kenner et al., 1971) at the National Environmental Research Center in Cincinnati determined that fecal coliforms survived for at least 21 weeks after a single sludge application in the spring. The bacterial pathogens studied, Pseudomonas aeruginosa and Salmonella Sp., were less hardy under the study conditions. Under winter conditions in Cincinnati, the indicators and pathogens lasted longer.

Intestinal bacterial pathogens are either destroyed or their numbers greatly diminished by heated anaerobic digestion for 14 days (Hinesly, 1972a). The manner in which most digesters are operated does not ensure that all sludge removed will have been in the digesters long enough for pathogens to be killed. Some bacteria, viruses, and parasites may survive digestion and remain viable in the digested sludge. The degree of disease hazard involved in spreading undisinfected sludge varies with the land use. Pathogens or parasites on soils where people come into direct contact with the soil would present more of a hazard than on soils devoted to producing farm crops. Low growing fruits and vegetables can become contaminated with sludge-borne pathogens. Undisinfected sludge placed on shallow soils underlaid by porous material or on soils that crack when dry may cause pathogens to reach ground water. Good soil and water conservation practices are needed to prevent erosion from sloping land. Percolation of water through 5 feet of unsaturated soil should remove pathogenic organisms.

If disinfection is needed, pathogens in sludge can be destroyed through:

(1) storing for long periods;

(2) pasteurizing at 70° C for 30 minutes;

(3) adding lime to raise pH to 11.5 or higher and maintaining the pH above 11.0 for 2 hours or more;

(4) using chlorine to stabilize and disinfect sludge; or

(5) using other chemicals. (Dotson et al., 1973)

Long storage of sewage has been suggested as one of the simplest methods of reducing pathogenic organisms (Berg, 1966). Storing sludge for 30 days reduced fecal coliforms by 99.9 percent (Hinesly, 1972a), although some parasites probably persist much longer when sludge is stored in lagoons. Most large municipalities that dispose of sludge by spreading on land store it in lagoons--this provides the flexibility needed at times when sludge cannot be spread.

Sludge spread on pastures during the grazing season in Germany and Switzerland is pasteurized. Maintaining a temperature of 70° C for 25 to 30 minutes kills pathogens, viruses, cysts, worm eggs, and oöcytes (Liebman, 1967). Direct steam injection avoids fouling and sealing of heat exchangers. Heat recovery is uneconomical for small plants.

Pasteurizing digested sludge has been studied at the National Environmental Research Center in Cincinnati. Pathogens were killed when steam was injected into a tank truck raising the temperature of the sludge to 75° C and maintaining it for one hour. The sludge killed bluegrass when applied to the lawn at a temperature greater than about 60° C. The cost for pasteurizing four 5,000-gallon truckloads of sludge per day was estimated at $12.50 or less per ton of solids (Dotson et al., 1972).

In 1967, Triebel reported the cost of pasteurization in German marks (Dotson et al., 1972). The dollar cost, with four marks equal to one dollar, is estimated as:

Tons of digested sludge pasteurized annually	Cost per ton of sludge solids, 1967
780	$8.60
1560	6.42
5000	1.85

Liming digested or physical-chemical sludges to pH 11.5 killed pathogens in batch tests at the EPA pilot plant at Lebanon, Ohio, with costs estimated at about $10 per ton of solids (Farrell et al., 1972).

Application of Sewage Sludge

Insufficient stabilization may limit the places that sludge can be applied and the rate of application. High oxygen demand increases the hazard of odors and temporary toxicity either in storage or on land. When the volatile solids content of raw sludge is reduced by less than 50 percent, the sludge is incompletely stabilized and could cause odor and fly problems. Applying well-stabilized sludge in thin layers avoids nuisance and toxicity problems associated with thick applications.

Digested sludge has been shown to be toxic to germinating corn (Hinesly et al., 1972a). Ammonia has been identified as one of the toxins, but not the only one. Anaerobic decomposition of organic waste also produces volatile organics toxic to plant roots and seedlings. Aging digested sludge or delaying applications for about 3 weeks after planting of the crop should avoid the problem.

Many other factors might limit the way and the rate where sludge can be spread. Soil properties, legal restraints, and sludge properties may serve as constraints on sludge spreading. Public resistance to spreading municipal wastes in rural communities has been general. Many instances of apparently mutually advantageous utilization of municipal wastes to improve rural land have been rejected by local residents because they were not convinced it was beneficial to them. Spreading sludge to improve soils and crops for the benefit of the local community according to a plan developed and publicized with local residents is much more likely to be received with enthusiasm than one that is planned and unilaterally implemented by city officials.

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METHODS OF LIQUID FERTILIZER APPLICATION

By

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Robert O. Carlson, Principal Agricultural Engineer

METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

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Municipal Effluents and Sludges"

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METHODS OF LIQUID FERTILIZER APPLICATION

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Robert O. Carlson, Principal Agricultural Engineer

The Metropolitan Sanitary District of Greater Chicago (MSDGC) applies anaerbically digested sewage solids (liquid fertilizer) to strip mined land to restore its organic matter content, and to supply plant nutrients for crop production. The methods of application used are: a tank truck equipped with a manifold across the rear end; various irrigation systems; and an incorporation method that is being developed. This presentation will describe each of the systems used.

Tank Trucks

The manifold is an eight foot pipe, eight inches in diameter, mounted on the rear of the tank truck and connected to the tank. Opening a valve allows the fertilizer to flow, by gravity, from the tank to the manifold. The manifold has a series of holes along the bottom to allow the fertilizer to flow onto the ground. The forward speed of the truck controls the rate of application.

Flood Irrigation

A simple flood irrigation method has been used to apply the liquid fertilizer to a leveled sanitary landfill. This method achieved some degree of success. While the liquid portion flowed across the field the solids had a tendency to settle out near the inlet, resulting in uneven application of solids across the field.

Ridge and Furrow

A ridge and furrow system has been used. Gated irrigation pipe conveys the fertilizer to the field where it flows into furrows formed by a lister. A row crop is planted on the ridges and the furrows distribute the fertilizer between the rows. This method requires a great deal of land preparation.

Wheel Roll

SEMCO (Soil Enrichment Materials Corporation), a firm with expertise in liquid fertilizer application to farmland, applied liquid fertilizer with an irrigation system called a "wheel roll". Eight inch diameter pipe was used to convey the liquid fertilizer one-half of a mile across a field. Spray nozzles spaced along the top of the field piping were used to apply the liquid fertilizer. The pipe also serves as the axle for the wheels which move the irrigation system across the field. To move the system the flow is shut off which causes the pressure to drop. This pressure drop opens valves on the underside of the pipe allowing the water to drain out. When the pipe is emptied the whole system is moved across the field to a new position.

When using this system the drain valves often plugged, thus the entire half mile length of pipe remained full of liquid fertilizer. Attempts to move the system with the pipe full resulted in twisted pipe or broken wheels - making the system inoperable.

Center Pivot

Some companies which manufacture center pivot irrigation systems have shown considerable interest in altering their systems to apply liquid fertilizer. The problem with the center pivot irrigation systems is that the nozzles nearest the point of pivot must be of a small diameter (1/16 to 3/16 of an inch) since they have only a small area to irrigate. The nozzles get larger as they become progressively further from the point of pivot. At the outer end the nozzles are three fourths of an inch in diameter or larger. Experience has shown that to apply liquid fertilizer the nozzles must be at least one inch in diameter and the nozzle pressure about 50 psi.

Traveling Sprinkler

The most successful sprinkler system used to date is the traveling sprinkler. A single nozzle mounted on a carriage travels across the field applying a swath about 300 feet wide. A flexible hose, 660 feet long and five inches in diameter, is pulled along with the traveling sprinkler and connects the sprinkler to the irrigation piping. Nozzles that are 1.5 to 1.9 inches in diameter with a nozzle pressure of 50 to 80 psi have been used satisfactorily. To date this system has caused no plugging and will apply 400 to 700 gpm. Figure 1 shows this irrigation system applying liquid fertilizer.

Incorporation System

The Sanitary District has developed equipment which incorporates the liquid fertilizer into the ground. A manifold mounted on a heavy duty disc harrow or two-way plow delivers liquid fertilizer to the inside of each disc blade or mold board which then covers the liquid fertilizer as the unit moves forward. The source of supply is the same hose that supplies the traveling sprinkler irrigation system described above. Figure 2 shows a disc equipped to apply liquid fertilizer.

Rates of Application

The speed of the applicator across the field governs the rate of application. For example, if the flow rate is 800 gpm, it would take 34 minutes to apply one acre inch of liquid fertilizer. If the system applies the fertilizer to a swath 300 feet wide, the unit would have to travel 145 feet during 34 minutes to apply to one acre. Thus the unit travels 4.25 feet per minute. If the solids content is 5% this acre inch contains 11,300 pounds of solids. Weather and soil conditions dictate the allowable rate of application, within the limits set by the Illinois Environmental Protection Agency. These limits are 75 dry tons per acre per year on strip mined soils and 25 dry tons per acre per year on unstriped soils.

The District intends to apply the equivalent of 75 dry tons of liquid fertilizer the first year, 60 the second, 54 the third, and 30 dry tons the fourth year. These application rates apply only to strip mined land, which is devoid of organic matter. This totals 219 tons per acre during the first four years. These application rates were established after several years of research by the University of Illinois, College of Agriculture.

Above average precipitation during the last half of 1972 prevented application of more than a token amount of liquid fertilizer. The 75 dry tons will require the application of 13 acre inches while the 60, 54, and 30 dry ton applications will require 11, 10, and 5 acre inches respectively. Because the higher application rates will be difficult to attain in one year, application may apply less than 75 dry tons the first year but more than 30 dry tons the fourth year. Considerable effort is being directed towards increasing the solids content of the irrigant, since this is the primarly limiting factor with irrigation systems.

Transportation and Application

The District transports liquid fertilizer from Chicago to

Fulton County by barge. The distance is 180 miles. At a dock just west of Liverpool, Illinois, pumps remove the fertilizer from the barges and transport it by pipeline to a pumping station about 1000 feet from the river. This pumping station, with three pumps powered by 300 HP electric motors, pumps the fertilizer through a 20 inch underground pipeline 11 miles to the holding basins on Sanitary District property.

Figure 3 shows diagrammatically the distribution and application system. A dredge floating in the basin removes the liquid fertilizer from the basin and pumps it to a holding tank adjacent to a pumping station. The pumping station conveys the fertilizer to the fields through 10 inch spiral welded steel pipe laid on the soil surface. Eight inch aluminum irrigation pipe conveys the fertilizer from the steel pipe to a five inch rubber hose. The hose is 660 feet long and is connected to the application unit.

The systems for applying liquid fertilizer to land are still in their infancy. The District continues its efforts to develop these systems to increase the efficiency of liquid fertilizer application.

Figure 1. Irrigation System used in Fulton County to Apply Liquid Fertilizer to Strip-mined Land.

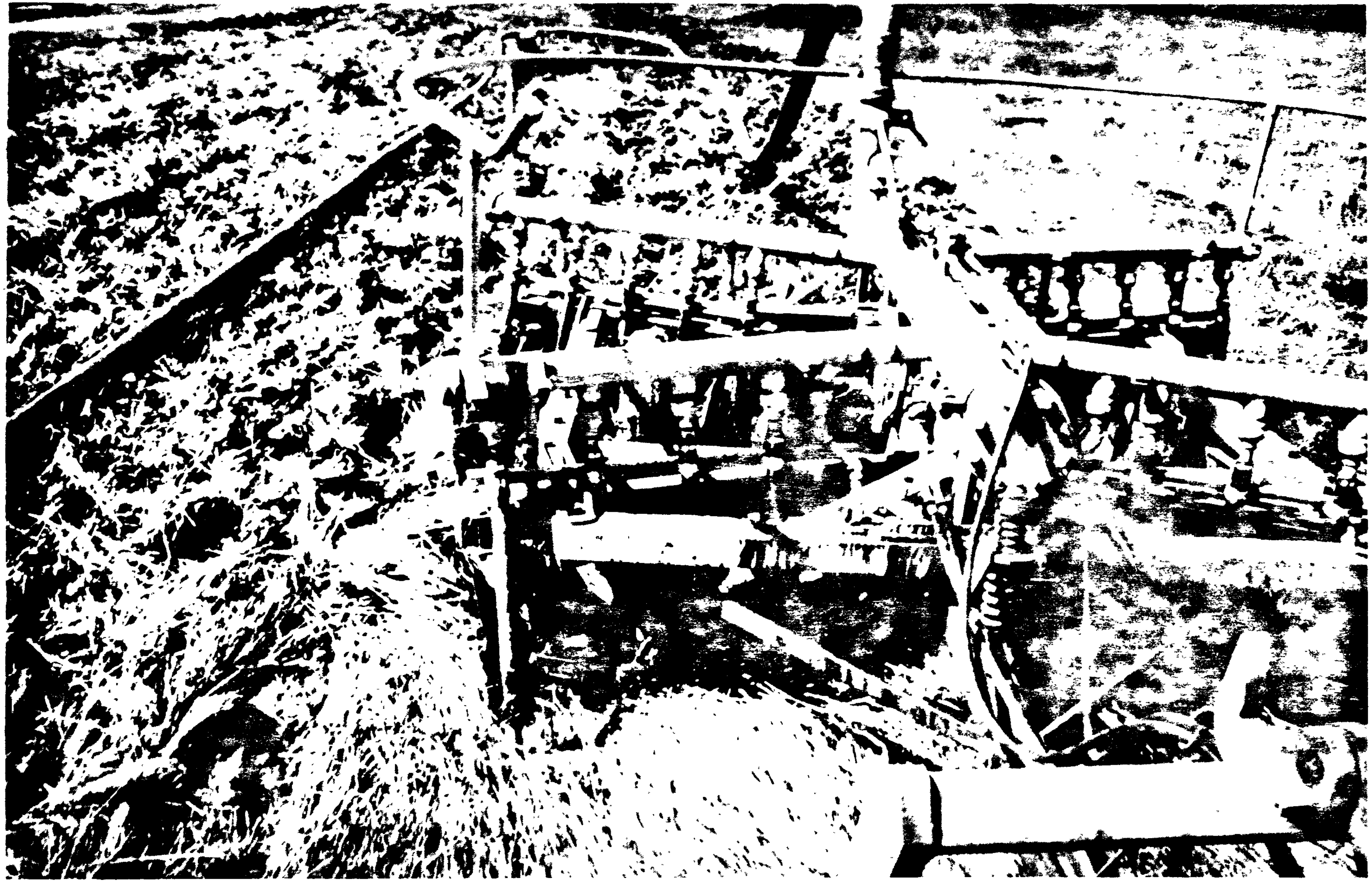

Figure 2. The Incorporation System Applying Liquid Fertilizer to Strip-Mined Land in Fulton County

A BASIN

B FLOATING DREDGE

C FLOATING PIPELINE

D 57,000 GAL. TANK

E PUMPING STATION

F 10" DIA. SPIRAL STEEL PIPE, ON SOIL SURFACE

G ALUMINUM IRRIGATION PIPE, 8" DIA.

H 5" DIA. RUBBER HOSE, 660 FT. LONG

I NOZZLE MOUNTED, FOUR WHEEL CARRIAGE

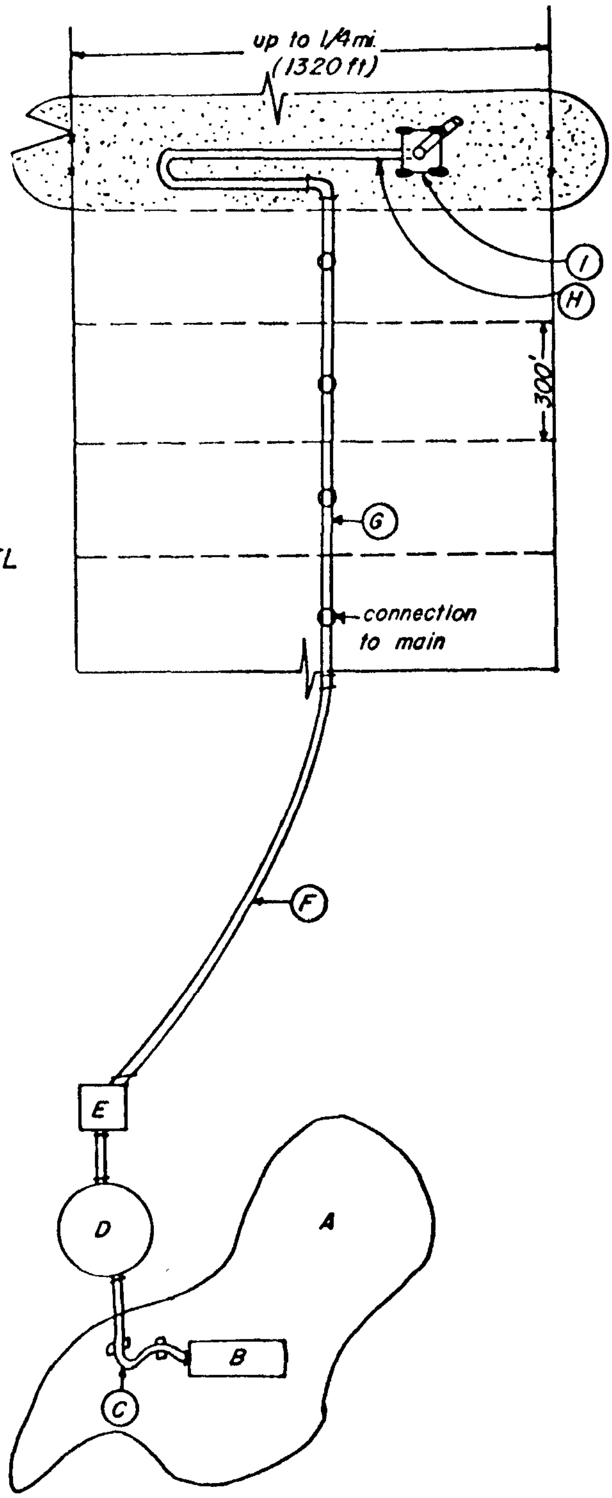

FIGURE 3 Diagram of the Distribution and Application System for Liquid Fertilizer Application.

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EQUIPMENT FOR INCORPORATING SEWAGE SLUDGE AND ANIMAL MANURES INTO THE SOIL

by

Charles H. Reed*

For centuries, man has applied animal manures and human sewage to the soil to improve crop production. The principal technique was to spread them on the land and then work them into the soil.

With the expanding population, depletion of our natural resources, and intolerable pollution of the atmosphere and hydrosphere (1), there is an urgent need for techniques to recycle biodegradable wastes INTO the upper horizon of the soil where they are degraded and utilized, resulting in a beneficial effect upon the environment. Bohn and Cauthorn (2) state, "In summary, compared to air and water, the soil has a vastly greater potential for waste disposal and transformation....and it has the capacity to absorb far more material than it can produce or than is added to it."

The incorporation of wastes directly into the soil is superior to surface spreading because there are no odors, no opportunity for flies or other pests to feed or breed, no runoff or surface erosion of wastes, and the wastes are placed in the best possible media for immediate degradation to plant nutrients and utilization by plants. These techniques conform to the concept of land treatment as defined by Stevens et al.(3):

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* Professor of Agricultural Engineering, Department of Biological and Agricultural Engineering, Rutgers University, New Brunswick, New Jersey, March 1973. Journal Series paper. Paper presented at Conference on Land Disposal of Municipal Effluents and Sludges. March 12-13, 1973. College of Agriculture and Environmental Sciences, Rutgers University, New Brunswick, New Jersey.

Land treatment is any of several methods of waste water treatment and sludge application "which consider the qualities of land, waste water and sludge in the design of facilities. Land treatment conveys the reciprocal, beneficial relationship between the land and the waste. Most such facilities are designed to produce valuable end products, such as green crops and pure effluent as a result of the treatment processes.

"Land treatment differs from land disposal, a term used to describe any method which applies sewage, raw or treated, to the earth; and land application, a term used by EPA to describe all methods of waste water disposal associated with the ground, i.e., sewage farms, land treatment, septic systems, and underground disposal."

The design of an effective land treatment system and the selection of appropriate equipment necessitates the consideration of many factors, some of which are outlined below:

Wastes to be incorporated into soil.

Kind and previous treatments.

Physical and chemical properties, i.e., % solids (wet basis).

Rate of production (daily, weekly).

Storage available or required.

Transportation.

Distance to sites.

Mode of

Site characteristics or limitations.

Acreage.

Topography.

Existing vegetation.

Soil characteristics.

Ground water (Depth, quality).

Location of human habitation.

Distance.

Prevailing wind.

Climatic limitations.

Temperature. Duration of frozen soil.

Rainfall. Seasonal, normal, and extreme variations.

End product desired. Crops to be raised, use of land, etc.

Irrigation of sewage sludge and effluent is receiving considerable attention at this time (4,5). Only thin slurries with low solids content can be irrigated. Because of the high water content (more than 95% as it comes from the digesters) conveyance to disposal sites by pipeline may be the only practical transportation system. Storage structures at the sites will be required during periods of sub-freezing temperatures, frozen impervious soil, saturated soil, and other periods of shut down. Unless thoroughly digested, surface applications of sewage sludge may generate odors and attract flies. Any surface applications are susceptible to surface runoff. There is a possibility of soil-clogging and waterlogging when sewage sludge is irrigated (3,6). Also, there may be damage to foliage when large quantities of sludge are repeatedly sprinkled on plants. There will be large power requirements. The aerosol effect may limit high-pressure irrigation on some sites.

Irrigation of effluent containing only dissolved solids can be managed without many of the above disadvantages of sewage sludge, and may be considered for irrigation of crops when needed or ground water recharge. The limiting factor usually is the amount of water which can be added to the soil at different seasons of the year; i.e., ice buildup, or saturated soil.

Composting is an ancient technique of recycling biodegradable wastes. Modern techniques and equipment have been developed to compost balanced mixtures of biodegradable wastes; including sewage sludge, animal manure, and solid wastes. See Compost Science, Vol. 13, No. 3, May-June 1972, for information on General Motors' Terex-Cobey Composter. These techniques are relatively expensive and may generate some localized odor. Well-cured compost can be spread on the land without attracting flies, is not as susceptible to surface runoff as in non-composted waste, and is an excellent soil conditioner. An outstanding advantage of compost is that it can be readily stored in piles at low cost without nuisance until an appropriate time for application in the soil.

Land spreading is the most ancient method of utilizing both human and animal excreta. When plowed or disked immediately after application it is an effective method of incorporating them into the soil. When large quantities are involved, this may be the most economical, but if not properly treated, it will not be the most sanitary technique.

The ridge-and-furrow technique might be considered a surface method of application unless covered immediately. The furrows can be made on-the-contour or slightly sloping to permit the water to filter into the soil. Ridge-and-furrows on the contour have been used experimentally at the New Jersey Agricultural Experiment Station as a low-cost winter storage. Aerobic conditions should be maintained in and at the bottom of the furrow.

Equipment has been developed which will incorporate wastes directly into the soil, either in one or two operations by Sub-Sod-Injection or Plow-Furrow-Cover.

Sub-Sod-Injection (SSI) equipment is available which will inject any slurries that will flow by gravity or under pressure through a 6-inch diameter hose 2 ft. long. Animal manures with up to 20% solids and sewage sludge with up to 10% solids can be injected by gravity into the soil at the rate of 400 gallons per minute in a band up to 2 inches thick and 28 inches wide and from 6 to 8 inches beneath the surface without turning over the soil. The injector has a standard Category 2 three-point hitch with a spring-trip release for passing over subsurface objects. It is comparable to a two-bottom plow in weight and durability. This equipment is not yet available commercially, but can be assembled from existing components.

The Plow-Furrow-Cover (PFC) method is the most adaptable of any of the previously mentioned techniques. Equipment is available, or can be assembled from manufactured components, to incorporate directly INTO the upper 8 inches of the soil up to 300 tons per acre of biodegradable wastes, ranging from thin slurries (septic tank pumpouts) to semisolids (sewage cake). PFC leaves the soil plowed and ready for disking and seeding. Two types of equipment will be described for PFC: one for 25% solids or less, and the other for greater than 25% solids.

One of the two recently developed pieces of equipment were assembled by Agway, Inc., of Syracuse, New York. The first one was used at the University of Connecticut in a research demonstration project to study the effect of incorporating septic tank pumpouts into the soil. In this project more than 100,000 gallons of slurry were incorporated into the soil in 2 months. The capacity of the tank is 800 gallons. A 9-inch auger with ample hydraulic power from an auxiliary hydraulic pump on the tractor, and 12-inch as well as 6-inch valve openings will unload much heavier solids than would the previous prototypes. The highest limit of solids content which it will unload has not yet been determined. This equipment will not unload low-moisture sewage cake, semisolid animal manures with bedding, or caked poultry manure reinforced with feathers. A gooseneck tongue is built permanently into the tank to provide easy maneuverability of either a 16-inch single-bottom moldboard plow or a sub-sod-injector which are mounted on the three-point hitch of the tractor.

A second unit, constructed in 1973, is identical, except that it has a capacity of 1,500 gallons, a 9-inch ribbon auger, and a slurry spreader on the rear. The augers, valves and spreader are powered by the hydraulic system on the tractor.

To plow-furrow-cover, a 16-inch single-bottom moldboard plow is mounted on the 3-point hitch of a standard farm tractor. A slurry with up to 25% solids can be deposited into a 6-to-8-inch-deep plowed furrow. Immediately after deposition, and in the same operation, the plow covers the waste and opens the next furrow. With properly adjusted equipment, 1½ to 2 inches of slurry can be completely covered. This is approximately 170 to 225 tons of slurry per acre. A well-formed furrow, 16 inches wide, 7 to 8 inches deep and 400 feet long with 1½ inches of slurry, contains 500 gallons, or approximately 2 tons. PFC leaves the soil well-plowed and ready for disking and seeding. The equipment has been designed to operate at 3 mph and unload up to 200 gallons of slurry per minute. The axle of the trailer is adjustable so that the trailer is offset, permitting the right rear trailer wheel to travel in the newly formed clean furrow.

A combination transport and field unit was assembled. It consists of a tank on a four-wheel-drive, 1½ ton truck chassis with flotation tires, and is equipped with a hydraulic pump, controls, and a Category 2 3-point-hitch. The tank has a capacity of 500 gallons. With a 12-inch ribbon auger in the bottom of the tank and a 12-inch diameter valve, semisolid animal manures with up to 30 percent solids and sewage sludge with up to 20 percent solids have been unloaded. Because the hydraulic power is limited, the full performance capabilities of the 12-inch auger have not been determined. A spreader can be installed on the rear for land spreading.

A ridge-and-furrow opener can be mounted on the 3-point hitch of the tractor or mounted on the tongue of the trailer. This consists of right-hand and left-hand moldboard plows, bolted together on the same trip-release beam. The 12-inch opening in the center of the trailer tank permits a high capacity application of semisolids into the furrow. Presently the furrows are closed or covered in a second operation.

The best equipment field-tested to date at the New Jersey Experiment Station, for unloading semisolids and cake with more than 25% solids, is a New Idea Flail Spreader. It can be adjusted for a wide range of surface applications, which are plowed under in a second operation. A conveyor similar to the one on a forage wagon is being adapted to this spreader to convey the waste into a furrow for PFC.

International Harvester sells an attachment to convert one of their heavy-duty manure-spreaders into a self-unloading forage wagon. At this time it has not been demonstrated for unloading a gummy, sticky semisolid into a furrow.

There should be no difficulty in adapting either of these pieces of equipment to PFC for either one or two operations.

Plans are underway at the New Jersey Agricultural Experiment Station to make these adaptations.

There are outstanding advantages in handling dewatered sludge with a solids content of 15% or greater.

(1) As solids content increases, volume and weight decreases. For example, to inject one ton of solids in a 5% solution, twenty tons of slurry must be handled; for one ton of solids in a 15% solution, 6-2/3 tons; and only 3-1/3 tons if a semisolid with 30% solids, dry-weight basis.

(2) It can be stored in contoured furrows or piles on well-drained sites to be incorporated into the soil when weather and soil conditions are optimum.

(3) It can be transported in regular dump trucks without leakage on the highway.

(4) Sludge with a solids content of 15% represents the minimum solids content which can be incorporated into the soil by PFC at the rate of 40 tons dry-weight equivalent per acre in one application: i.e., 2.27 inches of depth in the furrow can be completely covered. Greater rates of application can be applied in one operation if the sludge contains less moisture and more solids, and also because greater depths can be covered in the furrow. This rate of application represents the performance capabilities of the equipment and not necessarily the optimum or safe amount which the soil can tie up, degrade and recycle. Smaller quantities can be applied.

In order to utilize the continuous output of sewage treatment plants, daily PFC applications at the desired annual rate may be made in contiguous strips or furrows, resulting in the entire plot receiving the total annual treatment. At any time when there is sufficient area of contiguous strips of plowed ground, it may be disked and seeded to the crop appropriate for that particular season. After some forage crops, e.g., Hybrid Bermuda Grass, have been established, one or two applications can be made annually by PFC or SSI without replanting. For maximum recycling and utilization of nutrients from the sludge, crops should be raised on and harvested from the treated sites when mature or at the end of the period of their maximum assimilation. Numerous crop management plans and rotations are possible, depending upon the sites and the end product desired.

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SLUDGE DISPOSAL STUDIES AT BELTSVILLE

by John M. Walker[1] [2]

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SLUDGE DISPOSAL STUDIES AT BELTSVILLE

by J. M. Walker

Our research at Beltsville on the use of dewatered sewage sludge for soil improvement has been a cooperative study involving the Agricultural Research Service (ARS), the Maryland Environmental Service (MES), the Environmental Protection Agency (EPA), and about 15 other state, local and federal agencies. I will be highlighting results of 4 different field studies and a number of laboratory studies.

The goal of our research has been to use sewage sludge to improve soils at a reasonable cost, with minimum hazard to health, and with minimum soil and water pollution. We also have been very interested in helping the Blue Plains sewage treatment facility, which serves much of the Washington Metropolitan Area, find a use for the 600 tons of dewatered sewage sludge produced each day (20% solids). This much sludge can cover a football field to a depth of about 3 feet in 10 days.

With this much sludge to dispose of, our primary concern necessarily has been with what limits the amount of sludge that you can safely apply to soils. We have grouped these limitations into two categories. The first category includes short-term limitations: The initial toxicity of sludges to plants, pathogen presence and survival, and excessive quantities of nitrogen. The second category is toxicity from heavy metals such as zinc, cadmium, copper, and nickel, which limit the amount of sludge that you can add to the soil in the long run. These heavy metals, which are present in the sludge, can injure and kill plants and possibly even cause food chain problems.

One method for incorporating sewage sludge in soil has been by plowing, disking or rototilling. We began application studies in October 1971. In a preliminary unreplicated experiment, we mixed a digested sewage sludge from Blue Plains into a fill clay soil to the 2-foot depth at rates from 0 to 160 dry tons per acre. Soil was excavated with a bulldozer, a layer of sludge was spread with the dozer and rototilled in, then a layer of soil was spread on top. This process was repeated until the 2-foot depth of incorporation was completed. Although the rates of application are stated as dry tons per acre, dewatered filter cake sludge with 80% liquid content was used in this and all other experiments.

Rye was planted immediately after sludge incorporation. Growth of rye was best on the area receiving 40 dry tons of sludge per acre (rye vegetative growth in May was 7.4 tons dry matter per acre). There was respectively less growth at 80, 120 and 160 dry tons sludge per acre (5.9, 3.4 and 3.2 tons dry matter per acre). Growth on the control where no sludge and little nitrogen fertilizer was applied was even lower (0.9 ton dry matter per acre). Rye growth on the control contrasted sharply with growth on the area receiving 80 dry tons per acre (Figure 1).

Sweet corn and Kentucky 31 tall fescue were grown on these same plots in June following the rye. Growth of both fescue and corn was worse than that of rye where no sludge or little nitrogen fertilizer was added (fescue yield was too small to measure). Corn yields were not determined because of the limited area planted but a good sampling of fescue was possible. First cutting yields of fescue were 1900, 2000, 2700, and 3100 pounds per acre for treatments of 40, 80, 120, and 160 dry tons of sludge per acre respectively.

We believe that high applications rates of sludge reduced rye yields because of the initial toxic effects on growth. These initial toxic effects may be caused by high salts, high ammonia, low oxygen, and toxic anaerobic breakdown products such as methane gas and hydrogen sulfide. The initial toxic effects apparently had subsided by the time fescue and sweet corn were grown.

In a different experiment, digested sludge was disked into the surface 6 inches of a loamy soil at rates of 0, 25, 50 and 100 dry tons per acre. This research was conducted cooperatively with the University of Maryland on their plant research farm. Growth of soybeans and field corn was very good at both the 25- and 50-ton rates. However, growth of the soybeans, in particular, was reduced by one-half at the 100 ton sludge rate. We believe this is another example of an initial toxic effect of sludge on crop growth.

We also studied the survival of microorganisms in the sludge that was added to the clay soil. Table 1 shows that fecal coliform organisms persisted for as long as 15 months before they could no longer be detected in the soil. We also wanted to determine whether these microorganisms would move down through the clay soil into the well water about 10 feet below the soil surface. Thus far we have not detected any sludge microorganisms in this well water, nor have we detected any nitrogen moving down from the sludged soils into the well water.

We have also been investigating the effect of these sludge amendments on heavy metal uptake by different plants. We found that Swiss chard absorbed nearly 10 times more zinc than did fescue (Table 2). When soils were limed to pH 7 as compared to 5.5, plant uptake of metals was reduced two- to sixfold. This illustrates two very important points to be considered when growing crops on sludged soils. First, soil pH must be maintained near neutral, and second, crops must be selected that will not absorb excessive quantities of heavy metals. Results of an analysis of the Blue Plains sludge (Table 3) show that although the heavy metal concentration does not make this sludge unsuitable for use on soils, it does limit the amount that can be applied safely.

Higher rates of sludge application were desired than we could achieve by mixing the sludge into the soil surface. Also, much of the sludge from Blue Plains is raw rather than digested. Therefore, we investigated a trenching technique as an alternative method for incorporating sludge into the soil.

In May 1972, sludge was placed in trenches that were either 2 feet wide, 4 feet deep and 6 feet apart on centers (500 dry tons/acre), or 2 feet wide, 2 feet deep and 4 feet apart on centers (320 dry tons/acre). Sludge was placed in trenches with a front-end loader. A trenching machine simultaneously dug a trench and covered the previous sludge-filled trench. This soil, when evenly spread over the sludge-filled trenches and intervening soil, provided a 12- to 15-inch soil cover which eliminated both contamination of surface water and odor, buried disease-causing organisms, and permitted digestion of the sludges in the field (thereby reducing the population of disease organisms). The trenched sludge apparently has remained anaerobic since incorporation except at the edge of each trench. Thus, mineralization of nitrogen has been slow and denitrification apparently has been occurring. Up to 500 dry tons of sludge per acre can be applied in one shot deep in the soil profile by trenching. This lowers the cost of the operation and restricts additional sludge application unless future tests show that it is safe to do so.

Roots of crops that were planted over the trenched area could grow into the sludge or into the soil. This was particularly important because roots will not readily grow into raw sludges until considerable field digestion has occurred. Meanwhile, roots that grow down between the trenches can benefit from nutrients released slowly from the sides of the trenches. Observations indicated that this was true for the fescue, corn, and fruit trees grown on these plots.

About 40 groundwater wells were installed in an area of approximately 75 acres. These were monitored before and after sludge application to determine the extent of any possible pollution from nitrogen or microorganisms. The plot area covered about 5 acres of the 75-acre site. Surface and groundwater were drained into a catchment pond. Samples from the pond and pond drainage stream were taken periodically, and analyzed for nitrogen, chemical constituents, viruses, and microorganisms. There has been little contamination of the pond or wells with nitrogen or microorganisms. However, one well, immediately adjacent to a raw sludge plot, has shown increased levels of nitrogen (up to 22 ppm NO_3 nitrogen) and microorganisms, indicating contamination from the plot. The subsurface drainage system also is intercepting some contaminated groundwater (10 ppm NO_3 nitrogen). If any significant contamination with disease organisms or nitrate occurred, the ground water could be chlorinated, or filtered by applying on surrounding land. Thus far, however, such measures have not been necessary.

Possible movement of nitrogen or microorganisms from the trenches was investigated further by digging a pit at right angles across the incorporated sludge in the trenches. The soil and sludge were analyzed at specific locations in and around the trench. Analyses of these samples showed little movement of nitrogen or coliform organisms beyond about 2 feet from the bottom of the trenches. Studies of persistence of disease organisms in these trenches showed that salmonella organisms persisted for at least 7 months. Although the salmonella organisms did persist, they would also persist if the sludge were landfilled or dumped into waterways. It is encouraging that epidemiological evidence has not indicated adverse effects on human health in areas where digested sludge has been applied to soils as fertilizer. More research is needed, and our sampling for persistence is continuing.

We have run field studies on the effects of liming sludges up to pH's of 11.5 before incorporating them into the soil. Although initially the high lime nearly eliminates salmonella and fecal coliform organisms, the remaining organisms appear to multiply within a month as the pH drops to 7.0 or 8.0. The microorganisms then were at comparable or even slightly higher levels than in the sludges that had not been limed to such high pH's. Therefore, liming sludge to pH 11.5 is not adequate to insure that sludge microorganisms will be eliminated.

I would express a note of caution on the results with pathogens, nitrates, and heavy metals in the field. The studies are continuing and results may differ with time.

Although the trenching system is technically feasible and offers a solution to the problem of sludge disposal, it may not always be acceptable to residents in an area where the system might be used. This emphasizes the necessity for participation by local citizens and their elected officials in planning the solutions for waste problems.

Another alternative for sludge disposal is composting. In September 1972, we learned that equipment was available for large-scale field composting of materials like sewage sludge. In fact such equipment had been used in Los Angeles for this purpose. We believe that composting may be a solution to the sludge problem at Blue Plains.

ARS and MES held a public meeting to explain their plans for a cooperative research demonstration project. We expected to develop technology for composting up to 600 tons of dewatered sewage sludge per day and to study its safety and proper agronomic use. We told the audience that sludge had been dried and essentially composted in the Los Angeles area and then marketed successfully over the past 40 years. We indicated that our goal was not necessarily to produce a marketable product but rather to produce a product that could be disposed of more safely than raw or digested sludge. The project was accepted by the public.

In preliminary studies we have been developing methods for composting sludge. Briefly, the procedure involves mixing a bulking agent such as paper, sawdust, or woodchips with the sludge in the ratio of about 3 parts bulking agent to 1 part sludge. In this manner the initial 80 percent moisture content of sludge is reduced to 60 to 65 percent. Because air can readily penetrate this blended mixture of sludge and bulking agent, the sludge decomposes rapidly without generating objectionable odors. The thermophillic microbial activity generates temperatures up to about 150°F. The heat drives off excessive moisture and has a pasteurizing effect on the pathogens present in the sludge. Pathogens are also killed by the antibiotics produced during composting.

An isolated site previously used as a burn dump and landfill was chosen for the large-scale composting project in a wooded area on the Beltsville Agricultural Research Center. A sketch of the planned compost site is shown in Figure 2. Basically, a stabilized compost pad of about 5 acres should permit the composting of sewage sludge at the rate of 250 tons per day. Windrow-composting will be accomplished with a General Motors-Terex Cobey[3/] composting machine which has a high volume output. Sludge and bulking agent will be mixed and composted on the pad for approximately 14 days. We expect that composted sludge can be utilized as a bulking agent for new additions of sludge. This recycling of the compost as a bulking agent is a key to the success of the operation.

Once operations reach the 250-ton-per-day level, the excess compost that is not needed for bulking will be moved to the 2- or 3-acre storage area and stored in a huge pile for curing. During curing, some additional composting takes place and high temperatures can be reached for a final pathogen kill. After storing and curing for approximately 1 to 2 months, the sludge will be made available for distribution -- maybe even to homeowners if tests show it be be safe.

3/ Trade names are used for the benefit of the reader and do not imply endorsement by the U.S. Department of Agriculture.

We will be studying the fate of pathogens, nitrogen, carbon, and heavy metals during the composting and curing processes. We also will be studying the agronomic and horticultural use of the compost.

I did not have time today to cover all of the interesting work we are doing on this project at Beltsville. I hope that you will visit with us here today and at Beltsville if you would like to know more about our work.

Thank you very much.

Table 1. Fecal coliform survival in digested sludge-amended clay soil. (Sludge incorporated October 1971).

Sludge dry tons/acre in surface 2 ft.	Fecal coliform, cells/g			
	5 months March 1972	9 months July 1972	13 months Nov. 1972	15 months Jan. 1973
Control	<0.03	2	4	0.02
80	1,500	540	19	<0.02
120	27,000	350	56	<0.02
160	24,000	240	4	<0.02

Table 2. Zinc uptake by Swiss Chard and fescue on sludge-amended soil with and without lime

Sludge applied tons/acre in surface 2 ft.	Zinc uptake, ppm			
	Swiss Chard		Fescue	
	No Lime	Lime	No Lime	Lime
0	-	60	31	-
40	-	150	68	38
80	1050	184	83	39
120	1940	566	86	42
160	1690	627	112	198

Table 3. Heavy metal and nutrient concentrations in digested sludge from Blue Plains sewage treatment plant.

Heavy metals ppm		Macronutrients %		Micronutrients ppm	
Zn	2000	N	2.5	B	23
Cu	1100	P	1.0	Mo	8
Mn	180	K	0.5		
Ni	100	Ca	1.5		
Cd	20	Mg	1.0		
		S	0.9		

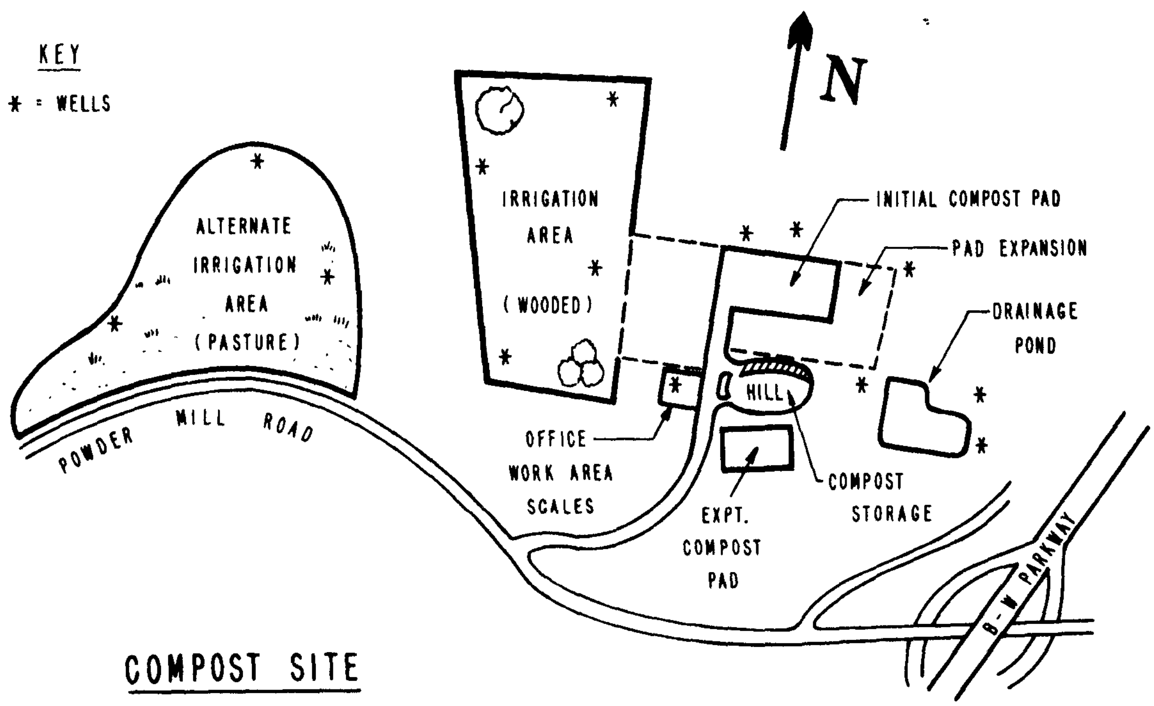
LIST OF FIGURES

Figure 1. Yield of rye, May 1972; planted October 1971. Digested sewage sludge was incorporated into the surface 2 feet at 0 (left) and 80 (right) dry tons per acre.

Figure 2. Field composting site on the Agricultural Research Center at Beltsville.

Figure 1.

Figure 2.



COMPOST SITE

MERCHANDISING HEAT-DRIED SLUDGE

C. G. Wilson, Sales Manager & Head Agronomist
Sewerage Commission, City of Milwaukee

Eight days before this meeting I was adjusting sludge blankets in our East Plant clarifiers, running effluent chlorine residuals, and increasing chlorination levels in both East and West plant effluent to assure citizen safety in drinking water supplies. At the same time I was helping to destroy some $8,500.00 worth of sludge that should have been made into Milorganite.

Poor sales, and or, poor merchandising were not the reasons for these special actions on my part. We had a municipal strike on that Sunday in question, and it became management's duties with limited help to worry first about water purification.

Incidentally, and whether or not it would be a function of the E.P.A., someone should be making in depth studies on methods other than strikes to solve municipal labor problems. The strike certainly solves the problem of waste disposal for those located on water courses, but is hardly the way to go today.

We elected to go the route of heat-dried disposal in the early 1920's. In fact, Milwaukee pioneered the activated method of sewage disposal, and from the start anticipated a market for the by-product to help offset costs.

The Annual Report of the Sewerage Commission for the year 1923 mentioned investigations underway at the University of Wisconsin to determine the by-products fertilizer value, and the establishment of a fellowship for a Mr. O. J. Noer to work on the project. The late Mr. Noer later became our Agronomist and was recognized as this country's foremost turfgrass agronomist. He also preceded me as Sales Manager for the Commission.

In the 1925 Annual Report our Commission was advised that as a result of a six months contest the trade name "Milorganite" was chosen over 232 other names suggested for the by-product. The fertilizer brokerage firm Mc Iver & Son of Charleston, South Carolina won the $250.00 first prize for suggesting "Milorganite" which embraced the words Milwaukee - Organic - Nitrogen.

The first Milorganite (500 tons) was sold in 1926. Since then, with but two exceptions we have sold everything we can produce in a given year. I have a Sales, Traffic, and Invoicing staff of five. We do approximately a 3-1/2 million dollar a year business, with sales offsetting about 25% of our operating budget. The sales exceptions were a couple of years during the depression and again in the mid 1960's. During the early depression no one had money for fertilizer used primarily on turfgrass, and in the mid 60's production suddenly jumped from 69,000 tons to 87,000 tons per year. It took us a bit over a year to sell the increase. Fortunately, we can store about 20,000 tons in bulk on Jones Island.

Production has slipped since the high year because we are now diverting some of the gallonage that used to come to our Jones Island Plant to the new South Side Plant where no Milorganite is produced.

The fact that we chose another way to go at the South Side has not gone unnoticed by many who thought activation and by-product sale is the only way to go.

In 1964, a production year similar to 1971, it cost us about $9.00 to dispose of a ton of Milorganite. In 1971 the cost exceeded $27.00 per ton. During this period I increased our distributor cost by about $8.00 per ton despite a declining organic market internationally, and depressed prices for chemical or inorganic fertilizer because of over production.

The reason for such bad news despite successful sales is our high fixed cost, increasing wages and fringe benefits, and inability to offset this with increased production.

The unfortunate point, and this, incidentally, is my opinion only, was our decision not to produce Milorganite at the South Side Plant. I should also say, that at the time this decision was made in the early 1950's, primary treatment would suffice, and an automated digested gas producing plant seemed the most economical approach to Milwaukee's growth. What with the need for secondary and tertiary treatment, today, and our inability to get rid of the sludge in lagoons would make some with hindsight question the wisdom of this decision.

Our South Side lagoons are filling rapidly and the initial offer to remove their contents when converted to a dry (less than 5% moisture) basis as Milorganite is sold exceeded $70.00 per ton just to haul it away.

So, from this standpoint it is still economical to sell Milorganite, and in my opinion is still the best way to purify an effluent and completely recycle a worthwhile fertilizer through stimulating plant growth.

Increased production would be the best answer to our high costs. There is a limit as to how much further increase in price will be accepted prior to increases being made by the fertilizer industry.

For example, the large institutional or farm type purchaser is aware that the cost formula favors the use of the pure chemical source of high analysis. One takes the cost per ton and divides this by the % nitrogen in the product times 2,000 the pounds in a ton. If, say, Urea is selling for $90.00 per ton its cost of nitrogen (45%) then comes to 10¢. In some areas Milorganite (6% nitrogen) sells for the same amount, thus its nitrogen cost becomes 75¢, or 7-1/2 times greater.

Our customers are not ignorant. The reason Milorganite can command this premium is that it does a better job.

Several other things have conspired through the years to help our marketing activity. As with any other successful merchandising effort luck has also played a part.

In the late 1920's and through the 1930's natural organic materials were part of all mixed fertilizers. As higher analysis materials became available to dry up this market our golf and lawn sales increased. Then, shortly after World War II started, chemical nitrogen sources went to war and ours was about the only nationally sold product available for victory gardens, lawns, etc.

As the highly advertised lawn fertilizers became available following the war, coupled with our inability to furnish the demand, we started to lose some place in the lawn market but this was rapidly absorbed by our golfing friends. And today, the environmental interests of our citizens makes a yearly application of Milorganite almost the patriotic thing to do.

Through all of this we also had time to develop a strong distributor service. All of our distributors are on restrictive quotas, or allocations; constantly clamor for more product; and are financially sound so they pay invoices promptly.

However, before anyone dashes out to build their plant certain sobering figures must be considered.

Alvord, Burdick and Howson (consulting engineers) in a 1956 report to our Commission stated it would cost 50 million dollars to build a 50 million gallon per day capacity activated plant from input through incineration. We conservatively estimate our investment in Jones Island at 80 million dollars, and if A, B & H's estimate is correct it would have taken 200 million to duplicate our facilities in 1956 and we know how much costs have gone up since then.

Our dewatering costs with the present plant paid for exceed $20.00 per ton, and freight on a 50-ton rail car from Milwaukee to the West Coast exceeds $26.00 per ton. Although the customer pays for the latter, one must think about freight costs, constantly, when dealing with low analysis materials.

My best guess is that under present costs and prices our production and sales would have to exceed 100,000 tons a year to reach a break even point. I am sure we could find a market for this much Milorganite. Others might not find it so easy. They would have to establish markets, assure supply, maintain quality control, and stay free from political pressures.

All sewage sludges are by no means alike. Granulation is important to the applicator and the plant being grown. Our industrial complex is responsible for an additional one to two percent nitrogen over what other cities might be capable of producing.

In summary, then, the following have been important to us in merchandising heat dried activated sludge.

1. Knowledge of what the by-product will do in growing plants. Possibly more important knowledge of what it won't do.
2. A national market to even out seasonal and climatic variables.

3. Quality control and absence of political interference.

4. Sales based on agronomic service rather than wheeling and dealing.

5. A strong distribution system.

Slides were shown proving the superiority of Milorganite over other nitrogen sources in growing quality turfgrasses. Milorganite fertilized grass had less disease, insect and water stress injury in tests at leading Agriculture Experiment Stations throughout the nation.

CGW/bmr

Prepared for E.P.A. - Rutgers Meeting
March 12 & 13, 1973.

OUTLINE OF PRESENTATION MADE BY MICHAEL GRITZUK, P.E., EXECUTIVE DIRECTOR, OCEAN COUNTY SEWERAGE AUTHORITY AT THE "LAND DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES SEMINAR" ON MARCH 12, 1973 AT RUTGERS UNIVERSITY

OCEAN COUNTY SEWERAGE AUTHORITY
WASTEWATER SOLIDS UTILIZATION ON LAND DEMONSTRATION PROJECT

A. INTRODUCTION

1. The Ocean County Sewerage Authority will shortly start construction of a county-wide regional sewerage system that:

   a. Will serve 33 municipalities which will have a combined design population of approximately 800,000 people by the year 1990.

   b. Will have four regional treatment facilities with a combined design flow of 92 MGD.

   c. Will produce 60-70 dry tons of sludge daily or nearly 25,000 dry tons per year.

2. Since the Authority's creation in July 1970, we have been asking ourselves "How will we dispose of the 25,000 dry tons of sludge in light of recent developments, controversies and restrictions on sludge disposal?"

   We have been faced with finding a feasible, economical, and from an environmental viewpoint, the most desirable solution for the disposal of wastewater solids.

   In addition, the 1972 Amendments to the Federal Water Pollution Control Act indicates the national "goal" is to totally recycle wastewater and its byproducts.

B. PRELIMINARY INVESTIGATIONS

1. Several geographic features of Ocean County that should be known before we discuss a sludge reuse plan:

   a. Primarily flat terrain

   b. Almost entirely sand

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c. Densely populated along coastal area. Non-populated barren land in western part of County.

d. Pine barrens in nutrient deficient soil.

2. The Authority established criteria requiring that whatever sludge disposal method is chosen must be:

   a. Environmentally desirable

   b. Economically feasible

   c. Publically acceptable.

3. From the preliminary evaluations of various methods of sludge disposal, which included barging to sea, incineration and landfill, it was concluded that sludge utilization or reuse was definitely worth evaluating for Ocean County.

C. DEVELOPMENT OF DEMONSTRATION PROJECT

1. During the past few years we were able to solicit the support of Federal and State agencies to develop a pilot project to demonstrate that sludge reuse is possible, economically feasible and environmentally desirable in Ocean County.

2. The participants in the demonstration project are:

   New Jersey Division of Environmental Quality
   New Jersey Division of Fish, Game and Shell Fisheries
   New Jersey Division of Water Resources
   Ocean County Sewerage Authority
   Rutgers University
   U. S. Environmental Protection Agency
   U. S. Geological Survey

3. In June 1972, The Ocean County Sewerage Authority received a $200,000 demonstration grant from the U. S. Environmental Protection Agency for its project entitled:

   "Wastewater Solids Utilization on Land Demonstration Project."

D. BENEFITS OF RECYCLING

Initial research of existing data indicates that certain benefits can be derived from utilizing sludge. In particular for the barren leached-out Ocean County soils, the following benefits appear likely:

1. Can build up the organic content of arid and marginal soils.

2. Acts as a mild fertilizer by providing nutrients to the soil.

3. Can supply moisture-retaining capabilities to leached-out soils.

4. Acts as a soil conditioner.

5. Encourages the growth of more desirable vegetation.

6. Reclaims land for more productive purposes such as food production for wildlife, recreation and crop production.

7. Economical.

E. SLUDGE FOR REUSE

1. Only anaerobically digested domestic sludge will be used. Standard Rate two-stage digestion will be utilized which will have an average detention period of 30 days in primary digestion and 15 days in secondary digestion.

2. Characteristics of anaerobically digested sludge:

   a. Reduces pathogenic bacteria populations by 99.8%

   b. Reduces BOD by at least 90%

   c. Emits little odor

   d. Easier to handle through pipelines and spray equipment.

3. The digested sludge will be applied in the wet state which will normally consist of 4 to 6 percent solids.

F. GOALS OF THE DEMONSTRATION PROJECT

The primary goals which will be thoroughly investigated in the project are as follows:

1. Determine proper equipment and application techniques.

2. Determine quantity and frequency of application.

3. Determine any pollutional effects on ground water.

4. Establish ground water quality standards.

5. Determine value of wastewater solids as a fertilizer and soil conditioner for crop production and scrub pine and oak growth.

6. Public education and public acceptance.

7. Aesthetic evaluation.

8. Evaluate long-term effects.

G. PROJECT ACTIVITIES

The activities of the three and one-half year project are:

1. Site selection

Three distinct soil types which are common to the eastern seaboard will be evaluated. These soils are:

a. Lakewood sand.

b. Woodmansie sand and sandy loam.

c. Downer sandy loam, slight clay.

2. Evaluation of application methods

Various methods of application will be evaluated in light of practicality, economics and minimal environmental hazards. As a minimum, the following methods will be evaluated:

a. High pressure spray method (Rain gun).

b. Contoured furrows.

c. Plow-furrow-cover method.

d. Sub-sod-injection method.

3. Hydroligic and geologic characteristics of test sites-ground water monitoring.

A major evaluation in the project will be to determine the effects of the wastewater solids on the ground water. Test wells will be located within and around each test site to permit sampling of the ground water before, during and after the application of any solids.

Before the application of any solids the subsurface geology will be mapped, ground water flow nets will be determined and charted. Base-line ground water quality will continuously be determined at the control plot. A typical layout of the test plots and control plot is shown in Figure 1.

The parameters to be tested and monitored in determining the baseline ground water quality is shown in Figure 2.

4. Survey of soil conditions and vegetation. Planting of agricultural crops.

Soil testing will be performed before and after application of solids and after crops have reached maturity. Plant tissues will be analyzed to determine any buildup of chemical and biological constituents.

5. Atmospheric and meteorological monitoring.

Atmospheric monitoring will include gaseous ammonia and particulate aerosol samplings and odor measurements. This is particularly important in respect to bacterial-aerosol transmission if spray equipment is to be used.

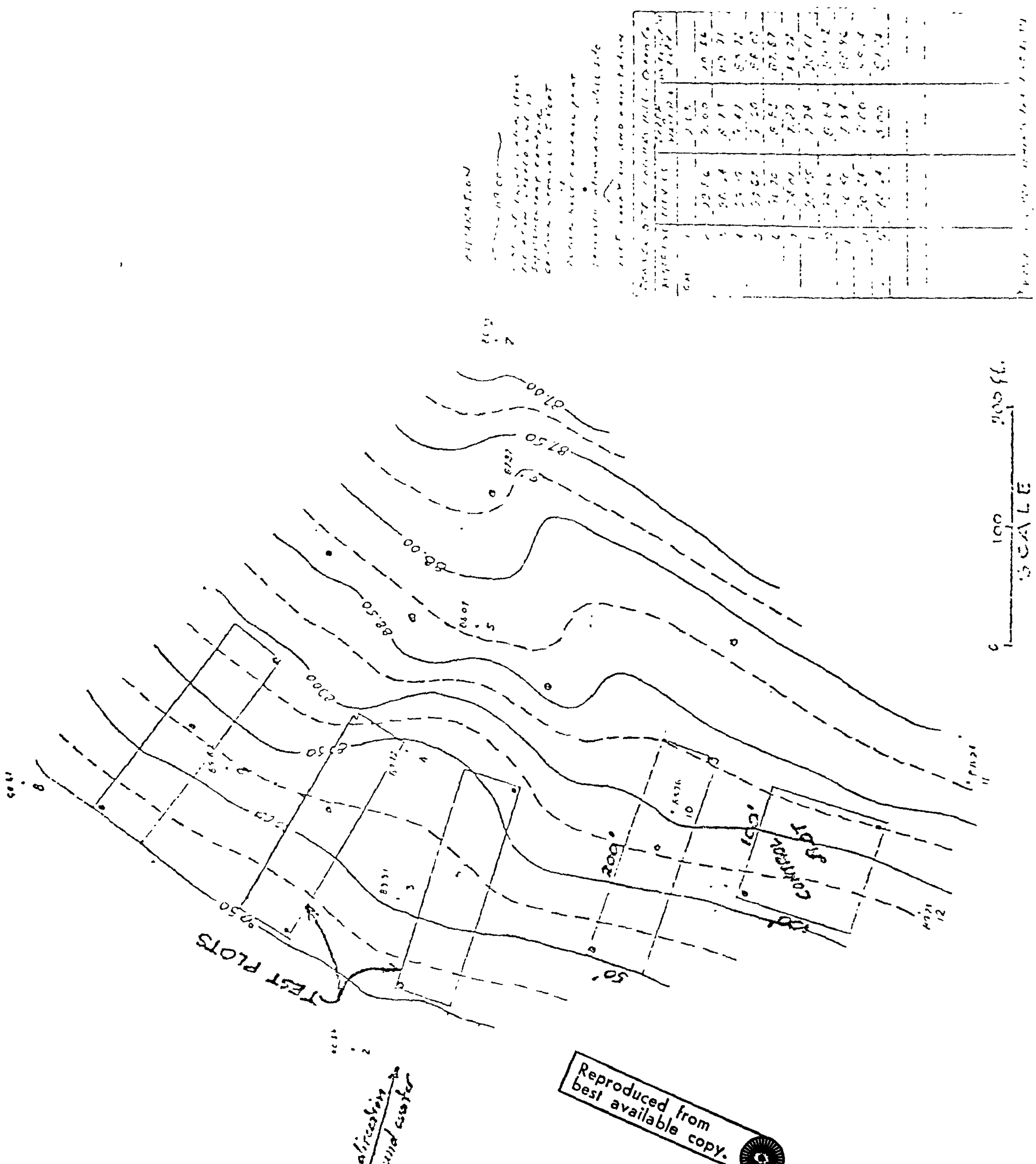
TEST PLOTS
SCALE
Flow direction of ground water

FIGURE 2

GROUND WATER MONITORING

Coliform (total, fecal)	Temperature
Virology	pH
Dissolved solids (fixed, volatile)	Turbidity
Nitrogen (Kjeldahl, organic, NO_2, NO_3, NH_4)	ABS
Phosphorous (Total, PO_4)	Specific Conductance
Alkalinity	Silica (SiO_2)
Hardness	Potassium (K)
Bicarbonate (HCO_3)	Sodium (Na)
Total Organic Carbon	Calcium (Ca)
Chloride (Cl)	Sulfate (SO_4)
Fluoride (F)	Boron (B)
Metals (Hg,Zn,Cr,Mn,Fe,Mg,Pb,Cd,Cu,Ni,Al)	

6. Determination of loading rates and application frequency.

Optimum loading rates will be determined based upon crop growth, land reclamation values and ground water loading. The frequency of application will be determined by crop utilization of nutrients and soil assimilation capabilities.

Initially loading rates of 10, 20 and 40 dry tons/acre/year will be utilized. Adjustment of these rates may be warranted after approximately 12 months of data is available.

(10 dry tons/acre/year = 2 inches 5% sludge = 3/16" dried)

7. Effects on wildlife; aesthetic evaluation; public acceptance.

A study of wildlife will be made to determine their preference, if any, for fertilized vegetation. Aesthetic value will be determined by reaction of the public. Public opinion will be solicited at general public meetings, seminars, and through the news media.

To conclusively determine the effects of recycling wastewater solids on land, it is expected that in excess of 150,000 analytical tests will be performed in the 3 1/2 year evaluation period.

H. COST COMPARISON

A cost comparison of wastewater solids recycling to the more popular sludge disposal methods are as follows:

REUSE ON LAND (5% Solids)	$19.*
LAGOONING	$18.
OCEAN DISPOSAL (Digested, 10% Solids)	$28.
LANDFILL (Dewatered & Digested)	$35.
INCINERATION (Dewatered, Raw)	$40.
DISPOSAL THROUGH OUTFALL (Raw)	$ 1.

*Capital and operating cost, $/Dry Ton

EPA VIEWPOINT

ON

LAND APPLICATION OF LIQUID EFFLUENTS

by

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EPA VIEWPOINT ON LAND APPLICATION OF LIQUID EFFLUENTS

I AM PLEASED TO PARTICIPATE IN THIS CONFERENCE ON LAND DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES BECAUSE OF THE DEEP IMPORTANCE OF ITS CENTRAL THEME. IT FOCUSES ON AN AREA OF TECHNOLOGY THAT HAS BEEN WITH US FOR MANY DECADES BUT HAS MORE RECENTLY GAINED IMPORTANCE DUE TO THE EVER INCREASING AWARENESS OF ENVIRONMENTAL ISSUES.

IT IS ENCOURAGING TO SEE COUNTY AND MUNICIPAL SANITARY ENGINEERS, OFFICIALS AND MANAGERS OF RESEARCH PROGRAMS, MEMBERS OF UNIVERSITIES AND CONSERVATIONIST COMMUNITIES HERE TO BECOME ACQUAINTED WITH THE CURRENT STATE OF THE ART, RECENT TECHNICAL ADVANCES AND ACTUAL FIELD EXPERIENCE IN DISPOSAL OF MUNICIPAL EFFLUENTS AND SLUDGES ON THE LAND.

IN MY TALK THIS MORNING, I WILL ATTEMPT TO CONVEY TO YOU THE ENVIRONMENTAL PROTECTION AGENCY'S VIEWPOINT ON LAND TREATMENT OF MUNICIPAL EFFLUENTS. I WILL PRIMARILY BE SPEAKING FROM MY PERSPECTIVE AS A PERSON INVOLVED IN THE MUNICIPAL TECHNOLOGY RESEARCH PROGRAM. MY ASSOCIATE, MR. RALPH SULLIVAN, CHIEF OF CONSTRUCTION GRANTS BRANCH, OFFICE OF AIR AND WATER PROGRAMS, WILL BE ADDRESSING THE ISSUE FROM THE CONSTRUCTION GRANTS SIDE OF THE EPA PROGRAM.

AT THE OUTSET, WE SHOULD TAKE NOTE OF THE ASTOUNDING GROWTH OF THE ENVIRONMENTAL MOVEMENT DURING THE PAST TWO AND ONE-HALF YEARS. IT WAS INDEED JUST A LITTLE OVER TWO YEARS AGO THAT THE ENVIRONMENTAL PROTECTION AGENCY ITSELF CAME INTO BEING THROUGH A REORGANIZATION PLAN - ADOPTED BY PRESIDENT NIXON. SHORTLY THEREAFTER, THE CLEAN AIR AMENDMENTS OF 1970 WERE ENACTED. AT THE END OF THIS PAST SESSION, CONGRESS ENACTED A NEW FEDERAL WATER POLLUTION CONTROL ACT. IT ALSO ENACTED MAJOR NEW LEGISLATION TO REGULATE OCEAN DUMPING, NOISE, PESTICIDES AND COASTAL ZONE MANAGEMENT.

THE IMPACT OF THESE NEW LAWS IS AND WILL BE MOMENTOUS. ESPECIALLY IN REGARD TO AIR AND WATER POLLUTION, THESE LAWS SPELL OUT THE STATUTORY AUTHORITY FOR A TRULY COMPREHENSIVE, FAR REACHING COSTLY NATIONAL EFFORT TO ACHIEVE BRIGHT SKIES AND SPARKLING WATER. BOTH LAWS ESTABLISH BOLD STRUCTURES OF REGULATION TO DEAL WITH EXISTING POLLUTION PROBLEMS AND ALSO NEW SOURCES. WITHOUT QUESTION, THEY SET THE STAGE FOR A DECADE ON CONCENTRATED ENVIRONMENTAL RECONSTRUCTION.

THE AMENDED FEDERAL WATER POLLUTION CONTROL ACT IS OF PRIMARY CONCERN FOR US TODAY. IT ESTABLISHES A NEW REGULATORY SCHEME, BASED PRIMARILY ON A NATIONAL EFFLUENT DISCHARGE PERMIT SYSTEM FOR ALL MUNICIPAL, INDUSTRIAL, AND CERTAIN OTHER DISCHARGERS. THE ACT DIRECTS THE ACHIEVEMENT BY JULY 1, 1977, OF EFFLUENT LIMITATIONS FOR DISCHARGES WHICH REQUIRE APPLICATION OF BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE, AND THE ACHIEVEMENT BY JULY 1, 1983, OF EFFLUENT LIMITATIONS WHICH REQUIRE BEST AVAILABLE TECHNOLOGY. THE LAW SETS FORTH AS A LONG RANGE GOAL, BUT NOT A REQUIREMENT, THE ACHIEVEMENT OF "NO DISCHARGE" BY 1985.

ANOTHER BILL OF PRIMARY IMPORTANCE TO US IS THE MARINE PROTECTION, RESEARCH AND SANCTUARIES ACT OF 1972 WHICH WILL HAVE THE IMPACT OF LIMITING OCEAN DISPOSAL OF SEWAGE SLUDGE AND OTHER MATERIAL NOW DISCHARGED TO THE OCEAN.

I GIVE YOU THIS BACKGROUND INFORMATION FOR IT HAS A GREAT IMPACT ON DEVELOPMENT OF TECHNOLOGY FOR LAND TREATMENT SYSTEMS. MANY TOWNS, COMMUNITIES AND CITIES ARE INVESTIGATING THE LAND TREATMENT ALTERNATIVE FOR TREATMENT OF SEWAGE SLUDGE AND/OR SEWAGE EFFLUENTS.

LAND TREATMENT CAN MEAN A VARIETY OF THINGS, DEPENDING UPON THE CONTEXT OF WHAT IS SAID AND WHAT THE LISTENER DESIRES TO HEAR. FOR THE PURPOSE OF THIS PAPER, LAND TREATMENT IS INTENDED TO BE USED IN ITS BROADEST CONTEXT AND CONFINED TO ITS USE FOR TREATMENT AND RENOVATION OF MUNICIPAL WASTEWATERS. SINCE SOLID MATERIALS ARE ONE OF THE PRODUCTS OF WASTEWATER TREATMENT AND CAN, UNDER PROPER CONDITIONS, BE APPLIED TO THE LAND, THE APPLICATION OF MUNICIPAL SEWAGE SOLIDS (SLUDGE) TO THE LAND IS CONSIDERED AN INTEGRAL PART OF LAND TREATMENT.

WITHIN THE ABOVE DEFINITION, LAND TREATMENT CAN BE GROUPED IN THE FOLLOWING CATEGORIES:

(1) <u>INFILTRATION-PERCOLATION</u>: THE APPLICATION OF MUNICIPAL EFFLUENTS TO THE SOIL BY MEANS OF RECHARGE BASINS, RIDGE-AND-FURROW BASINS OR FLOODING BASINS.

(2) <u>CROPLAND IRRIGATION</u>: THE APPLICATION OF MUNICIPAL EFFLUENTS TO THE SOIL FOR BENEFICIAL PRODUCTION OF CROPS NOT FOR DIRECT HUMAN CONSUMPTION. COMMON METHODS OF APPLICATION INCLUDE BROAD IRRIGATION AND SPRAY IRRIGATION.

(3) <u>SPRAY-RUNOFF</u>: THE APPLICATION OF MUNICIPAL EFFLUENT TO THE SOIL IN A MANNER CONCLUSIVE TO OVERLAND SHEET FLOW IN A CONTROLLED MANNER. THE PHYSICAL, CHEMICAL AND BIOLOGICAL PROCESSES TAKE PLACE AS THE LIQUID MOVES SLOWLY OVER THE SURFACE. MORE THAN HALF OF THE APPLIED EFFLUENT IS RETURNED DIRECTLY TO THE SURFACE WATERS.

(4) <u>SOLIDS BENEFACTION</u>: THE APPLICATION OF SOLIDS PRODUCTS OF WASTEWATER TREATMENT TO THE LAND FOR BENEFICIAL IMPROVEMENT OF THE SOIL. SUCH APPLICATION MUST BE ACCOMPLISHED IN A MANNER WHICH IS ENVIRONMENTALLY SOUND AND AESTHETICALLY ACCEPTABLE.

ACCURATE INFORMATION ON THE EXTENT AND SUCCESS OF LAND TREATMENT SYSTEMS IN THE UNITED STATES IS DIFFICULT TO OBTAIN AND EVALUATE. THOMAS RECENTLY SUMMARIZED AVAILABLE DATA ON THE NUMBER OF U. S. COMMUNITIES UTILIZING ONE OR MORE OF THE LAND TREATMENT METHODS. THESE DATA INDICATE THAT IN 1972 THERE ARE 571 COMMUNITIES APPLYING WASTEWATERS TO THE LAND FROM A COMBINED POPULATION OF 6.6 MILLION PERSONS. THIS IS A SUBSTANTIAL INCREASE FROM SIMILAR DATA FOR 1940, WHEN 304 COMMUNITIES SERVING 0.9 MILLION PERSONS UTILIZED LAND TREATMENT. AS INDICATED ABOVE, THE ACCURACY OF THE FIGURES IS SUBJECT TO QUESTION. THOMAS, FOR EXAMPLE, POINTS OUT THAT ONE LARGE SYSTEM SERVING 654,000 PERSONS WAS OMITTED FROM THE 1972 DATA - AN ERROR OF 10 PERCENT.

THESE FIGURES ALSO APPLY ONLY TO APPLICATION OF MUNICIPAL EFFLUENTS AND DO NOT INCLUDE FIGURES FOR LAND APPLICATION OF THE SOLIDS BY-PRODUCTS OF TREATMENT. CROP IRRIGATION IS THE METHOD USED BY THE LARGEST NUMBER OF COMMUNITIES (316), IN 13 WESTERN STATES. NATIONAL INVENTORIES OF MUNICIPAL WASTE FACILITIES IN THE UNITED STATES INDICATE THAT THE POPULATION SERVED BY LAND TREATMENT FACILITIES NEARLY DOUBLED BETWEEN 1962 AND 1968.

NO ATTEMPT HAS BEEN MADE TO ACCOUNT FOR THE NUMBER OF SEPTIC TANK-SOIL ABSORPTION SYSTEMS WHICH CAN BE PLACED IN THE INFILTRATION-PERCOLATION CATEGORY. 40-50 MILLION PEOPLE ARE SERVED BY SUCH SYSTEMS IN THE UNITED STATES.

SPRAY-RUNOFF SYSTEMS HAVE NOT BEEN UTILIZED FOR TREATMENT OF MUNICIPAL WASTEWATERS, BUT HAVE BEEN UTILIZED IN THE INDUSTRIAL AREA. EXPERIENCE GAINED FROM INDUSTRIAL APPLICATIONS INDICATES THAT THIS TYPE OF SYSTEM MAY ALSO BE APPLICABLE TO MUNICIPAL WASTEWATERS.

THE 1962 AND 1968 INVENTORIES DO NOT CONTAIN DATA ON THE ULTIMATE DISPOSAL OF WASTEWATER TREATMENT WORKS SOLIDS. THE 1968 INVENTORY LISTS 6,893 TREATMENT WORKS UTILIZING SLUDGE BEDS, MECHANICAL DEWATERING OR LAGOONS AS SLUDGE PROCESSING METHODS. 3,069 FACILITIES ARE LISTED IN THE MISCELLANEOUS CATEGORY WHILE 4,456 PLANTS HAVE NO PROCESSING FACILITIES OR USE NO ORGANIZED METHOD. WHILE THE INVENTORY CONTAINS NO INFORMATION ON THE METHODS OF DISPOSAL OF THE DEWATERED SOLIDS, KNOWLEDGE OF COMMON PRACTICE LEADS TO THE CONCLUSION THAT MOST OF THESE SOLIDS GENERATED AT A RATE OF OVER 4 MILLION TONS PER YEAR EVENTUALLY REACH THE LAND IN ONE FORM OR ANOTHER.

AS THE ABOVE DISCUSSION INDICATES, THERE IS EXTENSIVE USE OF THE LAND FOR TREATMENT OF MUNICIPAL WASTEWATERS IN THE UNITED STATES. NUMEROUS INSTALLATIONS ALSO EXIST IN OTHER COUNTRIES INCLUDING GREAT BRITAIN, GERMANY, FRANCE, AND AUSTRALIA. WHILE NO HARD, SUPPORTIVE DATA EXIST, IT CAN READILY BE ASSUMED THAT MOST COUNTRIES UTILIZE THE LAND EXTENSIVELY FOR DISPOSAL OF THE SOLIDS BY-PRODUCTS OF TREATMENT WORKS.

UNFORTUNATELY, ALTHOUGH MANY OF THESE SYSTEMS HAVE BEEN IN EXISTENCE FOR MANY YEARS, THERE IS RELATIVELY LITTLE RELIABLE DATA AVAILABLE ON SYSTEM PERFORMANCE. THE PHYSICAL, CHEMICAL, AND BIOLOGICAL SYSTEMS ACTIVE AND PERFORMING THE TREATMENT ROLE IN LAND TREATMENT ARE LARGELY UNDEFINED. UNDEFINED IN THIS INSTANCE MEANS THAT THE SYSTEMS ARE NOT UNDERSTOOD SUFFICIENTLY WELL THAT PREDICTIONS OF PERFORMANCE OF A GIVEN DESIGN ARE NOT AS RELIABLE AS SIMILAR PREDICTIONS FOR "CONVENTIONAL" TREATMENT WORKS. MODIFICATIONS SUCH AS CONTOURING AND UNDERDRAINING CAN BE MADE TO THE LAND TO RECEIVE EFFLUENTS, BUT THE TOTAL TREATMENT SYSTEM

IS PRIMARILY AN UNCONTROLLED NATURAL FUNCTION TYPICAL ONLY OF THE SPECIFIED SITE UNDER CONSIDERATION. THIS IS QUITE UNLIKE CONVENTIONAL PROCESSES WHICH, IF BIOLOGICAL PROCESSES ARE EMPLOYED, PROVIDE A CONTROLLED ENVIRONMENT FOR ENCOURAGEMENT OF OTHERWISE NATURAL PROCESSES.

GROWTH OF LAND TREATMENT SYSTEMS IN THE UNITED STATES WILL TAKE PLACE IN A PRODUCTIVE, ENVIRONMENTALLY ACCEPTABLE MANNER ONLY IF ENOUGH INFORMATION AND KNOWLEDGE OF HOW THE LAND FUNCTIONS AS A WASTEWATER TREATMENT SYSTEM IS OBTAINED.

THE OFFICE OF RESEARCH AND MONITORING, EPA, HAS AN ACTIVE RESEARCH PROGRAM DESIGNED TO DEVELOP AND DEMONSTRATE THIS KNOWLEDGE. WE FEEL THIS INFORMATION MUST BE OF A DEPTH AND QUALITY THAT WILL PERMIT SOUND DESIGN AND RELIABLE PERFORMANCE PREDICTION OF LAND TREATMENT SYSTEMS.

I WOULD LIKE TO NOTE THAT A PORTION OF THE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAMS OF EPA AND ITS PREDECESSOR AGENCIES HAS BEEN DEVOTED TO LAND TREATMENT FOR BOTH MUNICIPAL AND INDUSTRIAL WASTEWATER FOR 15 YEARS. HOWEVER, UNTIL RECENTLY, THIS EFFORT HAS BEEN LOW KEY.

APPROXIMATELY 14% OF THE TOTAL BUDGET FOR FISCAL 1974 FOR THE MUNICIPAL TECHNOLOGY RESEARCH PROGRAM IS PLANNED FOR DEVELOPMENT OF LAND TREATMENT TECHNOLOGY. (THIS INCLUDES SLUDGE APPLICATION TO THE LAND.) THIS AMOUNTS TO APPROXIMATELY $1.2 MILLION AND IS EQUIVALENT TO THE FUNDS AVAILABLE IN THE FY 1973 PROGRAM.

I WILL NOT GO INTO DETAIL ON THE VARIOUS RESEARCH ACTIVITIES SINCE MY ASSOCIATE, DR. ROBERT DEAN, HAS ALREADY SPOKEN TO THE LAND APPLICATION OF SLUDGES AND ANOTHER ASSOCIATE, DR. WILLIAM DUFFER, WILL SPEAK LATER TODAY ON EFFLUENT LAND APPLICATION RESEARCH ACTIVITIES. BUT, BRIEFLY I WILL SURFACE SOME OF THE PHILOSOPHY BEHIND THE PROGRAM.

IN GENERAL, WE FEEL THAT A PRIME REQUISITE FOR ANY WASTE TREATMENT TECHNOLOGY IS THAT A POLLUTANT FROM ONE MEDIUM BE PREVENTED FROM CREATING POLLUTION IN ANOTHER MEDIUM. WE HAVE TAKEN THIS APPROACH IN OUR DEVELOPMENT OF TECHNOLOGY FOR ADVANCED WASTE TREATMENT SYSTEMS AND WE FEEL THIS APPROACH IS ALSO APPLICABLE TO LAND TREATMENT TECHNOLOGY.

WE DO NOT FEEL THAT LAND TREATMENT IS THE PANACEA, BUT IT IS AN ALTERNATIVE TO ADVANCED WASTE TREATMENT. THERE ARE MANY UNRESOLVED ISSUES IN LAND TREATMENT TECHNOLOGY THAT CAUSES SOME HESITATION ON OUR PART, THAT IS, EPA, TO COMPLETELY ENDORSE CURRENT PRACTICES.

PERHAPS THE PARAMOUNT PROBLEM IS THE FATE AND EFFECT OF PATHOGENS AND THE POSSIBILITY OF THE TRANSMISSION OF HUMAN AND ANIMAL DISEASE AND INFECTIONS. QUESTIONS HAVE BEEN RAISED CONCERNING POTENTIAL HAZARDS FROM THE CONSUMPTION BY HUMANS AND ANIMALS OF CROPS GROWN ON SOIL TREATED WITH SEWAGE SLUDGE OR EFFLUENT. THIS PROBLEM IS PERHAPS OF MORE CONCERN WHEN CONSIDERING THE LATTER PROCEDURE OR WHEN RAW SLUDGE IS APPLIED TO THE LAND. WE FEEL THAT THERE IS LESS CONCERN FOR DISEASE TRANSMISSION WHEN APPLYING TO LAND DIGESTED SEWAGE SLUDGE. HOWEVER, IN ANY CASE, CAUTION IS NECESSARY.

QUESTIONS HAVE BEEN RAISED CONCERNING TOXIC SUBSTANCES AND NON TOXIC ORGANIC WASTE MATERIALS OCCURRING AS CONSTITUENTS OF SLUDGE OR LIQUID EFFLUENT. THESE QUESTIONS ARISE AS DISCHARGES FROM INDUSTRIAL PROCESSES SUCH AS THE CHEMICAL PRODUCTION OF TEXTILES, PLASTICS, PHARMACEUTICALS, DETERGENTS AND PESTICIDES ENTER THE DOMESTIC SANITARY COLLECTION SYSTEM. WE DO NOT KNOW WITH CERTAINTY THE EFFECTS, SHORT AND LONG RANGE, OF THESE MATERIALS WHEN PLACED ON THE LAND. THERE ARE OTHER QUESTIONS BEING RAISED, HOWEVER, I WILL NOT GO INTO THESE FOR SHORTNESS OF TIME.

THE EPA IN ITS RESEARCH PROGRAM IS ATTEMPTING TO ANSWER THE QUESTIONS RAISED IN THE PRECEEDING DISCUSSION AND OTHERS. WE ANTICIPATE THAT GUIDELINES FOR LAND APPLICATION OF EFFLUENTS AND SLUDGES WILL BE GENERATED IN THE NEAR FUTURE. THESE GUIDELINES WILL BE BASED, OF COURSE, ON THE CURRENT STATE OF THE ART, AND, THEREFORE, SHOULD BE EVALUATED VERY CAREFULLY FOR EACH PROPOSED LAND TREATMENT SYSTEM.

THE EPA HAS INITIATED A COMBINED EPA-USDA-NATIONAL LAND GRANT UNIVERSITY COORDINATING COMMITTEE FOR ENVIRONMENTAL QUALITY. THIS COMMITTEE IS SPONSORING FOUR AD-HOC SUBCOMMITTEES, ONE OF WHICH IS ON THE SUBJECT OF RECYCLING URBAN AND INDUSTRIAL EFFLUENTS AND SLUDGES TO THE LAND.

THIS AD-HOC SUBCOMMITTEE HAS THE PRINCIPAL OBJECTIVE OF DEVELOPING AND IMPLEMENTING INSTITUTIONAL PROCEDURES TO EFFECTIVELY USE THE RESOURCES AVAILABLE WITHIN THE EPA-USDA-UNIVERSITY STRUCTURES FOR A COOPERATIVE AND COORDINATED RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM. IT HAS BECOME MORE APPARENT AS THIS COMMITTEE WORKS TOGETHER, THAT IT IS ESSENTIAL TO HAVE A MULTI-DISCIPLINE AND MULTI-ORGANIZATIONAL APPROACH FOR THE IDENTIFICATION OF THE SLUDGE PROBLEM AND IDENTIFICATION OF THE ALTERNATIVES AVAILABLE TO SOLVE THE PROBLEM. A PROBABLE OUTCOME OF THIS WORKING COMMITTEE WILL BE A REDIRECTION OF RESEARCH EFFORT FOR EPA-USDA-UNIVERSITIES IN ORDER TO AVOID COSTLY DUPLICATION OF RESEARCH PROGRAMS.

THE AD-HOC SUBCOMMITTEE IS PLANNING A FOUR DAY CONFERENCE WORKSHOP TO BE HELD IN EARLY JULY. THE PURPOSE OF THIS CONFERENCE IS TO IDENTIFY WHAT IS KNOWN ABOUT SLUDGE AND LIQUID EFFLUENT APPLICATION TO THE LAND, AND WHAT RESEARCH IS NEEDED FOR SUCCESSFUL APPLICATION OF WASTES TO THE LAND FROM ECONOMIC, ENGINEERING, HEALTH, AND ESTHETIC POINTS OF VIEW.

HOPEFULLY, THIS CONFERENCE WORKSHOP WILL PROVIDE A WORKING BASE FOR AN INTENSE COOPERATIVE EFFORT IN THE FEDERAL-UNIVERSITY COMMUNITY THAT WILL IMPACT THE PUBLIC COMMUNITY BY HELPING TO SOLVE AN ACUTE ENVIRONMENTAL PROBLEM.

"LAND TREATMENT AND ENVIRONMENTAL ALTERNATIVES"

by

Barbara Reid
Project on Clean Water Natural Resources Defense Council

I. Introduction: The Water Pollution Control Problem

Our rivers and lakes are clogged with filth. Many are in the throes of ecological death. Instead of serving as national assets, our waterways have become liabilities, acting as transmitters of viruses and heavy metals, as sluiceways for industrial and municipal wastes. Episodes like the following are commonplace:

--On March 30, 1971, the U.S. Geological Survey found significant concentrations of seven toxic metals (mercury, arsenic, cadmium, lead, chromium, cobalt, and zinc) in many of the nation's streams and lakes.

--In April, 1972 a study of "properly treated" drinking water in Billerica and Lawrence, Massachusetts found the presence of viruses capable of causing respiratory and heart disease, nonbacterial meningitis, muscular paralysis, hepatitis, diarrhea, vomiting and flu.

--In our nation's capital, the Potomac River is lined with signs reading, "Danger--Polluted Water" and instructions warning anyone coming into contact with the water to get a tetanus shot. Bacterial counts have consistently ranged 200% to 3400% above the recommended U.S. Public Health Service standards for at least the last five years.

--In the summer of 1972 the coastal waters of Massachusetts and New England were hit by an outbreak of "red tide" which shut down the clam and oyster industry, causing the loss of millions of dollars.

Examples like these demonstrate the failure of government at every level to control the dumping of wastes into our national waterways. The effort to control pollution has been haphazard. Laws have been weak and tepidly enforced, promoting a don't-do-more-than-necessary attitude among decision-makers.

The recently passed Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), however, promise a new beginning. Through this legislation, Congress has discarded the philosophy that waterways should "assimilate" pollution up to their natural capacity. Instead, it has set a national goal of zero discharge of pollution by 1985; interim deadlines for industrial and municipal sources of pollution should force progress toward that goal.

The state and federal fight against pollution has not only been hampered by poor laws, however--it has also been weakened by a lack of technological choices. Few industries recycle their wastewater. Many of them discharge into municipal systems that are already over burdened with human sewage and street runoff. For their part, municipalities have fallen back on a 50-year-old system of primary-secondary treatment, which screens the effluent and reduces its biological demand through bacterial decomposition. Nutrients (such as nitrogen and phosphorus), most heavy metals and many other chemicals cannot be removed by such systems--and no primary-secondary plant can achieve the high goals for pollution control that the new law sets for the 1980's.

Recent chemical extensions of primary-secondary treatment into a new tertiary stage ("advanced biological" and "physical-chemical" systems) offer some promise of cleaner municipal effluents. Such chemical systems have major drawbacks, however. They are expensive. They consume large quantities of fuel, electric power and chemicals. And they produce vast amounts of chemical sludge which must be disposed of by land filling or by burning. Above all, chemical innovations such as advanced biological (sometimes called Advanced Waste Treatment or AWT) still handle sewage nutrients as noxious substances to be <u>disposed</u> or rather than as resources to be <u>used</u>.

There is an ecological alternative to the wasteful strategies of the past and the chemical options described above. This alternative is the confinement and purification of wastewater on the land. By returning all human and most industrial wastes to the land, this system uses the natural processes of time, sun, wind, vegetative growth and the physical and chemical makeup of soils to purify wastewater. As Senator Edmund S. Muskie (D-Maine) explained while submitting the Federal Water Pollution Control Act amendments to the Senate in November, 1971: "These policies ... simply mean that streams and rivers are no longer to be considered part of the waste treatment process."

The land treatment alternative can accommodate solid waste disposal sites, greenbelts, and other elements in a broad resource management program for any community. It is preeminently an <u>ecological</u> system. Yet it has been generally overlooked by most state and federal water pollution control agencies and, indeed, by most environmental groups.

One reason the land treatment alternative has received so little attention is that water pollution control has been vested in the sanitary engineering profession rather than in the water resources management discipline. The result has been a heavy emphasis on disposal techniques instead of recycling and reuse techniques.

A large land treatment system, scheduled to begin operations in Muskegon County, Michigan in the spring of 1973, should spark national interest in the new alternative. Based on engineering bids and other preliminary data, the Muskegon system will cost less to build and operate than any comparable chemical treatment plant. It also dovetails the waste treatment, greenbelt and solid waste management functions on one site.

In light of the new national goal of "zero discharge of pollutants", I urge you to survey the requirements for water pollution control in your community with an eye toward future needs and federal standards. Land disposal is a viable, natural alternative for many large and small areas—an alternative that has gone largely unnoticed in our rush to find a technological "fix" for our environmental ills.

II. Land Treatment: State-of-the-Art

Land treatment is a complex system which must be carefully planned and engineered to assure that the rate of application of treated wastewater conforms to local climate, i.e., soil, vegetative and geologic conditions. If this is not done, soil systems may be overloaded and desired levels of treatment may not be achieved. In general discussions of land treatment, questions have been raised about four major considerations: 1) performance; 2) costs, in terms of capital, operations, outlays, and returns or profits; 3) political acceptance and 4) public health.

Performance

The question of performance concerns the ability of the land to purify wastewater. Naturally, one factor determining this ability is the nature of the effluent. Some land recycling systems may have to cope with an overabundance of phosphates or heavy metals that could, with time, build up in the soil. Heavy metals (now being dumped into our streams and rivers primarily by industry) would have to be carefully diluted and spread over wide areas of land. Without careful monitoring and control, they could slowly build up in the soil and become toxic to some plants. But monitoring of soil conditions would anticipate any toxicity problems which could be met in a number of ways, including industrial pretreatment.

Several studies have been made of the quality of reclaimed water to be expected from land treatment systems. Two of these were performed for the U. S. Army Corps of Engineers. The first, "Wastewater Management by Disposal on the Land", was carried out by the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire; the second study was conducted by an interdisciplinary team at the University of Washington in Seattle. According to these studies and other laboratory tests, the final effluent of a well-managed land recycling system should have the following characteristics:

Parameter	Effluent Quality (in parts per million--ppm)	% Removal
Chemical Oxygen Demand	6	
Biological Oxygen Demand (5 day)	2	99
Suspended Solids	c 0.0	99+
Soluble Phosphorus	c 0.01	99
Nitrogen (in organic form)	c 0.0	
Nitrogen (in ammonia form)	c 0.0	
Nitrogen (in nitrate form)	2	
Total Nitrogen		80-90
Oils and Greases	c 0.0	
Phenols	c 0.0	
Viruses and Bacteria	c 0.0	99+
Trace Metals	c 0.0	
Boron	c 0.0	
Arsenic	c 0.0	
Cyanide	c 0.0	
Heavy Metals		99
Organic Compounds		99

(some of these categories overlap)

The effluent quality shown here is higher than the recommended U. S. Public Health Service drinking water quality standards.

The above standards can be achieved by a properly designed system. Some of the health concerns that the public-at-large has expressed stem from the possibility that a land treatment system might not be properly constructed; engineers should, in a sense, translate these concerns into design parameters. Among the necessary parameters are the infiltration of the soil, the ability of crops to remove nitrogen and phosphorus, the depth of ground water, the geology of the area, the nature of the effluent after pretreatment, and the ability of any particular soild to achieve high levels of wastewater treatment.

Designers of land treatment systems must also study climatic and plant cover conditions. The length of the growing season may be important (although wastewater has been applied successfully to forest land during the winter months). As an alternative to forest irrigation, the treated wastewater may be stored during the winters. Large storage lagoons have been built for the Muskegon project to hold the effluent (plus rainfall and runoff) during periods when it cannot be absorbed by the soil. The need for winter storage will vary with each community according to its climate and length of growing season.

Costs

While there is continuing debate over the costs of both land treatment and other tertiary systems, certain empirical evidence is already available. This preliminary information indicates a fovorable economic position for land treatment.

As noted earlier, the costs for construction, land and family relocation in Muskegon County total only 83¢ per gallon of treatment capacity. A comparable advanced biological project in Chicago--the Salt Creek plant--will cost about $1.40 per gallon of capacity. The difference lies largely in the costly chemical apparatus, extensive chemical storage and sludge removal facilities required for the Chicago project.

A recent Corps of Engineers study of alternative sewage treatment systems for metropolitan Chicago and the urbanized South end of Lake Michigan has provided additional data for the analysis of the feasibility of land treatment in major metropolitan areas. Each of the basic systems considered--advanced biological treatment, physical-chemical treatment, and land treatment--was designed to treat 100% of the projected 1990 municipal and industrial flows (2076 mgd) and 50% of the urban runoff (30 mgd). Compared with current engineering costs, the results showed land treatment to have the lowest capital costs and by far the lowest operation and maintenance costs. Capital costs per gallon of installed capacity for the land treatment system were projected at 84¢; its closest competitor, physical-chemical treatment, was a comparatively high $1.26.

Land treatment costs are directly affected by the length of the growing season. For example, in Muskegon the five-month storage period drives the land requirements up to 230 acres per million gallons of wastewater a day, or more than 40% greater than the land required if year-round irrigation is practiced. Other variables influencing land costs include:

1) State regulations that call for buffer strips around the irrigation site (no minimum width for such buffer zones has yet been universally agreed upon).

2) Applicatioı. rates either regulated by state law or by environmental considerations.

3) The physical method of irrigation; and

4) Topography (rarely is irrigation practiced on greater than 15% slopes without some form of terracing).

The cost of a land treatment system will also depend on whether the irrigation land is purchased outright, leased, or contracted. But it is important to note that the use of the land for agriculture will not be changed--merely the manner in which the crops are irrigated and fertilized. In a time of rapid disappearance of rural land due to uncontrolled suburban development, irrigation sites should offer invaluable greenbelts and new opportunities to control metropolitan land use patterns.

There is a little historical experience from which we calculate <u>operating</u> costs of alnd treatment systems. The estimated cost of Muskegon's first year of operation now stands at 9¢ per thousand gallons of treated sewage. This figure should be compared with the 30¢ per thousand gallons cost of the Lake Tahoe advanced biological system now in operation on a limited scale. Significantly, the extraction, refining, and transport of chemicals required by chemical treatment systems creates a major pollution problem whose costs are rarely calculated. The advanced biological and physical-chemical processes are lavish in their use of chemicals such as lime, alum, and chlorine. The cost of chemicals alone for the 309-mgd Blue Plains advanced biological plant now being built in Washington, D.C. will amount to 8¢ per thousand gallons of treated water--nearly as much as the <u>entire</u> Muskegon system's operating costs.

Political Acceptance and Management

Many questions regarding land treatment systems are political and psychological in nature. Understandably, many people experience an idea of using domestic sewage to irrigate land from which crops and animals may be taken for human consumption. This is a cultural concern that must be faced. Open forums and public presentations of various alternatives in the management of wastewater will help to expose and deal with the problem; which is technically and biologically soluble.

Of equal consideration is the question of how the irrigation land should be managed. Should it be owned by the federal or state government, the community, the regional waste treatment management agency, or the farmer who would lease or contract with the appropriate wastewater agency? Who should work the land? Answers to these important questions can influence the attitudes of the rural and semi-rural population toward land treatment. All land tenure options should be considered.

A fundamental fact is the need for substantial tracts of open space in a land treatment system. The actual amount of such land will vary according to the length of the growing season, and the amount of winter storage required. In Muskegon County, 230 acres of land per million gallons per day of wastewater will be required. While at Penn State University 130 acres are needed. Using an average for estimates on a national scale of 180 acres per million gallons of wastewater per day, the amount of land required for national land treatment is estimated to be 7.5 million acres. This corresponds to 6% of the land area of the state of Texas and about 1% of land on which the 59 major agricultural crops are grown in this nation today. The current land use of this acreage will not change. Only the method of fertilization and irrigation would be altered by the land treatment approach.

In the event of family relocations, which may be inevitable with any large public works project, reimbursement is available through the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970. Such assistance was very helpful in the Muskegon land acquisition program which relocated 195 families.

Public Health

Public concerns about the potential health effects of land treatment systems have been voiced in debates over sewage treatment for some time.

From a communicable disease standpoint, however, a study by a researcher at the Department of Communicable Diseases, Hahnemann Medical College, Philadelphia, has concluded that "land disposal is far less hazardous than disposal into rivers and streams". The researcher, Dr. Melvin A. Benarde has said, "The actual hazard, or petential hazard, to a community's health would be realted to the degree of treatment or the ultimate quality of the reused waste". In other words, the higher the degree of treatment, the safer the community's health.

It is important to remember that an integral part of a well-designed land treatment system is the pretreatment of wastewater before land application. This means the equivalent of primary and secondary treatment (including chlorination for disinfection). Thus, the effluent at the time of spray irrigation should meet a standard of water quality suitable for recreational purposes.

Many state and federal agencies have begun to establish guidelines to insure proper health protection for all land treatment systems. Included in the U.S. Surgeon General's guidelines are the following considerations: pretreatment, non-potable identification, vector (disease carrier) control, surveillance, aerosol control, and access limitation (buffer zones).

Since disinfected secondary treated effluent is being sprayed on the land, the possibility of contaminating the air with air-borne viruses is very small. However, to further minimize any possibility of contamination through aerosol drfit, irrigation nozzles may be directed downward. Their pressure may also be kept low to insure large droplets. Irrigation need not take place during times of high winds, rainfall or low temperatures--conditions generally associated with aerosol drift.

On further precautionary measure is the provision of buffer strips around spray sites to prevent any accidental drift and any direct contact with the irrigation spray.

Ironically, the success stories about land treatment heretofore have come from systems which have utilized none of the above precautions; most of them have applied raw sewage to land producing crops that are fed directly to livestock and/or to people. Melbourne, Australia, and Paris, France, have long used irrigation projects of this type. No health problems have been attributed to either of these systems.

For several years the U. S. Army has practiced spray irrigation of a Colorado golf course, using wastewater originating from a large hospital specializing in tuberculosis treatment. Data accumulated since 1953 indicate that no health hazard can be detected from spray irrigation of the treated wastewater even though the tuberculosis-causing bacteria can be found in the untreated water.

III. A Final Word

The effects of the 1972 Water Pollution Control Act will soon be felt in every community. You will be asked to respond to three basic policy changes the legislation makes in the nation's water quality program. These are, first, the replacement of a waste disposal strategy with a management-and-use strategy; second, the transformation of an essentially single-purpose water quality program into a multipurpose resource program; third, the change from a federal subsidy program into a federal investment program that has the potential to produce revenue. The irrigated crops, solid waste disposal sites, and use of land treatment storage lagoons for industrial cooling can all generate income for communities that choose the land recycling alternative. This income is theirs to finance other environmental improvements.

NEW YORK STATE'S

VIEW OF LAND DISPOSAL

by

Frank O. Bogedain, P.E.

INTRODUCTION

The disposal of wastewater to the land is not a new concept either in the United States or more particularly in my State of concern - New York State. Koelzer (ref. 1) points out that the method is an old one predating secondary plants. Called "sewage farms" and empirically developed, the method is variably successful. Melbourne (ref. 2), Australia reports that the Board of Works Farm at Werribee, operational since 1892, it was successfully handling a median daily flow of approximately 100 MGD in 1969.

It should also be noted that the present advocation of land disposal is engendered, at least in part, by Sec. 101, subd. (1) of PL 92-500 which states:

> "... it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985;"

In New York State, approximately 3,800 MGD of wastewater from municipal and industrial sources are now generated. This volume is almost equivalent to twice the average low freshwater flow of the Hudson River and would require large land areas and attendant costs (ref. 3) if uniformly applied.

The 'zero discharge' advocates have pointed to land disposal as the new panacea. However, if land disposal is examined objectively, it must be concluded that it is neither new nor a panacea.

MUNICIPAL SYSTEMS

As far as the author is able to discern the first municipal plant to dispose of waste effluent to the land is the Lake George Village plant of which you'll hear more of later in the program. It has been operating in this mode since

1936. However note should be taken that this plant and the other municipal plants listed in Table I do not employ Spray Irrigation (SI), Overland Runoff (OR) but use Rapid Infiltration (RI) in the form of tile fields, leaching pits or non-underdrained, intermittently-dosed sand filters.

The proportion of communal plants utilizing land disposal in New York State is small. Of 477 municipal plants designed to handle a total of 2,430 MGD, 24 plants are designed to process 9.5 MGD for ground discharge.

In reviewing TABLE I, it is apparent that these systems serve very small comparatively isolated communities or are located on Long Island where a trend to groundwaters recharge is distinct.

INDUSTRIAL SYSTEMS

In similar fashion to the municipal picture in New York the proportion of industrial waste disposal to the ground has been minimal. Of 284 industrial systems designed to process 437 MGD, 12 plants are designed to dispose of 5.2 MGD to the land by spray irrigation.

All of our regulatory agency experience comes from these 12 systems. Indeed much has been learned on a first hand basis. TABLE II summarizes these 12 systems.

Spray irrigation as a viable method of industrial waste treatment evolved in New York primarily because of unique circumstances surrounding the food processing industry of which all 12 systems serve. This industry is primarily seasonal with wastewater generation occurring during periods of low stream flow, warm temperatures and production facilities primarily located at the higher end of watersheds where streams are ephemeral. Such locations being rural in nature, land is readily available. These locational factors demand high levels of treatment efficiency for short periods of time if discharge to a surface watercourse can be considered. Biological treatment is virtually precluded.

INDIVIDUAL SYSTEMS

In 1970, it was estimated that 14.6 million people in New York State were served by community sewerage. This represents approximately 80% of the resident population of 18.3 million persons. The remainder - 20%, or 3.6 million persons - are served by individual home disposal systems of the septic tank/tile field (or leaching pit) variety. Thus land disposal plays an important role at the family level of social development in an agrarian setting.

RESEARCH

In the area of Land Disposal, New York's research effort has been directed to the following:

1) A literature search, which constitutes 130 references.
2) Specific investigation for determining phosphorus adsorption capacities of soils, including methodology, with particular reference to the design of septic tank/percolation systems for lake watershed protection. In this regard an application has been made to EPA for a Research and Development Grant pursuant to Sec. 105 of PL 92-500.

In regard to the latter project, our concern is not only related to developing a groundwater recharge method which removes BOD, solids, bacteria and phosphorus but also is part of our continuing research effort into cause, effect, prevention and control of lake eutrophication.

REGULATORY AGENCY ATTITUDE

Contemporary writings (ref. 4, 5, 6) claim many advantages to Land Disposal when compared to secondary treatment:

a) Lower capital and operating costs;

b) Upgrading of marginal agricultural land and concomitant benefits;

c) Reduced sludge disposal problems;

d) Nutrient recycling;

e) High removal of viruses, toxic materials, BOD, Solids, etc.;

f) Groundwater recharge;

g) Protection of surface waters.

to name a few.

Counter arguments are:

a. Social and economic impact of relocating farm families;

b. Availability of suitable land;

c. Buildup of toxic and solid material which may be detrimental to the project and environment;

d. Costs picture difficult to assess because of lack of actual operating experience for large scale systems;

e. Transmission costs to land disposal areas;

f. Economic impact of taking land out of production and removing such land from the tax rolls;

g. Acceptability for meeting the 'zero discharge' imperative;

h. Effect on groundwaters.

Presently we regard 'Land Disposal' as an acceptable alternate to disposal of wastewater to surface waters, with the inference being that 'land disposal' is a catch-all categorization for methods which are essentially groundwater disposal and/or recharge methods.

For municipal application, rather complete engineering evaluation is required of any feasible alternative especially because of the fact that the State of New York, along with EPA, participates in such projects through the construction grant mechanism. Additionally New York State can provide up to 33-1/3% of annual operating and maintenance grants. Such an economic evaluation derives from the impelling need to achieve the most effective treatment per unit cost.

What about guidelines? At present New York has no formally adopted design guidelines published, but is developing them and will be in a future paper. Pennsylvania's manual on spray irrigation (ref. 7) is a valuable effort and is to be commended.

Our own surveys have shown that several points are key to attaining a successfully operating system. These are:

1) Failure to rotate and maintain fields;
2) Spray nozzles clogged with stones causing either nonuniform application with localized flooding;
3) No operator assigned to manage the system;
4) Unanticipated wastes of high strength allowed to enter the disposal system;
5) Lack of equalization and detention;
6) Excessive pH variation 'shocking' crop cover;
7) Extremely high application rates causing runoff.

CONCLUSIONS

This paper has attempted to present the relative position of Land Disposal as regarded by the State of New York.

Accordingly it is shown that -

1) Land Disposal is an established method of waste disposal but is little used.
2) Numerous problems can be encountered with this approach, as well as with any other system.
3) Competent planning, design, construction and operation are needed stages which cannot be omitted.
4) The many pro and con arguments can only be answered by detailed studies of increasingly larger installations.

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ABOUT THE AUTHOR

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TABLE I

MUNICIPAL WASTEWATER TREATMENT PLANTS DISCHARGING TO LAND

Name/Location	Treatment	MGD Design	MGD Actual
REGION 1 - STONY BROOK			
Farmingdale Sanitarium Oyster Bay (T), Nassau County	Imhoff Tank Sand Filter	0.120	0.063
Mitchell Field Hempstead (T), Nassau County	Primary Settling Sand Filter	1.200	0.535
Meadowbrook Hospital Hempstead (T), Nassau County	Trickling Filter Cesspool	0.900	0.663
Scavenger Plant Oyster Bay (T), Nassau County Chemical/Sand Filter	Cesspool	0.052	0.035
Stratmore at Coram (Private Disposal Corp) Brookhaven (T), Suffolk County	Contact Stabilization Cesspool	1.360	0.225
Stratmore at Stony Brook Brookhaven (T), Suffolk County	Contact Stabilization Sand Filter	0.360	0.289
Holbrook Sanitary District Brookhaven (T), Suffolk County	Trickling Filter Cesspool	0.720	0.053
Stratmore at Huntington Huntington (T), Suffolk County	Extended Aeration Sand Filter	0.236	0.162
Scavenger Plant Babylon (T), Suffolk County	Chemical-Physical Sand Filter	1.000	0.107
Manorville Scavenger Plant Brookhaven (T), Suffolk County	Extended Aeration Sand Filter	0.050	?
REGION 2 - NEW YORK CITY	None		

TABLE I (Continued)

Name/Location	Treatment	MGD Design	MGD Actual
REGION 3- NEW PALTZ			
Chichester Hamlet Shandakin (T), Ulster County (New York City Plant)	Septic Tank/Tile Field	0.060	0.060
REGION 4 - ALBANY			
Williamsburg (Private) Guilderland (T), Albany County	Septic Tank/Tile Field	0.010	?
REGION 5 - RAY BROOK			
Clifton Knolls (Private) Clifton Park (T), Saratoga Co.	Contact Stabilization Sand Filter	0.300	0.160
Clifton Gardens (Private) Clifton Park (T), SaratogaC o.	Extended Aeration Sand Filter	0.800	0.045
Geyser Crest (Private) Saratoga Springs (C), Saratoga Co.	Extended Aeration Sand Filter	0.185	0.124
Round Lake Assoc. (Private Owner) Round Lake (V), Saratoga Co.	Septic Tank/Tile Field	0.004	0.012
Bolton Sanitary District Bolton (T), Warren County	Trickling Filter Sand Filter	0.300	0.120
Lake George Village Lake George (V), Warren County	Trickling Filter Sand Filter	1.745	0.450
Reservoir Park San. District Queensbury (T), Warren County	Septic Tank/Seepage Pit	0.012	?
REGION 6 - WATERTOWN			
Glenfield Sanitary District Martinsburg (T), Lewis County	Septic Tank/Tile Field	0.040	?

TABLE I (Continued)

Name/Location	Treatment	MGD Design	MGD Actual
REGION 7 - SYRACUSE			
Fenton Sanitary District No. 1 Fenton (T), Broome County	Septic Tank/Cesspool	0.014	?
Ruhanah Sanitary District Onondaga (T), Onondaga County	Septic Tank/Cesspool	0.022	?
REGION 8 - AVON	None		
REGION 9 - BUFFALO			
Lewiston Estates Sanitary District Lewiston (T), Niagara County	Septic Tank/Cesspool	0.022	0.034
Idlewood Sanitary District No. 13 Hamburg (T), Erie County	Septic Tank/Sand Filter	0.010	0.007

TABLE II

INDUSTRIAL WASTEWATER TREATMENT PLANTS DISCHARGING TO LAND

Company	Design Flow MGD	Application Rate* (Max.)	Soil	Cover Crop	Product	Pretreatment	No. of Sprinklers	Spray Area	Field Schedules**	Spray Schedule Use/Rest
Curtice Burns Sodus (T), Wayne County	0.644	2.5 in/day	Williamson Silt Loam Hilton Loam	Reed Canary Grass	Cherries Beets Apples Beans	Lagoons	200	12,500 ft^2	12 hr/day July-Dec	1/4
Curtice Burns Bergen (V), Genesee Co.	1.0	1.15 in/hr	Cazenovia Silt Loam Ontario Silt Loam	Reed Canary Grass	Pea Corn Beans Carrots	pH Adjustment			12 hr/day June/Dec.	12 hr/60 hr
Curtice Burns Leicester (V), Livingston Co.	1.85	0.25 in/hr		Reed Canary Grass	Corn Peas Beets Carrots	pH Adjustment	310	0.23 acre	18 hr/day July-Nov.	1/4
Comstock Greenwood Waterloo (V), Seneca Co.	0.4	0.6 in/day		Blue Grass	Beets Red Cabbage	Lagoons	75	0.13 acre	Aug-Dec.	
Gro-Pack Eden (T), Erie Co.	0.17	0.32 in/day	Gravel, Silt	Rye Grass	Beans Peas	Lagoons	60	0.3 acre	18 hr/day July-Sept.	
Libby, McNeil & Libby Geneva (T), Ontario County	0.5	0.32 in/day	Schoharie Clay Loam		Green Beans Sauerkraut	Lagoons	80	7850 ft^2	16 hr/day Jan-Dec.	1/4

TABLE II (Continued) Industrial Wastewater Treatment Plants Discharging to Land

Company	Design Flow MGD	Application Rate* (Max.)	Soil	Coyer Crop	Product	Pretreatment	No. of Sprinklers	Spray Area	Field Schedules**	Spray Schedule Use/Rest
Sodus Fruit Farm Sodus (T), Wayne County	0.1	1.3 in/day	Williamson Silt Loam	Japanese Miller	Apples Cherries Prunes	Lagoons		29 acre total		1/8
Deltown Food Delhi (T), Delaware Co.	0.3	3.8 in/day 0.25 in/hr		Red Top Red Fescue	Milk Cheese	Equalization	20	31,400 ft^2	6 hr/day Jan-Dec.	1/4
Cuba Cheese & Trading Co. Cuba (T), Allegany Co.	0.025	1.37 in/day	Chenango Gravel	Reed Canary Grass	Cheese	Screening	20	0.09 acre	9 hr/day Jan-Dec.	1/4
Lasaponara & Son Goshen (T), Orange Co.	0.006	0.56 in/day 2 fields	Loam, Gravel	Canary Grass	Milk Cheese	Equalization Tank	5	9,850 ft^2	8 hr/day Jan-Dec.	1/2
Friendship Dairy Friendship (T), Allegany Co.	0.16	1.2 in/day	Gravel Silt	Timothy & Meadow Grass	Butter Cheese Sour Cream	Lagoons	15	5,000 ft^2	12 hr/day Jan-Dec.	1/6

* Sample calculations of the average application rate in in./hr.

** Except for Deltown Foods spraying occurs only during daylight hours.

Municipal Effluent Characteristics

by

Joseph V. Hunter *

The effect that the land disposal of municipal treatment plant effluents will have on soil permeability, ground water quality, cropping, subsequent land reuse, etc., will to a large extent be determined by the biological, physical and chemical characteristics of the effluents applied. Assuming a minimum of secondary treatment and that biological quality problems can be handled by suitable effluent disinfection, this paper is mainly concerned with the physical and chemical characteristics of secondary effluents.

Physical Characteristics

Even casual observation of municipal secondary effluents indicates the presence of other than soluble materials. Typical physical distributions of both organic and inorganic materials for an efficient (i.e., 90% BOD reduction) municipal activated sludge treatment plant are shown in Table I. The size classifications are as follows:

Class	Size Range
Settleable	>100 µ
Supracolloidal	1-100 µ
Colloidal	1mn-1 µ
Soluble	<1mu

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The data in Table I, of course, represent average values, and variations with time are typical. Table II demonstrated this variability of the physical distribution of effluent particulates (suspended solids may be approximated by the sum of the settleable and supracolloidal groups noted above) as a function of time.

Organic Composition

It has been estimated that secondary plants treating municipal wastewaters produce effluents that contain approximately 55 mg/l organic matter (3). Of this, approximately 52 mg/l was added during use. The BOD associated with this concentration of organics should be about 25 mg/l. As can be observed from Table I, about three-quarters of the organics found in the effluent are either colloidal or soluble.

Table I

Total Solids Distributions for an Activated Sludge Effluent.

(all results in mg/l)

Effluent Fraction	Winter, 1965-66 [a] Organic	Winter, 1965-66 [a] Inorganic	Spring, 1967 [b] Organic	Spring, 1967 [b] Inorganic
Soluble	71	223	62	250
Colloidal	2	1	6	2
Supracolloidal	16	3	24	4
Settleable	1	0	0	0
Total	90	227	92	256

(a) from reference (1)

(b) from reference (2)

Table II

Variation in Effluent Quality of an Activated Sludge Plant[a]

(all results in mg/l)

Date	BOD AM	BOD PM	Suspended Solids AM	Suspended Solids PM
5/ 5/69	12	4	17	8
5/ 6/69	9	6	19	19
5/ 7/69	8	10	21	27
5/ 8/69	8	16	30	39
5/12/69	13	13	38	33
5/13/69	14	15	43	43
5/14/69	9	6	21	11
5/15/69	10	10	21	21
5/19/69	12	16	36	43
5/20/69	17	25	41	54
5/21/69	10	11	26	16
5/22/69	19	27	41	59

(a) Courtesy of the Johns-Manville Co., Manville, N. J.

This is also true of the distribution of other general organic parameters such as TOC and COD, as is shown in Table III.

Due to the soluble nature of most of the effluent organics, research into the chemical nature of these materials has mainly involved the colloidal-soluble materials, or such approximations of these catagories as filtrates or centrifugates. Initial investigations into the nature of these organics did not reveal too much information. Analysis of American effluents indicated that about 10% of the average effluent COD was ether extractable organics, about 10% was proteins, about 10% was anionic surfactants, about 5% carbohydrates and about 5% tannins and lignins (4). Thus, about 65% of the effluent organics were unaccounted for in the survey. In a subsequent study of a British trickling filter effluent (Table IV), only 26% of the effluent soluble-colloidal organics were detected (5). A subsequent investigation of an Israeli trickling filter effluent (Table IV) indicated that a significant part of the previously undetected soluble organics were humic acid like materials (6).

Table III

Organic Parameter Distributions for an Actual Sludge Effluent (a)

(Spring, 1967)

Effluent Fraction	Volatile Solids mg/l	COD mg/l	TOC mg/l
Soluble	62	46	16.5
Colloidal	6	3	1.5
Supracolloidal	24	13	6
Settleable	0	0	0
Total	92	62	24

(a) from reference (2)

Table lV

Chemical Composition of Soluble-Colloidal Organic Matter in a Trickling Filter Effluent

Constituent or Group	British (a) mg/l TOC	Israeli (b) mg/l COD
Ether Extractables	1.7	19.6
Carbohydrates	0.2	20.2
Amino Acids - Proteins	0.3	38.9
Anionic Detergents	1.4	23.7
Tannins	-	2.8
Fulvic Acid	-	41.6
Humic Acid	-	19.2
Hymathomelonic	-	13.7
Recovery, %	26	97

(a) from reference (5)

(b) from reference (6)

In addition to these comprehensive surveys, certain specific organic materials have also been detected by interested investigators at various times. Thus the lower aliphatic (i.e., fatty) acids have been detected in the 10-100 $\mu g/l$ range (7), Pyrene in the <1 $\mu g/l$ range (8), cholesterol and coprostan 1 in the 10 - 100 $\mu g/l$ range (9), uric acid in the 5 - 10 $\mu g/l$ range (10), and various non-ionic surfactants in the <1 mg/l range (11).

There has been relativeiy little work done on the composition of effluent particulate organics. The one comprehensive study noted in Table V detected only 39% of the particulate organics present in the trickling filter effluent (5). Saturated fatty acids such as lauric,myristic palmitic and stearic have been found in effluent particulates in concentrations from 0.1 $\mu g/l$, and unsaturated fatty acids such as oleic, linoleic and linolenic μ 0.1-2 $\mu g/l$ (12). The amino acids cystine, lysine, histidine, arginine, serine, glycine, aspartic acid, threonine, gluconic acid, alanine, proline tyrosine, methionine, valine, phenyl alanine, leucine and isoleucine have been detected in dried activated sludge in concentrations of 10-40 mg/g (13), and the vitamins thiamine, riboflavin, pyridoxine, nicotinic acid, panthothenic acid, biotin, folic acid and B_{12} have been detected in concentrations of 0.1-10 μg/100g (14). Finally, such sugars as glucose, lactose and arabinose are present in the particulate carbohydrates(15).

Table V

Composition of Trickling Filter Effluent Particulates(a)

(for a British Sewage)

Constituent	Concentration mg/l TOC	Constituent	Concentrations mg/l TOC
Fatty Acids	0.12	Muramic Acid	0.05
Fatty Esters	0.12	Amino Sugars	0.38
Soluble Acids	0.13	Anionic Detergents	0.05
Carbohydrates	1.39	Proteins	2.74

(a) from reference (5)

Inorganic Constituents

Unlike the organic materials found in effluents which represent the organics added to the water during use and modified by secondary treatment, effluent inorganics reflect largely the quality of the original water supply. Thus, there is little general applicability of one set of inorganic analyses to other circumstances, except for those materials largely added during use such as ammonia and phosphate. Actually, it is of more general interest to note the approximate increases in the inorganic constitutent that occurs after each use by man, and these and general effluent inorganic characteristics are presented in Table VI. As is implicit in both Tables I and VI, effluent inorganics are almost all soluble. The difference between such nationwide averages and local effluents may be considerable, as can be observed from examination of Table VII.

Table VI

Average Inorganic Composition of Municipal Secondary Effluents [a]

Constituent	Concentrations mg/l	Increment Addition mg/l
Sodium	135	70
Potassium	15	10
Calcium	60	15
Magnesium	25	7
Ammoniums	20	20
Chloride	130	75
Nitrate	15	10
Nitrite	1	1
Bicarbonate	300	100
Sulfate	100	30
Silica	50	15
Phosphate	25	25

(a) from reference (3)

Summary

Although there have been extensive investigations into the nature of the organic constituents of effluents, most of the particulate organics are still unknown and even the soluble organics have only been classified by solubility and extractive procedures rather by the molecular species present. As it represents a simpler analytic area, more is known as to the nature of effluent inorganic constituents, but as this reflects the original water quality as well as its use such information is not generally applicable. Perhaps one of the best ways of summarizing the generalities of effluent composition would be to examine Tables VIII and IX. which give the various constituents of a large number of secondary treatment plants in the New York metropolitan area (6). These data, which reflect much of the previously described analyses, give a picture of not only the median effluent characteristics, but also the range over which these characteristics may vary. It is interesting to note from this data the presence of significant amounts of copper and zinc in the effluents, and the detection at times of many of the other heavy metals as well. These are constituents more usually associated with treatment plant sludges, and their presence in effluents adds another facet to their possible environmental impacts.

Table VII

Average Inorganic Composition of Bernardsville, N.J. Secondary Effluent.

Constituent	Concentration mg/l	Constituent	Concentration mg/l
Sodium	55	Chloride	41
Potassium	4	Carbonates	23
Calcium	15	Nitrate	1
Magnesium	4	Sulfate	1
Silica	12	Phosphate	33

Table VIII

General Composition of Secondary Treatment Plant Effluents (a)

(New York Metropolitan Area)

Constituent	Value Distribution		
	Minimum mg/l	Median mg/l	Maximum mg/l
pH (2)	3.9	6.9	7.7
Biochemical Oxygen Demand	2	29	149
Total Carbon	17	60	204
Organic Carbon	8	31	174
Suspended Solids	1	25	155
Settleable Solids	0	9	109
Turbidity (3)	3	16	99
Ortho Phosphate - P	0.3	4	19
Ammonia - N	0.5	15	105
Nitrite - N	0.01	0.1	3
Nitrate - N	0.2	0.9	22

(a) from reference (16)

Table IX

Heavy Metal Constituents of Secondary Treatment Plant Effluents (a)

(New York Metropolitan Area)

Constituent	Value Distribution		
	Minimum mg/l	Median mg/l	Maximum mg/l
Copper	<0.02 (b)	0.05	1.50
Zinc	<0.02 (b)	0.08	0.92
Chromium	<0.05 (b)	<0.05 (b)	6.80
Lead	<0.20 (b)	<0.20 (b)	0.20
Iron	<0.10 (b)	<0.40	3.50
Nickel	<0.10 (b)	<0.10 (b)	0.80
Cadmium	<0.12 (b)	<0.02 (b)	6.40
Manganese	<0.02 (b)	0.10	0.50
Mercury	<0.0001 (b)	0.0009	0.1250
Silver	<0.05 (b)	<0.05 (b)	<0.05 (b)
Cobalt	<0.05 (b)	<0.05 (b)	<0.05 (b)

(a) from reference (16)

(b) below detection limit

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FATE OF MATERIALS APPLIED

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FATE OF MATERIALS APPLIED

When wastewaters are applied to the land, a substantial quantity of suspended and dissolved solids is deposited on the land. The fate of these materials is an important factor to consider in the selection of a land-based alternative for management of wastewaters. There are four repositories which may receive and store appreciable fractions of the materials applied to the land at a wastewater management site: (1) Some of the material may be volatilized and released to the atmosphere; (2) another fraction of the material may be released directly to surface waters with runoff; (3) particulates and some dissolved material will be temporarily or permanently retained in the soil; and (4) the remainder of the material will be leached down through the soil to be stored in the groundwater. The distribution of materials among these four repositories is dependent on physical, chemical and biochemical interactions which take place in the soil. These interactions in the soil are influenced by many factors related to the characteristics of the wastewater and to characteristics of specific land treatment sites. Some of these factors are beyond the control of man while others can be managed to control the fate of applied materials.

The purpose of this presentation is to describe several management approaches which can be used to influence the fate of materials applied to land treatment sites. The materials to be included will be grouped into three units for convenience. The units will be designated as suspended materials, major plant nutrients, and other constituents. Within each unit, the fate of materials will be discussed in relation to three approaches to land treatment of wastewaters. These approaches to land treatment are based on hydrological behavior and can be described briefly as follows: (1) Infiltration systems which are operated at relatively high hydraulic rates and emphasize groundwater recharge as the fate of the applied wastewater; (2) irrigation systems which are operated at relatively low hydraulic rates and emphasize both groundwater recharge and evaporative losses as the fate of the applied wastewater; and (3) spray-runoff systems which are operated at intermediate hydraulic rates and emphasize runoff to surface waters as the fate of the applied wastewater.

SUSPENDED MATERIALS

Suspended materials in a wastewater settle out quickly or are filtered out as the applied wastewater percolates through the soil. The results of numerous studies can be cited to show essentially complete retention of suspended materials in the soil after relatively short travel distances of a few inches to a few feet depending on the texture of the soil. Obviously continued retention and storage of suspended solids in the soil pores would lead to clogging of the soil pores and a sharp reduction in the permeability of the soil. This phenonmenon has been studied extensively and researchers have identified many factors influencing the clogging of soil pores.

Articles by McGauhey and Krone (1), Thomas, Schwartz, and Bendixen (2), or Thomas and Law (3) are good reference sources to obtain a more complete understanding of the clogging process. Fortunately, a major fraction of the suspended solids are volatile and are biochemically oxidized to products which prevent clogging of the soil pores. In fact, the biochemical oxygen demand exerted by this biodegradable fraction of the suspended material is a key factor in determining the successful operation of many land treatment systems and hence the fate of all materials applied to the system.

Information from practical experiences with land disposal of wastewaters shows a wide divergence in the amount of biodegradable solids which can be applied to the soil without inducing conditions that cause soil clogging and the undesirable effects which accompany soil clogging. Blosser and Caron (4) recommend biochemical oxygen demand (BOD) loadings of up to 200 lbs./acre/day for disposal of pulp and paper mill effluents. Thomas and Bendixen (5) report that sewage sludge loadings equivalent to 170 lbs./acre/day of organic carbon can be applied to sandy soils for extended periods of operation. Bouwer (6) reports a BOD loading of 45 lbs./acre/day for secondary sewage effluent. Parizek et al. (7) report BOD loadings of less than 2 lbs./acre/day for irrigation with secondary effluent. An important point to consider is covered by Thomas and Bendixen (5) in their discussion of the degradation of sewage organics in soil. They cite several references which indicate that organic carbon additions of as much as 25 lbs./acre/day are needed to maintain a static organic matter content in the soil. Such additions help to maintain the tilth of a soil and would not be expected to pose problems of soil clogging. With this concept in mind, one can make useful projections about the fate of suspended materials applied to the soil through the three approaches to land treatment.

Typical suspended solids concentrations found in secondary effluents should have little effect on the operation of well designed and well managed wastewater-irrigation systems. We can illustrate this by assuming an effluent with 50 mg/l of suspended solids (of which 70 percent are biodegradable) and an irrigation rate of 2 inches per week. Such a system would result in a total suspended solids loading of 3 lbs./acre/day and biodegradable suspended solids loading of 2 lbs./acre/day. The BOD exerted by the biodegradable fraction of these solids is substantially less than the 25 lbs./acre/day of organic additions required to maintain a static organic matter content in soils. The residual of the nonbiodegradable fraction of the suspended materials also represents a small contribution to the total volume of affected soil. An acre-inch of a mineral soil weighs about 300,000 lbs. while the 1 lb./acre/day of nonbiodegradable suspended solids amounts to an addition of only 365 lbs./acre/year. It would be more than a decade before the added residue amounted to one percent of the weight of the surface inch of soil and many decades before the residue amounted to one percent of the soil normally mixed by plowing. From this illustration, it is clear that the suspended solids added to the soil through wastewater irrigation at irrigation rates of less than eight feet per year do not pose a problem of soil clogging. The fate of much of the suspended solids is biooxidation to gases, water, and minerals. The fate of the nonbiodegradable fraction is accumulation in the soil, but the quantity which may accumulate represents a very minor addition to the total soil volume. Qualitative information from numerous wastewater irrigation operations bears out the fact that suspended solids do not pose specific operational problems, and the results of research investigations such as the 14-year study by Day, Stroehlein, and Tucker (8) show that irrigation with activated sludge effluent did not alter soil organic matter content relative to irrigation with well water.

Suspended solids added to the soil by the infiltration approach have a major influence on system operation and performance because hydraulic loading rates can range up to 300 feet per year. The high loading rates characteristically used for infiltration systems greatly increase the potential for soil clogging to interfere with the successful operation of a system. The same theoretical composition of effluent we used to illustrate the irrigation approach will clearly demonstrate this increased potential for soil clogging.

With our suspended solids content of 50 mg/l (70 percent biodegradable) and a hydraulic loading of 120 feet per year (an intermediate value), the total suspended solids load is 45 lbs./acre/day. This load exceeds the organic addition needed to maintain a static organic matter content in many soils. The BOD exerted by this amount of biodegradable material can exceed that available in the soil environment and lead to severe clogging of soil pores. This phenonmenon of soil clogging is well documented, and many research studies on this subject were reviewed by McGauhey and Krone (1). The importance of available oxygen for prevention of clogging is discussed by Thomas, Schwartz, and Bendixen (2). Intermittent dosing and drying periods are effective for avoiding the problem of soil clogging and assuring that the fate of suspended materials is biooxidation to gases, water and minerals. Successful operation of infiltration systems for decades at many locations throughout the United States provides qualitative support on the fate of suspended solids, but quantitative data are unavailable or meager for most of these installations. Quantitative information available from the results of research studies does verify that the fate of suspended solids is biooxidation with accumulation of some residue in the surface soil. Research conducted by Bouwer at Phoenix, Arizona, resulted in excellent suspended solids removals with a BOD loading of 45 lbs./acre/day at a hydraulic loading of 300 feet per year with an activated sludge effluent. Studies by

Larson at Detroit Lakes, Minnesota (10), indicated successful operation with a BOD loading of 23 lbs./acre/day at a hydraulic loading of 95 feet per year with secondary effluent.

Suspended solids added to the soil through the spray-runoff approach pose a different situation for removal. The liquid does not percolate downward through the soil, and the filtering capability of the soil is not involved in the removal of the suspended materials. The principal mechanism of removal is still biooxidation, but the biooxidation must be accomplished as the liquid moves slowly across the surface of the soil. There is no problem of potential soil clogging, but the suspended solids still have a major influence on system operation through the BOD which they exert. The successful operation of spray-runoff systems is dependent on maintaining an oxygen level in the soil which sustains biooxidation of organic materials applied to the soil. Since maintenance of biooxidative conditions is a prerequisite for successful operation of a system, the fate of biodegradable suspended solids is oxidation to gases, water, and minerals. The use of the spray-runoff approach for land treatment of wastewaters has been limited, and there are only a few examples to substantiate the fate of suspended solids added to the soil by the spray-runoff approach. Law, Thomas, and Myers (11) reported 94 percent reduction in suspended solids concentrations at a loading of 20 lbs./acre/day of suspended solids (48 lbs./acre/day of BOD) for a spray-runoff system treating cannery wastewater applied at the rate of 0.36 inches per day. Kirby (12) reports that the grass filtration system at Melbourne, Australia, achieves 95 percent removal of suspended solids at a loading of 34 lbs./acre/day of suspended solids (68 lbs./acre/day of BOD) with raw domestic sewage applied at the rate of 0.75 inches per day. The spray-runoff approach to land treatment does not achieve the virtually complete removal of suspended materials achieved by the irrigation approach and the infiltration approach because some material usually remains in suspension and is carried in the runoff from the treatment plots.

MAJOR PLANT NUTRIENTS

The major plant nutrients which are of particular concern at this time are nitrogen and phosphorus. Each of these nutrients enter into many interactions within the plant-soil complex. Dr. Erickson has covered the mechanisms of these interactions in a companion paper, and I shall limit my discussion to the fate of these nutrients for practical utilization of the three approaches to land treatment of wastewaters.

Typical nitrogen and phosphorus concentrations in secondary effluents are such that crop uptake plays an important role in the fate of these nutrients for the wastewater irrigation approach. Turning once again to our theoretical effluent, we can add characteristic concentrations of 20 mg/l for nitrogen and 10 mg/l phosphorus to illustrate the fate of these nutrients. With our irrigation rate of 2 inches per week and applications during a projected growing period of 30 weeks, the nitrogen loading would be 270 lbs./acre and the phosphorus loading would be 135 lbs./acre. A 25 ton/acre yield of ensilage corn is one example of many crops which could utilize essentially all of the 270 lbs./acre of nitrogen applied to the soil. This removal of nitrogen by crop uptake is essential to the irrigation approach because excess nitrogen is converted to the mobile nitrate ion which is carried into the groundwater by soil percolate. Our 25 ton/acre yield of ensilage corn would remove approximately 30 lbs. of the 135 lbs./acre of phosphorus added to the soil in the applied wastewater. As discussed by Dr. Erickson, the phosphorus in excess of that removed by the crop is not readily leached from the soil. In fact, many soils have the capacity to retain thousands of pounds of phosphorus within the soil profile while the leachate from the soil contains only a trace of phosphorus. This capability of the soil to retain and fix phosphorus is as important to the removal of phosphorus as crop uptake is to the removal of nitrogen since phosphorus applications exceed potential crop uptake by a substantial margin. The experimental study at Pennsylvania State University (7) is a good example of nitrogen removal by crop uptake and phosphorus removal by retention in the soil. Of particular local interest is the work of Ellis and Erickson (13) on the phosphorus retention of many Michigan soils.

The high application rates used for the infiltration approach negate the influence of crops as a factor in the fate of major nutrients. Applying the 20 mg/l of nitrogen and 10 mg/l of phosphorus of our theoretical effluent to the 120 feet per year hydraulic loading for the infiltration approach produces a nitrogen loading of about 6,500 lbs./acre/year and a phosphorus loading of about 3,300 lbs./acre/year. Crop uptake can account for little of these totals, and crop removal is not a significant factor in the fate of major plant nutrients for the infiltration approach to land treatment. The fate of nitrogen applied by the infiltration approach is largely dependent on nitrogen removal by microbial denitrification of the nitrogen to gaseous nitrogen with release to the atmosphere. Management techniques to promote this process are in the early stages of development, and much of the applied nitrogen can be expected to appear in the underdrainage or groundwater in the nitrate form. Management techniques to promote denitrification were studied by Bouwer (6), and he achieved up to 80 percent removal of the 21,000 lbs./acre/year of nitrogen applied to the soil. The operational procedures followed by Larson (10) promoted microbial nitrification rather than denitrification, and nitrate nitrogen concentration in the groundwater rose to 31 mg/l. Phosphorus removal for the infiltration approach is achieved by retention in the soil through the mechanisms described by Dr. Erickson in his companion paper. Finer textured soils have the best capability to retain phosphorus, but coarse textured soils suitable for the infiltration approach can also achieve excellent phosphorus removal. The process of phosphorus removal is also less dependent on specific management techniques. Continuing with the same research studies, we find that Bouwer (6) reported about 95 percent removal of the 21,000 lbs./acre/year of phosphorus applied with his management techniques after about 200 feet of lateral movement through the soil while Larson (10) reported 75 percent removal of the 2,400 lbs./acre/year applied with his management techniques after about 10 feet of vertical movement through the soil. These examples serve to indicate that infiltration systems can be managed so that retention in the soil is the fate of the applied phosphorus.

The application rates used for the spray-runoff approach also reduce the importance of crop uptake as a factor in determining the fate of nitrogen and phosphorus. With the projected concentrations of 20 mg/l for nitrogen and 10 mg/l for phosphorus in our theoretical effluent and a hydraulic load of 0.4 inches per day [comparable to rates reported by Kirby (12) and Law, Thomas, and Myers (11)], the nitrogen loading would be 650 lbs./acre/year and the phosphorus loading would be 325 lbs./acre/year. Crop uptake of 250 lbs. per acre of nitrogen and 30 lbs. per acre of phosphorus are appreciable, but they leave the major fraction of the nutrients for a fate other than crop removal. The major mechanism for nitrogen removal in the spray-runoff mode of operation is by denitrification. An environment which promotes denitrification must be achieved by adjusting the hydraulic load and hence the BOD load to maintain a low dissolved oxygen level which is favorable for denitrification. Kirby (12) reports 60 percent removal of total nitrogen from raw sewage applied at a rate of 0.8 inches per day but does not indicate the nitrogen balance. Law, Thomas, and Myers (11) reported 90 percent mass removal of nitrogen from cannery wastewater with a nitrogen loading of 515 lbs./acre/year. Phosphorus removal by the spray-runoff mode of operation is relatively inefficient with present operating procedures. The processes which retain phosphorus in the soil cannot be brought into play as the liquid moves over the surface of the soil. A substantial fraction of the phosphorus applied in the spray-runoff mode of operation will be carried in the runoff unless special steps are taken to improve the removal of phosphorus. Kirby (12) reports 35 percent removal of phosphorus for spray-runoff treatment of raw sewage applied at 0.8 inches per day. Law, Thomas, and Myers report two levels of phosphorus removal for cannery wastewater with a phosphorus loading of 224 lbs./acre/year. Daily applications of wastewater applied over a 6 to 8-hour period of spraying resulted in phosphorus removals of about 55 percent or 120 lbs./acre/year, while the same amount of total application put on with 12-hour spray periods three times per week resulted in phosphorus removals of 88 percent which would amount to 180 lbs./acre/year of the 224 lbs./acre/year applied to the soil.

OTHER CONSTITUENTS

Treated wastewaters contain a host of other constituents in widely varying amounts including substantial quantities of soluble salts such as sodium chloride and minor amounts of trace constituents such as heavy metals and pesticides. This grouping of other constituents is a highly variable component depending on the source of the original water supply and the sources contributing to the final composition of the wastewater during collection. In addition to the variability due to source, individual constituents may undergo many different interactions in the plant-soil environment. Fragmentary information is available about the fate of many specific constituents of interest, but much remains to be learned about the behavior and hence the fate of trace constituents added to the soil through the various approaches of land treatment for wastewater management. Although it is impractical to make many generalizations based on the fragmentary information currently available, there are some readily predictable results associated with the three approaches to land treatment for management of wastewaters.

The fate of soluble salts or total dissolved solids applied to the land is usually surface waters through runoff or groundwater through percolating soil water. The soil has little capacity to retain most soluble salts commonly found in treated wastewaters, and the only mechanism for appreciable accumulation of total dissolved salts in the soil is a lack of sufficient percolating water to leach the salts from the soil. Since the primary fate of total dissolved solids is the effluent from the land treatment system or the "renovated wastewater," it is important to remember the fate of the water applied to the land through the irrigation, infiltration, and spray-runoff approaches to land treatment. The loadings of 2- to 8-feet per year for the crop irrigation approach are such that the balance between evapotranspiration and rainfall can substantially influence the fate of the applied water and the concentration of total dissolved salts in the water percolating downward through the soil. An excess of evapotranspiration over rainfall reduces the amount of water percolating downward but increases the concentration of dissolved solids in the percolate. If the excess of evapotranspiration over rainfall is great enough, the fate of some of the dissolved solids will be an accumulation in the soil. An excess of rainfall over evapotranspiration increases the amount of water percolating downward through the soil and decreases the concentration of dissolved solids in the percolate. The high loadings employed for the infiltration approach nullify the effects of evapotranspiration or rainfall on the concentration of dissolved solids in the underdrainage. For example, the projected loading of 120 feet per year which has been used to illustrate the fate of suspended solids and major plant nutrients would not be appreciably affected by net differences between evapotranspiration and rainfall found anywhere in the United States. The spray-runoff approach is intended to minimize the amount of water percolating through the soil to the groundwater and return a substantial fraction of the applied wastewater to surface waters after treatment. The primary fate of the dissolved solids becomes surface waters in much the same manner as the fate of dissolved solids is surface waters for conventional treatment approaches. The concentration of dissolved solids in the water discharged to the surface waters is influenced by the day-to-day balance between evapotranspiration and rainfall, and a minor fraction of the dissolved solids are carried downward with the soil percolate. To summarize the fate of dissolved solids briefly one can say that dissolved solids applied by the irrigation and infiltration approaches end up in groundwater unless the underdrainage is intercepted and diverted to another sink such as a surface stream while the dissolved solids applied by the spray-runoff approach are released directly to surface waters.

Heavy metals and pesticides are two groups of other constituents which are in the limelight at the present time. The presence of both of these groups of other constituents in wastewaters is highly dependent on the industrial contribution to the wastewater, and most of the members of these two groups undergo physical, chemical, or biochemical interactions in the soil. Fragmentary information about the fate of many specific constituents of interest is available, but much remains to be learned about the behavior and hence the fate of trace constituents such as heavy metals and pesticides. Many of the heavy metals are strongly held in the soil by the mechanisms

Dr. Erickson has described in the paper he prepared for this Conference. Retention of heavy metals in the soil may be a desirable fate or it may be an undesirable fate. Allaway (14) presents an interesting review on the cycling of trace elements in relation to crop production and human health. He suggests that future agricultural management practices may include control of trace element concentrations in plants through the control of trace element concentrations in soils. The report of the National Technical Advisory Committee on Water Quality Criteria (15) includes a discussion of both heavy metals and pesticides in waters to be used for crop irrigation. This discussion includes a tabular presentation of concentration limits as they pertain to irrigation on various types of soils and for short-term use (up to two decades) versus continuous long-term use. An important factor to remember when dealing with trace constituents such as heavy metals and pesticides is that the total mass of material involved is small, and what would appear to be rather insignificant factors can account for appreciable fractions of the total applied mass.

SUMMARY

The foregoing is a brief summary of the fate of suspended solids, major plant nutrients of environmental concern, and other selected constituents of wastewaters when these wastewaters are applied to the soil by the crop irrigation, infiltration, or spray-runoff approaches to wastewater management. The content of this presentation is intended to give one an insight into the mechanisms involved and the practical aspects involved in the treatment or renovation of wastewater by applying the wastewater to the land. The coverage of the many topics involved is of necessity brief, and one wishing to have a deeper understanding of the subject matter should refer directly to the cited literature and other pertinent reference documents on interactions in the plant-soil environment.

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PROTECTION OF THE PUBLIC HEALTH

by

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The public health aspects of wastewater treatment or wastewater reclamation by land disposal are dependent upon a number of variables, the most important of which is the ultimate use of the wastewater. Possible uses include: (a) discharge to a surface body following percolation through the soil; (b) groundwater recharge; (c) crop irrigation; and, obviously, any combination of the first three. The ultimate use of the wastewater along with the method of application of the wastewater are intimately interrelated with soil character and application rates.

Another area of importance is the degree of pre-treatment for the wastewater prior to land disposal. Common sewage treatment practices remove significant amounts of many of the important sewage constituents. However, none of the common treatment practices can reduce the level of all pollutants to the extent which would permit the effluent to be employed for direct reuse as a municipal potable water supply. The effects of these prime variables are grouped into three areas of consideration: physical; biological; and chemical.

PHYSICAL CONSIDERATIONS

Physical considerations are somewhat secondary in that they relate, to a large degree, to both the biological and chemical considerations. Particular attention must be paid to the removal of suspended material, which will insure that both the distribution system and the soil treatment system do not become clogged. The physical characteristics of the soil treatment system are infinitely important. Okun[1], in 1971, pointed out that wide variations in soil characteristics make it mandatory that each potential land disposal site be intensely studied before land disposal practices are instituted. Many investigators have indicated that clays are chemically the most important size faction of soil. Ion exchange capacity is a major factor and must be considered in land wastewater disposal plans. As you will see shortly, the physical characteristics of the soil are very closely interrelated with both the biological and chemical considerations of land disposal.

BIOLOGICAL CONSIDERATIONS

Most standards on land disposal of wastewater provide for use restrictions depending on how crops are processed or land is used. For example, the California standards[2] require "adequately disinfected filtered wastewater"... for irrigation of forage crops, landscape in

[1]Okun, D. A., "New Directions for Wastewater Collection and Disposal", *Journal Water Pollution Control Federation*, 43:11:2171, (1971).

[2]Foster, H. B., Jopling, W. F., "Rationale of Standards for Use of Reclaimed Water," *Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers*, 95:SA3:503-514 (Jun 69).

public areas, and for filling impondments for recreation. These standards define "adequately disinfected filtered wastewater" as water which has been oxidized, coagulated or filtered, and chlorinated to the extent, that the seven-day median residual coliform count does not exceed 2.2 or 23.0 organisms per 100 ml, depending on the specific application. In another section of the California standards "disinfected wastewater" is defined as "water in which pathogenic organisms have been destroyed". (Just as a side thought, it appears that there is a slight conflict in these two statements, in as much as complete destruction of pathogenic organisms and the presence of as many as 23 coliforms/100 ml are inconsistent).

Evidence collected in the field has shown high coliform levels on the surface of vegetables irrigated with raw sewage. Other researchers have suggested that if sewage irrigation is stopped one month before harvest, raw food would not likely be an effective transmission medium of bacterial enteric disease. However, there is sufficient information to substantiate the current requirement for disinfection of wastewater before irrigation of vegetables or any other crop for direct human consumption. Health problems, however, can arise from the use of either inadequately disinfected or undisinfected wastewater.

It has been repeatedly demonstrated that many pathogenic microorganisms pass through activated sludge treatment even though they are greatly reduced in number. A wide variety of microorganisms have been found in secondary effluents, including the typhoid group, colorea, tuberculosis, and many viruses including coxsackie, polio virus (I, II and III), echo viruses, and others. Even after chlorination, many enteric microorganisms can be found in secondary effluents. Kruze and co-workers[3] have demonstrated that in the presence of ammonia, amino acids or other nitrogen compounds, the absence of coliform organisms does not necessarily mean virus inactivation. The effectiveness of disinfection, as measured by the residual coliform bacteria, does not by any measure insure the destruction of viable enteric viruses. It is clear from the literature that, chlorination as practiced, does not provide complete disinfection of pathogenic bacteria or viruses. As a consequence, wastewater spraying could result in biological aerosol formation and could, and I emphasize could, disseminate many of the pathogenic organisms found in wastewater.

[3]Kruze, C., Y. C. Hsu, A. Griffiths, R. Stringer, "Halogen Action on Bacteria Viruses and Protoza," *Proceedings of the National Specialty Conference on Disinfection*, University of Massachusetts, Amherst, Massachusetts, Jul 1970, (1970).

The application of wastewater to soil has been studied to some extent with regard to pathogen mobility and destruction in soils. Basically, pathogen removal in soils is a function of the characteristics of the soil. Under certain conditions, such as limestone crevicing, pathogens have been found to travel miles. On the other hand, it appears that heavy textured clay soils thru adsorption and filtration, will remove viruses, bacteria as well as the larger pathogens, on and near the soil surface. The pathogens which are collected in the soil can be inactivated after land application. Exposure to ultraviolet light, oxidation, dessication and antagonistic soil organisms are the most important destructive mechanisms. On the other hand, there is ample literature citation to indicate that pathogens can survive these deletarious effects in soil for relevantly long periods after sewage application.

These facts allow us to reasonably inquire about some potential health hazards. One may ask, first, if soil runoff, either during effluent application or following precipitation, may allow significant numbers of pathogens to enter surface waters. Much of this problem could be controlled or avoided by proper design of the application site. However, this may be difficult in sites spread over considerable land areas, such as golf courses, forests, and crop lands, where runoff collection and retention may be impractical. It is also important to consider pathogen concentration near the soil surface. Consideration should be given to the effects of long term application of non-degradable organic materials that may clog the soil surface and other organics that tie-up soil adsorption sites; the effect of cation species and concentration with respect to soil tightness and adsorption; the effects of high pH on soil filterability and reduced adsorption capability; and lastly, the reduced treatment capabilities of soil for pathogens after shock loading of a toxic effluent (from spills).

It has also been shown that coliform organisms do not survive in soil and on vegetation as long as certain other bacteria such as *salmonella, klebsiella,* and some worm eggs. Virus survival on soil is essentially unexplored. It is likely, however, that viruses will survive longer than coliform organisms. It is important to consider whether pathogenic organisms from sewage effluent can survive on soil and vegetation for extended times, since they may be concentrated on or near the soil surface. Human contact with organisms on soil surfaces may result from dusts or other particles, winds, machinery, or other human activity such as walking, which may reaerosolize these organisms and make them accessible to inhalation.

Aerosols are defined as particles in the size range of .01 to 50 or so microns (μm) which are suspended in air. Specific studies of biological aerosols emitted by spray irrigation of wastewater have not been found in the literature. However, some preliminary work at the University of Utah has demonstrated that the spraying of chlorinated effluent for landscape watering resulted in approximately 1 1/2 times the number viable organisms that were detected from a trickling filter. Specific quantification of this work is difficult because of the lack of experimental control, but it does demonstrate that spray irrigation of chlorinated effluent produces biological aerosols in the same order of magnitude as observed from non-chlorinated wastewater applied to trickling filters. Some investigations have been conducted on biological aerosols from trickling filters and activated sludge systems. In general, it was found that bacterial aerosols remain viable and travel further with increased wind velocity, increased relative humidity, lower temperatures and darkness.

Direct means of human infection by biological aerosols is by inhalation. The infectivity of a biological aerosol is further dependent on the depth of respiratory penetration. Biological aerosols in the 2-5 micron size range are primarily captured in the upper respiratory tract. These particles are removed by the bronchial cilia and may ultimately pass into the digestive tract. If gastro-intestinal pathogens are present in these aerosols, a certain degree of infection may result. However, a much higher incidence of infection will result when respiratory pathogens are inhaled into the alveoli of the lung. The greatest alveolar deposition occurs in the 1-2 micron range and then decreases to a minimum at approximately 0.25 micron. Below 0.25 micron, alveolar deposition again increases due to Brownian movement in the lungs. For comparative purposes, it has been observed in one study that approximately 82% of the 1 micron particles; 28% of the 0.1 - 0.3 micron particles; and 51% of 0.03 particles are deposited in the alveoli. Deposition of the smaller particles becomes significant when consideration is given to the size of a virus (about 0.01 - 0.1 micron).

It is reasonable to postulate that, if disinfection of sewage is not complete and the pathogenic organisms are aerosolized, even very low numbers of these organisms may be a potential public health hazard. On the positive side of the ledger is the fact that dessication and oxidation of microorganisms in aerosols is probably very important in eliminating their overall viability. Studies of evaporation rates show that a 50 micron water droplet will evaporate in 0.31 seconds in air with a 50% relative humidity and a temperature of 22°C. Coliforms are known to dessicate quite rapidly whereas *klebsiella* and other organisms are known to be relatively resistant to dessication. In all, it is a large area which has not been completely explored at this point.

Another area where considerable emphasis is developing is the effect of wastewater land disposal on the changes in both the population and the disease incidents amongst wild animals, birds, and mosquitos.

Some work has been directed toward these areas and more is underway. For example, it has been demonstrated that surface ponding can develop on the spray irrigation site, and the existence of these ponds will result in increased mosquito breeding by several known disease vector species. Additional areas in which information is needed include the fate, possible spread and control of protozoan parasites; the possible passive spread of microorganisms by flying insects; and the capacity of wildlife, including migratory birds, to carry infection great distances from the primary focus.

CHEMICAL CONSIDERATIONS

The public health aspects of land disposal of wastewaters must also consider organic and inorganic chemical movement in the soil. This evaluation could be extremely broad in scope if industrial wastewaters are considered, either separately or combined with domestic wastewaters. Heavy metals or toxic organic compounds are two groups of materials that would require special consideration. Certain heavy metals including chromium, copper, manganese, lead, and zinc, have increased in concentration in soil when digested sludge has been applied. Of these metals, zinc and manganese have increased in concentration of the leachates, also.

It is recognized that essentially no definitive information is available as to the specific organic chemical makeup of effluents from secondary sewage treatment processes. Because of this, it is extremely difficult to accurately assess the long range effect of these chemicals and their relationship to the public health aspects of land disposal. The movement of dissolved inorganics with percolating water is primarily dependent on the nature of the filtering soil. There have been several instances of groundwater contamination by soluable industrial wastes. For example, in one case in Germany, picric acid traveled several miles and caused abandonment of a groundwater supply. Chemical elements are primarily removed in soil media by the process of ion exchange. Therefore, the chemical clarification ability of the soil is generally proportional to its cation exchange capacity. Clay and organic soils have the greatest cation exchange capacity.

Pesticides are a special case and they persist in soil and water systems for varying periods of time. Their length of persistence depends on such factors as the chemical nature of the pesticide itself and the chemical, physical and biological factors which promote degradation, translocation or metabolism.

In 1971, Hermanson and co-workers[4] established persistency indices for various organochlorine insecticides applied to soils over a 11-year period. They found relative persistences of pesticides in the soil: from DDT - .26; Dieldrin - .22; Endrin - .20; Heptochlor - .14; Chloradane - .13; where unity is equal to no degradation or other disappearance during the first year. Due to the persistence of pesticides, consideration must be given to their possible build-up in the soil at wastewater disposal sites.

Another compound of particular interest is nitrogen. Biologically treated domestic wastewater contains between 5 and 30 milligrams/liter of total nitrogen. The primary source of this nitrogen metabolism in man. The dominant nitrogen form depends on the specific type of pretreatment process, but it is usually in the form of ammonia or nitrate. If ammonia exists as the dominate nitrogen form, it will be adsorbed by the soil and eventually be used in plant growth, evolve as a gas or be biologically oxidized to nitrate. Thus, if nitrate is not applied initially, it may be formed biologically on or near the soil surface. Ample information is available which indicates that nitrate ions are not adsorbed by the soil and will eventually get into the groundwater system if not utilized immediately. As you will recall, nitrate ion has been demonstrated as the causative agent for methemoglobinemia in children. Nitrate-nitrogen levels may develop to above 10 mg/l in areas where land wastewater disposal is used for groundwater recharge and where the recharge water is cycled back through the water supply system. Studies at the Penn State University have demonstrated that selected crops can remove considerable quantities of nitrate-nitrogen.

Another element which may be of concern is sodium. Sodium has been shown to be a problem with cardiac patients, and, further, has been shown to pass essentially uneffected through the soil treatment system. Again, the only potential problem from nitrate-nitrogen and sodium would be in areas where land disposal is the first step in a water recycle program.

In summary then let me attempt to put all this information into perspective. There are very few, if any, public health problems that have been demonstrated as a result of spray irrigation or land disposal of wastewater. However, a significant number of questions have been raised and it appears to be judicious to conduct well planned investigations which will demonstrate beyond a shadow of doubt, whether these potential problems do or do not exist. In general, then, it can be concluded that:

[4]Hermanson, H. P., F. A. Gunther, L. D. Anderson, M. J. Garber, "Installment Application Effects upon Insecticide Residue Content of a California Soil," *J. Agr Food Chem,* 19:4:722, (1971).

1. Many of the potentially detrimental health and hygiene aspects of land disposal would be significantly reduced by proper wastewater pretreatment, including secondary treatment, filtration and complete disinfection.

2. Site selection is extremely important.

3. By choosing a land disposal site that has from five to ten feet of continuous fine soil, biological contamination of groundwater should be avoided.

4. If significant numbers of organisms are present in the effluent, the probability of inhaling pathogenic aerosols near a spray irrigation site would be significant.

5. Chemical components of sewage may enhance the viability of bacteria, virus and protozoans in aerosols.

6. Pathogenic microorganisms (bacteria and viruses) may survive longer in sewage aerosols and in soil than common indicator organisms such as coliform organisms.

7. As a result of ponding in land disposal areas, mosquito breeding is enhanced.

8. In areas where land disposal is the first step in a water recycle program, total dissolved solids, sodium and nitrate ion build-up in the groundwater supply can eventually be a problem.

Many of the unknown areas relating to the public health problems associated with land disposal of wastewater can be more clearly identified when results of six basic study areas are available:

1. The evaluation of the survival, distribution and hazard of aerosolized pathogenic microorganisms disbursed by spray irrigation machinery.

2. The comparison of pathogen survival in soils and aerosols vs estimated indicators of bacteriological water quality.

3. The evaluation of the long range effects of land wastewater disposal on plants, animal and disease vector ecology.

4. The evaluation of the persistence and translocation of toxic trace organics, pesticides and heavy metals in soils at wastewater disposal sites.

5. An investigation into advanced treatment and disinfection methods required to eliminate any identified problem chemicals and microorganisms from applied wastewater.

6. The performance of a well planned epidemiological investigation at a relatively large, operating land wastewater application site.

EXPERIENCES WITH LAND SPREADING OF MUNICIPAL EFFLUENTS

by

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EXPERIENCES WITH LAND SPREADING OF MUNICIPAL EFFLUENTS*

by

Richard E. Thomas and Curtis C. Harlin, Jr.**

Introduction

The U.S. Environmental Protection Agency (EPA) is a very young agency which was created in December 1970. Although the agency is less than two years old, its experiences with land spreading of municipal effluents extend over more than 15 years. This longer period of experiences stems from the efforts of our predecessor agencies which include the Federal Water Quality Administration, the Federal Water Pollution Control Administration, and the U.S. Public Health Service. These past efforts were conducted as a result of the Federal Water Pollution Control Act of 1956 and subsequent amendments of this Act.

Within the current organization of EPA, the National Water Quality Control Research Program located at the Robert S. Kerr Water Research Center, Ada, Oklahoma, is actively participating in research to improve our understanding of the processes which influence and

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limit the performance of land-based wastewater management systems. The primary goal of this research is to advance the state of the art so that sound technology will serve as a base for reliable design of systems to achieve desirable and specific levels of performance.

Our evaluation of the current state of the art leads us to conclude that there are several distinctly different approaches to the spreading of municipal effluents on the land which show promise for further development and widespread use. It is convenient to group these land spreading approaches into three categories which we refer to as (1) infiltration-percolation, (2) cropland irrigation, and (3) spray-runoff. We use this grouping because each of these approaches has well-defined differences regarding land area requirements and the resulting interactions with the plant, soil, and water components of localized ecosystems.

The infiltration-percolation group includes systems frequently referred to as recharge basins, ridge-and-furrow basins, or flooding basins. Systems of this type are operated on the basis that the applied wastewater moves downward through the soil for treatment. Coarse textured soils are preferred in order to achieve the desired areal loadings which range up to 400 feet per year under ideal conditions.

The chief functions of plants are the relatively minor roles of shading the surface of the soil and helping to stabilize good physical conditions in the soil. Physical, chemical, and biochemical interactions in the soil are the major processes contributing to treatment of the applied wastewater. Surface runoff is prohibited; evaporative losses are relatively minor; and substantially all of the renovated water becomes groundwater.

Crop irrigation is an immediate and direct reuse of a municipal effluent for beneficial production of crops not for direct human consumption. Common broad irrigation or spray irrigation techniques are used to apply the effluent to crops at normal irrigation rates or somewhat in excess of these rates. Land area requirements are large because areal loadings are one to two inches per week with total growing season applications of less than 8 feet per year. Plants play a prominent role in the removal of plant nutrients such as nitrogen and phosphorus. Physical, chemical, and biochemical interactions in the soil are less dominant in achieving desired performance because of the relatively low rate of areal loading. Surface-runoff may or may not be controlled; evapotranspiration losses may be equal to or greater than the amount of water moving through the soil to become groundwater. This large percentage of evaporative losses can result in a substantial increase in the total salt content of the water percolating down through the soils.

The spray-runoff is especially suited to use with impermeable soils and falls intermediate between the infiltration-percolation approach and the crop irrigation approach in land area requirements. Vegetative cover is necessary to stabilize the carefully prepared runoff slopes and terraces, but the harvesting of a crop is secondary to the objective of treating the applied effluent. The physical, chemical, and biochemical processes take place as the liquid moves slowly over the surface of the soil by sheet flow. More than half of the applied effluent is returned directly to surface waters as planned and controlled runoff of the renovated water. The remainder of the water is either lost through evaporative processes or percolates down through the soil to become groundwater. A comparison of selected characteristics of the three land-spreading systems is presented in Table 1.

Now, let us consider some research studies which have been conducted or financially supported by EPA or its predecessor agencies. Discussions of the results of these studies will provide additional detail about system designs and management techniques which can be utilized to achieve specified treatment or reuse objectives. The three categories of land spreading will be discussed in the same sequence in which they have been described in preceding paragraphs.

Infiltration-Percolation Systems

Infiltration-percolation approaches such as septic tank-soil absorption systems, ridge and furrow basins, and flooding basins have been utilized for many decades as a convenient disposal practice. Design and operation of these systems have emphasized the disposal concept, and it is only within the last decade that an effort has been made to emphasize the treatment capability of the infiltration-percolation approach. EPA and its predecessors have been involved in six research projects having the objective of utilizing the infiltration-percolation approach to treat municipal effluents for subsequent reuse. Four of these studies were conducted in the water-short southwestern states and two were conducted in water-rich north central states.

First, let us consider the objectives and results of the four studies conducted in the water-short southwestern states. A study at Whittier Narrows, California was conducted to study the effectiveness of the infiltration-approach for direct recharge of a potable groundwater supply with secondary effluent (1). The results of this study showed that spreading periods of about 9 hours followed by drying periods of about 15 hours produced a clear and highly oxidized water acceptable for recharge at this site. This method of operation resulted in conversion of almost all applied nitrogen to nitrate and produced nitrate concentrations in the renovated water two to three times more than acceptable limits for drinking water. Due to the high nitrate concentration, it was recommended that dilution with low nitrate water would be necessary before repumping for use as a water supply.

A concurrent study at Santee, California evaluated the use of infiltration-percolation to make municipal effluent suitable to fill and maintain the water level in recreational lakes (2). Locating the infiltration-percolation basins in the alluvium of a shallow stream channel provided substantial lateral movement underground after about 10 feet of vertical percolation. In addition to excellent removal of solids, oxygen-demanding substances, pathogens, and phosphorus, total nitrogen in the renovated water was reduced to 1.5 mg/l (from 25 mg/l applied to spreading basins) after about 1,500 feet of lateral underground travel. Emphasis was placed on evaluating this nitrogen removal at a Phoenix, Arizona study using a similar mode of operation (3). Results of the Phoenix study showed that the frequency of application has a major influence on nitrogen removal. Spreading and drying periods of a few days or less promoted nitrification and resulted in less than 10 percent total nitrogen removal whereas spreading and drying periods of 10 to 20 days resulted in apparent denitrification and up to 80 percent nitrogen removal. This study also highlighted the importance of underground residence time and/or distance of travel for achieving phosphorus removal at the high loadings used for the infiltration-percolation approach.

Another important factor related to local hydrological conditions was graphically demonstrated by a study at Hemet, California (4). An unusually wet winter season at this location caused the local water table to rise up to the bottom of the spreading basins. The resultant reduction in hydraulic acceptance rate and deterioration of treatment efficiency made it necessary to quickly develop an alternate method for handling their effluent.

Now let us look at the results of the two infiltration-percolation studies in the cool and semi-humid climate of the north central states.

One of these entailed a four-year experiment using 20-hour spraying periods followed by 4-hour drying periods to apply about 98 feet per year of effluent on a sandy soil (5). Our definitions place this system in the infiltration-percolation category even though it uses spray application and is referred to as a spray irrigation system. It is significant that the use of short spreading and drying cycles in this climate produced nitrogen and phosphorus interactions comparable to those for studies in the Southwest. Nitrogen was converted to nitrate which appeared in the groundwater (at a concentration comparable to that in a municipal effluent) while 70 percent of the phosphorus was removed after no more than 20 feet of travel distance through the soil. The other study in this climate was a one-year evaluation of the performance of an existing ridge and furrow basin (6). The system was located on a silt loam soil and a loading of about 45 feet per year was obtained with wetting periods of two weeks followed by drying periods of two weeks. As was the case for the study in Arizona, the long spreading period resulted in about 70 percent removal of total nitrogen without affecting the removal capacity for other measured parameters.

Our experiences with the use of the infiltration-percolation approach to land spreading of municipal effluents are encouraging for future use on a much larger scale. Technological data are already available to design and operate systems for a limited number of situations, but of more importance is the apparent utility of the approach under widely differing climatic conditions. We are optimistic that further research efforts can establish well-defined design criteria and management techniques for use throughout the United States.

Cropland Irrigation Systems

Cropland irrigation with municipal effluents is a well-established practice in the southwestern United States and has been practiced continuously for over 50 years at many municipalities. This practice has developed to satisfy a need for more water as well as a need to manage municipal effluents in an acceptable manner. Utilization of the practice has grown steadily since the first operations were initiated around 1900, and there are over 300 active operations at present. In spite of this impressive number of operating installations, there has been little research conducted to establish a technological base for predicting the long-term influence of various management techniques on the crops, the soils, the groundwater, or the overall ecology cf the area of influence. EPA is initiating several projects to assess the current state of our knowledge and to improve management of cropland irrigation systems.

One group of projects is directed to locating and evaluating currently available quantitative information on application rates, crop responses, soil changes, and groundwater quality changes from systems which have been operating for varying periods of time. This effort should be very useful in defining management techniques for general use in the Southwest as well as furnishing a base on which to build for other geographic locations.

Another group of projects is oriented toward field development of management techniques for the cooler and more humid regions east of the Mississippi River. One of these projects has been in operation at Pennsylvania State University since 1963 (7). The results of this project over the first seven years of operation have shown that cropland irrigation can be practiced in a cool and semi-humid climate in a manner that will promote crop production while contributing substantial recharge to the groundwater. Results reported to date from the Pennsylvania State University project indicate that an application rate of 2 inches per week over a 30-week growing season (a total application of 60 inches per year) is the most beneficial for general use under conditions existing at this site. The other field development projects are the Muskegon County Wastewater Management System currently under construction at Muskegon, Michigan, and a smaller but similar project just initiated at Belding, Michigan. It will be several years before field data from these projects will be available for reliable interpretation and subsequent use in establishing improved management practices.

Our experience with the cropland irrigation approach to land spreading stems largely from qualitative information on the performance of existing systems concentrated in the semi-arid Southwest. In general, the performance of these systems has been judged to be satisfactory; yet there is a general lack of quantitative data to substantiate this judgment. A carefully managed experimental system located at Pennsylvania State University has produced quantitative information over a 7-year period which indicates that cropland irrigation with municipal effluent can be a practicable wastewater management technique in cool and semi-humid climates.

Spray-Runoff Systems

The spray-runoff approach has not been utilized for treatment of municipal wastewaters, but it has been employed at many industrial plants. Experiences at some of these industrial plants indicated that spray-runoff had considerable potential for treatment of any wastewater containing biodegradable organics.

In 1967, our research group at the Robert S. Kerr Water Research Center initiated a cooperative study with the Campbell Soup Company to conduct a one-year research study at their Paris, Texas plant. The objective of the study was to evaluate the performance of the spray-runoff system at this location which had been in operation for 5 years. The results of the study on this 3 mgd capacity system showed that the spray-runoff approach was indeed a very efficient system for removal of suspended solids, oxygen-demanding substances, and nitrogen from the cannery wastewater produced at this plant (8). The results of this investigation encouraged us to explore the capability of the spray-runoff approach for other wastewaters in which biodegradable organics were the major source of pollutants to be removed by a treatment process. We are currently conducting in-house research to develop the spray-runoff approach for treatment of raw domestic sewage and for runoff from beef cattle feedlots. Preliminary results for both of these wastewaters are very encouraging for development of practicable systems. For example, the experimental spray-runoff system we have designed for the treatment of raw comminuted domestic sewage is producing an effluent that is of tertiary treatment quality without producing any sludge to handle. The spray-runoff system designed for treatment of the runoff collected from beef cattle feedlots has produced equally encouraging performance data. A technical report covering five months of field evaluation data for the feedlot runoff system will be available soon.

Technology to utilize the spray-runoff approach for management of domestic wastewaters is in the rudimentary stage of development. The exploratory research which we have in progress indicates that spray-runoff treatment of raw domestic wastewater is feasible but many more questions must be answered before the process can be developed for general use.

Summary

The foregoing is a brief summary of the EPA's involvement in land spreading of municipal effluents for treatment and/or reuse.

Coverage of the many research projects introduced has, by choice, been limited and selective in order to highlight the objectives of this presentation. Further information about many of the projects has been reported in readily available technical publications in addition to those cited in this paper. For those projects currently in progress at the Robert S. Kerr Water Research Center of the EPA, the authors can be contacted to obtain further information.

TABLE 1

COMPARATIVE CHARACTERISTICS OF SYSTEMS

Factor	Type of System: Crop Irrigation	Spray-Runoff	Infiltration-Percolation
Application Rate	2 to 8 feet per year	8 to 15 feet per year	15 to 400 feet per year
Land Required for 1 mgd flow (3.1 ac. ft.)	140 to 560 acres plus buffer zones	75 to 140 acres plus buffer zones	3 to 75 acres plus buffer zones
Application Techniques	Spray or Flood	Spray	Usually Flood
Soils	Moderately permeable soils with good productivity when irrigated	Slowly permeable soils such as clay loams and clay	Rapidly permeable soils, such as sands, loamy sands, and sandy loams
Probability of influencing groundwater quality	Moderate	Slight	Certain
Needed Depth to Groundwater	About 5 feet	Not Known	About 15 feet
Fate of Wastewater	Predominately evaporation or deep percolation	Surface discharge dominates over evaporation and percolation	Percolation to Groundwater

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NATIONWIDE EXPERIENCES IN LAND TREATMENT

by

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NATIONWIDE EXPERIENCES IN LAND TREATMENT

Introduction

The information to be presented in this paper is a preview of some of the highlights of a study by Metcalf & Eddy, Inc., for the EPA on land application of wastewater. The objectives of the study were to:

1. Isolate key parameters for design.
2. Evaluate effects on the environment.
3. Determine the risks to health and safety.
4. Evaluate costs.
5. Identify those areas that need additional study.

Historically, the use of sewage effluents for the various forms of land application has been termed sewage farming. We have encountered references to sewage farming as far back as the 1550's, as indicated in Table 1. It is interesting to note that some of these systems in the past have covered very large acreages, some of which are still in existence, particularly Mexico City which now covers 112,000 acres and disposes of 570 mgd of effluent. The Mexico City installation dates back to at least 1902 and has grown with the years. Other notable non-United States installations are Berlin, Germany; and Melbourne, Australia. In the United States, sewage farming references were found as far back as 1872. Some of these installations have been abandoned, such as Augusta, Maine; and Pullman, Illinois, but others are still in existence such as Cheyenne, Wyoming; and Bakersfield, California. The data shown in Table 1 are for the initial year unless otherwise noted.

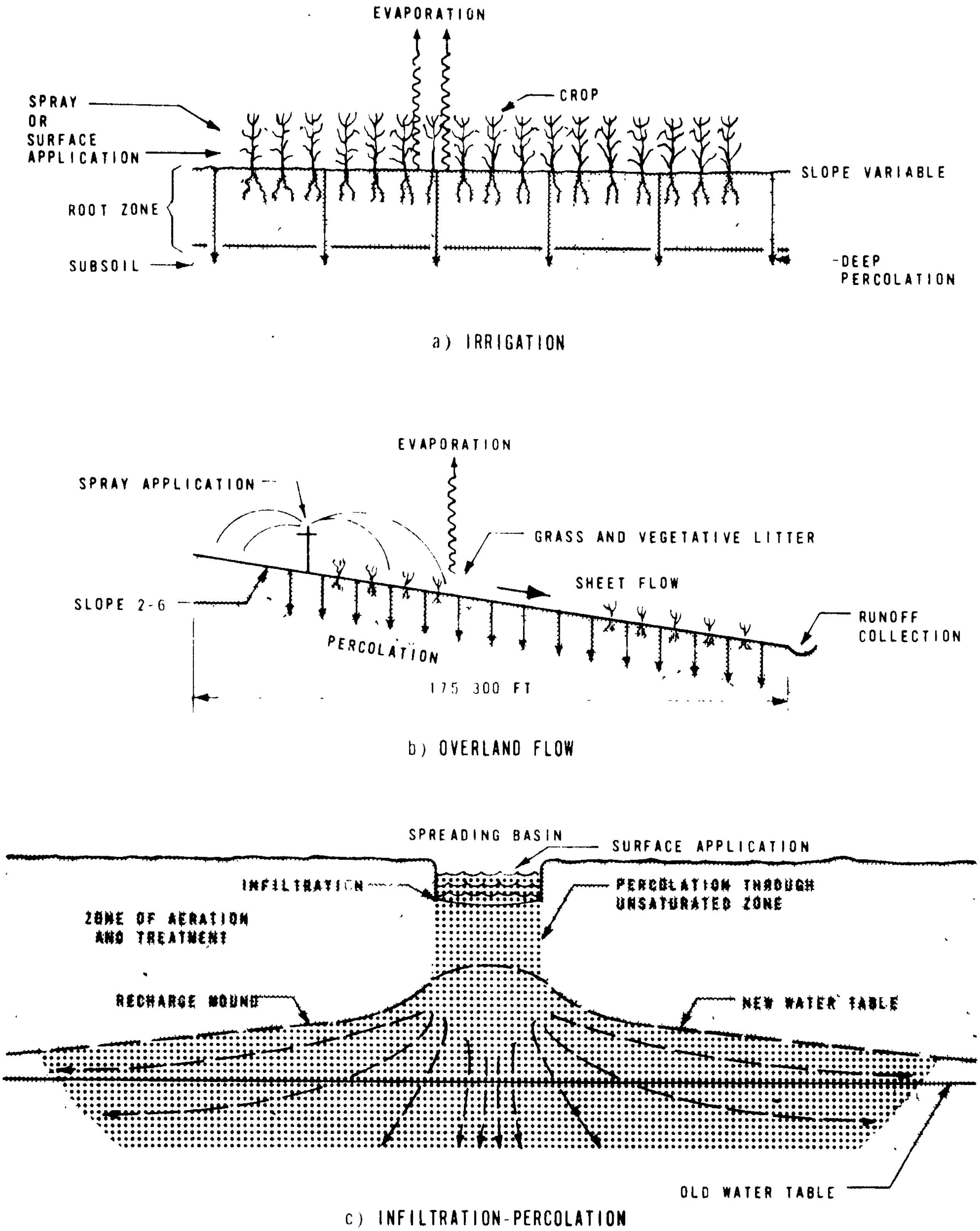
There are three basic modes of land application of wastewater: crop irrigation, overland flow or spray-runoff, and infiltration-percolation. These three modes or approaches to land application are shown schematically in Figure 1. Irrigation is the application of water or wastewater to the land to sustain plant growth. Overland flow consists of spraying wastewater onto gently sloping, relatively impervious soil planted to vegeta-

Table 1

HISTORY OF SEWAGE FARMING

Date	Location	Description	Wetted area, acres	Flow, mgd	Average Loading in./week	Reference
Non-United States						
1559	Bunzlau, Germany	Sewage farm	--	--	--	1
1861	Croydon-Beddington, England	Sewage farm	420	4.5	2.8	2
1864	South Norwood, England	Sewage farm	152	0.7	1.2	2
1869	Berlin, Germany	Sewage farm	27,250[a]	150[a]	1.4	2
1875	Leamington Springs, England	Sewage farm	400	0.8	0.5	3
1880	Birmingham, England	Sewage farm	1,200	22	4.7	3
1893	Melbourne, Australia	Pasture irrigation	10,376[b]	50[b]	1.2	4
	Melbourne, Australia	Overland flow	3,472[b]	70[b]	5.2	4
1902	Mexico City, Mexico	Sewage irrigation	112,000[b]	570[b]	1.3	5
1923	Paris, France	Sewage irrigation	12,600	120	2.5	2
1928	Capetown, South Africa	Pasture irrigation	--	--	--	6
United States						
1872	Augusta, Maine[c]	Irrigation	3	0.007	0.6	7
1880	Pullman, Illinois[c]	Irrigation	40	1.85	12.0	7
1881	Cheyenne, Wyoming	Irrigation	1,330[d]	7.0[d]	1.3	5
1887	Pasadena, California	Irrigation	300	--	--	2
1895	San Antonio, Texas	Irrigation	4,000[a]	20[a]	1.3	2
1896	Salt Lake City, Utah	Irrigation	180	4	5.7	7
1912	Bakersfield, California	Irrigation	2,400[d]	11.3[d]	1.2	--
1928	Vineland, New Jersey	Irrigation	14	0.8	14.7	8

a. Data for 1926.
b. Data for 1971.
c. Abandoned around 1900.
d. Data for 1972.



a) IRRIGATION

b) OVERLAND FLOW

c) INFILTRATION-PERCOLATION

FIGURE 1
LAND APPLICATION APPROACHES

tion. Biological treatment occurs as the wastewater trickles through the vegetative litter and contacts the biota. Infiltration-percolation is the application of water or wastewater to the land with nearly all the water infiltrating the surface and percolating through the soil pores. Many factors are pertinent to the design and operation of all three modes, the two most important categories being site and wastewater characteristics.

Site Characteristics

Site characteristics include such items as climate, topography, soil type, underdrainage, and groundwater. Climate is most important in the design and operation of irrigation and overland flow systems as it affects crop growth and net microbial activity in and on the soil Topography may dictate the method of application such as spraying as opposed to the ridge and furrow or flooding techniques. Soil types may dictate the type of cover crop, method of application, and the mode of application. For example, a sandy soil may be suitable for infiltration-percolation systems whereas a tighter loam soil would be suitable for either overland flow or crop irrigation. Underdrainage involves soil structure, texture, and depth, as well as underlying geological formations. Drainage is a key parameter in determining hydraulic loading rates. Groundwater is important both in its level and movement as it affects the hydraulic and renovative capacity of the system and in its quality.

Wastewater Characteristics

Municipal wastewater characteristics may be classified as physical, chemical, and biological. In land application, important physical characteristics are suspended solids content, temperature, and odor. Suspended solids can clog sprinkler heads and can be a limiting factor in the design of infiltration-percolation systems. Temperature is not a great problem for municipal wastewater because it has a fairly even temperature, 50 deg. F to 70 deg. F, which is not harmful to soil or vegetation. Odors, caused by decaying organics, can be reduced by maintaining aerobic conditions throughout the system.

Chemical characteristics include organic matter and dissolved inorganics. Organics are measured as BOD or COD and are important in that they are trapped and decomposed on or in the soil. The biological characteristics of municipal wastewater are chiefly bacteria and viruses.

The important wastewater parameters in the design of land treatment systems are organic and nutrient loads, particularly the nitrogen application, because of possible contamination of the groundwater or surface water with nitrates. The chemical constituents are important because they may produce a salinity buildup both in the groundwater and in the upper soil layer, resulting in toxicity to the cover crop. Specific ion toxicity such as boron and one or more heavy metals may also be a problem. Boron may adversely affect some plants at concentrations as low as 0.5 mg/L. Metal ions such as sodium, calcium and magnesium, which are part of the sodium adsorption ratio, are also important because if this ratio exceeds 15 in clay-type soils, there may be a total sealing of the soil surface. Bacteria and virus are important from a public health standpoint, particularly the possibility of contaminating groundwater and edible crops.

Crop Irrigation

Irrigation is the most widespread and well developed of the land application modes. It is practiced throughout the nation but most heavily in California, Arizona, New Mexico, and Texas. This discussion will cover briefly the items of design, management, health aspects, and costs for forest, landscape, and crop irrigation.

Design. In considering design criteria for crop irrigation with municipal effluents, two particular points are important: loading rates and cover crops. In addition, all of the techniques standard to agricultural irrigation practices must also be considered. Some loading rates versus soil types and crops, that were encountered in a literature survey or in site visits, are listed in Table 2. Loading rates are given in inches of effluent

Table 2

LOADING RATES VERSUS SOIL TYPE AND CROP

City	Loading rate in./wk	Soil type	Crop
Heavy application > 7 in./wk			
Vineland, N.J.	12.0[a]	Sand	None
Eglin AFB, Fla.	11.2[b]	Sand	Forest
Dinuba, Calif.	10.5[a]	Silt,sand	None
Quincy, Wash.	7.2	Silty sand	Corn, wheat
Moderate application > 3 in./wk < 7 in./wk			
Hanford, Calif.	4.2[a]	Sandy loam	Corn,oats,cotton
Tallahassee, Fla.	4.0[b]	Sand	Corn,millet, sorghum, grass
Lake Havasu, Ariz.	3.8[b]	Sand,gravel	Grass
San Bernardino, Calif.	3.7[b]	Sand	Grass
Hillsboro, Ore.	3.2[b]	Sandy loam	Grass,forest
Light application < 3 in./wk			
Abilene, Texas	3.0[a]	Clay loam	Cotton,maize, coastal bermuda grass
Alamogordo, New Mexico	2.5[a]	Loam,silt, clay	Corn, oats, sorghum, alfalfa
Pleasanton, Calif.	2.2[b]	Loam	Grass
Ely, Nevada	1.7[a]	Sandy loam	Alfalfa
Rawlings, Wyoming	1.5[a]	Gravel	Alfalfa
Bakersfield, Calif.	1.2[a]	Clay loam	Cotton, corn, barley, alfalfa

a. Surface irrigation

b. Spray irrigation

applied per week and include a single complete cycle of wetting and drying.

Table 2 has been divided into three hydraulic application rate classifications: heavy, moderate, and light. The listings in the heavy classification range from about 12 in./wk down to 8.4 in./wk; those in the moderate classification range from 4.2 to 3.2 in./wk; and those in the light classification range from 3 in./wk down to 1.2 in./wk. As one might suspect, the heavy applications were without exception found in soil types consisting essentially of sand and application rates were lower as the soil types became finer in texture. Further, the heavy applications in the sandy soils were done in some cases without cover crops whereas all of the heavier soils required cover crops in order to enhance the application rates and, in most cases, offset a part of the operating costs of the irrigation system.

Hydraulic loading is usually critical. However, where water is applied at such rates that it will percolate through the soil matrix into the groundwater, nitrogen loading may become the most critical loading parameter. Considering an effluent with 20 mg/L of total nitrogen applied at a rate of 3 in./wk, the nitrogen loading would be approximately 680 lb/acre/yr. Even if 30 percent of this nitrogen were nitrified and then denitrified and lost to the atmosphere, there would still be approximately 480 lb/acre/yr remaining to be taken up by the crop.

Some nutrient uptake rates by several selected crops are listed in Table 3. Coastal bermuda grass appears to be a large user of nitrogen and would take up sufficient nitrogen to satisfy the example just illustrated. In some parts of the country it is possible to double and even triple crop, but nonetheless there is a limit to the amount of nutrient uptake by crops. During our survey we have noted loadings from 15 to 1,500 lb/acre/yr of nitrogen with a median value of approximately 120 lb/acre/yr.

Management. Management of a crop irrigation system must be such that removal efficiencies of wastewater constituents are suitable

Table 3

CROP UPTAKE OF NUTRIENTS

Crop	Uptake, lb/acre/year		Reference
	Nitrogen(N)	Phosphorus(P)	
Alfalfa	155-220	16-21	9
Coastal bermuda grass	480-600	35	10
Corn	155	25	9
Red clover	120	12	9
Reed canary grass	226	36	11
Soybeans	99-113	14-18	9
Wheat	62-76	12-14	9

for the particular conditions. Some typical removal efficiencies reported in the literature are shown in Table 4. These numbers should not be compared to each other because each one has a particular set of conditions, including various application rates, soil types, and depth of measurement. Also, some represent removal efficiencies based on secondary treatment and others on primary treated or untreated wastewater. Nevertheless, it can be seen that with application rates of 4 in./wk or less, very high removal efficiencies can be expected at soil depths of 3 to 6 ft as suggested by the Penn State and Melbourne, Australia, references. It is interesting to note that with lower hydraulic application rates, a higher removal of nitrogen can be obtained. This is because the nitrogen loading approaches the nutrient uptake levels of the crops or forage being irrigated. Even at high hydraulic loading rates, the BOD removal rates are normally above 95 percent and nitrogen removals will be 50 percent or better except in coarse grain sands.

Monitoring of a system that is being used for wastewater irrigation is a must. Although crop irrigation has been used for centuries for the treatment and disposal of wastewaters, there is still much to be learned about the effects of wastewaters on soil, vegetation and underlying groundwaters. Some of the reasons for monitoring include identifying (1) salt buildup in the upper layer of soil which may become toxic to vegetation, and (2) leaching of salts into the underlying groundwater body which may contribute to excessive TDS in drinking water supplies. Also, monitoring will provide the necessary management tools for determining rest periods for particular plots as well as the addition of fertilizers or soil amendments that may be needed to perpetuate the use of the land for wastewater irrigation.

Insect problems are a definite management problem in crop irrigation systems. Several industrial installations in California were in acceptable positions with the water quality control agency but were in conflict with the Mosquito Abatement Districts. All efforts must be taken to prevent standing ponds

Table 4

REMOVAL EFFICIENCY AT IRRIGATION SITES

Location	Loading Rate, in/wk	Removal Efficiency, %					Reference
		BOD	SS	N	P	E.Coli.	
Lake Tahoe[a]	13.4	--	--	56	91	96[b]	12
Westby, Wisconsin[c]	11.2	88	--	70	93	--	13
Cincinnati[d] (sand)	11.2	95	--	20	30	--	13
Cincinnati[d] (silt loam)	11.2	95	--	50	96	--	13
Cincinnati[d]	11.2	--	--	85	99	--	14
Penn State[c]	4.0	98	99	91	99	99	15
Melbourne[e]	1.3	98	97	90	80	98	16
Estimated[f] Removals	2.0	99	99+	80-90	99	99	17

a. Data on runoff during 1964, operation ceased in 1968.
b. Removal from chlorinated secondary effluent
c. Removals from secondary effluent at 3 ft. depth.
d. Experimental outdoor lysimeters 6 ft. deep at Taft Sanitary Engineering Center.
e. Removals from raw wastewater at 4-6 ft. depth.
f. Estimated for ideal conditions.

of water that will contribute to the propogation of mosquitoes and other insects.

Health Aspects. Public health aspects of wastewater treatment and disposal systems cannot be overlooked. This is particularly true in crop irrigation systems where edible crops are grown or where livestock are grazing on the field. Some of the survival times of various organisms on different media are listed in Table [illegible]. Th[illegible] *Ascaris* ova probably have the longest survi[illegible]l time in soil, reported up to seven years. However, the remainder of those organisms most usually associated with waterborne problems fall within 70 days and many of them less than 30 days. It is interesting to note that the *Ascaris* ova on vegetables have a survival time of 27 to 35 days whereas in the soil they may persist up to 7 years. To some degree this can also be noted on the *B. typhosa*, *Endamoeba histolytica*, and *Salmonella typhi*. It appears that the environment above ground is more harsh than in the soil. Nevertheless, care must be taken to disinfect the effluent prior to application to any form of crops or vegetables that may be for human consumption. In California the present requirement is 2.2 coliforms per hundred ml for unrestricted irrigation with wastewaters.

Costs. Capital and operating costs for crop irrigation with municipal effluents are difficult to obtain and are not necessarily comparable to each other. For instance the capital cost for crop irrigation in Bakersfield, as shown in Table 6, is [illegible]i¢ per gpd of plant capacity and in Ephrata, Washington, is 47¢ per gpd. The Bakersfield cost is the sum of costs that have occurred over the years in developing the site for ridge and furrow irrigation, whereas the Ephrata, Washington, system is small, employs spray irrigation, and is relatively new, consequently the costs are substantially greater. The same thing applies to other costs that have been assembled. It is extremely difficult to adjust these to some standard because of the continuing upgrading and modifications that have taken place over the years. Operation and maintenance costs are somewhat different and substantially easier to compare. Costs range from 3¢ to 12¢ per thousand gallons applied and average

Table 5

SURVIVAL TIMES OF ORGANISMS

Organism	Medium	Type of Application	Survival Time	Reference
Ascaris ova	Soil	Sewage	up to 7 yr	18
	Vegetables	AC[a]	27-35 days	19
B. Typhosa	Soil	AC	29-70 days	19
	Vegetables	AC	31 days	19
Cholera vibrios	Spinach, lettuce	AC	22-29 days	18
	Non-acid vegetables	AC	2 days	18
Coliform	Grass	Sewage	14 days	19
	Tomatoes	Sewage	35 days	19
Endamoeba histolytica	Vegetables	AC	3 days	19
	Soil	AC	8 days	18
Hookworm larvae	Soil	Infected feces	6 weeks	18
Leptospira	Soil	AC	15-43 days	18
Polio virus	Polluted water	--	20 days	19
Salmonella typhi	Radishes	Infected feces	53 days	18
	Soil	Infected feces	74 days	18
Shigella	Tomatoes	AC	2-7 days	18
Tubercle bacilli	Soil	AC	6 mos.	18
Typhoid bacilli	Soil	AC	7-40 days	19

a. AC = Artificial Contamination.

Table 6
CAPITAL AND OPERATION COSTS
MUNICIPAL IRRIGATION SITES

Year Started	City	1972 Flow, mgd	Capital Cost[a] ¢/gpd	O&M Cost[b] $/mg	O&M Cost[b] ¢/1000 gal
1957	Oceanside, California	1.5	92	116	11.6
1966	St. Charles, Maryland	0.5	19	87	8.7
1957	Pleasanton, California	1.3	27	74	7.4
1935	Golden Gate Park, San Francisco, California	1.0	--	70	7.0
1953	Colorado Springs, Colorado	5.5	24	69	6.9
1972	Ephrata, Washington	0.44	47	68	6.8
1959	Santee California	1.0	4	66	6.6
1912	Bakersfield, California	12.3	21	48	4.8
1908	Ely, Nevada	1.5	11	40	4.0
1933	San Angelo, Texas	5.0	4	30	3.0
1965	Calabasas, California	3.0	23	27	2.7

a. Capital improvements made from initial year to 1972.
b. Based on 1972 budget.

somewhere between 6 and 7¢ per thousand gallons. The figures were based on the 1972 budgets from each of the facilities listed. All installations listed in Table 6 use spray irrigation, except Bakersfield as noted above, Ely, Nevada, and San Angelo, Texas which use flood irrigation.

Overland Flow

Although overland flow has been used in several industrial applications throughout the country, there are no known applications of this approach with municipal effluents within the U.S. Melbourne, Australia has used this mode successfully and it is presently under study at EPA's research center at Ada, Oklahoma. Several articles have been written on the overland flow system for cannery wastewater at Paris, Texas. The climatology, microbiology, hydrology, and agricultural aspects of that installation have been studied (11,20). At Melbourne, Australia a loading rate of 5.2 in./wk is used during the 6 month operating period. Italian rye grass is used and reported removals are BOD 96 percent, suspended solids 95 percent, detergents 50 percent, total nitrogen 60 percent, total phosphorus 35 percent, and E. Coli 99.5 percent (16). This mode appears to have considerable potential for municipal wastewater treatment, but needs development.

Infiltration - Percolation

This mode of application has been successful as a means of groundwater recharge, examples of which are Phoenix, Arizona and Hemet and Whittier Narrows, California. Difficulties with these installations have involved the high nitrate concentrations in groundwater which have either required dilution with higher quality water or will eventually call for improvements in pretreatment or modifications in the hydraulic loading cycle.

This method has also been used for disposal without consideration of groundwater recharge. Three installations utilizing high application rates are located at Lake George, New York; Detroit Lakes, Minnesota; and Vineland, New Jersey. Lake George, New York, applies approximately 7 to 15 in./wk to percolation beds constructed over a sandy stratum of soil. Ice and snow have not produced any difficulties because the ice simply floats on the water as it is applied to the spreading basin. Detroit Lakes, Minnesota, applied approximately 42 in./wk and Vineland, New Jersey, applies about 12 in./wk. Lower rate applications of wastewater for disposal using the infiltration-percolation mode can be found at Orland and Kingsburg, California, using rates of 2.2 in./wk and 1.5 in./wk, respectively.

Modifications of the infiltration-percolation procedure are being considered at Flushing Meadows near Phoenix, Arizona, in which effluent would be introduced into the ground by infiltration-percolation and then withdrawn by pumping (21). The soil in this case would be used as a filter and the withdrawn waters would be used for agricultural purposes. The remaining nitrogen would be no problem because of this ultimate use.

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A SURVEY OF
LAND APPLICATION OF WASTEWATER FACILITIES

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The American Public Works Association in 1972 conducted a field survey of 100 facilities where land application of domestic or industrial wastewater effluents were applied to the land, as contrasted to the conventional method of discharging such effluents to receiving waters. In addition, an extensive bibliography was compiled (to be published separately); data were gathered from many other existing land application facilities across the country; determinations were made as to state regulations governing the use of land application facilities; and a survey was made of experience gained in many foreign countries.

The facilities surveyed were relatively large, with long-established operations in order that as much viable operating experiences as possible could be obtained. The surveyed land application facilities utilizing domestic wastewaters were predominantly located in the western and southwestern portions of the nation, while industrial facilities were generally sited in the northeastern section, because this is where the majority of such installations are in service.

Agricultural wastes facilities and evaporation-percolation or spray runoff type facilities were not included in the investigation project.

A full report is being prepared as fulfillment of Contract 68-01-0732 from the U. S. Environmental Protection Agency and will be available in the Summer of 1973.

Presented at a Symposium on Land Disposal of Wastes, Rutgers University, March 13, 1972.

The practicability of the application of sewage and wastes effluents onto land areas rather than directly into water sources is dependent, as are other means of treatment, upon complex and interacting circumstances and conditions.

This "alternative" method of disposing of wastewaters which could affect the quality and usefulness of surface waters, or require advance degrees of treatment to prevent such adverse effects on the water environment, has been under intensive and extensive study and evaluation, particularly in recent years.

The basis for acceptance of land disposal, or "sewage farming," as described at the turn of the century, by M. N. Baker in his historic pamphlet, "Sewerage and Sewage Disposal," a page of which is shown in Figure 1 is no longer adequate to meet new approaches to, and concepts of, land application systems. The propriety of this process has been investigated to demonstrate its applicability to the clean-waters criteria of the 1970's and the economic, ecologic and effectiveness factors involved.

The study by the American Public Works Association is one of the several investments of scientific time and funds to put the land application process into proper perspective with so-called conventional methods of discharging effluents of varying degrees of purity into watercourses.

It is apparent that any decisions to utilize effluent land application methods, in lieu of treatment and discharge of high trade effluents into surface waters, must be based on facts which will establish the process as the best alternative "practicable waste treatment technology" and one which will provide effective disposal "over the life of the works," in consonance with the intent of the Federal Water Pollution Control Act Amendments of 1972. Decisions thus arrived at must involve consideration of the factors covered by the current study.

Figure 1

SEWERAGE AND SEWAGE PURIFICATION

by
M. N. Baker, PH. B. C.E.
Associate Editor, "Engineering News"

Broad Irrigation or Sewage Farming

Where sewage is applied to the surface of the ground upon which crops are raised the process is called broad irrigation, or sewage farming. The practice is in most respects similar to the ordinary irrigation of crops with clean water, the sewage being applied by a variety of methods, according to topographical and other natural conditions and the kind of crops under cultivation.

The land employed for this method of purification should preferably be composed of a fairly light, porous soil. The crops should be such as require, or at least develop best under a large amount of moisture. Where the soil is heavy and wet, and the crops cannot stand much water, the sewage must be applied sparingly, and so a large amount of land and much labor must be provided. As broad irrigation areas may be prepared at comparatively small expense it is sometimes feasible to make use of land not so well suited to the purpose as might be desired, provided it can be obtained cheaply enough and too much stress is not laid upon the raising of crops. The less the attention paid to cropping, generally speaking, the greater the amount of sewage which can be put on a given area of land. Wet, clayey soils can take but little sewage under any circumstances, but sometimes improve with cultivation and the application of sewage.

The application of an average of from 5,000 to 10,000 gallons of sewage per day to one acre of land is considered by many as a liberal allowance. On the basis of 100 gallons of sewage per head of population this means that one acre of land is sufficient for a population of from 50 to 100 persons. More could be purified if the crops would stand it, but for each kind there is a limit which if passed means the destruction of the crop.

Allowing even 10,000 gallons of sewage, or 100 persons, to an acre in a city of 20,000 inhabitants would require 200 acres. To find suitable land at a low price near cities is not always easy. The larger the city the greater the difficulty. Labor, too, is a big item in sewage farming on this side the Atlantic, especially near cities. As a partial offset to th.s, great cities afford excellent and never-failing markets. Another great obstacle to adequate financial returns from sewage farming in America is the deplorable fact that political ends and not business principles govern in large numbers of our cities, though there is good reason to predict a great change in this respect ere long. Where such conditions do prevail, however, the positions of both superintendents and laborers on sewage farms are almost sure to be considered rewards for and encouragements to party service, with results most unfavorable to the enterprise in hand. Sewage farming means the selling as well as the raising of crops, and perhaps of live stock, and so requires business ability and agricultural skill. The latter must be accompanied with the faculty of handling considerable bodies of men.

These apparently discouraging statements are meant rather as warnings. They are necessary because of the glowing representations which have been made regarding the profits of sewage farming by those who have not looked at all sides of the question. I am not unmindful of the results of sewage farming abroad, but European conditions are far different from ours. Many of the European farms are most admirably managed, both from an agricultural and business standpoint, and not a few of them have to contend with soil far less favorable than could be found in many sections of the United States. I do not say that an American city could not conduct so great an enterprise in a creditable manner, for we have found many well-conceived and well-operated municipal works of great magnitude. I do say that high prices for land near large cities, costly labor, a constant warfare against corruption with too frequent surrenders, and our sudden and complete changes in government all make sewage farming more difficult here than abroad.

For the present, sewage disposal cannot be accomplished in this country at a profit. It is sometimes possible to regain, through the raising of crops, a part of the expense entailed in removing and purifying sewage, and this is the only method by which any considerable portion of the expense has yet been recovered here or elsewhere. We should be thankful for the day of small things, and wherever a revenue can be obtained from irrigation area or filtration beds our efforts should be to secure it. But the logic of figures will often show that some method of disposal that carries with it no financial returns is the cheapest, in which case instead of crying over spilt and wasted sewage, we may laugh over a saving in capital, interest and maintenance.

Wherever irrigation, pure and simple, that is the application of water to crops for the sake of moisture, can be practiced to advantage, sewage farming should receive serious consideration, for in such localities every drop of water is valuable. As ordinary irrigation may yet be used in the East as well as in the West, (it is already practiced to some extent in the South) the use of sewage for mere watering as well as fertilizing may some day be seen here and there throughout the length and breadth of the land. This is a subject which demands careful investigation and perhaps might be taken up with advantage by some of our agricultural experiment stations and by any live official in a position to do so.*

*For an article on "The Use of Sewage for Irrigation in the West" see *Engineering News* for Nov. 3, 1892: the substance of the article is also given in Rafter and Baker's "Sewage Disposal in the United States." A later treatment of the subject may be found in "Sewage Irrigation," Nos. 3 and 22 of Water Supply and Irrigation Papers of the U.S. Geological Survey, by Geo. W. Rafter, M. Am. Soc. C.E. In March, 1905, the author of this book visited the sewage farm of Pasadena, Cal., and also land to which some of the sewage of Los Angeles is applied. As a result, he is more than ever convinced of the wisdom of using sewage for irrigation wherever water is scarce.

There is nothing new about the basic concept of spreading sewage or other liquid wastes, in treated or untreated form, on the land as a means of disposal. What is new is the objective of making this method of disposal a scientifically evaluated, technically designed, and properly operated and maintained treatment procedure which can meet the criterion of a "best practicable technology." Also of relatively new significance is the more specific definition of land application as referring to the application of effluents onto land areas after degrees of treatment approaching those normally required for effluents discharged to receiving waters. The application of sludges of wastewater residues to land areas is a supplemental ramification of effluent land application.

Land application of sewage predates any known artificial means of treating liquid wastes prior to discharge into receiving waters. Even though early practice involved the disposal of untreated wastes onto farm properties, it had the merit of providing the "purification" which absorption, adsorption and mechanical retention on soil particles and in their interstices could accomplish. It was better than discharge by dilution into watercourses.

Actual application of sewage to the land can be dated back to periods prior to the development of sewer systems. Municipal wastes were discharged onto nearby farms at Berlin, Germany, as far back as the 16th century. In Scotland, fields in the vicinity of Edinburgh were used as the recipients of sewage in the 1840's; Berlin purchased tracts of land for sewage irrigation purposes in 1869 and various English communities utilized farm lands for sewage farming during the last three decades of the nineteenth century.

With the turn of the century, United States cities in Wyoming, Utah, Montana and California applied sewage to farm lands for crop improvement or groundwater supplementation. In Texas, San Antonio initiated irrigation with sewage or sewage effluent on over 3,000 acres of land in 1900. The use of some form of treated effluents for land disposal purposes, rather than raw sewage application, dates from the 1930's. A land irrigation system using untreated sanitary wastes of the City of Mexico City D.F. was begun in 1902 and expanded to the use of secondary effluent for watering farm lands, sport areas and creating artificial lakes in recent years. Among the other cities surveyed for this report, 10 were established before 1920 and 10 more by 1940, with 26 municipal systems begun since 1960.

If land application of effluents is a valid alternative method of wastes treatment, it is obvious that it is an alternative to other means of disposal. Land application decision must not be selected without full evaluation of its merits, economically, ecologically and effectively, as compared to other means of disposal. Such an evaluation is presupposed by the requirements of the 1972 Amendments to the Federal Water Pollution Control Act. It involves a weighing of the advantages and limitations of each method of disposal in relation to the other alternatives, and the examination of the comparative merits of each.

I hope to focus attention on some of the general factors involving land application which must be balanced in determining the applicability of land application management procedures.

If land application is an alternative procedure, the reasons for utilizing this technique offer various alternatives: (1) as a means of disposal without the necessity of constructing outfall lines to distant water courses--the get-rid-of procedure; (2) as a means of improving the effluent by natural soil treatment and thereby avoiding the necessity of advanced treatment by conventional "artificial" processes; (3) as a means of augmenting the groundwater table; or (4) as a means of irrigating crops and improving yields in agriculture or silviculture. The land application installations investigated during the course of the current study cover examples of all these reasons for this method of effluent management, as well as other more or less valid purposes.

The ability of soil to remove organic pollutants by mechanical, physical and biological forces has been utilized in conventional sewage treatment methods, in the form of sand filters. Obviously, there is a direct relation between the artificial use of soil-wastewater contacts for treatment purposes and the application of effluents to natural land areas to "get rid of" wastewaters and to utilize the purifying capabilities of the soil to provide a form of physical-chemical-bacteriological improvement of quality.

Those early land disposal installations which applied untreated or only partially treated wastes to land areas were depending on the purifying capabilities of the land to provide "free" treatment. Today's concept of land application--and the basic definition of land application as investigated under the terms of the current contractual studies--involves the application of treated effluents, of proper quality to assure the protection of the surface environment, groundwater, the use of crops grown on irrigated land, and the health and safety of on-site and off-site persons.

The movement of water on and through soil formations is a complex physical reaction which involves chemical-physical-biological reactions. Under proper soil conditions and control measures, improvement in water quality can occur during this movement. It can produce an effluent end product that is of markedly higher quality than the applied wastewater which has received the equivalent of secondary treatment by pre-irrigation means. This improvement is one factor that must be weighed in evaluating the applicability and workability of land application versus advanced degrees of treatment by other means.

The ability of soils to remove a major percentage of the nutrients in sewage effluents has led to the advocacy of land application as an anti-eutrophication procedure. If the transfer of effluent discharge from waters subject to nutrification and algal stimulation resulted in the mere shift from nitrates and phosphates in surface waters to their presence in groundwaters, less value could be attributed to land application methods. However, the mechanics of soil uptake and the utilization of such nutrients by plant life offers advocates of land application the valid argument that an ecological liability can be converted into an agriculutural asset.

Similarly, the uptake of other potentially deleterious substances in effluents by soil mechanics represents another factor which must be weighed in placing land application in proper perspective with other methods of effluent management. These could include metals and chemical components which can be absorbed or adsorbed in or on soil particles or ingested by plant life. However, the effect of such chemicals on the soil composition and friability and filterability, or on the safety of crops grown on such soils, must be considered.

References to the mechanics of soil management of effluent liquids and their quality improvement must be augmented by a brief comment on what has been defined as a "4-R cycle"--Return; Renovation; Recharge; Reuse. Liquid wastes are returned to the land by alternative means, including rapid filtration, spray irrigation, and other means of surface spreading. Irrigation can be accomplished by spray application, ridge and furrow flows and flood spreading.

Surface soil layers renovate the effluent by removal or conversion of pollution materials. The improved liquid is then used to recharge the groundwater. The renovated liquid is reused.

The land application process offers the possibility of meeting the conservationist goal of "returning to the soil that which came from it." The nitrogen cycle and the carbon cycle involve land in the completion of their reduction-oxidation-reconstitution sequences. If the organics in wastewaters and the chemicals of vegetative value, together with other exotic substances such as hormones, could be utilized to grow food from which the organics and other elements originally stemmed, the recycle of these materials by means of land application would be achieved. For example, the reuse in the "4-R" concept described above, involves the reuse of not only the water component of waste effluents but the nutritive composition of the liquids and trace elements therein.

The land application technique, as an alternative effluent management procedure, must be placed into proper focus with other frameworks than specific engineering, technology and economics. The effect of setting aside large acreages for effluent application or the dislocation of farm dwellers must be considered as a sociologic-demographic problem of significance. The impact of land application on land use planning, zoning and long-range metropolitan-regional development must be considered. The effects of aesthetics are part of any thorough ecological evaluation of this alternative method of effluent disposal. Health and safety impacts must be considered.

Comparative costs of the various means of handling effluents, after suitable stages of treatment of municipal and industrial wastewaters, are difficult to compute and evaluate. They depend on such variable factors that no rule-of-thumb can claim to represent fiscal factors involved in any one specific project. These comparative costs must be placed into perspective with the goal of all-out elimination of pollutional discharges into the nation's water sources, whether it be by degrees of advanced treatment which will provide "zero pollution" in direct effluent discharges, or the elimination of direct discharges by means of such alternative practices as land application.

No single answer could possibly become the panacea for all pollution control challenges in all areas. What may be the best and most economical solution for one region, one specific location, one actual wastewater flow, cannot be assumed to be the answer for another, even if superficial similarity can be found.

The following highlights from the field surveys is presented in order that a composite picture of observed facilities might be obtained:

1. Communities generally use their land application system on a continuous basis. Food processing plants, the predominant industrial users of the system, generally practice discharge to land systems for three to eight months per year.
2. Ground cover utilized for municipal systems is divided between grass and crops. Industries generally use grass cover.
3. Land application systems are generally used on a daily basis, seven days per week.
4. Application rates for crop irrigation are very low in terms of inches of water per week. Two inches or less was commonly used (Two inches per week equals 48,000 gallons per acre per week.)
5. Many types of soils were used, although sand, loam and silt were the most common classifications given. Two systems using application over many feet of sand were applied up to 8 inches per week, and one system on clay was applying only 0.1 inch per day.
6. Most operating agencies, municipal and industrial, are planning to either expand or continue their land application installations. The few examples of systems which had been abandoned were due to either the desire to make a higher use of the land, or because of reported overloading and poor operation of the land application facilities.
7. Industries surveyed generally treat their total waste flow by land application. Practices of municipalities varied from less than 25 percent to all wastewaters produced.
8. Secondary treatment is generally provided by municipalities prior to land application, often times

accompanied by lagooning. Industrial systems often treated their process wastes by screening only.

9. Spray irrigation is the most frequently used (57 facilities) method of application, although most municipalities use more than one method. Ridge and furrow irrigation is used at 23 facilities and flooding irrigation is used by 34 systems. Industry generally used spray irrigation.
10. Land use zoning for land application sites is predominantly classified as farming, with some residential zoning in contiguous areas.
11. Wastewater generally is transported to the application site by pressure lines, although a number of municipalities are able to utilize ditches or gravity flow pipe lines.
12. Many community land application facilities have been in use for several years---more than half for over 15 years. Industrial systems are relatively more recent.
13. Renovated wastewater is seldom collected by underdrains; rather, evaporation, plant transpiration, and groundwater recharge take up the flow.
14. Land application facilities generally do not make appreciable efforts to preclude public access. Residences are frequently located adjacent to land application sites. No special effort is made to seclude land application areas from recreational facilities and from those who use these leisure sites.
15. Monitoring of groundwater quality, soil uptake of contaminants, crop uptake of wastewater components, and surface water impacts is not carried out with any consistency.

The largest system which was surveyed serves Mexico City. One of the more advanced systems which has not received as much publicity as Penn State or Tallahassee is Colorado Springs, Colorado. Engineering reports concerning both systems are included to give an indication of the extent and use made of wastewater at these two atypical facilities.

Mexico City has an elevation of approximately 7,500 feet in a valley completely surrounded by high mountains. Population of the City of Mexico is approximately eight million and an additional two million people live immediately adjacent to the Federal District boundaries.

In 1902 a canal and tunnel system was dug to convey wastes approximately 70 kilometers (44 miles) north to the Tula area.

The City of Mexico is sinking 8 to 10 centimeters per year and it is now necessary to pump into the canal system.

The City is served by a combined sewer system which has a dry-weather flow of approximately 25 cubic meters per second (570 mgd). Wet-weather flows reach 2,000 cubic meters per second (4,560 mgd). The potable water system for the area is from a well field some distance away. Approximately 35 cubic meters per second (800 mgd) are supplied to the city.

Due to the increases in storm runoff and possibility of flooding the central part of the city at any time because of pump failures or excessive storm flow, a deep tunnel system is being constructed at a cost of 4 billion pesos ($320,000,000). The annual cost of disposal will be reduced by the pumping costs now required, an amount equal to amotization of about one-half of the construction cost. The tunnel is from 150 to 750 feet deep with 37 shafts. The tunnel is to be completed in March 1974, at which time approximately 70 percent of the dry-weather flow of the canal will be diverted to the tunnel. The tunnel is being designed for a storm flow of 200 cubic meters per second.

The tunnel is 6-1/2 meters (26 ft) in diameter and has a design velocity of one meter per second for dry-weather flow and six meters per second for storm flows. The Mexico City area has 700 millimeters (27 inches) of rainfall per year.

In addition to the untreated flow, 4 cubic meters per second are treated in five secondary treatment plants within the city, which have a capacity of 7.5 cubic meters per second. This flow is used for irrigation of parks, playgrounds and other large public areas, as well as for the filling of lakes in parks and for fountains. Solids from the treatment plants are discharged to the untreated flow. The flow used within the city is chlorinated prior to application and is used in Chapultepec park, the University of Mexico and Olympic sports arena and parks.

The treatment plants are operated only during the dry season---November through May. The Federal District has determined its costs for treating the effluent for watering within the city at 25 centavos per cubic meter (8 cents per 1,000 gallons) as contrasted to the cost of treating and distributing drinking water at 50 centavos per cubic meter (16 cents per 1,000 gallons).

The balance of the sewage, approximately 30 cubic meters per second, is discharged to the irrigation canal. It is estimated that approximately 95 percent of this flow reaches the land; the balance is lost to evaporation and infiltration.

The irrigation area was formed as a cooperative; the government owns the land but has given it to farmers as long as the land is used for farming. In the Tula Hidalgo approximately 47,000 hectares (111,746 acres) are being irrigated at this time and plans exist for a phase two of 27,000 hectares irrigated, and for phase three, an additional 13,000 hectares will be irrigated. In the Tula Hidalgo 24,837 hectares are farmed by 20,295 Ejidos (heads of families). The balance of the 20,369 hectares are owned by 8,278 persons.

The area is served by the Tepeji River and flow not used for irrigation eventually flows to Tampico. There are three storage reservoirs for irrigation waters, totaling 201 million cubic meters. During the dry season sewage and irrigation water are jointly used and during the wet weather natural river water is stored for use during the dry season. On an annual basis, approximately 700 million cubic meters (185,000 mg) of sewage are used and 200 million cubic meters (54,000 mg) irrigation water are used. In 1971, 672,654,000 cubic meters were used on the 47,000 hectares.

Upon the 47,000 hectares, 1,476,749 tons of food products were raised, with a value of 333,783,710 pesos ($26,701,000). Crops are grown by farmers in response to market demand. They have not found sewage to be toxic to any natural crops. Only one crop per year is produced, with the exception of alfalfa where ten cuttings are made. Crops include alfalfa, corn, wheat, tomatoes, chiles, flowers and other truck garden crops. Table 1, Summary of Agriculture Production 1971-1972, presents the tons of crops raised in the Tula Hidalgo.

The Tula Hidalgo is operated by the Federal Department of Agriculture and the costs of the operations are paid by the Ejidos on the following basis: 30 pesos ($2.40) per hectare for 40 percent of the land farthest from the head of the district and 20 pesos ($1.60) per hectare for the remaining 60 percent by individual holdings per time of irrigation. Each irrigation is 20 centimeters (7.8 inches) of water on the land.

The farmers have found that the alfalfa commands a premium and also is heavier than normal due to the use of sewage.

Drinking water for the 100,000 residents of the area is from springs above the Hidalgo. Land adjacent to the project is worth 500 pesos per hectare ($17/acre). The irrigated land is worth 30,000 to 50,000 pesos ($100 - $160 per acre) per hectare. The irrigation area receives 400 cm (16 inches) per year of rainfall. The Hidalgo has excellent records indicating the amount of return flow to the river because of gauges on the river above and below the district.

Observations were not available as to the changes in the quality of the flow at the point of distribution, as compared to inland. It is apparent that the canal acts as one long oxidation ditch and that slime growths and such along the canal must be oxidizing part of the material. ABS is a problem, inasmuch as Mexico has not switched to soft detergents. Foaming was noticed at the canal and gate structures. Odors along the canal are not noticeable. The area which is farmed has few homes adjacent to the farm land. Most people live in the villages where conveniences are available. All work is done by hand. No farm equipment was seen.

TABLE 1

SUMMARY OF AGRICULTURE PRODUCTION - PRODUCTION YEAR 1971-1972
03 IRRIGATION DISTRICT - TULA HIDALGO

CROP	CROP	HECTARES	METRIC TONS
ALFALFA VERDE	ALFALFA	12396.40	1181,376.920
AJO	GARLIC	94.50	258.456
ARVEJON	PEAS (LARGE)	12.89	20.820
AVENA VERDE	GREEN OATS	2998.75	54,426.711
CALABACITA	SQUASH (SMALL)	674.33	7,282.764
CEBADA GRANO	BARLEY GRAIN	1865.43	3,645.410
CEBADA PAGO	BARLEY (FORAGE)		4,059.874
CEBOLLA	ONION	23.79	168.903
CILANTRO(SEMILLA)	PARSLEY SEED	3.53	4.589
COL	CABBAGE	27.95	501.843
CHICHARO	PEAS	1.00	7.900
CHILES VERDE	GREEN HOT PEPPERS	768.80	8,231.350
FLORES	FLOWERS	10.41	
FRIJOL GRANO	NAVY BEANS	1259.02	1,563.870
FRIJOL EJOTE	AM.STRING BEANS	58.30	151.580
ESPINACA	SPINACH	0.82	9.020
FRUTALES	FRUIT TREES	25.08	213.180
GIRASOL	SUNFLOWER	37.49	230.578
HABA	LIMA BEANS	95.84	1,990.070
JITOMATE	AM. TOMATO	1554.65	49,437.870
LECHUGA	LETTUCE	74.47	1,457.764
MAIZ GRANO	CORN(KERNELS)	17053.60	70,260.525
MAIZ RASTROJO	CORN(FORAGE)		65,179.023
MAIZ VERDE	CORN(SWEET)	101.20	7,084.000
NABO FORRAJE	FORAGE TURNIPS	112.37	1,011.330
MELON	MELON	1.00	7.100
PEPINO	CUCUMBER	34.74	166.752
PRADERA	MEADOW GRASS	12.80	2,080.000
TOMATE	TOMATOE	216.90	2,051.706
TRIGO GRANO	WHEAT GRAIN	7,293.79	13,865.494
SANDIA	WATERMELON	0.40	3.960
		46,809.95	1,476,749.371
		ACRES	U.S. TONS
		115,620.65	1,624,424.30

NOTE: 1 metric ton = 1.1 (U.S.) tons
1 (U.S.) ton = 0.907 metric tons
1 hectare = 2.47

NOTE: The crop hectares listed are more than the hectares of land available since a second crop in some instances has been produced on the same land.

Source: City of Mexico, D. F.

The City of Colorado Springs, after severe droughts in 1953, initiated a limited program to water municipally owned grassed areas with wastewater treatment plant effluent. Severe watering restrictions placed on all residents had previously resulted in the loss of large grassed areas.

The present system is divided into two lines. The western line is composed of a pressure line to an abandoned water reservoir from which the effluent is again pumped to the facilities to be irrigated. These include a median strip where an old gravity irrigation system was previously used for flood irrigation of the wide median strip, Colorado College, and a new, exclusive country club area, "Kissing Camels." The latter area has its groundkeeper personnel water the golf course and the lawns of numerous high-class residences on the grounds.

On the pressure lines, a series of fire hydrants have been located, painted a distinctive blue and white color. These fire hydrants may be used by contractors who can utilize the low-quality water for purposes such as construction and tree watering. An annual fee is paid. In addition, the Fire Department may use the lines in an emergency.

The eastern line is pumped to an abandoned water reservoir from which, by gravity, several facilities, including a cemetery, park, a private development (Printers Union Home and Office), and a golf course are watered.

The system has been designed to provide water for irrigation along the Interstate Highway System. Although the State Highway Department participated in the cost of one of the pressure lines, it has not used the system.

Private customers are charged a rate of 10 cents per thousand gallons plus pumping, which averages approximately 14 cents per 1,000 gallons. The 1969 sales were $24,090; 1970 sales $36,815; 1971 sales $36,598. In 1971, tertiary treatment was added. Flows for irrigation are subjected to either physical-chemical treatment or sand filtration. The cost for new sales of water will be 30 cents per thousand gallons plus pumping.

The operating cost by the City for the irrigation operation was: 1969-$42,965; 1970-$34,197; and 1971 with tertiary treatment flow - $137,689.

The reservoir on the west section is open to the public and public fishing is allowed. On public properties, in accordance with Colorado State regulations, some signs exist pointing out that a nonpotable water source is used for watering. On public property, either underground sprinkler systems or portable aluminum pipe systems are used.

Some odor complaints have been received by the City when the reservoirs have been allowed to hold water for several days because of rain. The entire system is operated on the basis of demand for watering and the water is taken only as desired by the users.

During 1971, 336 million gallons were treated by the tertiary plant. Two hundred thirty were used for irrigation and 133 for industrial use.

The area of facilities watered on the east line includes the Waste Water Reclamation Plant, 27 acres; Evergreen Cemetery, 206 acres; Memorial Park, 115 acres; ITU, 50.5 acres; Lunar Park, 3.4 acres; Otis Park, 2.4 acres; and Patty Jewitt Golf Course, 235 acres. On the west line: Colorado College, 55 acres; parkways, 2.3 acres; Acacia Park, 3.7 acres; and Kissing Camel Golf Course, 82 acres.

The cost of the improvements to the western line was $62,000; to the eastern line $196,890; and for the tertiary treatment, $1,054,000.

In summary, the land application of treated wastewater presents an important treatment alternative which must be considered in evaluating construction of new or upgraded facilities.

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APPENDIX

FACT SHEET - IRRIGATION OF LIQUID DIGESTED SLUDGE - MOVIE, WEALTH FROM WASTE - HERTFORDSHIRE, ENGLAND,
by Belford L. Seabrook, Sanitary Engineer

This is a film, made for public relations purposes, aimed at the public in England within the distribution area of the sludge that is produced by one English sewage authority. The hydraulic volume references in the film are in British Imperial gallons. All volume references in this fact sheet are in U.S. gallons.

The West Hertfordshire Main Drainage Authority, located at Rickmansworth, about 20 miles north of London, England, serves an area of 210 square miles with a population of 550,000. 141,000 cubic meters (37 mgd) of waste water each day, 80% of which is from domestic sources, is treated in a two-stage treatment facility. The Authority was organized in 1939, but the irrigation of digested sludge was not commenced until 1952. To avoid public reference to sewage, sewage connected terms, and the connotation associated with the use of such terms, the digested sludge has been given the name of HYDIG. The effluent from the secondary treatment plant, having a quality better than 10/10 (Royal Commission standards: 20 ppm SS & 30 ppm BOD), is discharged into a river. The effluent at discharge into the river contains on the average 18 ppm of oxidized nitrogen (.03 ppm ammonia) and 5 ppm of phosphorus. This satisfactorily disposes of 97% of the problem. The rest of this story concerns the remaining 3%, most of which is digested sludge.

The primary objective is to apply the digested sludge to the land, that is to dispose of it in a manner that is not objectionable to the community. A secondary objective is to reduce to a minimum the amount of waste water that must be irrigated along with the sludge. This is an economy measure intended to substantially reduce the volume of materials being handled. Since 97% of the secondary effluent has been improved in the biological treatment plant to such an extent that it is better than the receiving stream, it is discharged into a river. The remaining effluent, which contains about 3% solids in the form of digested sludge, is used for irrigating crop land. The Authority officials believe that if a feasible means, at a reasonable cost, can be found to increase the solids content up to 5% or 6%, it could be applied to the land with the same equipment.

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The primary and activated sludges are fermented in digestion tanks for 20-24 days at temperatures of 90-98°F. The production of digested sludge is a continuous method; some sludge is irrigated every day except Sundays, the amount being approximately 1/24 of the contents of the digestion tanks, or from 250,000 gallons to 500,000 gallons. The capacity of the secondary sludge storage tanks is approximately 8 1/2 million gallons, which permits winter storage up to 6 weeks.

The daily flow of 37 million gallons of waste water produces about 90 million gallons per year of liquid digested sludge. The sludge has a solids content of 3%, more or less, which is applied to the land, either by spreading from tank trucks as they roll across the fields, or by irrigation from pits or large stationary storage tanks located adjacent to the fields. Approximately 1000 acres are owned by the Authority and used as experimental farmland, and the balance of the 6000 acres is operated or owned by some 62 private farm units. The cost of transporting and applying the HYDIG is about $6 per 1000 gallons which contrasts with the cost of ocean dumping of about $9 per 1000 gallons. The disadvantages of tank truck operation are more than offset by the savings that result from having neither investment in 5000 acres of privately owned farmland nor farm operating expenses on this land.

The irrigation is done on gravel soils that are fairly firm and easily drained. The crops grown include grass, forage crops, English black beans, grains, potatoes and other root crops. There have been no build-up of toxic salts, no cattle disease, no objectionable odors, no fly problem, and no community objections. The public health officers are satisfied that the Herts irrigation procedure is not a threat to public health. There have been some individual complaints, but the majority of these have involved the use of the highways by the large tank trucks. The principal problem appears to be the potential long-term harmful effects of certain undesirable trace metals in the sludge. The toxic metals most frequently found are zinc, copper and nickel. Research work by the British Ministry of Agriculture has established that nickel is 4 times more toxic to plant life than copper which is itself, twice as toxic as zinc. This discovery made it possible to simplify the composite effect of the metals in any particular sample of sewage by expressing the effect as "ZINC EQUIVALENT."

The Authority has set for itself these tentative guidelines pending further research work. In a sample of virgin soil which is free from metal traces, if no more than 250 ppm of zinc-equivalent is allowed to build up in the top soil, then there is no risk of damage to plant life due to the metals. Unfortunately, the build-up appears to be cumulative. The Authority has tentatively selected a 30-year period for the application of sludge to a particular piece of land, and is currently limiting the annual dressing to no more than 1/30 of the 250 ppm arbitrary maximum. Research is also being done to determine whether or not over a prolonged period the minute traces of lead, cadmium, arsenic and mercury will have any deleterious effect upon plant life. Chromium as a chromium salt in sewage was found to be non-toxic, except in high concentrations. Boron unlike the other metal traces quickly leaches down into the sub-soil. The other principal and tentative injunction which the British Ministry of Agriculture rendered related to the avoidance of an acidic soil condition. It has been found that when the soil becomes more acid than pH 6.5 it seems to accelerate the toxic effects of certain trace metals on the plant life. As a general precaution livestock should not be allowed to graze fields to which sewage has recently been applied until after rain has washed the edible plant sections clean. Rain will reduce the potential hazard to livestock from ingestion of lead and mercury which may have been deposited on the plant surfaces. The Hertfordshire Authority points out however that there is no evidence to show that there has ever been a problem from ingestion of such metal traces when livestock have grazed fields that have not been washed clean by rain. In fact, palatability tests have led to observations that the cattle feed avidly upon grass which has received a fresh application of liquid digested sludge. However the Authority officials say that clearly it is common sense to let the sludge be washed off the grass before grazing.

With due care for these precautions, this technique could become a viable alternative in response to Section 304(d)(2) of the new amendment. Public Law 92-500, enacted October 18, 1972, of the Federal Water Pollution Control Act of 1956, which calls for EPA publication of information on alternative waste treatment systems and techniques. As stated in PL-92-500 sections 301(b)(1)(A) (best practible control technology by 1977) and (b)(2)(A) (best available technology by 1983), this is needed to accomplish the national goal of eliminating the discharge of all pollutants. It is definitely an improvement over the Australian and German applications of raw sewage directly to the land. It would appear to be an improvement over the Muskegon, Michigan design, when that project becomes operational in 1973 or 1974.

With the emphasis under the 1972 Amendments to the Act on finding alternative techniques to the conventional methods of treating waste water, there are no sludge irrigation operations in the United States with anywhere near the 20 years experience of the Hertfordshire system. Perhaps the nearest in terms of experience is the experiment at Penn State University. This experiment was started in 1961, using about 5-6% of the secondary effluent (500,000 gallons per day) from the local municipality's treatment plant. The primary objective of the Penn State experiment is to renovate the secondary effluent, that is, to make it suitable for reuse for other purposes (but not necessarily potable water). During the last two years at Penn State, however, liquid digested sludge equivalent in volume to that produced by the effluent being irrigated has been injected into the irrigation pipelines so that the sludge can be irrigated along with the secondary effluent. The solids content of the mixture of effluent and sludge is of course a great deal lower than the 3% figure at Herts. The Penn State managers have said that they have experienced no difficulties with this procedure, although they have not yet reported any conclusions from it.

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It seems to me, in contrast to the problems created by the dumping of sanitary wastes into rivers, lakes and oceans including the metals in such wastewater, that currently the metals problem involved in sewage irrigation on land is by far the lesser problem. The technique of treating the secondary plant effluent so that 97% of it can be discharged directly into surface waters and so that the balance can be irrigated in the form of liquid digested sludge has now been adopted by approximately 40% of all municipal treatment works in England. From the standpoint of the hydraulic volumes to be handled, this technique has substantial advantages. 97% of the daily flow is treated and renovated sufficiently to permit it to be returned to surface streams with a quality higher than the receiving waters. Only the remaining 3% in the form of liquid sludge needs to be irrigated. Since the 3% consists of effluent plus digested sludge, free of objectionable odors, and brings no associated fly problem with it, it comes closer than any other sludge irrigation technique to meeting the aesthetic requirements of the community in which it would be used. While it may not yet be feasible for a large megalopolis, certainly the Hertfordshire experience over the last two decades has demonstrated that it is acceptable and practical for certain communities of 500,000 population.

THE FOLLOWING PAGES ARE DUPLICATES OF ILLUSTRATIONS APPEARING ELSEWHERE IN THIS REPORT. THEY HAVE BEEN REPRODUCED HERE BY A DIFFERENT METHOD TO PROVIDE BETTER DETAIL

Figure 1. Irrigation System used in Fulton County to Apply Liq Fertilizer to Strip-mined Land.

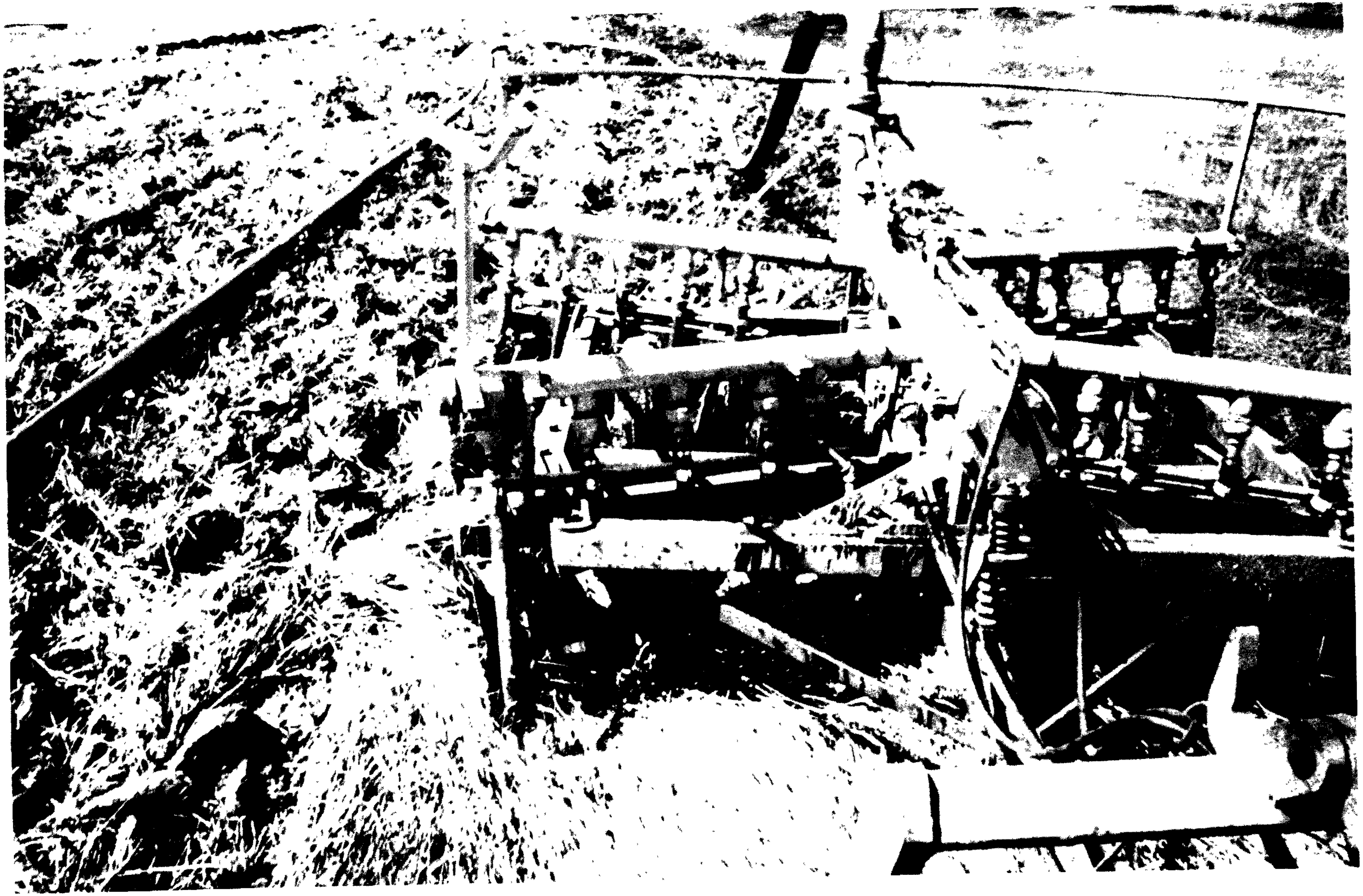

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Figure 2. The Incorporation System Applying Liquid Fertilizer to Strip-Mined Land in Fulton County

Figure 1.

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