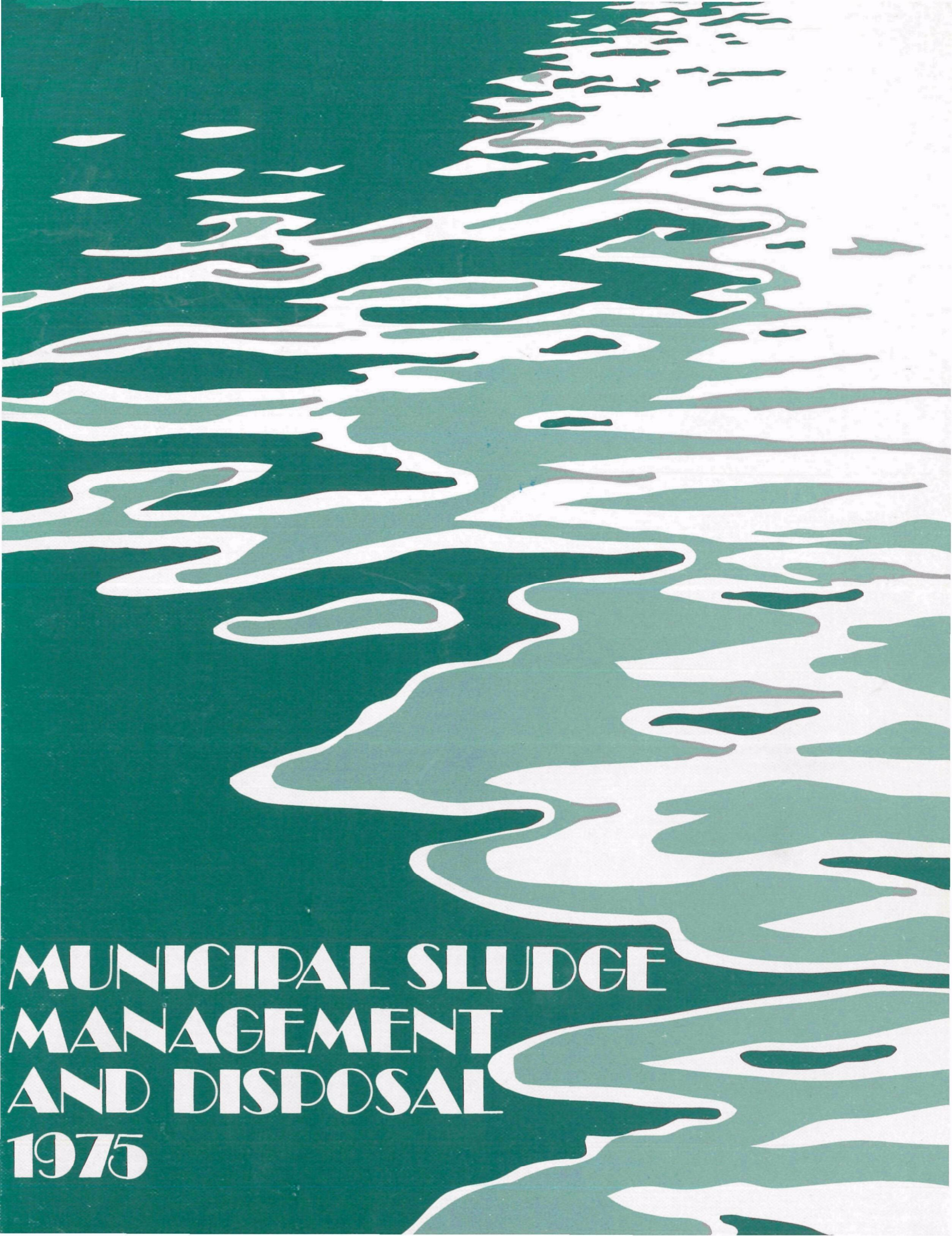
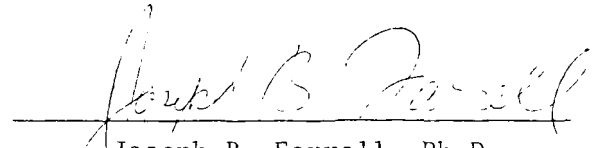

MUNICIPAL SLUDGE
MANAGEMENT
AND DISPOSAL
1975

MUNICIPAL SLUDGE MANAGEMENT--1975

The EPA Research and Development Representative in your Federal Region has requested that this copy of the "Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal" be sent to you. The Conference, which was held at Anaheim, California, was cosponsored by the Office of Research and Development of the U.S. EPA and Information Transfer, Inc., Rockville, Maryland.

Enclosed for your information is a copy of the Organization Chart for the Office of the EPA's Assistant Administrator for Research and Development. The research and development program on treatment, processing, and disposal of municipal wastewater sludge is conducted by the Ultimate Disposal Section (Wastewater Research Division) in Cincinnati's Municipal Environmental Research Laboratory. Headquarters' coordination is carried out by the Waste Management Division in Washington, D.C.

Mr. Don Ehreth (phone: 202/426-0265) and I (phone 513/684-7645) will be pleased to respond to your questions about the program.



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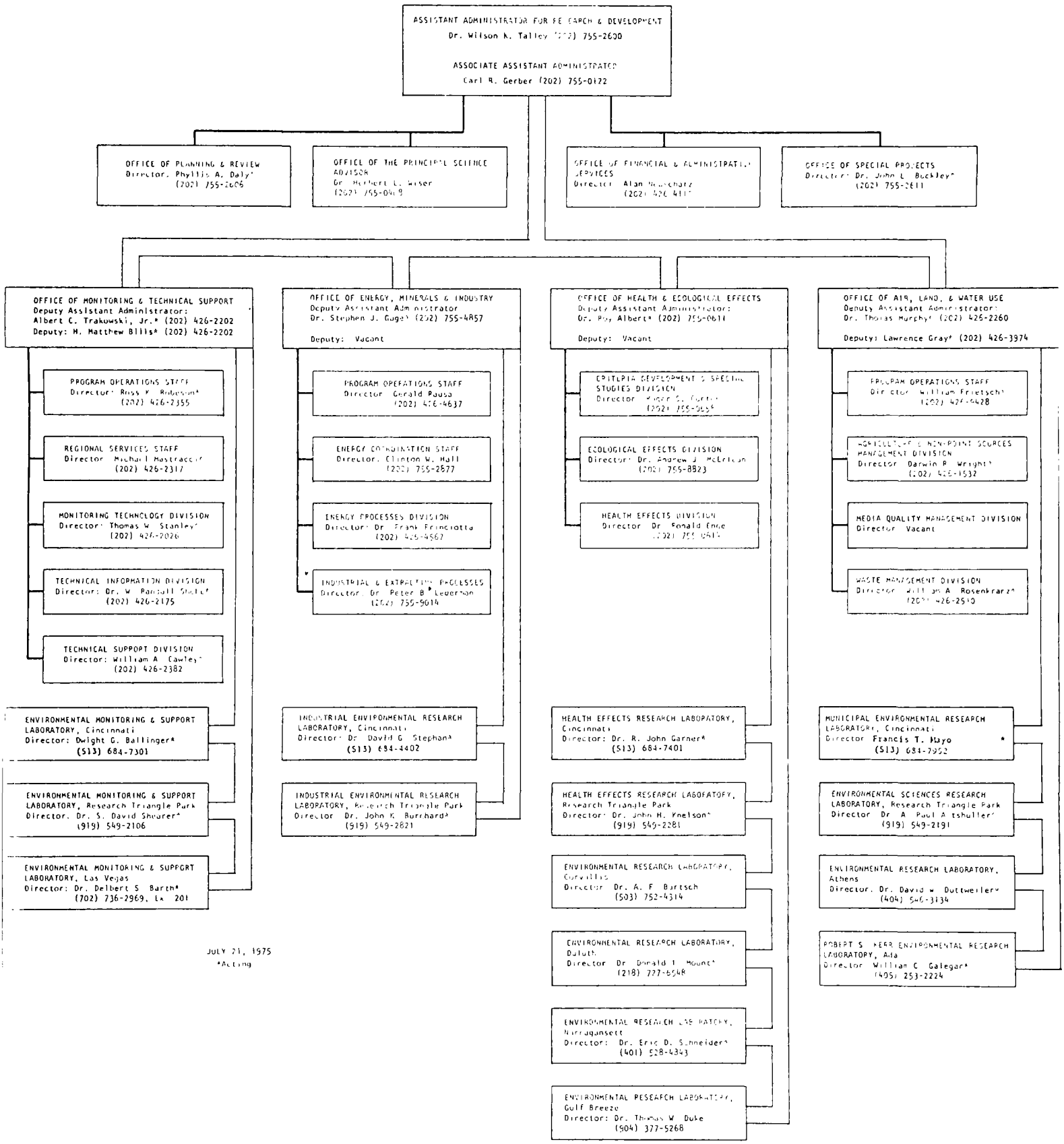

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PROCEEDINGS OF THE 1975 NATIONAL CONFERENCE ON

MUNICIPAL SLUDGE MANAGEMENT AND DISPOSAL

AUGUST 18-20, 1975
Anaheim, California

Sponsored by:
The Office of Research and Development
United States Environmental Protection Agency
Environmental Quality Systems, Inc.
Information Transfer, Inc.

Printed in the United States of America
Library of Congress Catalog No. 75-39534

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Information Transfer, Inc.
1160 Rockville Pike
Rockville, Maryland 20852

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MUNICIPAL SLUDGE MANAGEMENT AND DISPOSAL

"EVERYTHING IS CONNECTED TO EVERYTHING ELSE"

The Honorable George E. Brown, Jr.
United States Congress
(36th. C.D. — California)
Washington, D.C.

I am glad to be here today with such a distinguished group of specialists in the esoteric field of sludge management and disposal. My presence is apparently a concession to the fact that with such a diversity of expertise as is represented here, it might have been difficult to find a speaker with a sufficiently broad background to encompass all of these specialties. Under these circumstances it is appropriate to call on a politician, who is sometimes defined as one who knows less and less about more and more, until finally he knows nothing about everything.

I welcome this opportunity, because I have a genuine interest, both personal and legislative, in your problems.

I also have some very serious reservations about the kinds of technological developments which characterize our society, developments which have, in the course of solving certain kinds of problems, brought on other problems of an even more serious nature. Your meeting here reflects that situation; for you are called upon to find new solutions to those second-order problems created by the nature of our technological growth.

I am especially pleased to see that your program and your participants reflect a multi-disciplinary and multi-institutional approach to the problems you are addressing. It is my sincere hope that gatherings of specialists, such as this one, will move us towards solutions to real problems. That is, after all, the major reason for having it. But I continue to be skeptical. Let me explain why.

The current dilemma with sludge disposal has come about as we developed from a rural, thinly settled, fairly unspecialized society toward an urban, densely settled and highly specialized society. We simultaneously grew away from our frugal and thrifty beginnings to become the most affluent and thriftless society in the world. The growth of industry and continental markets, and the existence of hugh inventories of cheap energy and other resources, lead to a new emphasis on material consumption and a new disregard for conserving and recycling materials, and minimizing waste. Inevitably this has led to the necessity of meetings such as this, to seek solutions to the problem of disposing of a resource that has been labeled waste. Not only has our system mis-labeled this resource, for much of it is not only useable, but increasingly valuable, but the system has diluted and dispersed it so as to make its recovery and use many times more difficult.

We have developed an enormous, highly specialized, single purpose waste disposal system which has, at least until quite recently, been regarded as largely unconnected with other systems in the society. Largely hidden from public view, the waste disposal system has attracted little public attention or interference, except on the infrequent occasion of a major breakdown.

As the system expanded by orders of magnitude, formerly adequate waste disposal and dispersal methods became inadequate. Land, air, rivers and even oceans proved too small in capacity to absorb the by-products of a profligate society without harmful side-effects on human and other life. And now we have entered the era of the legislative solution, seeking by law and regulation to control the excesses of our every-growing and more prosperous society.

As a corollary to the problem of over-abundant waste, we face another growth problem—that of inadequate supplies of materials and energy. Dramatic increases in the prices of oil, natural gas, fertilizers and chemicals derived from hydrocarbons, and a host of other things and processes based on them, have now forced us to change our perspective on what constitutes waste, and how it can be re-cycled, re-used, and beneficially disposed of in natural systems.

None of this is new to the members of this audience. It is part of your daily environment, and the cause for conferences such as this one.

As we enter the era of increased Federal legislation, and corresponding legislative action at state and local levels, we find that in the usual course such legislation can frequently be categorized as single-purpose, crisis-response legislation. It is designed by its authors to solve one problem at a time, and not to deal with the multitude of inter-connected issues that surround any important social problem. Such is the nature of the legislative process.

Legislators are aware of this failing, if such it is and usually include in such legislation a suitable number of catch-all clauses which have as their purpose the directing of the administrators in the executive branch to perform all necessary related duties and functions required to solve the particular problem. There are many examples of such legislation.

The technical community has sometimes contributed to this legislative failing by not developing, synthesizing, and publicizing broadly adequate solutions to socio-technical problems, and forcefully channelling such prospective solutions into the legislative process on a consistent basis. Frankly, the narrow reach of most scientific and technical fields, at least in comparison to the scope of the problems facing us, has contributed to this failing. I see developing within the scientific and technical community, however, a growing awareness of the importance of integrative mechanisms which will bring together not only the knowledge specialties, but the total knowledge component, with the action components of society into new forms of problem-solving systems. Perhaps this conference is an example of such developments.

Which brings me to one of my major concerns, which is reflected in the title of my remarks, "Everything is connected to everything else." Most of you will recognize that I have stolen this from Barry Commonor, who cites it as one of the four rules for solving environmental problems.

I am fearful that you, as specialists, will seek to devise another specialized approach to the management and disposal of municipal sludge, and leave the larger problems, the problems caused by the "connections with everything else", for others to solve. You would be justified in opting to solve your own problems first, but I believe that you would be neglectful of your full responsibilities if you did not at least ask the question—Does the solution to my problem create problems for someone else? Could a different solution help to solve someone else's problem? Clearly, these are difficult and complicated questions that may be impossible to fully answer, but they are not irrelevant questions.

Your conference has a genuine cross-section of experts who can and probably will, address the entire range of issues that relate to sludge management and disposal. Each speaker will have a small, but important piece of the puzzle contained in their presentation. If you are fortunate, you will leave here this week with some real solutions to your problems, at least theoretically. And then you will encounter a whole new set of difficulties. You may find that the public will not accept your solution, or that the solution requires the development of complicated inter-connections with other economic sectors, such as agriculture or energy. Or you may find that the economics of your solution do not impress those who hold the purse strings. Whatever difficulties you encounter, they will be accentuated by the fact that you will be a specialist, attempting to communicate with others who do not share your experiences or expertise.

This situation is not unique to waste management. But I'm optimistic that the opposition to certain sludge disposal methods, especially land disposal, will be on grounds that should be surmountable. The ease with which you can sell your disposal technique will vary with special circumstances, but I can assure you that certain trends, already well underway nationally, will continue to restrict some of your options and will tend to highlight the importance of those remaining options that are not precluded by law.

These trends include a continued increase in energy prices, thus changing much of the economics of the past in such divergent areas as incineration and fertilizer costs. There will be a continued effort to reduce air pollution emissions. There will be a continued effort to reduce the release of pollutants into the water systems. Finally, and perhaps most importantly, there will be increasing need for and effort to reduce the amount of metals and other persistent chemicals released into the air, land, and water.

Given the nature of the restraints being forced upon sewage plant operators, it is unfortunate that the Environmental Protection Agency does not yet have adequate research results to set standards for acceptable methods of sludge disposal. It is especially disappointing that regulations for the control of heavy metals are not yet established, especially since the main sources of these metals are industrial, and fairly easily controllable. You will be hearing more about this as your conference goes along. I hope that the results of your discussions move up rapidly towards the promulgation of guidelines for fully acceptable methods of sludge disposal.

Eventually, and probably fairly soon, the combination of forces which I have dealt with here only briefly will force a situation where we will be controlling the quality of our wastes much more carefully in order to fully reclaim those constitutents having value for use in energy or fertilizer production, with true, unusable wastes being the only remaining sludge. Such a situation might even lead to sewerless communities that compost their own domestic wastes, and recycle or specially treat industrial wastes. Such communities would, of course, have to be far more integrated and aware of wastes than are today's cities and towns, and would in all likelihood, have to become better integrated with regular agricultural practices. In such a community the motto, "Everything has value" would be practiced. Such a community could have animals recycling agricultural and animal wastes back to new food, while the people could recycle much of the remainder of the wastes back to energy production for the food or industrial cycle from which it came.

Many of our colleagues who have returned recently from Mainland China describe a society which, in a primitive way, contains many of the features which I have mentioned. While I am not ready to advocate that

we adopt the Chinese system or life-style, I think we can learn from them how to maximize the use of limited resources. And all societies, including our own, are now forced to recognize the fact that there are real limits to resources and to the carrying capacity of both the planet Earth, and our own little piece of that planet.

The Chinese, and many other more primitive societies have learned how to close the loop of natural cycles. In many cases they are learning after centuries of failing to do so. On a limited scale, and in certain isolated situations, small groups in our country are seeking to develop "closed loop" styles of living—systems which might be described as relatively self-sufficient, low-throughput types of systems.

Such systems tend to be smaller rather than larger. Our fascination with bigness may have reached the end of the line. The book, *Small is Beautiful* has become a best seller. The gigantic, all-encompassing centrally-planned and directed system, whether it be a Social Security computer, such as we have seen revealed in all of its weaknesses in the past few days, or a continental or global economic or governmental system, may carry such a heavy weight of problems that these problems constitute a built-in self-destruct system.

Perhaps this is the next great challenge to face us in building a new human culture—the challenge to create, with our unsurpassed scientific and technological abilities, a new emphasis on networks of small, closed-loop, largely self-sufficient, self-defining and self-directing communities, including economic and social entities, and all other forms of human organizations and activities.

If such is indeed the case, then you here today are among those who must accept a major responsibility to help "close the loop." The linear approach of passing our wastes out to somewhere else, to some mythical "away", is no longer practicable. But in order to close the loop, to do your job of waste management, you must convince the people who are sending their wastes away to take them back.

These people, quite rightly, want assurances that what you are bringing back is safe and useful. Some of your speakers will be telling you that it may not be safe. It is especially not safe if the slduge you wish to bring back is contaminated with heavy metals, and these heavy metals then enter the biological chain. But this problem can be, and will be solved. It can be solved by source controls, and by consistent sludge test and monitoring procedures, prior to land application, just as we test and monitor drinking water before it enters the domestic supply system.

But, even with assurances of safety and healthfulness, there remains a complex problem of community acceptance of recylced sewage sludge. How do we address that problem?

The average citizen does not know how his community works. He may know where the sewer goes, but most likely he will only be aware of the tax bill and the sewer connection charge. Even elected officials, who are among the few mandated generalists in our society, are seldom aware of the details of community infra-structures such as waste disposal systems. And elected officials are highly unlikely to oppose an angry, even though uninformed, constituency over a waste disposal issue. And the people are leary of sludge and sludge disposal sites.

A recent example from our Nation's Capitol may be instructive. The National Park Service began applying municipal sludge to the area along the Mall near the Washington Monument. Since the White House is just across the street and in need of soil conditioner, the Park Service offered to supply the need from their sludge. The deal seemed closed, until some higher official got wind of the proposal, so to speak, and it was suddenly off. The White House will use artificial fertilizer, but not sewage sludge. So much for leadership.

I must say, before closing, that your work will continue to have strong support in the Congress. In handling the EPA Office of Research and Development authorization bill this year, under our new House jurisdictional arrangements, I found that one of the few areas receiving increases above the President's recommended budget, by insistence of the Committee on Science and Technology, was that of solid waste disposal, and particularly the matter of sludge disposal research and development. I expect the Committee and the House to continue their favorable attitude toward this subject.

I am personally extremely well disposed toward increased research and development, particularly so where it recognizes the importance of some of the parameters which I have tried to sketch. The importance of research and development is implicit in Berman's Rule, enunciated by your distinguished keynote speaker at last year's conference, who said "While we can do as much planning and discussing of numerous alternatives as we care to, while we can develop all types of "systems" approaches, and while we can develop "models" to our hearts content, no *one* solution will ever solve *all* of our municipal sludge problems. Rather, a series of approaches are required which I am confident, will eventually lead to the gradual elimination of the seemingly gigantic problem which faces us today."

EVERYTHING YOU WANTED TO KNOW ABOUT SLUDGE BUT WERE AFRAID TO ASK

Harold Bernard
Environmental Quality Systems, Inc.
Rockville, Maryland

INTRODUCTION

This paper supplies an overview for the remainder of papers in the Proceedings. It indicates the impact on sludge volumes and characteristics of legislation, of sources of wastewater, sewage treatment, and agronomy practices. The paper describes the uniqueness of sludge characteristics and its dependence on its immediate past history. Sludge is placed in a perspective with other industrial practices and natural occurrences that similarly impact on the environment.

Impact of Population

Figure 1 is a Bureau of Census map of the United States, showing the location of municipalities of 10,000 people and greater. Therefore, the map also depicts the location of sewage treatment plants of about one mgd or greater, on the assumption that municipalities of this size must have a sewage treatment plant. The significant density is around the Mississippi River and increases as you go east with other pockets of density along the West Coast, in the Los Angeles area, San Francisco, San Diego, and in the upper northwest extremities of the country. The Bureau of Census has projected about a two percent increase in population annually. For that reason, we don't feel that the population increase will have a significant impact on the quantity of sludge that will be generated over the next decade.

Impact of Legislation

The sections of the Federal Water Pollution Control Act Amendment of 1972 and their associated impacts are indicated in Table 1 and described as follows:

1. Section 301 establishes effluent limitation for both publicly owned and non-publicly owned treatment wastes. It may be expected that by 1977-1978, municipal sludges resulting from application of secondary treatment to all publicly owned treatment works will be significantly increased. Effluent limitations at the best available technology stage will produce significant amounts of non-public or industrial wastes, sludges, and process residues by 1983-1985.
2. Section 306 establishes "the national standards of performance for various industrial categories." Originally in PL 92-500, 27 major categories of industry were included. The Environmental Protection Agency couples the promulgation of national standards of performance with effluent guidelines for these 27. As time passed, additional listing of industrial categories was promulgated. The EPA has plans to continue promulgating the effluent guidelines and national standards of performance and it is likely that at some point in time virtually every category of industrial waste will be covered. The National Pollution Discharge Elimination System will ensure that these provisions are enforced. The end result will be to significantly increase sludges and process residues, initially from the 27 primary categories and as time passes into the 1980's and early 1990's, from every industrial category.
3. Section 307 establishes toxic and pretreatment effluent standards. The net effect of the requirement of this section in locations where publicly owned treatment works accept industrial wastes will be increases of sludges and other process residues from industrial and other establishments which have installed new treatment works to meet pretreatment requirements or to eliminate the discharge of toxic and hazardous materials to the sewer systems and subsequently to the publicly owned treatment works. These residues will require programs for disposal of sludges and other residues in urban areas, particularly where land space or space for additional sludge treatment and ultimate disposal including incineration is limited.
4. Section 402 of the Act establishes the National Pollutant Discharge Elimination System (NPDES) and associated permit scheme which will be operated on a continuous basis either by the EPA or by each of the states as they become eligible to exercise the

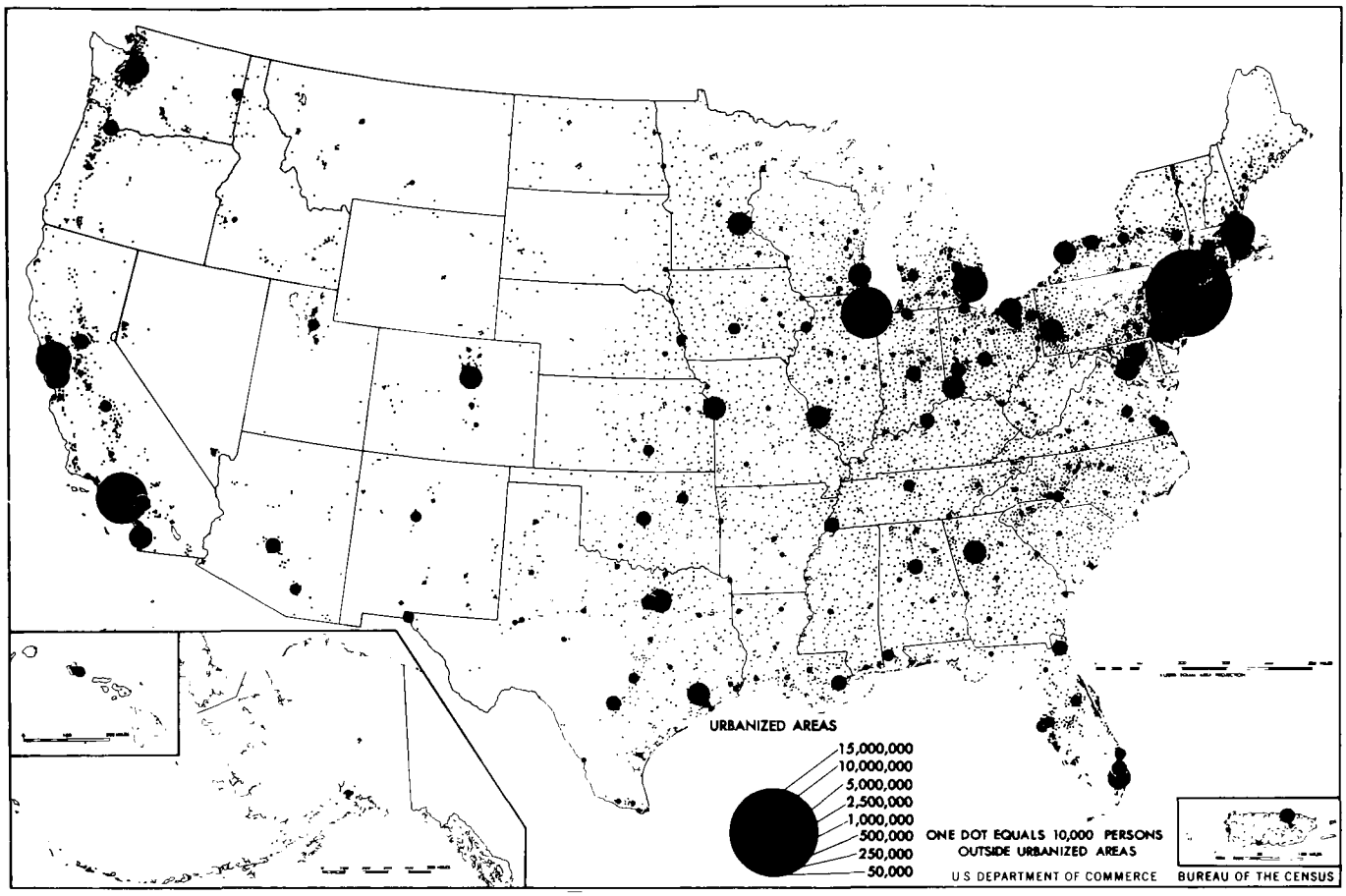


Figure 1: Population Distribution — 1970 Census.

requirements of this section of the Act. The permit scheme constitutes an enforcement mechanism updated on a regular basis and will require attention, by state, Federal and local regulatory agencies, to discharges, whether public or private, to the nation's waters. In the past, the enforcement of water pollution control requirements has not been nearly as consistent or continuing as this section of the Federal law requires. As a result, sludges and process residues resulting from additional treatment as described above, will receive continuous attention. Also, sludges and process residues which may have been disposed of properly in the past will result in even greater quantities. The enforcement of PL 92-500, including Section 309, the continuing capability for civil suits, and additional criminal penalties will significantly improve the pollution abatement picture in the United States over the coming years and of course, will contribute substantially to the production of additional sludges and process residues.

TABLE 1
Sections of PL 92-500 That Impact on Production of Sludges

EFFLUENT LIMITATIONS

NATIONAL PERFORMANCE STANDARDS

(EFFLUENT GUIDELINES)

NPDES - PERMIT REQUIREMENTS

TOXIC AND PRETREATMENT REQUIREMENTS

LIMITATIONS ON OCEAN DISCHARGE

POTENTIAL RESIDUES FROM TREATMENT OF

NON-POINT SOURCES

5. Very large sludge quantities are currently being discharged to the ocean environment, particularly from the east coast into the New York Bight. Section 403 of the Act requires the establishment of ocean discharge criteria. The Administrator of the EPA acting through this section and also through Section 405 of the Act relating to the disposal of sewage sludge has in recent months been taking an increasingly harder position against any disposal of sludges or process residues to the ocean environment. This factor alone may as much as double the requirement for land space or other techniques

for the disposal of sewage sludge within a very short time, over the next five years.

6. Section 404 of the Act requires permits for the disposal of dredged or silt material. Section 403 limits the alternatives for the disposal of this material as time passes.
7. The analysis of alternative treatment techniques and the "ultimate disposal of sludge in a manner that will not result in environmental hazards" are requirements for projects before they receive public funds (Section 201).
8. Other requirements of PL 92-500 will also affect the production of sludges and process residues. Increasing attention is required for control of drainage from mine sources. Additionally, requirements are placed, for the first time, related to nonpoint sources of pollution. It is clear that as time passes, and the point sources are controlled, non-point sources will assume increasing importance, particularly in those watersheds where point sources of pollution have been completely eliminated through recycle or high degree of treatment, and in those areas where advanced waste treatment is being used now or will be used in the near future for the control of nutrients. Control of pollution from construction activity particularly land stripping, strip mining activities, logging practices and other potential non-point sources of pollution must be reviewed on a continuing basis for production of process residues.

In summary, the nation will see larger increases in residues from the treatment of wastewaters than from any increases due to population growth. For example, it was estimated that in 1973 there was slightly under five million dry tons of municipal sludge (see Table 2). In 1975, that figure will increase only slightly. We have seen how sludge quantities will change, but what of sludge characteristics. Sludge varies from one community to another and even in the sewage treatment plant from one day to another. About 10 to 15 years from now, when the fishable-swimmable and "no discharge" sections of PL 92-500 become effective, sludge quantities will have doubled.

TABLE 2
Impact of 1977, 1983, 1985 Goals of PL 92-500

1973	4.7 MILLION TONS
1977	SECONDARY TREATMENT REQUIRED
	5 MILLION TONS
1983	"FISHABLE SWIMABLE"
	BEST PRACTICABLE WASTE TREATMENT
	TECHNOLOGY
1985	NO DISCHARGE
	8.0 MILLION TONS
1990	10 MILLION TONS

Sludge Variability

The factors affecting the variability of sludge are indicated in Table 3. One of the factors to which little attention is paid is the source of the water itself. The source of water supply determines, to a large extent, the quantity and quality of inorganic dissolved solids in the sewage water. The source of the actual sewage would also play an important role. For example, household wastes, from a community such as New York City, which is a relatively old city with small industries, and without residential garbage, would be very different from a community such as Anaheim, which is a relatively new 20-year-old community which has little industry and almost every household has a garbage disposal unit. Commercial establishments, both number and type, will impact on the sewage characteristics. The type of industry, whether or not it requires pretreatment, will have an impact on the characteristics of sewage. Combined sewers would have a tremendous impact. In the community described later in the proceedings, the daily dry weather flow, even with some infiltration, is about 3 to 3½ million gallons; the wet weather flow is well over ten million gallons, all flowing through the sewage treatment plant.

TABLE 3
Factors in Variability of Sewage Source

WATER SUPPLY

HOUSEHOLD WASTES

COMMERICIAL ESTABLISHMENTS

INDUSTRIAL WASTES

RAW

TREATED

COMBINED SEWERS

INFILTRATION

The various factors perhaps, explain why sewage treatment plants differ in solids generated per capita as indicated in Table 4. In a comparison of four plants, the minimum/maximum values between the four plants vary by a factor of almost four. As mentioned before, the type and variability of the sources will significantly impact on both the quantity and the character of the sewage, and therefore, the residues. The sewage treatment

TABLE 4
Solids Generation Rates* From Four Plants

Plant	Minimum	Maximum
1	0.338	0.491
2	0.137	0.146
3	0.201	0.296
4	0.140	0.270

*lbs/cap/day (multiply by 0.454 for kg/cap/day)

process itself, such as activated sludge, trickling filter or chemical treatment, will generate completely different types and quantities of sludge. Tables 5 and 6 indicate the quality and quantity of sludges generated by the various types of treatment plants. Different days in the same plant, depending upon the character of the operation on that particular day, as well as the character of the sewage being received, will produce different residue characteristics. For example, lime treatment for the removal of phosphorous, would increase residue volumes by approximately one and a half percent of the volume of wastewater treated. Recalcination and recirculation drastically reduces that quantity. Alum or sodium aluminate would add about one pound of alum per four pounds

TABLE 5
Factors in Variability of Sludge Produced by the Type of Sewage Treatment

PRIMARY TREATMENT % OF SEWAGE VOLUME

ACTIVATED SLUDGE PROCESSES AND VARIATIONS-% OF SEWAGE VOLUME

TRICKLING FILTER % OF SEWAGE VOLUME

CHEMICAL TREATMENT

LIME TREATMENT
98% PHOSPHORUS REMOVAL
SLUDGE 1.5% OF WASTEWATER VOLUME
RECALCINATION

ALUM OR SODIUM ALUMINATE TREATMENT
80-90% PHOSPHORUS REMOVAL
4 LBS. OF SLUDGE/LB. OF ALUM

IRON TREATMENT
80-90% PHOSPHORUS REMOVAL
SLUDGE 2.5 LBS./LB. OF Fe

DENITRIFICATION TECHNIQUES
REFRACTORY ORGANICS REMOVAL TECHNIQUES
800 2500 LBS./MG. WITHOUT REGENERATION

DISSOLVED SOLIDS REMOVAL TECHNIQUES

TABLE 6
Estimated Dry Sludge (D.S.) Production For Various Wastewater Processes

	lbs./MG
Primary sludge	1,000
Waste activated sludge	700
Trickling filter sludge	650
Extended aeration waste sludge	830
Aerated lagoon sludge	830
Filtration sludge	125
Algae removal sludge	125
Chemical addition to clarifiers*	450

*Based on application rate of 80% alum and 20% Fe^{+3}

of sludge produced, or about 25 percent of the characteristics of the sludge will be composed strictly of the alum that was added to treat the sewage for the phosphorous removal. Iron denitrification techniques also add different quantities of additives and create different characteristics in the sludge. As noted (in Table 7) in the 22,000 sewage treatment plants in the country, ten percent of them are collection systems only, another ten percent are primary treatment with sedimentation, and

TABLE 7
The Number and Type of Municipal Wastewater Treatment Facilities in the United States and the Population Served by Each

Type of Treatment Process	Population Served	Number of Plants
Collection System Only - No Treatment	2,890,676	2,404
Minor Treatment - Screening and Chlorination Only	780,135	72
Primary Treatment - Sedimentation	37,904,943	2,714
Intermediate Treatment - Chemical	6,780,241	70
Secondary Treatment - Biological	2,506,245	1,980
Secondary - Activated Sludge	47,561,508	1,831
Secondary - Extended Aeration	3,963,602	2,694
Secondary - Trickling Filter	29,688,917	3,523
Secondary - Effluent to Land	410,444	144
Secondary - Oxidation Pond	7,680,982	5,031
Secondary Filter	1,606,110	309
Secondary - Miscellaneous	10,798,203	1,245
Tertiary - Physical, Chemical	2,373,698	809
Total	154,945,105	22,054

the other 80 percent vary between intermediate treatment and secondary treatment of various types. Tertiary treatment, using physical chemical treatment concepts, now only makes a small contribution to the overall sludge generation picture, consisting of only 800 out of

the 22,000 plants. Their impact will increase as "best practical" and "best available treatment" concepts are instituted.

As noted previously, quantities and sludge characteristics vary between treatment plants using the same concept. Table 8 compares the variability of some heavy metals in sludges in three activated sludge plants and between activated sludge and a trickling filter plant. The quality of the influent varies between the plants. Removal rates or percentages are also different. In all likelihood, operational characteristics also affect the quantities and characteristics of sludges removed.

TABLE 8
Fate of Metals Through Sewage Treatment Process

Metal	Bryan, Ohio, Activated Sludge: Influent Sewage, (mg/l) Average	Influent Sewage, (mg/l) Range	Final Effluent, (mg/l) Average	Final Effluent, (mg/l) Range	Percent Immobilized in Sludge
Chromium	0.8	0.6-1.1	0.2	0.2-0.3	--
Copper	0.2	0.2-0.3	0.1	0.04-0.1	--
Nickel	0.05	0.03-0.1	0.05	0.03-0.1	--
Zinc	2.2	1.4-3.0	0.2	0.2-0.3	--
	Grand Rapids, Michigan, Activated Sludge				
Chromium	3.6	0.7-5.6	2.5	1.0-3.3	40
Copper	1.4	0.7-2.4	1.6	0.4-2.9	16
Nickel	2.0	1.3-3.4	1.8	1.0-2.5	12
Zinc	1.5	0.6-2.5	0.8	0.6-1.2	58
	Richmond, Indiana, Activated Sludge				
Chromium	0.8	0.2-2.1	0.2	0.01-0.5	82
Copper	0.2	0.1-0.4	0.07	0.04-0.2	73
Nickel	0.03	0.01-0.1	0.02	0.01-0.03	78
Zinc	0.3	0.1-0.5	0.1	0.1-0.2	85
	Rockford, Illinois, High-Rate Trickling Filter				
Chromium	1.8	0.5-2.9	1.2	0.6-1.5	37
Copper	1.4	0.6-3.3	1.0	0.5-3.6	23
Nickel	0.9	0.2-1.9	0.9	0.5-1.4	8
Zinc	2.7	1.2-3.4	1.3	0.8-1.7	53

Table 9 indicates further impact on ranges of trace elements due to sludge handling. Undigested sludge is quite different than secondary digested sludge. Vacuum filter cake sludge also has a different constituency because of the removal of dissolved solids in the liquid filtrate.

TABLE 9
Range of Trace Elements Found in Sewage Sludge
In Relation to Treatment Process

Element	Undigested Liquid Sludge [a]	Secondary Digestor Sludge [b]	Vacuum Filter Cake [c]
Mercury	1.2 - 3.4	2 - 56	0.6 - 27
Chromium	66 - 7,800	22 - 9,600	28 - 10,600
Copper	200 - 1,740	260 - 10,400	84 - 2,600
Nickel	44 - 740	14 - 1,440	12 - 2,800
Zinc	900 - 8,400	1,120 - 16,400	480 - 9,400
Cadmium	6 - 166	2 - 1,100	2 - 480
Lead	150 - 26,000	240 - 12,400	80 - 3,000
Arsenic	3 - 16	4 - 18	2.8 - 11

a) From 6 treatment plants
b) From 22 treatment plants
c) From 14 treatment plants

As mentioned at the outset, and as shown in Table 10, the industrial contributions will add a tremendous amount of residues that must be considered in an overall municipal sludge management concept. In the top two categories of "inorganics" and "iron and steel", the smaller number indicates the tonnage that can be recycled back to the respective industry. The difference is that tonnage which must be considered for disposal into the environment. As you can see, the net tonnage of residue that must be disposed of in 1977 and 1983 from the ten industries will be approximately 13 million tons. As mentioned previously, in 1977, municipal sludge will be only about five million tons, so there will be about two and a half times more industrial residue to be expected in the next several years than from the municipal area.

TABLE 10
National Generation of Wastewater Sludge
From the Major Industrial Sectors (in 10^6 tons)

	1971	1977	1983
Inorganics	$17.07_{/14.6}$	$26.02_{/22.3}$	$32.00_{/29}$
Iron and steel	$3.47_{/1.8}$	$6.85_{/3.1}$	$8.03_{/5}$
Pulp and paper	1.08	2.24	3.41
Meat products	0.42	0.92	1.09
Petroleum refining	0.69	0.85	1.02
Textiles	0.19	0.52	0.74
Organics	0.21	0.41	0.48
Plastics & synthetics	0.14	0.24	0.32
Fruits & vegetables	0.05	0.07	0.11
Electroplating	0.04	0.07	0.07
TOTAL	$23.34_{/16.4}$	$38_{/25}$	$47_{/34}$
NET TOTAL	7	13	13

(Tons 1.1 kkg)

As indicated in Table 6, the actual treatment concepts given to the sludge will have a tremendous impact on the characteristics of the sludge. Figure 2 indicates the potential unit processes and sludge handling systems that can be given to the sludge such as stabilization, conditioning, dewatering, heat drying, reduction, and then the final disposal methods such as disposal onto land, land reclamation, power generation, etc. There are approximately a quarter of a million combinations one can synthesize with just these eight unit processes that make up a sludge disposal or sludge treatment system.

Operations within the same treatment plant vary over a tremendous range, as shown in Table 11 for the Calumet Treatment Plant of the Metropolitan Sanitary District of Greater Chicago. The various constituents, ammonia, phosphorus, chromium, cadmium, copper, etc., vary over a range from double to almost an order of magnitude.

TABLE 11
Sludge Variability
Composition of Digested Sludge from the
Calumet Treatment Plant,
Metropolitan Sanitary District

Component	Concentration, ppm
Total N	1000 - 3500
Ammoniun-N	500 - 2000
P	700 - 1550
K	150 - 175
Cr	10 - 50
Cd	10 - 35
Cu	30 - 45
Pb	15 - 33
Mn	7 15
Ni	1 3
Zn	72 - 292
In solids	-----
C	22 - 27%
H	3 - 4%
N	3 - 3.5%

In addition to the variables within the treatment plant, disposal onto the land adds an additional 20 variables. These are indicated in Table 12. Metal uptake usually increases with pH. The type of soil, the clay fractions in the soil, the organic fractions in the soil, and in the sludge, affect uptake. Permeability of the soil or the residence time of the sludge leachate in the soil affects uptake. Soil temperature, the previous soil moisture, the existing soil moisture, the plants being cultivated on the land will have a unique impact on the uptake and transport characteristics of the sludge. The plant age, the sludge age, the form of the heavy metal, whether it's an oxide, or a carbonate, what other heavy metals are present, will all have an impact or interfere with the uptake of metals. The total quantity of metals that exists in the sludge and in the soil at the time of sludge application, the actual age of the metal, whether the land is seeded immediately, or whether the sludge is aged for a week or two before the seed is applied, will determine uptake. The actual laboratory method that one used to indicate the removal or uptake of metals will affect apparent uptake analyses.

TABLE 12
Factors Affecting Uptake of Heavy Metals

TYPE OF SLUDGE
pH OF SOIL AND SLUDGE
TYPE OF SOIL
CLAY FRACTIONS
ORGANIC FRACTIONS
PERMEABILITY
CLIMATE
SOIL TEMPERATURE
SOIL MOISTURE
PLANT TYPE
PLANT AGE
FORM OF HEAVY METAL
INTERFERENCE OF OTHER HEAVY METALS
TOTAL QUANTITY OF HEAVY METALS
PAST HISTORY OF APPLICATION
EXCHANGE CAPACITY OF SOIL
AGE OF METAL (FORM?)
PRESENCE OF HYDROUS OXIDES
LABORATORY METHOD

One method gives a low estimate of uptake. One extracts even the constituents that were tied very tenaciously to the soil before the sludge was applied, so the analyses actually indicates an over-conservative amount of metals taken up by the plant. The impact of these variables is illustrated in Table 13 which indicates the range of constituents in the soil and in the sludges, varying from 0.1 to 40 micrograms per gram, in the soil, and 0.1 to about five in the plants. Table 14 illustrates the fate of five metals in various crops grown in untreated soil and soil treated with sludge. It is not necessary to dwell on any particular sludge, but important to indicate the tremendous variation one can expect.

TABLE 13
Total Concentrations of Trace Elements Typically
Found in Soils and Plants

Element	Conc. in Soils (µg/g) Common	Range	Conc. in Plants (µg/g) Normal	Toxic[1/]
As	6	0.1 -40	0.1 -5	
B	10	2 -100	30 -75	>75
Cd	0.06	0.01-7	0.2 -0.8	
Cr	100	5 -3000	0.2 -1.0	
Co	8	1 -40	0.05-0.5	
Cu	20	2 -100	4 -15	>20
Pb	10	2 -200	0.1 -10	
Mn	850	100 -4000	15 -100	
Mo	2	0.2 -5	1 -100	
Ni	40	10 -1000	1	>50
Se	0.5	0.1 -2.0	0.02-2.0	50-100
V	100	20 -500	0.1 -10	>10
Zn	50	10 -300	15 -200	>200

1/ Toxicities listed do not apply to certain accumulator plant species

In applying sludge to the land, one is always concerned about the fate of the bacteria and the virus usually inherent in sludge. The observed distance of travel, time of travel, and whether or not bacteria or virus will survive, is shown in Tables 15 and 16. The viruses have a longer lifetime than bacteria, surviving up to 27 weeks. One must also place survival in the context of time of

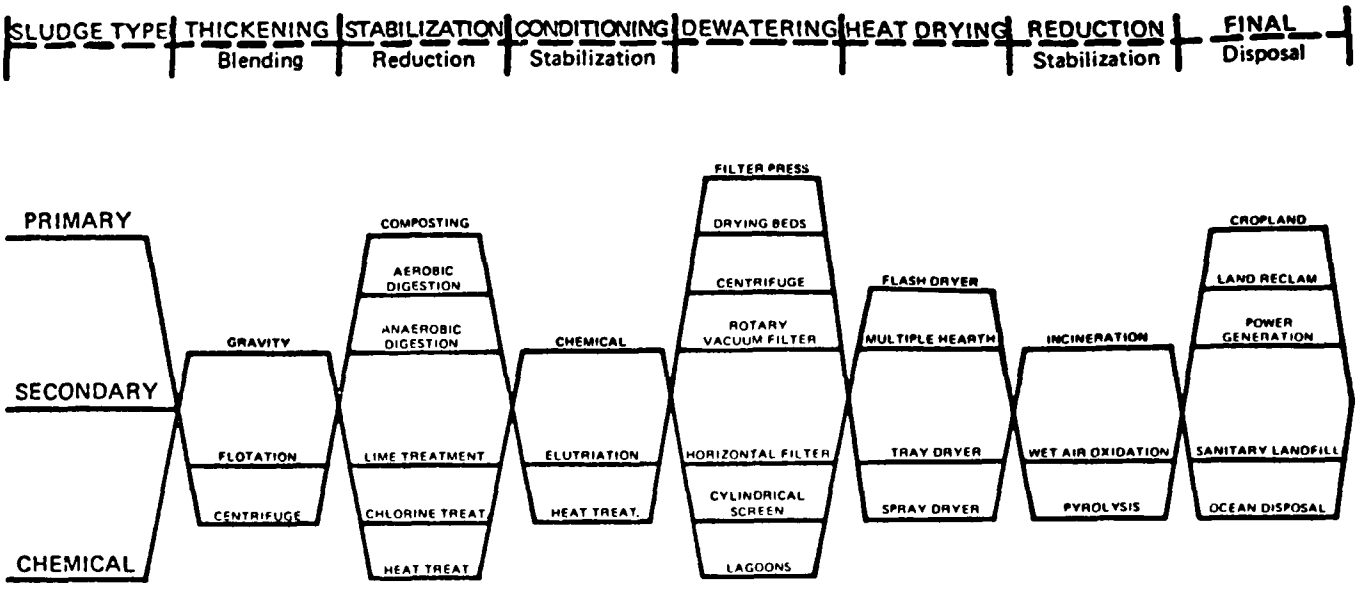


Figure 2: Unit Processes—Sludge Processing and Disposal.

TABLE 14
Trace Element Composition of Crops Grown on Soil Treated with Sludge at an Average Rate of 66 M. Tons/Ha/Year for 19 Years

Treatment	Concentrations of Trace Element in Plants				
	Cr	Cu	Mo	Ni	Zn
	μg/g dry matter				
			Leeks		
Untreated	0.71	5.7	0.50	2.0	46
Treated	0.54	16.0	1.10	7.0	135
			Globe Beet Tops		
Untreated	0.85	8.5	0.45	3.2	169
Treated	1.0	10.0	0.65	16.5	>505
			Globe Beet Roots		
Untreated	0.3	11	0.1	1.65	102
Treated	0.8	18	0.25	13.0	250
			Potato Tops		
Untreated	1.70	4.2	0.37	1.7	90
Treated	3.0	8.2	1.0	5.2	120
			Potato Roots		
Untreated	0.09	9.5	0.40	0.25	30
Treated	0.03	9.5	0.27	0.57	27
			Carrot Tops		
Untreated	0.41	8.2	0.58	1.28	47
Treated	0.88	9.9	0.84	3.0	99
			Carrot Roots		
Untreated	0.03	6.3	0.12		34
Treated	0.06	4.6	0.12		42

1/ Leeks, beets, and potatoes are means of 2 plots. Carrots were grown on soil 7 years after treatments were discontinued.

TABLE 15
Summary of Reported Distances of Travel of Pollution in Soil and Groundwater

Nature of Pollution	Pollutant	Observed distance of travel [a]	Time of travel
Sewage polluted trenches intersecting ground water	Coliform bacteria	65 feet	27 weeks
Polluted trenches intersecting ground water	Coliform bacteria	232 feet	-
Sewage in bored latrines intersecting ground water	Coliform bacteria Anaerobic bacteria	10 feet 50 feet	
Sewage in bored latrines lined with fine soil	Coliform bacteria	10 feet	
Sewage in bored latrines intersecting ground water	Coliform bacteria	35 feet	-
Sewage in bored latrines intersecting ground water	Coliform bacteria	80 feet regressed to 20 feet	
Coliform organisms introduced into soil	Coliform bacteria	50 meters	37 days
Sewage effluents on percolation beds	Coliform bacteria	400 feet	-
Sewage effluents on percolation beds	Bacteria	150 feet	
Sewage polluted ground water	Bacteria	a few meters	-
Introduced bacteria	Bacillus prodigiosus	69 feet	9 days
Chlorinated sewage	Fungi	300 feet	-

a) For bacteria, the distance observed was the extent of travel.

travel in the terrestial environment. For example, in the 27 weeks, mentioned above, the bacteria moved only 65 feet. If the land is larger than this, the survival characteristics of the bacteria or virus may be inconsequential.

TABLE 16
Survival Times of Organisms

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

a) Unlikely to move in the unsaturated zone
b) Artificial Contamination

Sludge in Perspective

Constituents in sludges should be placed into perspective with other residues and with other operations that contribute the same constituents to our environment.

Figure 3 shows the percentage of municipal sludges related to residual generation from other sources.

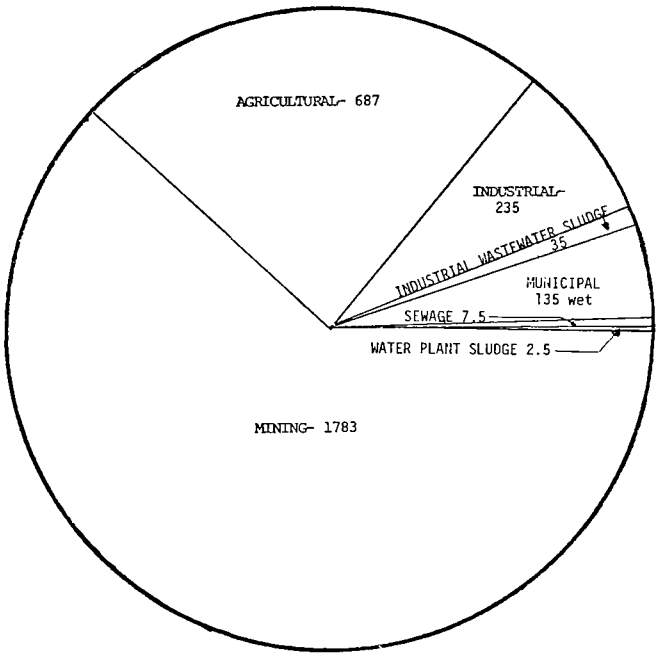


Figure 3: Estimated Industrial Versus Other Residual (Aug. 1970-1974((Dry Weight in Million Tons Per Year).

Sludge accounts for only 7.5 dry tons of the total quantity of residues generated. As can be seen, the other residues far outweigh the 7.5 tons for the sanitary sludge.

The industrial wastewater sludge, for example, is 35 million tons per year and is of much greater significance than the municipal sludge. Industrial process residues produce six times as much as the municipal sludges. Mining waste is mostly overburden. Another viewpoint is to compare sludge with sediment runoff as shown in Table 17. Within the three billion tons of soil that erodes annually is found three million tons of nitrogen, 4.5 million tons of phosphorus, and 45 million tons of potassium. The 5 to 7.5 million tons of municipal sludge (composed of from three to six percent nitrogen) in orders of magnitude less than that being contributed to the environment from the erosion of sediment.

The nutrient and metal contributions from fertilizer shown in Table 18 were obtained from the Department of Agriculture publications. Normal agronomy practices

TABLE 17
Nutrients in Sediment Runoff

3 BILLION TONS OF SOIL ERODES ANNUALLY

3 MILLION TONS OF NITROGEN

4.5 MILLION TONS OF PHOSPHOROUS

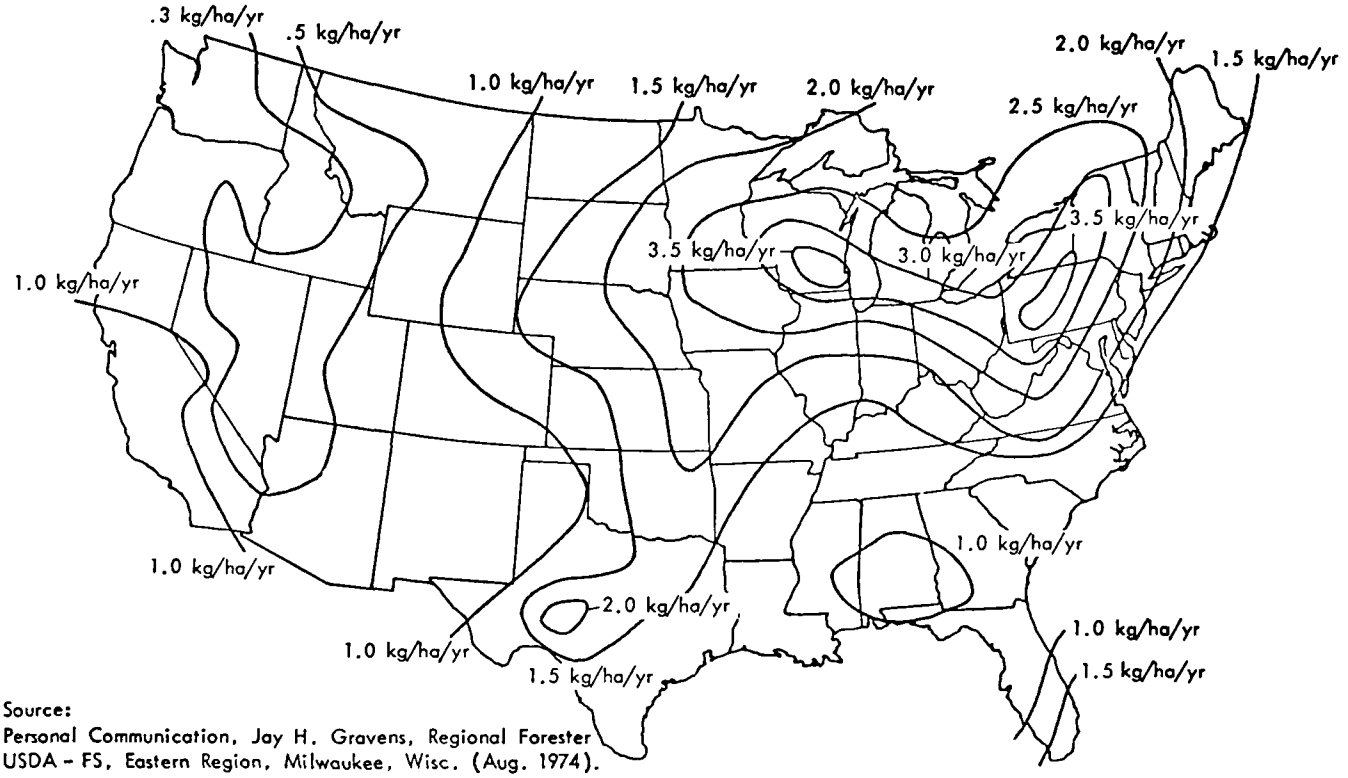
45 MILLION TONS OF POTASSIUM

TABLE 18
Plant Nutrients Applied to the Land from Fertilizers

NITROGEN	9 MILLION TONS/YEAR
PHOSPHATE	2.5 MILLION TONS/YEAR
POTASSIUM	3.5 MILLION TONS/YEAR
COPPER	2500 TONS/YEAR
IRON	3300 TONS/YEAR
MANGANESE	11,000 TONS/YEAR
ZINC	15,000 TONS/YEAR
MOLYBDENUM	80 TONS/YEAR

apply the same constituents to the land for which we express concern in municipal and industrial sludges. The differences are obviously the concentration of constituents that are applied to the soil.

Figure 4 indicates the quantity of nitrogen that can be contributed to the terrestrial environment by rainout. These vary from about 3.5 kg per hectare per year in the industrial northeast and around the Great Lakes, Chicago, and Minneapolis area, to about one kg/hectare/year in the southwest. Source of nitrogen and phosphorus content in the top one foot of soil also varies from about .04 percent to about .3 percent in the various parts of the



Source:
Personal Communication, Jay H. Gravens, Regional Forester
USDA - FS, Eastern Region, Milwaukee, Wisc. (Aug. 1974).

Figure 4: Nitrogen (NH_4 —N and NO_3 —N) in Precipitation.

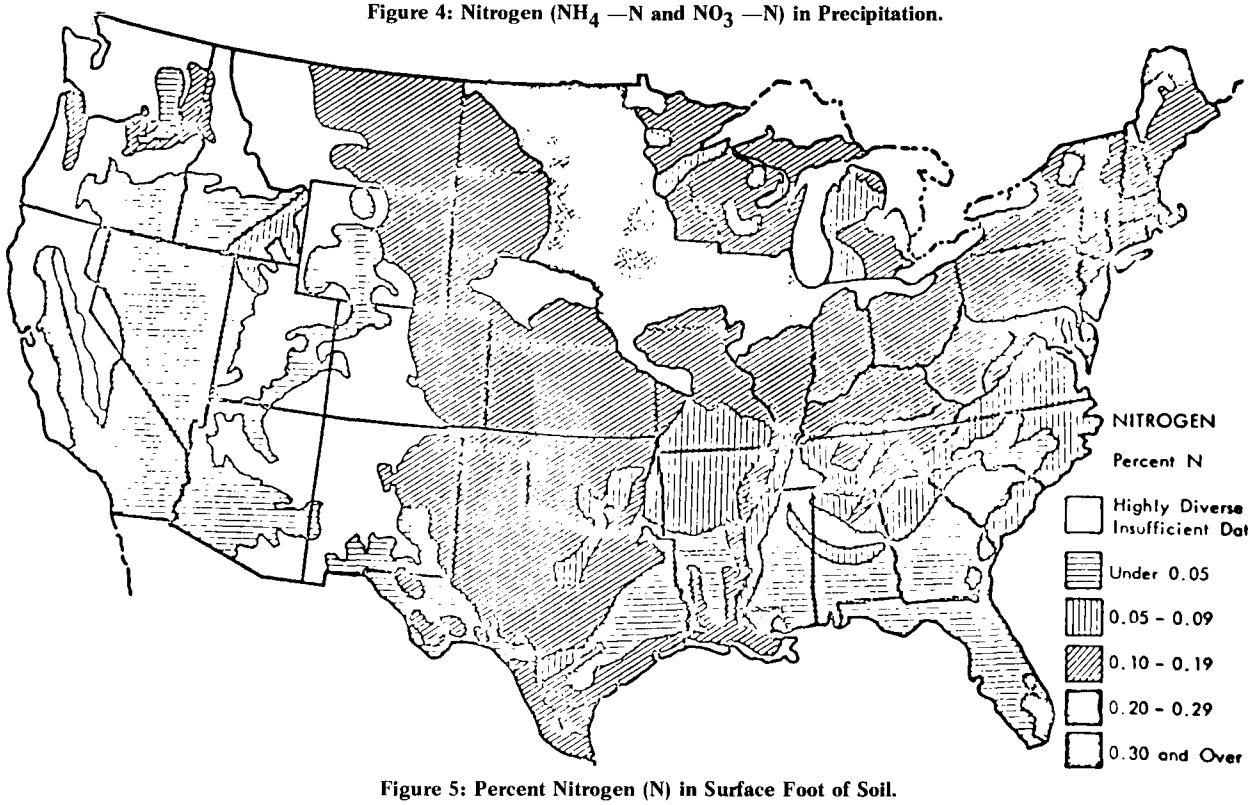


Figure 5: Percent Nitrogen (N) in Surface Foot of Soil.

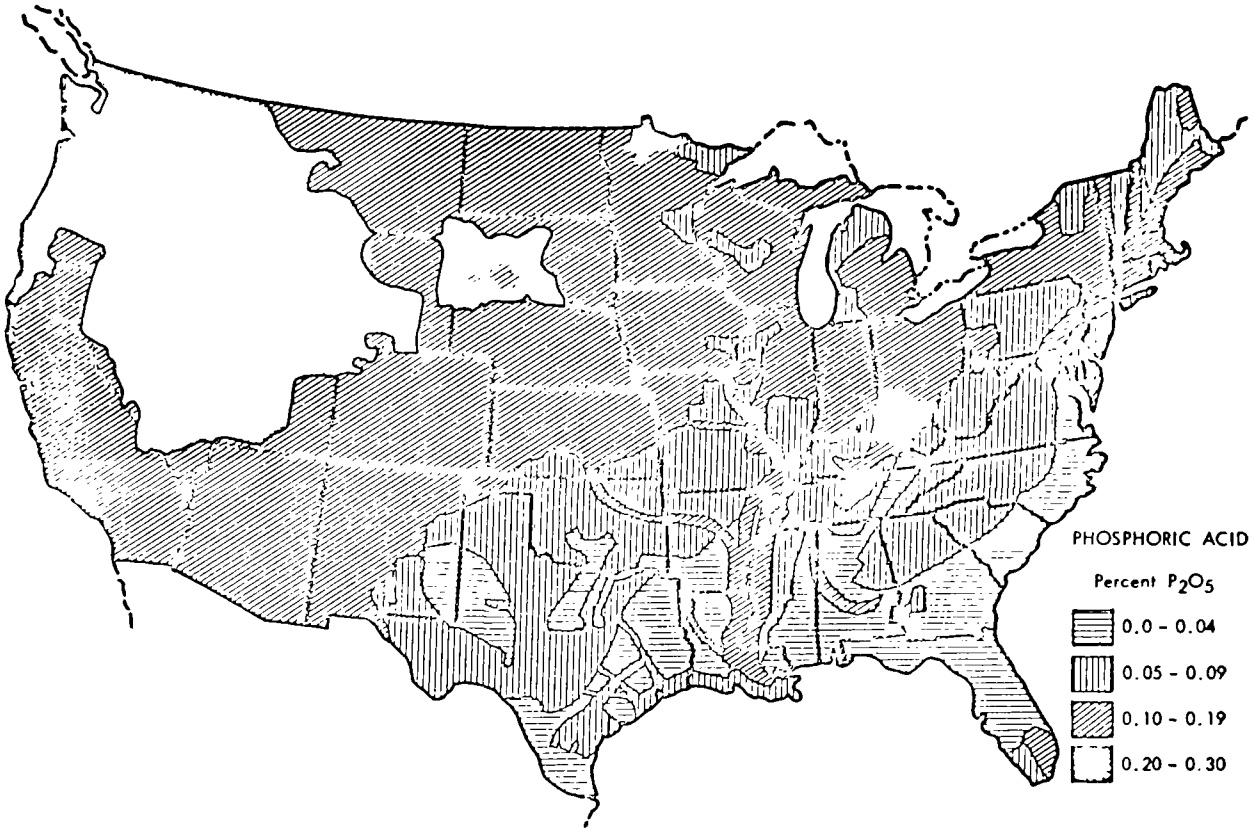


Figure 6: Phosphorus Content in the Top One Foot of Soil.

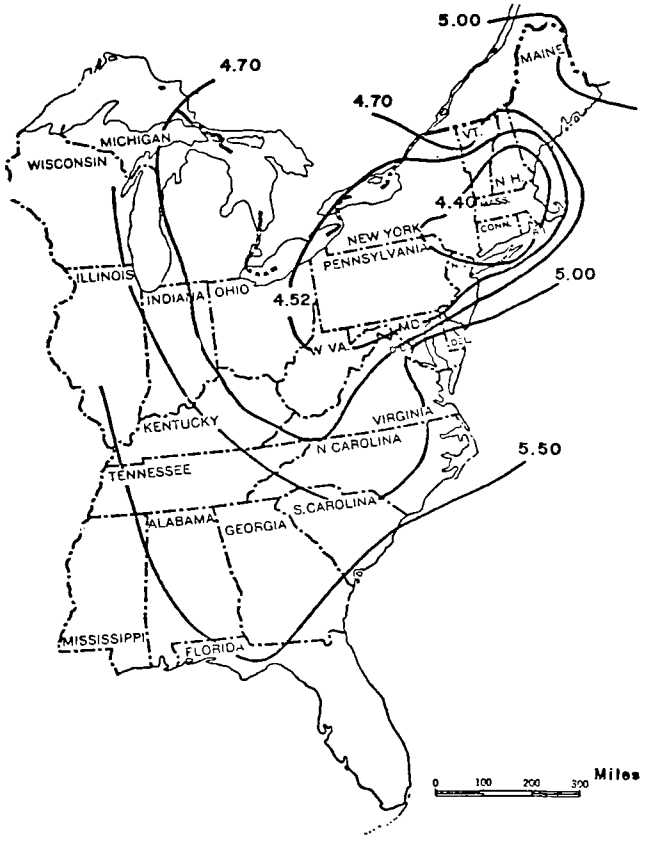


Figure 7: Predicted pH of precipitation over the eastern United States, 1965-1966.

country, as shown in Figures 5 and 6. The pH of the rain-out also varies considerably throughout the nation (Figure 7). Metals tend to leach faster in an acid soil environment.

In summary, I would again like to indicate that *your* sludge is unique. It will have different characteristics than anybody else's and will probably vary daily. Your environment is also different than anybody else's. You cannot use field data and laboratory data from other investigators per se; you can use other data as guidance to direct your particular solution(s).

In additon, it is unlikely that national guidelines will be useful. Such guidelines will have to be overly conservative and may require inordinately high acreage to dispose of the sludge. Any guidelines should permit flexibility to take into consideration the broad variability in sludges, the environment and various acceptable controls.

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IMPACT OF INDUSTRIAL WASTEWATER PRETREATMENT ON SLUDGE MANAGEMENT

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INTRODUCTION

It is easy to say, "Yes, there is an impact on sludge management practice resulting from pretreatment of industrial wastewater." It is, however, significantly more difficult to describe and critique the nature of this impact for an audience that is made up of those involved in sludge management, those that produce the industrial pollutants and those that regulate and monitor the environment. A moment of thought on the triad just mentioned is an underlying reality which has significant bearing on pretreatment and its effect on residue management and or . . . . perhaps the inverse that is residue control and its relationship to the need for pretreatment.

With the implementation of a pretreatment strategy for industrial sources the institutional considerations of industrial or private sector motives and economies are linked with those of the local public authority and the institutions of state or Federal government. Figure 1 portrays the initial and very basic options which the industrial discharger must consider knowing that one option will transfer the water pollution problem to the municipal sector with strings attached. Such a linking of "ways and means" for the purpose of improving our environment is always a challenge to those charged with turning complex strategies into realistic and workable solutions.

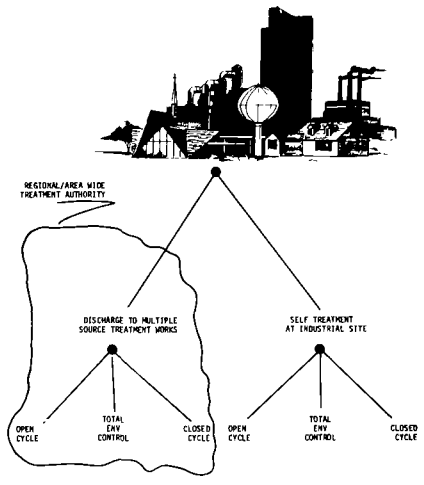

Figure 1: Joint Is An Option.

Before exploring the relationships between residue control practices and the pretreatment of industrial effluents, it is well to consider the terminology of pretreatment. In its rudimentory form pretreatment implies a need to:

1. make the industrial waste similar in characteristic to that used as a design norm for a municipal waste treatment facility; or
2. to render the industrial wastewater "compatible" with an existing control system capability to assimulate.

Other terms that are pertinent to the topic and frequently confused in environmental jargon include:

- Assimulate - to make similar
- Reuse to use again
- Residue something that remains after
- Disposal orderly placement or distribution
- Dump - to get rid of irresponsibly

It is interesting, now, to reference a concept. With an understanding of the above terms and study of Figure 2 it can be rationalized that: to reuse residues (to an optimum degree) would avert the need for their disposal thereby eliminating the need to dump. To achieve reuse, however, requires the assimilation of a residue into a proper environment. The question remaining, therefore, is what is the proper environment for the residue especially an industrial one.

Although, in theory, it may be possible to completely avert the need for disposal of residues from the treatment of industrial wastewater, the current but limiting state-of-the-art does not yet justify the practicality in many cases, particularly for small and medium volume discharges.

The current assessment by some individuals is that to eliminate the discharge of pollutants (toward "zero discharge") would be a severe economic requirement. Such conclusions have been made, in many cases, by ignoring the impact future technology will or could have in alleviating the economic penalty of basic pollution control,

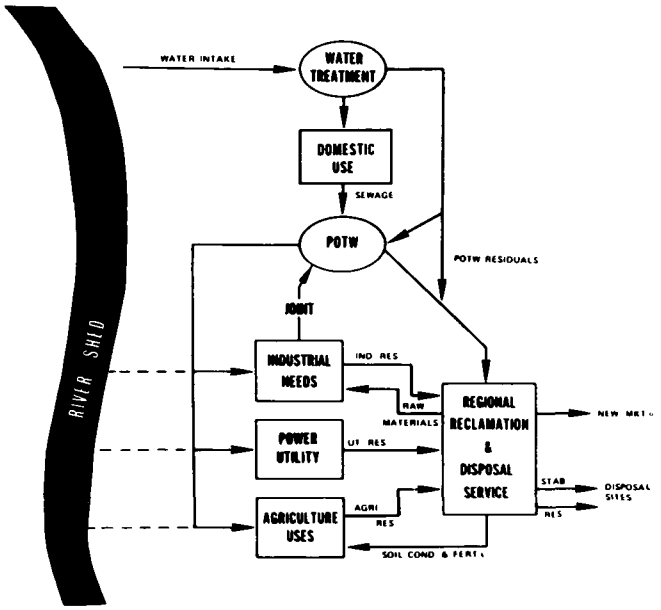

Figure 2: The Basin Cycle.

and/or in addition may not have included proper credits for resource recovery. It is a contention that the net cost of pollution control solutions via the route of water reuse and residue recovery could well be at an acceptably low cost and in some cases actually profitable; after all the majority of industrial pollutants are in fact lost products or raw materials, both of which have an inherent greater economic value than the heterogeneous constituents of domestic sewage residues.

Experience to date with the EPA Industrial Pollution R&D program, coupled with a few basic principles of chemistry and environmental considerations leads one to the following qualitative technological forecast concerning the pollution control techniques that will or are evolving in the near term. Table 1 is a summary of this forecast for selected residue classes by major chemical constituent. The assigned numbers 1-3 indicate the probability of the designated technological approach establishing itself as commercially viable and environmentally acceptable, during the next decade. Table 1 suggests that the residues listed below domestic sludge contain the potential to be managed in an environmentally desirable way at no net cost to an industrial operation. This is to say that the recovery value of the residue ingredients should generate sufficient income to offset the cost of recovery or reconstitution operations. Those listed above domestic sludges will in all probability be difficult to reuse in a significant manner that would result in a net profit over the cost of their stabilization and/or disposal. Although there have been a few success stories with reuse of brines the base line reference used is the domestic organic sludges from sewage treatment plants which are envisioned as resulting in a net cost to produce by-products or reuse in any effective manner. The forecasts themselves are fairly optimistic in that they project that with the proper technological solution

TABLE 1
Industrial Residue Classes and Technology Forecast[1]

RESIDUE CLASS	Residue Reuse (Product Reconstitution)	By-Product Recovery (Conversion)	Residue (Land Disposal) Stabilization	Disposal (Ocean)
1. NaCl	2(2)	3(2)		1(2)
2. Na_2SO_4/SO_3			-	1
3. $CaCl_2/SO_3$	-	2	3	1
4. Biox-Organic Sludges (Domestic)		3	1	2
5. Primary SS Sludges (Domestic)		1	3	2
6. $CaSO_4$	-	2	1	3
7. Biox-Organic Sludges (Chem. Ind.)	-	1	2	
8. Red Muds		1	2	
9. PO_4-Slimes (F^-)	1	2	3	
10. Primary SS Sludges (Food Ind.)	2	1	3	
11. $Fe(SO_4)_2$-$(SO_4)_3$	1	2	-	3
12. $FeCl_2$-Cl_3	1	2		3
13. Cl-Organics	-	1	2	-
14. Cr/Zn/Cu/Pb-Cd-Hg	1	2		

(1)Disposal to land or oceans

(2)Potential solution probability (1 high, 3 low)

the majority of significant residue chemical classes should result in the reuse of the polluting constituents rather than their disposal.

On the municipal front we find considerable anxiety over the cost and adequacy of sludge management practices. In addition, we know that depending upon the disposal technique selected there may be limitations needed to control the quality of the sludge. If land application is under evaluation certain cover crops could not successfully be cultivated and harvested in the presence of large quantities of metals. On the other hand, other crops are more tolerant to the presence of metals.

There is an ever-present complexity cause by a variety of factors which ultimately justifies the selection of one residue management practice over another. The impact of applying pretreatment for the purpose of controlling sludge quality to meet a design norm is concealed in a residue is a quantity of material that remains after a long chain of conveyances and treatment.

Pretreatment: Past and Present

The use of pretreatment as a strategy and as a specific pollutant control technique is certainly not new to the practice of water pollution control. The universal reason for its use has essentially been for the purpose of preventing the discharge of pollutant materials which threaten the safety and are otherwise detrimental to the efficient operation of a treatment works. The specific technologies used were for the purpose of rendering the industrial fraction similar to the norm (domestic wastewaters) either through partial or near complete removal of certain pollutants. The overall purpose for instituting pretreatment was predicated on maintaining some level of aggregated water quality in a receiving body of water. Only, in specific instances can we show that the need for pretreatment resulted from a particular residue management problem. In fact the similar presence of a pollutant and its impact on residue control in one city need not have the same impact in an other system. This inconsistency of impact is easily understood when one considers the varied and complex criteria governing the fate of a pollutant and the use of alternative residue control practices.

We experience considerably more anxiety over residue stabilization and assimilation into our environment than we do about the new frontier of recovery and reuse. The "use it again" option, however, is in its infancy and is a visible research frontier. In the interim there is concern over the "fate and effects" that residues will or could have on the environment. There is an expanding data base suggesting that unstabilized residues (i.e., raw sludges) discharged in the past to our ultimate sinks, the land and sea, have detrimental environmental impacts. In other words, we are now realizing the true cost of past dumping practices.

Having referenced the past philosophy for pretreatment, the nation is now exposed to a supplemental condition for pretreatment as the result of Public Law 92-500, the most recent water pollution control legislation. In this law, a supplemental or minimum level of pollution control is required; that is a level of control that can be achieved by the use of available, practicable and economically achievable technology. The rigorous exercise of developing guidelines and standards to meet this criteria is no doubt familiar to all. One of the guidelines and standards to be developed under the PL 92-500 program are the industrial pretreatment guidelines and standards.

It is difficult to estimate at this point what impact new pretreatment standards will have on residual management practices because the exact nature of the regulations relative to policy, procedures, and numerical limitations is still under review by EPA. It is interesting to speculate that when the regulations are ultimately set forth, the impact on sludge management can be predicted only after taking account of the physical and chemical effects of a treatment system followed by the proper factoring of the sludge management practice. In addition a new wrinkle is introduced via the PL 92-500 logic because not only is the old philosophy of pretreatment for "incompatibles" emphasized but it is proposed that regulations be developed to prevent the discharge of pollutants which will "pass through" a publicly owned treatment works (POTW).

Relationship of Pretreatment and Residues to Other Environmental Concerns

It is necessary to divorce the discussion from the uncertainty of Federal standards and look at the relationships between residue management, pretreatment and the entire environmental control picture. Perhaps one of the more useful viewpoints from which to consider the issues is that of the research technologist. By training he is an engineer, by experience he is seeking new and better ways of achieving a goal, and by discipline he is hopefully unprejudiced by institutional limitations.

In the industrial technology research program of EPA there is an underlying policy of minimizing inter-media pollutant transfer in the development of control technology for the industrial source. This basic premise acknowledges that the fate of pollutants is transferable from media to media as shown in Figure 3, impling that there is a driving force to move residues from media control activities toward the land media or oceans; these sinks containing the potential for ultimate disposal by their inherent capacity for containing and assimilating matter.

The media "relative sensitivity" rating values of 1, 2 and 3 indicate the relative difficulty to confine, control or clean up an emission into the media; one (1) being the most difficult, and three (3) the least difficult. The most visible form of this pollutant shifting trend is the residue or sludge which in most cases is destined for land disposal.

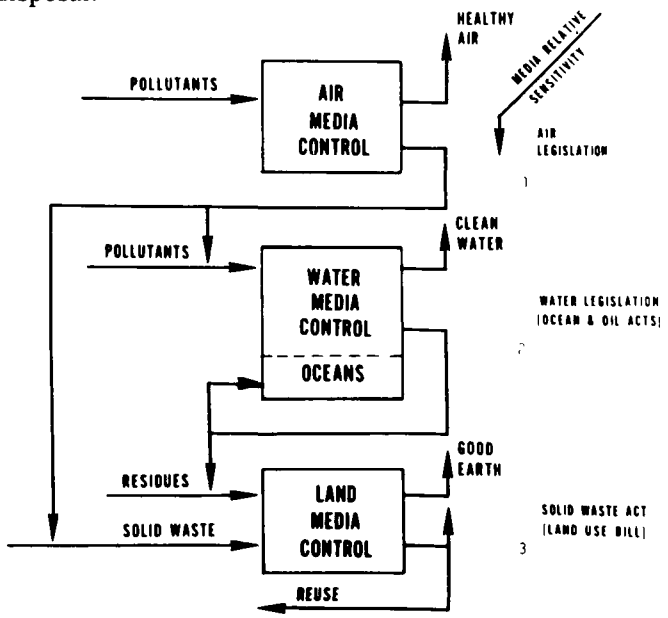

Figure 3: Inter-Media Fate of Pollutants.

In addition to the macro scope of environmental control we find that pretreatment has a unique place in the sequence of regulatory initiatives and in addition is a control option for other water quality problems. If pretreatment is to ascend from the status of a local option to a national strategy it must prove to be a reasonable equilizer between the industrial state-of-the-art for pollution control and that of the municipal sector. Its wide spread use as a national or local control mechanism must not significantly effect: (1) the desirability of maintaining a positive overall environmental impact, and (2) the viability of having combined industrial and municipal systems. The same criteria is curiously relevent to the selection of a residue control practice and the related need for pretreatment (see Figure 4).

Impact Considerations - A Case Study

In further discussing the relationships we will take advantage of a case study that was initiated by the Office of Research and Development of EPA. The investigation, currently about 70 percent complete, was intended to elucidate on the impacts of implementing a Federal pretreatment program in a large metropolitan/industrial area. The City of Buffalo, New York, was entertaining similar thoughts of a study and the EPA and the city initiated a grant project to answer questions of mutual interest.

The only disappointment to date is that one of the significant inputs to the study, the pretreatment regulations, are still not firm. There is, however, valuable information in the form of trends that are visible and will be integrated into the discussion as appropriate.

Consider a situation where a municipal treatment system serves a significant number of industrial customers. The community is potentially subject to a number of water pollution strategies dealing with secondary treatment, pretreatment, user charges, and cost recovery. In making adjustments to the existing industrial and municipal complex so as to comply with regulatory requirements, the objective is to maintain a favorable cost effectiveness, economic achievability, technical viability, and an over-all positive environmental impact. Realizing that residue disposal practices may dictate criteria for pretreatment or that pretreatment for other reasons may effect sludge management, the following considerations are pertinent.

1. What is the significance of industrial wastewaters in the municipal system?

Quantity/Quality

-630 industrial sources (many industries still discharge to waterway)
-23 MGD industrial/180 MGD total
-industrial contribution
13% by flow
25% by BOD
13% by SS
26% by PO
ph 0.9-12.0
COD loadings of 152,000 lbs./day

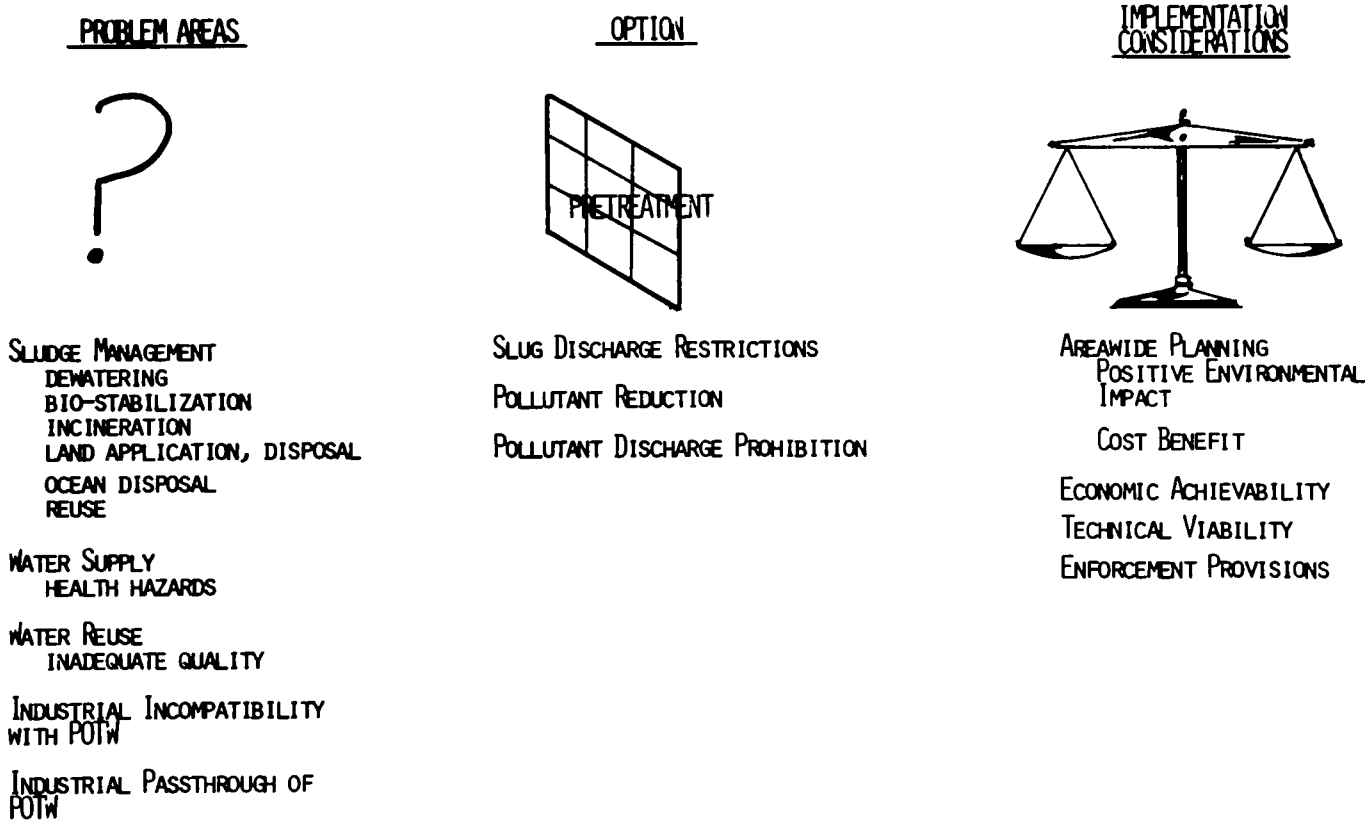

Figure 4: Pretreatment—A Control Option.

Elements	#/Day	mg/l (180 mgd)
Cr_T	877	0.6
Zn	619	0.4
Cu	383	0.3
Ni	140	0.09
Cn	57	0.04
Pb	55	0.036
Cd	8	0.009
Hg	0.3	0.0002
As	0.02	0.00001

Revenues (Anticipated under new ordinance)
-industrial contribution
17% of capital costs
27% of O&M

2. Given the technological control limits to be achieved, what changes in current POTW and industrial discharge practice are needed?

Control limits are yet to be determined ... (Is it secondary treatment or is it secondary plus an added degree of control for the industrial wastewaters based on selected incompatibles? Will the industrial limits be based on concentration or a quantity of pollutant?)

3. Is there a need for pretreatment of industrial wastewaters because of problems in disposing of the sludge?

To be determined . . . .

Current practice (primary treatment) includes sludge digestion and incineration. The municipal system will be upgraded to secondary treatment with $FeCl_3$ assisted precipitation in primary tanks for PO_4 control. No operational problems currently exist relative to incineration or stack gas emissions. Study efforts will continue to evaluate the effect of an increase in metal content in the sludges and the continued viability of incineration.

4. Is an absolute industrial pretreatment strategy the best alternative to achieve new levels of control for the combined municipal and industrial wastewater.

To be determined . . .

It is realized the initial problem, that is to control the incompatible characteristics of industrial wastewaters, can be accomplished at two sites - the industrial site and the POTW. To choose either location arbitrarily would not give proper emphasis to technical and economic achievability and long term viability. A significant judgement point occurs when the degree of control, purpose of control (technology standard, water quality standard) and discharge permit are referenced.

Research Needs

Each of the topics, pretreatment and sludge management, have inherent research needs. In the pretreatment area, the desire to regulate incompatible and pass through industrial pollutants has stressed our understanding of the relationship of the industrial point source and the POTW. The specific research needs can be identified with the following items:

1. Chemical reactions in a POTW;
2. Completeness and consistency of operating data for industrial compatibility;
3. Concept of combining industrial and municipal wastes to take advantage of favorable reactions;
4. Identification of inhibiting, toxic and pass through pollutants;
5. Impact of localized and or regional implementation of a pretreatment strategy.

In analyzing the current pressures for adequate sludge management, we find an immediate concern for the economic achievability of technologies together with a growing interest in the fate and health aspects of pollutant assimilation into the environment. For the long term there is little doubt that new information on the fate and health aspects of pollutants will inturn generate new control requirements at which point the cycle of effect and control begins anew.

CONCLUSIONS

The pressure for environmental imporvements, as partially stimulated by Federal regulatory programs, is focusing more and more attention to the situation of area wide or even combined industrial and municipal point source control. The situation is both existing in many metropolitan areas and is preserved as a future option through areawide and comprehensive planning programs of EPA. Although the actual mixing of industrial and municipal wastewaters and integration of subsequent control systems is not the only way to achieve areawide management of point sources, it is the most perplexing in terms of making adjustments or changes to meet new regulations.

The current concerns for adequate sludge management practices as prejudiced by the presence of industrial components and the more basic concern for the degree of industrial incompatibility relative to technology standards are examples of current topics requiring the attention of the research community and equitable analysis from those that write the laws, develop the regulations and ultimately enforce the programs.

It is worthy to consider that the two mandates of the 1970's, economic achievability and resource conservation, are two factors which show signs of significantly influencing both research and implementation of programs dealing with industry and its relationship with the environment.

FOR CALIFORNIA—A MODEL INDUSTRIAL WASTE ORDINANCE

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Control of industrial wastes entering municipal sewage collection and disposal systems has been a concern of engineers for many years. The probelm has been made more acute in recent times through the simultaneous growth of industries, increasingly strict receiving water requirements for waste dischargers and much more sensitive and sophisticated municipal waste treatment processes. Passage of Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972, made control of industrial wastes a major element in the nation's goal of "Clean Water". Construction grant funding is contingent upon establishment of effective industrial waste regulations.

The national emphasis toward better industrial waste controls did not find California industries and municipal waste dischargers unprepared. Substantial efforts have been made toward better industrial waste control and treatment by the California Water Pollution Control Association (CWPCA). In the fall of 1973, a Uniform Ordinance Subcommittee was formed of members of the CWPCA's Industrial Waste Committee to explore the feasibility of uniform practice in industrial waste control. The subcommittee was composed of members from regulatory agencies, public sewerage agencies and industrial associations.

Work on the Uniform Ordinance was assisted by the Bay Area Sewage Services Agency (BASSA), a nine-county regional agency created by the California legislature to develop and implement water quality management plans for the San Francisco Bay region. As part of its regional services program, BASSA has undertaken a source control program to assist local and subregional entities in surveillance, planning and education. The Model Ordinance is a vital component of this program. Early work of the Uniform Ordinance Subcommittee immediately recognized the need for regional uniformity in industrial waste control. Industrial waste regulations varied from one neighboring jurisdiction to another even though treated effluents were being discharged into the same receiving body after similar degrees of treatment. Furthermore, many jurisdictions were in the process of revising or updating their own existing regulations to conform to new state and Federal requirements for construction grants. The Subcommittee felt that timely preparation of a model ordinance suitable for direct adoption or adaptation by local agencies with as few changes as necessary, would be a valuable public service, with the following benefits:

- Establishment of uniform practices for enforcement and to facilitate disposal of waste pollutants.
- Promotion of greater efficiency among regulatory and municipal agencies in carrying out industrial source control programs.
- Provision of a basis of equity and fairness to industry and private wastewater dischargers who must comply with regulations which can vary from community to community.
- Elimination of undesirable relocations of industries from one jurisdiction to another.

As a basis for the model, the Subcommittee took a draft ordinance being considered by the East Bay Dischargers Authority—a joint powers subregional agency comprised of the cities of San Leandro and Hayward, and the Castro Valley, Oro Loma and Union Sanitary Districts—and added critical review and comment from all parts of the region. This included recommendations of Federal and state regulatory agencies, industry, cities and special districts. In writing the model ordinance, efforts were made to incorporate latest state and Federal regulations. All provisions are designed with flexibility to meet Federal and state industrial cost recovery requirements.

Response to the model ordinance has been enthusiastic and widespread since its presentation at the April 1974 convention of the California Water Pollution Control Association, where through the subsequent months, demand for the document both within and outside California has necessitated a second printing. Comments have been received from many agencies and individuals, which will be considered in a future revision of the Model Ordinance. Acceptance of the ordinance by local agencies has been encouraging. In the Bay Area, the large

East Bay Dischargers Authority and its agencies, and several other dischargers in the region have adopted the model ordinance with minor changes.

Highlights of the Model Ordinance

Prohibitions

Prohibited hazardous, toxic and incompatible wastes are wastes which can cause any of the following: fire or explosion; flow obstruction or plant damage; endanger life; create nuisance; pollute air; interfere with treatment processes; prevent effluent or sludge reclamation; adversely affect receiving waters; cause local agency's treatment works to be in violation of any statute or regulation; or overload collection or treatment facilities. Storm and cooling waters are also prohibited except under special permit issued by the local agency. Special permission is also required for discharge of radioactive wastes and wastes from holding tanks. Garbage grinder usage is limited to shredding of food wastes prepared for consumption on the premises or under special permit. Garbage grinders shall not be used for shredding plastic, paper products, inert materials or garden refuse.

Effluent Limitations

Limitations are placed upon wastewater discharges to assure control of toxic or hazardous materials while continuing to provide an acceptable level of public service to all segments of the community. Limits for heavy metals are based upon ocean water discharge requirements and allow for a 10:1 dilution (or removal) in the community collection and treatment process (see Table 1).

TABLE 1
Effluent Limitations

	Allowable Concentration mg/l
Arsenic	0.1
Cadmium	0.2
Copper	2.0
Cyanide	1.0
Lead	1.0
Mercury	0.01
Nickel	1.0
Silver	0.2
Total Chromium	0.5
Zinc	3.0

Other prohibitions include temperature, oil and grease, pH, chlorinated hydrocarbons and phenols, as shown in Table 2.

Provisions are included for effluent limitation under Public Law 92-500 to apply in instances where these are more stringent than the Model Ordinance.

Compatible Pollutants

Treatment plants are designed to meet the needs of the communities served. Fundamental to waste treatment processes is the disposal of so-called "compatible pollutants". These are defined in the Model Ordinance as biochemical oxygen demand (BOD); suspended solids; pH (greater than 6.0); fecal coliform bacteria; and other pollutants identified in NPDES permit if compatible to local treatment.

TABLE 2
Other Limitations

	Limits
Temperature	150°F (65.5°C.) max.
Oil and grease (vegetable origin)	300 mg/l max.
Oil and grease (petroleum origin)	100 mgl/l max.
Chlorinated hydrocarbons*	0.02 mg/l max.
Phenolic compounds*	1.0 mg/l max.

Determination of Wastewater Volume

User charges are applied against the total amount of water used from all sources unless discharged to community sewers. The total amount of water used from public and private sources is determined by means of meters installed and maintained at the expense of the user and approved by the Agency.

For users where significant portions of water received from metered sources do not flow into the community sewer user charges are applied against net volume discharged into the sewer.

For users where it is unnecessary or impractical to install meters, wastewater volume may be determined upon estimated prepared by the Agency. These are based upon rational determinations in consideration of such factors as number of fixtures, population equivalent, annual production of goods and services or other determinants of water use.

Administration

Application of source control management to a waste treatment system must rely upon effective administrative procedures. Fundamental to the Model Ordinance's approach is a system of permit for major wastewater dischargers and a practical reporting system. Emphasis should be placed upon development of a spirit of cooperation among industrial users and a sense of awareness of the problems of municipal waste treatment.

Figure 1 shows the permit process which begins with the user completing a permit application questionnaire. The local agency determines if the user is a major contributor, that is, if the industry meets any of the following criteria: (1) flows in excess of 50,000 mgd; (2) flows in excess of five percent of treatment plant design capacity or capability to treat; (3) discharges toxic pollutants in toxic amounts; or (4) have a significant impact, either singly or in combination with other industries, upon the collection or treatment system.

Wastewater Discharge Permits

Discharge permits may contain the following: (1) rates and charges; (2) average and maximum waste constituents and characteristics; (3) limits on flow rate and time of discharge or requirements for flow regulation and equalization; (4) inspection and sampling facilities; (5) monitoring programs; (6) discharge reports; (7) mainte-

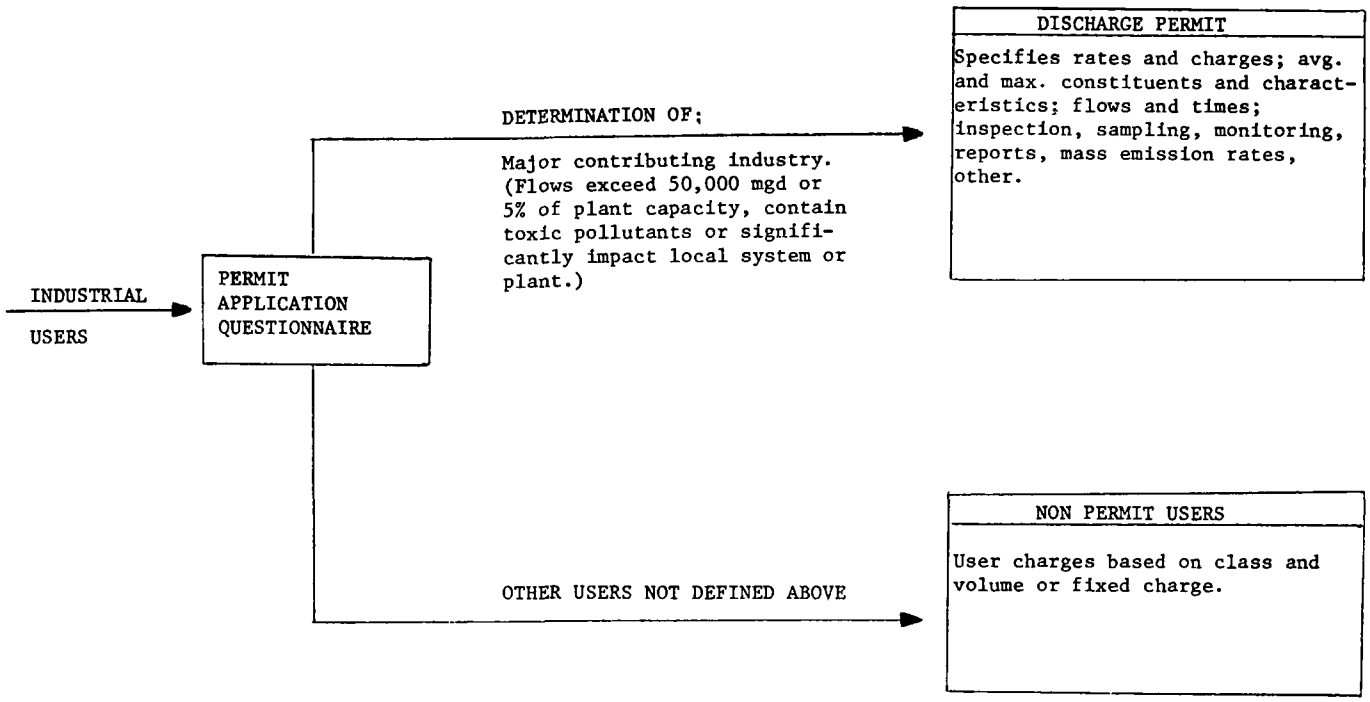

Figure 1: The Wastewater Discharge Permit Process for Industrial Source Control.

nance of plant records; (8) mass emission rates; (9) other conditions as may be appropriate.

Permits are issued to specific users for specific operations. Permits cannot be reassigned, transferred, sold, moved to new premises or applied to a changed operation.

Permits are issued for specified periods of time not to exceed five years. Permits may be revoked for the following reasons: (1) incorrect or improper reporting of waste constituents and characteristics; (2) failure to report significant changes in operations or wastes; (3) refusal of access to premises for inspection or sampling; and (4) violation of permit conditions. Monitoring facilities may be required to be built at the user's expense for inspection sampling and flow measurement. Local agency representatives shall be provided reasonable access at all times for purposes of inspection or sampling.

Users shall make wastewater acceptable before discharging to sewers. Facilities required to pretreat wastewater to acceptable levels shall be provided and maintained at the user's expense. Plans showing pretreatment facilities and operating procedures must be acceptable to the local agency before construction, but review of such plans and operating procedures does not relieve users from the responsibility of modifying the facility as necessary to produce effluents acceptable under the provisions of the Model Ordinance. All subsequent changes in pretreatment facilities or methods of operation shall be reported to the local agency.

Every user shall provide protection from accidental discharge of prohibited materials or other wastes. Detailed plans showing facilities and operating procedures to provide protection shall be submitted to the local agency for review, and must be acceptable before construction.

Information and data on users obtained from reports, questionnaires, permit applications, permits and monitoring programs and from inspections shall be available to the public or other governmental agency without restriction unless users specifically request and demonstrate that the release of such information would divulge information, processes or methods which would be detrimental to the user's competitive position.

User Charges and Fees

Users are classified by assignment to a "User Classification" category according to the principal activity conducted on the premises based on typical wastewater constituents and characteristics. The purpose of classification is to facilitate regulation if discharges based on constituents to provide effective means of source control, and to establish a system of user charges and fees to insure equitable recovery of the local agency's cost. Wastewater constituents and characteristics may include, but not be limited to the following: suspended solids, BOD, COD, oil and grease, and chlorine demand.

User classification charges may be adopted for each category based upon charges for average wastewater constituents and characteristics. The charges for each wastewater constituent and characteristic established by the local agency and set forth in the local agency's schedule of charges and fees which may include: (1) user classification charges; (2) fees for monitoring; (3) fees for permit applications; (4) appeal fees; and (5) charges

and fees based on wastewater constituents and characteristics including industrial cost recovery provisions of the Federal Act.

Users who are not required to obtain Wastewater Discharge Permits must pay applicable user charges as established by the Agency. These shall be determined by multiplying user classification charge by the wastewater volume. The local agency may elect to set a fixed unit charge for certain user classifications based on wastewater constituents and characteristics. The minimum charges should be based upon typical average strength of domestic wastewater.

Enforcement

Enforcement effort should be directed toward practical correction of waste discharge problems with emphasis placed upon prevention rather than punishment. Local authorities must consider sanctions such as termination of service, misdemeanor penalties, civil damages, etc. in the overall context of the laws under which their individual agencies operate. The severest criticism of the early version of the Model Ordinance came from legal counsel from special districts whose organic acts differed on matters of enforcement and penalties.

Accidental discharges in violation of the Model Ordinance must be reported immediately by the user to enable possible countermeasures to be taken. Appropriate followup should be made, including advising plant employees of permit requirements and accidental discharge prevention measures.

When a discharge of wastewater has taken place, in violation of the Ordinance, or the Wastewater Discharge Permit, the local agency may issue an order to cease and desist, and direct that those persons not complying with such prohibitions, limits, requirements, or provisions to: (1) comply forthwith; (2) comply in accordance with a time schedule set forth by the Agency, or (3) take appropriate remedial or preventive action in the event of a threatened violation.

Abatement of violating circumstances relies upon court action, assessment of charges for local agency repair costs, civil damages not to exceed $6,000 for each day in which violations occur. Any misrepresentation of facts or interference with collection monitoring or inspection data is an ordinance violation subject to its penalties. Following notice and hearing, the local agency may terminate service.

SUMMARY

The Model Ordinance Subcommittee encouraged by the response to its efforts is in the process of preparing an updated version of the Model Ordinance which should be available later this year. Many members of the Subcommittee consider the Model Ordinance an essential first step toward development of a broadly based industrial waste code capable of easy adoption by reference by local agencies. Questionnaire and permit forms have been prepared in a convenient booklet format to assist Model Ordinance users. Copies of the Ordinance and other information may be obtained from the Bay Area Sewage Services Agency, Hotel Claremont, Berkeley, California 94705.

INSTITUTIONAL PROBLEMS OF THE SMALL TREATMENT PLANT

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INTRODUCTION

This is a real problem. It happened in a real community. For obvious reasons the names of the community and the involved state are omitted. Some people here may recognize the problems as their own. The story begins some eight or nine years ago when the community started to grow and the existing plant became overloaded. At that time, the treatment plant had a capacity of about one mgd. In the middle 50's, as with all communities, they really started to grow and the plant soon became undersized. The community engaged a consulting engineer. In this case, a local consulting engineer that actually lived in the community. The consulting engineering firm designed the plant on the basis of the requirements of the Clean Water Act of 1965 and the various state laws of that time period. Unfortunately, soon after the plant was placed in operation, the Water Pollution Control Act and Amendments of 1972 (PL 92-500) became the national law and the environmental laws of the State also changed dramatically. In addition to the limitation of the design due to the laws of the time, the plant also had some unique design problems; the operators had operational limitations in regard to the new unit operations planned for the enlarged plant and the state and EPA played various roles to compel compliance of performance for both the original design and the new legislation.

The Problem

As mentioned, the plant was a one mgd. It included activated sludge with some digestion capabilities. The engineer designed the new plant to be a six mgd activated sludge plant with what he thought was also future capacility to include some phosphorus removal. The design replaced digestion with wet oxidation. The engineering report was submitted to the community about the end of 1967. By the time the city approved the design it was well into 1968. Construction did not actually start until 1969. The plant went into operation in 1971, and about a year later, in 1972, PL 92-500 became the nation's law with its "best practical treatment" and its "best available treatment" concepts.

Since this plant was located in the Great Lakes Basin, "best practical treatment" required extensive removal of phosphorus. PL 92-500 also required sewer infiltration reduction programs, industrial surveys and sewerage treatment cost participation (described in detail by Mr. Charles Ris in a subsequent paper) determination of compatibility of industrial wastewater sources with the municipal treatment plant, and a fair share charge for the industrial contributors. Negotiations were initiated in 1972, between the community, the state, and the Federal government (and are still continuing in 1975) for the plant to be upgraded in accordance with PL 92-500 and to correct difficult sludge handling problems. Table 1 indicates the chronology just mentioned.

TABLE 1
Plant Chronology

	EXISTING PLANT A/S WITH DIGESTION 1 MGD
1966	CLEAN WATER ACT
1967-8	ENGINEERING FIRM SUBMITTED ENGINEERING REPORT TO CITY WHICH WAS ACCEPTED
1969	CONSTRUCTION STARTED
1971	PLANT WENT INTO OPERATION 6 MGD
1972	PASSAGE OF 92-500
	BPT BAT INFILTRATION REDUCTION INDUSTRIAL SURVEYS
	PERMIT NEGOTIATIONS
1975	EPA
	OEPA

There are real villans and heros in this episode, sometimes changing roles as you will see. As mentioned previously, the new plant was designed as a six mgd waste activated sludge plant with phosphorus removal capability. Sludge is recycled back to the primary tanks, periodically withdrawn to a concentration tank. It is then pumped to the wet oxidation unit for heat processing. The heat treated sludge is decanted in a small storage vessel, and then applied to a new vacuum filter with the filtrate going back to the head end of the plant, and the sludge being disposed of in a sanitary landfill. However, as the plant was designed for phosphorus removal, and due to the new requirements of PL 92-500, the state is requiring that the community reduce its phosphorus concentration in the effluent from about three milligrams per liter to about 0.3 milligrams per liter. Unfortunately, the existing plant already has fantastic sludge disposal problems stemming from many sources, but principally related to the sludge handling system. Because the community already had received a construction grant from the Federal government and the state, it now had a very low priority for receipt of any additional funds for upgrading the plant. Consequently, there probably is no chance of the city getting additional funding for many years. In addition, the Federal government is withholding $175,000 of the remaining original construction grant funds until the plant is upgraded as they specified.

The design engineer thought he was designing a plant on the basis of requirements existing in 1968-69, and those that he could reasonably project. Besides not being able to project the requirements of PL 92-500 into the design of the new plant, the designer also did not provide adequate flexibility in the sludge handling process system in the plant. Only one new filter was added to an existing 15 year old vacuum filter. About a year after the new plant went into operation, the old filter went out of operation. Because of the age, parts became increasingly difficult to get, and it finally became too expensive to keep running.

There is also only one wet oxidation unit, which is sized very close to the existing operating conditions of the plant. Moreover, the afterburners on the off-gas system were improperly designed. They provided a gas temperature of only 800°F instead of the 1400° to 1800°F necessary to eliminate all odors. Moreover, the boiler feedwater sub-unit supplier did not conduct adequate boiler feedwater analyses. As a result the heat exchange units frequently corroded, plugged up or malfunctioned. In addition, the same personnel that operated the one mgd activated sludge plant were available to operate this plant with little or no training in the areas of boiler feedwater control and pressure vessel operation. They could not properly cope with the needs of the thermal units or their peculiar sludge handling requirements. This inadequate training resulted in many problems developing with the boiler feedwater supply and the wet oxidation units. The result was that these two units caused the sludge handling portion of the plant to be inoperative about 75 percent of the time.

As mentioned previously, sludge storage is inadequate. Treated sludge lies around the outside of the buildings until it is loaded onto a truck to be hauled to a sanitary landfill. Odors abound around the treatment plant and the neighborhood. The local residents continually decry the odorous atmosphere around the plant and the neighborhood even when the thermal units operate, so there is a reluctance to operate these units even when they perform as designed. Due to the odor and because the thermal units are inoperative most of the time the sludge is recycled to the head end of the plant. The entire treatment plant must then be operated as an extended areation plant, and the one vacuum filter that is in operation must handle the entire sludge requirements. In addition, the high wet weather flow diverted to the plant is about ten mgd (as compared with the dry weather flow of about three mgd). This creates a flushing effect which from a plant operators point of view may really be "heaven sent". It momentarily solves all sorts of sludge problems.

On top of the sludge problem indicated, the state and EPA are insisting on phosphorus removal and odor reduction. This is in spite of the fact that increasing phosphorus removal will add 50 percent to the existing sludge handling problem and *really* make the remaining units undersized and probably compound the plant operation, sludge dewatering and odor problems.

It should be emphasized that the community does wish to comply. It wishes it had a well operated plant without the aforementioned problems. It will initiate a wastewater survey for the fair share contribution from the industries just as the Federal law 92-500 indicates it should. The city also wishes to incur no additional capital investments, and sorely wishes to minimize plant operating costs concomitant. They also wish to obtain additional sources of revenue. As this is an election year the city would like to be able to announce a reduction in residential sewerage charges. And of course they would like to receive the $175,000 EPA is still withholding so it can make some of the costly modifications. The municipality did resolve its odor problem rapidly. They are now using masking agents at an annual cost of more than $20,000, and will probably continue to do so through the critical warm weather or until the forthcoming elections.

In summary, almost all of the problems mentioned above stem from those problems associated with the sludge handling system and unit operations, as indicated in Table 2. If the various sludge handling unit operations were designed correctly and they were operated satisfactorily there would be fewer problems.

The solutions to the various treatment plant ills and the conflicting requirements between the state's desires and the city's ability to comply (at least through the eyes

TABLE 2
Sludge Related Problems

1. NO REPLICATION OF SLUDGE HANDLING EQUIPMENT
2. INADEQUATE STORAGE
3. INADEQUATE THICKENING
4. MAKESHIFT SLUDGE TRANSFER
5. QUESTIONABLE CAPACITY OF SLUDGE FILTERS
6. USE OF ACTIVATED SLUDGE SYSTEM FOR SOLIDS STORAGE
7. ONE HEAT TREATMENT UNIT WITH ASSOCIATED PROBLEMS
   a. Boiler heat exchanger coils continually corrode
   b. Afterburner is inadequately sized and combustion temperature is too low creating odors
   c. Solids separator (oxidized sludge) source of problems
   d. Scaling on inside of pressure vessel
   e. Inadequate training of personnel
   f. Inadequate assignment of personnel by plant to operate unit
   g. System sized too closely to plant needs
   h. Inadequate heat treated sludge storage

TABLE 3
Short Term Solutions to Plant Problems

1. HEAT TREATMENT UNIT (HTU) MANUFACTURER PLANT TRAINING AT NO COST
2. PLANT ASSIGNED ONE OPERATOR TO BECOME INTIMATELY FAMILIAR WITH UNIT
3. CHEMICALLY TREAT SLUDGE AND USE THE ONE VACUUM FILTER TO MAXIMUM CAPACITY
4. USE HTU AS STANDBY
5. SHIP SLUDGE OFF-SITE TO LANDFILL OPERATION THAT HAS PERMIT (AT 3.5¢ PER GALLON WET OR $4.5/CU.YD. FOR SOLID)
6. RECYCLE WASTE SLUDGE TO PRIMARY SYSTEM AND OPERATE SYSTEM AS AN IXTENDED AERATION PLANT
7. NO LIME ADDITION FOR PHOSPHOROUS REMOVAL
8. NEGOTIATE WITH STATE FOR
   A. PLANNING FUNDS
   B. TIME EXTENSION ON P REMOVAL
   C. CONSTRUCTION GRANT

TABLE 4
Long Term Solutions to Plant Problems

1. INDUSTRIAL SURVEY
2. INFILTRATION SURVEY
3. LABORATORY EXPANSION
4. UPGRADE PERSONNEL
5. OBTAIN PERMANENT OFFSITE SLUDGE DISPOSAL ARRANGEMENTS
   A. TO LANDFILL
   B. TO FUTURE REGIONAL TREATMENT PLANT
6. REDESIGN SPECIFIC UNITS IN THE PLANT
7. REPLICATE CRITICAL UNITS
8. MEET ALL FEDERAL AND STATE REGULATIONS

of the community) resolved themselves into short term and long term solutions, as indicated in Tables 3 and 4.

The principal sludge treatment method suggested revolves around recirculating the sludge to the plant, chemical treatment, and dewatering with the one vacuum filter that is available. The thermal units would be used as a back-up when the vacuum filters were down for maintenance or repairs.

Offsite disposal was considered for both concepts because of the nature of the heat treatment equipment, the inflexibility of the sludge transfer system, inadequacy of sludge storage, the odor problems, and the fuel costs associated with the operation of the heat treatment unit. However, it was necessary to dewater to the maximum extent possible. At costs of 3.5 cents/gal or 4.5 cents/C.Y., annual sludge disposal costs could vary from about $120,000 for a sludge with six percent solids to $16,500 for a sludge with 30 percent solids. The relative success achieved with chemical addition to the highly oxidized (recirculated) sludge made that operation relatively simple, provided a 30 percent solids cake and made offsite disposal of the dewatered sludge attractive.

SUMMARY

Given a reasonable time and some cooperation from the U.S. Environmental Protection Agency and the State Environmental Protection Agency, I am sure that everybody's concerns about compliance and the proper performance from this plant will be satisfied.

REGIONAL WASTEWATER SOLIDS MANAGEMENT PROGRAM LOS ANGELES-ORANGE COUNTY METROPOLITAN AREA

David Burack
Los Angeles - Orange County Sludge Program
Whittier, California

I am grateful for a chance to tell you about a major sludge study which is just getting off the ground in the Southern California area. Perhaps those of you with similar problems will be interested in the conduct of this study. You might wish to provide information which will help us in our task.

Lately there has been a lot of talk about the ultimate disposal of wastewater solids originating in the Southern California coastal area. The two horns of the dilemma are familiar to all of us.

On the one hand, restrictions regarding sludge disposal are becoming more stringent. In California, in addition to P.L. 92-500 and the Marine Protection, Research and Sanctuaries Act, we have the State's "Water Quality Control Plan for Ocean Waters of California." This plan prohibits, outright disposal of sludge to the ocean as a long-term solution.

On the other hand, Federal requirements to upgrade municipal wastewater treatment plants and projected growth patterns will result in a substantial increase of wastewater solids.

Restrictions on disposal plus increase in production equals one big problem.

Sludge processing and disposal projects, now under way or in the planning stages in the Los Angeles region, appear likely to provide immediate short-term solutions to this problem.

For the long-term solution, a Step 1 grant under Section 201 of P.L. 92-500 has been secured for a basinwide wastewater solids management program, to be conducted under a Joint Powers Agreement by the three major wastewater agencies in the region, with assistance of the State of California and the United States Environmental Protection Agency.

The Program will study all feasible alternative solutions to the long-term disposal of wastewater solids originating in Los Angeles and Orange Counties.

Figure 1 shows the study area, which includes all of Los Angeles and Orange Counties. The area is 120 miles long in its greatest extent and runs 30 to 80 miles in from the ocean. All together, this is an area of about 4,800 square miles with a population of 8.5 million. We also intend to look at potential reclamation or disposal sites and conveyance routes beyond these boundaries.

The dimensions of the problem now and in the future are shown in Figures 2 and 3. The three major wastewater agencies now generate about 1,200 tons of sludge per day on a dry solids basis (Figure 2). Of this, about 700 tons is discharged to the ocean, either in sludge-only or sludge-plus-effluent ocean outfalls. About 180 tons goes to landfills or is composted and sold to nurseries and home gardeners. The balance of the 1,200 tons are organics removed during anaerobic digestion.

If and when state and Federal requirements are met, the solids disposal picture will change drastically (Figure 3). By 1985, our estimates indicate an increase of 100 tons over present production, due to population growth. Of the total 1,300 ton input, 100 tons will still go to the ocean even with full secondary treatment, 800 tons will go the land, with the balance volatiles lost during digestion.

From 700 tons to sea . . . to 800 tons to land. Here comes the sludge, all right. Can we compost it? Can we pyrolize it with garbage and possibly get some energy or metals credits? Or are we going to face a worse uphill environmental battle than now with ocean dumping? These are just some of the questions our Program hopes to answer.

Figure 4 shows the organization of the program. The State Water Resources Control Board representative chairs the Policy Board. Other members include a representatives from: (1) Region IX, EPA; (2) Los Angeles County Sanitation Districts; (3) City of Los Angeles; and (4) Orange County Sanitation Districts.

The three local agencies mutually agreed that the Sanitation Districts of Los Angeles County would act as lead agency. The lead agency provides the routine administrative functions required by the Policy Board and the Project Manager.

The Project Manager is directly responsible to the Policy Board and has overall responsibility for the conduct of the study and preparation of the final project re-

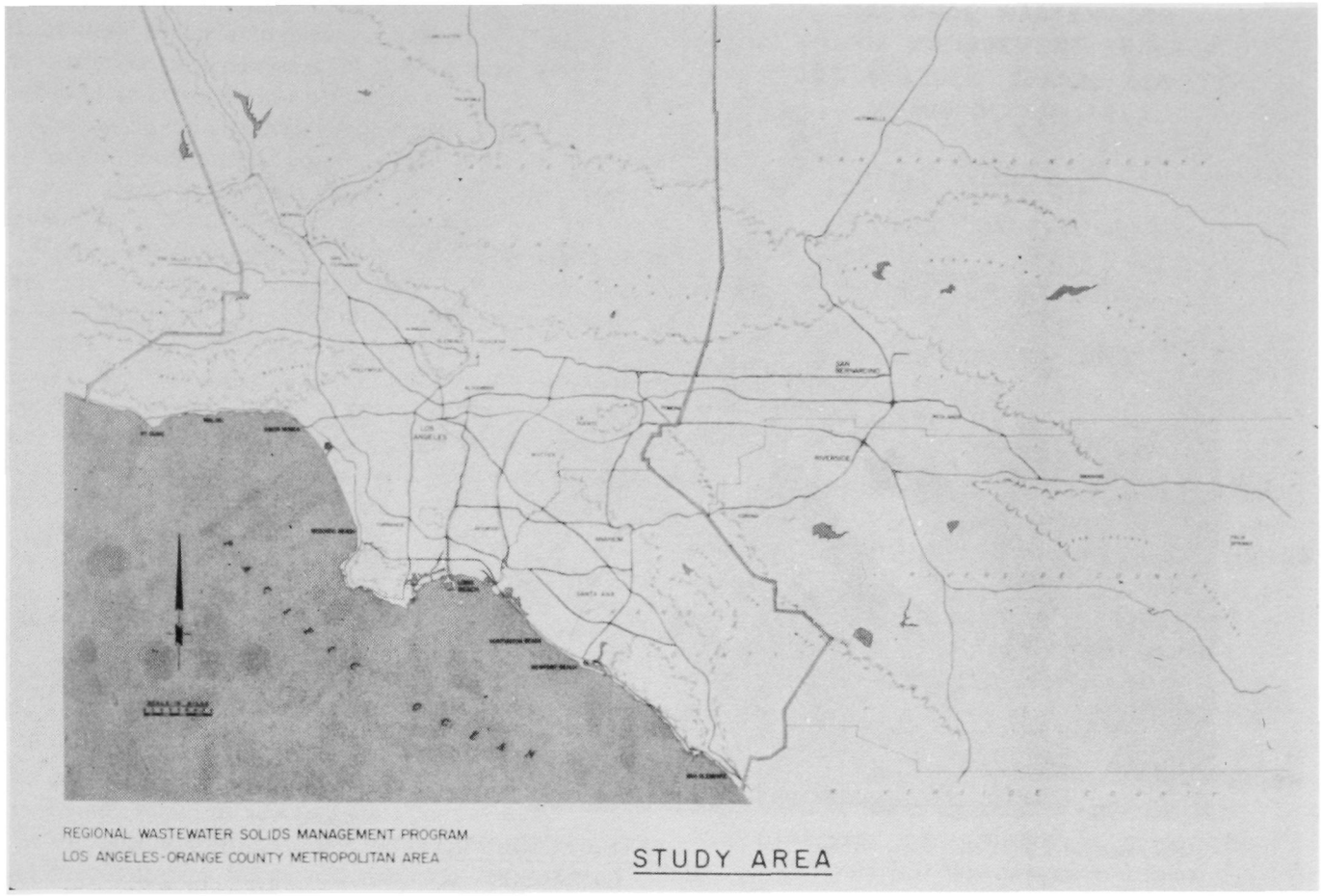

Figure 1: Study Area.

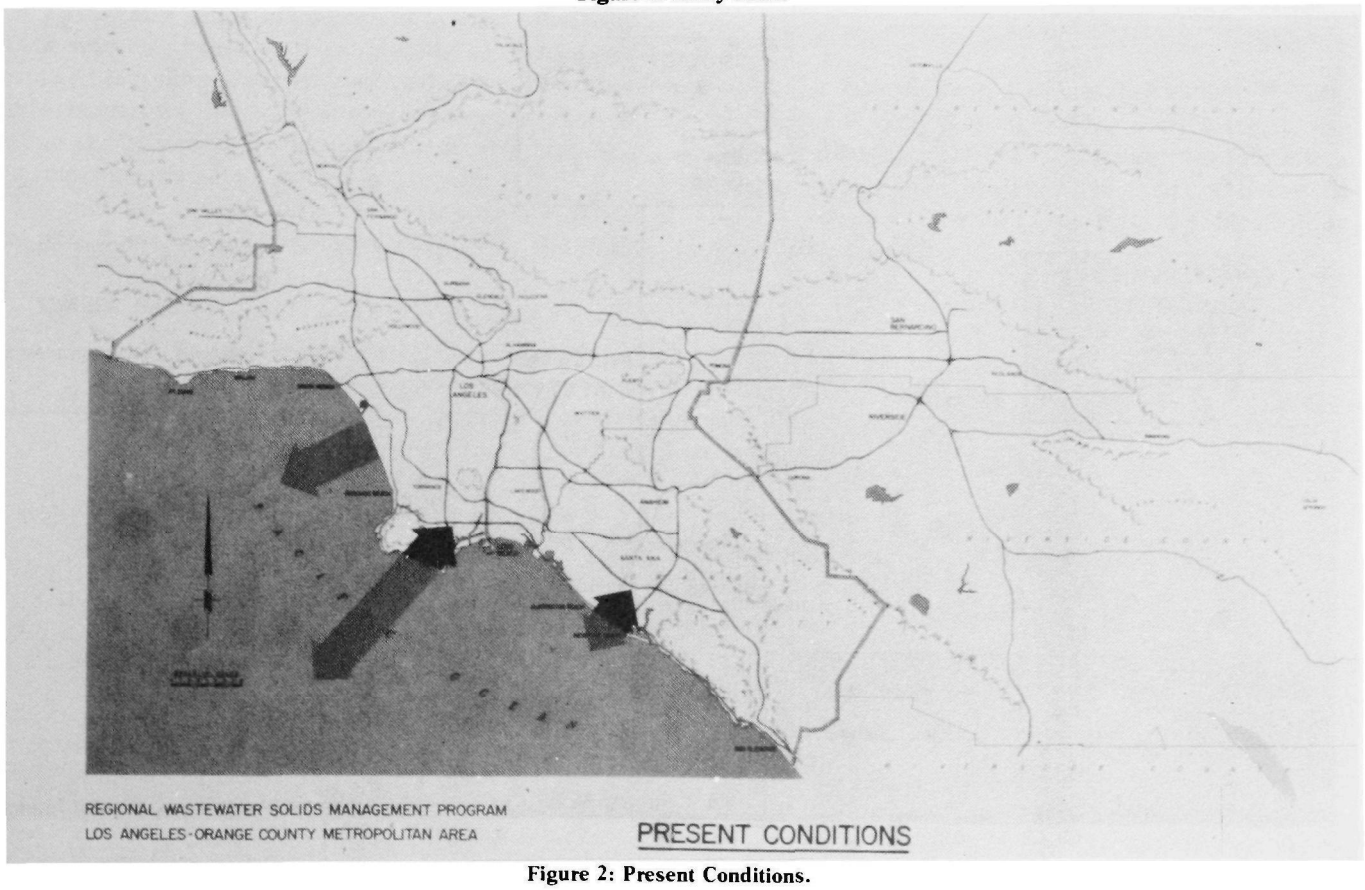

Figure 2: Present Conditions.

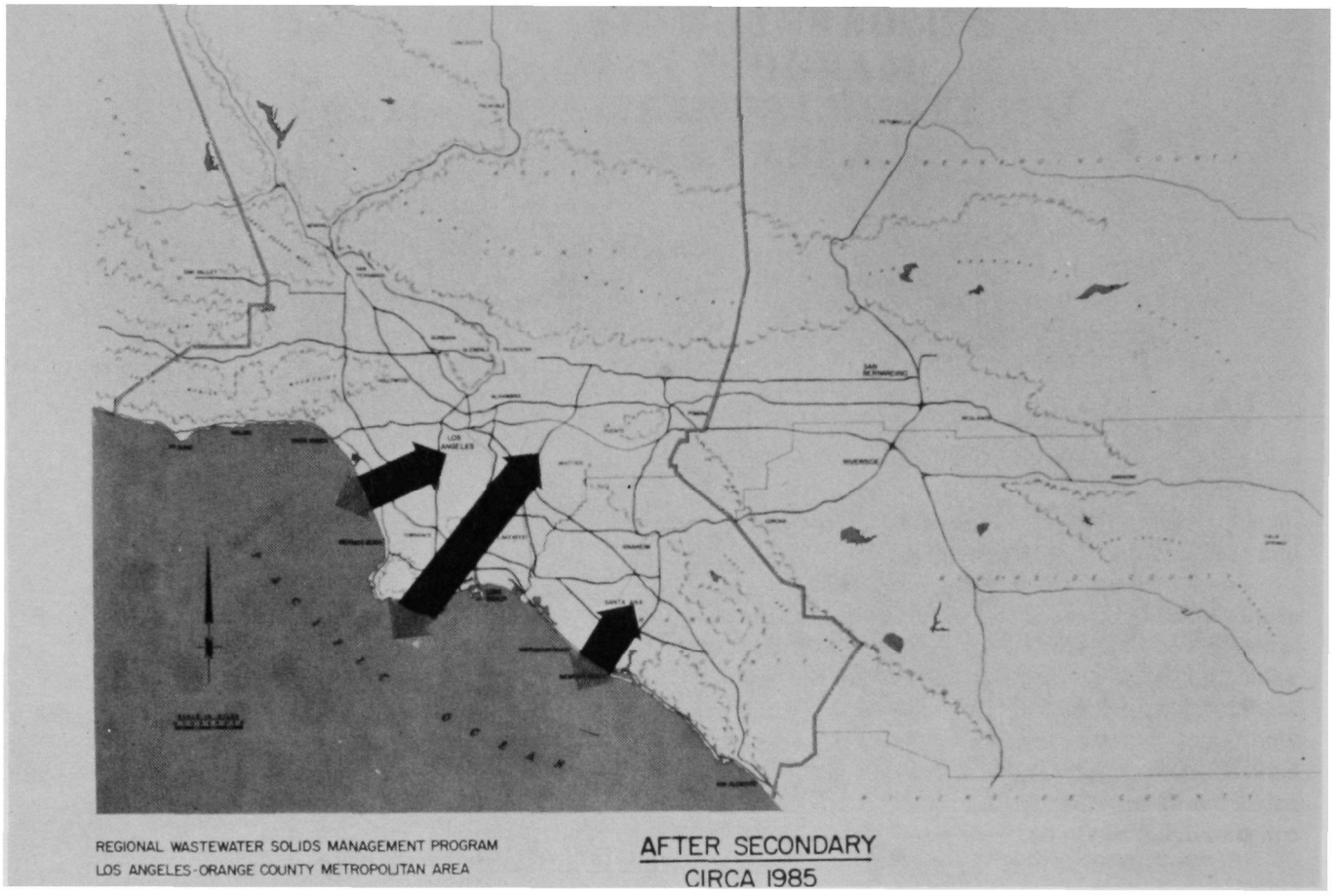

Figure 3: After Secondary (Circa 1985).

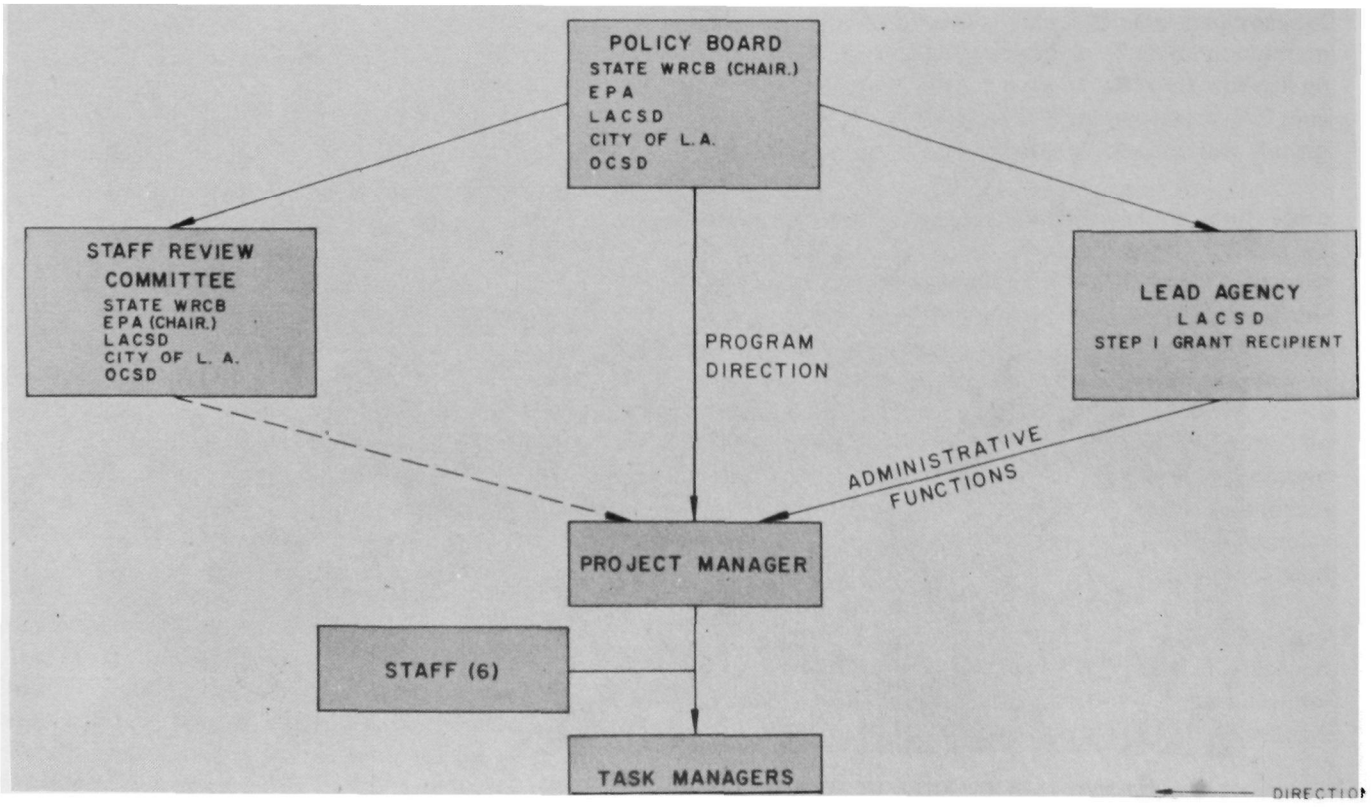

Figure 4: Organization of Regional Wastewater Solids Management Program, Los Angeles—Orange County Metropolitan Area.

port. The Project Manager is assisted by a Staff Review Committee, which is comprised of representatives from the participating agencies and has his own staff of four technical and two clerical personnel.

Also serving in an advisory capacity will be many interested individuals and organizations. We aren't sure yet how these groups will mesh with the overall program, hence, the drawing is not complete.

Figure 5 shows the meat of the program, the series of tasks to be considered during the study. These tasks will be performed by the participating agencies or by outside contracts. The Project Manager is responsible for assigning and scheduling tasks, in addition to personnel and budget items. Each task group will have a designated task manager, whose activities will be coordinated by the Project Manager and his staff. As indicated, disposal or recycling alternatives to be studied and evaluated are:

- Recycling of wastewater solids for agricultural uses, reclamation of soils, and use as soil supplement.
- Disposal of wastewater solids to land, i.e., sanitary landfills, evaporation basins, and spreading on dedicated land.
- Disposal of wastewater solids to ocean.
- Incineration and pyrolysis processes for volume reduction and resource recovery.
- Conditioning, dewatering and composting.

In conjunction with these alternatives, transportation and processing of solids and disposal of industrial sludges will also be studied.

A wastewater solids management system ultimately will be selected, based on the evaluation of various disposal and recycling alternatives, consistent with identifiable constraints. The system may be a combination of various sludge handling, disposal, or recycling methods, and may be regional or local in concept.

The schedule for the study presently covers a three-year period, with completion expected in 1978. The work involved is now estimated to cost two million dollars. However, it is likely that this estimate will increase significantly when the detailed work program is submitted, especially since the question of disposal of industrial sludges, not now included in the plan of study, will be considered in depth.

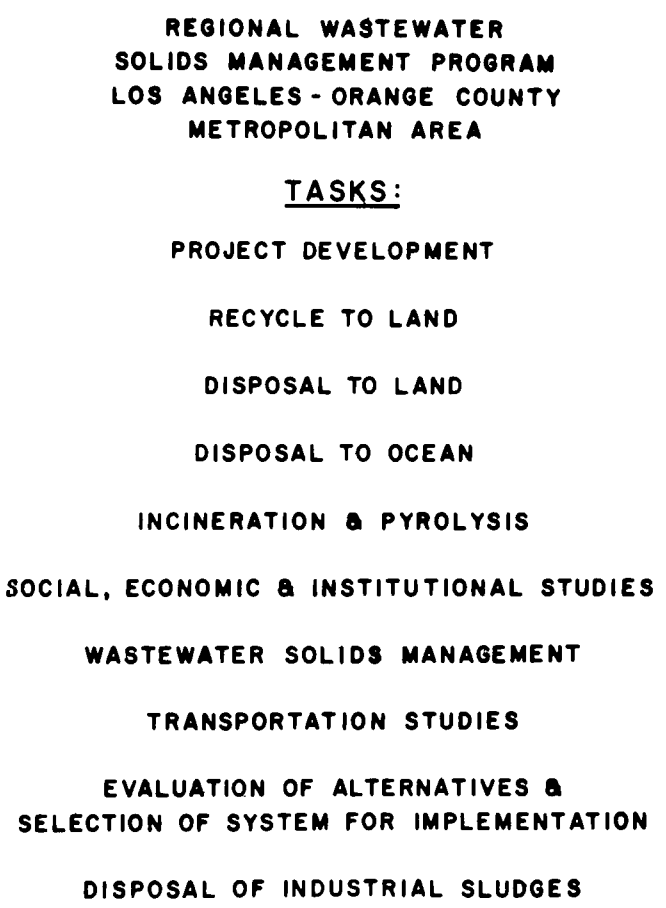

Figure 5: Series of Tasks to be Considered During the Study.

COMPUTER EVALUATION OF SLUDGE HANDLING AND DISPOSAL COSTS*

Robert Smith and Richard G. Eilers
United States Environmental Protection Agency
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INTRODUCTION

Treatment and disposal of sludges produced in municipal wastewater treatment plants can account for as much as 60 percent or as little as 20 percent of the total cost of treatment. Careful consideration should, therefore, be given to selecting the sludge treatment and disposal scheme which meets the site-specific constraints at a minimum cost. Some factors which determine the scheme selected are the nature of the sludges produced, ultimate disposal options available, the local cost of electrical power or fuel oil, and the subjective preference of the designer or the community officials. Thus, it can be seen that many of these factors are site specific and some are difficult to quantify. In this report, a digital computer program which is capable of examining the cost and performance of a wide variety of alternative sludge handling schemes is described, and the results of sample calculations are presented. This computer program can be used as a management tool to narrow the range of sludge treatment and disposal options when the site-specific conditions are known.

For example, in rural communities the least-cost method of sludge disposal might be lime stabilization followed by application of the sludge to the land. However, in some localities the land might be wet for several months of the year necessitating undesirable storage of the sludge. The computer program is capable of estimating the cost of this method, but the subjective and aesthetic factors associated with storage of the sludge cannot be quantified. In urban communities, the land available for sludge spreading might be far from the treatment plant and transportation charges could equal the cost of more complex treatment and disposal at the plant site.

Another option might be to reduce the mass of the organic sludge economically by the use of anaerobic digesters. Anaerobic digesters have the added advantage of producing methane gas which can be either sold or used in the plant for heating or to supply internal combustion engines. The internal combustion engines can be directly coupled to air blowers or water pumps or can be used to drive electrical power generators. However, anaerobic digesters have been known to fail as a result of toxic substances being introduced with the raw wastewater or as a result of improper charging. For this and other reasons, anaerobic digesters are sometimes not included as part of the treatment scheme.

To demonstrate the capability of the program a large number (261) of alternative sludge treatment and disposal schemes are considered in this report and the cost is estimated for each treatment scheme. The basic computational program used is called the Executive program; and the details of this program have been published previously. The Executive program contains a subroutine for each of the liquid and sludge treatment processes. It contains the rate and mass balance relationships necessary to generate the effluent stream vectors when one or more influent stream vectors are supplied together with certain decision variables. The subroutine also sizes all structures and equipment and estimates the capital and operating and maintenance costs associated with the process. The stream vector is a list of parameters which fully characterize the stream. The definition of each component of the stream vector is shown in Table 1 along with the values used for the raw wastewater. The Executive program contains the necessary logic to call each subroutine needed in a way which allows for solution of all stream vectors when the processes used and the interconnecting piping network are supplied as input to the program. When recycle streams are involved an iterative procedure is followed until the components of all stream vectors converge. Equipment and structures associated with each process are sized within the subroutine, and the construction and operating and maintenance costs are both estimated.

*This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not necessarily constitute endorsement or recommendation for use.

TABLE 1
Contents of the Stream Vector
(I designates the stream number)

Row No.	FORTRAN Variable Name		Parameter Definition	Nominal Value for Plant Influent
1	SMATX (1,I)	I	Stream Number	
2	SMATX (2,I)	Q	Volume Flow, mgd	10.
3	SMATX (3,I)	SOC	Solids Organic Carbon, mg/l	53.8
4	SMATX (4,I)	SNBC	Solid Nonbiodegradable Carbon mg/l	15.
5	SMATX (5,I)	SON	Solid Organic Nitrogen, mg/l	5.
6	SMATX (6,I)	SOP	Solid Organic Phosphorus, mg/l	.8
7	SMATX (7,I)	SFM	Solid Fixed Matter, mg/l	60.
8	SMATX (8,I)	SBOD	Solid BOD, mg/l	72.5
9	SMATX (9,I)	VSS	Volatile Suspended Solids, mg/l	115.
10	SMATX (10,I)	TSS	Total Suspended Solids, mg/l	175.
11	SMATX (11,I)	DOC	Dissolved Organic Carbon, mg/l	72.5
12	SMATX (12,I)	DNBC	Dissolved Nonbiodegradable Carbon, mg/l	11.
13	SMATX (13,I)	DN	Dissolved Nitrogen, mg/l	20.
14	SMATX (14,I)	DP	Dissolved Phosphorus, mg/l	9.
15	SMATX (15,I)	DFM	Dissolved Fixed Matter, mg/l	500.
16	SMATX (16,I)	ALK	Alkalinity, mg/l	250.
17	SMATX (17,I)	DBOD	Dissolved BOD, mg/l	115.

Two basic types of municipal wastewater treatment plants are considered in this report; primary sedimentation plants and activated sludge plants. In the primary sedimentation plant, the sludge stream to be treated is the underflow stream from the primary settler. In the activated sludge plant, two sludge streams must be treated; the underflow stream from the primary settler and the waste activated sludge (WAS) stream which is split off the underflow stream from the final clarifier. When the cost is expressed as dollars/dry ton of sludge solids, the mass flow in one or both streams is being used as the basis.

The next section of this report outlines the basis for computing the mass and concentration of sludge produced in liquid handling processes. Following sections describe the content of the subroutines which characterize the individual sludge handling processes. Finally, the alternative sludge handling schemes considered are identified and the estimated cost for each scheme is given.

Although the Executive program is capable of sizing and estimating the cost of any size plant all example computations discussed in this report will be for plants having a design capacity of ten mil gal/day.

The FORTRAN method of writing mathematical equations is used in this report. An explanation of the FORTRAN method is given in the Appendix.

Estimaton of Sludge Production

The Executive program was used to make all performance and cost calculations given in this report. The stream vector selected for the raw wastewater stream is shown in Table 1.

The primary settler subroutine (PRSET) used in the Executive program assumes that the fraction removed (FRPS) has the same value for all species of suspended solids. For example, the fraction of inorganic suspended solids removed equals the fraction of organic suspended solids removed. The value of FRPS is 0.6 for all computations. The overflow rate (GPS) expressed as gal/day/sq ft of surface area needed to accomplish the specified removal rate (0.6) is found from the following relationship:

$$FRPS = 0.82/(2.71828^{**}(GPS/2780)) \quad (1)$$

Therefore, it can be seen from equation (1) that the required primary settler overflow rate to achieve 60 percent removal of suspended solids is 868 gpd/sq ft. Since the assumed concentration of suspended solids in the raw wastewater is 175 mg/1, the production of primary sludge is 875 lb/mil gal treated with no recycle of WAS to the primary settler. The primary sludge is 66 percent volatile. When WAS is not returned to the raw wastewater stream entering the primary settler, the concentration of primary sludge is taken as five percent; when it is returned, the concentration of the sludge stream from the primary settler is taken as three percent.

The model used for the activated sludge process is described in Reference 2. The mixed liquor suspended solids concentration (MLSS) held in the aerator is set at 2000 mg/1. The required concentration of BOD in the final effluent stream is always set at 13 mg/1.

Thus, when the BOD load on the activated sludge process is increased by recycle streams, the size of the aerator and final clarifier are increased to achieve the same BOD quality in the final effluent stream. As shown in Reference 2, the fraction of the MLSS which escapes in the final effluent stream is a function of the hydraulic detention time, the MLSS, and the hydraulic overflow rate for the final clarifier. The aerator volume (VAER) expressed in mil gal is calculated from the following relationship where Q is the volume flow in mil gal/day (mgd), BODIN is the concentration (mg/1) of BOD in the primary effluent stream and BODOUT is the concentration of BOD in the final effluent stream (13 mg/1).

$$VAER = Q^{*}(BODIN - BODOUT)/(MLSS/1000)/BODOUT/24 \quad (2)$$

When no recycle streams are returned to the primary settler, the value for the activated sludge process influent volume flow (Q) is 9.97 mgd. The value for BODIN is 144.1 mg/1, and the value for BODOUT is 13 mg/1. VAER can be calculated from equation (2) as 2.095 mil gal, and the corresponding value for hydraulic detention time is five hours.

The sludge retention time (SRT) at this operating point is 3.32 days. The volatile sludge wasted is 757 lb/mil gal of plant flow, and the total wasting rate is 935 lb/mil gal. Thus, the WAS is 80 percent volatile. With no recycle streams, the total sludge production is 875 lb/mil gal for primary sludge and 935 lb/mil gal for WAS for a total of 1810 lb/mil gal.

Production of sludge in the activated sludge process is difficult to estimate because it depends on the nature of the feed stream as well as the operating policy used. Vosloo[3], using the data reported by Hopwood and Browning[4] and Wuhrmann[5], developed the following relationship:

lb sludge/lb BOD applied = $1/(1 + 0.05*SRT)$ (3)

This relationship is plotted in Figures 1 and 2. Similar data collected at the Hyperion Plant in Los Angeles was reported by Bargman and Borgerding[6]. These data points are plotted in Figures 1 and 2. The data reported by Vosloo and the data points from Hyperion are both for settled municipal wastewater. Sludge production at Hyperion was somewhat less than that reported by Vosloo, but the scatter in the data is great.

The Executive program was used to generate similar sludge production data and these computed points are also shown in Figures 1 and 2. In general, this calculated data agrees well with the estimates made by Vosloo. To generate the data, the value of BODOUT was varied from 40 mg/1 (corresponding to an SRT of 0.87 days) to five mg/1 (corresponding to an SRT of 13 days). The value used for MLSS was 2000 mg/1. All of the computed data reported are around the design point corresponding to 3.3 days SRT.

Lime Stabilization

Sludges which are not biologically digested or incinerated are stabilized by the addition of lime. The target pH for stabilization is 11.5, and the estimated dose to achieve it is 212 lb of lime (CaO)/ton of dry solids.

When dewatering is effected by vacuum filters or centrifuges, a sludge holding tank with a minimum detention time of three days is used. Therefore, only the cost of lime slaking and feeding equipment is added when lime stabilization is required. When no dewatering is provided or dewatering is achieved in sand drying beds, a sludge holding tank with a detention time of three days is provided to mix lime into the raw sludge.

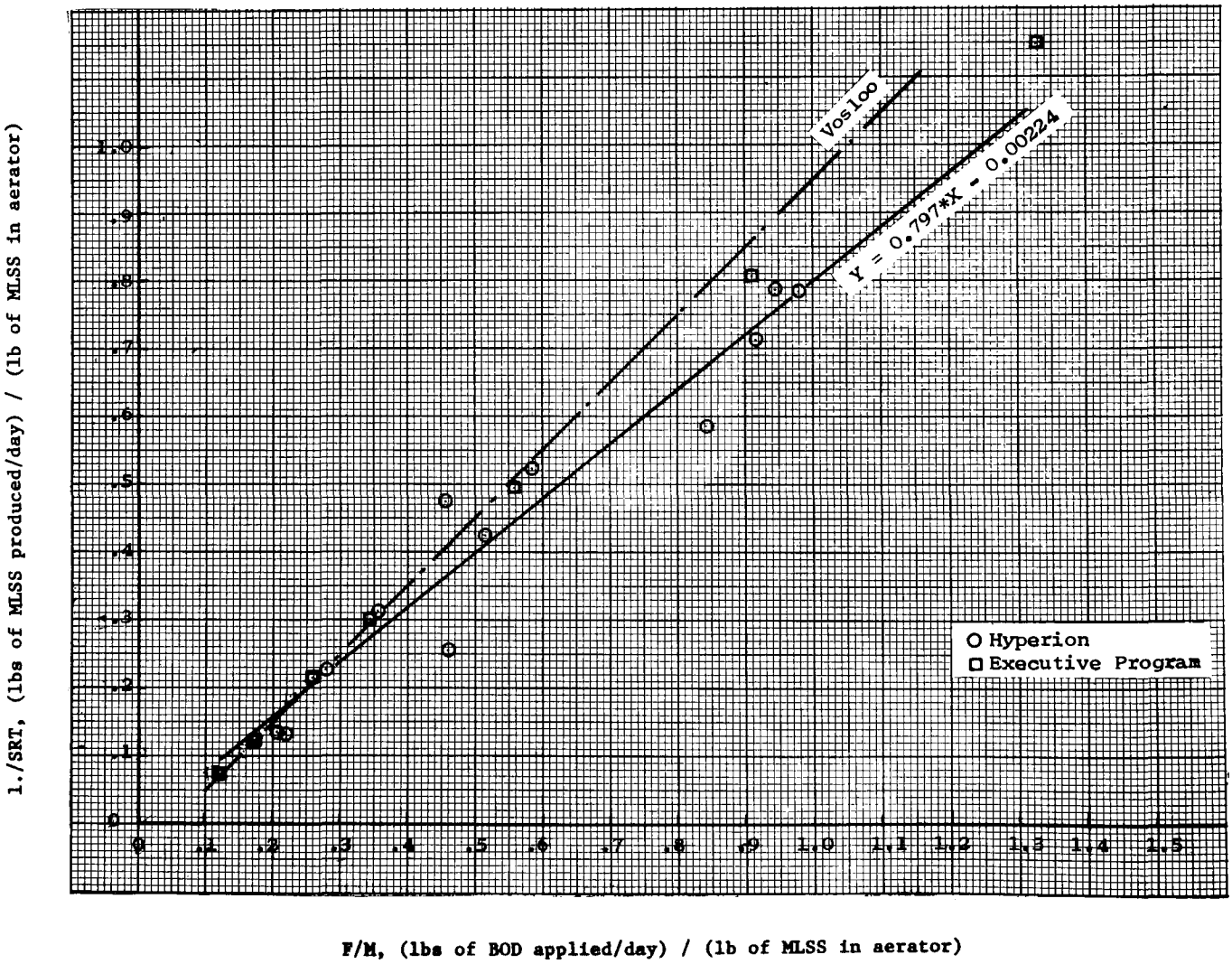


Figure 1: Estimation of Sludge Production in the Activated Sludge Process.

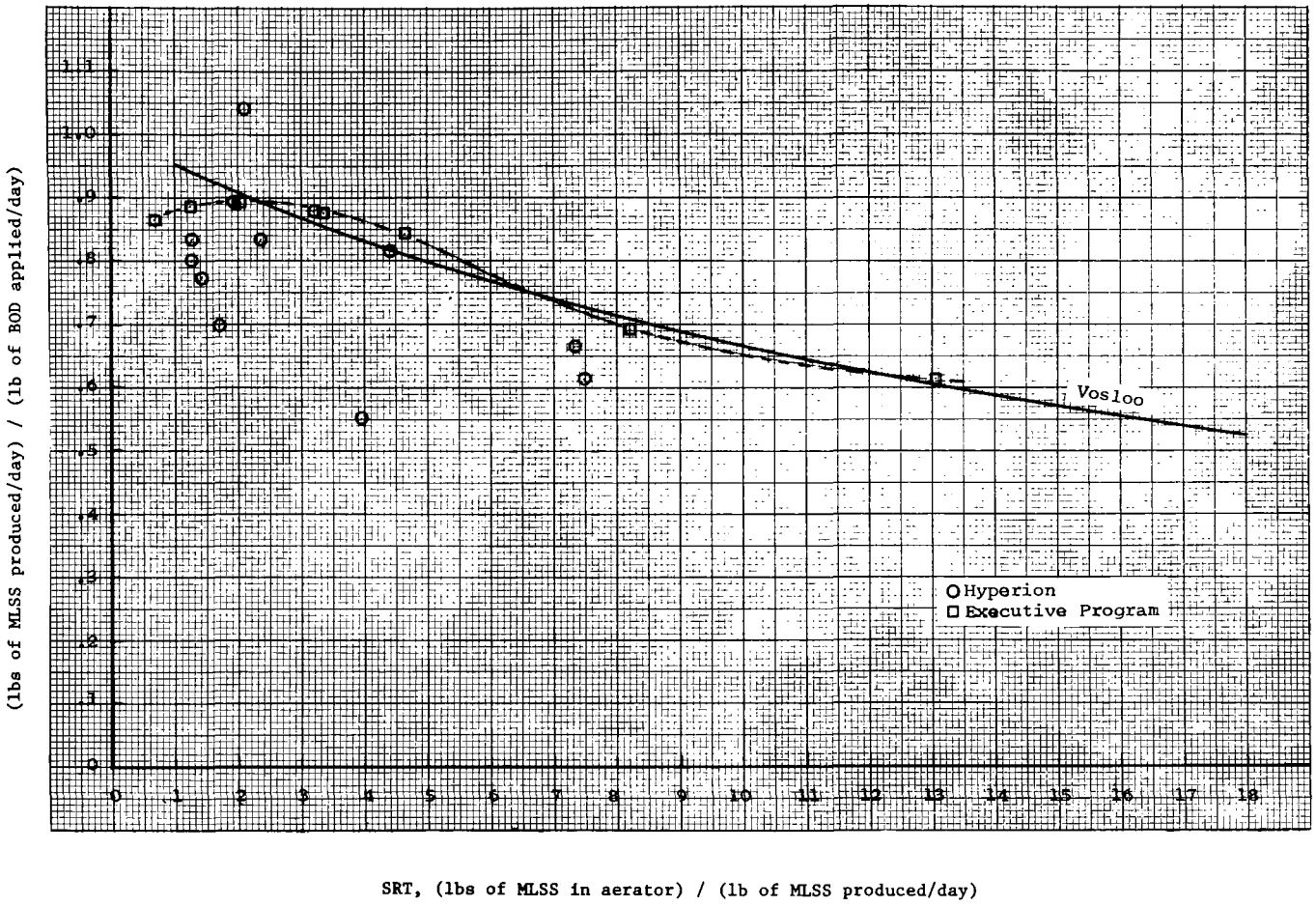


Figure 2: Estimation of Sludge Production in the Activated Sludge Process.

The cost of lime slaking and feeding equipment was taken from Reference 7. Estimates of man-hours for operation and maintenance were developed by W.F. McMichael and reported in an in-house memorandum [8]. Relationships for estimating the cost of lime slaking and feeding are shown in Figures 3 and 4. For example, a ten-mgd primary sedimentation plant produces 8,834 lb of raw primary sludge per day and used 936 lb of lime fc stabilization at a cost of $25 per ton. Therefore, the lime cost is $11.74/day or 0.117 cents/1000 gal of water treated. Lime slaking and feeding equipment is sized for the peak diurnal flow. The following relationship between average daily flow and peak diurnal flow is used:

$$QP = 1.78*QA**0.92$$

QP = peak diurnal flow, mgd

QA = average daily flow, mgd

Construction cost for slaking and feeding equipment is about $20,300 and the cost of the sludge holding tank with a three day detention time is about $49,600. Adding 36 percent for interprocess piping and other ancillary costs gives a total capital cost of $95,400. Amortizing this amount at six percent over 25 years results in a cost of $20.45/day or 0.204 cents/1000 gal treated. Operation and maintenance costs for the sludge holding tank and the lime addition facilities total 0.335 cents/1000 gal. Adding the cost of lime and debt service gives a total treatment cost of 0.657 cents/1000 gal for lime stabilization of primary sludge.

Gravity Thickening

The gravity thickener subroutine considers two influent and two effluent streams. The first influent stream is the sludge stream to be thickened. The second influent stream is the wash water normally split off the final effluent stream. The first effluent stream is the thickened sludge stream and the second effluent stream is the supernatant normally returned to the head end of the liquid handling train. A total of five decision parameters are necessary to specify the size and performance of the thickener.

The first decision parameter is the recovery factor (TRR), which is defined as the fraction of the sludge mass in the first influent stream which exists in the first effluent stream. The second decision parameter is the sludge concentration in the thickened sludge stream. The third decision parameter is the hydraulic overflow rate (GTH) expressed as gal/day/sq ft of surface area and the fourth decision parameter is the solids loading rate (GSTH) expressed as lb of sludge solids/day/sq ft of surface area. Since the basic sizing parameter for the thickener is the surface area the fifth decision parameter

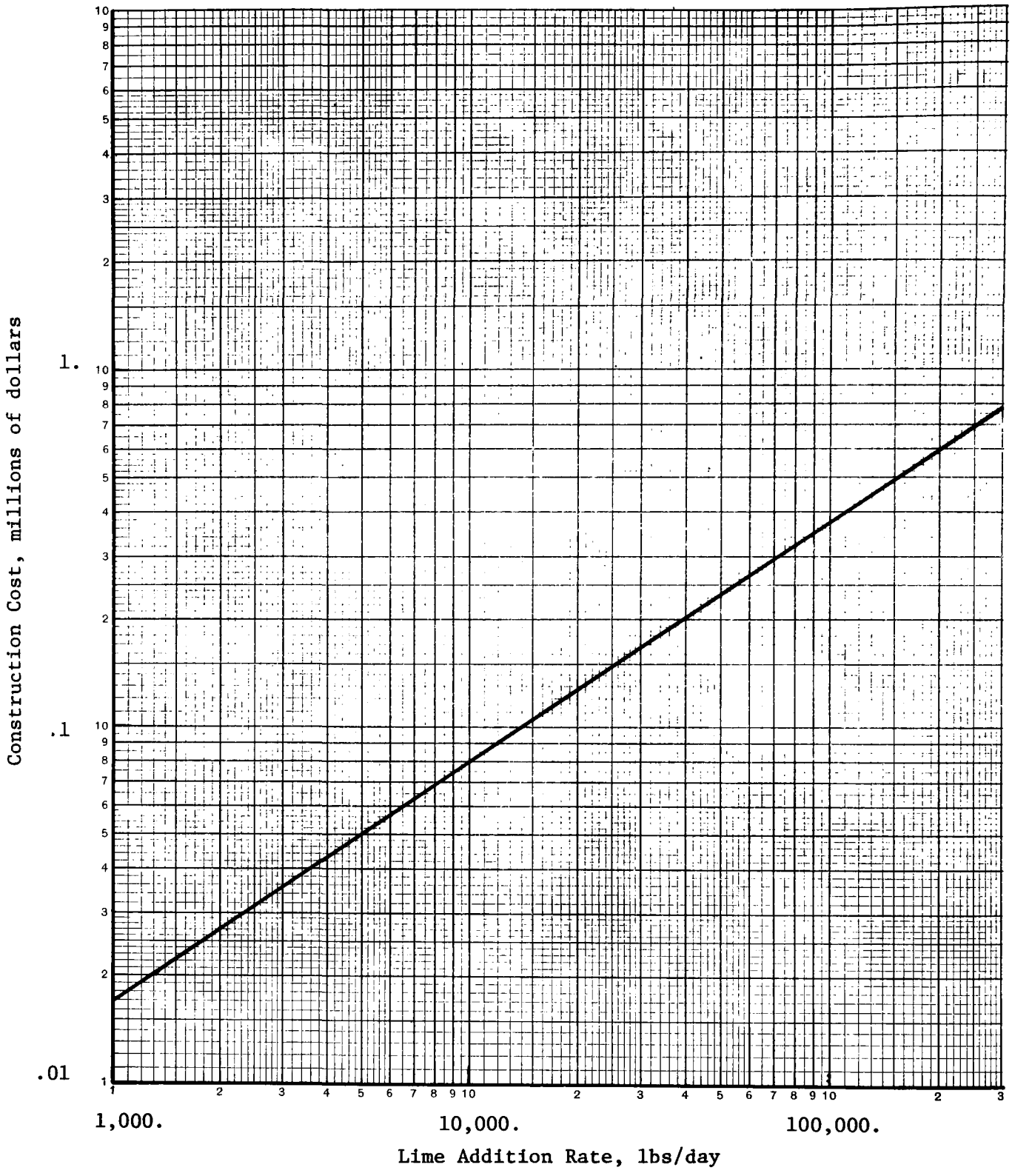


Figure 3: Construction Cost for Lime Slaking and Feeding in January 1971 Dollars.

is the excess capacity factor applied to surface area.

If the thickener is to be operated with no wash water the surface area is taken as the greater of the two values for surface area; the first is based on GTH and the second is based on GSTH. If the thickener is to be operated with wash water the wash water ratio (WRT) is found which will make both GTH and GSTH equal the input values. WRT is defined as the ratio of volume flow in the wash water stream to the volume flow in the unthickened sludge stream.

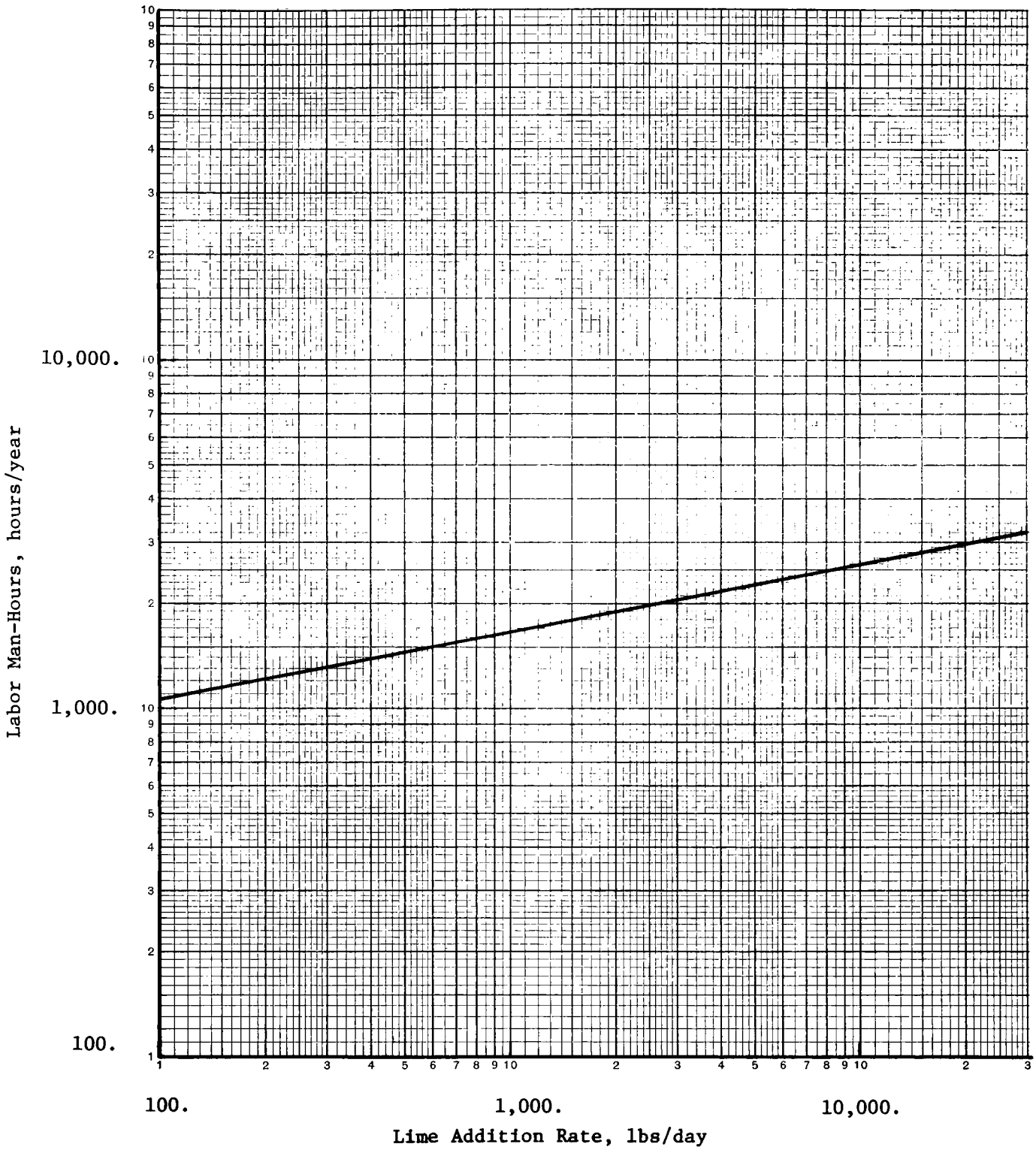


Figure 4: Operation and Maintenance Labor Man-Hours Required for Lime Slaking and Feeding.

The concentration of sludge solids in the supernatant stream is found from a mass balance relationship. The ratio of organic to total solids in both effluent streams is found by assuming that solids entering the process in the two influent streams are thoroughly mixed. The same assumption is used to find the ratio of organic to total dissolved matter in both effluent streams.

Cost estimating relationships for sedimentation given in Reference 20 are used to estimate construction cost and operating and maintenance cost using the computed value for surface area as the independent parameter.

The value used for GTH is 700 gpd/sq ft in all cases. The concentration of raw primary sludge from the primary settler is taken as five percent with no recycle of

WAS and three percent when WAS is recycled. The concentration of WAS is taken as one percent. When primary sludge is gravity thickened alone, the value for GSTH is 16 lb/day/sq ft and the sludge is thickened to eight percent. When primary sludge and WAS are mixed before being thickened the value for GSTH is eight lb/day/sq ft and the mixture is thickened to four percent. When WAS is returned to the primary settler influent, the three percent sludge in the settler underflow is thickened to six percent with a value of eight lb/day/sq ft for GSTH. When WAS is gravity thickened alone, the value for GSTH is six lb/day/sq ft, and the sludge is thickened to two percent.

When wash water is added to the incoming sludge the concentration of the diluted sludge stream can be found from the following formula:

$$\text{Diluted sludge concentration, \%} = \text{GSTH/GTH/0.0833} \quad (4)$$

If the diluted sludge concentration exceeds the concentration of the incoming sludge no wash water is added and the value for WRT is zero. The concentration of suspended solids in the overflow stream can then be calculated simply as the product of the diluted sudge concentration and the factor (1-TRR). For example, using a value of 0.9 for TRR it can be seen from equation (4) that the diluted concentration for primary sludge will be 2740 mg/1 and the suspended solids in the overflow will be 274 mg/1. Similiarly, for a mixture of primary and WAS the diluted sludge will have a concentration of 1372 mg/1 and the overflow will contain 137 mg/1 suspended solids. For gravity thickening of WAS the diluted sludge will be 1030 mg/1 and the overflow will contain 103 mg/1 suspended solids.

Air Flotation Thickening

The sludge handling schemes discussed in this report use air flotation thickening only for WAS and the basic sizing parameter is GSTH. If no polymers are used, the recommended value for GSTH is ten lb/day/sq ft. When a dose of ten lb of polymer/ton of dry solids is used, the recommended value for GSTH is 30. In computing the cost of air flotation thickening, it is assumed that polymers are used at a cost of $0.45/lb.

A secondary sizing parameter is GTH and its maximum allowable value is 1150 gpd/sq ft. The concentration of suspended solids in the influent sludge stream necessary to satisfy values for GSTH and GTH simultaneously is given by the following relationship:

$$\text{Influent sludge concentration, mg/1} = \text{GSTH*1000,000/GTH/8.33} \quad (5)$$

Therefore, if a value of 30 is used for GSTH, GTH will not exceed 1150, unless the solids concentration of WAS is less than 3131 mg/1. It is assumed that the thickened WAS is four percent solids. The fraction of influent suspended solids which escape in the overflow stream is expressed by TRR. No dilution water is added to WAS. Therefore, if the concentration (mg/1) of unthickened WAS is called TSS1, the concentration of thickened sludge is called TSS3, and the concentration of suspended solids in the overflow is called TSS4, the following relationship can be used to find TSS4:

$$\text{TSS4} = \text{(1-TRR)*TSS3/(TSS3/TSS1-TRR)} \quad (6)$$

Using 40,000 mg/1 for TSS3, 10,000 mg/1 for TSS1, and 0.95 for TRR the value for TSS4 can be computed as 164 mg/1. The value assumed for TRR in the calculations reported here is 0.95.

The excess capacity factor used for the flotation thickener is determined by the assumed operating hours per week and the commercially available sizes. It is assumed that weekly operating hours are related to the design capacity of the plant as follows; less than two mgd, 40; two to five mgd, 80; 5-20 mgd, 100; over 20 mgd, 168.

For example, if a one mgd plant produces 893 lb WAS/day and operates the flotation thickener 40 hr/wk the required size is (893/30)*(168/40) or 125 sq ft. The next larger commercially available size is 150 sq ft, so the excess capacity factor is 150/125 or 1.2. Construction, operating, and maintenance costs for flotation thickeners are given in Reference 9.

Anaerobic Digestion

The Executive program contains two subroutines for anaerobic digestion: the first (DIG) represents a completely mixed anaerobic digestor; the second (DIG2) represents the second-stage anaerobic digester, which is treated as a thickener with no wash water added. The relationships used to represent the first-stage completely mixed digester are taken from the work of McCarty [10]. A full discussion of the model for the first-stage digester can be found in Reference 2. The anaerobic destruction of biodegradable organic solids and dissolved material is represented by a Monod type of rate equation with no recycle of active solids. The concentration of biodegradable dissolved and particulate organics entering the digester is known from the influent stream vector. Dissolved and solid biodegradable organic material are assumed to be destroyed at equal rates. If F equals the concentration (mg/1) of biodegradable material (expressed as carbon in the effluent stream from the first-stage digester), then F is calculated as follows:

$$F = K2/(K1*TD \quad 1) \quad (7)$$

$$K1 = 0.28/2.71828**0.036*(35 \quad T) \quad (8)$$

$$K2 = 700.*2.71828**0.10*(35 \quad T) \quad (9)$$

T = digester temperature, °C

TD = hydraulic detention time, days

The TD used for the first-stage digester is 15 days, and the temperature of the digester is set at 30°C. Therefore, the value for F is 463 mg/1 as carbon. The value for F does not depend on the concentration if biodegradable carbon in the influent stream. Using the stream vector shown in Table 1, we can see that the concentration of biodegradable carbon entering the anaerobic digester is

11,124 mg/1 when unthickened primary sludge is digested. Therefore, about 96 percent of the biodegradable carbon in the influent stream is destroyed by anaerobic digestion. The corresponding reduction in volatile solids is 66 percent, and the reduction in dry solids is 44 percent. Nitrogen released by destruction of organic solids is assumed to leave the digester is dissolved form.

The standard cubic feet (scf) of methane produced is found by assuming that 5.61 scf are produced per pound of COD destroyed and that the ratio of COD to carbon is taken as 3.5. Therefore, in the example cited, 36,771 scf of methane is produced per day. Since 359/12 scf of methane plus carbon dioxide must be produced per pound of carbon digested, the production of carbon dioxide is 19,311 scf/day. Thus, about 15 scf of digester gas is produced per pound of volatile solids destroyed, and the gas is 66 percent methane.

The second-stage digester is treated as a thickener with a detention time of 15 days. The concentration of dry solids in the thickened sludge stream is taken as five percent. The solids recovery factor (TRR) is the fraction of entering solids that leave the second-stage digester in the thickened sludge stream. TRR is set at 0.81. Therefore, if the concentration of solids in the effluent from the first stage digester is 28,135 mg/1, the concentration of solids in the overflow stream is 9,823 mg/1. The concentration of dissolved species is assumed to be the same in both effluent streams.

Aerobic Digestion

Although the physical and biological principles involved in aerobic digestion are well known, design relationships are not well established in terms of the capacity of equipment and structures for a specified degree of treatment with a known feed stream. A sketch of the aerobic digestion process is shown in Figure 5.

Several operational alternatives are available in designing the process. For example, it can be designed to handle WAS alone or raw primary sludge can be added to the aerobic digester. In larger plants it is common practice to install a settler after the aerator to separate the solids from the supernatant and return them to the aerator. The supernatant is commonly returned to the main plant. Aerobically digested sludge is often disposed of on the land either directly or after being dewatered on sand-drying beds. Centrifuges or air flotation can be used to thicken aerobically digested sludge.

The basic design variable for the aerator is either TA (aerator volume/average influent flow volume) or SRT (sludge mass/average sludge wasting rate). The aerator is sometimes sized using pounds of volatile solids fed per day per 1000 cu ft of aerator capacity as the principal design variable. Several laboratory studies have been made to relate the percent of volatile solids destroyed to TA or SRT. The best known and most widely quoted data of this sort are reported by Jaworski, Lawton, and Rohlich[11], and are shown plotted on semi-log paper in Figure 6. One of the fundamental problems in using this kind of data is to estimate the fraction of the volatile solids that is essentially nonbiodegradable. Another related problem is to estimate the shape of the curves shown in Figure 6 when the mix of primary sludge and WAS is varied. Information which would allow for this kind of design is not available.

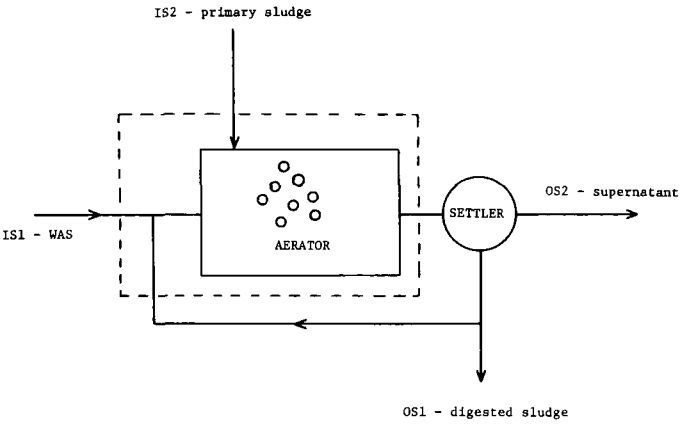


Figure 5: Diagram of the Aerobic Digestion Unit Process.

The data shown in Figure 6 are for a mixture of primary sludge and WAS in the proportion of 1.75 to 1.0. It can be seen that when the temperature is 20°C the digestion process is almost complete after 15 days, even though primary sludge represents the greater proportion. On the other hand when the temperature is 15°C, about ten percent of the biodegradable volatile solids remains at 30 days of TA.

In the Executive program, the subroutine AEROB is used to represent aerobic digestion. The process can be designed with or without a final settler depending on the input value for the parameter XAFS; without settler if XAFS = 0 and with settler if XAFS = 1. The aerator is sized using a specified TA. When WAS is digested alone, the TA specified is ten days. When raw primary sludge and WAS are aerobically digested in the same basin, the TA is set at 20 days. Regardless of the nature of the feed stream, it is assumed in AEROB that all biologically degradable material is fully degraded within the process.

The stream vector used classifies solid and dissolved pollutants as organic or inorganic and further classifies the organic constituents as biodegradable or nonbiodegradable. Solid constituents (mg/1) of WAS are classified as MLASS (active solids), MLBSS (biodegradable volatile solids), MLNBSS (volatile nonbiodegradable solids), MLDSS (volatile debris solids), and MLISS (inorganic solids). To compute the fraction of the volatile solids that is not degraded in the aerobic digester, the assumptions contained in Reference 2 are used. Some of these assumptions are; the ratio of BOD to volatile suspended solids is 0.84, and the yield coefficient representing production of active solids from MLBSS is 0.65. The fraction of MLASS remaining after cell lysis is 0.18. The compaction ratio representing the concentration of

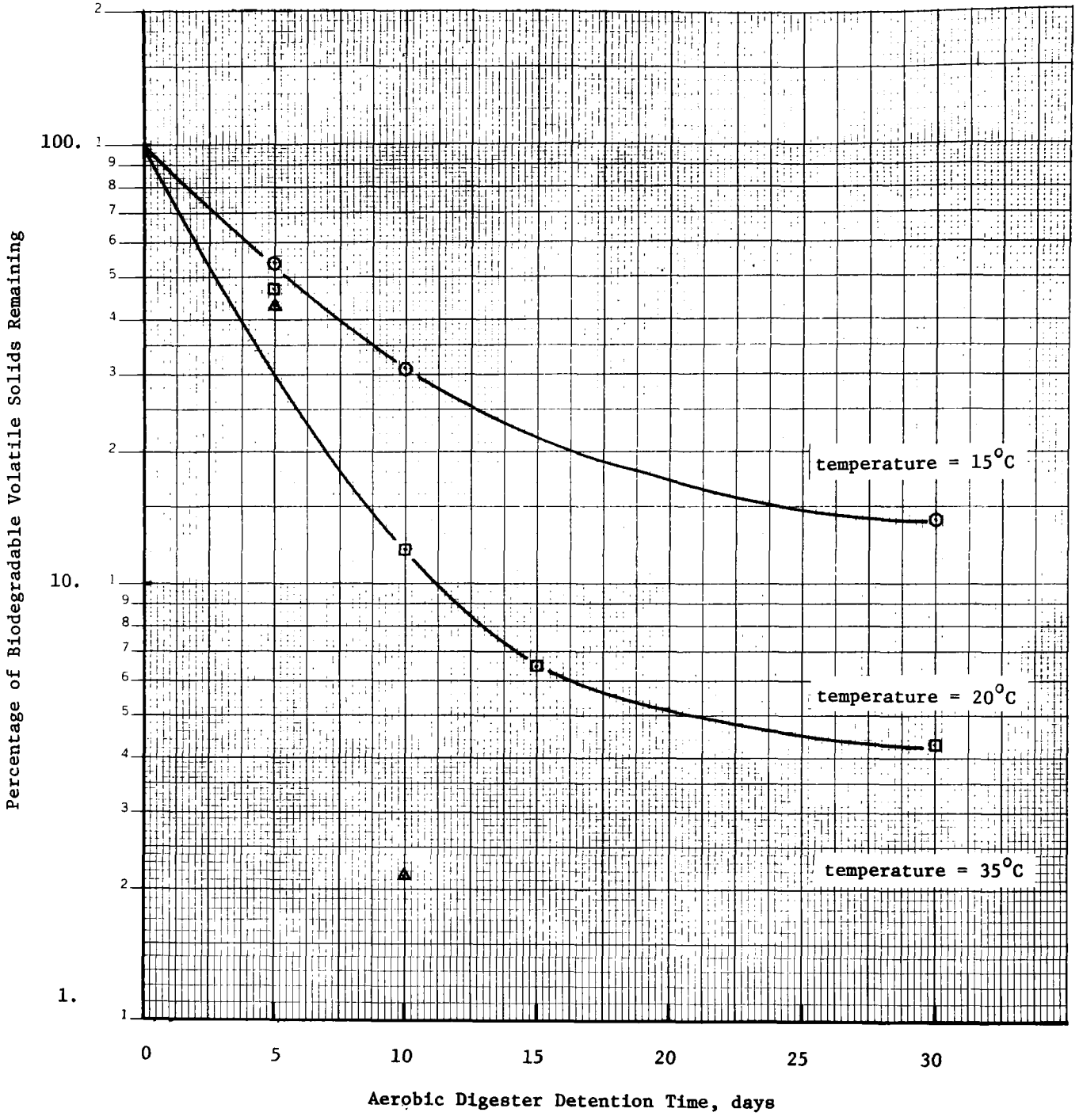


Figure 6: Aerobic Digestion Performance as Reported by Jaworski.

solids in the WAS divided by the mixed liquor suspended solids concentration (MLSS) is URSS with a value in the range of three to five.

Using these assumptions, the concentration of nonbiodegradable material which enters the aerobic digester in the WAS stream can be calculated as follows:

Nonbiodegradable solids in WAS, mg/1 =

URSS*(MLASS*0.18 + MLBSS*0.84*0.65 *0.18 + MLNBSS + MLISS + MLDSS) (10)

A similiar relationship can be used for finding the concentration of nonbiodegradable material which enters the aerobic digester in the raw primary sludge stream. To make this calculation it is assumed that the ratio of volatile suspended solids to solid nonbiodegradable organic carbon (SNBC) is 2.13, the concentrations (mg/1) of particulate and dissolved BOD are designated as SBOD and DBOD, and the concentration (mg/1) of inorganic material is designated as SFM. The relationship for primary sludge is as follows:

Primary nonbiodegradable solids, mg/1 =

2.13*SNBC + (SBOD + DBOD)*0.65 *0.18 + SFM (11)

As an example, consider a one mgd plant that has a raw wastewater suspended solids concentration of 175 mg/1. Assume that the primary settler removes 60 percent of the solids, that the solids removed are 66 percent volatile, and that 72 percent of the volatiles is biodegradable. The mass of sludge in the primary sludge stream is therefore, 875 lb/day. The mass of volatile sludge is 577 lb/day and the mass of biodegradable sludge is 416 lb/day. The mass of biodegradable sludge remaining after aerobic digestion can be found by multiplying 416 lb/day first by 0.84 to convert to BOD, by 0.65 to find the microorganism yield, and by 0.18 to convert the microorganism yield to debris solids. Thus, the mass of biodegradable solids remaining after aerobic digestion is 41 lb/day. When this amount is added to the nonbiodegradable mass (875-416 = 459 lb/day) it can be seen that 500 lb/day of sludge remains after aerobic digestion. The remaining sludge is 41 percent volatile and the reduction effected is 43 percent.

The solids remaining after aerobic digestion of the WAS can be calculated similiarly. At the design point used for the computations, the 2000 mg/1 of mixed liquor is divided as follows: 638 mg/1 for MLASS, 621 mg/1 for MLBSS, 223 mg/1 for MLNBSS, 104 mg/1 for MLDSS, and 414 mg/1 for MLISS. Using equation (10) with a value of five for URSS it can be seen that the concentration of solids remaining in the WAS stream after aerobic digestion will be 4585 mg/1 representing a 54 percent reduction in WAS solids. The remaining solids are 55 percent volatile. The amount of WAS produced in a one mgd plant was 861 lb/day. Therefore, about 396 lb/day of WAS remains after aerobic digestion. A detailed accounting of these calculations is shown in Table 2.

When the concentration of primary sludge is five percent and the concentration of WAS is one percent it can be seen that if the TA is set at 20 days and both sludge streams are aerobically digested the size of the digester will be 33,200 cu ft. If WAS had been digested alone the size of the aerator with a TA of ten days would have been 13,800 cu ft.

TABLE 2
Inventory of Sludge Entering and Leaving the Aerobic Digester

	Entering lb/day	Leaving lb/day
I. PRIMARY SLUDGE	875	500
1. nonvolatile	298	298
2. volatile	577	202
a. biodegradable	416	41
b. nonbiodegradable	161	161
II. WASTE ACTIVATED SLUDGE	865	396
1. nonvolatile (MLISS)	179	179
2. volatile nonbiodegradable (MLNBSS)	96	96
3. volatile debris solids (MLDSS)	45	45
4. active solids (MLASS)	276	50
5. biodegradable volatile solids (MLBSS)	265	26
TOTAL AMOUNT OF SLUDGE FROM AEROBIC DIGESTER		896
Reduction in sludge solids		49%
Reduction in volatile solids		67%

At least one principal supplier of aerobic digesters recommends the use of the parameter 0.05 lb of sludge solids/day/cu ft of digester volume. If the mass of primary sludge and WAS to be digested is 1740 lb/day as shown in Table 2 the aerobic digester volume would be 34,800 cu ft using this method. If WAS only is digested the size of the digester would be 17,300 cu ft. When the parameter TA is used to size the digester, prethickening of the sludge will have a significant effect on the digester size.

When a final setter is used it is sized for an overflow rate in the range 100 to 150 gpd/sq ft. Therefore, when primary sludge and WAS are digested in a one mgd plant the surface area of the settler will range from 83 to 125 sq ft with a diameter of 11 to 13 ft.

Diffused air is preferred over mechanical aerators for supplying oxygen to the aerobic digestion process because it minimizes problems associated with the changing level in the aerator. When no settler is provided the contents of the aerator are allowed to settle periodically and the supernatant is removed by decantation. The minimum amount of air needed to keep the solids in suspension is 20 std cu ft of air per minute (scfm) for each 1000 cu ft of aerator volume. Thus, if the size of the aerator is 34,800 cu ft the air supply must be at least 696 scfm. Oxygen needed for biological activity can be estimated by noting that one pound of oxygen must be supplied for each pound of COD destroyed. The ratio of COD to volatile solids can be estimated as 1.5. Therefore, since it is shown in Table 2 that a total of 840 lb/day of volatile solids or 1260 lb/day of COD are destroyed it follows that the oxygen demand will be 1260 lb/day. Nitrification of ammonia nitrogen is also likely to occur in the aerobic digester, and this also demands oxygen. The concentration of ammonia nitrogen in the influent sludge streams might average 20 mg/1. Nitrogen is also released when the sludge solids are degraded. Organic material normally contains about 7.5 percent nitrogen. Therefore, if 840 lb/day of volatile solids are degraded the ammonia nitrogen released will be about 63 lb/day. The ammonia nitrogen entering with the sludge streams will be only about 2.1 lb/day giving a total of 65.1 lb/day of ammonia nitrogen to be oxidized. Since about 4.6 lb of oxygen are required to oxidize one pound of ammonia nitrogen this will increase the oxygen demand by 300 lb/day for a total demand of 1560 lb of oxygen/day. If the oxygen transfer efficiency is five percent the air supply for biological activity will be about 1250 scfm. Notice that this is almost twice the amount needed to keep the solids in suspension. In the subroutine AEROB the air supply is computed both ways and the larger value is used for sizing the blower installation.

Phosphorus released as a result of destruction of organic material is assumed to leave the digester in the

dissolved state. Organic material is assumed to contain one percent phosphorus. When a final settler is used in the process the recycle pumps can be sized by writing a mass balance for volatile solids (VSS) around the control volume shown by the dashed rectangle in Figure 5. Let Q equal the influent volume flow and QR equal the return flow in mgd. Let FR equal the fraction of the influent VSS destroyed and URSS equal the compaction ratio. If the mixed liquor volatile solids concentration is MLVSS the following equations will express the mass balance for VSS:

$$Q*VSS + QR*MLVSS*URSS = (Q + QR)*MLVSS + FR*Q*VSS \quad (12)$$

Solving for the ratio QR/Q, we find:

$$QR/Q = (1 - (1-FR)*VSS/MLVSS)/(URSS-1) \quad (13)$$

Using the data in Table 2 it can be seen that the value for VSS will be 12,150 mg/1 and the value for FR will be 0.667. Thus, if MLVSS is estimated as two percent and URSS as 1.5 the ratio QR/Q will have a value of 1.6.

The concentration of solids in the sludge stream from the aerobic digester is estimated as four percent when primary sludge and WAS are combined and 2.5 percent when WAS is digested alone. The supernatant stream is assumed to have a suspended solids concentration of 200 mg/1 and a total BOD concentration of 100 mg/1; 50 mg/1 dissolved and 50 mg/1 in the form of particulate. These assumptions are applied whether or not a final settler is provided.

For a more thorough discussion of the aerobic digestion process, including a study of the time-dependent aspects, see Reference 12.

Elutriation

A recognized way of reducing the chemical demand for sludge conditioning before vacuum filtration is elutriation or sludge washing. The subroutine ELUT is used in the Executive program to calculate mass balances around the elutriation process, to size the equipment, and to estimate the cost. The subroutine ELUT is very similiar to that for gravity thickening. The principal difference is that the wash water rate (WRE) is supplied as input. WRE is defined as the volume flow (mgd) of the wash water stream (usually secondary effluent) divided by the volume flow of the feed sludge stream.

Values are supplied as input for the design parameters hydraulic overflow rate (GE, gpd/sq ft) and the solids loading rate (GES, lb/day/sq ft). The required surface area for the elutriation basin is computed using each of the design parameters, and the larger area is selected for cost estimation. The solids recovery (ERR) and the concentration of solids in the underflow stream are supplied as inputs, and the stream vectors for the two effluent streams are computed in a manner identical to that used for the gravity thickener. The solids concentration in the thickened sludge stream is usually set at six percent, and the ERR is estimated as 76 percent.

Vacuum Filtration

The size of a vacuum filtration installation is expressed as square feet of filtering area, which is determined by using two principal parameters; (1) the vacuum filter loading rate (VFL) expressed as gal/hr/sq ft of water removed from the sludge; and (2) operating hours per week. In small plants, the number of operating hours/week is usually determined by the smallest commercially available vacuum filter equipment. In intermediate plants (for example, ten mgd) the filter is commonly operated only seven hr/day, five days/week, since one-half hour is allowed each day for both startup and cleanup.

Traditionally, vacuum filter performance has been expressed as filter yield (F) with the dimension of lb dry solids filtered/hr/sq ft of filter area. Using vacuum filter performance data gathered before 1957 McCarty showed that the performance could best be described in terms of VFL [13]. F is related to VFL by the following simple mass balance relationship given by McCarty.

$$F = VFL*8.33/100/(1/SF—1/SC) \quad (14)$$

SF = solids concentration of feed sludge, %

SC = solids concentration of sludge cake, %

McCarty found that when the sludge is to be disposed of at a land fill the value for VFL averaged 6.2 gal/hr/sq ft, but when it was to be incinerated the value more closely approximated four gal/hr/sq ft.

McCarty also found that the solids content of the sludge cake correlated well with the solids concentration of the feed sludge stream. The following relationship was found:

$$SC = 100 — 88/SF**0.123 \quad (15)$$

If the solids content of the cake is found from equation (15) and substituted into equation (14), then F can be expressed adequately by the following equation:

$$F = VFL*0.07856*SF**1.1667 \quad (16)$$

Thus, it can be seen that filter yield is almost directly proportional to the concentration of the feed sludge stream. Performance data collected by McCarty are shown plotted as a function of feed sludge concentration in Figure 7. A line with a slope of 1.1667 is shown in Figure 7 using a value of 6.2 gal/hr/sq ft for VFL. It can be seen that the line fits the data reasonably well. A couple of the data points collected by McCarty involved the use of lime and ferric chloride but the use of chemicals had no clear effect on the relationships found.

Since 1957, however, the use of polymers for sludge conditioning prior to vacuum filtration has come into practice and there is evidence that higher filter yields are possible with the addition of polymers. Current estimates of F which can be reliably used for sizing vacuum filter installations are given by equipment manufacturers and by data contained in Reference 15. The data given in Reference 15 is plotted in Figure 8. Yields achieved with and without the use of polymers are shown but the yields expected when polymers are used are sig-

nificantly higher. The points marked with tails represent performance with polymers. The line corresponding to a value of 9.0 for VFL is shown by the solid line, and it appears to be a reasonable fit for the yield achievable with polymers. This line is used to size vacuum filters in the calculations presented here. The same relationship is used whether or not the sludge is to be incinerated. For example, if equation (16) is used with a value of 9.0 for VFL it can be seen that when the concentration of sludge to be filtered is five percent the filter yield will be 4.6 lb/hr/sq ft and when the sludge is gravity thickened to eight percent before vacuum filtration the yield will be eight lb/hr/sq ft. Therefore, since the amount of sludge produced in a ten mgd primary plant is 8,750 lb/day and the filtering time is 35 hr/week the size of the vacuum filter installation must be at least 219 sq ft when the sludge is thickened and 380 sq ft when it is not. The doses of sludge conditioning chemicals used prior to

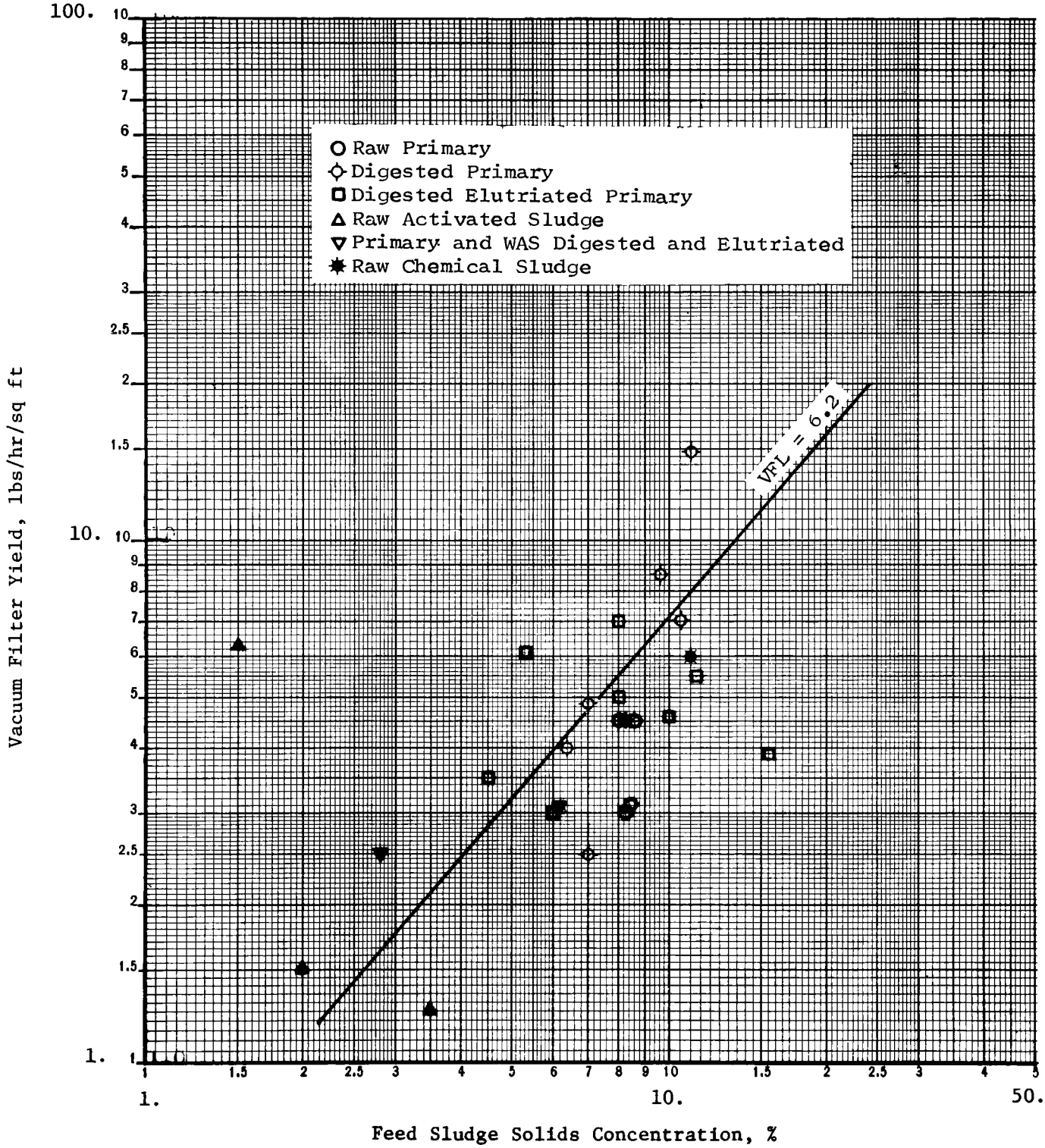


Figure 7: Vacuum Filter Performance as Reported by McCarty.

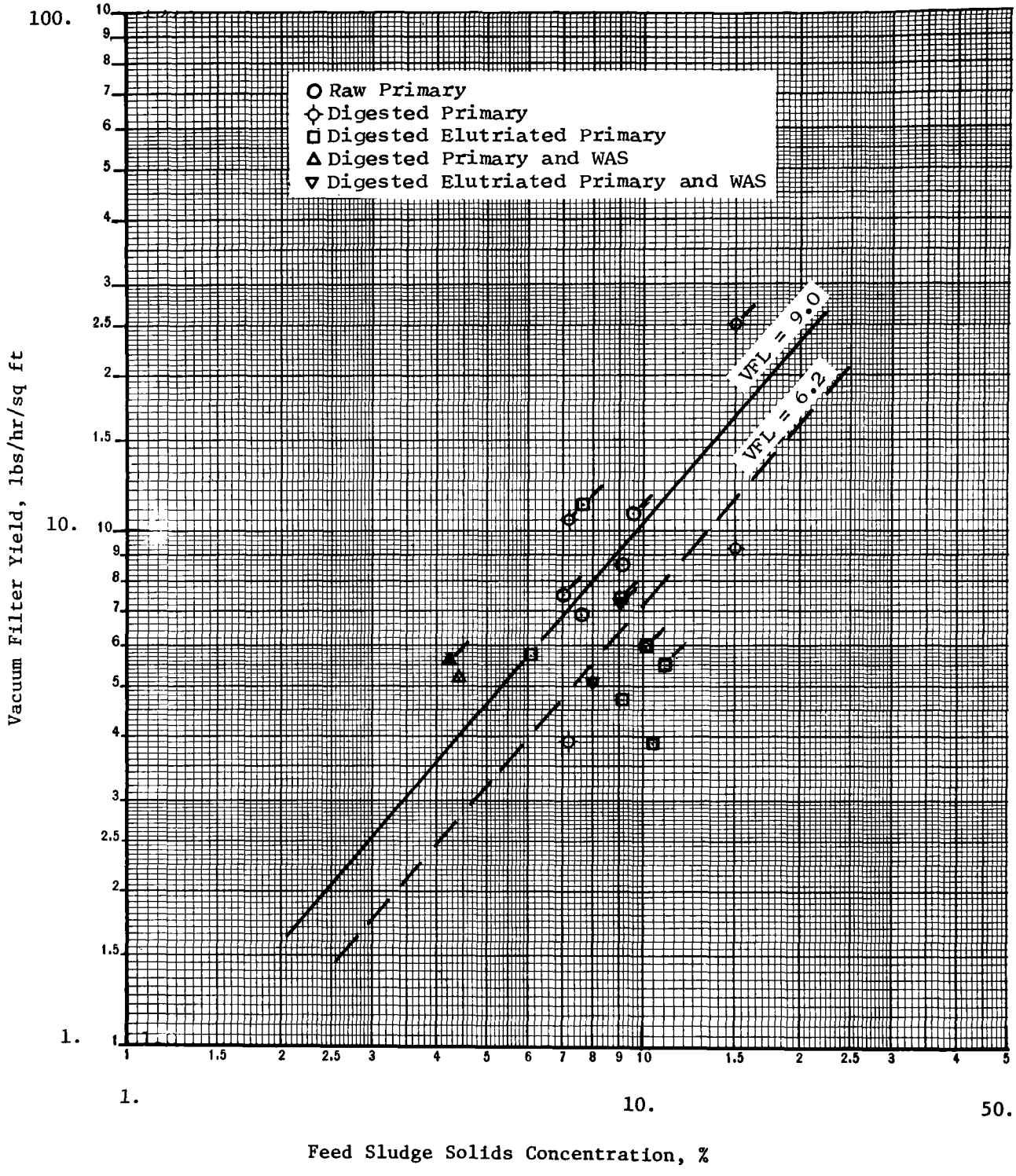


Figure 8: Vacuum Filter Performance as Reported in the Technology Transfer Manual.

vacuum filtration, as shown in Table 3 must be interpreted in the following way. Ferric chloride is used with or without lime but polymer is never used with ferric chloride. Estimated costs reported here assume that lime and ferric chloride are used in all cases.

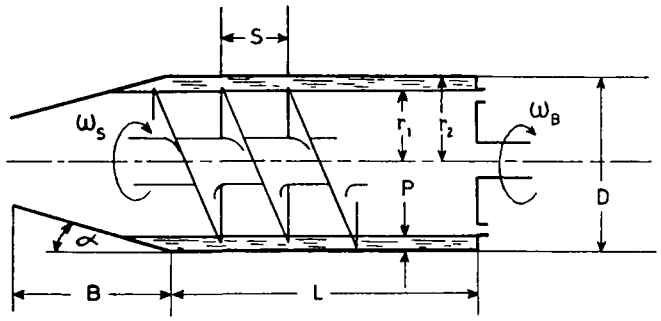
Centrifugation

In principle, a centrifuge used to dewater sludge is analogous to a gravity thickener except that the force of gravity is increased by as much as 3000 times by rotation of the bowl. A sketch of the solid-bowl, scroll-conveyer centrifuge considered in this report is shown in Figure 9. The cylindrical settling volume (sometimes called the pool) in the centrifuge, which is analogous to the liquid volume in the gravity thickener, has a length (L) and a depth of $(r_2 - r_1)$. Thus, it can be seen that the shallow depth of the settling volume is another major advantage over the gravity thickener. Feed sludge flows into the

TABLE 3
Estimated Chemical Conditioning Dosage
for Vacuum Filtration

		CaO Dose lb/ton	$FeCl_3$ Dose lb/ton	Polymer Dose lb/ton	Cao + $FeCl_3$ $/ton	Polymer $/ton
1.	Primary Sludge	176	42	5	5.01	1.65
2.	Limed Primary (212 lb CaO/ton)	0	42	5	2.81	1.65
3.	Digested Primary Sludge	240	76	20	7.86	6.60
4.	Digested/Elutriated Primary	0	68	9	4.56	2.97
5.	Raw (Primary + WAS)	200	52	18	5.98	5.94
6.	Limed (Primary + WAS)	0	40	5	2.68	1.65
7.	Digested (Primary + WAS)	372	110	36	12.02	11.88
8.	Digested/Elutriated (Primary + WAS)	0	125	24	8.38	7.92
9.	Aerobically Digested WAS + Anaerobically Digested Primary	372	110	36	12.02	11.88

Cost, $/lb: CaO, 0.13; $FeCl_3$, 067; Polymer, .33.



L — Bowl length
B — Beach length
D — Bowl diameter
P — Pool depth
S — Scroll pitch
α — Beach angle
ω_B — Bowl speed
ω_S — Scroll speed

Figure 9: A Solid Bowl Scroll Conveyer Centrifuge.

centrifuge through the center of the scroll shaft. The centrate overflows from the machine over the weirs located at the end opposite the beach end. Dewatered sludge is scrolled up onto the beach and out of the machine.

Parameters of interest to the process designer are: (1) the design capacity (gpm) for each size centrifuge operating on each type of sludge; and (2) the percent recovery and percent sludge cake solids achievable with a recommended polymer dose. Recovery is defined as the percentage of the solids entering the machine which leave the machine in the sludge cake.

It has been shown by Vesilind [16] and others that the two principal machine variables which determine performance are rotational speed and sludge retention time (defined as pool volume/feed sludge flow rate). Operating characteristics show that as the pool volume is increased, recovery increases but the percent of cake solids decreases. Current practice is to operate the centrifuge to achieve recoveries in the 85 to 95 percent range, but this can be done only when cationic polymers are added to the feed sludge stream.

Performance and sizing relationships used in this report are based on a specific line of four centrifuges. A fifth larger centrifuge is available but its use was not considered in this report. The nominal feed rate for the largest of the four centrifuges is given in Table 4 for seven sludge types. For each sludge type the nominal feed rates for the three smaller centrifuges are a fixed fraction of the nominal feed rate for the largest. For example, the smallest centrifuge has a feed rate which is 0.275 times the feed rate for the largest; the next larger size has a feed rate which is 0.350 times the largest feed rate, and the next larger size has a feed rate which is 0.590 times the largest. This relationship between feed rate and the centrifuge size is demonstrated in Figure 10.

TABLE 4
Performance Capabilities of a Typical Dewatering Centrifuge

	P-5400 Nominal Feed Rate gal/minute	Polymer Dose lb/ton	Cake Solids, %	% Recovery
1. Raw Primary Sludge	90	3	32	90
2. Limed Primary (270 lb/ton)	160	3	30	90
3. Digested Primary Sludge	100	2	25	90
4. Primary + WAS	80	6	19	90
5. Limed (Primary + WAS)	160	4	30	90
6. Digested (Primary + WAS)	80	4	22	85
7. Aerobically Digested WAS + Anaerobically Digested Primary	80	5	21	85

The polymer dose, the percent recovery, and the percent dry solids in the dewatered stream are shown in Table 4 for the seven sludge types. These three variables are assumed to depend only on the sludge type and are supplied as input to the Executive program subroutine (CENT) for sludge centrifugation.

The type of sludge to be centrifuged is identified by supplying the nominal feed rate (gpm) for the largest centrifuge. The minimum number of centrifuges in the installation (usually two) is also supplied as input together with the operating hours/week. Since the volumetric amount of sludge to be centrifuged is known and the operating hours/week are specified, the required design capacity per centrifuge can be calculated. The size of centrifuge with sufficient capacity is then selected from the set of four sizes. If the minimum number of the largest size centrifuge cannot handle the feed stream the number of centrifuges is increased until a sufficient number is found. Finally, each centrifuge installation is tested to make sure that all of the sludge can be centrifuged with 24 hr/day operation when one centrifuge is out of operation. If this criterion is not met, the number of centrifuges is increased until it is.

When the number and size of centrifuges in the installation are established, the construction cost is estimated from relationships given in Reference 20. The cost of polymer is computed from the specified dose and the cost per pound of polymer. Other elements of operation and maintenance cost are computed as functions of the annual tonnage of sludge processed according to relationships given in Reference 20.

Sludge Drying Beds

Sludge drying beds considered in this report are uncovered and are assumed to be located in a moderate climate. Sizing relationships used were taken from the work of Haseltine[17] who found that, after ambient air conditions, the concentration of dry solids in the sludge applied to the beds is the most important factor in estimating the bed area required. The moisture content of the sludge removed from the beds is also important in estimating the bed size but it is of secondary importance compared to the concentration of the feed stream. Haseltine collected sludge drying bed performance data from 14 plants and derived the following relationship between gross bed loading (FB) and the solids concentration (SF) of the feed stream:

$$FB = 0.96*SF - 1.75 \quad (17)$$

FB = lb dry solids applied/sq ft/30 days

SF = dry solids concentration of feed sludge, percent

A linear regression through the data collected by Haseltine has the following slightly different form. The correlation coefficient was 0.70.

$$FB = 0.694*SF - 0.107 \quad (18)$$

In an effort to take into consideration the moisture content of the sludge cake removed from the drying beds, Haseltine next plotted the product of FB and the solids concentration of the sludge removed (SC) versus SF. He found the following relationship:

$$SC*FB = 35.*SF - 50 \quad (19)$$

A linear regression performed on the data reported by Haseltine has the following form:

$$SC*FB = 29.84*SF - 33.3 \quad (20)$$

The correlation coefficient was 0.838 indicating a better fit than the relationship between FB and SF.

The discovery made by Haseltine that the allowable bed loading depends primarily on SF is the same conclusion reached by McCarty[13] with regard to vacuum

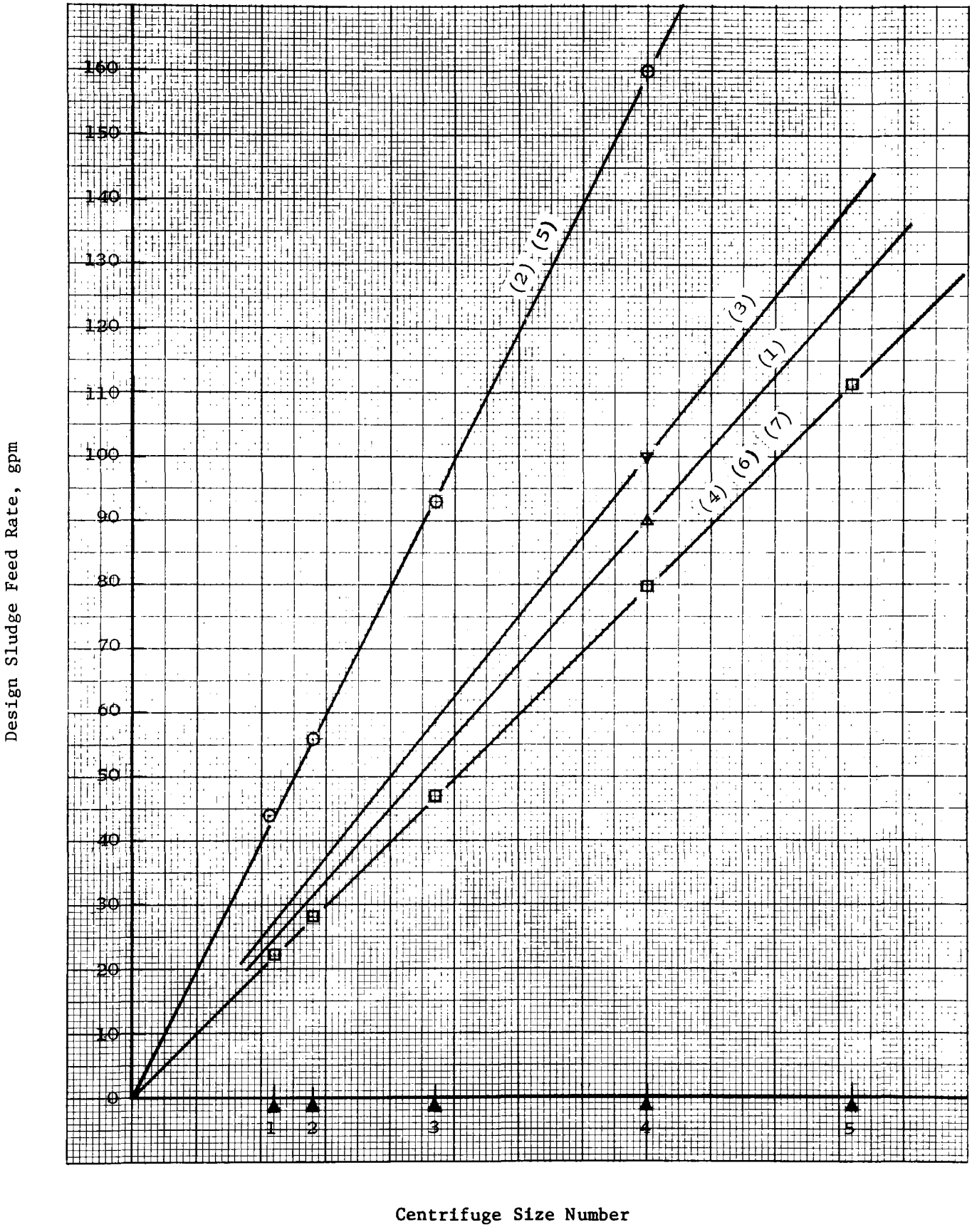


Figure 10: Design Flow Rates for Five Standard Centrifuge Sizes.

filters. McCarty concluded that the area of filter required to dewater a given mass of sludge solids is best expressed as a moisture removal rate. Data reported by Haseltine was analyzed using this concept and the results are shown in Figure 11. The regression line through the data points is shown below.

$$1/FB = 2.139*(1/SF - 1/SC) - 0.00189 \quad (21)$$

If the small constant (0.00189) is neglected, the moisture removal rate for sludge drying beds can be deduced from the constant 2.139 as 5.6 gal/sq ft/30 days. Therefore, the volume of sludge which can be dewatered on one sq ft of vacuum filter area in one hour is about the same as can be dewatered on one sq ft of sludge bed area in 48 days. Put another way, if the vacuum filter operates 35 hr/week, the ratio of sludge bed area required to equivalent vacuum filter area is 241. Equation (21) is used in the Executive program to size the sludge drying beds. For example, if five percent primary sludge is anaerobically digested in a single-stage, completely-mixed digester, the concentration of the digested sludge is 2.8 percent. If the moisture in the sludge cake is set at 35 percent, the required sludge bed loading is computed from equation (21) as 1.43 lb of dry solids/sq ft/30 days. The amount of sludge to be dewatered in a ten mgd primary plant over a 30 day period is about 148,000 lb. Therefore, the area of the sludge beds can be calculated

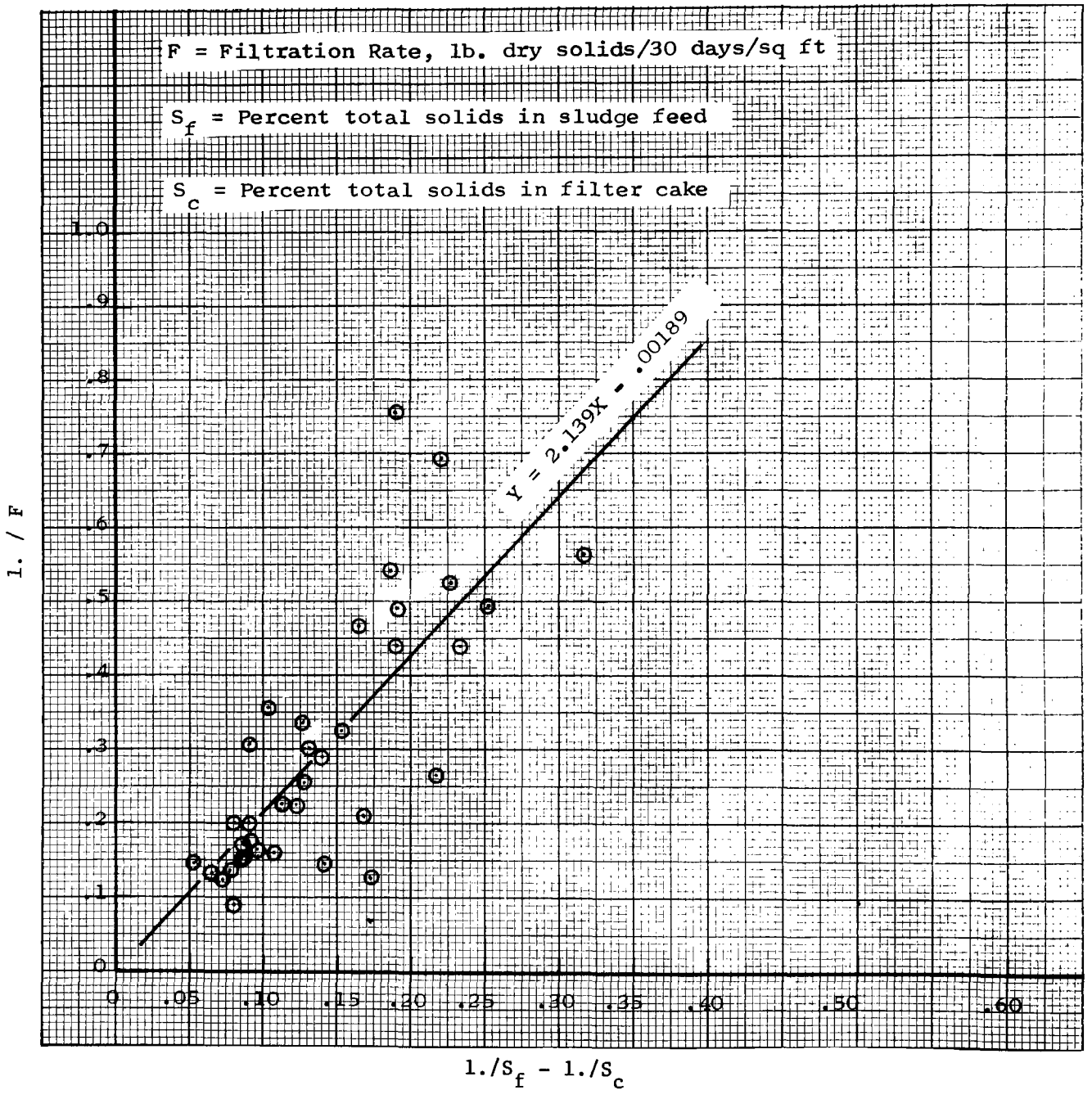


Figure 11: Haseltine Sand Drying Bed Data Correlated According to McCarty.

as 148,000/1.43 = 103,500 sq ft. If a second-stage digester is provided to thicken the sludge to five percent, the required area is only 45,000 sq ft.

Multiple Hearth Incineration

The subroutine for multiple hearth incinerators used in the Executive program (MHINC) is based on the model developed by Rocketdyne and described in Reference 18. The sizing parameter used is lb of dry solids fed/hr/sq ft of hearth area with a value of 2.0. The number of individual incinerators installed and the operating hours per week are inputs to the Executive program. Since the pounds per day of dry solids to be incinerated are known from the mass balance calculations, the hearth area for each individual incinerator can be calculated. A list of 59 standard incinerator sizes is included in the subroutine and the program finds the smallest incinerator with sufficient hearth area. For example, a ten mgd primary plant generates about 9,845 lb of dry solids per day, including sludge-conditioning chemicals. If the installation is to be made up of two incinerators both operating 35 hr/week, the hearth area needed for each incinerator is 492 sq ft. The next larger size incinerator has 510 sq ft of hearth area, is 10.75 ft in diameter, and has eleven hearths. Thus, the installation will consist of two 510 sq ft hearth area incinerators.

The subroutine next proceeds to calculate the fuel requirements. A sketch showing the principal heat losses and inputs is shown in Figure 12. Heat losses consist of the following eight components:

1. Heating and evaporation of water associated with the sludge
2. Enthalpy of the ash
3. Heat for calcining of calcium carbonate
4. Heat for decomposing Fe(OH)
5. Radiation and convection losses
6. Heat associated with discharged cooling air
7. Enthalpy of gaseous combustion products
8. Heat for temperature cycling

The heat balance is based on incineration of one pound of dry volatile solids (DVS) for which the higher heat value is taken as 10,000 Btu/lb.

The largest single heat loss is due to evaporation of the water in the feed sludge. In the example cited above, the sludge to be incinerated is 71 percent water and the dry solids are 60 percent volatile. Therefore, to incinerate one pound of DVS, 4.1 lb of water must be evaporated. Operation of the incinerator is controlled to hold the temperature of the exhaust gas stream at 800°F. Therefore, since the enthalpy of water vapor at 800°F is 1,404 Btu/lb, the heat required to evaporate the water associated with the sludge cake is 4.1*1,404 or 5,756 Btu/lb of DVS.

A small amount of heat is lost in the ash discharged from the incinerator. The temperature of the ash is taken as 400°F and the specific heat of the ash is assumed to be 0.2 Btu/lb. The temperature of the feed sludge and the ambient air is taken as 60°F. Therefore, the heat lost in the ash is (400-60)*0.2*0.67 = 46 Btu/lb of DVS.

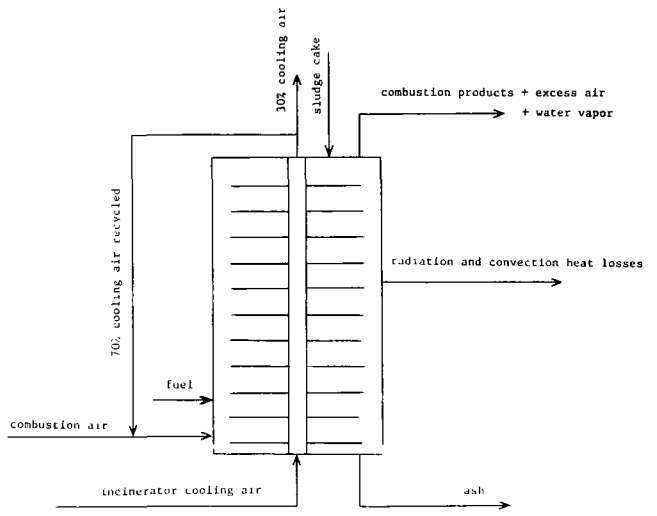


Figure 12: Principal Heat Inputs and Losses from a Multiple Hearth Incinerator.

When digested primary and WAS are vacuum filtered before incineration 200 lb of lime and 150 lb of ferric chloride per ton of DVS are often used to condition the sludge. Since, in the example cited, there are 1.67 lb of dry solids per lb of DVS, 0.167 lb of CaO and .125 lb of ferric chloride are added for each lb of DVS. When one lb of CaO is added to the wet sludge 1.79 lb of $CaCO_3$ will be formed. Similiarly, one lb of ferric chloride added to the sludge results in 0.66 lb of $Fe(OH)_3$. Heat required to calcine one lb of calcium carbonate is 761 Btu, and the heat required to convert ferric hydroxide to Fe_2O_3 is 227 Btu/lb of $Fe(OH)_3$. Therefore, the heat consumed in calcining the carbonate is 227 Btu/lb of DVS and the corresponding heat consumed by the iron is 19 Btu/lb DVS giving a total of 246 Btu/lb DVS.

The amount of heat lost by convection and radiation depends on the surface area of the incinerator (SAREA), which can be estimated from the hearth area (FHA) as follows when both SAREA and FHA are expressed as sq ft.

$$SAREA = 64.03*FHA**0.51 \quad (22)$$

The temperature difference between the incinerator shell and the ambient air is taken as 100°F. The heat transfer coefficient (HC) is expressed as a function of wind velocity (WV, mph) as follows:

$$HC = 1.735*(1 + 0.374*WV) \quad (23)$$

Heat lost by convection and radiation (QTRAN, Btu/hr) is then calculated as follows:

$$QTRAN = 100*SAREA*(1.279 + HC) \quad (24)$$

In the cited example, it is assumed that the incinerators are housed and the wind velocity is zero. Therefore, the heat loss is 1.125×10^6 Btu/hr. Converting this to Btu/lb DVS by dividing by the average incineration rate for volatile solids gives an estimate of 952 Btu/lb DVS.

If the fuel value (10,000 Btu/lb DVS) is reduced by the losses resulting from water in the sludge cake (5,756

Btu/lb DVS), the loss in the ash (46 Btu/lb DVS), the loss due to conditioning chemical (246 Btu/lb DVS), and the loss through radiation and convection (952 Btu/lb DVS), the amount to be lost in the products of combustion and the discharged cooling air must be 3,000 Btu/lb DVS.

In order to consider the heat loss in the cooling air the following relationship between the cooling air blower capacity and the incinerator hearth area is used.

$$\text{Blower capacity, scfm} = 3.102*\text{FHA} \quad (25)$$

Therefore, in our example, the blower capacity is 1,582 std cu ft/min for each incinerator or a total of 3,164 scfm. Since the incineration rate is 23.4 lb DVS/min, the rate at which cooling air is supplied is 10.1 lb cooling air/lb DVS. If the cooling air is discharged at 325°F, the heat lost in the cooling air is (325-60)*0.24 = 63.6 Btu/lb of air or 642 Btu/lb DVS. The amount of cooling air recycled to the combustion air inlet varies between 60 to 80 percent. Since the heat lost in the discharged cooling air is small, it is assumed that the fraction recycled is 70 percent and that the loss is 30 percent of the cooling air discharged to the atmosphere is 193 Btu/lb DVS. Thus, the heat lost in the combustion products must equal 2,807 Btu/lb DVS.

Combustion is represented by the following chemical equation.

$$(F_C/12)C + (F_{H2}/2)H_2 + (F0_2/32)0_2 + (F_S/32)S + (F_{N2}/28)N_2 + (X/32)0_2 + 3.31\,(X/28)N_2 \rightarrow A(CO_2) + B(H_20) + D(SO_2 + E(N_2) \quad (26)$$

In this equation the F's are the mass fractions of carbon, hydrogen, oxygen, sulfur, nitrogen and oxygen in the fuel and A, B, C, & D are moles of combustion gases. Chemical symbols identify the elements. For example, $F_C/12$ is the moles of carbon in a unit mass of the fuel. The symbol X represents pounds of combustion oxygen supplied per lb of fuel. Since air is assumed to consist of 23.2 percent oxygen and 76.8 percent nitrogen by mass, 3.31 lb of nitrogen are associated with each lb of oxygen. Values used for fuel mass fractions are shown below.

	MW	Dry Sludge Solids	Fuel Oil	Natural Gas	Digester Gas
carbon, C	12	.55	.86	.67	.50
hydrogen, H_2	2	.06	.11	.22	.12
oxygen, 0_2	32	.35	.00	.01	.38
nitrogen, N_2	28	.03	.00	.10	.00
sulfur, S	32	.01	.03	.00	.00

If the moles of carbon, hydrogen, oxygen, sulfur, and nitrogen on one side of the equation are set equal to the number of the other, the following relationships are obtained.

$$F_C/12 = A \quad \text{(carbon)} \quad (27)$$

$$F_{H2}/2 = B \quad \text{(hydrogen)} \quad (28)$$

$$F_{02}/32 + X/32 = A + B/2 + D \quad \text{(oxygen)} \quad (29)$$

$$F_S/32 = D \quad \text{(sulfur)} \quad (30)$$

$$3.31(X/28) + F_{N2}/28 = E \quad \text{(nitrogen)} \quad (31)$$

Using equations (27-30) the mass of oxygen needed to combust a unit mass of fuel can be found as follows.

$$X = 32\,[F_C/12 + F_{H2}/4 + F_S/32] - F_{02} \quad (32)$$

Substituting the mass fraction values for the four fuel types into equation (32), the mass of oxygen needed to combust a unit mass of each fuel can be calculated with the following result.

Dry Volatile Sludge Solids	1.607 lb 0_2/lb fuel
Fuel Oil	3.203 lb 0_2/lb fuel
Natural Gas	3.537 lb 0_2/lb fuel
Digester Gas	1.913 lb 0_2/lb fuel

If the fraction of excess air used is represented by EXAIR, the mass of gaseous combustion products resulting from combustion of a unit mass of fuel can also be found from equations (27-31) as follows.

	Sludge Solids	Fuel Oil	Natural Gas	Digester Gas
CO_2	2.017	3.153	2.457	1.833
H_2O	0.54	0.99	1.98	1.08
SO_2	0.02	0.06	.00	.00
0_2	1.607*EXAIR			
N_2	5.32*(1 + EXAIR) + .03			

Values (Btu/lb/°F) for the average specific heat of combustion gases at constant pressure over the temperature range of 60 to 800°F are:

CO_2	.239
H_2O	.467
SO_2	.175
N_2	.254
0_2	.233

The average specific heat for water does not include the heat of vaporization at the base temperature (60°F). Thus, if the higher heating value for the fuel is used, an additional term must be included to provide for 1060 BTU/lb of water for vaporization. Using these estimates for the enthalpy and mass of combustion products, the enthalpy of the combustion products is expressed as follows:

$$\text{BTU/lb DVS} = 2113 + 1223*\text{EXAIR} \quad (33)$$

The recommended range for EXAIR is 0.5 to 1.5. In the example, the enthalpy of the combustion products must equal 3,000 Btu/lb DVS minus the heat lost in the cooling air (193 Btu/lb DVS) or 2807 Btu/lb DVS. From equation (33) it can be seen that this will occur when EXAIR has a value of 0.567.

From this type of calculation it can be seen that the moisture and volatile content of the feed sludge cake must be held within relatively narrow limits if the use of auxiliary fuel, on one hand, and overheating of the incin-

erator, on the other hand, are to be avoided. This is shown graphically for the example used in Figure 13. It can be seen from the graph that when the volatile fraction is 0.6 the sludge moisture content can be as high as 71.2 percent before auxiliary fuel is needed. Similarly, when the volatile fraction is 0.6, the exhaust products will exceed 800°F if the moisture content is less than 66.2 percent.

To illustrate the computation of auxiliary fuel oil needed, notice that if the moisture content of a 60 percent volatile sludge increases from 71 percent to 75 percent about 0.23 lb of water is added /lb DVS for each percentage point. Thus, about 25.8 lb or 3.5 gal (7.5 lb/gal) of fuel oil is needed for each ton of dry solids per percentage point of added moisture. In the example used about 4.9 tons/day of dry solids are incinerated and the

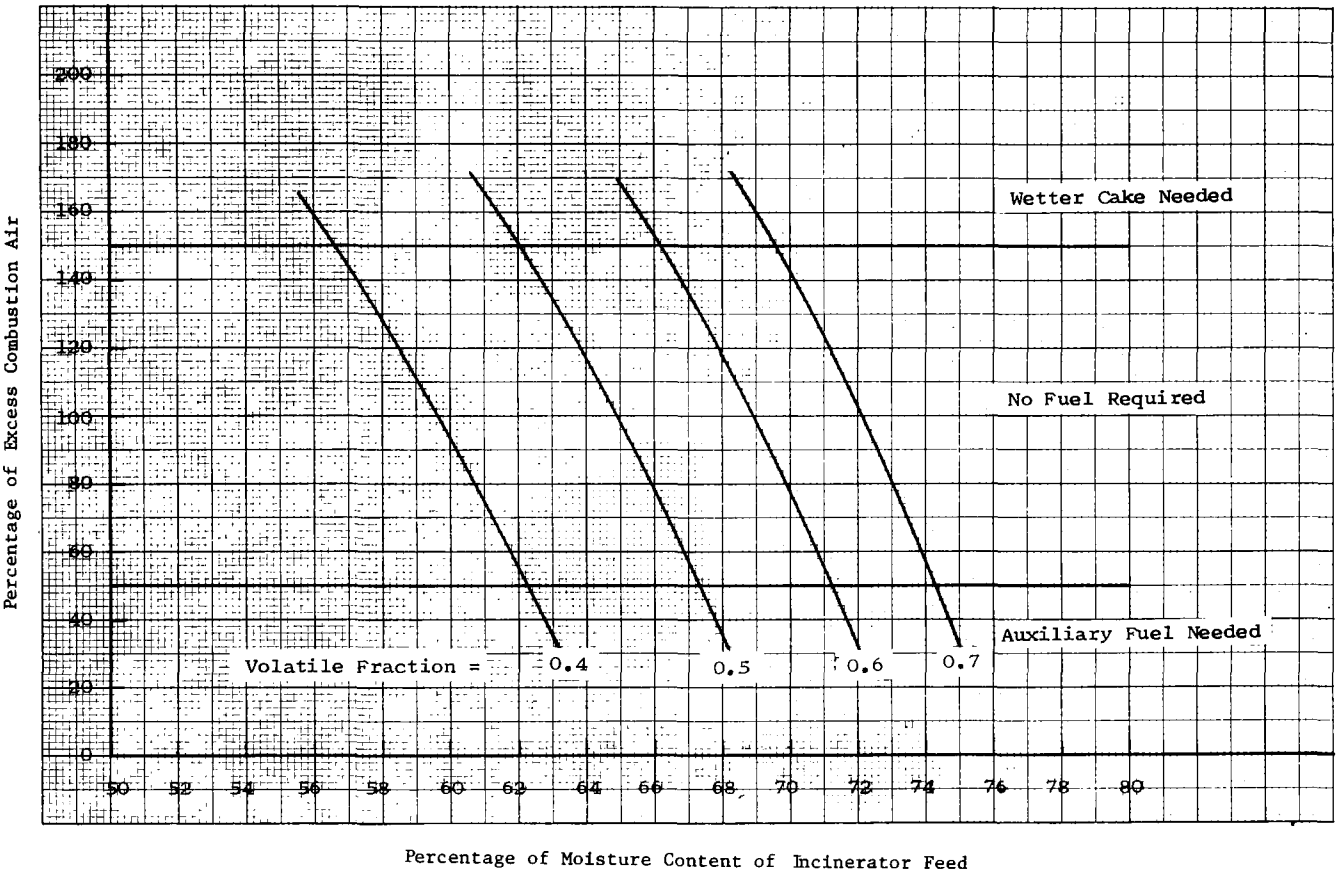


Figure 13: Determination of the Percentage of Incinerator Excess Combustion Air from the Moisture Content of the Sludge.

When auxiliary fuel is needed to keep the stack gas temperature at 800°F, the type of fuel can be specified in the subroutine by setting TYPE equal to one for fuel oil, two for natural gas, and three for digester gas. Since the auxiliary fuel is burned with zero excess air, the net heat generated by the addition of auxiliary fuel is simply the higher heat value of the fuel minus the heat lost in the combustion products. The higher heat value for fuel oil is taken as 19,000, 21,000, and 12,000 btu/lb for fuel oil, natural gas, and digester gas, respectively. From the mass of combustion products produced and the average specific heats given, the net heat produced from the combustion of one pound of fuel oil is 15,019 Btu/lb, 15,581 Btu/lb for natural gas, and 8,967 Btu/lb for digester gas. Since 1,404 Btu are required to raise the temperature of water to 800°F, one pound of fuel oil is required for each 10.7 pounds of water which enters with the sludge cake.

auxiliary fuel oil used will be about 17.2 gal/day/percentage point. If the cost of fuel oil is taken as $0.30/gal and the moisture content is increased from 71 percent to 75 percent the annual cost for auxiliary fuel will be $7,535. This corresponds to a cost of about $4.20/ton of dry solids incinerated.

Auxiliary fuel is also needed for thermal cycling of the incinerator. In the model devised by Rocketdyne, a characteristic heatup time in hours (CYT) was found as a function of FHA. CYT is expressed as a discontinuous linear relationship covering the range from zero to 3,000 sq ft of effective hearth area. This relationship is contained in the Executive program and when FHA is known the value for CYT can be found. In the case of the incinerator having a hearth area of 510 sq ft, the value for CYT is 25.24 hr.

Two basic types of thermal cycles exist. The first is the cold cycle which is used when the incinerator tempera-

ture is reduced to ambient level for inspection and maintenance and is then brought back up to operating level. The second, called a hot cycle, is employed when the temperature is reduced to 1200°F and the incinerator is allowed to "soak" while not in service. Both cycles contain periods for heatup and periods for soaking. The rate of fuel useage is estimated as 1,913 Btu/hr/sq ft of hearth area for raising the temperature and 315 Btu/hr/sq ft of hearth area for maintaining the incinerator at the soak temperature. The cold cycle contains heatup periods totaling 5/9 CYT and soak periods totaling 4/9 CYT. The heatup period for the hot cycle is 1/9 CYT but the soak period can be of any duration.

To calculate the fuel needed for thermal cycling, the operating hours per week (HPWK) and the number of startups per week (SPER) are supplied as inputs to the subroutine. Typical values are five for SPER and 35 for HPWK. Using these values the annual heatup hours for hot cycles is 5*52*(1/9)*25.24 or 729 hr/yr for each incinerator. Thus, the fuel requirements for two incinerators will be 1,422 X 10^6 Btu/yr and taking the cost of fuel oil at $0.30/gal the annual cost for fuel will be $3,800/yr. The standby or soak hours can be calculated as (7/9)*(52*7*24 — 52*35) or 5,379 hr/yr per incinerator. The heat requirement is 1,728 X 10^6 Btu/yr, and the cost of fuel oil is $4,600/yr. It is also assumed that each incinerator will be shut down for inspection and maintenance twice each year. The total heatup time is (10/9)*CYT and the soak time is (8/9)*CYT for each incinerator. Therefore, the total heat requirement for two cold cycles is 30.96 X 10^6 Btu/yr for each incinerator. If fuel oil is used the annual cost for two cold cycles for each of two incinerators will be $165/yr. Thus, in this example, the total cost of thermal cycling is $8,565/yr. This corresponds to $4.80 per ton of dry solids incinerated.

Hauling and Spreading Liquid Sludge

The work of McMichael [19] was used as the basis for calculating the cost of hauling and spreading liquid sludge on the land. The principal design parameter is tons of dry solids spread/acre/yr and the value used is 15. A lagoon is provided to store liquid sludge when the ground is unsuitable for spreading. The liquid volume of the lagoon is calculated from a specified detention time (lagoon volume/annual volume of sludge produced) taken to be 0.25 yr in this report. It is assumed that the liquid sludge is transported from the plant site to the spreading site by truck. The three standard truck capacities recognized in the subroutine are 1200 gal, 2500 gal and 5500 gal. The truck size is supplied as input and for the results reported in this report the truck size used was 2500 gal. The useful life of the truck is also supplied as input and for the 2500 gal truck this was set at six years. Finally, the round trip hauling distance is supplied to the subroutine in miles. The assumed distance for this report was ten miles.

The average road speed for the truck is estimated at 25 mph and it is assumed that 15 minutes are required to load and to unload the truck. Therefore, the maximum number of trips per year can be calculated as 2080 working hr/yr divided by the average time per trip (10/25 + 0.5) or 2311 trips/yr. The amount of limed primary sludge produced in a ten mgd plant is about 7.66 million gal/yr. Using a 2500 gal truck the number of truck trips needed per year is 3066 and it can be seen that at least two trucks will be required. The cost of two 2500 gal trucks is $72,800 and the amortization cost assuming six percent interest and a useful truck life of six years is $14,800/year.

Annual operating hours for hauling, assuming one driver per truck, is found by multiplying the annual trips (3066) by the time per trip (0.9 hr) or 2759 hr/yr in this case. Wages for the driver are taken from data published U.S. Dept. of Labor for Water, Steam, and Sanitory Systems Non-Supervisory Workers and 15 percent is added for overhead. The hourly wage used in this report is $4.35/hr or $5/hr with overhead. Maintenance and fuel costs for the trucks are taken as $0.475/mile for the 5500-gal truck, $0.425 for the 2500-gal truck, and $0.305/mile for the 1200-gal truck. Therefore, in the example the annual cost of operating the two trucks is $13,795 for wages, $13,030 for mileage, and $14,800 for amortization. The total cost of sludge hauling is $41,625/yr and since 1780 tons of dry solids are transported per year the hauling cost is about $23/ton.

Since it is assumed that land is not depreciated by application of sludge, the cost of land is taken as the interest charges only. The land needed to dispose of 1780 dry tons/yr will be 119 acres. If the land cost is taken as $1000/acre and the interest rate as six percent the land cost will be $7140/yr. The construction cost for the lagoon is about $35,000 and the amortization cost will be $2700/yr when the life of the lagoon is 25 yr and the interest rate is six percent. Operating and maintenance cost for the lagoon is about $530/yr. The cost of removing 445 ton/yr of sludge from the lagoon at $13/ton is $5785/yr. The total cost of sludge hauling and spreading for this example is $57,780/yr or about $32/ton.

Estimated Costs for Alternative Sludge Treatment Schemes

The twelve sludge treatment processes described in this report can be arranged into a large number of feasible treatment schemes. The particular scheme adopted is likely to depend on the site constraints, the cost, and the preference of the plant designer. When the design of a specific plant is being considered and the design variables are known, the Executive program can be used as a tool to narrow the range of alternative schemes by calculating the cost of candidate schemes. To demonstrate the capability of the Executive program for this use, design variables for ten mgd primary and activated sludge plants have been arbitrarily assigned values to show the range of costs to be expected.

A logical grouping of the possible alternative sludge treatment schemes is shown in Table 5. The processes

TABLE 5
Enumeration of Sludge Handling and Disposal Schemes

I. Treat and Dispose of Primary Sludge Separately (1-42)*

II. Treat and Dispose of WAS** Separately (43-51)

III. Treat Combined Primary and WAS with Group II Schemes (52-60)

IV. Return WAS to Primary Settler and Use Group I Schemes (61-102)

V. Gravity Thicken Combined Primary and WAS (103-123)

VI. Gravity Thicken Primary and WAS Separately and Mix (124-144)

VII. Gravity Thicken Primary, Air Flotation Thicken WAS and Mix (145-165)

VIII. Aerobically Digest WAS, Anaerobically Digest Primary, Mix and Land Dispose with or without Dewatering on Sand Drying Beds (166-189)

IX. Aerobically Digest WAS, Anaerobically Digest Primary, Mix, Dewater by Vacuum Filter or Centrifuge and Dispose to Land or Incinerate (190-213)

X. Same as IX Except WAS is Gravity Thickened (214-237)

XI. Same as IX Except WAS is Air Flotation Thickened (238-261)

* Identifying numbers for individual schemes shown in Table

** Waste activated sludge

used in each scheme, the type of sludge treated in each process, and the cost of sludge handling as compared to the total plant cost are shown in Table 6. Note that many of the schemes enumerated in Tables 5 and 6 might be eliminated on qualitative grounds. For example, the use of large incinerators near population centers could pose the threat of an air pollution nuisance. Inadvertent dumps of toxic chemicals could make the use of anaerobic digestion unpractical. Some experience has shown that when aerobically digested WAS is mixed with anaerobically digested primary sludge before application to the land, a severe odor problem can occur. Therefore, some schemes in Groups VIII-XI may be unpractical because of this potentially undesirable odor problem.

With these qualifications the treatment schemes listed in Table 6 can be used as a rough screening of alternative sludge handling methods on the basis of cost. Table 6 contains an estimate of the mass of dry sludge solids processed, the costs of treating and disposing of the sludge, and the total costs for plants using 261 different sludge treatment and disposal schemes. All cost estimates are adjusted to January, 1974 dollars.

In schemes 1-42, primary sludge is treated separately and the cost estimates are for primary sedimentation plants. In all other schemes, the cost estimates are for conventional activated sludge plants. However, in schemes 43-51, primary sludge and WAS are treated separately. For this reason, the cost estimates for the entire plant are not given, and the amount of sludge shown and the costs for treating it are for WAS only. In schemes 61-102, waste activated sludge was returned to the primary settler influent stream. An MLSS concentration of 2000 mg/1 could not be held in the aerator while still achieving the 13 mg/1 target concentration for BOD in the final effluent stream. It was necessary, therefore, to reduce the demand MLSS level to 1750 mg/1. For all other schemes, the MLSS level was 2000 mg/1 and the BOD concentration of the effluent stream was 13 mg/1.

In Table 6 the kind of sludge treated in each process is identified by symbols such as P, for primary sludge, A for WAS, (P+A) for a mixture of primary and WAS, and (P/A) to indicate that the process is used twice; once for primary sludge and once for WAS.

The mass of sludge processed per million gallons of wastewater treated is found by adding the dry sludge solids mass flow (lb/day) in the primary settler underflow stream to the dry solids mass flow in the final settler underflow stream and dividing by ten.

Most estimates for construction and operation and maintenance costs were taken from Reference 20. Additional cost relationships that were used are given in the text of this report and in Reference 1.

TABLE 6
Cost Estimates for Alternative Sludge Treatment and Disposal Schemes

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
1	883	1.829	9.10	0.203	2.16	48.98	P											P
2	941	1.847	8.76	0.211	1.79	38.12	P	P										P
3	894	2.306	9.83	0.696	2.92	65.45	P							P				
4	894	2.899	11.32	1.296	4.43	99.21								P			P	
5	946	1.978	9.71	0.362	2.79	59.19	P								P			
6	939	2.747	11.79	1.142	4.90	104.42									P		P	
7	947	2.196	9.65	0.573	2.70	57.12	P	P						P				

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
8	948	2.782	11.13	1.167	4.20	88.72		P						P			P	
9	1007	2.044	9.92	0.417	2.96	58.94	P	P							P			
10	1000	2.604	11.23	0.986	4.29	85.90		P							P		P	
11	883	2.023	9.20	0.405	2.27	51.59				P								P
12	884	2.104	8.75	0.490	1.84	41.71				P						P		
13	932	2.243	9.10	0.629	2.19	47.11				P	P							P
14	932	2.230	9.22	0.618	2.31	49.71				P	P					P		
15	941	2.015	8.81	0.386	1.85	39.40		P		P								P
16	941	2.049	8.70	0.423	1.74	37.14		P		P						P		
17	992	2.252	9.28	0.626	2.33	47.09		P		P	P							P
18	992	2.246	9.30	0.623	2.35	47.56		P		P	P					P		
19	895	2.587	10.17	0.980	3.27	73.22				P				P				
20	974	2.368	9.65	0.756	2.74	56.30				P			P	P				
21	895	3.028	11.92	1.426	5.03	112.46				P				P			P	
22	974	2.781	11.13	1.175	4.23	87.05				P			P	P			P	
23	915	2.443	10.46	0.835	3.55	77.81				P					P			
24	915	2.864	11.96	1.260	5.07	110.96				P					P		P	
25	936	2.504	10.14	0.897	3.24	69.41				P	P			P				
26	1022	2.608	10.35	1.001	3.45	67.69				P	P		P	P				
27	936	2.923	11.60	1.320	4.71	100.83				P	P			P			P	
28	1022	3.001	11.76	1.398	4.87	95.44				P	P		P	P			P	
29	964	2.475	10.37	0.867	3.46	71.98				P	P				P			
30	964	2.877	11.80	1.274	4.91	101.90				P	P				P		P	
31	948	2.440	9.89	0.821	2.95	62.33		P		P				P				
32	1034	2.404	9.79	0.782	2.84	55.05		P		P			P	P				
33	948	2.872	11.49	1.257	4.56	96.29		P		P				P			P	
34	1034	2.811	11.24	1.194	4.31	83.34		P		P			P	P			P	
35	974	2.265	9.79	0.643	2.85	58.60		P		P					P			
36	974	2.679	11.28	1.062	4.35	89.43		P		P					P		P	
37	995	2.518	10.21	0.899	3.27	65.89		P		P	P			P				
38	1086	2.632	10.46	1.013	3.52	64.89		P		P	P		P	P				
39	995	2.930	11.66	1.315	4.73	95.11		P		P	P			P			P	
40	1086	3.020	11.84	1.405	4.91	90.57		P		P	P		P	P			P	
41	1025	2.496	10.46	0.877	3.52	68.77		P		P	P				P			
42	1025	2.892	11.88	1.277	4.95	96.58		P		P	P				P		P	
43	895	-	-	0.405	4.06	90.86	A											A
44	901	-	-	0.896	3.93	87.39						A						A
45	901	-	-	0.929	3.79	84.31						A				A		
46	914	-	-	0.437	3.15	69.17	A		A									A
47	916	-	-	1.201	4.81	105.23			A			A						A
48	916	-	-	1.184	4.68	102.26			A			A				A		
49	929	-	-	0.202	1.70	36.80	A	A										A

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
50	929	-	-	1.028	4.11	88.53		A				A						A
51	929	-	-	1.005	3.97	85.69		A				A				A		
52	1779	3.423	16.92	0.496	5.18	58.31	P+A											P+A
53	1792	4.368	18.38	1.452	6.65	74.25						P+A						P+A
54	1793	4.453	18.07	1.540	6.35	70.92						P+A				P+A		
55	1823	3.471	16.48	0.536	4.72	51.82	P+A		A									P+A
56	1827	4.116	16.54	1.199	4.81	52.70			A			P+A						P+A
57	1827	4.712	18.95	1.799	7.23	79.22			A			P+A				P+A		
58	1866	3.305	15.37	0.347	3.54	37.95	P+A	A										P+A
59	1868	4.547	18.73	1.611	6.94	74.40		A				P+A						P+A
60	1868	4.574	18.39	1.641	6.61	70.83		A				P+A				P+A		
61	1754	3.575	17.89	0.416	5.24	59.86	P+A											P+A
62	1898	3.523	15.74	0.315	2.98	31.49	P+A	P+A										P+A
63	1678	4.627	18.07	1.565	5.83	69.50	P+A							P+A				
64	1678	5.490	20.52	2.432	8.28	98.75								P+A			P+A	
65	1925	3.858	17.73	0.706	5.13	53.31	P+A								P+A			
66	1903	4.715	19.61	1.571	7.02	73.88									P+A		P+A	
67	1900	4.040	17.07	0.851	4.35	45.79	P+A	P+A						P+A				
68	1901	4.916	19.42	1.734	6.71	70.63		P+A						P+A			P+A	
69	1957	3.655	16.76	0.471	4.05	41.40	P+A	P+A							P+A			
70	1932	4.671	19.32	1.497	6.63	68.67		P+A							P+A		P+A	
71	1754	3.983	18.26	0.836	5.65	64.46				P+A								P+A
72	1760	5.031	18.06	1.886	5.42	61.67				P+A						P+A		
73	1782	4.205	16.30	1.135	4.04	45.43				P+A	P+A							P+A
74	1913	4.312	16.88	1.163	4.26	44.55				P+A	P+A					P+A		
75	1898	3.716	15.59	0.518	2.86	30.17		P+A		P+A								P+A
76	1900	3.796	15.31	0.599	2.57	27.07		P+A		P+A						P+A		
77	2062	3.981	15.81	0.779	3.06	29.73		P+A		P+A	P+A							P+A
78	2062	4.003	16.01	0.803	3.26	31.65		P+A		P+A	P+A					P+A		
79	1821	5.282	19.35	2.140	6.74	74.03				P+A				P+A				
80	1923	4.359	16.99	1.279	4.70	48.91				P+A			P+A	P+A				
81	1821	5.927	22.38	2.789	9.77	107.40				P+A				P+A			P+A	
82	1923	4.993	19.21	1.917	6.93	72.17				P+A			P+A	P+A			P+A	
83	1911	4.399	17.93	1.251	5.31	55.63				P+A					P+A			
84	1911	5.006	20.24	1.863	7.63	79.89				P+A	P+A				P+A		P+A	
85	1794	4.617	17.94	1.553	5.70	63.56				P+A	P+A			P+A				
86	2269	4.849	18.40	1.748	6.08	53.65				P+A	P+A		P+A	P+A				
87	1794	5.237	20.00	2.177	7.77	86.62				P+A	P+A			P+A			P+A	
88	2269	5.476	20.62	2.379	8.31	73.29				P+A	P+A		P+A	P+A			P+A	
89	2088	4.600	18.30	1.457	5.71	54.77				P+A	P+A				P+A			
90	2088	5.202	20.60	2.063	8.02	76.85				P+A	P+A				P+A		P+A	

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
91	1922	4.364	17.17	1.173	4.44	46.24		P+A		P+A				P+A				
92	2254	4.314	16.98	1.109	4.26	37.80		P+A		P+A			P+A	P+A				
93	1922	4.980	19.46	1.794	6.74	70.13		P+A		P+A				P+A			P+A	
94	2254	4.936	19.19	1.736	6.48	57.53		P+A		P+A			P+A	P+A			P+A	
95	2062	4.165	17.19	0.968	4.45	43.21		P+A		P+A					P+A			
96	2062	4.761	19.48	1.570	6.75	65.50		P+A		P+A					P+A		P+A	
97	2075	4.385	17.42	1.190	4.69	45.21		P+A		P+A	P+A			P+A				
98	2462	4.645	17.96	1.440	5.24	42.59		P+A		P+A	P+A		P+A	P+A				
99	2075	4.992	19.47	1.802	6.74	65.05		P+A		P+A	P+A			P+A			P+A	
100	2462	5.263	20.13	2.062	7.42	60.30		P+A		P+A	P+A		P+A	P+A			P+A	
101	2269	4.332	17.56	1.131	4.82	42.54		P+A		P+A	P+A				P+A			
102	2269	4.926	19.84	1.730	7.11	62.73		P+A		P+A	P+A				P+A		P+A	
103	1970	3.309	14.96	0.319	3.04	30.88	P+A	P+A										P+A
104	1993	3.844	16.34	0.872	4.45	44.71	P+A	P+A						P+A				
105	1994	4.739	18.77	1.774	6.90	69.25		P+A						P+A			P+A	
106	2224	3.543	16.47	0.550	4.55	40.92	P+A	P+A							P+A			
107	2197	4.619	20.20	1.637	8.29	75.52		P+A							P+A		P+A	
108	1970	3.503	14.80	0.524	2.90	29.51		P+A		P+A								P+A
109	1973	3.588	14.51	0.611	2.60	26.41		P+A		P+A						P+A		
110	2142	3.768	14.99	0.788	3.09	28.91		P+A		P+A	P+A							P+A
111	2142	3.789	15.19	0.813	3.29	30.78		P+A		P+A	P+A					P+A		
112	1998	4.164	16.39	1.193	4.50	45.05		P+A		P+A				P+A				
113	2294	4.094	16.18	1.114	4.28	37.32		P+A		P+A			P+A	P+A				
114	1998	4.783	18.52	1.817	6.64	66.48		P+A		P+A				P+A			P+A	
115	2294	4.719	18.22	1.744	6.33	55.25		P+A		P+A			P+A	P+A			P+A	
116	2143	3.949	16.37	0.975	4.48	41.84		P+A		P+A					P+A			
117	2143	4.548	18.66	1.580	6.78	63.33		P+A		P+A					P+A		P+A	
118	2156	4.173	16.61	1.201	4.72	43.87		P+A		P+A	P+A			P+A				
119	2516	4.425	17.16	1.448	5.27	41.93		P+A		P+A	P+A		P+A	P+A				
120	2156	4.783	18.49	1.816	6.62	61.46		P+A		P+A	P+A			P+A			P+A	
121	2516	5.046	19.19	2.074	7.32	58.21		P+A		P+A	P+A		P+A	P+A			P+A	
122	2340	4.113	16.73	1.139	4.85	41.48		P+A		P+A	P+A				P+A			
123	2340	4.708	19.01	1.739	7.14	61.08		P+A		P+A	P+A				P+A		P+A	
124	1970	3.352	15.13	0.363	3.21	32.60	P+A	P/A										P+A
125	1993	3.886	16.51	0.915	4.62	46.40	P+A	P/A						P+A				
126	1994	4.782	18.94	1.817	7.07	70.93		P/A						P+A			P+A	
127	2224	3.586	16.64	0.594	4.71	42.42	P+A	P/A							P+A			
128	2197	4.663	20.36	1.681	8.46	77.03		P/A							P+A		P+A	
129	1970	3.546	14.97	0.567	3.07	31.22		P/A		P+A								P+A
130	1973	3.631	14.67	0.654	2.77	28.12		P/A		P+A						P+A		
131	2142	3.811	15.16	0.832	3.26	30.47		P/A		P+A	P+A							P+A
132	2142	3.833	15.36	0.857	3.46	32.34		P/A		P+A	P+A					P+A		

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
133	1998	4.207	16.55	1.237	4.66	46.73		P/A		P+A				P+A				
134	2294	4.137	16.34	1.158	4.44	38.76		P/A		P+A			P+A	P+A				
135	1998	4.826	18.68	1.860	6.81	68.16		P/A		P+A				P+A			P+A	
136	2294	4.763	18.39	1.789	6.50	56.69		P/A		P+A			P+A	P+A			P+A	
137	2143	3.992	16.53	1.019	4.65	43.40		P/A		P+A					P+A			
138	2143	4.591	18.82	1.623	6.95	64.88		P/A		P+A					P+A		P+A	
139	2156	4.216	16.77	1.245	4.89	45.42		P/A		P+A	P+A			P+A				
140	2521	4.338	16.40	1.493	5.43	43.15		P/A		P+A	P+A		P+A	P+A				
141	2156	4.826	18.66	1.860	6.79	63.00		P/A		P+A	P+A			P+A			P+A	
142	2516	5.091	19.36	2.119	7.48	59.51		P/A		P+A	P+A		P+A	P+A			P+A	
143	2340	4.157	16.89	1.183	5.01	42.89		P/A		P+A	P+A				P+A			
144	2340	4.752	19.17	1.783	7.31	62.49		P/A		P+A	P+A				P+A		P+A	
145	1922	3.553	16.48	0.589	4.63	48.26	P+A	P	A									P+A
146	1959	4.292	17.69	1.344	5.87	59.95	P+A	P	A					P+A				
147	1960	5.191	20.13	2.249	8.32	84.94		P	A					P+A			P+A	
148	2170	3.897	17.87	0.931	6.02	55.48	P+A	P	A						P+A			
149	2144	4.835	21.07	1.877	9.23	86.18		P	A						P+A		P+A	
150	1922	3.808	16.48	0.855	4.65	48.42		P	A	P+A								P+A
151	1927	4.010	15.81	1.056	3.97	41.29		P	A	P+A						P+A		
152	2092	4.116	16.22	1.160	4.39	42.02		P	A	P+A	P+A							P+A
153	2095	4.139	16.43	1.186	4.60	43.94		P	A	P+A	P+A					P+A		
154	1965	4.690	17.96	1.743	6.14	62.55		P	A	P+A				P+A				
155	2245	4.391	17.27	1.433	5.43	48.42		P	A	P+A			P+A	P+A				
156	1965	5.319	20.35	2.376	8.53	86.88		P	A	P+A				P+A			P+A	
157	2245	5.020	19.32	2.067	7.49	66.76		P	A	P+A			P+A	P+A			P+A	
158	2095	4.320	17.73	1.370	5.91	56.48		P	A	P+A					P+A			
159	2095	4.923	20.03	1.977	8.22	78.52		P	A	P+A					P+A		P+A	
160	2107	4.525	17.86	1.576	6.04	57.36		P	A	P+A	P+A			P+A				
161	2463	4.798	18.48	1.847	6.67	54.22		P	A	P+A	P+A		P+A	P+A				
162	2107	5.139	19.74	2.194	7.93	75.36		P	A	P+A	P+A			P+A			P+A	
163	2463	5.423	20.53	2.476	8.72	70.87		P	A	P+A	P+A		P+A	P+A			P+A	
164	2289	4.473	18.01	1.523	6.20	54.19		P	A	P+A	P+A				P+A			
165	2289	5.072	20.30	2.126	8.50	74.28		P	A	P+A	P+A				P+A		P+A	
166	1791	4.198	17.90	1.281	6.17	68.95				P		A						P+A
167	1793	4.313	17.30	1.397	5.57	62.20				P		A				P+A		
168	1867	4.325	17.99	1.388	6.20	66.48		A		P		A						P+A
169	1870	4.423	17.57	1.486	5.78	61.80		A		P		A				P+A		
170	1827	4.471	18.59	1.554	6.87	75.20			A	P		A						P+A
171	1828	4.570	18.17	1.653	6.44	70.47			A	P		A				P+A		
172	1888	4.231	17.65	1.285	5.84	61.94		P		P		A						P+A
173	1889	4.302	17.39	1.358	5.58	59.10		P		P		A				P+A		
174	1972	4.365	17.75	1.397	5.87	59.61		P/A		P		A						P+A

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
175	1974	4.414	17.65	1.446	5.77	58.52		P/A		P		A				P+A		
176	1926	4.544	18.56	1.598	6.75	70.14		P	A	P		A						P+A
177	1927	4.562	18.27	1.617	6.45	67.00		P	A							P+A		
178	1878	4.430	17.99	1.514	6.27	66.80				P	P	A						P+A
179	1878	4.457	17.85	1.543	6.12	65.26				P	P	A				P+A		
180	1960	4.563	18.06	1.626	6.28	64.12		A		P	P	A						P+A
181	1961	4.568	18.10	1.633	6.32	64.50		A		P	P	A				P+A		
182	1914	4.703	18.68	1.787	6.96	72.72			A	P	P	A						P+A
183	1915	4.716	18.71	1.801	6.99	73.06			A	P	P	A				P+A		
184	1974	4.484	18.21	1.539	6.40	64.94		P		P	P	A						P+A
185	1975	4.513	18.06	1.571	6.25	63.36		P		P	P	A				P+A		
186	2065	4.624	18.29	1.656	6.41	62.16		P/A		P	P	A						P+A
187	2066	4.628	18.32	1.661	6.44	62.43		P/A		P	P	A				P+A		
188	2015	4.764	18.92	1.819	7.11	70.57		P	A	P	P	A						P+A
189	2016	4.776	18.94	1.832	7.13	70.79		P	A	P	P	A				P+A		
190	1823	4.952	19.35	2.042	7.63	83.77				P		A		P+A				
191	1960	4.825	19.12	1.912	7.40	75.58				P		A	P	P+A				
192	1823	5.584	21.62	2.678	9.91	108.79				P		A		P+A			P+A	
193	1960	5.448	21.21	2.539	9.50	96.97				P		A	P	P+A			P+A	
194	1954	4.681	19.37	1.772	7.66	78.50				P		A			P+A			
195	1954	5.292	21.75	2.386	10.05	102.95				P		A			P+A		P+A	
196	1896	4.950	19.53	2.041	7.82	82.52				P	P	A		P+A				
197	2049	5.100	19.94	2.193	8.24	80.48				P	P	A	P	P+A				
198	1896	5.574	21.57	2.668	9.87	104.17				P	P	A		P+A			P+A	
199	2049	5.722	22.03	2.818	10.34	100.95				P	P	A	P	P+A			P+A	
200	2055	4.875	19.89	1.969	8.20	79.82				P	P	A			P+A			
201	2055	5.484	22.26	2.581	10.58	103.00				P	P	A			P+A		P+A	
202	1912	4.870	19.25	1.930	7.45	77.98		P		P		A		P+A				
203	2058	4.907	19.41	1.966	7.61	74.00		P		P		A	P	P+A				
204	1912	5.496	21.40	2.560	9.60	100.47		P		P		A		P+A			P+A	
205	2058	5.529	21.50	2.592	9.71	94.39		P		P		A	P	P+A			P+A	
206	2059	4.691	19.39	1.752	7.60	72.82		P		P		A			P+A			
207	2059	5.300	21.76	2.364	9.98	96.98		P		P		A			P+A		P+A	
208	1993	5.011	19.75	2.073	7.96	79.87		P		P	P	A		P+A				
209	2147	5.169	20.19	2.231	8.40	78.27		P		P	P	A	P	P+A				
210	1993	5.633	21.80	2.698	10.01	100.49		P		P	P	A		P+A			P+A	
211	2147	5.790	22.28	2.854	10.50	97.83		P		P	P	A	P	P+A			P+A	
212	2159	4.945	20.14	2.007	8.35	77.42		P		P	P	A			P+A			
213	2159	5.552	22.51	2.617	10.73	99.44		P		P	P	A			P+A		P+A	
214	1891	4.939	19.23	2.006	7.45	78.83		A		P		A		P+A				
215	2036	4.759	18.85	1.823	7.06	69.46		A		P		A	P	P+A				
216	1891	5.419	21.01	2.489	9.23	97.63		A		P		A		P+A			P+A	

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
217	2036	5.208	20.34	2.275	8.56	84.12		A		P		A	P	P+A			P+A	
218	1969	4.772	19.44	1.839	7.67	77.91		A		P		A			P+A			
219	1969	5.222	21.18	2.292	9.41	95.66		A		P		A			P+A		P+A	
220	1969	4.881	19.27	1.948	7.49	76.17		A		P	P	A		P+A				
221	2130	5.026	19.63	2.094	7.86	73.87		A		P	P	A	P	P+A				
222	1969	5.340	20.74	2.410	8.97	91.15		A		P	P	A		P+A			P+A	
223	2130	5.459	21.06	2.529	9.30	87.36		A		P	P	A	P	P+A			P+A	
224	2065	4.829	19.43	1.897	7.66	74.26		A		P	P	A			P+A			
225	2065	5.264	21.10	2.334	9.34	90.52		A		P	P	A			P+A		P+A	
226	1988	4.838	19.09	1.874	7.21	72.60		P/A		P		A		P+A				
227	2141	4.838	19.12	1.870	7.24	67.70		P/A		P		A	P	P+A				
228	1988	5.304	20.68	2.342	8.82	88.75		P/A		P		A		P+A			P+A	
229	2141	5.276	20.57	2.311	8.70	81.28		P/A		P		A	P	P+A			P+A	
230	2075	4.708	19.17	1.742	7.30	70.43		P/A		P		A			P+A			
231	2075	5.147	20.87	2.185	9.00	86.81		P/A		P		A			P+A		P+A	
232	2074	4.936	19.47	1.972	7.60	73.32		P/A		P	P	A		P+A				
233	2236	5.090	19.86	2.124	7.99	71.49		P/A		P	P	A	P	P+A				
234	2074	5.385	20.91	2.423	9.05	87.31		P/A		P	P	A		P+A			P+A	
235	2236	5.518	21.30	2.549	9.40	83.90		P/A		P	P	A	P	P+A			P+A	
236	2172	4.899	19.67	1.934	7.80	71.91		P/A		P	P	A			P+A			
237	2172	5.322	21.30	2.360	9.44	87.01		P/A		P	P	A			P+A		P+A	
238	1850	5.099	19.88	2.186	8.16	88.23			A	P		A		P+A				
239	1989	4.932	19.54	2.017	7.82	78.71			A	P		A	P	P+A				
240	1850	5.597	21.70	2.687	9.98	107.94			A	P		A		P+A			P+A	
241	1989	5.404	21.10	2.491	9.39	94.42			A	P		A	P	P+A			P+A	
242	1933	4.916	20.06	2.004	8.34	86.36			A	P		A			P+A			
243	1933	5.386	21.87	2.477	10.16	105.17			A	P		A			P+A		P+A	
244	1924	5.055	19.96	2.144	8.24	85.73			A	P	P	A		P+A				
245	2080	5.216	20.40	2.307	8.70	83.65			A	P	P	A	P	P+A				
246	1924	5.535	21.51	2.626	9.80	101.92			A	P	P	A		P+A			P+A	
247	2080	5.674	21.91	2.766	10.21	98.24			A	P	P	A	P	P+A			P+A	
248	2025	4.970	20.05	2.060	8.34	82.42			A	P	P	A			P+A			
249	2025	5.426	21.80	2.518	10.10	99.81			A	P	P	A			P+A		P+A	
250	1942	5.003	19.75	2.061	7.95	81.88		P	A	P		A		P+A				
251	2089	5.030	19.89	2.085	8.08	77.39		P	A	P		A	P	P+A				
252	1942	5.489	21.42	2.550	9.62	99.12		P	A	P		A		P+A			P+A	
253	2089	5.492	21.42	2.550	9.62	92.13		P	A	P		A	P	P+A			P+A	
254	2035	5.010	20.38	2.068	8.58	84.35		P	A	P		A			P+A			
255	2035	5.470	22.15	2.531	10.36	101.82		P	A	P		A			P+A		P+A	
256	2025	5.113	20.17	2.171	8.37	82.70		P	A	P	P	A		P+A				
257	1865	5.061	19.78	2.164	8.13	87.26		P	A	P	P	A	P	P+A				
258	2025	5.583	21.69	2.644	9.89	97.71		P	A	P	P	A		P+A			P+A	

TABLE 6 (Continued)

Case Number	Mass of Sludge Produced by Liquid Handling Processes, lb/mg	Capital Cost for Complete Plant, millions of dollars	Total Treatment Cost for Complete Plant, cents/1000 gallons	Capital Cost for Sludge Handling Processes, millions of dollars	Total Treatment Cost for Sludge Handling, cents/1000 gallons	Sludge Handling Cost, dollars/ton dry solids	Lime Stabilization	Gravity Thickening	Air Flotation Thickening	First Stage Anaerobic Digestion	Second Stage Anaerobic Digestion	Aerobic Digestion	Elutriation	Vacuum Filtration	Centrifugation	Sludge Drying Beds	Incineration	Land Spreading of Liquid Sludge
259	1865	5.735	22.16	2.790	10.33	94.64		P	A	P	P	A	P	P+A			P+A	
260	2128	5.059	20.36	2.118	8.56	80.54		P	A	P	P	A			P+A			
261	2128	5.505	22.08	2.566	10.29	96.78		P	A	P	P	A			P+A		P+A	

P primary sludge treated
A waste activated sludge treated
P+A mixture of primary sludge and WAS treated
P/A primary sludge and WAS treated separately with the process indicated

Except for centrifuges, which were amortized over a ten year period at six percent interest, capital costs for equipment and structures were amortized over 25 years at six percent interest. Capital cost is defined as the construction cost plus the costs of yardwork, land, engineering, legal-fiscal-administrative services and interest during construction. Total treatment cost is defined as the sum of amortization and operation and maintenance costs.

The cost for treating and disposing of sludge expressed as dollars per ton of dry solids is also included in Table 6. This figure ranges from about $30 per ton for anaerobic digestion followed by dewatering on sand drying beds to over $100 per ton when the sludge is dewatered by vacuum filtration or centrifugation and then incinerated. The cost of treating and disposing of sludge approaches 60 percent of the total treatment cost for the entire plant. Therefore, it can be seen that the method selected for sludge handling has a significant effect on the total cost of treatment.

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APPENDIX

FORTRAN Method of Writing Mathematical Equations

The use of the FORTRAN mode of expression has several advantages. First, all expressions can be written using ordinary typewriter symbols on a single line. Second, ambiguity and misunderstanding can be avoided when the simple rules are understood. Third, when a computer program is being described, the variable names used in the digital computer program can be used thus making the computations performed better understood by the reader.

FORTRAN provides five basic operations: addition, subtraction, multiplication, division, and exponentiation. Each of the operations is represented by a distinct symbol as follows:

Addition	+
Subtraction	—
Multiplication	*
Division	/
Exponentiation	**

In writing FORTRAN expressions, using the operations shown above, the following rules must be observed:

1. Two symbols of operation must not appear next to each other. Thus, A*—B is not a valid expression but A*(—B) is valid.
2. Parentheses must be used to indicate groupings just as in ordinary mathematical notation. Thus, $(X+Y)^3$ must be written (X+Y)**3 to convey the correct meaning. Again, A—B+C and A—(B+C) are both legitimate expressions, but they do not mean the same thing.
3. When the hierarchy of operations in an expression is not completely specified by the use of parentheses, the sequence of operations is as follows: All exponentiations are performed first, then all multiplications and divisions, and finally all additions and subtractions.
4. When the order of consecutive multiplication and/or division or addition and/or subtraction is not specified by the use of parentheses, the operations are performed from left to right. Thus, A/B/C would be taken to mean A/(B*C) not (A*C)/B. Also, A—B+C would mean (A—B)+C not A—(B+C).

FORTRAN also provides for the use of certain common mathematical functions such as the following:

Square Root	SQRT	(X)
Natural Logarithm	ALOG	(X)
Exponential (ex)	EXP	(X)
Trigonometric Sine	SIN	(X)
Trigonometric Cosine	COS	(X)
Absolute Value	ABS	(X)

URBAN SLUDGE DISPOSAL OR UTILIZATION ALTERNATIVES SOCIO-ECONOMIC FACTORS

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The ability for rural cities to handle sludge generated in their municipal wastewater treatment facilities, using land application or incineration methods has on the whole been a relatively simple matter. As a matter of interest there have been instances where sludges being treated in drying beds had somehow vanished. The dryed sludge apparently being taken by some organic farmer. Resistance by neighboring communities to accept this natural resource has for the most part been minimal, at least in rural areas. Therefore, rural communities have in general had a high degree of success in utilizing sludge.

The receptiveness of neighboring areas to readily accept municipal wastewater treatment residue is, in my opinion, due to the socio-economic relationship which these outlying communities share with their rural city counterparts. Another important consideration is the availability of land in these outlying areas, which in many instances are abundant when compared to large metropolitan areas.

This same climate of receptiveness and cooperation apparently has not developed for many large metropolitan areas. Therefore, the rapport which many major cities share with their suburban and rural communities is in this regard less certain. The ability for a major metropolitan area to effectively handle its sludge and hopefully have society make full use of its value, perhaps in the reclamation of strip mines for their enhancement and increased productivity by upgrading soil conditions, while using the backhaul capability of empty coal railcars, has been extremely difficult to implement. Thus, fostering the practice of disposal and not utilization. This situation can be attributed to two main factors. One is the technical concern, i.e., potential health hazards of bringing a wastewater treatment by-product which may contain a host of materials some of which may be toxic or pose a health threat. The other is characteristic of human nature, namely not wanting the waste materials from a community which in general is removed socially, economically, and politically from the potential receptor. The latter factor may, from a psychological standpoint, affect the public's technical concerns of a land application system to the degree that their concerns may be exaggerated when weighed against the information and experience which has been gained, in the handling of municipal sludges which have been effectively stabilized.

A host of treatment systems have been examined that deal with the final sludge processing step. Incineration and various heat treatment techniques have been a favored approach for some time. But with current and future costs of natural fuels escalating at rates never believed possible, it is abundantly clear that incineration and other energy intensive systems will not prevail unless they are found to be cost-effective and not energy intensive. Concurrently we must also remain mindful of satisfying emission requirements so that we can maintain or improve applicable air quality standards. This requirement may in some instances prove to be both technically difficult and costly.

As for land spreading, the application of sludge in a liquid state appears to be one of the most attractive alternatives from an economical and environmental standpoint except when one compares it with the cost of ocean disposal for coastal megalopoli and the out of sight out of mind philosophy associated with this practice. Furthermore, the degradative effects and environmental stresses which we have monitored from ocean dumping these materials are vividly illustrated when one examines the effects it has rendered on the marine environment in the New York Bight and Philadelphia's sludge dumping site. There is every reason to believe that the resulting effects which society has witnessed by this disposal method may ultimately result in the demise of this practice. The method has an inherent shortcoming, namely the inability to control or manage the fate of these materials once the sludge has been discarded into the marine eco-system. The aforementioned shortcoming does not apply however to land application techniques, since prudent management practices can easily be implemented using this approach, thereby controlling the degree of environmental stress.

It is generally known that sludges from municipal sewage treatment plants vary markedly in both organic and inorganic content. This is obviously due to the variability and composition of the wastewater. The inherent characteristics of sludge are the result of three major considerations:

1. The domestic water supply system including the water supply source, treatment and conveyance system;
2. The compounds associated with industrial and domestic wastewaters;
3. Storm water and subsurface inflow into the collector system.

The composition of municipal wastewaters is basically dependent on the proportion and nature of the community's lifestyle and industrial base.

The residential diet has been shown to affect wastewater and sludge characteristics. For example, the daily normal digestion and excretion of zinc is expected to be approximately ten mg/person. The concentration of zinc in various food products have been detected from levels of less than one ppm in fruits to as much as 2300 ppm in oysters. It has also been established that today's automobile tires are manufactured from a variety of materials. Unfortunately one of these is zinc and, because of its inherit impurities, cadmium. Under normal use and wear it is naturally expected that these automobile tire materials and other heavy metals some of which may come from auto exhausts, automobile brake linings, the scrubbing of air pollutants, etc. would during periods of precipitation be scoured off road surfaces and into the municipal sewer system (Table 1). If the collector system is of the combined sewer type, significant quantities of these materials and associated metals will ultimately find their way into the municipal wastewater treatment facilities and the sludges generated therein. The fact that many of these heavy metals build up in the sludge, coupled with the degree of accumulation makes any final handling method considerably more difficult to manage from an environmental standpoint (Table 2).

In some cases, relatively high quantities of heavy metals were found to be accumulating in wastewater treatment plant sludges in a number of cities throughout our nation. This excess was and still is in some cases apparently thought to be due primarily by industrial discharges. However, as a result of a two-year comprehensive study dealing with sources of metals in New York City and a subsequent report published by New York City's Department of Water Resources, it was clearly shown that at least in a megalopolis of this size complete control of all industrial contributors would not result in any significant gain in the reduction of heavy

TABLE 1
Heavy Metals Loading Intensities
(Lb/Curb Mile)

	ZINC	COPPER	LEAD	NICKEL	MERCURY	CHROMIUM
San Jose-I	1.4	.49	1.85	.19	.20	.10
San Jose-II	.28	.020	.90	.085	.085	.14
Phoenix-II	.36	.058	.12	.038	.022	.029
Milwaukee	2.1	.59	1.51	.032	-	.047
Baltimore	1.3	.33	.47	.077		.45
Atlanta	.11	.066	.077	.021	.023	.011
Tulsa	.062	.032	.030	.011	.019	.0033
Seattle	.37	.075	.50	.028	.034	.081
Arithmetic Means	.75	.21	.68	.060	.080	.12

TABLE 2
Contents of Trace Elements in 57 Sewage Sludges from Locations in Michigan, U.S.A.

Element	Range		Mean	Median	No. Samples Within Range				
					1-10	10-100	100-1000	1000-10000	>10,000
	---------- µg/g----------								
Hg	0.1	56	5.5	3.0	49	4	0	0	0
Cd	2	1100	74	12	28	20	8	1	0
Cr	22	30,000	2031	380	0	19	18	18	2
Cu	84	10,400	1024	700	0	1	42	13	1
As	1.6	18	7.8	7.5	48	9	0	0	0
Ni	12	2800	371	52	0	33	15	9	0
Pb	80	26,000	1380	480	0	2	43	10	2
Zn	72	16,400	3315	2200	0	1	9	44	3

metals into the municipal wastewater treatment system. According to the authors it is claimed that approximately 91 percent of the copper, 94 percent of the zinc, 84 percent of the cadmium and 80 percent of the chromium would still get into the sewer system if 100 percent control were placed on these industrial discharges. Only in the case of nickel would a zero discharge by industry result in a significant reduction 38 percent of the current level. These findings should be corroborated by at least two other comprehensive surveys of this or greater magnitude.

If heavy metals continue to be a source of concern and frustration as related to our handling of municipal sludges and for that matter all sludges, it may be necessary that our society make some major changes in its lifestyles so that we can effectively control the movement of these materials. Perhaps we may have to give up tires having zinc derivatives, chromate compounds in cooling towers, copper sulfate as an algicied, etc.

One method which holds great promise in partially resolving the ultimate step in processing sludge, currently confronting large urban centers is that of land spreading stabilized sludge. Providing of course that suburban and rural communities become receptive and would permit these urban centers the opportunity to prove its full worth. A process which allows for man's utilization of this natural resource if prudent management practices are followed during the entire effort.

Small or relatively low applications of sludge containing an abundance of micronutrients such as boron, zinc, copper, manganese, etc., would normally be sufficient to satisfy most or existing soils which are deficient in these minerals. However, large applications of these materials when the concentration of these micronutrients are found to be high could promote deficiencies in growth yields and/or toxicities. Therefore, limits of application exist and must be defined so that the soil-plant-sludge inteface is not upset. It is essential that we realize the full beneficial value of the sludge from its fertilizer and soil conditioning standpoint. While sludge in a liquid state contains both major and minor nutrients for plant growth, it may not be a balanced fertilizer or a wide variety of crops and soils.

Sludge composition will undoubtedly change depending on factors previously enumerated and the methods of stabilization. Sludges are normally low in potassium, of medium value in available nitrogen and high in phosphorous. It may be inappropriate to compare it to commercial fertilizers from a handling standpoint because of the volumes which are needed to achieve the same nutrient objectives. Nevertheless, if arrangements can be implemented where the sludge is delivered and applied on fields at no cost to the farmer, liquid sludge can be utilized in a manner that is economical, suitable as a fertilizer supplement and excellent as a soil conditioner. As a result of the addition of organic matter which is rather abundant, in the sludge, to the soil, it has been shown that the sludge amended soils have in many cases improved significantly with regard to; ability to hold moisture, humus content, soil fertility and improved soil structure. Thus making the sludge far more valuable as a soil conditioner than that as a fertilizer.

This factor makes sludge a very effective material for the reclamation of marginal lands which may have been depleted of organic matter through misuse. In fact, the application of sludge on strip mined areas for purposes of reclamation has in a number of instances resulted in the growth of vegetation where none could develop, due to previous mining practices. A significant increase in the ph value was also noted with regard to surface runoff during periods of precipitation. Another benefit is the effective control of soil erosion and sediment transport

because of the ground cover which is formed during this reclamation process. The disposal of sludge which can be used as resource by society is inexcusable.

A number of different treatment techniques have amply demonstrated that significant reductions can take place with respect to bacterial concentrations. Although it also has been shown that some of these processes provide conditions which are hostile to these organisms, they are by no means lethal (Table 3).

to land environs has on the whole demonstrated the viability of this approach and that the risks to public health are slight if appropriate handling and management techniques are employed.

Finally and of major importance is the issue of cost. This factor has been found to vary considerably depending on the method of analysis, area of study, etc.. Unfortunately some of these efforts, in my opinion, appear to be compiled in a subjective rather than objective man-

TABLE 3
Bacteria in Sewage Sludge
(Per 100 ml)

	Fecal coli ($\times 10^6$)	Salmonella	Pseudomonas
Raw Primary	11.4	460	46,000
Trickling filter	11.5	93	110,000
Raw WAS [(a)]	2.8	74	1,100
Raw WAS (thickened) - B	20	9,300	2,000
Raw WAS - C	2.0	2,300	24,000
Anaerobic digested primary	0.39	29	34
Aerobic digested WAS	0.66	150	100,000
Anaerobic digested WAS	0.32	7.3	1,000
Iron primary	32	460	21,000
Lime primary pH 9.0	32	1,500	24,000
Lime primary pH 11.5	0.014	<3.0	<3.0

(a) Waste activated sludge

The potential for contamination of groundwater by pathogenic microorganisms is dependent on the ability of pathogens to survive and move through the soil system. Many factors govern their pathways and complicate the assessment of their movement through the soil mantle. Unfortunately, there is a dearth of information on this subject. Nevertheless, the information that is available regarding the effects of sludge land spreading practices and that also of applying wastewater effluents

ner and are thus misleading. A rigorous cost analysis is beyond the scope of this paper. However, some efforts that deserve mention will be briefly cited.

One analysis in particular was done for Metropolitan Sewer Board of the Twin Cities area. Nearly 300 processing combinations were considered which were initially pared down to 59. Based on this rigorous cost analysis, land spreading of sludge was listed as the most cost-effective candidate. Obviously each situation from a

cost analysis standpoint, for municipalities, is unique and what applies to one community may not be applicable to another. One other study although not as recent, but appropriate nevertheless, if the listed values are extrapolated to reflect inflationary trends, also shows the economic advantages of landspreading sludge in a liquid state (Table 4).

TABLE 4
Comparative Costs of Suldge Disposal (1970)
(Presented in English Units)

Method	Estimated cost, $/dry short ton
Incineration	50
Wet-air oxidation	42-50
Multiple-hearth	30-57
Fluidized-bed	30
Drying: fertilizer sale	45
Lagooning	
Pumping	7-49
Trucking 5% sludge	18
Trucking 10% sludge	12
Disposal at sea	
Pumping	11
Barging 5% sludge	12
Barging 10% sludge	9
Land application	
Landfill	25
Heat-dried sludge	50
Dewatered sludge	25
Liquid sludge	15
Strip-mine reclamation	16

The final sludge processing method which is eventually selected, has based on past experiences been influenced to a large degree by elements which are sociopolitical. This fact effectively dilutes the environmental-economic analysis and associated recommendations.

If we are to make significant progress in effectively managing our environment. We must make these latter elements which "really" influence the ultimate decision aware of the advantages and disadvantages of the options that are currently available.

The following recommendations are offered in the hope that we can effectively correct the current situation:

1. Develop an active public awareness program on the benefits and liabilities of the proposed sludge processing system, whether it be landspreading of sludge for cropland and/or reclamation purposes, power generation, ocean disposal, incineration, etc.

2. A realistic program in controlling heavy metals into our wastewater collection systems not only focusing on industry, but commercial uses where it is humanly practicable.

3. A sincere effort on the part of our leadership to apply those techniques which have been sufficiently developed and/or demonstrated and to highlight the pitfalls of those systems or approaches that failed to achieve either the performance or objectives under consideration.

4. That a research and demonstration effort which is meaningful in scope and commensurate with current environmental construction grant expenditures be implemented.

SLUDGE MANAGEMENT ALTERNATIVES FOR COASTAL CITIES

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INTRODUCTION

For many years the principal goal of wastewater treatment has been production of clear, high quality effluent water, whereas treatment and disposal of sewage solids removed from the aqueous stream has been considered a secondary activity of rather less concern. It has since become apparent that sewage sludge disposal must become an integral part of an overall land, air and water resource management plan. In Southern California, the problem of solids disposal has become a particularly serious concern in coastal communities, since these communities support the greatest part of the State's population and their traditional solution of ocean disposal is being blocked by regulatory action. The search for a more acceptable method of disposal for sewage sludge has to be conducted against a background of increasing public awareness of not only marine pollution, but also degradation of air quality and inappropriate land-use practices.

Recognizing the seriousness of the problem the Southern California wastewater agencies and state and Federal agencies concerned with environmental protection have conducted or are presently conducting a number of investigations of alternative sewage sludge management practices. Recently a well-funded study of the problem was commenced by a group of wastewater agencies and is expected to report its findings in approximately two years. In 1973-74 Engineering-Science, Inc. in association with J.B. Gilbert and Associates conducted a pilot study of the sludge disposal problem under a contract with the Washington Environmental Research Center of the Environmental Protection Agency.

The object of the pilot study was to compile regulations effecting the choice of sludge management options to develop an evaluation and comparison method for sludge management alternatives and to apply the system to the three largest wastewater dischargers in the Los Angeles area. The evaluation method should permit an equitable comparison of the advantages and disadvantages of different sludge management options yet satisfy the public's need to follow and understand the method.

This paper presents a summary of the findings of the study. Its conclusions are not based on extended or exhaustive evaluations; however, until the present more detailed study is completed they do provide some illumination of the problem and some of its possible solutions[1].

The Sewage Sludge Disposal Problem In Southern California

The average daily production of wastewater sludges by California coastal communities as reported in 1973 was 1,251 metric tons. The sludges result from treatment, principally primary, of 69 m^3/sec [1,575 mgd] of raw municipal wastewater. Table 1 summarizes present wastewater flow and sludge production rates in coastal California.

TABLE 1
Present Sludge Production (1973)

Area	Flow, m^3/sec	Sludge production, metric tons dry solids/day	Total sludge production, %
San Francisco Bay Area counties	19.6	485	38
Los Angeles County	34.3	528	42
Orange County	7.1	95	8
San Diego County	5.1	95	8
Other	3.0	48	4
Total	69.1	1,251	100

Reference: 1973 EPA Needs Survey

The wastewater flow treated by the three largest dischargers (City of Los Angeles, Los Angeles County Joint Outfall Facilities and Orange County) in the Los Angeles basin in 1973 was 40.8 ^{3}/sec [931 mgd] average daily dry-weather flow. The mass of sewage sludge generated by these three agencies was 48 percent of the total sludge tonnage generated by all of the California coastal communities.

On the basis of projections of coastal agencies in California, general adoption of secondary treatment will result in production of 4,000 metric tons of sludge each day

by 1995, approximately a threefold increase over the present rate and two-thirds of which is attributable to the higher level of treatment. In Southern California it is estimated that production will be 405 metric tons [445 short tons] of sludge daily at the City of Los Angeles Hyperion Plant. The Joint Works of Los Angeles County will produce 1,062 metric tons [1,168 short tons], and the County Sanitation Districts of Orange County will reach 315 metric tons [347 short tons] daily.

The basic characterization of sewage sludges and their constituents has often been reported and will not be repeated here. However, it is worth noting that the relative portions of total raw sewage flow representing industrial waste at the Joint Treatment Plant, Hyperion and Orange County are 35, 12 and 25 percent, respectively. Source control of industrial wastes will reduce the amounts of heavy metals and toxicants reaching treatment plants, but source control will take several years to implement and will never eliminate the problem of toxic material in sewage sludges. In terms of treated sewage sludge, Table 2 presents the changes to be expected in sludge characteristics from the most commonly used unit processes. Sludge processing unit performance characteristics are shown in Table 3.

TABLE 2
Changes in Sludge Constituents
Through Basic Processing

Constituent	Raw sludge	Digested sludge	Digested and dewatered	Raw dewatered and incinerated	Supernatant, centrate, filtrate or off-gas
Percentage of original water content	100	100	47	0	43 to 100
Percentage of original solids content	100	60	40 to 58	30 to 40	60 to 70 Varies with process efficiency
Percentage of original organic toxicants	100	Decreased by undetermined amount	Decreased by undetermined amount	0	Undetermined
Percentage of original inorganic toxicants	100	100	Estimated 80 to 95	Undetermined	Undetermined
Percentage of original organic matter	100	30 to 40	28 to 35	0	Varies with process efficiency

TABLE 3
Sludge Processing Unit Performance

Process	Feed	Total solids in	Total solids out	Volume reduction	Solids recovery
		percent wt		percent	
Thickening					
Gravity	Primary	1-3	5-8	50-60	98+
	WAS	0.5-1	2-3.5	50-60	98+
	Primary & WAS	2	4-5	50-60	98+
	Digested primary	2-5	5-8	50-60	98+
	Digested primary & WAS	2-3			98+
Flotation	Primary & WAS	2	5-7	65	95+
	WAS with chem.	0.5-1.5	4-5	65	95+
	WAS without chem.	0.5-1.5	3.5	60	95+
Treatment					
Aerobic digestion	Primary, thickened	5-8	3-5	10	60-65
	Primary & WAS, thickened	4-5	2-4	10	50-60
Anaerobic digestion	Primary, thickened	5-8	2-5	0	40-60
	Primary & WAS,	4-5	2-3	0	50-60
Incineration	Primary, dewatered	25	100	75-85	30-40
	Primary & WAS, dewatered	25	100	75-85	30-40
Wet oxidation	Primary or primary & WAS	4-8	4-8	0	98+
Heat	Any, thickened	4-8	4-8	0	98+
Lime stabilization	Primary, thickened	5-8	5-8	0	110
	Primary & WAS, thickened	4-5	4-5	0	110
Dewatering					
Drying beds	Any, digested	2-5	40	50	98+
	Any, lime stabilization	4-8	40	50	98+
Vacuum filter	Primary, conditioned	2-3	35	90	90+
	Primary & WAS, conditioned	2-3	25	85-90	90+
	Digested, conditioned	2-5	25-37	90	90-95+
Pressure filtration	Digested, conditioned	5-6	30-40	80-90	98+
Centrifuge	Digested	2-5	18-21	60-75	55
	Digested, conditioned	2-5	20-25	75-85	90-95
Heat drying	Digested	2-5	90	95+	98+

Sewage Sludge Disposal Criteria

Sewage sludge management practices may have an impact on many environmental elements. Ocean disposal of sludge obviously may affect water quality, land disposal of sludge may affect groundwater quality or soil productivity and sludge incineration will affect air quality.

The diversity of potential impacts of sewage sludge disposal is reflected by the plethora of governmental regulations that constrain the selection of choices with respect to sludge disposal. Tables 4, 5, 6, 7, and 8 summarize the relevant regulations and multi-media sludge disposal criteria applicable in coastal Southern California.

The Alternative Evaluation System

The need to systematically evaluate and quantify environmental impacts of alternative courses of action has spawned a variety of evaluation systems, the best-known of which are the U.S.G.S. Matrix, the Battelle Environmental Evaluation System, the Georgia Institute of Ecology's Optimum Pathway Matrix and the U.S. Bureau of Reclamation's method [2-5]. The U.S.G.S. Matrix is an inventory or checklist of factors that can be useful for selecting criteria relevant to an alternative. The Battelle

TABLE 4
Summary of Regulatory Authority Affecting Sewage Solids Disposal

Disposal System	EPA	California State Air Resources Board	Los Angeles County APCD	Orange County APCD	California State Water Resources Control Board Regional Water Quality Control Board	State Solid Waste Management Board	California State Department of Public Health California Coastal Zone Conservation Commission	Los Angeles County Engineer	Los Angeles County Regional Planning Commission Department of City Planning, Los Angeles	Orange County Planning Department	Orange County Flood Control District
Incineration											
Incinerator ash disposal to land			-	-	PS	PS	N	L	PS	PS	P	P		PS
Incinerator ash disposal to water	PS			-	PS	PS	-	L	PS	-				
Pollutant emissions to atmosphere	PS	PS	PS	PS			-	-	PS	-	-	-	-	-
Land Disposal														
Landfill of dewatered solids		-		-	PS	PS	N	L	P	PS	P	P		PS
Land disposal of liquids					PS	PS		L	P	PS	P	P	-	PS
Ocean Disposal														
Ocean discharge of sludge	PS	-	-	-	F	F	-	L	PS	-	-	-	-	
Ocean discharge of liquid waste	PS	-			PS	PS	-	L	PS		-		-	-
Reclamation-reuse														
Pollutant emissions to atmosphere	PS	PS	PS	PS	-	-	-	-	PS	-	-	-	-	-
Use of processed packaged soil conditioner	-	-	-	-				L		-			-	-
Use of raw or digested sludge for soil conditioning	-	-	-	-	PS	PS		L	-	PS	-	-	-	PS

KEY TO LETTER CODE:
P - Agency issues permits but not numerical standards
PS - Agency issues permits which include emission standards
N - Agency approves new disposal sites that have proved need and necessity
L - Agency has broad statutory authority but does not issue permits
F - Agency has a prohibition policy

TABLE 5
Summary of Emission and Equipment Criteria
Relating to Sewage Solids Disposal to the Atmosphere

Parameter	Federal Environmental Protection Agency	California Air Resources Board	Los Angeles Air Pollution Control District	Orange County Air Pollution Control Dist.
1. Ringelmann	none	Approves Local District Standards	shall not be ≥ No. 1 for more than 3 minutes	shall not be ≥ No. 1 for more than 3 minutes
2. opacity	≤ 20 percent		none	none
3. particulate matter	0.65g/kg dry sludge		varies according to process feed rate refer to text	varies according to process feed rate refer to text
4. beryllium	< 10g/24hr.		none	none
5. mercury	< 2,300g/24hr.		none	none
6. nuisance	none		prohibited	prohibited
7. equipment	none		multiple-chamber incinerator	multiple-chamber incinerator
8. oxides of nitrogen	none		125 ppm (gaseous) 225 ppm (liquid or solid)	125 ppm (gaseous) 225 ppm (liquid or solid)

TABLE 6
Summary of Regulatory Agency Disposal Criteria Relating to the Land

	California State Water Resources Control Board	California Regional Water Quality Control Boards	Los Angeles County Engineer	Orange County Flood Control District
1. Solid Waste	Standards for land disposal of solid waste are adopted by all agencies on a case basis in general conformance to disposal site classifications set forth in Subchapter 15, Chapter 3, Title 23 of the California Administrative Code and presented in Appendix 2.			
2. Liquid Waste	All agencies establish standards for land disposal of liquid waste on a case-by case basis.			

TABLE 7
Summary of Liquid Waste Disposal Criteria for Discharges to the Ocean

Parameter	Units	Federal Environmental Protection Agency	California State Water Resources Control Board		California Regional Water Quality Control Board		California Coastal Zone Conservation Commission
Liquid Waste			50 (1) Percentile	90 (2) Percentile	50 Percentile	90 Percentile	
Grease and oil	mg/l		10	10			
5 Day 20° BOD	mg/l	30(3) 45(4)	none	none			
Suspended solids	mg/l	30(3) 45(4)	50	75			
Setteable solids	ml/l	none	0.1	0.2			
Floating particulates (dry wt.)	mg/l	none	1.0	2.0			
Turbidity	JTU	none	50	75			
pH		units within the limits 6.0 to 9.0					
Fecal coliform	No/100 ml	200(3) 400(4)	none	none			
Arsenic	mg/l	none	0.01	0.02			
Cadmium	mg/l	0.32(7)	0.02	0.03			
Total chromium	mg/l	none	0.005	0.01			
Copper	mg/l	none	0.2	0.3			
Lead	mg/l	none	0.1	0.2			
Nickel	mg/l	none	0.1	0.2			
Silver	mg/l	none	0.02	0.04			
Zinc	mg/l	none	0.3	0.5			
Mercury	mg/l	0.1(7)	0.001	0.002			
Aldrin	µg/l	5.5(5) (7)	none	none			
Dieldrin	µg/l		none	none			
Benzidine	µg/l	1.8(7)	none	none			
FFD	µg/l		none	none			
DDE	µg/l	0.6(6) (7)	none	none			
DDT	µg/l		none	none			
Endrin	µg/l	0.6(7)	none	none			
Cyanide	mg/l	0.1(7)Q	0.1	0.2			
Total chlorinated hydrocarbons	µg/l	none	2.0	4.0			
Polychlorinated biphenyls	µg/l	10(7)	none	none			
Toxaphene	µg/l	1.0(7)	none	none			
Phenolic compounds	mg/l	none	0.5	1.0			
Total chlorine residual	mg/l	none	1.5	2.0			
Ammonia (as N)	mg/l	none	40	60			
Toxicity Concentration	tu	none	1.5	2.0			
Raw sludge, digested sludge, digester supernatant all untreated		none	expressly prohibited				
					Same as State Water Resources Control Board	Same as State Water Resources Control Board	Same as State Water Resources Control Board

(1) value not be exceeded more than 50 percent of time
(2) value not be exceeded more than 10 percent of time
(3) monthly average value
(4) weekly average value
(5) total combined concentration of Aldrin + Diedrin
(6) total combined concentration of DDD + DDE + DDT
(7) proposed Federal Standard

System considers 78 parameters within the framework of ecology, pollution, aesthetics and human interest. This system requires extensive local biota data and predetermines relative values of factors. The Optimum Pathway Matrix requires the use of a computer to calculate scores and places strong emphasis on economic and human use considerations. A panel of "experts" selects the relative values of environmental factors. The Bureau of Reclamation's system was developed for large-scale land reclamation or water diversion projects and focuses on national economic development, environmental quality and regional development.

The evaluation and comparison of many alternatives in an initial screening can become unwieldy and prohibitively expensive if one of these systems is selected. An initial evaluation procedure developed by Engineering-Science, Inc. and successfully used in water quality management plans in Utah and Pennsylvania was chosen for use in evaluating sewage sludge management alternatives. The first step in the procedure was the

TABLE 8
Summary of Ocean Discharge Criteria for Solid Wastes

Parameter	Units	Federal Environmental Protection Agency		Cal. Regional Water Resources Control Board	Cal Regional Water Quality Control Boards	Cal. Coastal Zone Conservation Commission
Solid Waste				State policy prohibits discharge of sewage sludge to ocean	State policy prohibits discharge of sewage sludge to ocean	Coastal Zone Conservation Commission's actions reflect state and regional board policy
Mercury & mercury compounds	mg/kg	0.75[1]	1.5[2]			
Cadmium & cadmium compounds	mg/kg	0.6[1]	3.0[2]			
Total organohalogens	mg/kg	limiting permis. conc.[3]				
Oil and grease	none	no visible sheen when material is added to water in the ratio of 1:100 waste to water limiting permis. conc.[3]				
Wastes Containing						
(a) Arsenic						
(b) Lead						
(c) Copper						
(d) Zinc						
(e) Selenium						
(f) Vanadium						
(g) Beryllium						
(h) Chromium						
(i) Nickel						
(j) Oxygen consuming or biodegradable matter						
(k) Materials on any EPA list of toxic pollutants						

[1] solid phase
[2] liquid phase
[3] that concentration of waste material or chemical constituent in the receiving water which, after reasonable allowance for initial mixing in the mixing zone, will not exceed 0.01 of a concentration shown to be toxic to appropriate sensitive marine organisms in a bioassay carried out in accordance with approved EPA procedures or 0.01 of a concentration of waste otherwise shown to be detrimental to the marine environment.

identification of all relevant evaluation factors; these factors were then divided into four groups: economics, environmental factors, feasibility factors and performance factors. The economic evaluation is relatively straight-forward because the cost of the labor and materials necessary to construct and operate the alternative sludge management systems can be expressed in monetary terms. Factors in the other three groups reflect non-monetary values and can only be evaluated in a subjective manner.

In order to determine the relative importance of each factor in the eyes of the individuals affected by the alternative courses of action it is necessary to sample opinion by interviews or questionaires. Every effort should be made to poll an appropriate sample in order that the importance values or weights assigned each factor reflect a typical cross-section of public opinion. Because of limited interests and time, a sampling of only wastewater treatment agencies and regulatory agencies along coastal California was obtained during this study. Table 9 shows the averaged results of a sampling of 40 agencies with a response of 15 agencies.

While the public is best qualified to weigh the individual factors, only experts can provide a consistent and fair rating of an alternative with respect to any factor with the exception of aesthetics. The evaluation system recognizes the subjective nature of most of the ratings,

TABLE 9
Environmental Evaluation Values[a]

Environmental Factors	Values	Feasibility Factors	Values	Performance Factors	Values
Water Quality	9	Financial	9	System	9
Air Quality	8	Feasibility		Effectiveness	
Land Quality	6	Public	8	Reliability	8
Flora and Fauna	6	Acceptability		Adaptability	5
Aesthetics	6	Land Use	7	Calamity	6
Public Health	9	Compatibility		Resistance	
Community Impact	6	Ease of Implementation	6	Permanence	6
Resource Conservation	5				

[a] based on a scale of 1 to 10; averaged results of survey; disposal and regulatory agencies

but it is felt that alternatives should be consistently rated among the same factors. A graduated and defined scale was used to define rating numbers from zero (worst case) to ten (best case or maximum benefit to the environment). The rating of an alternative with respect to a certain factor can then be multiplied by the previously assigned importance value or weight of that factor. The weighted ratings can be summed within each evaluation factor group and a score with respect to environmental factors, feasibility and performance obtained for each alternative.

Sludge Management Alternatives for Southern California

The alternatives evaluated for the major Los Angeles area dischargers included: (1) ocean disposal; (2) pro-

cessing for sale; (3) local landfilling; (4) landfilling at remote sites; (5) evaporation ponds in Antelope Valley; (6) reclamation of land in Antelope Valley; and (7) incineration. In each case appropriate treatment, such as anaerobic digestion and sometimes centrifuge dewatering, was assumed for primary and secondary level wastewater treatment sludges.

Ocean Disposal

Each of the three dischargers has in operation separate wastewater treatment facilities and ocean outfalls. Each discharger was considered a separate entity disposing of sludge locally with regionalization offering no advantages but containing a possible disadvantage in discharging a greater mass of sludge within a limited geographical area.

Processing for Sale

Los Angeles County composts dewatered digested sludge on their property and sells it for less than the actual costs of composting. Orange County sells dewatered digested sludge prior to composting. Envisioning a glut on the market where all dischargers produce this material, the sale price of compost to commercial packagers will drop significantly and for purposes of analysis was assumed to be zero.

Centrifuge centrate, which is estimated at 85 percent by volume of the feed liquor would be discharged back to the wastewater treatment system. Wastewater treatment facilities would be incrementally larger to accomodate this waste and an incremental rise in effluent constituents may be noticed.

Local Landfilling

Each of the three dischargers has several sanitary landfills, of Class II or better, located within 35 miles of their facilities and at least one major landfill within 20 miles. The disposal of dewatered sludges to a sanitary landfill can be considered as a solution to a solid waste disposal problem.

Remote Landfilling

It was assumed that it may become necessary to truck dewatered sewage sludges 100 to 130 miles to an inland disposal site.

Antelope Valley Evaporation Ponds

Doubts concerning the handling of sewage sludge centrate led to the development of common pipeline transport and disposal facilities to pump digested sludges to the high desert in the Antelope Valley to take advantage of an evaporation rate of six ft/yr.

Evaporation ponds based upon a design loading of three ft/yr would dry the sludge to 40 percent solids after which the sludge would be placed in a local landfill. Federal land for the ponds was assumed available at no charge.

Antelope Valley Soil Reclamation

Digested sludge would be pumped to a 40 million gallon storage lagoon in Antelope Valley. Based upon the Lahontan Regional Water Quality Control Board's application limit of two lb/acre of total nitrogen per day, 76,000 acres would be needed to accommodate the sewage sludge. To utilize the reclaimed soil as farmland, 271 million gallons/day of irrigation water would be needed. This quantity of water does not appear to be available; and the use of sewage sludge on currently productive land is not recommended [6,7]; therefore, no farming disposal system exists in the Southern California coastal area. Because the transport of treated wastewaters for irrigation appeared infeasible, this alternative was dropped.

Incineration

A separate multiple-hearth incinerator with air-pollution control equipment was assumed for each treatment facility complex. Vacuum filters would dewater raw sludges to 35 percent solids, sufficient to maintain combustion, and incinerator ash would be trucked to a local landfill.

Comparison of Alternatives

Preliminary cost estimates for southern California conditions were based upon annualized capital, operating and maintenance costs and reclamation revenue and included the entire processing train for each alternative, with credit given for existing facilities. Table 10 shows combined costs for the three agencies.

The relative ranking of the alternatives with respect to environmental considerations, feasibility and performance together with the principal difficulty associated with each alternative is shown in Table 11. Figure 1 compares graphically the characteristics of the alternatives. Weighted ratings for the alternatives are included in Appendix A.

The comparative ranking of alternatives demonstrates that the least-cost solution for municipalities with existing ocean outfalls is ocean disposal at $3.4 million annaually. The next best solution, at over double the annual cost, is composting. Incineration and local landfilling are within $1 million annually of each other at

TABLE 10
Costs of Alternatives

Alternative	Cost, $/metric ton dry solids
Ocean Disposal	8
Processing for sale	20
Local landfill	25
Remote landfill	44
Evaporation and landfill	48
Soil Reclamation	58
Incineration	30

TABLE 11
Non-Monetary Evaluation
of Alternatives

Alternative	Ranking: Environmental	Ranking: Feasibility	Ranking: Performance	Problems
Ocean disposal	4	3	4	Adverse effects on marine environment
Processing for sale	1	1	6	Unpredictable market for soil amendments
Local landfill	2	2	5	Dwindling capacity of acceptable sites
Remote landfill	5	5	1	Trucking operations inconvenience community
Evaporation and landfill	6	6	2	Hazards associated with pipeline transport
Soil reclamation	- unranked -			Unavailability of supplementary irrigation water
Incineration	3	4	3	Adverse effects on air quality

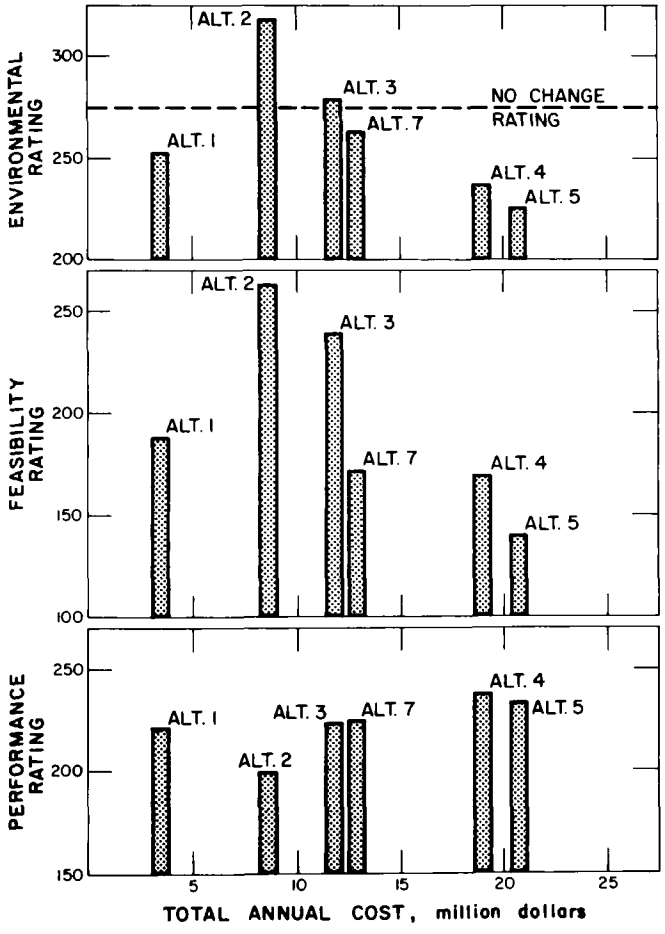

Figure 1: Comparison of Alternatives.

$11.8 and $12.8 million, while the remote disposal schemes in the Antelope Valley or remote landfills are the most expensive at $19 or $25 million annually.

The best environmental rating was achieved by composting for sale, followed by local landfilling and incineration. The most detrimental environmental ratings were achieved by remote disposal options. In terms of feasibility for implementation, composting for sale and local landfilling scored best, followed by ocean disposal and incineration. Again, the poorest alternatives were remote disposal.

Performance rating, which measures simplicity and continuity of operation along with proven dependability, rated the remote disposal options the highest followed closely by incineration, ocean disposal and local landfill, while the poorest alternative was composting for sale. The low rating of composting for sale was influenced by expected limitation in the market's ability to absorb compost.

CONCLUSIONS

Based upon the evaluations of the original seven alternatives, it would appear desirable to select composting for sale for each of the major agencies. Environmental risks are minimized and in fact some benefits are realized with composting. The system has very good public acceptability, land use compatibility, ease of implementation and financial feasibility. The performance rating could be substantially upgraded by allowing excess sludge production above market capacity to be buried at a local landfill. To a large extent this is the system being employed at Los Angeles and Orange Counties and indicates that natural selection processes of public pressure, economic considerations and environmental awareness have been at work.

It should be noted however that ocean disposal remains the least cost option by a wide margin. It would be a misallocation of resources to abandon ocean disposal entirely unless it is clearly demonstrated that its environmental impact is greater than that of the more costly alternatives.

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APPENDIX A

Evaluation Data

UNWEIGHTED PARAMETERS		ALTERNATIVE #1 Ocean Disposal	ALTERNATIVE #2 Processing	ALTERNATIVE #3 Local Landfill	ALTERNATIVE #4 Remote Landfill
ECONOMICS	CAPITAL COST	51,025,000	77,313,000	77,313,000	77,313,000
	ANNUAL CAPITAL AMORTIZATION	4,118,000	6,707,000	6,707,000	6,707,000
	O. AND M. COST	1,304,000	4,147,000	7,193,000	14,611,000
	RECLAMATION REVENUE	-2,070,000	-2,070,000	-2,070,000	-2,070,000
	TOTAL ANNUAL COST	3,352,000	8,784,000	11,830,000	19,248,000

WEIGHTED PARAMETERS		WEIGHT	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING
ENVIRONMENTAL FACTORS	WATER QUALITY	9	3	27	6	54	6	54	6	54
	AIR QUALITY	8	5	40	5	40	5	40	4	32
	LAND QUALITY	6	6	36	7	42	4	24	4	24
	FLORA AND FAUNA	6	4	24	6	36	6	36	4	24
	AESTHETICS	6	5	30	5	30	5	30	3	18
	PUBLIC HEALTH	9	5	45	5	45	5	45	5	45
	COMMUNITY IMPACT	6	5	30	5	30	5	30	4	24
	RESOURCE CONSERVATION	5	4	20	8	40	4	20	3	15
	TOTAL WEIGHTED RATING			252		317		279		236
FEASIBILITY	FINANCIAL FEASIBILITY	9	10	90	9	81	9	81	7	63
	PUBLIC ACCEPTABILITY	8	2	16	9	72	4	32	4	32
	LAND USE COMPATIBILITY	7	10	70	9	63	10	70	8	56
	EASE OF IMPLEMENTATION	6	2	12	8	48	9	54	3	18
	TOTAL WEIGHTED RATING			188		264		237		169
PERFORMANCE	SYSTEM EFFECTIVENESS	9	2	18	4	36	4	36	4	36
	RELIABILITY	8	8	64	7	56	7	56	6	56
	ADAPTABILITY	5	5	25	9	45	9	45	9	45
	CALAMITY RESISTANCE	6	9	54	8	48	8	48	7	42
	PERMANENCE	6	10	60	2	12	5	30	10	60
	TOTAL WEIGHTED RATING			221		197		215		239

Figure A-1: Evaluation of Alternatives.

UNWEIGHTED PARAMETERS		ALTERNATIVE #5 Antelope Ponds	ALTERNATIVE #6 Antelope Reclamation	ALTERNATIVE #7 Incineration	ALTERNATIVE
ECONOMICS	CAPITAL COST	213,020,000	284,325,000	112,600,000	
	ANNUAL CAPITAL AMORTIZATION	16,161,000	22,914,000	9,764,000	
	O. AND M. COST	6,710,000	4,106,000	3,055,000	
	RECLAMATION REVENUE	-2,070,000	-2,070,000	0	
	TOTAL ANNUAL COST	20,801,000	24,950,000	12,819,000	

WEIGHTED PARAMETERS		WEIGHT	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING
ENVIRONMENTAL FACTORS	WATER QUALITY	9	6	54			6	54		
	AIR QUALITY	8	5	40			3	24		
	LAND QUALITY	6	3	18			5	30		
	FLORA AND FAUNA	6	3	18			6	36		
	AESTHETICS	6	1	6			5	30		
	PUBLIC HEALTH	9	5	45			5	45		
	COMMUNITY IMPACT	6	4	24			5	30		
	RESOURCE CONSERVATION	5	3	15			3	15		
	TOTAL WEIGHTED RATING			220				264		
FEASIBILITY	FINANCIAL FEASIBILITY	9	6	54			8	72		
	PUBLIC ACCEPTABILITY	8	3	24			3	24		
	LAND USE COMPATIBILITY	7	7	49			10	70		
	EASE OF IMPLEMENTATION	6	2	12			1	6		
	TOTAL WEIGHTED RATING			139				172		
PERFORMANCE	SYSTEM EFFECTIVENESS	9	7	81			4	36		
	RELIABILITY	8	7	56			8	48		
	ADAPTABILITY	5	10	50			6	30		
	CALAMITY RESISTANCE	6	1	6			8	48		
	PERMANENCE	6	10	30			10	60		
	TOTAL WEIGHTED RATING			235				222		

Figure A-1 (Continued): Evaluation of Alternatives.

BY-PRODUCT SOLIDS MANAGEMENT ALTERNATIVES CONSIDERED FOR PHILADELPHIA

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INTRODUCTION

The City of Philadelphia Water Department, Water Pollution Control Division is responsible for the operation of wastewater collection and treatment for the City of Philadelphia as well as a number of suburban communities adjacent to the city. The tributary population to the city plants is estimated to be about three million and is projected to reach about 3,600,000 in 1990. The city operates three plants as follows:

	Estimated Flow MGD	
	1975	1990
1. Northeast	170	250
2. Southeast	130	150
3. Southwest	175	245
Total	475	645

By-product solids removed in the three Philadelphia plants in 1974 amounted to about 270 dry tons per day of raw solids not including grit, scum and screenings. These raw solids are stabilized by anaerobic digestion, and further processed in on-site holding basins to increase their solids concentration to about ten percent. The stabilized solids slurry are then dispersed into the ocean at a point approximately 50 miles off shore.

After completion of the current program of expansion and facilities improvement, it is projected that the raw by-product solids, not including scum, grit and screenings, removed in the design year 1990 will be about 518 tons per day, which is about 14,800 wet tons per day at 3½ percent solids. The stabilized solids quantity projected for 1990 is 332 dry tons per day which is about 9,500 wet tons per day at 3½ percent solids.

The dispersal of stabilized solids slurry at sea was initiated by the city in 1961 in an area eleven miles off shore and moved to the present dispersal site 50 miles off shore in May, 1973, a total one way distance of about 150 miles from the city. Since 1961, the city has arranged for a number of studies to consider the effects of management practices related to by-products removed from the Philadelphia Wastewater Treatment Facilities. In 1972, a comprehensive study of management alternatives related to by-product solids was undertaken with the results summarized in a written report dated June, 1973, under the title, *Report on Management of By-Product Solids from Water Pollution Control Plants*. After completion of the 1973 report further studies have been continuously underway to update the report findings, explore new alternatives and codify the results of additional investigations.

This presentation is a synopsis of the data, investigations, studies, discussions and other considerations given to the concept of management of by-product solids.

Basic Data

The by-products of water pollution control plants include screenings, grit, scum and other wastewater solids removed as settleable solids in the primary and final tanks. Facilities will be incorporated in the proposed additions to the northeast, southwest and southeast plants to process screenings, grit and scum in separate incineration units. These are not considered in this presentation. In connection with the processing of the remaining wastewater solids removed in the water pollution control plants, a number of alternatives have been considered. The quantities and characteristics of these solids have been summarized, as well as the design bases used in considering alternatives.

Based on the records maintained by the City of Philadelphia Water Department, the total pounds and volume of raw solids have been estimated as shown in Table 1. Included are estimates of the solids captured in the primary tanks, excess solids produced in the existing air activated sludge plant at the Northeast Plant and excess solids from the proposed new Northeast, Southwest and Southeast oxygen activated sludge plants.

Data on physical and chemical characteristics of both the raw and stabilized Philadelphia solids are limited. Furthermore, it is believed that a number of the characteristics will change significantly when the current program of additions to the water pollution control plants are completed. Table 2 presents recent data obtained on

TABLE 1
Estimated Solids Quantities

Description	1975	1980	1985	1990	1995
Sewage Flow-Mgd	475	530	570	605	645
Raw Solids					
Dry Tons Per Day	382	434	475	518	565
Million Gallons Per Day					
At 3½% Solids	2.62	2.97	3.25	3.55	3.88
At 10% Solids	0.92	1.04	1.14	1.25	1.36
Million Gallons Per Year					
At 3½% Solids	956	1085	1137	1295	1418
At 10% Solids	336	380	416	456	496
Stabilized Solids					
Dry Tons Per Day	245	280	305	332	362
Million Gallons Per Day					
At 3½% Solids	1.69	1.92	2.09	2.27	2.48
At 10% Solids	0.59	0.67	0.73	0.79	0.86
Million Gallons Per Year					
At 3½% Solids	617	701	763	829	905
At 10% Solids	215	245	267	288	314

TABLE 2
Solids Characteristics

Constitutent	Northeast (1)	Southwest (1)
Mercury	4.42	4.42
Cadmium	105.5	33.16
Total Solids	14.03%	6.05%
Lead	2,142	1,261
Copper	1,173	699.5
Iron	11,311	9,584
Zinc	5,386	2.031
Selenium	16.3	7.8
Maganese	1,205	584
Beryllium	1.4	2
Chromium	1,146	712
Nickel	315	148
Arsenic	1.04	1
Vanadium	4.7	2
COD	142.9 g/kg	48.5
TKN	18.4 g/kg	16.4 g/kg
Nitrates	.995 mg/l	.013
PO4 (as P)	31.3 g/kg	30.1
Hexane Extractable	137.9 g/kg	54.0 g/kg
Volatile Solids	49.7%	45.1%

Based on 1974 barged sludge data.

(1) All units mg/kg unless otherwise noted.

the characteristics of the solids barged to the sea from the existing plants.

For these studies, 1990 was selected as the design year to coincide with the design year used for the additions and improvements to the wastewater treatment plants. The characteristics and quantities of the combined wastewater solids from the three water pollution control plants which have been used in the studies reported herein, are summarized in Table 3.

For purposes of determining unit process costs, a life expectancy of 25 years has been used for most major equipment. The amount of raw solids to be processed, for purposes of determining the unit costs, were assumed to average 173,000 dry tons per year over the 25 year period.

TABLE 3
Design Bases[1]

Design Year	1990
Raw Solids Bases	
Total Raw Solids, dry tons per day	518
Total Raw Solids, dry tons per year	189,000
Total Raw Solids, mgd	2.3
Solids Content [2]%	5.4
Volatile Matter, %	70
Digested Solids Bases [3]	
Total Solids, % of raw	65
Total Solids, dry tons per day	332
Total Solids, dry tons per year	123,005
Total Solids, mgd	2.3
Solids Content, %	3.5
Volatile matter, %	54

1) For combined solids from all three plants.
2) After thickening of waste activated solids.
3) Assumes all solids digested at all three plants.

Note: Data reported in 1973 "Report on Management of By-Product Solids from Water Pollution Control Plants.

All unit costs presented herein have been expressed as cost per ton of dry raw (undigested) solids unless noted otherwise. The annual unit costs have been obtained by dividing the total annual cost by 173,000 tons of dry solids, the annual average quantity.

Alternative Projects Identified

The studies made included consideration of alternative projects that were characterized within the following three broad classifications:

1. Biological Processes
2. Physical-Chemical Processes
3. Special Category Processes

A number of alternatives were identified and described under the first two classifications. Studies were made to determine, in conceptual terms, the physical facilities required, the estimated capital investment and total annual costs, the apparent environmental considerations and the range of a timetable for implementation. The 15 alternatives identified for consideration are shown in Table 4.

A number of special category alternatives have also been considered by the City of Philadelphia Water Department. For the most part, these additional alternatives comprised proprietary processes suggested and proposed by private industry utilizing special equipment or processes developed by the industry. The proposals

TABLE 4
Basic Alternatives

1. Biological Processes

1. Sea dispersal of approximately 10 percent stabilized solids at a point 11½ miles off shore.
2. Sea dispersal of 12 percent stabilized solids at a point 11½ miles off shore.
3. Sea dispersal of 3½ percent stabilized solids at a point 50 miles off shore.
4. Land dispersal of stabilized solids slurry by center pivot irrigation.
5. Land dispersal of stabilized solids slurry by traveling gun irrigation.
6. Land dispersal of stabilized solids slurry by solid set irrigation.
7. Land dispersal of stabilized solids slurry by plow-in procedure.
8. Land dispersal of stabilized solids slurry by tanker application.
9. Land dispersal of stabilized solids cake by trenching procedures.
10. Land dispersal of stabilized solids cake by spreading and incorporating.
11. Land dispersal of stabilized solids cake by landfilling.
12. Land dispersal of stabilized and composted solids cake.

2. Physical-Chemical Processes

13. Incineration of raw by-product solids.
14. Pyrolysis of raw by-product solids.
15. Heat drying of raw by-product solids.

received and considered by the city have been categorized by application as follows:

Category A Disposal
Alternatives related to disposal of by-product solids presently stored in open lagoons on the site of the Southwest Water Pollution Control Plant.

Category B Combination Disposal
Alternatives related to combining wastewater treatment by-product solids with municipal refuse.

Category C Resource Recovery
Alternatives related to recovery of energy, nutrients and other resource by-products such as metals.

Description of Alternatives

Because many of the alternatives identified differed conceptually with regard to the overall processing of raw by-product solids, the studies made are related to "raw" solids. The descriptions included herein are based on outlining the solids processing steps necessary to convert the raw material to the final by-products.

Biological Processes Sea Dispersal

Sea dispersal of by-product solids comprises a two step procedure of stabilization and hauling. The studies were based on expanding the existing facilities for stabilization by anaerobic raw solids digestion. The hauling method considered was based on the continued use of a pipeline to a nearby dock where stabilized solids slurry are discharged into a barge for transporting to the dispersal site, approximately 50 miles from Cape May. A number of sub-alternatives have been considered and are described as follows:

Alternative 1. Dispersing stabilized solids slurry partially dewatered to about ten percent solids in existing lagoons, adding only the stabilization facilities required for the projected 1990 quantities. This is referred to as present practice.

Alternative 2. Dispersing stabilized slurry, partially dewatered to about twelve percent solids, by adding mechanical solids dewatering equipment for all solids and the additional stabilization facilities necessary for the projected 1990 solids quantities.

Alternative 3. Dispersing unthickened (3½ percent solids) stabilized solids slurry, adding only the stabilization facilities required for the projected 1990 solids quantities. All sea dispersal alternatives include an allowance for environmental monitoring of the dispersal site.

Biological Processes Land Dispersal

As in sea dispersal the land dispersal alternatives include the two steps of stabilization and hauling.

To estimate the cost of dispersing stabilized solids on land with an accuracy similar to sea dispersal, it would be necessary to identify a specific land dispersal site since the dispersal costs are highly sensitive to such variables as distance from Philadelphia, topography of land, availability, location, access, etc. These considerations are of paramount importance, particularly availability, since previous attempts to use Pennsylvania land for dispersal of solids have been met with significant discussion from the general public. However, in order to make comparisons, certain illustrative assumptions and cost allowances have been made and are generally summarized in the following herein.

Eight of the nine land dispersal alternatives considered were categorized as land reclamation or fertilization, except for the landfilling alternative which is considered disposal with no additional benefits. Accordingly, it was concluded that as such, the eight alternatives must meet the application limits stated on the proposed (draft) U.S. EPA guidelines*. Applying these guidelines to the Philadelphia solids, and using the modified equation included therein with the expected soils in Pennsylvania, the maximum allowable loading would be 60 tons of dry, stabilized solids per acre. The CEC value of twelve used in the computation was based on studies

**Acceptable Methods for Utilization or Disposal of Sludges* (EPA 430 (9-75) Technical Bulletin.

made by the U.S. EPA at a potential site selected by the U.S. EPA. For a 30-year project life, this would correspond to an average loading of two tons of stabilized dry solids per acre per year as used for the eight land reclamation alternatives. For landfilling, however, the solids application arrangement considered would result in an equivalent loading of 675 tons per acre per year.

It has been also assumed that land would be purchased by the city for eight of the nine land dispersal alternatives considered. Furthermore, because land availability appears to be a serious impediment and cursory investigation indicates that only remote land dispersal sites may be available, it has been assumed that a transfer point would be located 100 miles from Philadelphia for all cases.

Recent experiences, in other areas of the United States, have indicated that significant adverse public reaction can develop to odors identified as originating from open storage lagoons and solids slurry spray irrigation operations. For this reason, the solids slurry storage facilities for land dispersal alternatives include costs required to cover the storage lagoons. In the case of odors developing from spraying a solids slurry into the atmosphere, no countermeasure has been identified or included. For this reason, alternatives based on solid slurry spraying are not considered realistic and are included only for illustrative purposes.

Solids Slurry - 3½ Percent Solids

The land dispersal methods utilizing a solids slurry of 3½ percent solids concentration were considered to incorporate a pipeline from Philadelphia to a transfer point 100 miles away. Pumped slurry would be discharged into covered storage facilities and either repumped or trucked to the point of final application. The following alternatives were considered:

Alternative 4. Center Pivot Irrigation
Alternative 5. Traveling gun Irrigation
Alternative 6. Solid set Irrigation
Alternative 7. Plow-in
Alternative 8. Tanker application

The first two alternatives incorporate a system of moving sprays and the third has an immobile set of sprinkling nozzles. The systems would include a central pumping station at the transfer point and a piping network to the individual application areas.

In the plow-in alternative, slurried solids would be applied by an altered moldboard plow through a flexible hose. As a field is plowed, a layer of solids would be applied and covered with six inches of soil. A pumping system similar to the above arrangement would be used.

Slurry spreading by tank trucks is a method which has been popular for small scale solids dispersal operations. The solids are delivered to private land owners onto whose land it would be discharged as the (Water Department owned) trucks drive across the field. While this alternative eliminates the need for land purchase, it does require arrangements with numerous farmers possibly 2000 or more that would impose a serious logistical problem which has not been completely identified as part of these studies.

Solids Cake 20 Percent Solids

For these studies, four methods utilizing solids cake (20 percent solids) have been considered as follows:

Alternative 9. Trenching
Alternative 10. Spreading and Incorporation
Alternative 11. Landfill
Alternative 12. Composting - Spread and Incorporate

The solids cake alternatives were based on unit train transportation of cake to a transfer point 100 miles from the city from which cake would be trucked to the point of application. Since all of these alternatives require that trucks travel across fields, none may be used on wet ground.

For trenching operations, solids would be deposited in shallow trenches about two feet deep and two feet wide and two feet apart and covered with soil.

In the spread and incorporate alternative, spreading of solids on the surface of land would be done by trucks or wagons and incorporation would be accomplished by plowing, discing or rotary tilling.

Landfilling is similar to trenching except that the landfill cavities would be larger and deeper than trenches. The solids would be compacted and covered. Since this method of dispersal would have high application rates, care must be taken to prevent groundwater pollution.

For the composting - spread and incorporate alternative, it has been assumed that stabilized solids would be chemically conditioned and dewatered by means of a filter press to a cake containing about 35 percent solids. This cake would be transported by truck to a separate composting plant where it would be combined with municipal refuse and composted.

In the original studies, composting was based on the assumption that part of the costs of mixing by-product solids with refuse would be absorbed by the municipal refuse supplier. Alternatively, the by-product solids might be composted with recoverable wood chips at a similar total cost, or composted in situ without any other additional products. The compost would then be hauled by truck to farm land and dispersed by the spread and incorporate method of application. As an alternative means of ultimate dispersal, for which cost estimates were not prepared, the compost could be made available and given away at the composting site with no ultimate dispersal costs being incurred. However, because the total volume is great, it is doubtful that private citizens could accomplish the total hauling project.

Physical Chemical Processes

All of the physical-chemical processes considered use thermal energy to condition and convert, dewater or re-

duce raw wastewater solids. The three alternatives which were considered are as follows:

Alternative 13. Incineration
Alternative 14. Pyrolysis
Alternative 15. Heat Drying

For the incineration alternative, it has been considered that, prior to incineration in a multiple hearth furnace, the waste activated sludge solids would be thickened and combined with primary solids. The solids mixture would then be stored in holding tanks from which they would be fed to a low pressure heat treatment process for conditioning before being applied to a vacuum filter to form a 35 to 40 percent solids cake. This auto-combustible cake would be fed to the incinerator. The gases from the incinerator would be scrubbed and the ash would be hauled to a landfill.

Pyrolysis is an incineration type process where burning is carried out in an oxygen deficient atmosphere and the organic material does not lose all of its fuel value. Pretreatment of raw by-product solids would be similar to incineration. A product char, and possibly gases which are condensable to oils and tars, with fuel value could be obtained. However, volume reduction would not be as great as with incineration and input energy requirements would be higher. Pyrolysis would, of course, sterilize the solids. At the time of the original studies there was insufficient information available to develop detailed construction and annual maintenance and operation cost estimates for pyrolysis.

Heat drying is similar to incineration, except that the heating processes are stopped before the solids can be oxidized, producing a product containing nutrients and humus which can be marketed as fertilizer. Pretreatment of raw solids would be similar to incineration. Drying systems may be designed to be flexible enough to dry or incinerate. However, the fuel requirements of drying would be higher than incineration, since the solids are not burned. For these studies the costs estimated include bagging the unfortified product for distribution.

Special Category Alternatives

In addition to the biological and physical chemical processes, a number of special category alternatives were identified and grouped in the following categories.

Category A Disposal. Disposal methods suggested for the removal of lagooned solids at the Southwest Treatment Plant site to provide a pathway for the construction of Highway I-95 by the Pennsylvania Department of Transportation have identified a number of alternatives including transporting the material to other parts of the state, other parts of the world (such as the Bahamas), the conversion of the lagooned solids to a building material and the conversion of the lagooned solids to a landfill material. One such process is *solidification.*

In this alternative, proprietary chemicals would be mixed with the lagooned solids and, according to the manufacturer, in about three days the mixture would solidify to an inert, clean, nonpolluting product suitable for landfill. Based on our understanding of the process, it appears that there is no volume reduction and that there may be a volume increase.

Category B - Combination. A number of the alternatives suggested incorporate the ultimate disposal of the treatment plant by-product solids with municipal refuse. While the proposed alternatives are not limited to combined treatment with municipal refuse, they are grouped herein because the proposals, as outlined to the city, did incorporate municipal refuse. The following combined recovery process alternatives proposed by others were reviewed and are briefly described based on data submitted with the rudimentary proposals:

1. This process would receive a wet slurry of about 3½ percent solids and include equipment to dewater the slurry to 17 percent solids. This cake would be spray dried to about 75 percent solids using the exhaust gases from the final process step which could be fed to either a rotary kiln or a pyrolysis unit. Refuse would be introduced at an appropriate point in the flow sheet.
2. Wastewater treatment plant by-product solids would be burned with municipal refuse in water walled boilers to produce low pressure steam.
3. Wastewater plant by-product solids would be mixed with wet pulped and classified refuse and the mixture incinerated in a fluidized bed incinerator. Energy recovery, and/or the recovery of metals, glass and paper pulp would be possible objectives.

Category C - Resource Recovery. A number of alternatives have been suggested that are based on receiving wastewater treatment plant by-product solids as primary input and subjecting them to a process designed to recover those resources in the solids that can be recycled as useful products. The basic resources recovered in the proposed alternatives are nutrients and metals. The projects considered based on data submitted or developed in the studies are briefly described as follows:

1. Wet raw by-products solids would be mixed with appropraite amount of urea and formaldehyde. The mixture would be heat dryed, packaged and sold as a fertilizer with a chemical composition of about 12-4-0.
2. Wet raw by-products solids would be heat dryed using a proprietary dryer. The dried material, with a chemical composition of about 6-4-0, would be packaged for sale.
3. Raw by-product solids slurry at about 3½ percent solids would be discharged into an acid reactor, heated to about 450°F at a pressure of about 600 psi. It is our understanding that heavy metals, ammonia, organics, etc., could be separated and recovered.

4. Anhydrous and Liquid Ammonia Recovery: Raw by-product solids would be stabilized by anaerobic digestion to produce excess methane as well as reduce solids quantities. The system would be designed to convert excess methane to anhydrous ammonia, to concentrate digester supernatant to a liquid ammonium phosphate and to dewater and acid leach the solids to remove the bulk of heavy metals.

DISCUSSION OF ALTERNATIVES

The alternatives considered for by-product solids management have been classified as biological, physical-chemical and special category processes. The alternatives considered for land and sea dispersal of stabilized solids were characterized as biological processes since anaerobic digestion of the raw by-product solids was the first step in each.

Based on rudimentary studies, the Anhydrous and Liquid Ammonia Recovery alternative appears to have potential for converting the nitrogen content of the raw solids and the energy in the volatile suspended solids into readily usable form. Preliminary cost estimates, not included herein, indicate that the process is cost effective and it has been recommended for further consideration.

Based on the studies made of the 15 alternatives considered, the data shown in Table 5 present a summary, by annual costs, of these alternatives. Further, in order to consider the effects of energy and nutrient characteristics of each alternative, a cost comparison was developed which considers, in addition to the annual costs, the energy consumption and nutrient production of each alternative. This is shown in Table 6.

Among the sea dispersal alternatives, it is clear that some dewatering is necessary to reduce the total annual cost of the alternative. The exact amount of dewatering that is optimum is a function of barging costs.

TABLE 5
City of Philadelphia
Unit Cost of 1975 Alternatives
May, 1975

Alternative	Amortization				Operation and Maintenance				
	Treatment	Transportation	Ultimate Dispersal	Total Amort. Cost	Treatment	Transportation	Ultimate Dispersal	Total O&M Cost	Total Annual Cost
Sea Dispersal									
1. Present Practice	12.88	0.00	0.00	12.88	6.53	13.00	0.59	20.12	33.00
2. 12% Solids, Mechanical Dewatering	14.51	0.00	0.00	14.51	15.58	13.00	0.59	29.17	43.68
3. 3½ Solids	12.88	0.00	0.00	12.88	6.53	44.00	0.59	51.12	64.00
Land Dispersal									
4. Center Pivot Irrigation(1)	12.62	14.56	65.30	92.48	6.47	4.27	2.59	13.33	105.81
5. Traveling Gun Irrigation(1)	12.62	14.56	65.30	92.48	6.47	4.27	4.35	15.09	107.57
6. Solid Set Irrigation(1)	12.62	14.56	72.64	99.82	6.47	4.27	2.08	12.82	112.64
7. Plow-in	12.62	14.56	69.58	96.76	6.47	4.27	7.10	17.84	114.60
8. Tanker (2)	12.62	14.56	13.93	41.11	6.47	4.27	36.74	47.48	88.59
9. Trenching	14.30	0.00	65.43	79.73	25.74	7.25	9.41	42.40	122.13
10. Spread & Incorporate	14.30	0.00	65.43	79.73	25.74	7.25	10.49	43.48	123.21
11. Landfilling(3)	14.30	0.00	5.07	19.37	25.74	7.25	7.13	40.12	59.49
12. Composting with Land Dispersal	19.24	0.00	64.84	84.08	32.76	8.95	10.49	52.20	136.28
Physical-Chemical									
13. Incineration	42.43	0.00	0.00	42.43	37.68	0.79	0.00	38.47	80.90
14. Pyrolysis							No Basis for Estimate		
15. Heat Drying	44.85	0.00	0.00	44.85	76.85	0.00	0.00	76.85	121.70

All costs are dollars per ton of dry raw solids. No credits for any products.
1) Not acceptable because of odor problems.
2) Severely limited because it can be applied to grass crops only.
3) Not attractive because it takes useful land out of service.

Some of the special category processes as well as the physical-chemical processes require significant energy to reduce and convert the by-product solids. Because the special category alternatives require either more developmental work, combination with other projects, a specific commitment or further study, it was not possible to establish a common comparative base. However, those special category processes which produce marketable dry fertilizers were considered to be variations of the heat drying alternative.

Among the land dispersal alternatives, it should be noted that the costs are highly sensitive to a number of criteria for which only rudimentary estimates could be made at the time. The criteria which these alternatives are most sensitive to are those involving choice of solids application rate, number of acres of land purchased and capital costs of land purchased. Table 7 illustrates this sensitivity. Note, for example, the marked effect of changing annual solids slurry application rate of 20 T/A (as used in the original studies) to 2 T/A (based on 60

TABLE 6
Comparison of Alternatives on Unit Basis, Taking Credit for Energy and Nutrients Available

Alternative	Total Annual Cost	Energy	N	P	Net Cost
Sea Dispersal					
1. Present Practice	33.00	-3.57	0.00	0.00	29.43
2. 12% Solids, Mechanical Dewatering	43.68	-2.92	0.00	0.00	40.76
3. 3-1½ Solids	64.00	-2.43	0.00	0.00	61.57
Land Dispersal					
4. Center Pivot Irrigation	105.81	-3.70	-13.32	-17.53	71.26
5. Traveling Gun Irrigation	107.57	-3.70	-13.32	-17.53	73.02
6. Solid Set Irrigation	112.64	-3.70	-13.32	-17.53	78.09
7. Plow-in	114.60	-3.70	-19.03	-17.53	74.34
8. Tanker Application	88.59	-3.70	-13.32	-17.53	54.04
9. Trenching	122.13	-2.86	- 8.20	-15.33	95.74
10. Spreading and Incorporating	123.21	-2.86	- 8.20	-15.33	96.82
11. Landfilling	59.49	-2.86	0.00	0.00	56.63
12. Composting with Land Dispersal	136.28	-2.54	3.60	-13.03	117.11
Physical Chemical					
13. Incineration	80.90	4.41	0.00	0.00	85.31
14. Pyrolysis	No Basis		-13.32		No Basis
15. Heat Drying	121.70	20.41		-17.53	111.26

All costs are dollars per ton of raw, dry solids.
N is valued at \$300/T N H_3 (\$365 /T N).
P is valued at \$500/T P.
Energy is valued at \$1.00/million Btu.

TABLE 7
Effect of Loading Rates and Land Costs
Plow-In Alternative

	Amortized Cost Land	Amortized Cost Total	O & M	Total Cost
a. 20 T/A/yr				
1. @ \$400/A [1]	\$ 2.46	\$ 37.05	\$17.84	\$ 54.89
2. @ \$1000/A [1]	\$ 6.14	\$ 40.73	\$17.84	\$ 58.57
3. @ \$3000/A [1]	\$ 18.42	\$ 53.01	\$17.84	\$ 70.85
b. 2 T/A/yr				
1. @ \$400/A [1]	\$ 24.56	\$ 59.15	\$17.84	\$ 76.99
2. @ \$1000/A [1]	\$ 61.41	\$ 96.76	\$17.84	\$114.60
3. @ \$3000/A [1]	\$184.23	\$218.84	\$17.84	\$236.68

1. This is considered the net purchase price and includes allowance for selling at a future date and initial development of land.

T/A over project life of 30 years). The effect of purchasing land at \$400/acre or \$3,000/acre in capital cost is dramatic. The \$1,000/acre cost, as used for these studies, includes net purchase cost (purchase price less present worth of future sale price) and land forming costs.

The amount of land required for land dispersal must be considered. At 60 T/A (2 T/A/yr. for 30 years) loading rate 60,000 acres are required. Based on a utility factor of 50 percent of any land purchased as suitable for dispersing of solids, the total acreage required would be about 120,000 acres. This is equal to about half the tributary area served by the Water Department. In addition, based on these studies, it appears that most of the potentially available acreage is available only in small parcels averaging 63 acres each. On this basis, about 2,000 farms would be included in a land dispersal project.

The management input is further complicated by the fact that the center of operation most likely would be located at some distance from the water department operations center. Topographic observations made from map studies and reconnaissance level field investigations identify the rolling irregular nature of the Pennsylvania countryside adjacent to Philadelphia. The land features coupled with the large number of small farms, many angularly formed by a crisscrossing of roads and property lines, underscore the complex nature of site selection and site development of land tracts large enough to permit a land dispersal program.

CONCLUSIONS

The studies made in connection with our work for the City of Philadelphia indicated that the biological processes generally ranked better than the physical-chemical processes considered from a cost, energy, and nutrient utilization standpoint.

A number of land dispesal alternatives utilizing anaerobically digested solids appear to have potential as acceptable management programs that may be effective from a cost, energy and nutrient standpoint. However, any land dispersal alternative requires a great deal of land area and requires significant management input to resolve far reaching logistical problems associated with dispersal operations.

The significance of this problem can only be visualized in broad terms at this time. At this time, it does not appear that a land dispersal alternative, for the total amount of solids removed in Philadelphia, is feasible.

The sea dispersal alternative, also utilizing anaerobic digestion as the stabilization process, has proven to be simple, economical and easily controlled. The escalating cost of barging to sea may require further study of alternatives related to optimizing barging costs, however. Continuation of sea dispersal depends upon continued demonstration of the fact that sea dispersal, as practiced by Philadelphia, is not detrimental to the ocean.

Preliminary feasibility studies of the anhydrous and liquid ammonia alternative are promising. This alternative utilizes anaerobic digestion and converts excess digestion gas to the form of fertilizer commonly used for crop fertilization in the United States. Additional studies of the process have been recommended, including pilot work, cost studies, equipment requirements and product management studies. As a further area of interest, it is important that studies of the means and methods of improving gas production in anaerobic digestion process be investigated.

SLUDGE DISPOSAL ALTERNATIVES FOR BOSTON

George D. Simpson,
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INTRODUCTION

The Metropolitan District Commission (MDC) of Boston owns and operates two major treatment plants, the Deer Island and Nut Island Treatment Plants, which receive a combined average daily flow of about 450 mgd, and serve a population of about 2.2 million. Both of these treatment plants provide preparatory and primary treatment, anaerobic sludge digestion, and disinfection. Treated effluent is discharged through submerged outfalls to Boston Outer Harbor; digested sludge is discharged to the Harbor at the President Roads channel during ebb tide, from which point sludge is carried to sea.

This method of sludge disposal is considered inadequate, and the MDC has investigated alternative methods of sludge management. The MDC Boston Harbor Task Force stuided six alternatives for sludge management in 1972[1] and recommended that a detailed design study be undertaken to consider three specific methods of sludge management: application to land; dewatering and incineration; and wet air oxidation[2]. This paper presents the results of the study of these alternative methods, and describes the recommended project plan and its environmental assessment.

Alternatives were evaluated in light of four basic objectives of a good sludge management plan:

1. To stabilize organic matter and reduce the sludge volume.
2. To recover and recycle useful elements or energy to the greatest extent feasible.
3. To provide final disposal of residues at the lowest total annual cost.
4. To minimize adverse impacts on the water, land and air environments.

Preliminary Studies

Sludge Characterization

Preliminary studies included basic data such as population, flow evaluation of the existing plants, and laboratory analyses of sludges collected from each plant, with projections of sludge characteristics from the future secondary treatment processes. Results of the analyses and projections are shown in Tables 1 and 2. The data shows that sludge from both plants is relatively high in heavy metals; and that the Deer Island sludge contains unusually high concentrations of chlorides and other dissolved salts resulting from sea water intrusion into the sewer system. These factors influenced the evaluation of alternative plans of sludge management.

TABLE 1
Population, Flows, and Sludge Quantities

	1971-72(1)	1976(1)	1980(2)	1995(2)
Population Served:				
Deer Is.	1,345,000	1,393,000	1,430,000	1,551,000
Nut Is.	625,000	691,000	757,000	959,000
AVG. Wastewater Flow, Mgd.				
Deer Is.	321	334	347	390
Nut Is.	123	141	157	210
Raw Sludge Quantities(3)				
a) Total Dry Solids, tons/day				
Deer Is.	85	103	202	233
Nut Is.	60	75	129	169
B) Volatile Dry Solids, tons/day				
Deer Is.	61	75	149	170
Nut Is.	48	59	100	127

(1) Based on Primary Treatment

(2) Based on Secondary Treatment

(3) Quantities Exclude Grit, Screenings & Skimmings, which for 1995 Conditions Increase the Dry Solids Mass by 7.4 Percent.

Purchased Power

At both treatment plants, all power needs are supplied by direct engine drive or by electric generators driven by dual fuel engines; no outside power connection is used. Detailed cost investigations were made to determine whether in-plant power generation was economical in comparison with purchased power under current conditions. It was found that in-plant generation at Deer Island using digester gas as fuel is about 68 percent

TABLE 2
Sludge Characteristics*

	Deer Island		Nut Island	
	Primary Solids	Secondary Solids	Primary Solids	Secondary Solids
Heavy Metals Concent., Mg/l:				
Arsenic	2	3	2	3
Cadmium	40	60	20	30
Copper	600	900	300	450
Tot. Chromium	500	750	100	150
Lead	200	300	200	300
Mercury	4	6	8	12
Nickel	200	300	200	300
Silver	40	60	20	30
Zinc	1000	1500	800	1200
Soluble Components; Mg/l:				
Chlorides	2800		300	
Hardness	1200		200	
Sulfate	800		300	
Potassium	140		95	
Sodium	1700		250	
Boron	1		4	
Volatile Solids Characteristics:				
COD/VTS	1.6	1.4	1.6	1.4
TKN/VTS	0.04	0.12	0.04	0.12
P/VTS	0.01	0.02	0.01	0.02
Hexane Ext./VTS	0.30	0.06	0.30	0.06
Sulfur/VTS	0.009	0.028	0.009	0.028
BTU/VTS	11,000	11,000	11,000	11,000

* Yr. 1995 projected characteristics, based on laboratory analyses.

more costly than purchased power, and that generation using fuel oil is more than twice the cost of purchased power. At Nut Island, the present cost of in-plant generation is approximately equal to cost of purchased power, but when capital costs of expansions to handle larger future loads is considered, in-plant generation was found not economical at either plant. As a result of these findings, the design of alternate sludge management plans was based on the use of varying amounts of purchased power.

In order to predict the effects of leaching of materials from sludge residues, a series of citrate solubility analyses was performed on samples of sludge and sludge ash. The citrate solubility test simulates a weak organic acid environment similar to that which may be created by soil micro-organisms in a landfill site. Effects of leaching using the citrate test were compared with leaching by distilled water. Results are shown in Table 3; the data shows that the organic acid leachate contains three to ten times the concentrations of dissolved minerals then the distilled water leachate, and indicates that the system adopted for final disposal of sludge residue should incorporate facilities for recovery and treatment of leachate, or that discharges of mineral pollutants should be controlled at the source.

Recycle Waste Streams

Each of the processes considered generates certain waste streams recycled to process. These recycle streams may incude digester supernatant, wet oxidation decantrate, filtrate from dewatering, centrate, thickener overflow, and ash slurry decantrate. The cost impact of treating recycle streams was developed for each process considered, and the impact on main process effectiveness was evaluated.

TABLE 3
Distilled Water and Citrate Solubility of Selected Pollutants: Percent Soluble of Original Pollutant Mass

Parameter	SAMPLE								Percent Soluble Less Than N/D
	Digested Sludge (Not Treated)		Digested Sludge (Treated)		Raw Ash (Treated)		Digested Ash (Treated)		
	W	C	W	C	W	C	W	C	
Total Solids									
Dry Cake Solids	5	14	4	17	1	5	2	21	
Ash Solids					4	17	4	48	
Phosphorus	8	100	6	77	.004	31	.006	12	
Cadmium	N/D	N/D	N/D	N/D	N/D	8	N/D	28	0.02
Copper	N/D	2	N/D	2	N/D	6	N/D	28	0.01
Total Chromium	3	75	N/D	71	17	40	10	54	0.3
Lead	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	2.0
Nickel	N/D	62	N/D	61	N/D	12	N/D	30	1.8
Silver	N/D	10	N/D	N/D	N/D	17	N/D	10	1.2
Zinc	0.7	19	N/D	9	N/D	4	N/D	5	0.01

NOTES: W = Distilled Water Solubility

C = Citrate Solubility

Treated = Received ferric and lime conditioning chemicals

N/D = Not Detectable

Procedure: 25 gm of solvent/gm of solids, given 24 hours of contact, shaken every hour for the first eight hours, ashing (where applicable) at 1600°F., filtration with 0.45 filter.

The greatest impact was associated with decantrate from the wet oxidation and heat conditioning processes, since solubilization of organics occur in heating of sludge. Comparative cost studies revealed that for this application, separate pre-treatment of recycle prior to return to process was less costly than enlarging the main stream secondary treatment facilities to handle the total load. The other recycled streams were assumed to be returned to the plant process, with due allowance for this load in design of the plant.

Sludge Conditioning

The relative merits of chemical conditioning and heat conditioning of sludge prior to dewatering were examined in detail. For this application, chemical conditioning using lime and ferric chloride or polyelectrolytes was more cost-effective than heat conditioning. On a total annual cost basis, including amortization of capital costs and operation and maintenance charges, the heat conditioning system was eight percent higher in cost than the chemical system.

The high chloride content of the sludge had an important bearing in this case, since the corrosive effects of hot sludge required the use of special alloy materials in the heat conditioning system piping, heat exchangers and reactors. The use of titanium or Carpenter alloys was shown more economical than more frequent replacement of standard materials, but the cost of either option weighed against heat conditioning in comparison

with chemical. The greater recycle load on treatment process was also a substantial factor in favor of chemical conditioning.

Dewatering and Sludge Digestion

Vacuum filtration was compared with centrifugation as means of sludge dewatering. In the circumstances of this particular large-scale application, the study indicated that vacuum filtration was the more economical. Grit content of the sludge is relatively high, and the abrasive effect of grit, coupled with its high corrosive content, indicates a relatively high maintenance charge for centrifugation. Total annual cost of centrifugation was 16 percent higher than vacuum filtration for this application.

Aerobic digestion was examined as a means of reducing the organic loading to the various disposal processes. After allowances for the reduction in solids mass, for the increased power consumption, and for the heat recovery loss associated with the destruction of volatile solids it was found in this instance that aerobic digestion had a net total annual cost seven percent higher than an incineration system without aerobic digestion.

Incinerators and Air Pollution Control

Alternative types of sludge incinerators were evaluated, utilizing preliminary design layouts and estimates of capital and operating cost. Multiple-hearth incinerators were found to be about eight percent lower in total annual cost for this project, and were selected for evaluation.

Air pollution aspects of incineration were thoroughly explored. High efficiency air pollution control equipment, including heat recovery, was selected, and stack emissions of particulates, sulfur oxides, nitrogen oxides, heavy metals, pesticides, PCB's and hydrocarbons were quantified. The latest standards of the Metropolitan Boston Air Pollution Control District and the Federal EPA were reviewed and compared with the projected stack emissions. A review of stack emission tests conducted on modern sludge incinerators was made, together with recent studies of emissions from such installations by EPA.

The conclusions of these studies were that the projected incinerator installation would adequately meet or exceed all of the existing or presently proposed standards, and that incineration is a feasible alternative from the standpoint of air pollution. This conclusion is in agreement with recent findings of an EPA Tank Force, which stated that: "It has been adequately demonstrated that existing well designed and operated municipal sludge incinerators are capable of meeting the most stringent particulate emission control regulations existing in any state or local control agency[3]."

Sludge Management Alternatives

Three types of sludge management systems were considered: land application, incineration, and wet air oxidation. Within each of these general methods, a number of process variations were developed, and detailed evaluation was made of twelve alternative systems; two land application systems, four wet oxidation systems, and six incineration systems. Each alternate represents a major process sequence, so that comparison of the alternatives within a given general method constitutes a system optimization. The alternates studied are shown schematically on Figure 1.

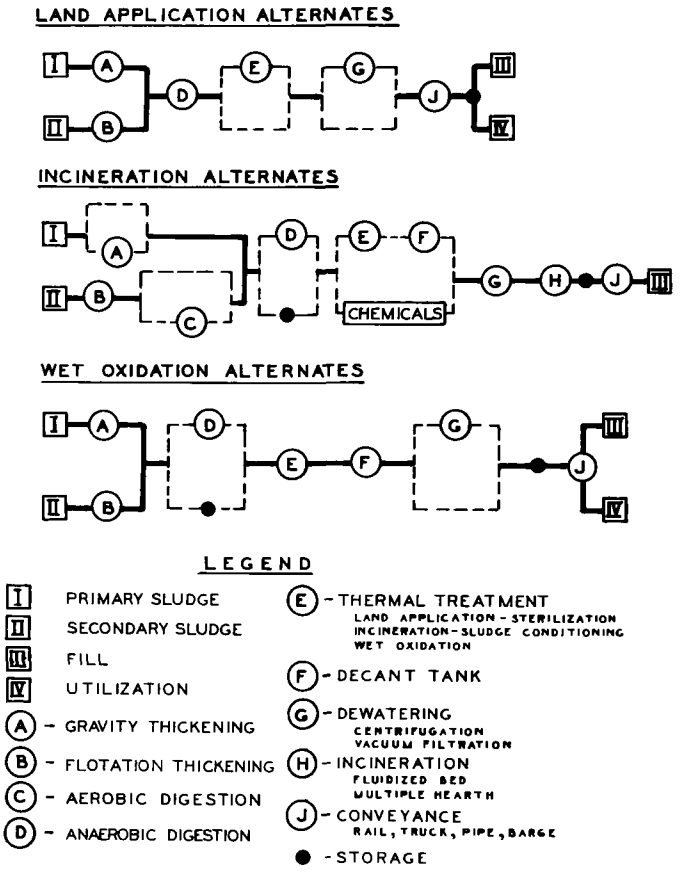

Figure 1: Sludge Management Alternates.

Land Application Alternates

In establishing criteria for land application of sludge, detailed consideration was given to: topography and soil characteristics in the eastern Massachusetts area; public health aspects; nutrient value of the sludge; sludge characteristics, effects on ground and surface waters; toxicity of sludge to soil and crops; transportation of sludge; and probable levels of revenue through sale of crops. The topography of land in eastern Massachusetts available for sludge application is relatively rough; hilly land predominates; rural areas are characterized by wooded hills interspersed with small farm tracts in the valleys. Soils vary, but clay soils and glacial tills of relatively low permeability predominate. Field reconnaissance indicated that in order to obtain coherent tracts of land of the acreage needed, total transportation distance from the treatment plants would be about 80 miles.

Three basic land application alternates were examined. Alternate L_1 includes thickening, anaerobic digestion, sterilization, pipeline transportation from the treatment plant to the land application site storage, and spray irrigation of sludge to croplands. Alternate L_2 includes thickening, anaerobic digestion, sterilization, vacuum filtration, storage, rail transportation of filter cake to the land sites, and spreading-plowing of cake to the croplands. Landfilling of cake was also examined under this Alternate. In each case, digester gas was recovered for power generation.

Loading Rates. Consideration of the nutirent content, heavy metals concentration and other characteristics of the sludge showed that nitrogen loadings would be the limiting factor in establishing sludge application rates. A nitrogen mass balance was prepared, quantifying the fraction of total and soluble nitrogen forms applied which would be removed by denitrification, by crop uptake, by fixation, by erosion, and by leaching through the soil into the groundwater. By limiting the amount of soluble nitrogen leached to groundwater to levels representing an increase in groundwater nitrates of less than 1 mg/1, a limiting total nitrogen application was established. This criterion, in turn, established the permissible sludge application rates, which ranged from 5.3 to 15.2 tons of dry solids per acre per year, depending upon whether sludge was applied as a slurry, as a dewatered cake, or as wet oxidized residue. Later information developed for the environmental assessment report indicates that the loadings might be limited to slightly lower values by heavy metal toxicity.

Application. Evaluation was made of four methods of sludge application to the land: spray irrigation, ridge and furrow irrigation, subsurface injection, and spreading and plowing. Because of the terrain involved, spray irrigation by "rain guns" was selected for slurry application over center-pivot rigs; and spreading and plowing was selected for those alternates involving application of dewatered sludge cake.

Public Health Considerations. Although there is no direct evidence that careful land application of digested sludge has caused clinical disease in humans or animals, the literature contains many examples of survival of pathogens, parasites and viruses after prolonged periods of digestion and storage. Survival of pathogens has been reported by Hinesly, et. al. after heating to 95°F., digestion for 30 days and storage for seven to eight months[4]. Kenner, et. al. observed fecal coliform survival in soils at least 21 weeks after application of digested sludge[5]. Little data is available on the fate of viruses in sewage treatment processes.

In the present case, where very large long-term land application systems are contemplated, it is believed that protection of public health should be as reliable as possible. For this reason, heat sterilization of sludge is included as part of the process sequence.

Wet sterilization for three minutes at 121°C and 200 psig was selected as preferable to standard pasturization (25 minutes at 70°C, atmospheric pressure). The high salinity of the Deer Island sludge was a distinct detriment in this regard, because of the corrosive effect on heat exchangers, and special materials of construction were assumed for the cost analyses. Sterilization costs amounted to about 7.5 percent to 9.5 percent of the total capital costs of the alternate systems considered.

Sludge Transportation and Storage. Transportation of sludge to the land application sites by pipeline, by barging, by trucking and by railroad were investigated and compared as to total annual cost for each alternate. Pipeline transportation was the least cost method for digested liquid sludge under Alternate L_1; rail transportation was the least costly for handling dewatered sludge cake under Alternate L_2.

Storage of sludge is necessary over the winter season and during periods of seed germination to prevent loss of sludge to surface or underground waters, and to protect crops. In the climate of eastern Massachusetts, examination of weather records indicates that storage capacity is required for about 150 days per year. Earthen basins with impervious linings were selected for liquid sludge storage, and the cost of the storage facilities was included in the evaluation.

Incineration Alternates

Six process variations were considered in the incineration alternative. These alternates were investigated to optimize the process and to illustrate the relative benefit/cost relationships of sludge thickening, anaerobic and aerobic digestion, chemical or heat conditioning, vacuum filtration or centrifugation, in various configurations prior to incineration. In each case, the incineration system includes waste heat recovery and the destruction of grit and screenings generated at the treatment plants, as well as small quantities of prepared refuse from nearby MDC recreational areas.

Comparison of the incineration alternatives showed that, *for this application*, construction of anaerobic digesters is not cost-effective; recovery of incinerator waste heat for power generation is economical; gravity thickening of primary sludge is not justified, but flotation thickening of waste activated sludge is economically feasible; chemical conditioning is preferred to heat conditioning; multiple-hearth incinerators are more economical than fluid-bed units; and that on-site landfilling of ash to create new land on Deer Island would be the most effective means of ash disposal.

The net amount of energy recovered in waste heat boilers and generators is estimated to vary from about 3,400 KW in 1976, to 10,000 KW delivered in 1995. The cost of power generation utilizing waste heat was calculated at about 0.86 cents/KWH (delivered to shaft) as compared to the cost of purchased power which was about 1.0 cents per KWH in 1973, and is currently about 3.0 cents per KWH.

Wet Oxidation Alternates

Four process variations of wet air oxidation were investigated. After detailed discussions with the manufacturer of the process equipment, it was determined that the evaluation would be made for alternative systems handling digested sludge or raw sludge; and that the design would be based on overall COD reduction of 50 percent to 55 percent, at reactor conditions of 800 psig, 475°F, and 15 to 30 minutes detention period. System design was based on the objective of producing a stable, inoffensive and sterile end product for final disposal. Volatile solids solubilization of 25 percent to 30 percent was assumed for evaluation of impact of recycled liquors.

For both raw and digested sludge alternates, two options for final disposal of residue were investigated: sanitary landfill, and application to croplands. Although the wet oxidation process destroys some organic solids, the mineral nutrients and part of the organic solids remain, which have some value in application to croplands.

As mentioned, the high chloride and sulfate content of the sludge required special consideration of construction materials for the wet oxidation components. Use of titanium for construction of heat exchangers and reactors was recommended by the manufacturer, and was shown to be more economical than more frequent replacement of other materials.

The studies showed that the digested sludge alternative utilizing landfill as the final disposal method and incorporating digester gas recovery was the most cost-effective wet oxidation option. As with the incineration alternate, leachate from the landfill site would be collected and returned to treatment.

Selection of Recommended Alternate

Cost Comparison

Capital costs of each of the twelve alternative systems were estimated, utilizing manufacturer's quotations on major items of equipment. Personnel requirements for operation and maintenance were developed, integrated with present staff schedules, and annual costs of operation and maintenance of each system were prepared for the median year, 1987. The cost estimates included appropriate credits for recovered electric power, and for revenue from sale of crops in the case of the land application alternatives. The most cost-effective alternate in each of the three categories of land application, incineration and wet oxidation was then selected, and these three systems were evaluated in detail.

Table 4 shows the comparison of the final three alternates in total annual cost. Incineration is clearly the least-cost option, being lower in capital cost than the nearest alternative by about $7.6 million, and lowest in total annual cost by about $1.6 million per year.

Environmental Comparisons.

In addition to cost, the three alternatives were evaluated in terms of nine environmental and non-cost elements of importance: effect on treatment process, quantity of residual solids, degree of resource recovery, impact on land, impact on the atmosphere, impact on the water environment, total energy required, public health and noise impact.

In each of these areas, an evaluation matrix was prepared, and the three systems rated with respect to a number of effects within the category. Table 5 summarizes this comparison in one of the categories, (Energy Required) as an illustration of the approach used. It is of interest to note that the incineration alternate requires only 50×10^6 KWH/Yr., about 60 percent of the total energy of the other two systems.

This rating evaluation showed that in non-cost and environmental areas, the incineration alternative rated equal to or better than the other two in seven of the nine categories; the land application alternate equal to or better in three of nine, and the wet oxidation equal to or better in one of nine.

After consideration of all of the pertinent factors, the incineration alternate was found to be superior to the other systems studied, and was selected as the recommended method of sludge management.

TABLE 4
Cost Comparison Total Annual Cost

Alternate	Capital Cost	Capital Cost Amortization	Annual O&M	Less Savings (1) Power (2) Crop Revenue	Net Annual Cost
Proposed Incineration Plan	$53,040,100	$3,469,500	$3,968,300	-2,540,000 (1)	$4,897,800
Land Application	98,580,700	6,275,100	6,653,800	-2,240,000 (1) -4,180,000 (2)	6,508,900
Wet Oxidation	60,699,200	4,071,000	5,622,800	-2,240,000 (1)	7,453,800

TABLE 5
Non-Cost Environmental Impact Comparison—Energy

ITEM	ALTERNATL L_1 LAND APPLICATION	I_5 INCINERATION	W_{2F} WET OXIDATION
Total Energy Demand	4	1	4
Recoverable Energy / Total Energy Demand	3	1	3
Natural Gas Energy Requirement	1	1	1
Electrical Energy Requirement	3	1	4
Gasoline and Diesel Oil Requirement	4	4	2
Transportation	3	1	2
Total Average Rating	3.0	1.5	2.7

Rating Code:

1. Most Favorable Impact 3.

2. 4. Least Favorable Impact

Recommended Project Plan

A detailed project plan was prepared for implementation of the recommended incineration system. Since the MDC is required to have a sludge disposal system on line by 1976, prior to construction of full secondary treatment, a two-phase program was developed. The Phase I project plan is designed to accommodate the sludge generated by primary treatment at both plants up to the period 1980-1985, and to be on line in 1976. The Phase II program enlarges the sludge facilities to handle the additional sludge generated by secondary treatment, to design year 1995.

In the Phase I project plan, anaerobic digestion will not be expanded, but existing digesters will continue in use at both plants up to their effective capacity. Due to severe site limitations, sludge from the Nut Island plant will be pumped to Deer Island for treatment and disposal. For this purpose the existing submarine force main will be extended to Deer Island, and a second pipeline will be built to provide standby reliability. During Phase I, digester gas will continue to be used for electric power generation at Nut Island, and the existing skimmings and screenings incinerators will continue in service.

At Deer Island, the Phase I project includes continued service of gravity thickeners and anaerobic digesters, up to their effective capacity, without addition of new units. Sludge from both plants will be chemically conditioned, vacuum filtered and incinerated at the new facility at Deer Island. Six vacuum filters (750 s.f. each) and three incinerators (25' dia. X 9 hearth) will be provided. Each incinerator will be fitted with afterburner, waste heat boiler, pre-cooler and high efficiency scrubber. A steam turbo-generator of approximately 3,400 KW capacity will be included for utilization of the waste heat.

Incinerator ash will be utilized for landfill to provide additional space required at the site for future secondary treatment. Ash leachate will be collected and recycled to treatment.

At Deer Island, the existing dual fuel engines which drive raw wastewater pumps will be replaced by electric motor drives, and an outside power supply will be provided to supplement that generated onsite by digester gas engines and waste heat recovery system. At Nut Island, the present digester gas power generation system will be adequate to satisfy Phase I power needs.

Under the Phase II program (commencing about 1980-85), secondary treatment will be added at both plants, and sludge facilities will be modified to handle the increased load. At this time digesters at both plants will be converted to storage tanks, and all sludge will be filtered and incinerated raw. Waste activated sludge will be thickened in flotation units, and the mixed sludge blended in the mixed storage tanks. Eight additional vacuum filter and four incinerators of the same sizes will be added, together with three turbo-generators. Total firm waste heat power generation capacity will be about 10,000 KW Existing dual fuel engine-generators will remain for standby service to provide backup in case of interruption of purchased power. Alternate power sources for standby reliability will be considered when the Phase II program is undertaken.

The estimated construction cost of the Phase I program is $22,016,000; and the Phase II program is estimated at $24,186,000.

A full environmental assessment has been prepared, on which a public hearing was held in April, 1975. The USEPA is currently preparing an environmental impact statement on the project.

For the MDC, the project is under the general direction of Mr. Francis T. Bergin, Chief Engineer, Engineering Division, and Mr. Allison C. Hayes, Director and Chief Engineer of the Sewerage Division. Mr. Martin Weiss, Director of Environmental Planning, was project manager for the MDC, and the studies were conducted by Havens and Emerson, Ltd., Consulting Engineers.

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ALTERNATIVES FOR DISPOSAL FOR THE METROPOLITAN DENVER SEWAGE DISPOSAL DISTRICT NO. 1

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After many years of trial and error and study, the Metro District has selected, based on environmental, engineering, economic and social consideration, the alternative which in its opinion is the most acceptable method for the processing of sludge removed from its wastewater treatment facilities. This method chosen for handling and disposing of the District's sludge is to beneficially use it for agricultural purposes.

As we see it, there appears to be three sludge disposal methods for the industry to use. They are water, atmosphere and land. Since the District's treatment facilities were put on-line in the fall of 1966, all three of these sludge disposal methods have been utilized at one time or another.

The water method for sludge disposal (this is the concept that the solution to pollution is dilution) is particularly inappropriate in the semi-arid climate of Colorado where water resources are seriously limited.

Disposal via the atmosphere method is never intentional, however, even inadvertent air pollution by incineration or any other means is rapidly becoming socially unacceptable.

The third method is the application of sludge to land. This method is currently being used by the District.

To provide some historical background, the District wastewater treatment facilities were initially designed to treat 117 mgd of wastewater and to achieve an 80 percent overall reduction in BOD. The original design concept for the handling and disposal of sludge removed from the processes were dewatering through dissolved air flotation, vacuum filtration, flash drying and/or incineration. The anticipated ratio of raw primary, anaerobically digested and undigested waste activated which comprised the vacuum filter feed sludge were expected to produce a filter cake solids concentration of 22 percent to 25 percent. The chemicals required for sludge conditioning prior to vacuum filtration were expected to average five percent ferric chloride and ten percent lime. If the proposed design parameters had been realized, the amount of water requiring evaporation at full plant capacity would have equalled 353 tons per day. The design engineers involved at that time provided three flash dryer/incinerator units each having a maximum evaporative capacity of 6.5 tons of water per hour. All three units operating at 100 percent capacity 24 hours per day would provide a total evaporative capacity of 468 tons of water.

Early in 1967 it became apparent that the ratio of waste activated sludge to the total sludge mixture was much greater than originally anticipated. The greater quantity of the difficult to dewater waste activated sludge had an adverse effect on the resultant vacuum filter cake solids. The dry solids averaged between 14 percent and 18 percent total solids instead of the expected 22 percent to 25 percent. This sludge ratio resulted in an increase over the original design estimate for chemicals required for vacuum filtration by more than 100 percent. The lower dry solids content resulted in a serious overload of the evaporative capability of the flash dryer/incinerators. Mechanical problems and breakdowns as a result of the overload conditions were compounded by corrosion failures of the stainless steel components of the dryer/incinerators which resulted from the ferric chloride used in the conditioning of the sludge.

By the fall of 1968 the sludge handling and disposal problem had reached crisis proportions. As a result of mechanical problems, less than half of the evaporative capacity of the dryer/incinerators was available for sludge processing. Activated sludge accumulation in the biological treatment system resulted in a rapid deterioration of the final effluent quality. To minimize the scouring of activated sludge from the secondary clarifiers into the South Platte River, lagoons were constructed for the temporary storage of the excess activated sludge. Forty acres of lagoons representing sixty million gallons of storage capacity provided temporary relief during the winter months of 1968 and 1969. By the spring of 1969 anaerobic decomposition of the waste activated sludge stored in the lagoons created serious odor problems and serious public relations problems. Consequently, a third alternative, land application of the vacuum filter cake, was initiated in May, 1969.

Land application of the vacuum filter cake was originally conceived to be a temporary expedient until the dryer/incinerator units could be restored to their design capability. The flash dryer/incinerators were operated primarily as incinerator units between 1966 and 1968. From 1968 until 1971 the units were operated for both drying and incineration. The change in the operational mode made from incineration to drying was prompted by the desire for greater utilization of the system. As dryers the units could be operated approximately 2,000 hours before cleaning and major repairs were required as compared to only 500 hours of operation for incineration.

The primary fuel source for the operation of the dryer/incinerators was interruptable natural gas with No. 2 diesel as a standby or backup fuel. During the winter of 1969-1970 the natural gas service was curtailed on many occasions and Metro did not have a sufficient allocation of standby fuel. This limited fuel supply forced the District to incinerate the sludge for its caloric value as a substitute for commercial fuel.

When the dryer/incinerators were being operated as incinerators flash fires occurred in the system when there was insufficient moisture to utilize the BTU's being generated in the fire box. With insufficient moisture the temperature in the drying system would rapidly increase until there was sufficient heat to ignite the sludge resulting in a flash fire or explosion. Explosions also occurred when slag accumulation on the walls of the fire box would slough off and fall into the wet bottom ash collection hopper. The hot slag resulted in creating vapor which would expand rapidly in the 3,000°F atmosphere of the fire box and an explosion would result. To minimize these explosions the units had to be shut down periodically so that the slag formations could be removed from the walls of the fire box. The slag removal process required many man hours and exposed the operators to dangerous situations.

The dryer/incinerator initially installed in 1966 met the existing Colorado air pollution standards. In 1970 these standards were revised drastically to reduce stack emission concentrations from stationary sources. During 1971 the units were operated under a temporary variance while modifications were being made to meet the new standards. It soon became obvious that the units could not be successfully modified to comply with the new standards. As a result of the air pollution, mechanical and energy problems the units were permanently shut down in August, 1971.

Between May of 1969 and August of 1971 the dryer/incinerators and the land application of filter cake were operated concurrently.

In 1969 the District acquired 160 acres of land located 26 miles southeast of the Metro District treatment plant. This land was part of the abandoned Lowry Bombing Range. The land was being leased to a rancher for the purpose of grazing cattle. The vegetation on this site was natural pasture grass typical of the range land in Colorado. The vacuum filtered sludge was transported in open 13 cubic yard dump trucks equipped with special rubber seals to prevent leakage during transport. Two methods of sludge application were utilized at the site, one for dry weather and the second for wet weather. The District hired a contractor to perform the necessary work under both modes of operation. During dry weather the sludge was tailgated directly from the transport vehicles onto the surface of the soil. A track vehicle equipped with a blade was then used to spread the sludge evenly over the surface of the soil to a depth of approximately one inch. The sludge was then allowed to dry for 24 hours before an industrial type rototiler (six feet wide) with a depth capability of 18 inches incorporated the sludge into the soil. This operation was satisfactory provided that rocks over five inches in diameter, dense vegetation and mud were not encountered.

During wet weather the sludge was dumped directly onto the surface of the soil and large track vehicles with front mount dozers were used to intermix the sludge with the soil. A satisfactory mix was accomplished when a ratio of five or more parts of soil were mixed with one part of sludge. During the winter months when the soil had frozen, the mixing of sludge and soil was extremely difficult. Peripheral surface water channels were dug around the site to retain the water which ran off during snow or rain storms. Analysis of the runoff did not indicate the presence of contaminants from the land application site.

In April, 1970 the District ceased application of sludge to the site because of concern that the high loading rates (376 dry tons per acre) might have an adverse effect on soil productivity and cause erosion. The site was then seeded with Brome and Crested wheat grasses. Since this area receives an average 13 inches of precipitation annually and no irrigation water is available, the complete revegetation process took three years. The major problem involved in the 1969-1970 operation was vulnerability to adverse climatic conditions.

In 1971 the District acquired an additional 640 acres of land at the Lowry Bombing Range and revised the land application operation to provide for a continuous year-round disposal of the total sludge generated by its treatment facilities.

Based on earlier experience, several changes in methodology were adopted. Metro purchased the equipment necessary for the land application system and utilized District personnel to operate the equipment. The method of operation consisted of transporting the filter cake from the treatment plant to the Lowry site in the same type of equipment used in the previous operation. At the land application site a ramp was constructed which allowed the transport vehicles to transfer the sludge directly into spreaders. The 13 cubic yard farm manure spreaders were sized to accommodate one truck load of sludge. The spreaders were modified to handle the relatively wet vacuum filter cake to keep the sludge

from flowing onto the areas where it was not desired. Special lighting was provided at the ramp to allow for 24 hour a day, seven day a week operation. A standby tractor and spreader was provided for the purpose of allowing the primary unit to be serviced. Sludge was spread approximately one eighth inch deep on the surface of the grass and usually dried within one-half hour after application. After application of three dry tons per acre a spike tooth harrow was used to break up any large particles. Cattle continued to graze on the pasture during this operation.

Soil and surface water testing and monitoring at the site indicated that there has been no contamination as a result of the District's operation. A major advantage of this method was that the operation did not disturb the native grasses. Based on visual observation the grass production at this site improved compared to the surrounding area that did not receive sludge application. Another major advantage of this type of operation was that its cost was only one-third of the cost of drying incinerator operation. Not only was this change in operation environmentally preferable, but much less expensive than the previous operation.

In November of 1971 the District entered into a two year contract with a private contractor to provide services for land application of sludge utilizing the technology which the District had developed. Concurrently, the District acquired additional land for a total of 2,000 acres.

The contractor utilized larger transport vehicles and constructed a large sludge storage hopper at the site to store sludge from the transport vehicles until it could be transferred into the spreaders. The spreaders used by the contractor were also larger than those used during the previous operations.

During the fall and winter the contractor spread the sludge in thin layers over the grass land. Early in the spring of 1972 the contractor experienced difficulty with access to the field. As a result, large quantities of vacuum filter cake were stockpiled three to four feet deep in a depression near a dry stream bed. Subsequent to the stockpiling of filter cake, snowstorms occurred which covered the stockpiled filter cake. District inspectors were therefore not aware of this unauthorized modification of the land application method previously agreed upon. As the snow melted the stockpiled sludge decomposed creating odors and people living in the area adjacent to the site complained to the County Commissioners. Another problem which occurred in late spring of the same year after the area had dried was fire. These fires started in the areas which had received many surface sludge applications and were a result of careless smokers and heavy equipment operating in the area. The smoldering fires were difficult to extinguish particularly during high winds.

The odor complaints resulted in a Public Hearing on June 20, 1972. At the Public Hearing the District proposed a revised method of land application to eliminate the odor and fire hazards previously experienced. This proposal was accepted by the County Commissioners and implementation began in June, 1972. A revised method consisted of applying the filter cake to the surface of the soil in two to three inch layers and within six hours of application incorporating the sludge to a depth of ten inches using a mold board or disc plow. After sludge incorporation the soil was tilled until a suitable seed bed had been prepared and was subsequently seeded with wheat or other foilage crops to provide a vegetative cover to protect against wind and water erosion. With the assistance of the Soil Conservation Service a plan was developed to establish contours to provide additional protection against wind and water erosion on the entire land application site. Presently, two crops are raised each year to provide food for the grazing cattle as well as reduce the nitrogen and other nutrients added to the soil.

While this method was satisfactory during dry weather special modification had to be adapted during winter operation. During the winter the sludge is spread on the land by tailgating to a depth of 24 inches and intermixed with the soil at a rate of at least five to one. The inclement weather site is prepared in advance by bench and terracing the area. Sludge loadings to the inclement weather site exceeded 300 dry tons per acre per year. Each inclement weather site is loaded only once. Inclement weather application generally takes place during December, January and February depending upon the severity of the winter. Since 1971 this methodology has ensured an adequate sludge disposal capability for all of the sludge generated by the District's treatment facilities, and has received strong support from nearly all of the area environmental groups.

In 1971 the District authorized their consulting engineers, CH_2M Hill to design an expansion to the central wastewater treatment plant and to investigate various sludge handling systems including incineration and land reclamation. CH_2M Hill recommended an agricultural reuse system in its study report "Sewage Treatment Plant Expansion—Predesign Study", April, 1972. This system was recommended because it would be the most economical method for the District and would make beneficial use of the sludge.

Under the system proposed in the April, 1972 report, the District would either purchase or lease 6,000 acres of land in western Adams County approximately 25 miles east of the central plant. The sludge would be pumped to the site through a force main and a system of booster pump stations. At the site dryland crops typical to the area would be grown utilizing the sludge as a fertilizer. It was also recommended that an anaerobic digestion system be used to stabilize the organic materials concentrated in the sludge prior to agricultural reuse. The anaerobic digestion process is highly efficient in converting organic material into relatively inert humus ma-

terial and gases including methane and carbon dioxide. In addition, the single stage high rate digestion process will reduce the total organic mass of the sludge by 40 percent to 50 percent.

Two public meetings were held during the winter of 1972-1973 with residents in the area of the 6,000 acre site. The concept of utilizing the organic materials for agricultural purposes was discussed. The residents expressed concern about the location of the project and about its management and operation. The residents also made several suggestions which could improve the proposed system.

Because of the residents' concerns, the District authorized CH_2M Hill to undertake another study of using anaerobically digested sludge for agricultural purposes. CH_2M Hill submitted a report entitled "Agricultural Reuse Program" March,1974 which presented a revised agricultural reuse system incorporating the residents' suggestions.

Under the revised system, sludge treatment would be accomplished by single step high rate digestion at the central plant. The liquid sludge would then be delivered from the central plant to the distribution site through a system of force mains and a booster pumping station. The drying and distribution site would include approximately 600 acres of drying basins for open air drying of the sludge, a storage area for stockpiling the dried material prior to distribution to the users, an area for subsurface injection of the sludge, demonstration plots and miscellaneous site facilities necessary for operation and maintenance.

A 2,000 acre drying and distribution site owned by the District was proposed for the project. Eleven sites were identified as potential locations for a drying and distribution center. These eleven sites were reduced to the three most viable sites located 20 to 25 miles east of the District central plant. The three sites were recommended on the basis of environmental and economic considerations.

The revised system was presented to the residents near the proposed sites in a series of public meetings. Meanwhile, CH_2M Hill was retained to do a predesign and site selection study for the revised system. Attempts were made in deciding on the design and location of the project facilities to incorporate the residents' suggestions and gain public support for the reuse project. The predesign and site selection study was presented in a report titled "Agricultural Reuse System Predesign".

The District also authorized a more detailed study of other sludge handling systems to investigate alternatives to the agricultural reuse system. The alternatives were analyzed on the basis of economic and environmental considerations, system reliability and the ability to incorporate the required facilities into the District's existing facilities. Alternative sludge handling systems were evaluated to determine the most viable method of treating and disposing of the District's wastewater treatment plant sludge. The following eight alternative sludge handling systems were found to be the most viable for the District.

Alternative 1 Existing System
Alternative 2 - Anaerobic Digestion - Beneficial Reuse
Alternative 3 - Filter Presses, Incinerators - Land Application of Ash
Alternative 4 - Heat Treatment - Vacuum Filters, Land Application
Alternative 5 - Heat Treatment - Drying Basins, Land Application
Alternative 6 - Heat Treatment - Vacuum Filters, Incinerators Land Application of Ash
Alternative 7 Anaerobic Digestion Filter Presses, Composting Fertilizer
Alternative 8 - Filter Presses - Composting, Fertilizer

Based on environmental, engineering and economic considerations the alternatives study concluded that the agricultural reuse system was the most desirable sludge management system for the District. One of the most important advantages of the system is that a former waste material would be recovered for beneficial use. The fertilizer or soil conditioner which would be produced from the sludge is a valuable agricultural resource, particularly in view of the current and projected fertilizer shortages. In addition, the agricultural reuse system would not depend on chemical or inert conditioners for its operation and would thus be independent of outside cost influences.

The system requires little power, compared to the other alternatives and methane gas, a byproduct of anaerobic digestion, would be used to heat and mix the digesters. Outside fuel or power would be needed only to operate the various pumps of the system and the vehicles at the drying and distribution center.

The reuse system is also attractive because of its relatively simple operation and inherent flexibility for final sludge use. Because of the simplicity in operating the system there will be comparatively low operation and maintenance costs. As a result, it is the most economical of all the alternatives. This system provides the flexibility for marketing liquid or air dried sludge and for using the sludge for either subsurface injection or surface application.

In January of 1975 the District, in cooperation with EPA, FDA, USGS and the Colorado State Geologist's Office, embarked on a two year $600,000 research effort to provide information required by the EPA guidelines for "Acceptable Methods for the Utilization or Disposal of Sludge" and to attempt to answer the questions which had been raised by the farm community and other regulatory agencies. The research effort consists of the following projects:

- Groundwater quality monitoring project.
- Investigation of the effects of feeding to cattle, crops that have been grown on sludge amended soil.
- Sludge characterization project.

- Pathogen (virus and parasites) project.
- Nitrogen management project.
- Greenhouse and crop rotation project.
- Heavy metals monitoring project.
- Sugarbeet fertilization project.
- Mine tailing reclamation project.
- Drying basin project.
- Subsurface injection project.

In conclusion, there are two items which could have a significant effect on all future construction. The first item was an article which appeared in the July issue of *Water and Wastes*, pp. 7:

> "Steep escalations in the price of commercially produced fertilizer may make the use of feedlot wastes and municipal sludge imperative in the future. Russell Train, EPA administrator, told the 5th Annual Composting and Waste Recycling Conference that the use of feedlot wastes and sludge from municipal plants could satisfy about 6.5 percent of national nitrogen requirements. Though he admitted that this was a small increment he said it "may mean the difference between sufficiency and shortage." The Department of Agriculture has reported that since the Phase IV price controls were lifted in 1973, the average price of fertilizer has increased from $75 a ton in mid-1973 to over $140 a ton by fall, 1974. Anhydrous ammonia alone has almost tripled in price. EPA will be starting up a resource recovery demonstration within the next three years in Delaware to show compost production and facilities to enrich the product with synthetic fertilizers. Another demonstration is planned for Maine which will demonstrate a new composting technology developed by the Department of Agriculture. Several other concepts, including some with waste involvement, will be tested in this fiscal year."

The second item is from the *Federal Register, Grant Regulations and Procedures - 30.420-6 Conservation and Efficient Use of Energy:*

> "Grantees must participate in the National Energy Conservation Program by fostering, promoting and achieving energy conservation in their grant programs. Grantees must utilize to the maximum practical extent the most energy-efficient equipment, materials, construction and operating procedures available."

The awesome natural resource issue has provided the catalyst for significant social and economic changes that are occurring in our world today. Therefore, it is imperative that we in the industry design and construct facilities which lend themselves to change and that our goals be established to derive the maximum benefit from the resource which we have for so long called waste. As the technology develops to selectively remove the precious materials from the sludge we should not find ourselves locked into systems which cannot be readily modified to accommodate the new technology. We in the industry should remove the words disposal and waste from our vocabulary and substitute beneficial reuse and resources in their place.

ENERGY CONSERVATION PRACTICES IN MUNICIPAL SLUDGE MANAGEMENT

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INTRODUCTION

Public Technology, Incorporated is a non-profit, public interest corporation that was organized and is sponsored by the so-called "Big Six" public interest groups; the International City Management Association, National Association of Counties, National League of Cities, U.S. Conference of Mayors, National Governors' Conference, and the Council of State Governments. PTI was established in 1971 by the Big Six to act as a research and development arm for local and state governments.

The primary objective of PTI is to promote the development, introduction, and utilization of innovative and advanced technologies in local and state governments. In accomplishing this broad objective, Public Technology works closely with all levels of government plus private industry.

PTI does not attempt to address itself to every city, county, or state technologically-based problem. PTI's overall methodology involves identification of high priority generic needs that are common to a large number of municipalities.

Several months ago, Public Technology became aware of such a generic need through studies conducted by cities participating in two of our major programs. These studies dealt with energy consumption patterns in municipal government operations. One of these studies was conducted by the City of Indianapolis, a participant in the Urban Consortium for Technology Initiatives program; the second study was conducted by the City of Nashville, a participant in the PTI operated Urban Technology System.

Before elaborating on the findings of these two important studies, a brief description of these two programs would perhaps be useful. The Urban Technology System, funded by the National Science Foundation, is an experiment designed to place an emphasis on the use of technology to solve urban problems. The system consists of 27 technology agents located in 27 randomly selected cities and counties in the 50-500,000 population range. These technology agents are scientists and engineers by training and are placed in these municipalities to address themselves to technological problems. Each technology agent is given support by a contractually retained back-up site which may be a Federal laboratory, university, not-for-profit research corporation, or a private company. The technology agent answers directly to the mayor, city manager or chief administrative officer in a municipality, thus possessing operating flexibility and authority. The UTS network has been operational since July, 1974.

The Urban Consortium for Technology Initiatives is also sponsored by the National Science Foundation and involves the 27 largest cities and six largest counties in the Nation. The primary objective of this program is to develop a national needs agenda for the largest U.S. cities and counties and to bring Federal and other available resources to bear upon a number of the most critical problems.

Municipal Inventories of Energy Consumption

In 1973, a profile of city government energy consumption patterns was conducted by the City of Indianapolis. The objectives of this inventory were to:

- determine the direct energy consumption patterns of city operations by major end sources;
- identify those city operations which represent major end uses of energy; and
- assist city officials in assessing the relative impacts of potential energy supply problems on city government operations and potential areas for energy consumption.

An inventory was made of the direct consumption of petroleum-based fuels, electricity, steam, and natural gas by city departments and the city-county building operations for 1972 [1].

The results of this study were somewhat surprising. The study showed that more than half of the petroleum based fuels used in city operations were used in wastewater treatment plants. Also, more than half of the electricity consumed by the city was used in wastewater treatment plant operations (Figure 1). Overall, waste-

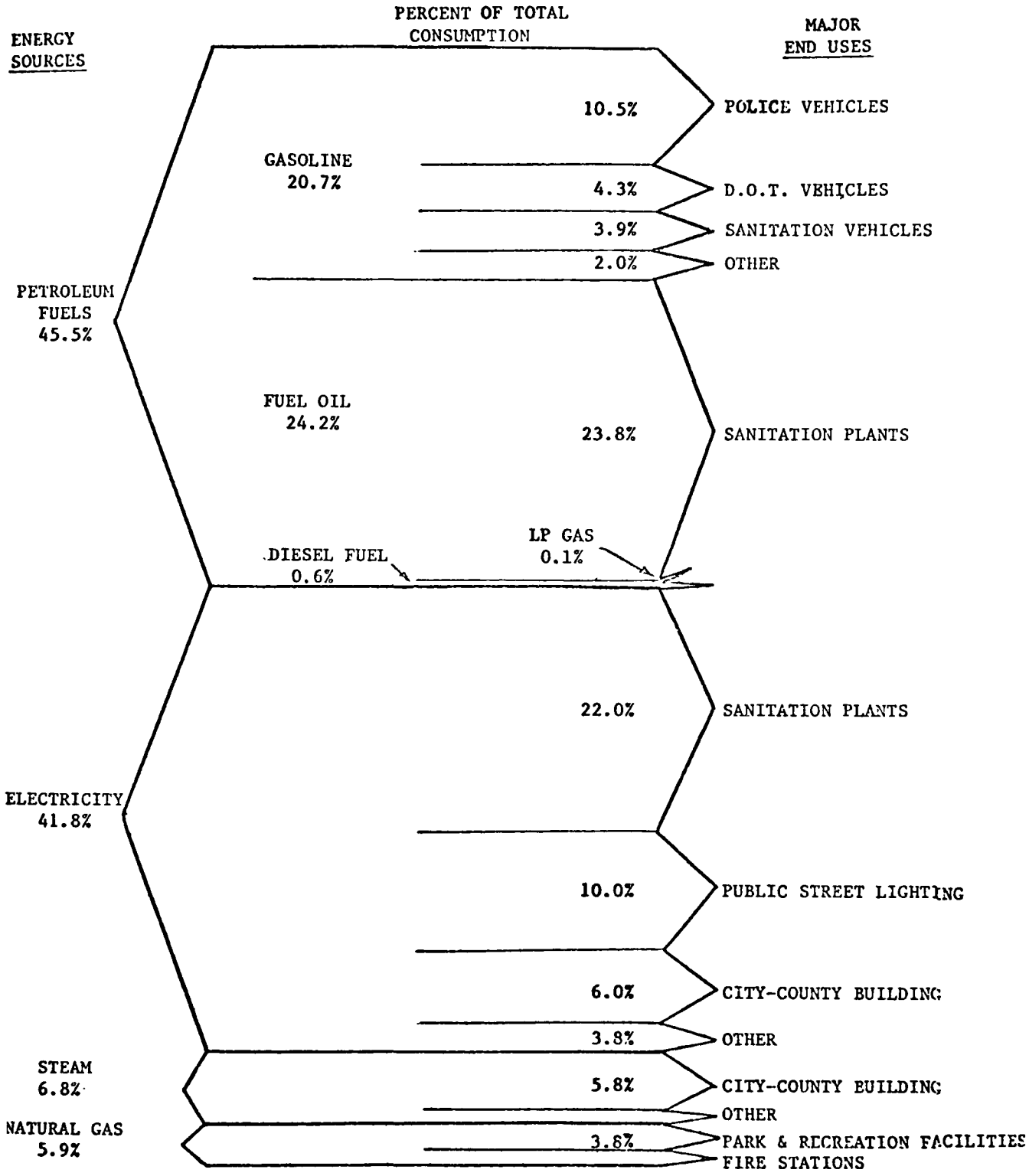

Figure 1: Direct Energy Consumption Patterns of City Operations in 1972.

water treatment plant operations accounted for 45 percent of direct energy consumption by major end uses (Figure 2). It should be noted that a major portion of that energy consumed in wastewater operations was used in sludge incineration.

In September, 1974, the Tennessee Valley Authority (TVA) appealed to its users to voluntarily reduce the amount of electrical energy consumed by 20 percent. This appeal by the TVA to its more than 2.4 million customers was necessitated by the steadily dwindling stockpiles of recoverable coal.

TVA provides electricity for some 160 municipal and cooperative power systems. One of these customers, the Nashville Electric Service, provides electric power to

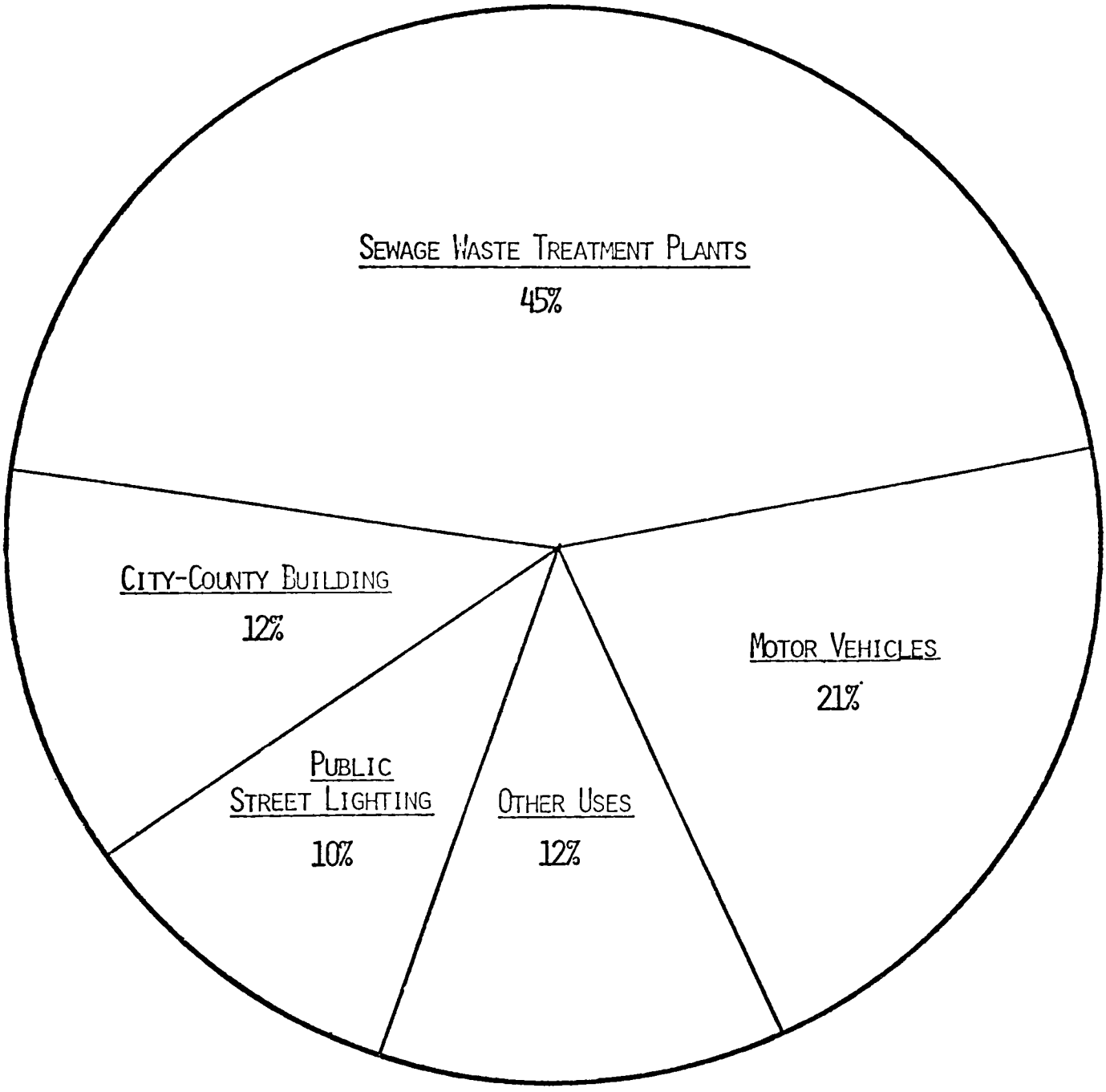

Figure 2: Direct Energy Consumption by Major End Uses - 1972.

Metropolitan Nashville and Davidson County. The Metropolitan Government of Nashville felt that possible mandatory cutbacks or rolling blackouts could have a catastrophic effect on the community because of its heavy dependence on electrical power[2].

Thus, on November 7, 1974, Mayor Briley of Nashville responded to this emergency by setting into motion a comprehensive mandatory electrical energy conservation program aimed at reducing Metropolitan Government electrical consumption by 20 percent.

A summary of the electrical energy conservation results, as of January 15, 1975, showed an 18.24 percent reduction of electricity energy use for the latter three months of 1974 when compared to consumption figures for the same period of 1973. This 18.24 percent reduction in electrical energy demand, however, did not include the Water and Sewer Services Department. Indeed, the Water and Sewer Services Department showed a 14.33 percent increase during this period. The overall consumption of electrical energy by this department for the fourth quarter of 1974 amounted to 30.9 percent of total end usage.

As a direct result of these findings, the UTS technology agent in Nashville requested that PTI furnish him any information on methodologies which would allow his

city to reduce energy consumption in wastewater treatment operations.

Sludge Disposal Costs

Pursuant to receiving the results of the Indianapolis and Nashville studies, PTI decided to conduct an informal survey to determine the extent of the energy problem in wastewater treatment.

One of the first sources of information reviewed was the General Accounting Office (GAO) report to the Congress of January, 1974 regarding Federal research and development programs needed to achieve water quality goals. As part of this study, the GAO surveyed 100 large municipalities to determine critical needs in wastewater treatment. The three top ranked problems are:

- Inadequate treatment facilities—research needed to reduce cost and improve secondary processes to *use less energy*;
- Combined sewer and storm water discharges—research needed to *reduce control costs*;
- Sludge handling and disposal—research needed to *reduce costs*, make process easier, *reduce use of energy*, and determine effects of disposal on land.

It can be noted that two of these problems deal with energy reduction and one in particular with energy reduction in sludge disposal.

Although our informal survey from this point continued to focus on wastewater treatment in general, we began to look more closely at sludge disposal. Sludge treatment and disposal has long been recognized by local authorities, consulting engineers, and Federal EPA officials as being the number one problem in wastewater treatment today. In its 1968 publication, *A Study of Sludge Handling and Disposal*[3], the Federal Water Pollution Control Administration estimated that up to 50 percent of the capital cost and 50 percent of the operating cost of a water reclamation facility was devoted to solids handling. More recent estimates have placed the operating costs even higher, in the 55 percent to 60 percent bracket[4].

Thus, in these days of rapidly escalating power costs, potential energy shortages, and local government budget deficits, it seemed only logical for PTI to inspect the capital intensive sludge disposal process as a potential area for energy savings and cost reduction.

OBJECTIVES AND SCOPE OF STUDY

Through a preliminary review of current literature and several telephone calls to local officials, we soon determined that the total question of economics in sludge disposal was too broad a study to attempt on a short-term basis.

A decision was made to limit the scope of the study to the following objectives:

1. Determination of the extent of utilization of digester gas and for what purposes;
2. Determination of the potential impact of organic conversion (including digester gas) on national energy demand; and
3. To obtain information on the cost/benefit tradeoffs in digester gas utilization.

Digester Gases As Energy Source

A well known potential source of energy is the methane gas produced in the anaerobic digestion process. This gas is currently utilized for numerous purposes in larger wastewater treatment plants throughout the country. Use of this gas to offset operating costs is well documented in the literature. Because of continually changing conditions, namely fluctuations in the economy, the emergence of newer sludge disposal technologies, and power costs, the "real" value of digester gas has also continually fluctuated.

The use of digester off-gases as a fuel source can be traced all the way back to 1895 when the street lights of a section of Exeter, England were operated by this gas[5]. Although much experimentation occurred, routine usage for plant heating, digester heating, and other uses did not take place until the 1930's. In the 1940's, the practice became commonplace due to technological advancements such as the development of the dual-fuel engine. Development of this type of engine gave wastewater plants the capability of utilizing varying compositions of sludge gas and other fuels, and relieved them of total dependency on digester gas alone[6].

Utilization of sludge gas became more widespread during World War II and then began to decline in the 1950's. A number of reasons can be cited as to why this decline occurred. The two most significant reasons were:

- the availability of inexpensive and abundant supplies of electricity, natural gas, and fuel oil; and
- the gradual shift from anaerobic digestion toward more energy-intensive methods of sludge stabilization.

In fact, the ready availability of energy in the late 1960's prompted the FWPCA[7] to state that "many utility rates are so low that it is uneconomical to install equipment to develop power from digester gas."

In 1975, however, the utilization of sludge gas is again receiving a considerable amount of attention. The apparent energy shortfall, skyrocketing fuel prices, and increased demands of energy resources for new and existing wastewater systems share the responsibility for this increased attention.

A number of recent literature articles can be cited which attest to this increased popularity. In a recent article, Mignone[8] analyzed the effects of the several different design parameters subject to the control of the design engineer which would increase the energy generation potential of anaerobic digesters. Adams[9] described how anaerobic gas production could be catalyzed and thus increased through the application of powdered acti-

vated carbon. Murphy [10] estimated the volume of potential fuel available if all sewage sludge were anaerobically digested, and described available energy conversion devices. Goeppner and Hasselmann [11] discussed the economic factors associated with energy production from sewage sludge.

Thus, the trend in sludge disposal may be shifting back toward anaerobic digestgion. Trends are hard to predict at this point in time, however, as various alternative methodologies are being investigated. In addressing the "First National Conference on Municipal Sludge Management," Dr. J.B. Farrell of EPA noted that "there has probably not been a more difficult time for forecasting disposal trends [12]."

Useful Facts About Digester Gas

There is an abundance of articles on anaerobic digestion and gas production in literature. Information concerning fuel value, gas composition, production rates, potential uses, and energy conversion devices is readily accessible.

The composition of digester gas is typically 60 to 65 percent methane (CH_4) with the remainder being composed mainly of CO_2 with traces of H_2S, N_2, and H_2. The fuel value of digester gas ranges from 600 to 650 Btu/ft^3. The rate of gas production is about 0.8 ft^3/capita/day. Six to eighteen standard cubic feet (scf) of gas are produced per pound of volatile solids destroyed.

A July, 1973 report [13] issued by the National Environmental Research Center estimated that in activated sludge plants, a maximum of two thirds of the power needed could be generated by using sludge gas.

Using the electrical demand and gas production figures outlined in that same document, calculations have been made which show that if all sludge were anaerobically digested, the energy available theoretically exceeds total plant energy demands. The NERC study estimates that, if the entire U.S. population were served by activated sludge plants, the average power consumption would be 0.113 kwh/capita/day. Assuming a gas production rate of 0.8 ft^3/capita/day, with a fuel value of 640 Btu/ft^3, energy availability can be calculated at 0.154 kwh/capita/day [14]. It should be emphasized that this figure is theoretical and does not account for fluctuations in production rates, or energy conversion efficiencies of engines and generators.

Looking at theoretical fuel values and production figures also does not take into account potential uses, methods of use, costs of transport if sold, and the damage which the impure gas can do to engines and generators.

Digester gas is dirty. The water and H_2S present in the impure gas can and does cause operating problems such as clogged gas lines and difficulties with control mechanisms. The water and CO_2 present in the gas makes it harder to burn. According to a *Monitor* article in a 1974 Journal of the Water Pollution Control Federation [15], the H_2S normally found in digester gas can: (1) damage metal surfaces, (2) cause pitting of engine walls, and (3) clog piston rings.

All of the contaminants can be removed by water scrubbing or other methods and the gas can then be pressurized, but each of these steps involves a substantial cost increment and reduces the overall attractiveness of the gas from an economic standpoint.

Digester Gas Uses

Energy in a wastewater plant is required to: (1) raise the temperature of the incoming sludge flow to digester operating temperature; (2) maintain digestion operating temperature; (3) operate various motors associated with digestion process, such as sludge pumps and heat exchangers; (4) operate pumps and motors in other parts of the plant; (5) furnish power to operate blowers in activated sludge plant; and (6) space heating for buildings.

Stated in a simple manner, the digester gas produced: (1) can be used directly to operate equipment and thus offset fuel oil and natural gas costs; (2) can be used to generate electricity; or (3) can be sold for commercial or industrial use. It is usually not practical to sell the gas if it is possible to utilize all of it within the plant.

Technologies Involved in Use

Digester gas can be used in a direct manner to heat boilers and produce steam. The resulting heat is then used for space heating in plant buildings, to maintain proper temperatures in the anaerobic digesters, and in some cases to drive large pumps such as raw sewage pumps. The equipment required for direct utilization of gases is not extensive, requiring only a gas-heated boiler or some type of heat exchanger.

The energy demands for the above listed plant operations are not great. The form of energy required to meet the primary needs of wastewater treatment facilities is electrical energy. Thus, the chemical potential energy must be converted to electrical potential energy if all the methane formed is to be utilized. This indirect gas use requires a larger capital investment but ultimately provides greater operating flexibility.

There are presently three types of systems available to convert chemical energy into electrical energy [16]: (1) steam turbine systems; (2) gas fueled direct conversion systems; and (3) fuel cells. Steam turbine systems are more expensive and thus are used in larger wastewater treatment plants which can afford a larger capital outlay. Efficiency of a steam turbine conversion system ranges from 12.5 to 35 percent [17].

Smaller plants generally use gas fueled (dual-fuel) engines which operate on a mixture of gas and diesel oil. The operating efficiency of the gas fueled direct conversion system ranges from 5 to 21 percent.

Since digester gas is not produced continuously, plants using the gas as a major source of energy usually have a storage sphere which allows usage at a constant rate. Two types of storage spheres are available; gravity spheres and pressurized spheres. The gravity sphere operates at a five to nine inch water column pressure. Pressurized spheres are usually designed for 40 to 50 psig.

Plants usually have an auxiliary fuel supply on hand for use during periods of inadequate gas production. This auxiliary supply in a well operated plant is seldom used, however. The plant manager of a large west coast plant noted in a telephone interview that "our back-up propane supply has not been used in years".

A third option for digester gas use is to sell the gas to a commercial or industrial source. The gas may be sold in either the "sour" or "merchantable" condition. A sour gas refers to the gas as it is produced containing the carbon dioxide and other impurities, and having a Btu value of at least 600 Btu/scf. A "merchantable" gas refers to a gas that has been cleaned, has a Btu value greater than 925 Btu/scf, greater than 95 percent methane, less than five percent carbon dioxide, less than 1.0 grain per 100 scf hydrogen sulfide, and a moisture content no greater than 0°F dewpoint [17].

Gas is usually not sold it it can be utilized in the plant itself. Cost of cleanup, pressurization, and transport must be borne by either the municipality or the buyer and these cost increments usually make the sale of the gas economically infeasible.

Municipal Experience in Digester Gas Utilization

Information on municipal experiences with digester gas utilization was obtained in two ways—telephone interviews and a review of current literature. In addition, PTI was able to access information gathered by the Water Pollution Control Federation for a similar survey.

The objective of this part of the survey was to determine:

- the various uses in selected wastewater plants;
- savings realized through digester gas utilization;
- impact of the energy crisis on gas utilization practices.

Plant managers of both large and small treatment systems were contacted. The contacts in larger cities included officials from the Los Angeles County Sanitation Districts, The Metropolitan Sanitary District of Greater Chicago, and the Blue Plains Wastewater Treatment Plant in Washington, D.C. Information on operating expeiences in Bloom Township, Illinois and Racine, Wisconsin was also acquired.

The Sanitary Districts of Los Angeles County have been utilizing the gas produced at their 340 mgd primary treatment plant for more than 30 years. The gas produced at this plant is used to satisfy plant demands; in addition, all excess gas (about 40 percent) is sold to an adjacent oil refinery.

All plant heating requirements are met, digesters are heated, and electricity generated by six large generators. The gas is also used to drive five 1100 hp reciprocal gas engines. These engines have been in service for more than 30 years.

As a result of the energy crisis of 1973, the Sanitation Districts embarked on a project to equip their automobiles with a dual fuel system. The Districts will build their own purification plant and will store gas for use in emergencies. Estimates of total savings through use of digester gas was not available.

The Metropolitan Sanitation District of Greater Chicago operates three major treatment works. The District currently utilizes an estimated 70 to 80 percent of the 3 to 4.5 million cubic feet of gas produced per day to heat the raw sludge feed, maintain digester temperature, and heat the digestion complex buildings. The District is currently investigating various means of utilizing the excess energy for various uses.

A 30 mgd advanced waste treatment plant has recently been completed and will use digester gas to generate steam at 13 to 15 psi. The plant will be heated in its entirety and an air conditioning system using lithium bromide absorption chillers will be operated with power produced from the digesters.

The Blue Plains Treatment Plant in Washington is currently looking at the cost/benefits of incineration versus anaerobic digestion. A summary of the cost analysis data is presented in the next section.

Bloom Township, Illinois buys no fuel during the winter months other than gas for the engines that power the blowers. Bloom Township has been using digester gas for 23 years. Edward Meers, Manager of the Sanitary District, estimates a savings of $58,000 in 1972 on fuel costs. Asked if the energy crisis had impacted the usage of digester gas, Meers noted that natural gas is now almost impossible to obtain during the winter months in the midwest.

Racine, Wisconsin's treatment plant produces sufficient gas to fuel the engines that drive the blowers in its aeration system. Estimated savings are $22,00/year [18].

Other cities utilizing most or all of their digester gas for various purposes include Philadelphia, Cleveland, Atlanta, Tucson, and the Hyperion Plant in Los Angeles.

Cost Analysis of Sludge Handling at Blue Plains

In order to objectively determine some of the cost tradeoffs of sludge disposal, Alan Cassel, Chief of the Research Division of the District of Columbia's Department of Environmental Services, was contacted concerning sludge disposal alternatives under consideration at the Blue Plains Wastewater Treatment Plant.

The plant, operated by the District of Columbia Government, services a 725 square mile area including the entire District of Columbia and portions of Northern Virginia. Sludge processing at the present time is by anaerobic digestion, elutriation, and vacuum filtration.

The plant was designed for 240 mgd and is currently under expansion ot 309 mgd. The average daily flow at the present time is 285 mgd. The plant serves approximately two million people in the Washington metropolitan area.

The production and disposal of sludge is currently being handled under an interim agreement among the various jurisdictions pending the completion of new incineration facilities. The funding of these incineration facilities is being held up by EPA until a comprehensive study on various methodologies for sludge processing and disposal is completed.

Meanwhile, the plant produces 300 wet tons per day of digested sludge as filter cake. An additional 240 tons of primary sludge is produced due to chemical addition designed to reduce the BOD_5 concentration of the effluent.

The digested sludge filter cake is either land filled or composted. The primary sludge is being disposed of mainly through burial by the trenching method.

Blue Plains' problem is hardly unique. They have difficulty in finding enough land to get rid of the sludge and as great a difficulty in getting the various political jurisdictions to share in the sludge disposal responsibilities.

Gas production at the Blue Plains plant is about 1,600,000 ft^3/day. In winter, 310,000 ft^3/day is used for heating plant buildings, 380,000 ft^3/day is used to maintain digester temperatures in the 95°F range, and 500,000 ft^3/day is used to drive three 100 mgd. raw sewage pumps.

The Blue Plains plant generated electricity from the digester gas from 1938 to 1968. In 1968, the conversion engine wore out and was not replaced. Since electricity was available at 0.7 cents/kwh at that time, it was not economically feasible to purchase a new engine.

Blue Plains now pays 2.5 cents/kwh and fuel oil has escalated in price from 12 to 14 cents/gal. to 31 cents/gal. in the same period of time. According to Cassel, it would now be feasible to purchase a new gas fueled direct conversion system.

In September, 1974, Cassel performed a total cost analysis [19] on keeping twelve digesters in operation versus total incineration of raw sludge. The study is too lengthy to be reproduced in its entirety. The results of the analysis are summarized below. It should be noted that the issue in question is not digestion versus incineration costs, but rather a cost-benefit analysis of *keeping* digestion when incinerators are installed.

All costs are based on FY 1974 operating data and include operation and maintenance labor.

The total cost in Table 1 must be balanced against savings realized in dewatering and incineration of less raw sludge, plus the benefits associated with using sludge gas. Table 2 tabulates the savings in cost associated with handling less sludge through the filtration-incineration system. The 862,000 pounds of dry solids per day is the amount of solids to be processed if all solids were incinerated. The 661,300 pounds figure is the amount to be incinerated if digesters remain operational.

TABLE 1

Operation - digestion through final disposal	$3,502,421
Methanol for denitrification	306,450
Total - All Costs of keeping a separate digestion process	$3,808,871

TABLE 2

	Cost at 862,200#/day	Cost at 661,300#/day
Filtration-Polymer & ferric chloride	$1,043,187	$ 800,301
Fuel oil	6,288,000	4,823,960
Power	1,176,030	902,214
Residue Disposal	619,563	475,310
	$9,126,780	$7,001,785
Total Savings	$2,124,995	

Methane produced from digestion is assumed to have a value which could reduce the fuel oil consumption. Table 3 summarizes the methane utilization.

TABLE 3

Total sludge gas production	1,190,000 scf/day
Average use in digester heating	242,873 scf/day
Amount available	947,127 scf/day
BTU available (600 Btu/ft^3)	568,276,200 Btu/day
Value at $2.84/MM Btu	$589,073

($2.84 is Btu value of oil at 40¢/gal)

Table 4 summarizes the value of all benefits derived from keeping digestion.

TABLE 4

Savings from Table 2	$2,124,995
Savings from Table 3	589,073
Total Savings	$2,714,068

In order to make digestion cost-effective, the value in Table 4 must be greater than the value in Table 1. This is not the case with the numbers used. The largest cost with keeping digestion is the ultimate disposal of that sludge. If a method were established to lower the $20.00 per wet ton figure, than the economics change. It is also true that if the price of fuel oil and power increase, then the comparative economics could change also. In general, however, the dollar figure associated with the methane is insignificant when compared to the other costs of operation.

Cassel's cost analysis used a $20 per wet ton figure for ultimate disposal. This number is higher than actual costs at the present time. However, Cassel expects the

costs (including land costs) to escalate to that figure in the near future. Also, he uses a 40 cents/gallon cost for fuel oil. This figure is also high at the present time.

While this cost analysis shows that incineration involves much higher overall operation and maintenance costs, it does not address the questions of finding available land for disposal of vast amounts of sludge and the difficulty in logistics of transport of this sludge.

Potential Impact of Bioconversion on National Energy Demand

The third objective of our study was to assess the potential impact of conversion of organic wastes to energy sources on national energy demand. Organic waste includes urban refuse, manure, agricultural crops and food wastes, industrial wastes, and sewage sludge. Tables 5 and 6, taken from a recent Council on Environmental Quality report on Energy Alternatives [20], show both the quantities of these wastes which are available and the percent of various fuels potentially represented by organic wastes.

If all organic wastes were collected, reserves could represent two percent of total U.S. energy input. Organic wastes, if all were converted, would represent three to four percent of crude oil demand; six percent of natural gas demand; or 6.8 percent of electricity generated in 1971.

It can be seen from Table 5 that 12,000,000 dry tons municipal sewage solids were generated in 1971. This amount is expected to increase to 14,000,000 dry tons in 1980. It should also be noted that the amount of sludge produced is the smallest amount in the organic waste category.

Thus, it is quite obvious that energy from sludge is not going to impact national energy demands now or in the future. It would appear from this data that energy from sludge can best be used to offset operating costs in wastewater treatment.

OVERALL CONCLUSIONS

This paper was not designed to attempt to resolve any critical issues. The purpose was rather to attempt to place the energy costs of wastewater treatment and sludge disposal into a useful kind of perspective.

From the qualitative information obtained in our desk-top study, it appears that utilization of digester gas to offest operating costs is undergoing a revival. Also,

TABLE 5
Quantities of Organic Waste by Source
(Dry Weight in Tons Per Year)

Source	Reserve 1971 (Readily Collectable)	Resource 1971 (Total Amt. Generated)	Resource 1980 (Total Amt. Expected)
Urban Refuse [a]	71.0 [b]	129	222
Manure	26.0	200	266
Logging and Wood Manufacturing	5.0	55	59
Agricultural Crops and Food Wastes	22.6	390	390
Industrial Wastes	5.2	44	50
Municipal Sewage Solids	1.5	12	14
Miscellaneous	5.0	50	60
TOTAL	136.3	880	1,061

Source: Anderson, 1972: 8, 13 [21].

[a] Domestic, municipal, and commercial components of this waste amount to 3.5, 1.2, and 2.3 pounds per capita per day respectively.

[b] Based on the 100 largest population centers in the United States.

TABLE 6
Percent of Various Fuels Potentially Represented by Organic Wastes

	Quantity Dry Organic Waste[a] (10^6 tons per year)	Percent of Total Energy Input[b] in 1971	Percent of Crude Oil Demand[c]	Percent of Natural Gas Demand[d]	Percent of 1971 Coal Demand[e]	Percent of 1971 Electricity Consumption[f]
Reserve (Readily collected now)	136.3	2	3-4	6	8-9	7
Resource 1971	880.0	13	19	39	50	44
Resource 1980	1,061.0	NA	NA	NA	NA	NA

NA = Not Applicable

[a] Anderson, 1972: 8, 13.

[b] Based on an average heat content for refuse of 5,260 Btu's per pound (Kasper, 1973: 7) and a 1971 U.S. energy input of 69.0×10^{15} Btu's (Senate Interior Committee, 1971: 85).

[c] Hydrogenation process at 1.25 net barrels per ton of dry wastes (Anderson, 1972: 3) and a 1971 crude oil demand of 5.7 billion barrels.

[d] Conversion to methane at 5 cubic feet per pound dry waste (Anderson, 1972: 3) and a 1971 natural gas demand of 23 trillion cubic feet.

[e] Coal demand of 600 million tons per year.

[f] Based on 2,000 billion kilowatt-hours consumed.

wastewater plants, both small and large, are endeavoring to utilize all of the gas rather than only a portion.

Overall conclusions of the study can be summarized as follows:

1. Energy consumption in wastewater treatment in general and sludge disposal in particular is a major consumer in municipal government operations.
2. Larger wastewater plants that process sludge by anaerobic digestion should analyze the cost-effectiveness of utilizing all of its digester gas.
3. More study of energy balances in wastewater treatment and sludge disposal are needed.

City managers and mayors across the country are searching for cost reduction methods to reduce budget deficits. Wastewater treatment has been shown to be a significant consumer of energy. Although even substantial reductions in wastewater operating costs will not constitute a panacea, it is a good place to begin.

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UPDATING THE 1974 PITTSBURGH CONFERENCE

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INTRODUCTION

The real value of most conferences such as this sludge management conference is the continuing dialogue which is developed between the participants. One year has passed since the last conference in Pittsburgh and we felt it would be timely to report on the status of the projects many of you heard about or read about at last year's conference.

This paper was designed to answer the question, "I wonder how that project we heard about last year at the Conference ever came out?" The credit for this presentation really goes to the original fourteen authors. They have submitted brief summary comments edited to fit a common format.

Recognizing that all papers would not necessarily need updating, the authors were asked to report on any other new and interesting work that they are involved in. You are encouraged to contact the authors directly for further information.

The following detailed comments from the authors are in the same order as the original papers were presented at the *First National Conference on Municipal Sludge Management.*

Thickening of Sludges

Richard I. Dick
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In Richard Dick's presentation on "Thickening of Sludges", thickening theory was reviewed and the interaction thickening with other sludge treatment and disposal processes was discussed. Then economic implications of the interactions between thickening and other sludge treatment and disposal processes were considered. This work on the interactions between various processes for sludge treatment and disposal is being continued and expanded.

The National Science Foundation has recently funded a research project on "Process Selection for Optimum Management of Regional Wastewater Treatment Residuals" to be conducted by Professor Dick. The purpose of the project is to study the interactions between various components of sludge treatment and disposal processes in order to develop a rational framework for devising strategies for managing sludges. This will be accomplished by:

1. Developing cost and performance models for the various individual processes of sludge treatment, reclamation, and disposal.
2. Integrating the individual processes into plausible schemes for sludge management at installations of various sizes.
3. Optimizing the performance of the integrated models and identifying sludge properties and design and operational variables which deserve special consideration in developing sludge management strategies.
4. Evaluating attributes of alternative sludge management schemes related to environmental impact and public acceptance.

It is hoped to obtain the data required to develop the cost and performance models from published literature, engineering reports, and plant operational records. Professor Dick invites those who may have such data on the cost performance of typical sludge handling procedures to contact him.

Anaerobic Digestor Operation at the Metropolitan Sanitary District of Greater Chicago

Stephen P. Graef
The Metropolitan Sanitary District of Greater Chicago
Chicago, Illinois

Mr. Stephen Graef reports that no major changes have taken place in the practice of anaerobic sludge digestion by the Metropolitan Sanitary District of Greater Chicago.

A Comparison of Diffused Air Aerobic Digestion with Pure Oxygen Digestion of Waste Activated Sludge

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The objective of this study was to determine which parameters have the greatest influence on the aerobic digestion of waste activated sludge (WAS). In the first experiment, dilute WAS (<1.0 percent TS) was aerated with coarse bubble diffusers in an uncovered aeration basin. In the second experiment, thickened sludge (four to five percent TS) was oxygenated in an open tank pilot plant. Two different ultra fine bubble oxygen diffusers were used, a fixed diffuser (FAD) and a rotating diffuser (RAD).

Major factors influencing aerobic digestion performance were; temperature, sludge retention time, mixing energy, solids concentration, and the initial volatile fraction of the feed sludge. The high intensity mixing oxygen diffuser accelerated solubilization of cells, which increased oxygen respiration rates beyond the capability of the diffused air system. Thickening of WAS had a detrimental effect of microbial cell decay rate. This effect was overcome by the oxygen high intensity mixing diffuser.

It was discovered that digestion performance could be predicted by using a temperature X sludge retention time factor. The critical factor required for good digestion was 150 degree-days. Either one of these two factors could be substituted for the other in the equation, as long as the multiple of time and temperature exceeded the critical value.

If the biomass temperature declined by 5°C or greater in less than five days, nitrification ceased. A critical value of 250 degree-days was necessary to buffer the system against such a cold temperature shock. Sludge retention time in the digester was directly correlated with air flotation chemical demand of the air digested sludge. Sludge dewaterability of vacuum filtration was improved after air digestion of dilute sludge, but adversely affected by oxygen digestion of thickened sludge. the volatile fraction of the digested sludge must be reduced below 60 percent to avoid obnoxious odors. A well stabilized sludge had an oxygen uptake rate below 3.0 mg 0_2/hr/g volatile suspended solids.

The microbial cell decay coefficient for volatile suspended solids (k_d) was found to be 0.07 $days^{-1}$, compared with 0.061 found in the literature. The highest biomass reduction rate in the air digestion system occurred when ecological diversity and rotifer population densities were maximal. High biomass reduction rates were also obtained in the oxygen digestion system, although protozoa and rotifers were not predominant. The organisms responsible for pure oxygen digestion of thickened waste activated sludge were heterotrophic mesophilic bacteria.

*David B. Cohen has presented results studied in Ontario, Canada by the Environmental Protection Service. At the Pittsburgh Conference, Dr. Cohen represented the Metropolitan Denver Sewage Disposal District No. 1. The paper presented was *Metro Denver's Experience with Large Scale Aerobic Digestion of Waste Activated Sludge.*

Pressure Filtration - Municipal Wastewater Solids, Cedar Rapids, Iowa

James W. Gerlich
Howard R. Green Co.
Cedar Rapids, Iowa

A detailed evaluation of pressure filtration was presented by Mr. Gerlich. At this time it is not possible to present new data and long records of successful operation with the Passavant pressure filter, since the performance of the units has changed very little. The following points should be made. The pressure filter process, as such, is a good one. The plant people attest to this. When the equipment is in good mechanical condition it performs better than anticipated in previous pilot work. Continued structural failures of equipment have occurred. Most of this has been attributed to poor quality control and workmanship in the manufacturer's shop and some to poor field service, operating instructions, maintenance instructions and related manufacturer's guidance.

At this time, Passavant has just completed the third set of new plates for one filter and are in the process of fabricating a completely new set for the second filter. In a three year period, operation at best has only been about 50 percent capacity due to structural failures.

These structural failures were identified in engineer reports as early as startup in 1972. Unfortunately, Passavant was reluctant to consider deficiency of structure. The facts, by Passavant observed measurements, were that the internal support columns on the plates (eight lines of stay-boss) were short about 4½ inches in the length of the filter. Therefore the plate diaphragms were not stable and allowed to move around. They failed by metal fatigue at the diaphragm.

Foreign manufactured equipment of foreign technology leaves a lot to be desired. These units were manufactured in the United States, however, the technology was German. Communication of technical information is a problem for the client and for the manufacturer. In the long run, foreign goods or technology can be a problem.

Some of the support equipment was poorly designed. Again, this was probably due to the limited technical input at the manufacturer's level.

The reconstructed filter, with new plates, has been doing a good job. Cakes are good, runs are short, things are clean, and the operating personnel are happy. Only time will evaluate how well the units last. However, a basic structural problem as experienced should have been solved with less time and expense.

Heat Treatment and Incineration

Dale T. Mayrose
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Mr. Mayrose's paper covered the combined processes of heat treatment, dewatering and incineration. No profound changes or developments have occurred over the past year which have altered Dorr-Oliver's basic recommendations on sludge disposal. Dorr-Oliver is more convinced that incineration is the ultimate answer to the enormous problem of disposal of huge volumes of municipal sewage sludges.

Heat treatment has been used for many years as an alternate process to aerobic and anaerobic digestion. Heat treatment, like digestion, will reduce the volume of sludge, but will still require the transportation of large volumes of sludge to be disposed of by dumping on the land or into the ocean. Dewatering by itself has also been utilized for many years on municipal sludges. Sludges consisting of at least 50 percent primary and 50 percent waste activated sludge can be digested and dewatered with centrifuges and vacuum filters to cake concentrations of approximately 16 to 22 percent solids with the use of conditioning chemicals. The same sludge, if heat treated, can be dewatered to cake concentration in excess of 35 percent solids without conditioning chemicals.

The combination of heat treatment and dewatering reduces the volume of sludge. Thermal conditioning improves the dewaterability of sludge which results in drier cakes discharging from the dewatering device.

In the United States there are hundreds of sewage treatment plants using incineration to burn dewatered sludge. Nearly all of these plants use centrifuges or vacuum filters to dewater chemically conditioned sludges to cake concentration of approximately 18 to 22 percent solids. At these cake concentrations, auxiliary fuel, usually No. 2 fuel oil, must be added to the incinerator to sustain combustion. The need for conditioning chemicals and particularly fuel oil to sustain combustion puts a strain on the economics of incineration.

Normal domestic sewage sludges will burn in a fluid bed incinerator at cake concentrations of approximately 35 percent solids, without the use of auxiliary fuel. There is enough heat value in the volatile content of the sludge to satisfy the thermal requirements necessary to evaporate the water present in the sludge, incinerate the solids, and produce a stack gas discharged at deodorizing temperatures of 1400° to 1500° F.

Each of these unit operations when considered separately do not provide a total answer to the most economical approach to sludge disposal. In the case of heat treatment and dewatering, solids, although reduced in volume, must still be disposed. Incineration alone, operating on sludge chemically conditioned and dewatered, will require auxiliary fuel to sustain combustion.

The basis of the Pittsburgh paper was to illustrate the economics of a sludge disposal system combining the three operations of heat treatment, dewatering and incineration: heat treatment to produce a sludge of greatly improved dewaterability; dewatering to produce a cake of 35 percent minimum solids concentration; and fluid-bed incineration to reduce the organic sludge to an inorganic ash without the use of auxiliary fuel or expensive conditioning chemicals.

The only fuel required to operate the combined sludge disposal system will be that required to operate the heat treatment system.

Heat-treated sludge is used to preheat the cold sludge in a sludge-to-sludge heat exchanger. The heat-treated sludge at 400°F will preheat the cold, or nonheat-treated sludge, to approximately 360°F. Steam is injected into the sludge in the second section of the heat exchanger to raise the temperature of the sludge from 360°F to 400°F. The steam is generated by a boiler operating on fuel oil or natural gas.

With today's energy crisis, the elimination of the fuel required to generate steam would be a significant economic improvement. During the last year, the use of waste-heat boilers has been incorporated into the design of the total sludge disposal.

The waste-heat boiler operates on the large volume of hot stack gases at 1500°F discharging from the fluid-bed incinerator to generate steam. The amount of steam produced in the waste-heat boiler is usually in excess of the amount of steam required to operate the heat treatment system. Heat recovery by the use of waste-heat boilers has been practiced by Dorr-Oliver for many years in various industrial processes using a fluid-bed reactor. Its application in the municipal market with sludge incineration in relatively new. However, the technology is not new. The design experience obtained from more stringent or severe industrial applications is transferable to the municipal market.

In Berlin, Germany, a new wastewater treatment plant has gone into operation. This plant has been operating for approximately ten months. The solids disposal system consists of heat treatment, vacuum filter dewatering, fluid-bed incineration and heat recovery by waste-heat boilers. The plant does not require conditioning chemicals for dewatering or fuel oil to operate the heat treatment or incineration systems.

The solids disposal system at the Berlin wastewater treatment plant is a wave of the future. It is a proven economic method of sludge disposal.

Dorr-Oliver is currently exploring the possibilities of using generated steam to operate steam turbines which could produce electrical power to satisfy the needs of the solids disposal system. This particular aspect is still under investigation and has not yet been incorporated into the design of any plant under consideration in the United States. If it proves to be practical, like the application of waste-heat boilers, it will make this particular approach to solids disposal even more economically attractive.

Drying of Sludge for Marketing as Fertilizer

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The sludge drying operation in the City of Houston is continuing as reported last year. The demand for the dried sludge is still very high.

However, in response to the energy crisis, the City of Houston is reviewing the use of natural gas as the fuel source. Even though natural gas is the fuel of choice, the external demands for natural gas not only have driven the costs up rapidly, but may also reduce the availability.

Consequently, studies have been initiated to develop alternative fuel sources for the drying operations at the two existing plants. Also, two new plants now in detailed design, will be built with alternate fuel capability. Operation is expected in 1980. A third plant is in the preliminary design stage. The sludge processing system is being reviewed to determine which is the best, based upon energy consumption.

Utilization of Digested Chemical Sewage Sludges on Agricultural Lands in Ontario

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Ontario Ministry of the Environment
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Mr. Black reported on the utilization of digested chemical sludges resulting from Ontario's phosphorus removal program, in which approximately 100 plants were affected by the December, 1973 deadline for phosphorus removal. The actual figure is 117 of which 116 are now on line with the required phosphorus removal with the compliance of the other being held up because of in-plant expansion. Of the 56 plants with a December, 1975 deadline, five are already effecting necessary phosphorus removal and we expect the remainder to be able to comply with the deadline.

The sludge research projects supported by the governments of Canada and Ontario are continuing, with some (virus, heavy metal analytical development, sludge decomposition, application equipment) scheduled for completion by March 31, 1976. A new project looking at survival of parasites in digested sludge has been initiated. Interim reports published under the Canada/Ontario Agreement on these projects are available from the Ministry of the Environment.

"Provisional Guidelines for Sewage Sludge Utilization on Agricultural Lands" have been prepared by joint ministerial committees of the Ontario Ministry of Agriculture and Food, Ontario Ministry of the Environment and Ontario Ministry of Health are to be used in regulating the application of sewage sludges to agricultural lands in Ontario. These guidelines, subject to approval, refer to fluid sewage sludge only, and discuss the acceptable and non-acceptable levels of sludge constituents such as heavy metals, nitrogen and phosphorus. Additional information concerning these draft guidelines can be obtained by contacting the author.

The Economics of Sludge Irrigation

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Springfield Sanitary District
Springfield, Illinois

The Springfield Sanitary District is currently applying both aerobically and anaerobically digested sludge on agricultural land at two sites. Sampling of the underdrainage from the two sludge disposal areas has continued. Unfortunately the data for the Spring Creek plant (the anaerobically digested sludge) does not amount to much at this point. Pump problems made it difficult to utilize the field. As soon as those problems were resolved, most of the field was taken out of service to accomodate some outfall sewer construction that ran across the field. As a result, little worthwhile data can be reported on this installation.

The Sugar Creek sludge application system (aerobically digested sludge) has been in full operation during the entire time. A number of samples of the underdrainage have been collected. Results of this project will be reported in an interim paper on the underdrainage water characteristics at the Water Pollution Control Federation Meeting in Miami in October.

In general, based upon sampling of the underdrainage water, the soil is very effective in removal of BOD, suspended solids, fecal coliforms, phosphate, ammonia nitrogen and total kjeldahl nitrogen. Data on removal of nitrates is somewhat cloudy at this point and will require additional data before drawing any conclusions.

Sampling of the underdrainage as well as the sludge applied will be continued for a minimum of one additional year. With the added data, conclusions with regard to the capability of the soil to remove some of the nutrients should be possible.

With regard to the crop grown on the areas at the Spring Creek plant, alfalfa has been planted with the hope that it will loosen up the soil to allow better percolation of the water in the sludge. Tight soil is not a problem at the Sugar Creek plant. Winter wheat was planted at the end of last summer in an effort to determine how it would react to the sludge application. The wheat crop has been harvested, even though difficulty with horse weed prevented complete harvest. In those areas where the wheat was combined, it seems to be an outstanding crop. One disadvantage with utilization of wheat as a crop is that when the wheat stops growing in May, the horse weeds are growing strongly and soon take over the field. For this reason, wheat may not be a desirable crop unless herbicides are used to control weed growth.

Orchard grass and alfalfa have also been planted along with the wheat in this field, but no results on the success of this crop are available at this time.

Sludge Management in Allegheny County

Richard M. Cosentino
Department of Works, Allegheny County
Pittsburgh, Pennsylvania

The project titled "Restoration of Strip Mine Lands Using Municipal Treatment Plant Residues and Fly Ash" was not funded by EPA. The project, which involves high lime treatment of dewatered, undigested sludge, has not yet been undertaken because of plant construction delays. A meeting is planned with the McCandless Township Authority's consultant to discuss a mutual project. At the present time, the possibility of utilizing a fluid bed reactor at our transfer station does not appear to be very likely.

However, the County has just received a grant offer from EPA for a project titled, "Management of Residues from the Treatment of Industrial Wastewaters". The purpose of the study will be to develop a regional industrial wastewater residue control management system for Allegheny County, which will be consistent with recent legislation, the needs of the economy within the County, and one which will create the proper environmental climate to attract new industries to Allegheny County.

In addition to the study above, the County has received a grant from the Pennsylvania Department of Environmental Resources to undertake a management study of municipal wastewater treatment plant sludges, water treatment plant sludges, septic tank pumpings, and spent acids. The objectives of the study will be to determine:

1. Amount, type and dispersal of sludges in the County.
2. Alternative methods for disposal including and undigested sludges and attendant problems.
3. The human and physical resources required to operate a municipal sludge management program.

Sludge Disposal by Incineration at ALCOSAN

George A. Brinsko
Allegheny County Sanitary Authority
Pittsburgh, Pennsylvania

In this year and it appears to be true today, the problem of solids disposal is still a major issue and still remains the most costly of all the processes.

Here in Pittsburgh, the odor problems were eliminated by the ducting of the foul gases from the sludge vacuum filters to the incinerators for thermal destruction and the utilization of hydrogen peroxide to oxidize the odor producing sulfides in the sludge. However, because of the odors, our public image has been stained and our community relationship has been strained. The public will not forget nor will they let us forget. Any odor that our neighbors smell or think they smell, although it may be coming from some other source, will result in a rash of complaints. It will take years for us to get back in good standing with our neighbors. The odors are gone but the public resentment still exists.

In 1974, solids increased 37 percent to 38,946 dry tons with a disposal cost of $65.30 a dry ton, an eight percent increase over the previous year. Disposal costs are spiraling with no end in sight. The fuel adjustment charge has caused a 55 percent increase in auxiliary fuel costs. This coupled with new Federal and state requirements on ash disposal due to the heavy metals has resulted in over a 110 percent increase in ash disposal costs. There has to be some relief from the regulatory agencies.

To counter-act the rise in auxiliary fuel costs, new and more efficient dewatering methods have to be developed or found. A dryer cake (around 35 percent) has to be obtained to economically incinerate sewage solids. Maybe the filter press or varnip press is the answer. Whatever the solution may be, less power or auxiliary fuel must be used. A mixture of solid waste and sewage solids with the generation of steam as a final product still appears to be the best answer to everyone's problem. Sludge disposal is a greater problem today than it was a year ago. A greater concentrated effort has to be put forth by all to help, if not solve, this major national problem.

Sludge Handling and Disposal at Blue Plains

Alan F. Cassel
District of Columbia Department of Environmental Services
Bureau of Wastewater Treatment
Washington, D.C.

Digested sludge disposal continues as before. Filter cake is plowed into the soil. Marginal lands have been used exclusively the past year.

Raw sludge disposal by the trenching method has been in full operation since mid-March, 1975. Currently, 180 wet tons per day of filter cake are disposed of by this method.

Composting raw sludge in static piles is a most promising research project ongoing at Beltsville. Dr. Elliot Epstein will report on this project at this conference. The finished compost product is finding widespread acceptance in the Washington area, particularly in large public projects such as the Bicentennial Gardens.

Organic Recycling had operational problems with fires and excessive wear in their dryer and associated equipment. They have only successfully dried and pelletized digested sludge to date. The fibrous nature of raw sludge has provided operation problems. They are making equipment modifications and should be in full operation by September, 1975. They are now a wholly-owned subsidiary of Universal Oil Products.

EPA Region III made a decision not to build the incinerators at Blue Plains until one more look was taken at all possible alternatives. The District hired Camp, Dresser and McKee, Inc. to conduct the study. The study will be completed by November, 1975 and hopefully a decision will be made then.

Energy Conservation and Recycling Program of the Metropolitan Sewer Board of the Twin Cities Area

Dale C. Bergstedt
Metropolitan Waste Control Commission
Saint Paul, Minnesota

Thermal energy conservation continues to be the dominant mode of thought in the Commission's engineering and planning. A summary of certain projects that were reported on in Pittsburgh, follows.

Pyrolysis of refuse along with sludge cake continues as a design project that has been carried forward by the Rust Engineering Company under the overall direction of our solids processing consultant, Toltz, King, DuVall, Anderson & Associates of St. Paul. The consultants have completed the specifications booklets and the necessary drawings to permit advertisement of the major capital items on a pre-buy basis. Bidding documents have been submitted to the EPA and to the state regulatory agency for grant approval. The intent is to purchase these major capital items and then design the physical facilities to the exact dimensional requirements while the equipment items are being fabricated. It is anticipated that substantial time will be saved and possibly avoid escalation of costs.

Waste heat recovery is programmed in the solids disposal expansion. The design of waste heat boilers that will be used for generating 300 to 400 psi steam, to operate sludge thermal conditioning facilities has been completed. These boilers will receive incinerator gases at 1250°F and drop the temperature to 600°F, with further heat recovery to be accomplished in sludge dryers.

Roll press (Impco "Vari-Nip") evaluation for sludge dewatering has continued. We have completed one year's investigation using this continuous roll press as a means of dewatering conditioned raw sludges. The system has worked well when primary sludge is fed, but it has not yet proved cost-effective when mixtures exceeding 30 percent secondary (waste activated) chemically or thermally conditioned sludge are fed. The press delivers cake in the range 35 percent to 40 percent solids, sufficient to be autogenous in multiple hearth furnaces, and thus eliminating the need for fuel.

On the general subject of utilization of fuels, the MWCC has just been awarded a grant of approximately $400,000 by the EPA for a two year study of co-incineration of solid fuels such as coal and combustible refuse with sludge cake. In this way, it is anticipated that these fuels will offset at least two thirds of the need for natural gas or fuel oil in burning sludge dewatered by presently installed vacuum filters. This project is a direct outgrowth of the coal and wood chip addition experiments reported in last year's paper.

Sludge Management System for St. Louis

Peter F. Mattei
Metropolitan St. Louis Sewer District
St. Louis, Missouri

The solids handling systems for the three treatment facilities of the Metropolitan St. Louis Sewer District were discussed by Mr. Peter Mattei.

Secondary treatment is still in design, therefore, the problems that were discussed are still the same, and the cures which we will have with the completion of construction of secondary treatment on the Mississippi River have not been solved. A whole new program has opened in St. Louis with the advent of Public Law No. 92-500 forcing political entities to join together in the solving of mutual treatment and sludge handling problems. Mr. Mattei would like to participate in a discussion of crossing political boundary lines for the purpose of protecting the health and welfare of the people we all serve. He is interested in finding out how other areas are handling or solving this complex problem.

Summary of "Pretreatment and Ultimate Disposal of Wastewater Solids Conference" - Held May 21-22, 1974, Rutgers University

Robert W. Mason
Research and Development Branch
Region II Office - EPA
New York, New York

This paper does not lend itself to an updating, so Dr. Mason has provided a summary of recent developments in EPA Region II.

During 1974, 4,680,000 cubic yards of sewage sludge corresponding to approximately 500 dry tons, were barged into the New York Bight and dumped at a site twelve miles off shore. New Jersey municipalities contributed about 2,000,000 cubic yards of this total, the rest coming from New York City municipalities. With the conversion of all primary sewage plants to secondary treatment and with the projected population growth, the volume of the secondary sludge is expected to increase to about 2,000 dry tons per day by the year 2000. A large portion of the increase will occur by 1980 with the upgrading of existing pollution control plants from primary to secondary treatment.

Since the United States Environmental Protection Agency (EPA), Region II, has committed itself to the phasing out of ocean disposal of both industrial and municipal wastes by 1981, provided a sound plan which is environmentally acceptable can be developed, the study of disposal alternatives is obviously a top priority job. To answer adverse criticisms generated by the continued use of the present dumping site, two new areas are under study by EPA. A site will be selected within one of the two areas when the environmental impact

statement has been prepared. This should occur in January, 1976 and dumping transferred to the new site sometime thereafter in 1976.

The U.S. EPA, Region II, has authorized, and through the Interstate Sanitation Commission, is funding a study of procedures for disposal of sludge—excluding ocean disposal.

Phase I of the study is now complete and a report will be issued in the middle of July. Recommendations for the New York Metropolitan Area are primarily pyrolysis, and to a limited extent, for selective sludges, land disposal. Pyrolysis in multiple hearth equipment preceded by filter press dewatering of sludge is the favorite procedure. Since pyrolysis in such equipment has not been demonstrated, it is planned to initiate a pilot study of the operation within the very near future. The recommendation to go to pyrolysis was based on environmental impact, economic feasibility, and energy recovery.

Only a limited quantity of sludge was recommended for land disposal. The limiting factors are the heavy metal content of most of the area sludges as well as the high cost of land.

As of the middle of July, Phase II of the study has been initiated. Pyrolysis and land disposal will be examined in depth in Phase II, the purpose being to develop, in specific terms, a recommended technical plan for sludge management on a regional basis in the New York - North Jersey Metropolitan area. Phase II will be completed by June 1, 1976.

Upon completion of Phase II, comparisions will be made between controlled ocean disposal (based on investigations concurrently being carried out by the National Oceanic and Atmospheric Administration and the U.S. EPA) and in-depth study of the selected alternatives in Phase II. Taking into account all of these sources of information, the Interstate Sanitation Commission will develop a New York Metropolitan Area Sludge management plan.

The objective of EPA Project 801871, Ocean County, New Jersey, is to demonstrate the disposal of wastewater solids by application on coastal plain soils. Work was started on July 1, 1973, and, with a supplemental funding, is scheduled to terminate on October 31, 1976.

Participating in the project are the following groups:

1. U.S. Environmental Protection Agency, Region II; and the Office of Research and Development
2. Department of Environmental Science, Rutgers University
3. Department of Agricultural Engineering, Rutgers University
4. Department of Soils and Crops, Rutgers University
5. New Jersey Division of Fish, Game and Shell Fisheries
6. New Jersey Division of Water Resources
7. U.S. Geological Survey
8. Ocean County Sewerage Authority

To date applications of liquid sludge (five percent solids) have been applied to quarter acre plots over a two-year period. (The first year of the grant, starting July, 1972 was devoted to selection and clearing of plots, drilling wells and establishing baseline data.) Three loading parameters were used: 10, 20, and 40 tons/acre/year. Crops of Rye and Midland and Bermuda grasses were grown. Sixty-nine wells have been installed to monitor groundwater quality. Multi-depth samplers were also employed to define the pattern of the pollution plume.

During 1973 and 1974 a total of 251 soil samples and over 2,000 groundwater samples have been analyzed. Grasses were harvested for yields, and plant tissue was analyzed for various nutrients and heavy metals. Soils were also analyzed throughout the period to measure the buildup of organic matter, nutrients, and heavy metals.

While correlations between soil loadings, crop yields and groundwater contamination were found in the two full year's growing study, the results are still inconclusive. It is evident that the study must be continued through another full growing season (to October 31, 1975) followed by one full year (to October 31, 1976) of measurement and analysis of all phases now under investigation.

On completion of the project it is anticipated that the following information relating to wastewater solids utilization on the land will have been developed:

1. Pollution impact on the groundwater, especially in regard to nitrate.
2. Economical application techniques.
3. Soil and plant impact.
4. Recommended monitoring systems.
5. Suitability of wastewater solids as a soil conditioner to increase the yield of wildlife and food plants.
6. Odor associated with applications.

SUMMARY

In summary, it is obvious that the participants from the 1974 Pittsburgh Conference still find sludge management a complex and interesting problem. Progress is being made towards the development and demonstration of new technology, but much more needs to be done. In addition, problems concerned with the institutional aspects related to Federal and state regulatory agencies must be resolved.

The impact of the energy problem is clearly evident. The high cost of fuel appears to indicate that better dewatering technology is needed. Energy recovery systems through the use of waste-heat boilers and pyrolysis units appears attractive. Land application of properly conditioned sludges may also result in a net reduction in energy requirements.

Much remains to be done, but it is encouraging to see that a tremendous amount of work is being actively pursued towards development of environmentally and economically acceptable sludge management systems.

Finally, a "thank you" to all of the contributing authors for providing the valuable information reported in this paper. Interested persons are encouraged to communicate directly with both the contributing authors and the participating EPA personnel to exchange any information on these projects or projects which you may be conducting. The free flow of technical information is vital to a successful ending in our joint fight to turn this waste product, sludge, into a national resource.

SUMMARY OF THE ASCE SEMINAR ON SLUDGE DISPOSAL*

C. Michael Robson
MCA Engineering Corporation
Baltimore, Maryland

The "Sludge Handling and Disposal" session was intended to provide information to practicing engineers in contrast to the research orientation of much of the Conference. Five speakers were invited to participate representing Federal and state agencies, the consulting engineering field and equipment manufacturing. Summaries of each presentation are provided, supplemented by the information provided in the subsequent question and answer periods.

Overview of Sludge Handling and Disposal

J.B. Farrell
National Environmental Research Center
U.S. Environmental Protection Agency
Cincinnati, Ohio

Dr. Farrell served as the keynote speaker for the session and effectively introduced the topics to be covered by the speakers. He pointed out that we are caught between the increasing amount of sludge and the increasingly stringent controls on sludge disposal. The 4 X 10^6 tons/year of sewage sludge generated in 1975 are expected to increase to 7 X 10^6 tons/year in the 1980's. Much of the sludge will be more difficult to handle as more plants are upgraded to include secondary and tertiary sludges. Also, the eastern and western cities are facing the problem of the apparent trend to phase out ocean disposal of sludge. Stricter rules on air pollution and heavy metals make sludge disposal even more difficult. Two other complicating factors are the rising costs of energy and fertilizer.

Dr. Farrell divided his presentation into two parts, sludge treatment and sludge disposal, but noted that there was frequently a hazy distinction between the two. Sludge treatment preceeds sludge disposal and generally does not impact upon the community except for odor. Therefore, processing choices are governed by cost and efficiency.

One of our primary goals today is to remove more water from the sludge. The removal of water reduces the energy required in the treatment process if sludge incineration is to be part of the sludge disposal process. Less water reduces hauling costs if sludge landfilling is the disposal method. Dr. Farrell reviewed the dewatering devices available in addition to the time honored vacuum filter. These include:

- Belt Filter Presses
  - Carter (German-Klein)
  - Tait Andritz
  - Permutit
  - Smith and Loveless
  - Envirotech
  - Unimat Tromel Filterpresse (Gevman)
- Plate and Frame Filter Press
  - Passavant
  - Nichols (British-Edwards & Jones)
  - Envirotech (Shriver)
  - Dart Industries
- Centrifuges
  - Bird
  - Dorr-Oliver
  - Rexnord
  - Ingersall-Rand (Kreuger)
  - Sharples

The EPA will publish a bulletin on sludge disposal in the Federal Rgister within the next few weeks. The bulletin covers all means of sludge disposal, but concentrates on sludge utilization. The highlights of the bulletin include: recommends the utilization of sludge but tries to establish a baseline for safe use; recommends non-agricultural use if possible; provides guidelines for agricultural use; requires pathogen reduction for sludge to be disposed on land with easy public access; establishes maximum loading rates for disposing sludge on agricultural land, because of metals. If crops are to be eaten raw, three years time must elapse between sludge application and crop harvesting. Even if crops are cooked or processed, the sludge must be free of indicator organisms.

*Summary of "Sludge Handling and Disposal" Session of the Second Annual National Conference on Environmental Engineering Research, Development and Design. Environmental Engineering Division, ASCE, held July 21, 1975, University of Florida.

The question of reducing pathogens presents problems. Methods to reduce pathogens include thermophilic anaerobic digestion, thermophilic aerobic digestion, radiation and pasteurization.

Another interesting concept was the wet oxidation process promoted by Barber Coleman, which includes a means of recovering metals from the sludge.

Incineration as a means of sludge disposal faces the problems of energy conservation and particulate matter. Our knowledge of the health effects of incinerating particulate matter must be increased to make it possible to establish effective standards. Otherwise, incineration may become less and less acceptable.

The energy problems associated with incineration have directed interest in pyrolysis systems combining sewage sludge and solid waste, such as the current study by the Bureau of Mines. Another pyrolysis system is the Purox system of Union Carbide. Kalinski has suggested an interesting concept of modifying a conventional multiple hearth incinerator to act as a pyrolysis unit.

Treatment of Sludge Processing Sidestreams

A.A. Kalinski
Camp Dresser & McKee, Inc.
Boston, Massachusetts

Dr. Kalinski pointed out that sludge processing sidestreams are frequently ignored by designers. The sidestreams are merely shown by an arrow illustrating a recycle back to the liquid treatment system without identifying the pounds per day of the constituents of the recycle flow. His awareness of the problem was intensified by being involved in the updating of the publication, *A Study of Sludge Handling and Disposal* by R.S. Buro. The updated document entitled *Handling of Municipal Sludges and Sidestreams*, soon to be published by EPA, places great emphasis on sidestream treatment.

Subsequently Dr. Kalinski was involved in a study for regional or subregional sludge processing facilities for the New York—New Jersey Metropolitan Area. No wastewater treatment plant was available for recycling and the possible treatment of the sidestreams produced. The required separate treatment of all sidestreams before discharge into any receiving water afforded an excellent opportunity to precisely identify all such treatment costs. In addition, total energy consumption was indicated. Such sidestream treatment costs can be a very high proportion of many sludge processing methods and increase the total energy requirements.

Dr. Kalinski's presentation utilized recycle streams from three sludge treatment processes to illustrate the unit costs of processing sludge solids. The following points were assumed for the presentation.

Basic Assumptions: (Quantity per Million Gallons Raw Sewage)

A. Sludge to Sludge Processing System
   1 ton dry solids

TABLE 1
Effect of Recycle Stream BOD_5

PROCESS	RECYCLE BOD_5			
	RANGE (mg/l)	AVERAGE (mg/l)	lb./ton D.S.	Inc. Aer. Req. (%)
ANAEROBIC DIGESTION	1000 to 3000	2000	100	8
HEAT TREATMENT	6000 to 10,000	8000	400	33
WET OXIDATION	—	10,000	500	40

* lb./ton D.S. - lb. BOD_5 in recycle per ton of dry solids processed.

B. Primary Effluent BOD_5 Without Recycle Streams
   1200 pounds BOD_5

C. Sludge Processing Recycle Flow
   6000 gallons

Table 1 illustrates the effect of recycled BOD_5 on sizing of the aeration tanks. It can be seen, based on the data presented, that the activated sludge aeration would be increased eight percent to account for anaerobic digester recycle liquids, 33 percent to account for heat treatment liquor, and 40 percent for wet oxidation recycle liquor. Table 2 illustrates the effect that ammonia in the recycle liquor would have on a treatment plant designed to nitrify. The study concluded that the treatment of sidestreams is a major expense and heat treatment and wet oxidation are not cost effective in the treatment of sidestreams.

Dr. Kalinski expressed concern on the effect of other sidestreams such as incinerator scrubbers or odor control scrubbers. Incinerator scrubber water contains volatilized metals such as lead and mercury in addition to particulate matter. Odor control for off gases from a Zimpro system required a wet scrubber, resulting in a 1000 mg/1 COD sidestream that was treated with activated carbon.

TABLE 2
Effect of Recycled Ammonia of Nitrification System

PROCESS	RECYCLE AMMONIA		
	AVERAGE (mg/l)	lb./ton D.S.*	lb. O_2/ton D.S.**
ANAEROBIC DIGESTION	500	25	100
HEAT TREATMENT	800	40	160
WET OXIDATION	1500	75	300

* lb. ammonia/ton dry solids processed

** 4 lbs. O_2/lb. ammonia nitrified

The following information evolved from the question and answer period.

The cost of energy in the New York area was mentioned as five cents/kWh, which was cited as a reason for emphasizing energy recovery.

The favored system included plate and frame filter press dewatering to 40 percent solids, incineration and recovery of waste heat to power portions of the process. Studies of these systems predicted a net recovery of 100 kWh per ton of dry solids processed. The heat value of the composited sludge was 5000 Btu per pound of dry solids because a portion of the sludge had previously been digested.

The study had favored pyrolysis for energy recovery as it appeared to have a lesser air pollution problem. However, Dr. Kalinski felt that pyrolysis systems were five years away from being proven for application. He foresaw incinerators being selected in place of pyrolysis for the next five years. However, he predicted that multiple hearth incinerators would be retrofitted to pyrolysis with few major changes.

Aerobic digestion had not been considered for sludge processing. A 1974 University of Texas publication "Recovery of Energy in Waste Treatment Plants" had shown a net potential energy recovery of 600 kWh per ton of dry solids processed anaerobically but a net input of 300 kWh per ton of dry solids digested aerobically. However, aerobic digestion was favored over anaerobic digestion in terms of total cost for plants less than ten mgd in size.

Energy Conservation Through Incineration

F.S. Howard
Envirotech Corporation
Belmont, California

Mr. Howard opened his presentation with a definition of sludge as provided to him by a European counterpart. "Sludge is a substance with few attractive properties, it is voluminous, it stinks, it is difficult to dewater on account of its colloidal character and it can be qualified hygenically as unreliable."

Historically, the primary concern of treatment plant designers, regulatory authorities and municipal personnel centered around the liquid portion of the plant. The solids generated in the plant were left to more or less take care of themselves through the utilization of some rather pedestrian methods, such as burial, spreading, barging and dumping. As time went on, the attention was still focused on the liquid portion with some slight improvement in the handling of solids. Sludge digestion and drying became more widely practiced, but grit, screenings and skimmings were still handled expeditiously by dumping out back or burying in landfill operations. Late in the 1930's a few plants built multiple hearth incinerators and sludge burning got off to a rather "smokey" start, burning sludge cakes vacuum filtered with the aid of chemicals and usually requiring considerable auxiliary fuel to establish combustion. Still the number of incinerators have increased and they handle more and more sludge.

Today the impact of rising energy costs and environmental concerns have caused us to review existing concepts. Incinerators can be designed to meet the most stringent air pollution standards, such as the recent design for Palo Alto, California. It can be shown that, in many cases, the air pollution resulting from truck hauling of sludge for land disposal is greater than incineration on site.

This paper was a result of practical experience and research concerning the improvement of the efficiency of sludge solids incineration. It is important to improve combustion efficiencies and reduce auxiliary fuel requirements as much as possible. To better understand an incineration system, we must deal with the basic components of combustion and how they might be altered through plant operation and/or design to reduce auxiliary fuel requirements; or to select more readily available fuels such as scum, coil, paper and low grade oils; or to make energy available for other plant functions through waste heat recovery.

The basic areas discussed were: (1) moisture; (2) volatiles; (3) excess air; (4) design and operation; and (5) waste heat.

Moisture. When incinerating sludge cake, the major fuel requirement is that needed to drive off the water in the feed cake. Each pound of water required 1400 to 1600 Btu under normal operating conditions. Autogenous burning is not too difficult if sufficient volatile solids and a high solids concentration exist. However, we still need fuel to control the furnace. As an example, for a plant in the five to ten mgd size range, operating a vacuum filter for dryness instead of yield would result in the cake solids content increasing from 20 percent to 25 percent with a resultant saving of ten gph of fuel oil.

Volatiles. The volatility of incinerator feed cake can be increased by feeding raw sludge in place of digested sludge. Also highly volatile materials such as grease, scum and tramp oil can be blended with the sewage sludge to increase the cake volatility. For a five to ten mgd treatment plant a saving of nine gph of oil could be achieved by increasing the sludge volatility from 50 percent to 75 percent.

Excess Air. Any excess air introduced to the furnace must be heated. Therefore, excess air should be reduced to a minimum, but operationally reasonable, level. While 50 percent excess is a good operational level, it is not uncommon to find 150 percent to 200 percent excess air being used at operating facilities. Reduction of the excess air from 150 percent to 75 percent was shown to reduce oil requirements by six gph.

Reduction of excess air may be achieved by a control loop, using exhaust gas oxygen levels to control the induced air fan damper. An example of successful application of this concept is the San Mateo, California Multiple hearth incinerator installation.

Combined Effect. The combined improvements of cake solids concentration increased from 20 percent to 25 percent, excess air reduced from 150 percent to 75 percent and volatility increased from 50 percent to 75 percent, resulted in a total oil saving of 25 gph.

Design and Operation. A good system design will include those features and controls necessary to all the operators to cope with feed variations and combustion requirements. Such features include providing more rabble arms and rabble arm teeth to improve contact of the sludge in the hearths with the flames; and providing a means of measuring the sludge cake input and relating it to the speed of rotation of the rabble arms.

The cost of an average sludge incinerator is approximately $2,500,000 without building. The specifications for a sludge incinerator call for startup training and assistance. This costs approximately $15,000, which is less than one percent of the cost of the furnace. A one year training program would result in better training and better operation and would cost approximately $100,000 or approximately four percent of the installed incinerator cost.

Waste Heat Recovery. Ideally, when all the foregoing factors have been optimized, the furnace will require auxiliary fuel for temperature control only. Excess heat will be available. Some designs lend themselves to including a waste heat recovery boiler generating steam for building heat or plant processes, such as a heat treatment sludge conditioning system. Such systems have been referred to as closed energy loops (CEL). These are normally continuously operating plants.

CONCLUSION

Thermal incineration continues to gain acceptance by providing convenient on-site reduction of sewage sludges to sterile ash. However, in spite of this popularity trend we must continually review present day designs in the light of present and future environmental and economic demands.

Most incinerator systems operating today were designed and built during times of low cost fuel and semi-stringent air pollution requirements. Today we have responded and in some cases over reacted to air pollution control demands. A balance can soon be reached, if we remain logical.

The fuel problem is more urgent and requires an immediate review of both our present practices and future plans. In the case of existing incinerator installation, it has been shown how minor changes in operation and design can greatly reduce fuel consumption. Further, the inclusion of facilities capable of producing drier sludge cakes results in autogenous incineration with elevated exhaust gas temperatures. The exhaust gases can then be used to develop sufficient steam for a sludge heat treatment system, building heat or other plant requirements.

Plant design incorporating these components can result in a closed energy loop system in which the sludge volatility provides most of the energy required for sludge reduction. The resultant sterile ash, incidentally, still contains virtually all chemicals of fertilizer value.

DISCUSSION

The following points were discussed in the subsequent question and answer period.

Pulverized coal works well as a supplemental fuel. Fairly poor grade coal may be used for this purpose. Selected refuse, after removal of metal and glass, may also be used as a supplemental fuel as it is high in volatile material and low in moisture. Sludge cake and selected refuse are added to the furnace at different hearth levels due to their differing burning characteristics.

Both fluidized bed and multiple hearth incinerators have their particular advantages under given conditions. Highly volatile wastes might favor selection of a fluidized bed incinerator. However, in a fluidized bed incinerator all inerts go out the furnace stack and place an additional load on the scrubber.

Multiple hearth incinerators can be converted to pyrolysis units in the manufacturing of charcoal. Such a conversion requires planning in the design stage.

Landspreading of Liquid Municipal Sludge

David L. Masse
Battelle Columbus Laboratories
Columbus, Ohio

Since the vast majority of active landspreading activities are not reported in the open literature, a literature review will not yield an accurate estimate of the proportion of United States sewage treatment plants which are routinely disposing of their liquid sludges via landspreading. Furthermore, an examination of the most recent inventory of municipal waste facilities, while providing information on sludge treatment and disposal methods, does not yield a reliable estimate of the extent to which landspreading is currently practiced in the United States.

Mr. Masse reported on the results of a study performed for the U.S. Environmental Protection Agency on the State of the Art of disposal of sewage sludge by landspreading. This report is published as EPA-670/2-75-049, *Review of Landspreading of Liquid Municipal Sewage Sludge*. An annotated bibliography is also available from the National Technical Information Service.

The paper presents the results of a mail and telephone survey of the more than 1900 sewage treatment plants of five Federal regions of the United States which are greater than one mgd in treatment capacity. Field visits to 26 plants were carried out to obtain pertinent unreported data. The five Federal regions were: Region 2 New York and New Jersey; Region 3 Pennsylvania, Maryland, Delaware, Virginia, and West Virginia; Region 4 - Kentucky, Tennessee, North Carolina, South

Carolina, Mississippi, Alabama, Georgia and Florida; Region 5 Minnesota, Wisconsin, Michigan, Ohio, Indiana, and Illinois; and Region 9 California, Nevada, and Arizona.

These regions were selected on the basis of the total population involved and on the fact that they represent the range of climate, topography, and soil conditions to be encountered throughout the United States.

The sewage treatment plants surveyed were catagorized by Federal region and plant size as shown in Tables 3 and 4.

TABLE 3
Treatment Plant Size Distribution

Plant Size, mgd	Region 2	3	4	5	6	Total
1-10	247	270	466	444	211	1,638
10-100	38	26	40	82	51	237
100	12	6	3	9	4	34
Total	297	302	509	535	266	1,909

TABLE 4
Estimated Number of Plants Using Landspreading

Plant Size, mgd	Region 2	3	4	5	6	Total
1-10	8	77	92	160	33	370
10-100		6	4	14	4	27
100		3		1		4
Total	8	86	96	174	37	401

Of this number 400 or 20 percent are estimated to be using landspreading, with landspreading most popular in Zone 5 and least popular in Zone 2. Most of the plants using landspreading were in the one to ten mgd size range, but most of all the plants are in this size range.

While the majority of the plants have practiced landspreading for less than ten years, several plants have used it for sludge disposal for 30 to 40 years. Landspreading is typically utilized in a secondary wastewater treatment system which digests sludge anaerobically. Sludge is hauled for disposal on agricultural land by means of tank trucks driven by plant personnel with a haul distance of less than ten miles. Other types of land used for disposal included parks, airports, gold courses, strip mines, landfills, cemetaries, and orchards.

Visits to 26 selected plants were carried out to collect further data (see Table 5).

Costs of operating land disposal systems are difficult to obtain due to the cost control systems of the average plant. However, Table 6 provides information derived from the study. It was observed that labor costs were 65 percent to 70 percent of the overall cost.

There is presently little or no monitoring of the effect of the sludges on the land. Springfield, Illinois was one of the few places to monitor for metals. The city returns the spreading area underdrainage to the plant, but there is little planning with respect to a loading rate. A cycling of land disposal is caused by weather conditions.

TABLE 5
Field Visits

State	Region	1-10	10-100
California	9	3	2
Florida	4	3	1
Illinois	5		1
Minnesota	5	5	
Ohio	5	3	3
Wisconsin	5	4	1
Total		18	8

DISCUSSION

The following points resulted from the question and answer period.

Public acceptance of sludge landspreading is probably better in smaller centers but has met strong opposition in Chicago and Philadelphia.

Direct ploughing of sludge into the land has not met with much favor due to the higher cost of equipment and labor. Boulder, Colorado practices this method of disposal.

The wastewater operations at the Penn State University Wastewater Treatment Plant cannot meet the demand for their metal-free aerobically digested liquid sludge. The presence of metals in the sludge makes disposal more of a problem. Better control of metals in the sewers is required, but control may be difficult in combined sewer systems if storm runoff contains metals.

TABLE 6
Land Disposal Costs (1972 Dollars)

Unit	Range	Average
$/100 gallons	1.22 to 15.00	3.90
$/Dry Ton	2.33 to 61.02	20.40

Treatment of Sludge for Land Disposal

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In 1972, the District of Columbia entered into a massive construction effort at the 300 mgd Blue Plains Wastewater Treatment Plant in order to meet new effluent standards for discharge into the Potomac River. This construction effort eliminated the existing sludge drying facilities and resulted in a huge sludge disposal problem pending completion of proposed sludge incinerators. In order to comply with discharge standards during the construction or interim period, the addition of metal salts to one-half of the secondary treatment units was used to reduce the discharged BOD_5 to less than the required 100,000 pounds or 40 mg/1 BOD_5. One result of this upgrading of the effluent quality was the daily production of 240 tons per day of raw (chemically precipi-

tated) sludge for which no method of disposal was immediately available.

The Blue Plains plant is a regional facility, receiving approximately 50 percent of its overflow from two adjacent Maryland counties. The State of Maryland accepted responsibility for disposal of raw sludge during the period of construction of the incinerators. This task was assigned to the Maryland Environmental Service, which is a publically-owned, nonprofit corporation created by the Maryland Legislature in 1971. With legislated powers in the field of water supply, wastewater treatment and solid waste treatment, MES is able to contract for service with both public and private customers. The Service has no regulatory powers and concentrates on providing needed services.

In the development of methods to handle sludge, the ideals of resource recovery and energy conservation were emphasized. Early involvement with the Agricultural Research Service of the United States Department of Agriculture provided the research science facilities necessary to evaluate different methods of land disposal.

The first efforts in land disposal were a series of experiments on land trenching of raw sludge conducted at the USDA Beltsville Maryland Experimental Station in early 1972. This served as a large-scale test to develop all-weather procedures for hauling and incorporating sewage sludge in the soil by trenching. This work was more fully described in the paper by Walker in the 1974 *Proceedings of the National Conference on Municipal Sludge Management.*

Composting was studied as another sludge disposal method. Construction of a sludge composting facility began in the fall of 1972 and continued until June of 1973. Since March, 1973, sludge has been composted on a regular basis at Beltsville. The compost site consists of a five-acre, crushed stone composting pad, material storage areas and office complex, with control of runoff and monitoring of groundwater. The initial method used was open windrow composting. The sludge is transported from Blue Plains by truck. Initially, the trucks were concrete mixers; later, watertight dump trucks were used. The sludge is mixed with wood chips to bring the moisture content down and to provide air voids.

Composting, which is the aerobic decomposition of organic matter, results in the production of heat in the piles. Temperatures in the mixture average between 120° to 140°F during the two weeks the chip sludge mixture is in the windrow. After windrowing, the chip sludge mixture is stockpiled. Temperatures in the stockpile reach 150° to 160°F and pathogens are substantially eliminated. The mixture of chips and sludge is then screened. Salvaged chips are returned to the process and the compost is ready for distribution. This work is more fully described in the paper by Epstein and Willson in the 1974 *Proceedings of the National Conference of Municipal Sludge Management.*

Experimental work is now being done on fixed bed composting of raw sludge. Fixed bed composting seems to have several advantages: higher process temperatures are achieved, the energy requirement is less than the open windrow method and there is better odor control possibility. This experimental work is now being done under a U.S. Environmental Protection Agency research grant.

In January 1975, raw sludge entrenchment site operations were started in the Maryland counties adjacent to the District of Columbia. Raw sludge, lime stabilized to pH 11.5 to 12.0 at 20 percent solids concentration, is transported in sealed container trucks and the sludge is pumped into the trenches. Every site has monitoring of surface and groundwater as well as erosion control features.

In 1974, the Service entered into a contract with Organic Recycling, Inc. for the dehydration of raw sludge and processing into a commercially acceptable fertilizer. This operation is still in the shakedown phase. Many problems with the materials handling and air pollution control equipment have held back full steady flow operation. However, redesign and persistence in this effort show that it still holds great promise.

The Blue Plains Wastewater Treatment Plant sludge disposal problem has offered a challenging opportunity to attempt large scale sludge disposal solutions other than incineration in a densely populated east coast location.

Alternate methods of sludge disposal hold promise and are consistent with resource recovery and energy conservation. The waste engineering profession is being called upon to evaluate all methods of sludge disposal and weight the merits of each. The work in Maryland has accumulated much background on several methods of sludge disposal.

THE PAST, PRESENT, AND FUTURE PROSPECTS OF BURNING MUNICIPAL SEWAGE SLUDGE ALONG WITH MIXED MUNICIPAL REFUSE

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INTRODUCTION

The incineration of municipal sewage sludge (MSS) in combination with mixed municipal refuse (MMR) has long been a desirable objective of municipal plant design to minimize the capital investment required for the thermal processing of these two waste materials. MSS is usually incombustible, even after extensive dewatering, since there is insufficient heating value available in the dry solids to evaporate the associated moisture. MMR, on the other hand, is generally autogenous, producing an excess of heat over that required to evaporate the moisture present in the refuse. By combining the thermal processing of both materials, it may be possible to utilize the excess heat available in refuse to dry and incinerate the MSS and, thus, eliminate the use of fossil fuels that are typically used in sludge incinerators to achieve thermal processing of the sludge. Burning MSS along with MMR will henceforth be referred to as co-incineration.

A number of co-incineration approaches have been tried in the past, some are being tried now, and others are planned for the immediate future. Under contract* to the United States Environmental Protection Agency, Roy F. Weston, Inc. was asked to provide a comprehensive evaluation of co-incineration. One phase of the project was to assess demonstrated and experimental co-incineration techniques. This report is based upon that State-of-the-Art assessment.

BACKGROUND

Conventional MMR incinerators (Figure 1) simply burn the refuse, producing a relatively inert residue with less weight and bulk than the original refuse. Furnace exit gas temperatures are controlled to less than 1800°F (982°C) by adding excess air to the furnace to prevent slagging on the refractory walls. When MMR incineration is desired, or necessary, to reduce the bulk and weight of the refuse prior to ultimate disposal, the entire cost of thermal processing and ultimate disposal of the incinerator residue is borne by the user, who is charged a tipping fee. That fee can be expressed in a number of ways, but basically, although not always, should take care of the cost of handling from that point on. Thus, the fee charged as the refuse is received should cover all the costs of incineration plus ultimate disposal of the residue.

When we add a steam-generating boiler to an MMR incinerator, we can decrease the amount of excess air required and use a smaller dust collector and induced-draft fan, and most importantly, generate additional revenues by selling the steam. The costs of the operation, less the steam revenues, can now be equated to a new tipping fee, which can be, but is not always, less than if steam revenues were not available. Steam revenues are highly dependent upon the presence of a nearby consumer willing to buy low-pressure steam on an interruptable basis.

Conventional MSS incinerators are principally of the multiple-hearth (Figure 2), or fluid-bed (Figure 3) type, or may be flash-dryer systems. Each of these sludge incinerators requires the use of an auxiliary fuel. Natural gas or light oil is preferred for multiple-hearth furnaces (MHF's). The fluid-bed furnaces (FBF's) can use almost any fossil fuel, but again, natural gas and light oils are preferred. Flash-dryer systems can be designed to use any fossil fuel.

If we marry refuse and sludge incineration, we have the potential to save a large amount of costly fossil fuel. One estimate of the quantity of fuel required in sludge incineration is based upon current practice in seven cities[1]. On the basis of this survey, it was estimated that 50 gallons (189 liters) of No. 2 oil was required to burn every ton (907 kg) of dry sludge solids.

If MMR can be used in place of the fossil fuel normally required for MSS incinerators, we would have a beneficial use for the refuse heat equal in value to the cost of the fossil fuel replaced. Since refuse is a waste material of which we have a great deal, and fossil fuel is in increasingly scarce supply, this is indeed a beneficial use.

*The work upon which this publication is based was performed pursuant to Contract No. 68-03-0475 with the Environmental Protection Agency.

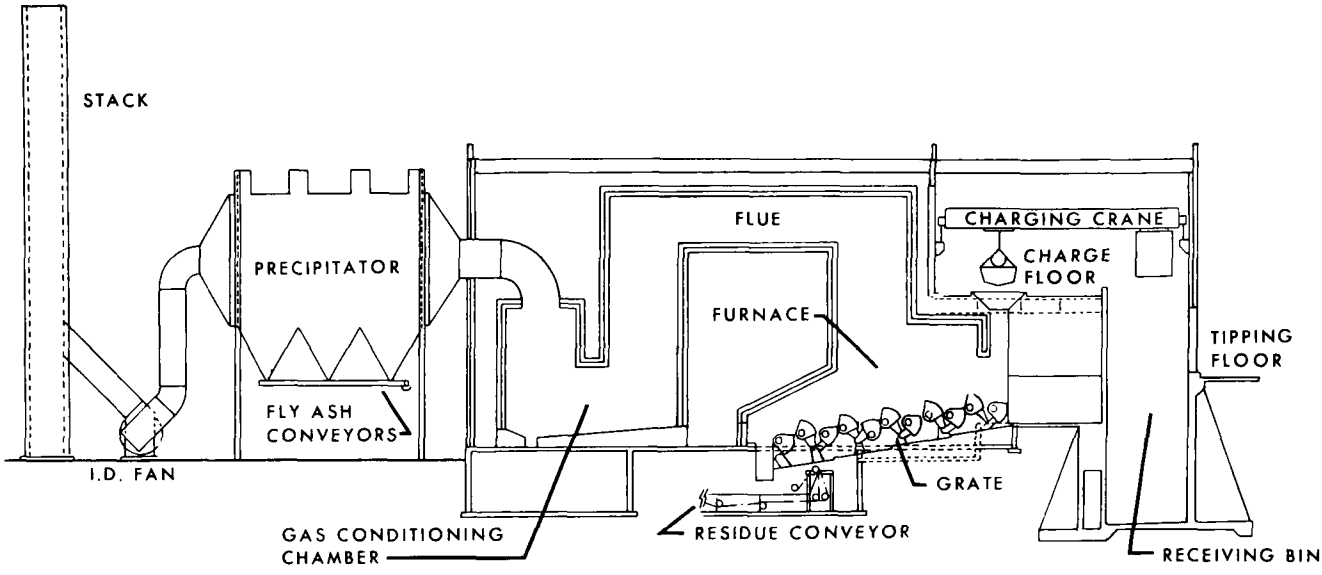

Figure 1: Continuous Feed Incinerator.

What quantities of refuse and sludge are we talking about? Our company estimated that the domestic refuse generation, based upon a major metropolitan area, would be 2.74 lbs/capita/day (1.24 kg/c/d) in 1980. To this, we can add one lb/capita/day (0.45 kg/c/d) of sludge at 20 percent solids (0.20 lbs. or 0.09 kg/c/d) for a total of 3.74 lbs/capita/day (1.7 kg/c/d) consisting of 41 percent combustible, 17 percent inert, and 42 percent water.

With 203 million people in the United States of America (1970 census), this amounts to 380,000 tons/day (345,000 tonnes/d) of which 100,000 (91,000) is MSS.

But, there is more. The 2.74 lbs. of refuse/capita/day (1.24 kg/c/d) represents only domestic refuse: if we add commercial, institutional, and industrial wastes, we could have nearly three times the domestic production, or 1,000,000 tons/day (900,000 tonnes/d) of refuse to dispose of. The sludge quantity of one lb/capita/day of MSS at 20 percent solids is based upon primary plus secondary treatment of domestic wastewater. Inclusion of industrial wastewaters will generate additional quantities of primary and secondary sludges, and when we add tertiary or physical treatment, we will have still more sludge.

But, enough of this—we all recognize that we do have a waste disposal problem in the United States.

Is co-incineration the most beneficial use of refuse? Is it better than resource recovery or steam generation? Frankly, we don't know—it is an alternative disposal method, and therefore, should be included in any shopping list of waste disposal options, possibly in combination with resource recovery or steam generation. Now, let's see where we have been, where we are, and where we might go.

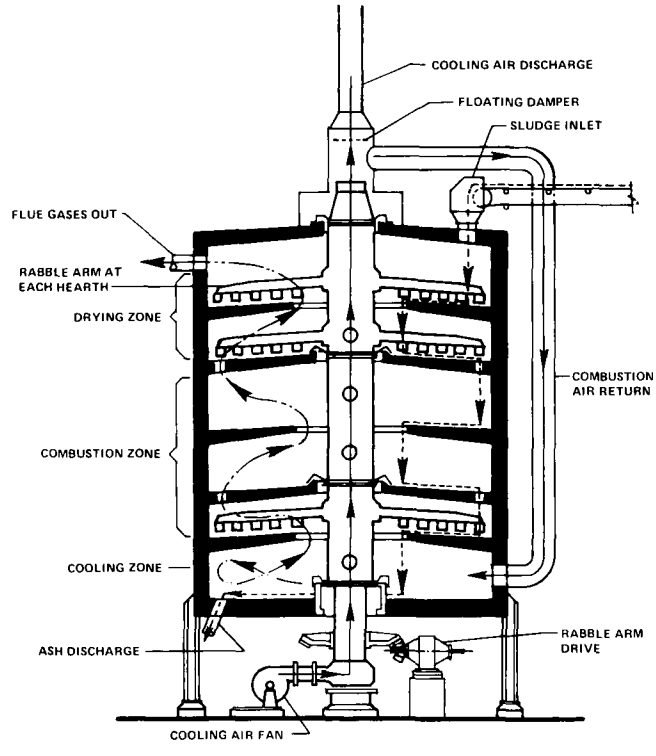

Figure 2: Multiple Hearth Sludge Incinerator.

The Past

Burd[2] prepared a study of sludge handling and disposal for the Federal Water Pollution Control Administration, which was published in May, 1968. In it, he identified a number of installations where sludge and refuse were, or had been, burned together. These incinerator sites were as follows:

Whitemarsh Township, Pennsylvania*
Frederick, Maryland*
Waterbury, Connecticut*
Neenah-Menasha, Wisconsin*
Kewaskum, Wisconsin*
Holyoke, Massachusetts
Chicago, Illinois*
Hershey, Pennsylvania*

Burd also reported that, "A large chemical company has successfully incinerated a thickened waste activated sludge (2.2 percent to 2.6 percent in a boiler furnace along with conventional fuels. However, inorganic deposits accumulated on the boiler tubes and eventually forced suspension of this disposal technique."

Balakrishnan, et. al.[3] in April of 1970 commented on the disposal of refuse with sewage sludge and added the following sites where co-incineration was reportedly being practiced:

Watervliet, New York*
Stamford, Connecticut*
Fond du Lac, Wisconsin*
Bloomsburg, Pennsylvania*
Louisville, Kentucky*

Eberhardt,[4] in May of 1966, had commented on European practice in refuse and sewage sludge disposal by incineration. He comments, "For burning sludge, the highest attainable degree of drying is of great importance. In view of the cost, water evaporation by means of auxiliary fuel should, if possible, be avoided in Europe." After describing a series of strictly sludge incinerators, he states that, "The most economical solution for the disposal of all waste products of a housing area is the combustion of sludge together with refuse by using the heat which is released by the combustion for the sludge drying." He then refers to a figure showing the design of a sludge-drying and refuse-incineration plant, where the dry material is sold as compost for fertilizer, with the remainder being burned. The design shown is very similar to what is known in the United States as a flash-drying system, although the design shown in Eberhardt's paper is not attributable to the prime U.S. manufacturer of this system. In this configuration, the dried sludge solids are fed to the furnace immediately above the refuse feed chute, and apparently by gravity. It is unclear whether this co-incineration plant was simply conceptual or was actually in operation; in any event, it is the only specific reference to a co-incineration plant design in Eberhardt's paper.

Fife,[5] in a paper dated January 29, 1968, comments on combined refuse and sludge incineration, listing a number of United States installations previously listed here, and adding an installation in Essen, Germany, where 2,000 tons per day of filter press sewage sludge solids are handled by a flash-drying system available from the German branch of the Babcock and Wilcox Company. He further refers to the Eastman-Kodak installation, where

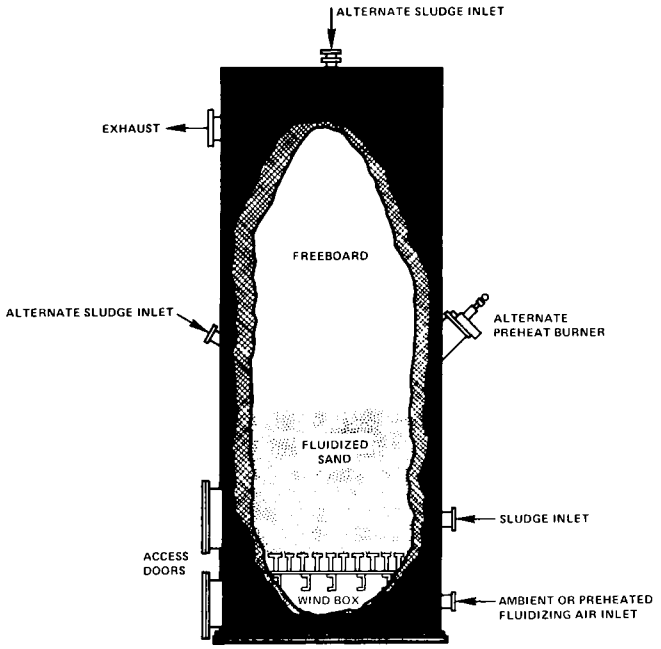

Figure 3: Fluid Bed Sludge Incinerator.

shredded refuse and flash-dried sludge are burned in a suspension-fired boiler (which was at that time proposed) and to another installation, reportedly in the study stage, for the City of Portland, Maine, where again a flash-dryer system was proposed to dry the sludge prior to burning the dried solids in a refuse incinerator.

In February of 1974, we were also aware of the following sites where co-incineration had been tried, proposed, or was in use:

Franklin, Ohio
Ansonia, Connecticut
New Albany, Indiana*
Harrisburg, Pennsylvania

We don't have the complete history of any of these 17 co-incineration installations, but we do have enough information to indicate that co-incineration has been something less than a roaring success. Thirteen out of the 17 listed installations have been shut down; no longer burn sludge, or never did burn sludge along with refuse.

Sludge was burned at the Whitemarsh Township incinerator,[6] but reportedly,[7] the practice of co-incineration was discontinued at this site long before other problems forced the original incinerator to be shut down. As far as we know, once the incinerator was rebuilt, there was no further attempt to burn sludge. The MMR incinerator was located at the site of a sewage treatment plant (STP), and reportedly, the vacuum-filtered raw sludge was mixed with the refuse prior to charging this

*Identifies an installation that has been shut down, that no longer burns sludge, or that never did burn sludge along with refuse.

continuous feed incinerator. This procedure is so simple that it has probably been tried many times, and rarely reported.

Neenah-Menasha[8] was scheduled to be shut down[9] at the beginning of this year, but not because co-incineration didn't work; it did. The incinerator shut-down was reportedly forced by the need to meet new and more stringent air pollution regulations, and it was decided that it was too expensive to retrofit this old incinerator (vintage 1958). The system at Neenah-Menasha used a Raymond flash-dryer to dry vacuum-filtered MSS. The Combustion Engineering/Raymond flash-drying system dried the MSS from 70 percent moisture to 15-20 percent moisture. The dried sludge was then separated in a cyclone and conveyed to the furnace by a belt conveyor and apparently added to the refuse at the furnace feed hopper. The plant consisted of two traveling grate-type furnaces designed for a capacity of 150 tons per day. The feed to the furnaces is reported to have been 30 TPD of garbage, 84 TPD of rubbish, and 35 TPD of dried sludge. The spent-dryer gases from the flash-drying system were discharged to the breeching before the stack, and the hot gases were apparently drawn from the residue end of the furnace.

Hershey, Pennsylvania used a Carver-Greenfield (C-G) multiple-effect evaporator system to dry the sludge before burning in a conventional steam generating boiler. The C-G system, which was in use from 1963 to 1972, is no longer in use [10], since extensive repairs are required and the present sewage treatment plant will be replaced by a regional authority plant. In the C-G drying system, oil is added to the sludge to facilitate handling through the triple-effect evaporator. Excess oil is then separated in a centrifuge for reuse, and the oily sludge solids are burned. The oil remaining in the solids resulted in a significant increase in the heating value of the sludge.

The Waterbury, Connecticut installation [11] consists of two 150 TPD batch-fed circular-type MMR incinerators equipped with a Raymond flash-drying system. The very fibrous sludge was vacuum-filter dewatered, dried, and charged to the incinerator along with raw MMR. The original STP was a primary plant, and when secondary treatment was added, multiple-hearth furnaces were installed and the sludge is now being burned in these MHF's. The original furnaces are in use, and the drying system is still in existence and could be used if necessary.

The Holyoke incinerator [12] was started in 1965 and is still operating. Here, vacuum-filter dewatered sludge is dried in a rotary dryer and the dried sludge injected into the incinerator by a high-velocity air jet. Much of the sludge solids burn in suspension above the burning refuse. The Holyoke installation is a good point at which to depart from the past and enter the present, since a similar installation has recently been constructed in Stamford, Connecticut [13], and another rotary-kiln dryer is in use in Luleå, Sweden [14].

The Present

A flow sheet for the Holyoke installation is shown in Figure 4; note that there is a pug-mill that blends recycled dried sludge with the cake from the vacuum filters before feeding it to the rotary dryer. Dry sludge recycle reduces the average moisture content of the dryer feed, thereby eliminating the build-up of deposits on the dryer walls. Note also that there is provision for auxiliary firing at the feed end of the rotary dryer. At Holyoke, the furnaces are batch-fed, and the flue gases experience periodic temperature excursions. Fuel oil is normally used at this plant to control the temperature of the gases entering the rotary dryer and to provide additional heat input, since all of the sludge is dried and co-incinerated during only 60 percent of incinerator operating cycle. At one time, the Holyoke incinerator handled a high tonnage of paper waste from nearby mills, at which time no auxiliary fuel was required. When pollution control regulations required a reduction of coated paper waste, it became necessary to fire auxiliary fuel, thus indicating the need for careful planning of refuse and sludge ratios when designing a co-incineration facility. As refuse is a notoriously variable fuel, it is perhaps advisable to consider an auxiliary fuel-use in many cases of co-incineration, even if the furnace is a continuous-feed unit. The Stamford [13] installation was started up early in 1975 and is very similar to the Holyoke installation.

At Luleå [14], in Sweden, there are two 360 TPD refuse incinerators, each equipped with a rotary dryer-incinerator. Waste oils are fired into the rotary drum with the exhaust gases passing into the refuse furnace flue upstream of a wet dust collector. At Luleå, the sludge is either dried or incinerated in the rotary drum. Therefore, the dried sludge is never burned in the MMR incinerator, as is the practice at Holyoke and Stamford.

At the Eastman-Kodak Company in Rochester, New York, dewatered sludge from the waste treatment plant is being hauled to a steam-generating incinerator that is suspension-fired with shredded refuse. The sludge is dried in a Raymond flash-drying system, and the dried sludge burned in suspension along with the shredded refuse.

Another flash-drying system was installed in Newburgh, New York [15], but is not now in use. The operators report [16] that they attempted to put the system into operation for approximately one year, but finally gave up. They report that starting with vacuum-filtered sludge and an initial temperature of 1700°F (927°C) the furnace temperature would drop drastically during operation of the flash-drying system. They were never able to maintain proper furnace temperatures and finally abandoned use of the system. Unusually high quantities of excess air, due to leaks in the furnace, resulted in excess heat loss; this probably is the cause of poor dryer performance. In earlier co-incineration attempts at Newburgh, sludge filter cake was charged to the incinerator feed hopper without pre-drying. The sludge cakes

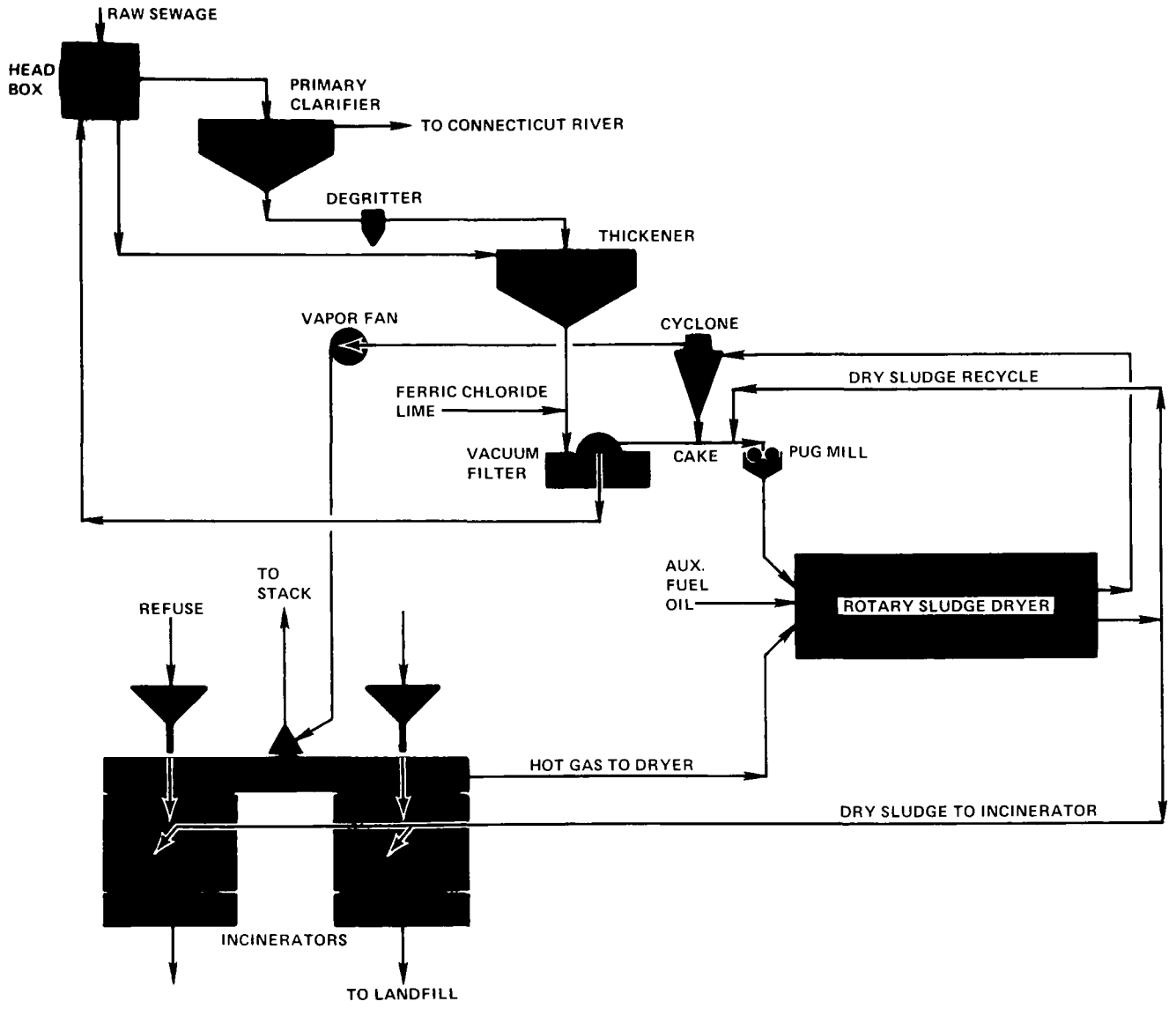

Figure 4: Holyoke, Massachusetts—Water Treatment and Incinerator Flow Sheet.

dropped through the grate without burning. This approach was abandoned in favor of the flash-drying system.

Another co-incineration installation is at Ansonia, Connecticut [17]. Here, a spray dryer is used to dry thickened sludge. The dried sludge can be pneumatically conveyed to the incinerator, where it is arranged to burn in suspension above the second grate; however, Ansonia generally does not burn the sludge, as local residents and the State Highway Department take most of the dried sludge for use as a fertilizer. While the spray dryer was designed to dry all the sludge generated by primary and secondary wastewater treatment, difficulties in obtaining sufficiently high dryer inlet temperatures restrict the unit to handling only about half of the sludge generated by the plant. Modifications have been made in the incinerator with the objective of increasing inlet temperature and dryer capacity.

There are a number of steam-generating incinerators in this country and abroad. Here, the appropriate means of drying the sludge prior to burning it is to use an indirect contact dryer of some kind using the steam or some other heat-transfer fluid as the heating medium.

There are no installations in the United States incorporating indirect contact dryers, although one is proposed for the Harrisburg, Pennsylvania [18] incinerator. In Europe, there is an installation in Dieppe, France [19] where thickened sludge at four percent solids is ground and then pumped to a scraped-surface, thin-film dryer where 180°C (356°F) steam at a pressure of ten kg/cm^2 (142 psig) heats the jacketed walls of the vertical vessel. The sludge is introduced at the top of the evaporator, and discharges from the bottom at a solids content of 52 to 55 percent. A conveyor belt then delivers the dried sludge to the MMR incinerator feed hopper.

But, do we have to dry the sludge before burning? Why not simply spray thickened sludge into the furnace? At Altrincham, England [20], just such a procedure was incorporated into the design of the plant. The plant was

designed to dispose of 160,000 kg (176 tons) of crude domestic refuse per day by direct incineration through a twin-stream system, each of the two independent incinerators being rated at 4,500 kg (five tons) per hour, giving a total plant capacity of 9,000 kg (ten tons) per hour. In addition to crude domestic refuse, the plant will burn limited amounts of industrial and trade refuse and approximately 109,000 liters (29,000 gallons) per day of raw primary and humus sewage sludge at 95 percent moisture content. The sludge was injected into the rear of the furnace over the burn-out portion of the grate, and the original sludge injection nozzle diameter was about 3/8ths of an inch. Later, it was determined that the minimum size that was practical to prevent blockage or plugging of the injection point was about three inches. At the rate of sludge injection with a three inch nozzle, however, there was insufficient heat generated within the furnace to evaporate the moisture that would be introduced; thus, sludge burning has been abandoned at this site, and co-incineration is no longer practiced.

Another attempt to inject thickened sludge directly into a refuse incinerator has been reported at Havant, England [21]. Special attention was given to the atomization of the sludge, and a dual-fluid spray nozzle is planned at this site. Tests were run with the spray nozzle using sludge at 3.5 percent solids, but in the final design, the spray nozzles will have to handle digested, thickened sludge at approximately seven to eight percent solids. This installation is expected to be in use in the latter part of this year.

Direct injection of thickened sludge to the furnace at Altrincham has been abandoned, and the Havant installation is yet to start up; but we still have the possibility of adding thickened or dewatered sludge to the refuse-fed MMR incinerator. We previously discussed the Whitemarsh Township incinerator and noted that the attempt at this plant had been abandoned. The question was "Why?", and we did not have an answer. One possible answer has been reported in the European literature by Lancoud [22]. Filter-pressed sludge containing 40 percent moisture was burned in a 200 TPD, continuous-feed, grate-fired, steam-generating incinerator. The grate was equipped with oscillating knives to improve combustion, and the incinerator manufacturer estimated that the feed could contain up to 20 percent pre-treated sludge cakes, without affecting combustion. It was reported that there appeared to be an excessive amount of combustibles remaining in the residue; consequently, a series of tests were run and it was finally concluded by Lancoud that the sludge was not satisfactorily destroyed by incineration due to the following:

1. Larger pieces of sludge cake move faster than refuse through the furnace, thus burning time is reduced.
2. A crust formed on the sludge cake, hindering complete combustion.
3. Poor mixing permitted sludge cakes to separate from the refuse, with poor air contact and resulting poor combustion.

The author suggested that the sludge cake be reduced in size to two cm (0.79 inches) or less, that more mechanical action be employed in the incinerator to break up crusted cakes, and that there be improved mixing of the sludge cakes and refuse.

Wet, damp materials such as watermelon rinds and halves of grapefruit do have a tendency to go through conventional incinerators without being burned. Sludge cakes would appear to fall into this same category, and this may well be the reason why previous attempts at simply adding dewatered sludge to the refuse bed have failed and been abandoned.

We have been talking about refuse incinerators that are modified to burn sludge along with the refuse. How about modifying a sludge incinerator to burn refuse? At Franklin, Ohio [23], there is a FBF that is burning the residue left over after resource recovery from municipal refuse shredded under water. At Franklin, material left over after the recovery operation is combined with thickened sludge and dewatered in a cone press, with the cake pneumatically conveyed to the freeboard of a fluid-bed furnace. This is a rather special unit, incorporating as it does a proprietary system for resource recovery ahead of the furnace.

There is, in Thunder Bay, Canada [24], a fluid-bed furnace that is burning wood wastes and sludge from a pulp and paper plant. Experimentally, municipal refuse has been burned in this furnace, and the manufacturer has announced sale of an FBF to handle MMR.

Some experiments were also run in Lausanne, Switzerland [25], where a variety of solid waste materials were fed by gravity into a fluid-bed sludge incinerator. Reportedly, there were no problems, but the materials fed were largely fine to begin with and all totally combustible.

In Europe and the United Kingdom, there are a number of multiple-hearth furnaces burning refuse and sludge, and at least one has been proposed in the United States. There are three installations in Switzerland, at Dübendorf [26], Bülach [27], and Uzwil [28]. In the United Kingdom, there is a MHF at Reigate [29] and another at Bowhouse [30] that are similar to the Bülach unit in Switzerland. The Bülach unit introduces sludge at the top hearth and shredded refuse at a mid-hearth area. This installation was reportedly plagued with odor problems and has been shut down. The manufacturer has stated that it no longer intends to offer this furnace arrangement for co-incineration. In the Dübendorf and Uzwil installations, the sludge and shredded-cleansed refuse are introduced to the top hearth of the furnace as is conventional practice with domestic sludge incinerators. The Uzwil installation is considered by some Swiss authorities as a model installation. The MHF as installed at Uzwil incorporated twelve hearths, but the two top

hearths have been removed, and the refuse is now deposited on the original third hearth, which is now the top hearth of the furnace.

In our country, an MHF co-incinerator has been proposed for Central Contra Costa County, California [31]. Tests were performed in November of 1974 at Envirotech Corporation's Brisbane, California test facility feeding MMR and MSS together to the top hearth. Later, sludge was fed to the top hearth and shredded refuse to the third hearth of this six hearth test furnace. The furnace was operated under reducing conditions, thus producing a pyrolytic gas that was burned in an afterburner to raise the off-gas temperature from approximately 800 to 1400°F (467-760°C) to assure complete oxidation of combustible materials in the off-gas.

There are also a number of proprietary incinerator designs under development. Among these are Union Carbide's Purox system [32], Carborundum's Torrax system [33], Monsanto's Landgard rotary-kiln system [34], and a Danish installation in Kalundborg [35]. All these units have apparently been tested at one time or another with MSS added to the MMR. The Torrax system is presently commercially available; none have been sold in the United States, but one is under construction in Luxembourg, and another has been sold in France. Union Carbide has not yet decided to offer its Purox system on a commercial basis. A 1,000 TPD Monsanto Landgard system is undergoing start-up in the City of Baltimore.

The Future

The future of co-incineration is still uncertain, since the final answers on so many attempts are not yet completely documented. Complete answers on those that have been shut down are not available, and there are competitive disposal methods that compete with the concept of co-incineration.

As long as land is available, landfills are less expensive than incineration, even after you add in the cost of linings and leachate collection and treatment systems.

Resource recovery is another disposal method that competes with incineration or co-incineration, but note that resource recovery can precede or follow thermal processing. The success or failure of resource recovery may well depend on the market for the recovered constituents. Paper is one main constituent of MMR that is highly desirable in an incinerator operation, since it is very combustible. The secondary market for paperstock is highly volatile—high prices can make resource recovery attractive. However, we have recently experienced the bottom dropping out of the secondary paper market which of course adversely affects any plans for resource recovery. The prices paid for materials in the secondary markets have always fluctuated widely, and will probably continue to fluctuate in the future.

One future co-incineration option is conventional incineration with or without heat recovery, because these units can handle raw MMR. There is no pre-processing of the refuse, except for segregation of bulky items. Conventional incineration is, therefore, an acceptable processing step to reduce the weight and bulk of MMR prior to ultimate disposal, and adding MSS burning provides a beneficial use of the excess heat that is normally available in MMR.

Table 1 summarizes the effect of burning sludge in a conventional refractory-wall MMR incinerator. The moisture present in MSS depresses furnace temperatures, but by cutting back on excess air, the furnace gas temperatures can be held within the desirable range of 1,400-1,800°F (760°C-982°C), except for thickened sludge feed. If we try to burn thickened sludge, we cannot maintain adequate furnace temperatures, even with zero excess air (theoretical combustion air requirements), and still handle the MMR and MSS generated in a given region. Therefore, it is necessary to dewater the sludge mechanically to about 20 percent solids, followed by drying, before the sludge solids are fed to the MMR incinerator. More intensive dewatering (i.e., pressure filtration) is not warranted, since there is sufficient heat available to dry and burn vacuum-filtered or centrifuged primary and secondary sludges.

Sludge drying is an indicated processing step because we can conveniently add a dryer circuit to the MMR incinerator, and past experience indicates that sludge drying is necessary. All known past attempts to directly add dewatered sludge to the MMR fed to the furnace have failed—probably for reasons similar to those cited by Lancoud [22].

Please note that the furnace temperatures reported in Table 1 presume introduction of the dryer gases into the MMR furnace to insure thermal destruction of any odorous compounds that might be liberated in drying the MSS.

Another future co-incineration option is the use of conventional sludge incinerators modified jto handle shredded and cleansed MMR. The refuse would, in large part, replace fossil fuel requirements except for startup and as a means of maintaining ignition of the feed mixture. Furnace off-gas temperatures would be similar to those shown in Table 1.

A third future co-incineration option involves experimental furnaces. Most of the proprietary incinerator designs that are sometimes called "advanced technology" are in various stages of development for the burning of refuse. The outcome of these tests and prototype installations will have to be watched closely, as many of these proprietary incinerators can be operated at highly efficient combustion conditions, making large quantities of heat available for sludge drying. The next step for these manufacturers should be an investigation of co-incineration in full-scale equipment and for extended periods of time.

TABLE 1
Furnace Exhaust Gas Temperatures
(Desired Temperature Range: 1,400-1,800°F (760°C-982°C)

	MMR		MMR and MSS	
Sludge Solids - % by weight	--	45	20	4
Excess Air - %				
Zero	3,054 °F (1,679 °C)	2,898 °F (1,592 °C)	2,519 °F (1,382 °C)	1,010 °F (543 °C)
100	2,039 °F (1,115 °C)	1,951 °F (1,066 °C)	1,745 °F (952 °C)	777 °F (414 °C)
200	1,547 °F (841 °C)	1,485 °F (807 °C)	1,345 °F (729 °C)	635 °F (335 °C)
300	1,252 °F (678 °C)	1,204 °F (651 °C)	1,099 °F (593 °C)	540 °F (282 °C)
400	1,055 °F (568 °C	1,015 °F (546 °C)	931 °F (500 °C)	472 °F (245 °C)

Base: 2.74 lbs./c/d (1.24 kg/c/d) raw MMR
0.20 lbs./c/d (0.09 kg/c/d) dry solids MSS

What is required for co-incineration? Certainly, adequate planning and design will be necessary to insure that sludge and refuse quantities are compatible in the process chosen, and that they will remain so during the life of the facility. Wide-area planning, for both refuse and wastewater collection and processing, will be required to insure the optimum design of a co-incineration system. And, improved communication and cooperation between those responsible for sludge disposal and refuse disposal will certainly be required if co-incineration is to be successfully practiced.

Which system will prevail? We don't know. However, there is enough work under way, enough installations in existence, that co-incineration should be included as a disposal option in any planning for solid waste and sludge disposal. The chief beneficiary would be all of us, since MMR can be substituted for scarce and increasingly expensive fossil fuels.

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HIGH ENERGY RADIATION IN SLUDGE TREATMENT—STATUS AND PROSPECTS

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INTRODUCTION

The fact that high energy radiation has an adverse effect on living organisms has been known since the early days following the discovery of X-rays and radioactive materials. This effect has been put to constructive use in recent years and is used to pasteurize and sterilize foods [1], bandages, and equipment used in medical procedures. The sources of high energy radiation utilized have been beta rays (high energy electrons) and gamma rays (high energy photons, emitted from the atomic nucleus). The high energy electrons used in sterilization are generated by electron accelerators. Beam energies generated are kept below ten MeV (million electron volts) to eliminate all danger of induced radioactivity in the object being irradiated. As Figure 1 shows, depth of penetration is low, and is inversely proportional to the density of the material. This is a basic limitation of the method, although it is offset by low cost of the electron accelerators and the high quantity of radiation they can focus on a small area.

The gamma rays used in sterilization are generated by radioisotopes. Generally, ^{60}cobalt and ^{137}cesium are used. Gamma rays emitted by these radioisotopes are low enough in energy so that there is no induced radioactivity in the irradiated substance. As Table 1 shows, penetration of gamma rays is much deeper than high energy electrons (beta rays). The effect on organisms is essentially the same because these gamma rays form high energy electrons within the material. The biological effects of gamma and beta rays are due to primary effects of these electrons and secondary effects that occur when the excited molecular species formed then react with other molecules in the irradiated material.

Radiation sensitivity of living substances is roughly proportional to the size of the organism and its metabolic condition. For example, large animals are killed by an absorbed dose of 1000 rads (one rad equals 100 ergs/g) whereas viruses may require in excess of a megarad for a lethal dose. Sporulating bacteria require much higher doses to destroy them than do bacteria that do not produce spores.

The use of high-level radiation to reduce or eliminate the pathogenic forms present in wastewater and sewage sludge has been seriously investigated as early as the 1950's [2]. Interest has continued at a modest level in the intervening years. The Metropolitan Sanitary District of Chicago sponsored several investigations and even developed a conceptual design of a plant for treating two mgd of wastewater or sewage sludge [3]. At the time, costs appeared to be excessive, as shown, for example, by Ballantine, et. al [4]. The changing world energy situation, the increasing consciousness of people and governments of the potential hazards from wastes, and especially, the construction of a plant-scale sludge irradiation facility in the Federal Republic of Germany have prompted a re-evaluation of the potential for high energy radiation treatment of wastes. During March 17-21, 1975, the International Atomic Energy Agency convened in Munich the "International Symposium on the Use of High-Level Radiation in Waste Treatment—Status and Prospects" to reassess the situation and give direction to further development. The objective of this presentation is to review the highlights of this symposium, particularly as they apply to sludge, and predict the course of future development.

State-of-the-Art

The state-of-the-art, up to the convening of the symposium was well summarized by Feates and George [5]. They point out that the interest in irradiation of wastes followed intensive work originally carried out on foodstuffs and the method became feasible when large radiation sources became available in the mid-1950's. The effects of radiation that are of interest are the following:

- destruction of microorganisms and parasites
- radiation-induced oxidation
- modification of molecular structure (to decrease toxicity or enhance biodegradability)
- changes in colloid systems (to improve settling or sludge dewatering)

Experimental work established that for sewage sludge highly significant levels of microbial reduction occurred

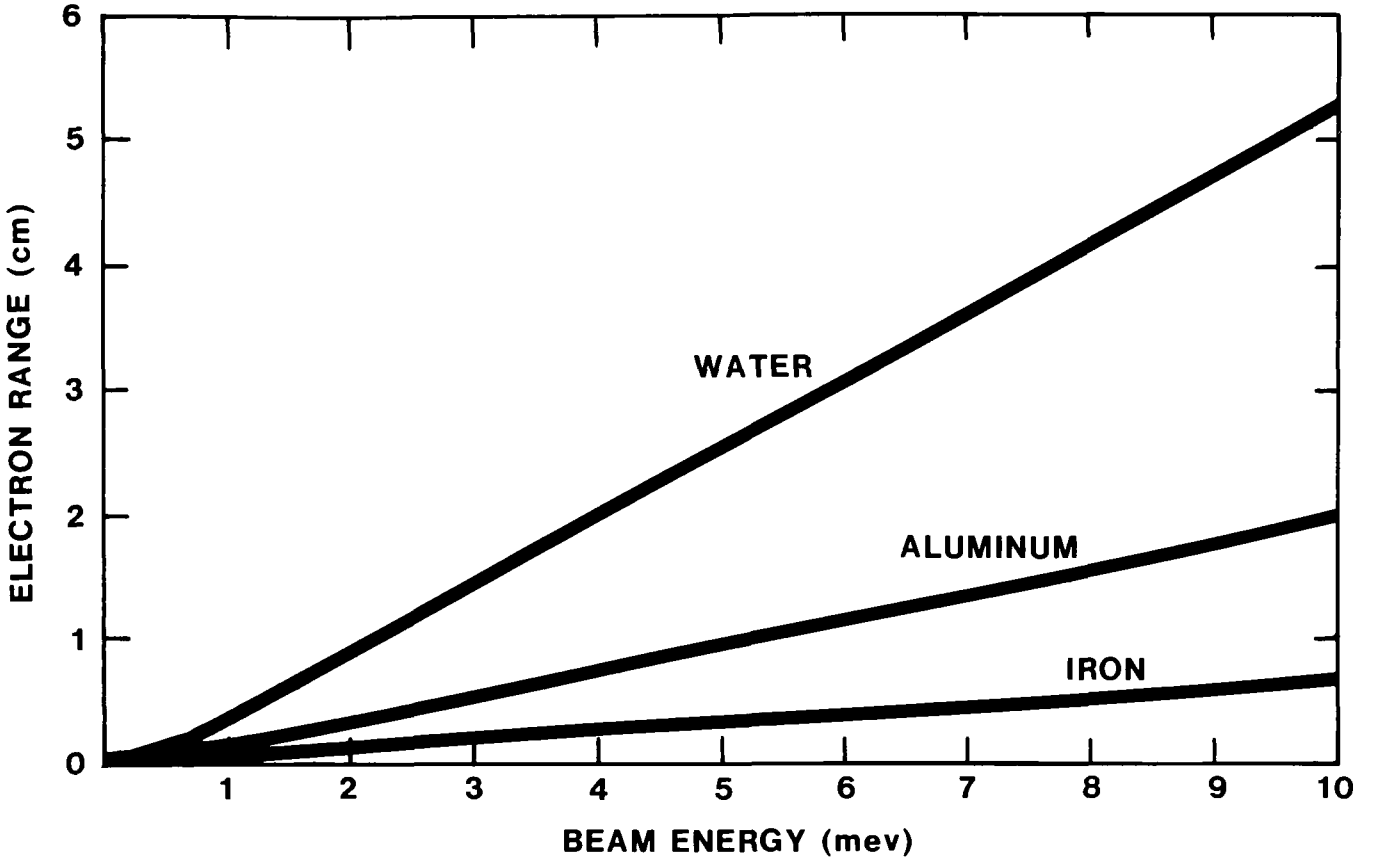

Figure 1: Range of Electrons in Various Materials.

at irradiation levels under 1.0 megarad. Cost studies indicated unrealistically high levels for sewage but not necessarily for sludge. Synergistic effects on reductions in microbial levels appeared to occur when radiation was combined with chlorine, heat, or zinc chloride.

Radiation reduced the COD levels for aqueous solutions of certain chemicals at radiation levels less than 0.2 megarad, but much higher levels were required for significant effects with sewage. For example, Touhill, et. at.[6] found that 0.2 megarad nearly completely destroyed cyanides and phenols, whereas Etzel and Condren[7] found that, under aerated conditions, 1.0 megarad was required to reduce the COD of a simulated wastewater by 80 percent.

Radiation treatment evidently improves the settling rate and filterability of sewage sludge although the effect is not large. Compton, et. al.[8] found that the effect of irradiation or filterability was about the same as two to four percent ferric chloride but not economically competitive with it.

Major Programs

The symposium revealed that, notwithstanding results with sludge that still indicate relatively high costs, major sludge irradiation investigations are underway in several parts of the world. This shows an optimism as to the future of radiation processing of sludge that is backed up by a major commitment of resources. Most impressive are three largescale projects currently underway which should provide practical information on feasibility, effects, and economics.

Geiselbullach

For a number of years, there has been concern in Germany and Switzerland about the transmission of infection to animals grazing on pasture that has been fertilized by application of liquid digested sewage sludge. As a consequence, pasteurization (heating to 70°C for ½ hour) has been carried out on sludges applied to lands during the spring and summer months when animals

TABLE 1
Absorption of Gamma Rays
By Common Materials*

	^{60}COBALT GAMMA RAYS	
	HALF-VALUE LAYER (CM)	TENTH-VALUE LAYER (CM)
WATER	27	64
CONCRETE (147 LB/FT^3)	13	28
STEEL	3.5	8.0
LEAD	1.8	4.5

* (AFTER BALLANTINE)[18]

might be grazing on sludge-treated soils. Numerous pasteurization plants have been erected in both the Federal Republic of Germany and Switzerland. The method evidently has not been without drawbacks. There have been reports of heat exchangers plugged by thermally induced deposits, and an amplification of malodors by the pasteurization process.

To increase reliability of pathogen removal and to avoid the above-mentioned drawbacks of the pasteurization process, a small plant for hygienization of sewage sludge by irradiation was erected by the German Ministry of Research and Technology at the wastewater treatment plant of the Abwasserverband Ampergruppe in Geiselbullach, ten kilometers west of Munich. The plant utilizes ^{60}cobalt and has an ultimate daily capacity of 150 m^3 of sludge irradiated with a dose of 300 krad. Currently the plant is charged with sufficient ^{60}cobalt to apply this dose to 30 m^3 per day. The experience of the German group, which has been led by Dr. A. Suess of the Bayerische Landesanstalt für Bodenkultur and Pflanzenbau in Munich, is described in a series of papers presented at the symposium [9-14]. A schematic diagram of the plant is shown in Figure 2. Sludge is introduced into the irradiation chamber and recirculated past the ^{60}cobalt rods until the sludge has received the desired radiation dose. The complete batch is discharged to make way for the next sludge charge.

Lessel, et. al.[9] give extremely practical information gained by operating the Geiselbullach plant for eighteen months, part of which is discussed below. They observed that irradiated sludge does not develop the strong odor that typically is generated when sludge is pasteurized. It does not increase in volume as does pasteurized sludge when it is heated with direct steam, and it settles better than either pasteurized or untreated sludge. Operating problems were encountered but easily overcome by minor design changes. Costs were slightly higher than for pasteurization for the Geiselbullach installation. However, the authors predict costs of about three DM/m^3 ($23.50/dry ton, based on five percent solids sludge) for a commercial installation of 150 m^3/da (8.25 dry tons per da), which is less expensive than pasteurization costs.

Wizigmann and Wuersching[10] showed that the 300 krad dose in the pilot plant reduced total bacterial count two logs, enterococcus two logs, and *Enterobacteriaceae* four to five logs. *Salmonella* species were discovered in 16 out of 25 samples of sludge before irradiation and in two out of 40 samples after irradiation. There were indications of regrowth after irradiation as is evidenced by the data in Table 2. The regrowth effect is noticeable for the enterobacterial count and exceptionally high for the total aerobic count. The high count of the aerobic forms is probably due to survival of bacterial spores, typically

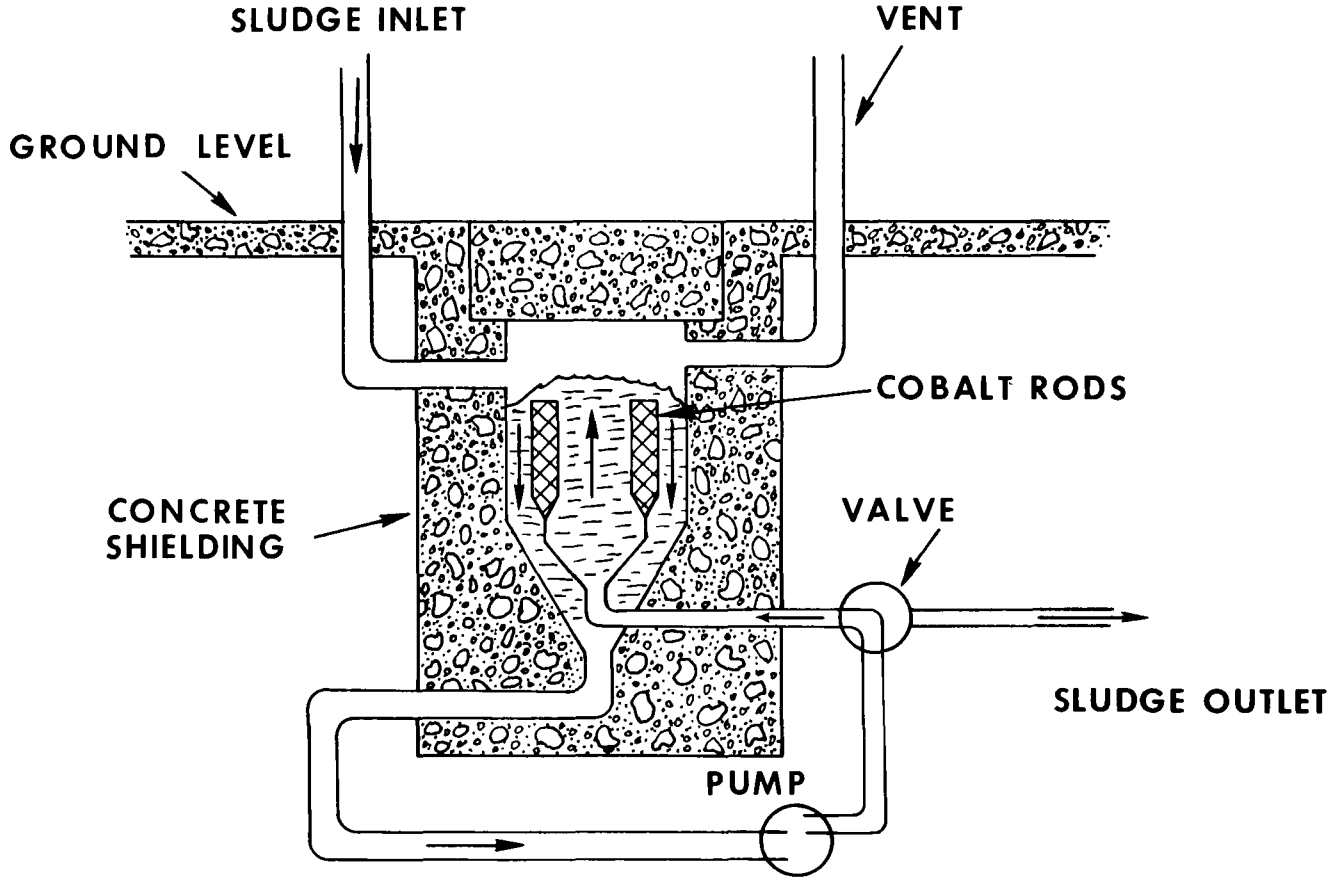

Figure 2: Schematic Representation of ^{60}Cobalt Irradiation Facility at Geiselbullach (design by Sulzer Bro. Ltd., Switzerland).

TABLE 2
Effect of Irradiation on Bacterial
Count in Sludge at Geiselbullach*

BACTERIA TYPE	NUMBER OF BACTERIA PER GRAM			
	DIGESTED SLUDGE	IRRADIATED SLUDGE		
		Special Outlet	Exit to Bed	Drying Bed
TOTAL COUNT				
	2,370,000	12,600	21,400	3,630,000
SAMPLES	(38)	(26)	(16)	(6)
ENTEROCOCCES				
	16,200	58	87	100
SAMPLES	(38)	(26)	(16)	(6)
ENTEROBACTER				
	49,500	0.1	850	93,000
SAMPLES	(28)	(26)	(16)	(6)

* Adapted from Wizigmann and Wuersching[10]

non-pathogenic, which multiply rapidly in a medium from which competitive life-forms have been eliminated. These results are not as good as predicted from bench-scale experiments and may be due to correctable deficiencies in the plant design (such as inadequate flushing of sludge in the part of the loop outside of the radiation zone).

Epp [11] carried out studies of the effect of irradiation in the pilot plant at 300 krad on viruses. Results show a tenfold reduction in concentration of attenuated Poliovirus Type 1 when capsules containing virus were inserted in the sludge and irradiated with 300 krads. Under natural conditions where the virus was added directly to the sludge, there was a fourfold reduction in virus concentration after irradiation in a limited number of tests.

Groneman [12] reported the substantial effect of irradiation on two measures of sludge filterability, specific resistance and compressibility. Irradiation of digested sludge at 300 krads at Geiselbullach reduced specific resistance by over 50 percent. The contrast with pasteruization is marked, since pasteurization treatment doubles specific resistance. Bench-scale experiments indicated reductions of over 75 percent at the same level of irradiation. Groneman attributed the difference to the shearing of the sludge that occurs as the sludge is recirculated through a centrifugal pump and piping (one pass per minute for 288 minutes) in the pilot plant. COD of the filtrates was doubled by radiation treatment. Groneman did not present data on total COD. Experiments by Suess, et. al. [13] indicated that the differences in crop response were negligible between plots fertilized with irradiated sludge or pasteurized sludge although there was more desirable microbiological activity in the soil with irradiated sludge.

The Geiselbullach plant, of course, is the first of its kind and it is expected that it show some shortcomings. As Groneman points out [12], if shearing were less, the effect on settleability of the irradiated sludge could be much more. Similarly, shortcomings in the self-flushing characteristics of the recirculation and sludge discharge systems may have contributed to the lower-than-expected microbiological reductions and regrowth. It is important to note that the German group is optimistic about the future of the process, and considers it superior to the alternative of pasteurization. There have been no complaints about the use of radioactive materials at a wastewater treatment plant, but more a feeling that the new method has replaced inadequate technology. The Geiselbullach plant could be the first step in the coming-to-age of radiation treatment of sludge.

M.I.T. Boston

Since May 1, 1974, studies on electron irradiation of sludge have been conducted at the Massachusetts Institute of Technology with the support of the National Science Foundation. Sinskey, et. al. [15] reported on the biological effects of irradiation, and Trump, et. al. [16] described an ambitious project, also supported by the National Science Foundation, to install an electron accelerator at Boston's Deer Island plant large enough to treat 0.1 mgd (380 m^3/da).

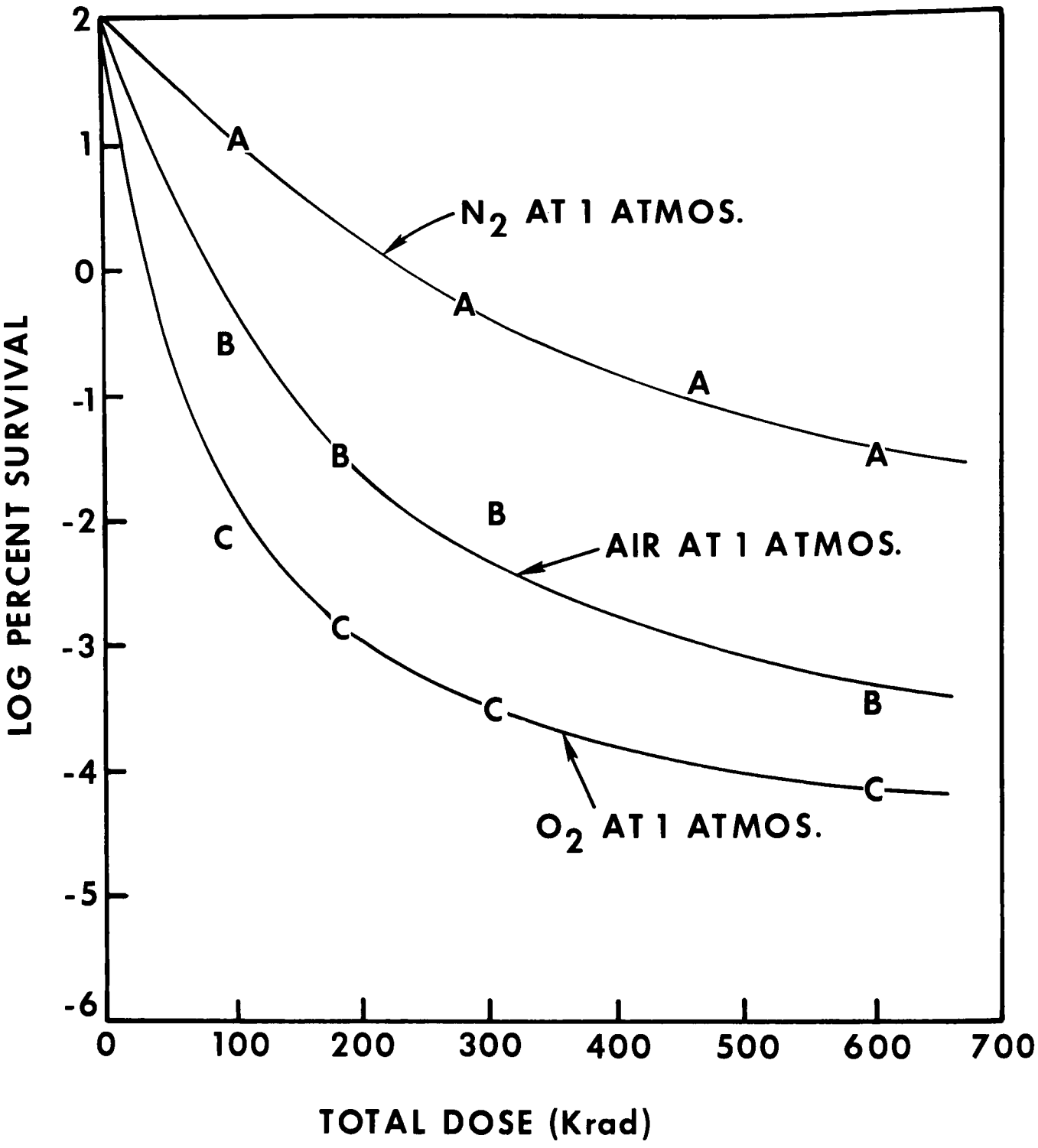

Figure 3: Reduction in Total Plate Count of Raw Sludge (5% solids) Irradiated by Electron Beam in Flow System (after Sinskey, et. al.).

The results of Sinskey, et. al. [15] were preliminary in nature, but indicated a significant synergistic effect of oxygen. As Figure 3 shows, at doses greater than 0.3 megarad, the total plate count reduction is two logs better when sludge is aerated prior to irradiation than when no oxygen is present, and is three logs better when the sludge is previously saturated with oxygen at 1.0 atmosphere pressure. Trump, et. al. [16] have noted that the COD reduction that occurs when sludge is irradiated is similarly influenced by the presence of oxygen.

The facility to be installed at Boston's Deer Island plant is described by Trump, et. al. [16]. It comprises a 50 kW electron accelerator which is capable of delivering a dosage of 0.40 megarad to 0.1 mgd (380 m^3/da) of sludge. This is equivalent to the digested sludge output of a community of about 400,000 people.

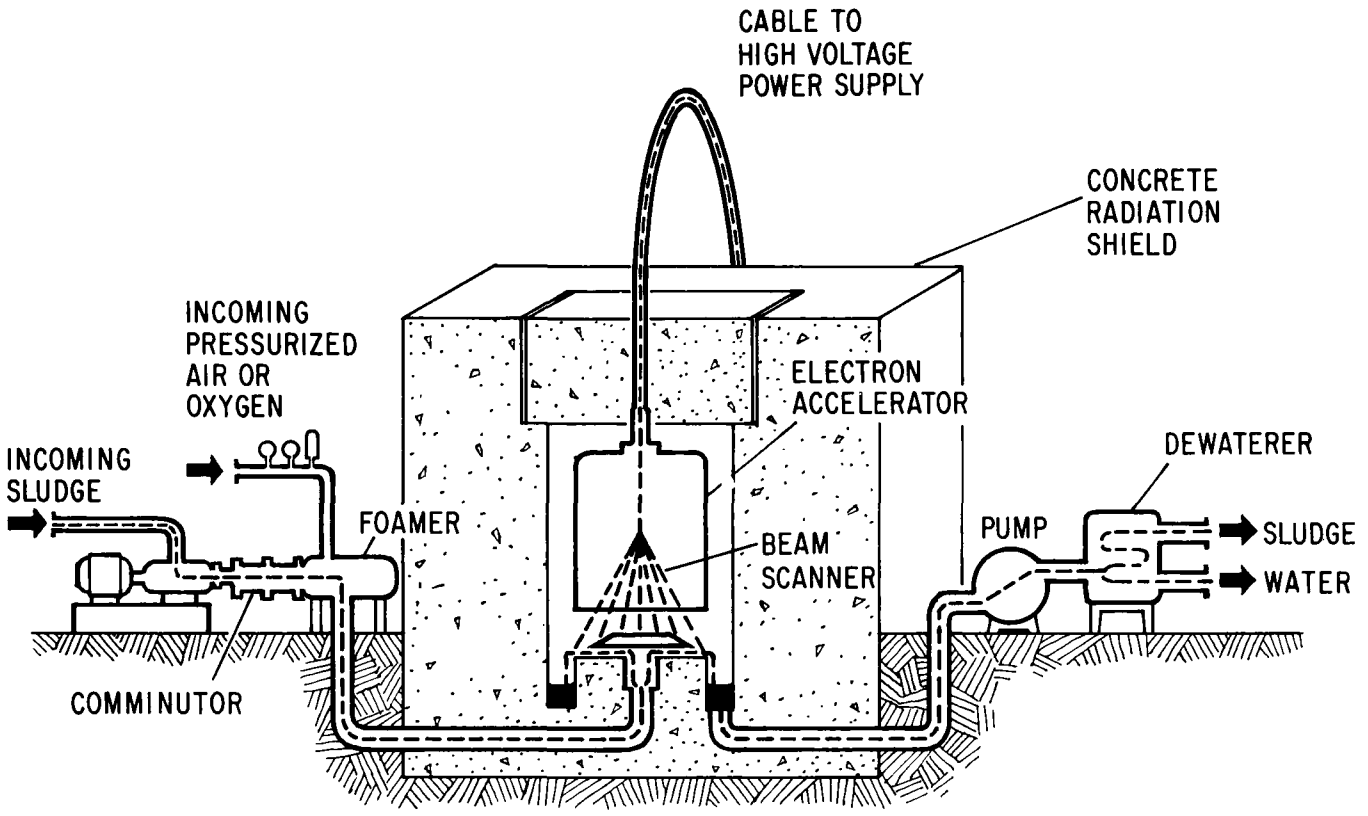

Figure 4: High Energy Electron Sludge Treatment (after Trump, et. al.).

The irradiation installation is represented schematically in Figure 4. The sludge is made to flow under the electron beam in a thin film. The high energy electron beam scans the sludge layer and irradiates it uniformly. Because of the high energy density of the electron accelerator, the sludge is exposed to irradiation for approximately one second. As noted earlier, the effect of irradiation is greater if the sludge is saturated with oxygen. Various means of carrying out this step will be tested.

The authors point out the intrinsic safety of electron beam irradiation. No large radioactive sources are needed. Although the installation must be shielded, the radiation stops completely when the power is shut off. The most obvious drawback of the method is the need to produce the sludge in a rapidly moving thin layer—in the order of two millimeters thickness. Thin layers are needed because of the relatively poor penetrating power of the high energy electrons. The M.I.T. group is investigating a number of ways of producing the sludge in thin layers and are confident that this problem can be solved.

Sandia

The Sandia Laboratories in Albuquerque, New Mexico, have been studying for several years the synergistic effects of heat and radiation on microorganisms. They have applied this method to sewage sludge and believe it has great potential. Their continuing work is supported in part by the U.S. Energy Research and Development Agency (ERDA) and by the U.S. Environmental Protection Agency (EPA).

The concept of thermoradiation is easily understood by referring to Figure 5. In this example, sludge is either heated at 66°C for various time periods, irradiated at a dose rate of 0.5 krad per minute at room temperature, or heated at 66°C and irradiated at 0.5 krad per minute (see Figure 5). The ordinate shows the effect of these treatments for various time periods. The combination of heat and radiation is obviously more effective than heat alone. Also shown in Figure 5 is the effect of radiation at room temperature. If this is considered the "radiation alone" case, it is evident that a synergistic or "greater-than-expected" effect occurs when radiation and heat are combined.

Sandia Laboratories are conducting an extensive investigation of temperature and radiation effects on viruses, bacteria, and parasites in sludge. They have constructed a one liter per minute single pass thermoradiation unit that will process enough sludge to allow investigation of physical characteristics such as filterability and settling rate, and they plan to construct, a 50,000 gpd (190 m^3/da) sludge irradiation pilot plant.

Economics

The plant in Geiselbullach has already provided cost information which has been presented by Lessel, et. al. [9]. Their cost comparisons are presented in Figure 6. Actual cost of irradiation at 0.4 megarad is seen to be

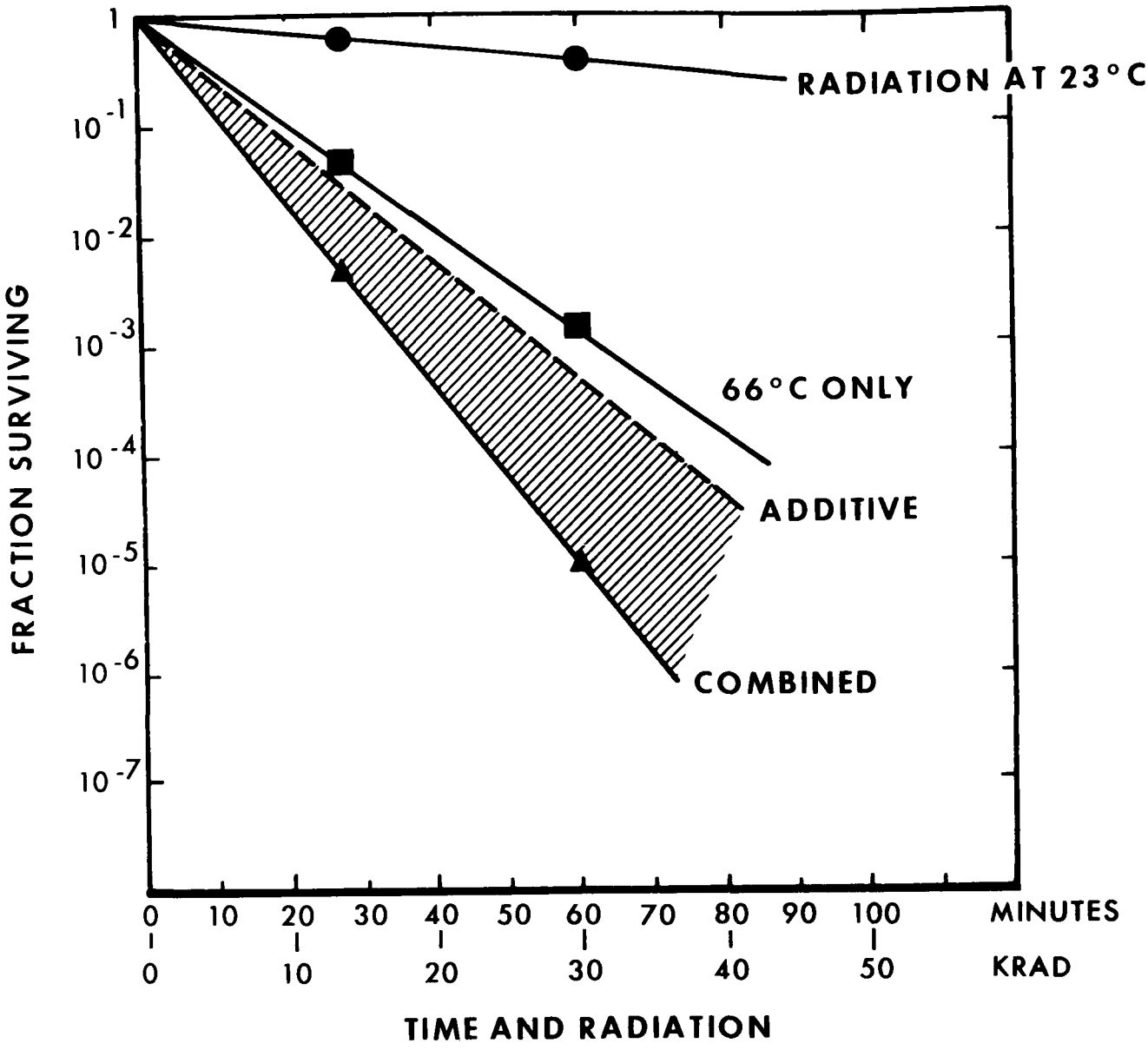

Figure 5: Heat-temperature Synergistic Inactivation of T4 Bacteriophage (after Sivinski, et.al.).

only slightly higher in cost than pasteurization at sludge flows greater than 100 m^3/da. This quantity of digested sludge is equivalent to a population of 100,000 in the United States. For commercial plants, Lessel, et. al. estimate that costs will actually be lower for irradiation than for pasteurization even down to small plant sizes. Conflicting considerations make the choice of the most economically desirable process less straight forward than the graphs would indicate. For example, on the one hand, we know that cost of fuel is escalating with time whereas irradiation costs will doubtlessly decrease. On the other hand, operating costs are the largest cost factor in pasteurization, so if there are periods when pasteurization is not needed, money can be saved by periodic shutdowns. This cost advantage is not possible with irradiation, because capital makes up most of the cost of irradiation. In the opinionof the Geiselbullach researchers, irradiating makes a superior product, which favors irradiation. Heat recovery could lower pasteurization costs, which favors pasteurization. The economic choice will evidently depend on specific site details, economic factors such as fuel cost, and sociological considerations such as unreasonable fears of radiation hazards or unwillingness to tolerate odors of pasteurized sludge.

Ballantine [18] has compared costs of irradiating sludge with a 0.2 megarad dose using several different sources of radiation. His figures, which are presented in Table 3, are useful for pointing out the differences in the individual components of the total costs for irradiation when different radiation sources are used. The capital cost, which includes source cost, is much higher for the ^{60}cobalt and ^{137}cesium than for the 3 MeV electron accelerator. Source replenishment cost is higher for

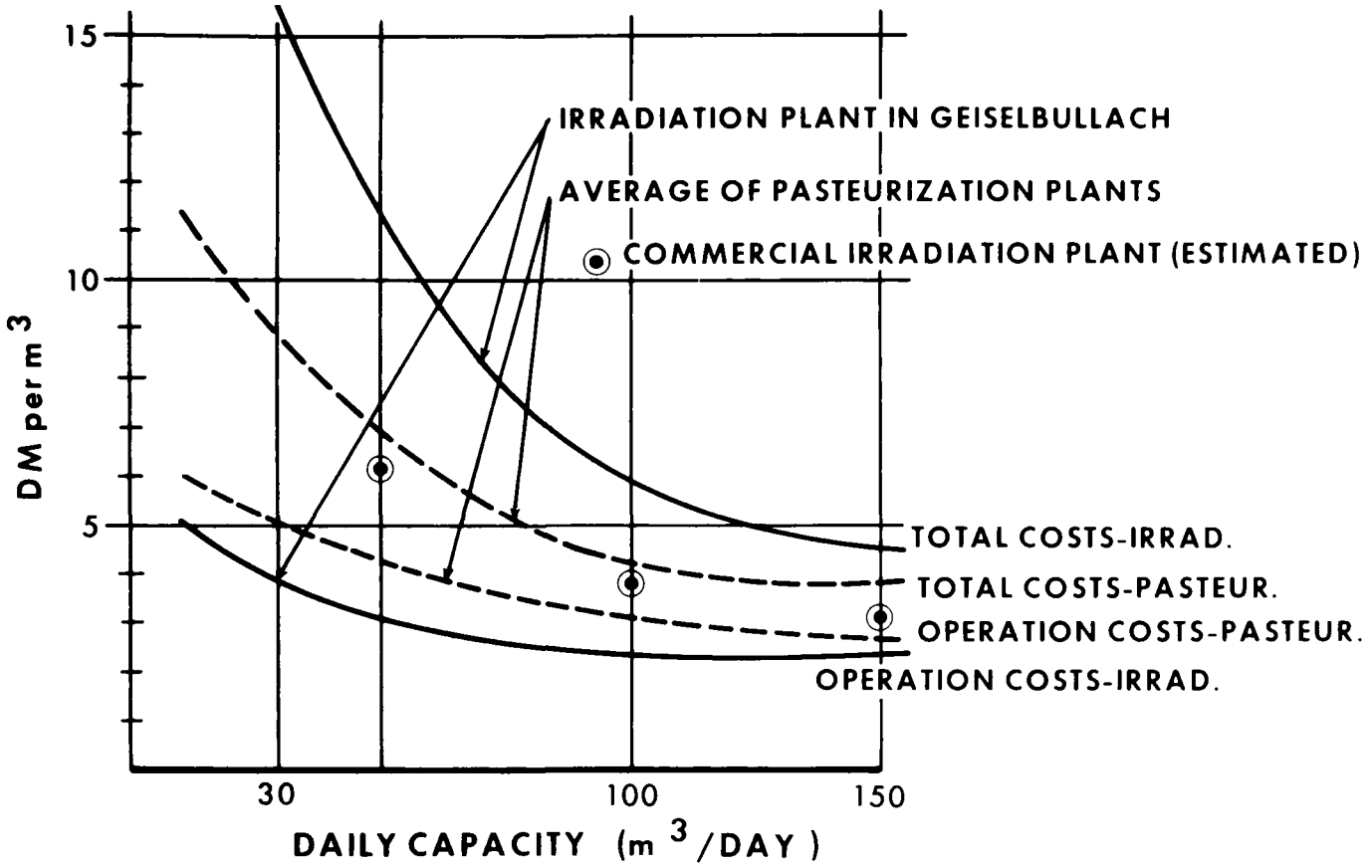

Figure 6: Comparison Between the Costs for Geiselbullach Irradiation Plant and Pasteurization Plants—DM X 0.43 = Dollars, M^3 X 264 = U.S. Gal (after Lessel, et. al.).

TABLE 3
Cost Comparison of Sludge Irradiation Methods*

	^{60}COBALT	^{137}CESIUM	3 MeV ACCELERATOR
CAPITAL COST ($) (SOURCE & SHIELDING)	800,000	1,120,000	250,000
AMORTIZATION (20 YR AT 7.75%)	80,000	112,000	25,000
SOURCE REPLENISHMENT, MAINTENANCE, LABOR	101,250	42,300	50,000
POWER (2¢/KWH, 50% EFFICIENCY)			7,000
TOTAL ANNUAL COST	181,250	154,300	82,000
$ COST/1000 GAL	3.36	2.86	1.52
$ COST/TON SOLIDS	16.1	13.7	7.30

* (AFTER BALLANTINE)[18] 150,000 GAL/DA. OF 5% SOLIDS SLUDGE AT 0.2 MEGARAD.

^{60}cobalt than for ^{137}cesium because the half life of ^{60}cobalt is considerably shorter (5 yr vs. 30 yr). The isotope irradiation methods have negligible power costs compared to the electron accelerator.

The calculated net processing cost per gallon or ton of sludge processed is substantially lower for the electron accelerator than for the radioisotope irradiation. This may prove to be the case in actual practice, but it should be understood that the effectiveness of the electron accelerator has still not been demonstrated in a continuous process on a practical scale. The poor penetrating power of electrons from a three MeV electron accelerator requires that the sludge be delivered under the electron "gun" in thickness of the order of one or two millimeters. This step could be difficult to accomplish and could increase cost to levels comparable with isotope irradiation.

Trump, et. al. [16] have also estimated costs for their installation at Boston. Costs for this 100,000 gal/da facility are $100,000 per year, which is equivalent to $2.74/1000 gallons or, based on five percent solids sludge, $13.20/dry ton. This is almost twice Ballantine's estimate, but the dose is 0.45 megarad, over twice Ballantine's dose. At this time, a dose of 0.45 megarad seems to be needed so Trump's figures are more indicative of the true cost of radiation treatment.

Anticipated Future Developments

A number of investigators reported at the symposium on synergistic effects when oxygen or chlorine was added to the sludge or wastewater when it was being irradiated. Trump, et. al. [16] intend to investigate the effect of oxygen addition in their work at Boston. The possibilities for improved radiation effectiveness, although

real, may be limited by the solubility of oxygen in sludge. The dose is applied in such a short time in electron accelerators that the oxygen must be in solution at the time of irradiation. A greater degree of oxygen synergism may occur if the irradiation is done with radioisotopes rather than with electron accelerators. With radioisotopes, the dose is applied over a longer time interval—at least several seconds (at Geiselbullach, 4.8 hours)—so there is time for mass transfer between a gaseous phase and a liquid phase. In addition, higher total pressures and partial pressures of oxygen can be maintained because the sludge is pumped through pipes and vessels that can be made to withstand high pressures.

In addition to these developments, which hold promise of reducing irradiation cost, there is also the possibility of irradiating raw sludge. This would eliminate the cost of the digestion step. What could be done with irradiated raw sludge is problematical, because it would still be rich in unstable compounds ready to putrefy under favorable conditions. If sludge were sufficiently low in mercury, cadmium, and hazardous organic materials, it could perhaps go directly to the ocean. It could be landspread by plow injection methods. Costs of irradiation would be higher because the mass of sludge is higher before digestion than after, and radiation dose most likely would have to be greater. This would counterbalance a substantial part of the savings generated by eliminating digestion.

Needs-Alternatives-Prospects

In Germany and Switzerland, there has been a substantial use of sludge on agricultural land and a concomitant concern about its potential infection hazard. This has led to regulations that sludge applied to pasture or agricultural land be reduced in pathogens beyond the level attained by digestion. Hess [19] presented new information on the transmission of *Salmonella* to cattle feeding on pasture after sludge spreading. Obrist [20] summarized the situation in Switzerland. Opinion is divided. Veterinarians believe that elimination of pathogens is needed but public health experts evidently do not. Until there are more definitive indications of harm, application of stabilized sludge to cropland after harvest and to pasture during the winter will be permitted.

In the United States, there is extensive use of digested sludge on pasture and agricultural lands under widely varying climatic conditions. For the most part, public health officials have not restricted its use. Notwithstanding this lack of overt disapproval, there would probably be much more extensive use of digested sludge than is currently the case if the sludge were free of infectious organisms. Many more options, such as spreading liquid sludge on highway median strips, are not being used to the extent possible because of a reluctance to expose the public to potential hazard. The U.S. EPA is expected to publish for public comment a bulletin on sludge disposal practice that will establish conditions of use and maximum content of pathogenic organisms if sludge is to be applied to land used as pasture or to grow food crops. It is anticipated that environmental groups and the general public will support and even spearhead moves to reduce infection hazard in sludge even if the need is not clearly established.

If a municipality is faced with the need to eliminate pathogens to continue or adopt the practice of sludge utilization on cropland or pasture, it can choose from a number of alternatives. It can abandon land utilization altogether and use some other method such as sanitary landfill or incineration. It can utilize the sludge for reclamation or for growth of a non-food crop where pathogen elimination would not be needed. If the decision is made to utilize the sludge on cropland or pasture, there are still alternative means for eliminating pathogens besides irradiation. Farrell and Stern [21] discuss the following methods: pasteurization, thermophilic anaerobic digestion, thermophilic aerobic digestion, and long-term lagooning. Municiaplities must make their choice between irradiation and these alternative methods. Cost will be an important consideration, but reliability of performance and simplicity of operation—considerations which favor irradiation—will have an important bearing on the final selection.

During the next few years, regulatory agencies at the several levels of government will become concerned with pathogens in sludge applied to land. Codes of practice will require either pretreatment of sludges applied to cropland and pasture to reduce pathogens or special application procedures or practices, such as subsurface application or application only after harvest. To give desired flexibility of operation, some of the communities affected will doubtlessly choose irradiation as a safe and sure method for eliminating pathogens. Unless there are some startling reductions in cost of radiation processing, however, it is unlikely that the method will be adopted by the majority of communities utilizing sludge on the land.

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MANAGEMENT OF MUNICIPAL WASTEWATER TREATMENT RESIDUALS*

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INTRODUCTION

The Division of Advanced Environmental Research and Technology of the National Science Foundation has currently, about 200 active research awards in:

- Regional Environmental Management
- Weather Modification
- Environmental Aspects of Trace Contaminants
- Environmental Effects of Energy
- Earthquake Engineering
- Fire Research.

Through its other divisions within the Applied Research Directorate and Research Directorate, the Foundation supports a broad spectrum of both basic and applied research consistent with the equally broad base of interests that characterizes the problem of pollution.

The period leading up to the middle of the last decade was characterized by a rather remarkable growth in public support of scientific research. Somewhere around the middle of the 1960's, the growth rate was estimated to be in excess of 15 percent per year. During this period, public confidence was high in the value of scientific research as an investment toward the future. The change in public perception of its responsiveness to needs of society was expressed by Dr. Lee DuBridge in a 1969 address to the scientific community when he said:

> "... the day is past when scientists and other scholars can sit quietly in their ivory towers unaware of and unconcerned with the world outside their laboratories, libraries, studies and classrooms ... they must ask the question of whether the scientific work in which they are engaged is of sufficient importance to the progress of knowledge and its application to be worthy of public support."

Another way to explain what was happening in the 1960's was that problems may have been developing at a faster rate than society's complex system of problem-solving was able to process. This certainly was true in the general area of what we call "environmental pollution." With particular reference to water pollution abatement, it is doubtful that in any year prior to 1973, that we had installed the water pollution abatement capacity to equal or exceed the incremental increase in pollutant discharge.

Whatever the reason, there was a perception of a widening gap between the rate at which problems were surfacing and solutions emerging. Assuming that science and technology had not lost their capability, was there some way in which these societal institutions could be directed toward societal needs?

In 1968, Congress amended the National Science Foundation statute by adding support of "applied research" to its responsibilities toward basic research and education. An implementation step taken by the Foundation in 1969 resulted in the creation of a program entitled, "Interdisciplinary Research Relevant to the Problems of Society."

This program further evolved into the program that is presently known as, "Research Applied to National Needs" (RANN).

The Applied Research Directorate is the programmatic home of RANN and the program focuses its attention on four major areas.

1. Environment
2. Energy
3. Productivity
4. Resources

Dr. Raymond Bisplinghoff, in his address to the 1972 meeting of the American Association for the Advancement of Science, best described the National Science Foundation's Program of Research Applied to National Needs. He suggested that problem-focused research is typically, externally motivated to satisfy the needs of society. Its role in providing support entitles society to insist that research objectives be influenced, if not totally determined, by ultimate utility of the research-results and that managerial responsibility for selecting research problems lies with the sponsor. He further suggested that research directed toward solving complex problems

*Remarks presented do not represent an official position of either the National Science Foundation or the Federal government.

of society was likely, itself, to be complex and this was attributable to the interlocking issues involving technical and scientific knowledge as well as social and human values. He further indicated that a measure of the value of research initiated be estimated before its initiation and that emphasis be placed upon its purpose—to provide solutions to important problems.

Problem-focused research is not research that leads only to the conclusion that more research is needed, although we would expect it to open new areas for further intellectual exploration. While we would expect it to provide opportunities for education and training, that is not its primary objective. Its success would be measured by its results. It seemed reasonable to expect that problem-focused research would be in reasonable balance with traditional basic and applied research and that not all researchers would yield their prerogative for decision as to the nature of their work nor submit to the discipline and directed attention that are required by problem orientation toward objectives.

How each of us perceives our "world" is a complex product of individual experiences interpreted against a background of personal observations that have been remembered which, in effect, constitute a "filter" that makes each additional event unique. With that qualification, I suggest that the change we observed was not a societal suggestion that all scientists and scholars give up concentrating on basic research and education, since to assume that, would be to concede that society had decided there was nothing to gain by long-range investments in a future. The action we observed may simply have been a signal that society was interested in answers to some short-range problems. That is, an expression of apprehension that if some of our shorter-range problems were not addressed and solutions found, there would be no opportunity to exercise the longer-range options.

The goal of research supported by the Division of Advanced Environmental Research and Technology is to provide foundations for good management decisions relating to factors that affect environmental quality. Good management may be characterized as the art of making wise decisions on the basis of information available and used.

The application of management principles to improvement of regional environmental quality requires that we improve our ability to predict effects of management decisions. This requires improvement in our comprehension and understanding of the problem and its potential solutions.

Rationale of the program of applied research directed toward residuals management is conceptually based upon fundamental resource-residuals relationships that are common to all ecosystems and essential for sustaining their vitality and viability and the assumption that new technologies approaches can provide more feasible solutions to both human and naturally caused environmental problems. Current program of objectives are:

- To identify capabilities and limitations of known processes for management of residuals.
- To evaluate new technological approaches for processing and management of municipal and industrial residuals.
- To achieve reconcilliation of processing economies-of-scale promised by regionalization of residuals management with apparent collection system diseconomies.
- To seek alternative management concepts for conversion of residuals into products or forms that minimize or eliminate risk to human health or to the life-support system upon which it is dependent.

Solid and liquid residuals from municipal and industrial sources are both a threat to regional environmental quality and a potential solution to its security as a viable ecosystem. Program development strategy is to couple research directed toward solutions to problems of residuals management with recovery of their potential resource value. Objective is to maximize potential for utilization of research-results.

Research Projects

In the context of these introductory remarks, there follows several briefly described research projects, currently underway or recently completed, that may be of interest to you. The examples will include approaches to management of municipal wastewater treatment residual effluent and sludge, selected approaches to management of industrial wastes and contributions to understanding of and potential response to diffuse sources of pollutants.

With reference to the major topic of this conference, Dr. James L. Smith of Colorado State University is currently investigating use of land in management of wastewater treatment residuals. The tractor-implement developed by him has the capability of injecting sludge into soil at the rate of up to 800 gallons per minute to 40 acres of land from a single hose-connection. Subsurface injection appears to provide a technically superior and more economical method of applying sludge to land. Objectives of his research include determination of relative economy of the method, esthetic and environmental acceptability and relative energy requirements. Concurrently, an analytical model of subsurface injection is being formulated and calibrated with field data from injection sites at Fort Collins and Boulder, Colorado and Williamsburg, Virginia. Close coupling of this research with potential users will provide a realistic assessment of its acceptability. Results will also provide a base for more comprehensive environmental impact assessment of land disposal and will provide local governments and their consultants with information and procedures for design of subsurface injection systems. Implementation of the project's utilization plan included two regional workshops held during 1974 (Boulder, Colorado and Dallas, Texas). A site visit/demonstration was held at

the Boulder injection site during the 1974 National Conference of the Water Pollution Control Federation in Denver. The eastern conference/workshop is scheduled to be held at Williamsburg, Virginia on November 13 and 14, 1975.

Increased attention directed toward more widespread use of land as part of a treatment-management concept for wastewaters and their residuals has resulted in questions regarding virus removal from wastewaters by conventional and advanced treatment concepts. While treatment processes remove most if not all virus particles originally present, results from an NSF/RANN sponsored study at the University of Texas, under the direction of Dr. Bernard P. Sagik and Dr. Joseph F. Malina showed that virus particles are incorporated as constituents of the residual sludges, are not inactivated immediately, and can be released from the sludge under some conditions.

To investigate the potential use of high-energy electrons for disinfection of municipal wastewater treatment residuals, a study was initiated at the Massachusetts Institute of Technology under the direction of Dr. John G. Trump and his colleagues, Dr. Edward W. Merrill and Dr. Anthony J. Sinskey. The influence of radiation-dose, rate of dose application, effect of availability of oxygen, temperature effects, and the influence of competing and synergistic substances were evaluated during an initial phase utilizing a three MeV electron accelerator. Results of the initial phase provided the basis for design of a research facility presently under construction at the Deer Island Wastewater Treatment Plant of the Metropolitan District Commission of Boston. This facility will be capable of in-line treatment of selected effluent or liquid sludge under controllable conditions utilizing a 50 kilowatt, standard electron-source to permit delivery of doses over the range of 100,000 to 2 million rads. Biochemical and engineering data obtained from the operation of this research facility will provide the basis for evaluation of the process including assessment of energy consumption, safety, modes of application, flexibility and costs. At the dosage anticipated adequate for disinfection of sludge (400,000 rads), this research unit will have the capability of irradiating 100,000 gallons per day.

In coordination with the Colorado State University research, Dr. Bernard P. Sagik at the University of Texas-San Antonio is investigating virus survival in soils being subjected to municipal sludge application. Groundwater and surface runoff water samples from injection sites are being analyzed to determine the fate of viruses. Parallel studies will utilize isotopically-labeled viruses incorporated into biologically active sludge and injected into undisturbed soil cores. These will be followed for the degree of viral leaching as a function of rainfall and/or irrigation level. Soil migration of virions will be followed by incorporation of high levels of poliovirus vaccine into a functional septic tank-tile field system in sandy, loam soil of Bastrop County, Texas. Water will be pumped from the gravel beds underlying the tile fields and from the adjacent dry stream bed to determine the characteristics of virion movement through soils. Soils from all locations will be examined to ascertain the possible accumulation of ova, cysts and other evidence of enteric parasites in the soil.

A study by Dr. Theodore Metcalf at the University of New Hampshire is investigating control of virus pathogens by irradiation in cooperation with the research underway at the Massachusetts Institute of Technology. Objectives include comparison of concentration, absorption and magnetic separation virus assay techniques for accuracy and reliability and application of these procedures to determine the effectiveness of electron irradiation for inactivation of viruses. Investigations will include determination of radiation dose for inactivation of viruses in the presence and absence of oxygen and under variations in pH, temperature and pressure.

A research project under the direction of Dr. Richard Dick at the University of Delaware has just been initiated to investigate process selection for optimum management of regional wastewater treatment residuals. Research objective is to synthesize a procedure for analysis of cost and performance of sludge treatment processes. Interactions between process elements for treatment and management of sludge generated in treatment of wastewater are being evaluated to characterize optimal sludge management systems. Mathematical models of the performance and cost of individual processes are being constructed and optimal combinations of processes and operating conditions are being identified by integrating combinations of processes into systems for residuals management. Fundamental sludge properties which influence performance of treatment and subsequent management procedures are being used as input variables in performance models. Operational and economic variables are being used to build cost and performance models. The combined effect of significant individual variables on overall process performance can thus be evaluated and the models applied to a wide variety of sludge types and local situations.

With regard to management of treated effluent, the Foundation is supporting research on the potential utiliization of wetlands for their ability to remove nutrients from domestic wastewater that has received secondary treatment. Research along those lines is underway at the Universities of Michigan and Florida. The Michigan research under direction of Dr. Robert Kadlec is associated with marshlands near Houghton Lake, a headwater marsh system. Research objective is validation of a dynamic simulation model of a peatland-marsh ecosystem to determine its capability of providing advanced treatment for effluents from domestic wastewater treatment plants. Potential benefits include conservation of effluent-contained nutrients and increased productivity of the wetland. Secondary effluent is being obtained

from the Roscommon Township treatment facility. Simultaneously with the construction of the simulation model, the response of the natural ecosystem to effluent application has been studied on a small scale. Application of effluent to a ten acre portion of the marsh has been started to determine effects of the effluent on the marsh and provide a first measure of the validity of the simulation as a significant step toward evaluation of feasibility.

In the study at the University of Florida feasibility of utilizing cypress wetlands for conservation of water and nutrients in effluent from municipal wastewater treatment plants is being investigated by Dr. Howard T. Odum. Cypress domes are being studied to determine their potential utilization for management of effluent from secondary treatment of municipal wastewater simultaneously providing regional, greenbelts, land use units for esthetic enhancement and wildlife protection. Recently burned domes, those with experimental inflow of groundwater, flowing cypress and typical acid water domes are being characterized with respect to hydrology, water quality and ecosystem qualities in four Florida counties. Results to date indicate that cypress wetlands can absorb application of as much as five inches of treated effluent per week to provide a means for qualitative and quantitative regional management of water resources. Ecosystem characterization of experimental and control wetlands includes considerations of water budget, vegetation responses, tree growth rates, nutrient absorption, heavy metal concentrations, microbial activities, forest metabolism, insect grazing, and species diversity.

Simulation using ecosystem models is being utilized to provide better understanding of water, nutrient, and general ecosystem functions. Feasibility and impact of using the cypress wetlands for water management and recycling will be estimated by including regional analyses of water, economic evaluation of this land use, effects of introduction of exotic species, the relationship of the managed systems to fire, compatible architectural designs and public attitudes necessary for acceptance of such projects for large-scale adoption. The final report will present detailed results and a handbook of cypress wetland utilization for use by planners. This project is receiving coordinated support from the Rockefeller Foundation which in addition is funding a study of virus fate in wastewater used for recharge. This phase of the study is directed by Dr. Flora Mae Wellings of the Florida Department of Health.

With reference to industrial waste management, placement of residuals into deep formation by use of injection wells may provide a regional response to management of some wastes. Research underway at North Carolina State University by Dr. Gerald Elkan is directed toward determining whether biodegredation of organic substances stored in deep formations can be utilized to reduce their pollution potential. Dr. William Walker at Virginia Polytechnic Institute recently completed a two-year study of legal aspects relating to deep-well disposal which was followed by a workshop/conference, the objective of which was to provide a definitive analysis of deep-well disposal for substantiation of policy determination leading to effective regulation of deep-well injection as a management option. A report is currently available in draft form with final publication expected before the end of this year.

At Washington State University, Dr. R.V. Subramanian is investigating concepts of encapsulation of hazardous wastes in polymeric resin matrices to yield solidified products having rigid, light-weight shock-proof structures for safe transportation and regional management by storage with minimal danger of environmental and ecosystem contamination. Metal processing residuals and other aqueous solutions can be mixed with a liquid, water-extensible polymer under conditions of high shear to form stable emulsions in which the residuals are dispersed as small droplets in the resin matrix. Polymerization induced by addition of a catalyst results in droplets that become individually encapsulated in a shell of polymer resin. Results are expected to yield knowledge of optimum conditions for encapsulation, physical properties and leaching characteristics of the solidified residuals for assessment of the environmental risk in further handling and storage.

In response to need for further insights into diffuse sources of pollution, research is being supported at the Smithsonian Institution's Chesapeake Bay Environmental Research Center under direction of Dr. David Correll. His research is directed at establishing relationships between various agricultural land management practices and pollutant-yield.

In cooperation with Dane County, Dr. Richard Koegel at the University of Wisconsin is developing improved methods for mechanical harvesting of rooted vegetation from lakes. Coupled with the objective of developing a more environmentally acceptable control procedure than provided by herbicides is that of providng a responsive technological approach to nutrients entering lake ecosystems from diffuse and discrete sources such as agricultural and urban land drainage.

In consideration of "regionalization" of wastewater systems to achieve "economies of scale," we are faced with the problem of optimization of capital investment between conduction and treatment. Dr. Donald Lauria at the University of North Carolina has been working toward a procedure that will permit consulting engineers to study a wider range of options in arriving at their recommendations in balancing these options. His academic colleague, Dr. Daniel A. Okun, has just returned from England where he studied regionalization of water authorities in Great Britain to determine what we can learn from those experiences. A related study was also sponsored by the Foundation at the University of Washington at Seattle under direction of Dr. Ralph

Johnson to determine the applicability of selected European laws, institutions and policies to the solution of environmental problems in the United States. A seminar/workshop is planned to be held in January 1976 at the Foundation with Dr. Okun and Dr. Johnson to explore the implications of their findings.

CONCLUSION

In conclusion to this brief overview of some research being supported by the National Science Foundation, the successful management of a region's residuals can provide a source of materials needed to sustain the vitality and viability of a region while simultaneously improving its environmental quality. Deliberate action and effort directed toward good management of residuals will ultimately be the criterion by which a region's capacity to function as an ecosystem will be measured. The level of effort directed toward solving problems relating to environmental quality seems to be advancing toward commitment of resources more comparable to levels associated with the creation of problems.

Nothing else is possible without achievement and maintenance of survival standards of environmental quality. Faced with the problem of need for response to any problem of residuals, the only three alternative solutions generally possible are movement away from the accumulated residuals, movement of residuals away to avoid their accumulation or management of residuals within the region.

Good applied research can provide the knowledge that is necessary to attain and maintain those levels of regional environmental quality that are consistent with other societal goals, one of which must be assumed to be its own survival. The key to solutions to problems of environmental quality lies in successful management of society's residuals. We cannot dispose of residuals, we can only learn how to manage them.

PYROLYSIS OF SEWAGE SLUDGE

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INTRODUCTION

Each day, sewage treatment plants in the U.S. produce about 13,000 dry tons of sludge of all types [1]. Each day, someone must do something with all of this sludge or it will get in the way of tomorrow's 13,000 tons. The question to be addressed here is what to do with this sludge.

Most of the sewage sludge produced in the United States is disposed of directly to the land in either a landfill or a landspreading operation. That sludge which is not disposed of to the land is either incinerated or disposed of through ocean dumping. Since the future of ocean disposal is, at the very least, somewhat precarious, the only currently secure options that can be planned are the land and the incineration alternatives.

The disadvantages of incineration are not difficult to list. It is costly. It can pollute the air if not properly controlled. It can consume large amounts of auxiliary fuel.

Perspective is required to foster an understanding as to why incineration is practiced at all. Incineration has some obvious advantages that make it attractive to people charged with sludge disposal. Incineration is fast. It rapidly achieves a substantial reduction in the volume of material for ultimate disposal. Incineration is compact, requiring minimal land area relative to the land intensive disposal techniques. Incineration takes place at the point of generation, thereby eliminating the need for transporting the sludge to distant disposal sites. Finally, incineration does not take place in someone's backyard. When its 10 to 15 years of useful life are completed, the incinerator can be replaced with another unit at the exact location as the first. The periodic search for a new disposal site and a friendly neighborhood to accept the exported sludge is not required.

The desire to retain the option of on-site disposal and the inadequacies of incineration have prompted a search for disposal alternatives that retain the advantage of incineration while dispensing with the disadvantages. A candidate system is pyrolysis. The pyrolysis process will be discussed in general here and then preliminary experimental results will be presented from a research project funded by the Environmental Protection Agency and conducted by the research staff of the U.S. Bureau of Mines.

Pyrolysis

Pyrolysis is the destructive distillation of organic materials under heat and/or pressure in the absence of oxygen. It is the process that is used to produce coke from coal and charcoal from wood. In the pyrolysis process, the organic portions of waste are reformed into lower molecular weight compounds as typified by the following simplified description of what happens to cellulose in pyrolysis.

$$C_6H_{10}O_5 + \text{Heat} \longrightarrow CH_4 + H_2 + CO_2 + C_2H_4 + C + H_2O$$

The product compounds can be in the physical forms of a combustible gas, tar and oil, and a solid char which also has an appreciable heating value. The relative proportions of the products that occur in each physical state as well as the fractions of each product chemical compound vary primarily with the amount of heat applied and secondarily with the presence of any moisture in the feed. Generally speaking, higher reaction temperatures yield simpler chemical products and larger quantities of gas at the expense of the liquid and solid product phases.

Pyrolysis of waste materials, even of sewage sludge, is not an entirely new concept. The literature contains references to pyrolysis experiments conducted in 1908 in England for the purpose of recovery of nitrogen in the form of ammonium sulfate [2].

In recent years, there has been much research activity in the United States in the application of pyrolytic and starved air techniques to the disposal of solid wastes. The earliest concentrated pilot plant work in the area of pyrolysis of waste materials for the purpose of conversion to fuel was reported by the U.S. Bureau of Mines in 1970 [3]. This and subsequent work by the Bureau of Mines demonstrated that any organic material yielded similar products of gas, oil and carbon char in the pyrolysis process [4-6].

Some systems for solid waste pyrolysis have proceeded to the point of full scale demonstration. Plants of from 75 tons per day to 1,000 tons per day have been operating or are under construction with product recovery ranging from oil and gas to steam and heat. A wide variety of hardware is employed with reactors taking the form of fluidized beds, rotary kilns, shaft furnaces and other devices[7].

The EPA-Bureau of Mines Research

While such materials as municipal refuse, scrap rubber tires, rice hulls, and cow manure were being pyrolyzed, little, if any testing had been performed on sewage sludge. Although the previous work had shown that most any organic material could be pyrolyzed successfully, it was felt that verification of the concept for actual sewage sludge was necessary. To this end, the Environmental Protection Agency entered into an interagency agreement with the U.S. Bureau of Mines. Under the terms of this agreement the Bureau of Mines would conduct pilot-scale tests on the pyrolysis of sewage sludge and sludge-solid waste mixtures at the Bureau's Pittsburgh Energy Research Center. The pilot plant equipment used for the tests is the same equipment that was employed in the previous tests with refuse, rubber tires, and manure. A schematic of the pilot plant is presented in Figure 1.

Basically, the pilot plant consists of a batch operated retort heated electrically, equipment for removing tars and oils, and equipment for cleaning, measuring and storing gas. The retort, depicted in Figure 2, is 18 inches in diameter and 26 inches deep and can accommodate a charge of from 50 to 80 pounds of dried material. The tar removal and gas cleaning apparatuses are shown in Figure 3.

Pyrolysis occurs at temperatures ranging from 500°C to 900°C. Depending on the test material and temperature, a test could last from six to twelve hours. In order to ensure a smooth flow of materials through the pilot plant sections, all materials were predried to no more than ten percent moisture. Higher moisture contents impose a large heat burden on the pyrolysis section due to burst vaporization. Both quantities and qualities of product gases are lower when larger amounts of moisture are present in the feed.

Tests were conducted at atmospheric pressure with primary, activated, primary-activated, and digested sludges. This discussion will focus on the data developed for waste activated sludge since it is the nearest to completion at this time and because it can be considered typical for sludges.

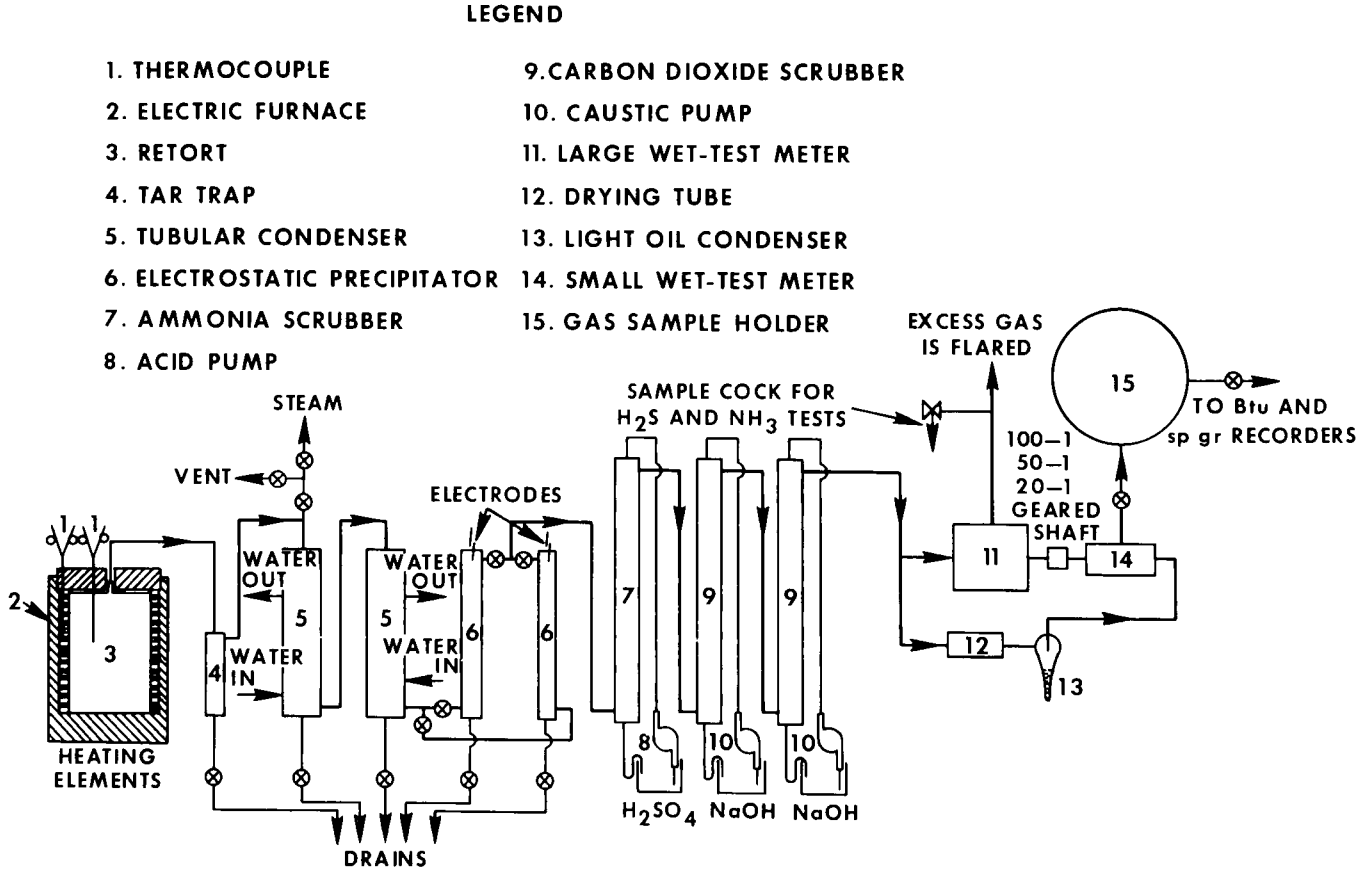

Figure 1: Pilot Plant Pyrolysis System.

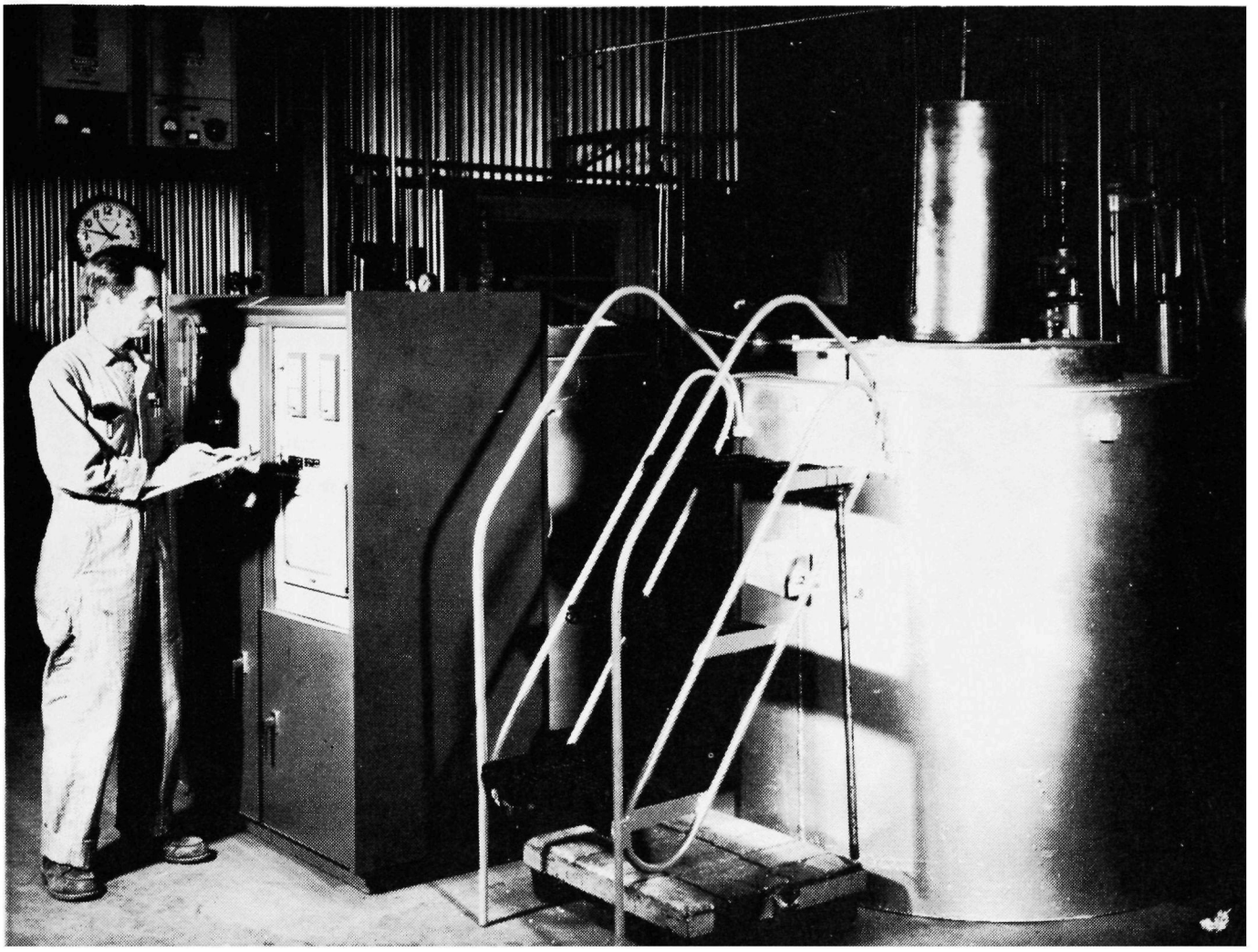

Figure 2: Pyrolysis Retort (*U.S. Department of Interior—Bureau of Mines*).

Pyrolysis of Sludges Alone

Table 1 describes the energy recovered through pyrolysis conversion in each fraction in millions of BTU per ton of feed material for primary sludge, waste activated sludge, and municipal refuse. The municipal refuse used was the light fraction from shredded, air classified refuse obtained from the Altoona, Pennsylvania, compost plant.

Table 2 summarizes the relative yields per fraction on the bases of weight percent of feed, quantity per ton of feed, and energy per ton of feed. Of significance is the fact that, while the portion of the yield that is attributed to the solid char is relatively insensitive to pyrolysis temperature, there is a considerable shift between the liquid and gas fraction as a function of temperature. The greater yields of gas with higher temperature must be considered a beneficial effect since the gas is a much more accessible energy form than the liquid mixture of tar, oil, and water.

Table 3 presents the analyses of the gases produced at the two temperature extremes. Note that, while the 900°C temperature produces a much greater quantity of gas than does the 500°C temperature, the high temperature gas has a much lower heating value than does the 500°C gas. This is probably due to the shift in quantities between methane and carbon monoxide at the two temperatures.

Table 4 demonstrates that the carbon char product is relatively unaffected by the temperature difference. Table 5 shows that, although much less liquid is produced at 900°C much less of the liquid fraction at the higher temperature is in the form of the valueless aqueous liquor. The heavy oil product is of the consistency of a heavier petroleum distillate and has a heating value of roughly 120,000 BTU/gal.

Feasibility of Pyrolysis of Sludge Alone

Pyrolysis is a process that, once started, is virtually selfdriving. However, in order to obtain the yields given in the previous data, the input sludge must not have a moisture content greater than ten percent of the total feed. When secondary sludges are involved, conven-

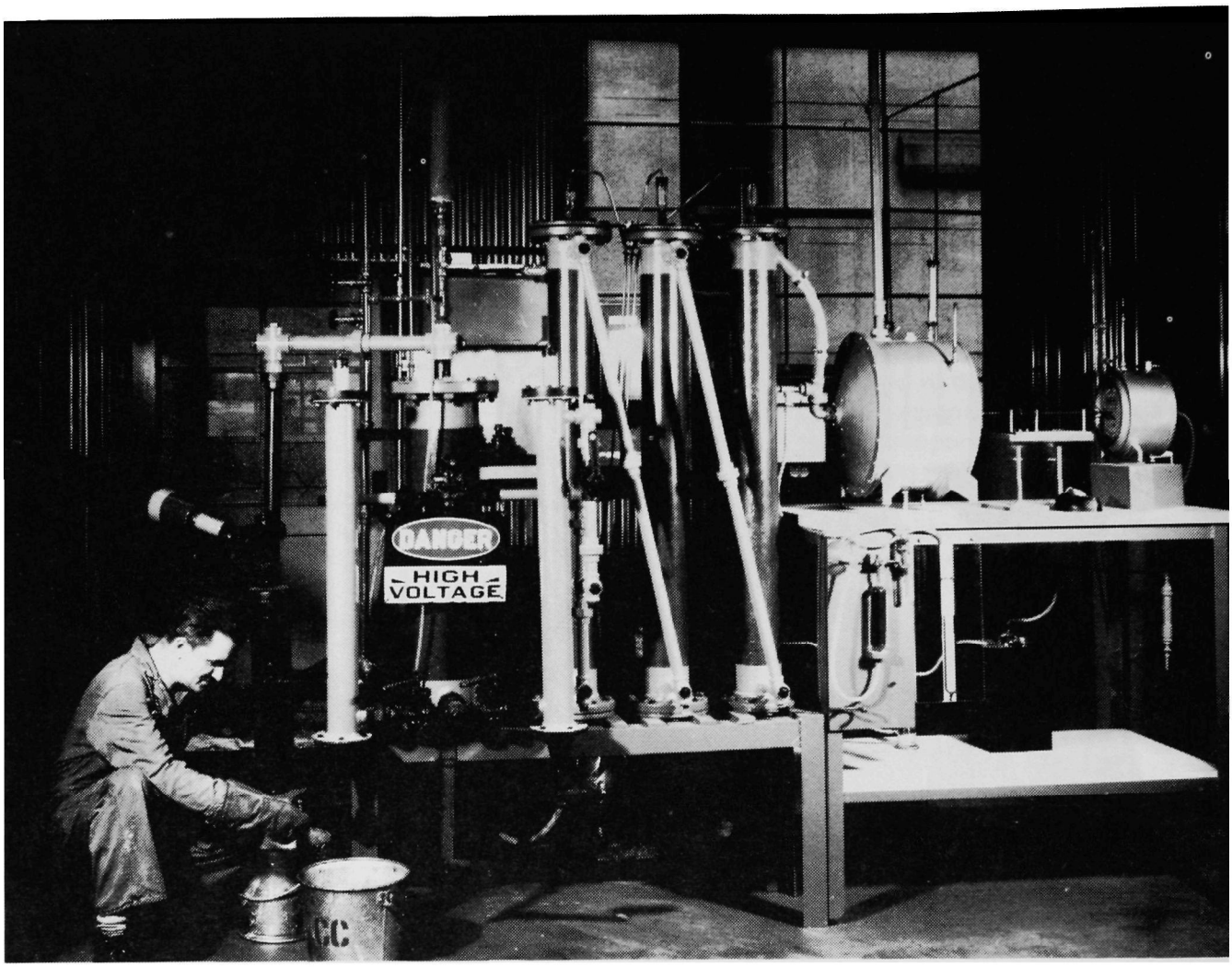

Figure 3: Tar Removal and Gas Cleaning Train (*U.S. Department of Interior—Bureau of Mines*).

tional vacuum filtration technology will yield a final cake solids content of 15 to 20 percent [8]. A cake in the midpoint of this range contains about 9,100 pounds of water for each ton of dry sludge solids. Assuming away an odor problem in a sludge drying process, this cake can be dried in a rotary dryer at roughly 300°F and 80 percent efficiency. Such an operation would require approximately 1460 BTU for each pound of water or 13 million BTU's for every ton of dry sludge feed [9].

The gas produced in the pyrolysis process would make an excellent fuel for the dryer. However, from Table 2, the gas fraction at 900°C contains only 5.4 million BTU's. In fact, the total energy conversion in the form of all three fractions does not total the required heat energy for the drying process.

Co-Pyrolysis of Sludge and Refuse

The pyrolysis of dried sludge alone, having been proved successful, represents a substantial improvement over conventional incineration with respect to fuel consumption and air pollutant emissions. However, the high moisture content of sewage sludge is an obstacle to pyrolysis in the same manner that it is a hindrance to incineration. It has been shown that, even without deodorization, the sludge drying process will consume about as much energy as is converted in the pyrolysis process. Experience with sludge drying at the Bureau of Mines indicates that a need for deodorization might exist. Conventional deodorization technology requires that the odorous gases be heated to temperatures in the range of 1200 to 1500°F. Such an operation would require substantially more heat input than the 300°F drying procedure described earlier.

One approach to solution of the moisture problem would be to simply feed a higher moisture cake into the reactor. However, this method requires that the entrained water be brought up to pyrolysis temperatures of 1650°F (900°C) instead of evaporated at a maximum temperature of 300°F. This is hardly a conservation of energy. Also the presence of large amounts of water in the feed substantially and detrimentally alters the com-

TABLE 1
Pyrolysis of Dried Materials

Material Pyrolyzed	Energy Available in Raw Material Million BTU/Ton	Energy in Pyrolysis Conversion Products Million BTU/Ton of Raw Material Gas	Char	Tar & Oil	Total	Percent of Energy Recovered
Raw, Primary Sludge						
500°C	15.00	1.2	5.5	8.0*	14.7	98.0
900°C	15.34	6.3	4.2	3.0	13.5	88.3
Raw, Waste Activated Sewage						
500°C	12.44	1.9	5.1	4.0	11.0	88.9
900°C	12.36	5.4	4.6	2.6	12.6	96.5
Classified Municipal Refuse - 900°C	17.7	7.1	5.9	2.3	15.3	86.5

*Preliminary

TABLE 2
Summary of Yields from Pyrolysis of Dried Activated Sludge

PYROLYSIS TEMPERATURE °C	500	900
Yields, Weight Percent of Feed		
Char	57.7	54.1
Gas	5.8	29.3
Tar, Oils, Aqueous	25.3	13.9
Yields, Per Ton of Feed		
Char, lb.	1154	1082
Gas, cu ft	2637	13415
Tar, Oils, Aqueous, gal	57.7	29.6
Ammonium Sulfate, lb	103.3	73.4
Energy, Million BTU/Ton of Feed		
Char	5.1	4.6
Gas	1.9	5.4
Tar, Oils, Aqueous	4.0	2.6

TABLE 3
Analysis of Gas from Pyrolysis of Dried Activated Sewage Sludge

PYROLYSIS TEMPERATURE, °C	500	900
Analysis, Volume Percent:		
Hydrogen	44.6	46.6
Carbon Monoxide	8.2	22.2
Methane	25.0	12.8
Ethylene	6.2	0.4
Carbon Dioxide	4.3	4.2
Oxygen	3.0	1.6
Nitrogen	5.1	10.3
Butane	1.8	< .1
BTU/cubic foot	735	405

position and quality of the pyrolytic conversion products [5].

A more positive approach to the problem lies in combining the sludge cake with a dry organic material that is readily amenable to pyrolysis. The combination of the wet sludge cake with sufficient quantities of the dry material will result in a feed material with a moisture content much lower than that of the sludge alone. This admixture would require much less of the converted energy for evaporation of entrained moisture. In fact, excess fuel for other in-plant uses or, even, for export could be made available through the pyrolytic conversion process.

TABLE 4
Analyses of Residue (Char) from Pyrolysis of Dried Activated Sewage Sludge

PYROLYSIS TEMPERATURE, °C	500	900
Ultimate Analysis Percent:		
Hydrogen	1.3	0.3
Carbon	27.0	27.8
Nitrogen	3.0	0.8
Oxygen	1.1	---
Sulfer	0.6	0.7
Ash	67.0	70.4
BTU/lb.	4370	4300

TABLE 5
Analysis of Liquid Fraction from Pyrolysis of Dried Activated Sewage Sludge

PYROLYSIS TEMPERATURE, °C	500	900
Yields, Weight Percent		
Tar (heavy oil)	38.3	62.6
Light oil	5.9	4.3
Free ammonia	0.8	3.6
Aqueous liquor	54.9	29.5
BTU/gal.	69,300	87,800

The admix material could be almost any organic material including coal, rubber, or wood. Substantial environmental benefit can be achieved by the combining of sewage sludge and solid waste. Such mixtures have been pyrolyzed at the Bureau of Mines pilot plant as part of the EPA-sponsored work on sludge pyrolysis. The refuse used was shredded, classified material obtained from the Altoona, Pennsylvania, composting plant.

Product yields, for various combinations of activated sludge and the shredded solid waste are presented in Table 6. For dried materials, the refuse to sludge ratio of 20:1 is roughly equivalent to the proportions of generation of the two materials. As evidenced by the data, the higher the ratio of solid waste volatiles to sewage sludge solids the greater the volume of gas generated per ton of feed.

A 20:1 mixture of solid waste (30 percent moisture) and sewage sludge cake (80 percent moisture) would result in a combined feed with a moisture content of roughly 32 percent. To dry this mixture under conditions identical to those for the sludge alone case would require

TABLE 6
Yields - Pyrolysis of Blends of Sewage Sludge and Municipal Refuse - 750-900°C.

Pyrolysis feed material	Feed* million Btu per ton	Gas* Percent weight	Btu per cubic foot	Cubic feet per ton	Million Btu per ton pyrolyzed	Char residue* Percent weight	Btu per pound	Pounds per ton	Million Btu per ton pyrolyzed
Municipal refuse and activated sludge 1-1 ratio	11.4	25.4	552	11,607	6.410	42.7	6,220	854	5.311
Municipal refuse and activated sludge 8-1 ratio	14.9	31.4	552	13,694	7.559	32.5	8,360	650	5.434
Municipal refuse and activated sludge 20-1 ratio	13.7	34.3	586	14,078	8.249	27.1	9,200	542	4.997

* All heat values and weights are on a water-free basis

approximately 1.1 million BTU per ton of solids pyrolyzed. Since the mixture generated over eight million BTU in the form of gas, a significant amount of converted energy is available for external application or sale. For the 20:1 feed situation, this amounts to roughly 12,000 cubic feet or seven million BTU in the form of gas available for external use per each ton of dried reactor feed.

Therefore, while pyrolysis of sludge alone compares favorably with sludge incineration, co-pyrolysis of sludge with solid waste is a more likely implementation of pyrolytic activity with respect to sewage sludge. A logical development would be the addition of sewage sludge to the solid waste feed to one of the functioning demonstration scale facilities described in Reference 7. In fact, EPA has recently awarded a grant to the City of South Charleston, West Virginia, to test the addition of dewatered sludge cake to the refuse feed at the 200 tons per day oxygen refuse conversion facility located in that city (see Figure 4).

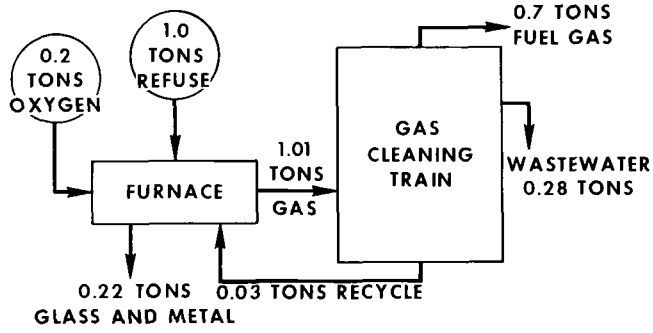

Figure 4: Inputs and Products of Purox System.

Environmental Aspects of Pyrolysis

Since little plant scale pyrolysis work has been performed, there is very little known about emissions from a pyrolysis facility. Theoretically, at least, pyrolysis emits no air pollution. The fact that pyrolysis operates without excess air and produces a smaller volume of gas for cleaning than does incineration would indicate that the airborne emissions problem from pyrolysis is at least as manageable, and probably, much less of a problem than from incineration.

Heavy metal emissions should not be a major problem in pyrolysis since temperatures are generally lower than in incineration. Heavy metals, in general, tend to be concentrated in the pyrolysis char. Pyrolysis is being invesitgated in Japan as a solution to the problem of the leaching of hexavalent chromium from sludge incinerator ash. In pyrolysis char, the chromium appears in the much more stable Cr^{+3} configuration [10]. Mercury can be expected to volatilize in pyrolysis as well as in incineration and if not removed in the scrubbing process may exit with the spent exhaust from combustion of the product gas.

Another area of concern is disposal of the aqueous liquor removed from the tar and oil fraction. This material can represent as much as 13 weight percent of the feed. While this material is 94 to 100 percent water it can contain sizeable portions of organic compounds identified as acids, ketones, and aldehydes. One possibility for treatment of this aqueous fraction would be to utilize the char fraction to absorb the organic compounds present in the liquor[3].

At this point, the only definitive statement that can be made about the environmental aspects of pyrolysis is that much further research is needed and planned for this area.

Economics

Capital costs for solid waste pyrolysis facilities, including product processing provisions, currently are in the range of $14,000 to $20,000 per ton per day of gross handling capacity [7-11]. This installation cost range is

roughly equivalent to that for pollution-free sewage sludge incineration [12]. Assuming that labor requirements for both incineration and pyrolysis are identical, the critical factor in cost comparison becomes fuel consumption.

It has been shown previously that pyrolysis of sludge alone is not quite fuel self-sufficient for the case of the 18 percent solids sludge cake. An energy balance reveals that combustion of the same sludge cake in a multiple hearth furnace without exhaust gas deodorization or heat recovery requires the input of 8.5 million BTU of additional energy in the form of auxiliary fuel for each dry ton of sludge feed [13]. This auxiliary fuel requirement is equivalent to 59 gallons of No. 2 fuel oil, the most common fuel for sludge incineration.

Additional capital economies as well as operational cost savings can be appreciated by combining disposal of solid waste and sludge into a single facility. In this latter case, the fuel products from co-pyrolysis would be available for external use or sale.

The carbon char remains an economic question mark. This material constitutes over 50 percent of the material feed. It is usually assumed, for the sake of discussion, that this material can be sold as an adsorption char or, at the least, given away for its fuel value. However, any complications with this material, such as the leaching of heavy metals, might detract from its value as an adsorption agent, or even, as a fuel. At any rate, combustion of this material, which is about 70 percent ash, will still leave a sizeable land disposal requirement.

If the char cannot be sold or given away, the pyrolysis process becomes less efficient as a volume reduction technique than is incineration. Disposal of the char can become a substantial economic deficit. In a similar vein, costs of processing and separating the tar, oil, and aqueous fractions prior to any constructive use must be taken into account.

As with the environmental aspects, the economics of sludge pyrolysis is an area requiring further investigation.

Potential for Sludge Pyrolysis

Aside from the pure aesthetics and economics of the process, the future growth in application of pyrolysis to sludge disposal is dependent of a number of variables, some of which will be discussed here:

First, what people decide to do with their solid waste is important. If solid waste authorities choose direct combustion-generation as in St. Louis, then the availability of the solid waste admix for co-pyrolysis is restricted.

Secondly, pyrolysis techniques must be developed that take advantage of existing equipment. Fuel may become extremely costly, but a municipality will nevertheless hesitate to abandon a recently constructed $20 million incineration plant because the hardware is incompatible with pyrolysis.

Thirdly, the development of mechanical dewatering devices that can economically produce an autogenous sludge cake might work against the implementation of sludge pyrolysis. While a drier cake requires less energy for pyrolysis as well as incineration, the production of an autogenous cake alleviates the fuel cost pressure at existing incineration plants and makes conventional incineration more feasible.

While the future for waste pyrolysis appears strong, enthusiasm for the process must be tempered by the fact that much development work lies ahead.

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SLUDGE PYROLYSIS FOR ENERGY RECOVERY AND POLLUTION CONTROL

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INTRODUCTION

The advantages of sludge pyrolysis over conventional incineration processes can be stated in terms of fuel economy, energy recovery (steam generation), and control of heavy metals. To make technical comparisons between incineration and pyrolysis processes, we have conducted fundamental engineering analyses using a heat and material balance.

To make the analyses consistent, we have made some assumptions regarding the thermodynamic properties and the chemical composition of the solid portion of the sludge. The following represents a typical municipal sewage sludge with a light industrial loading:

Analysis of Volatile Solids

	%
Carbon	52
Hydrogen	7
Oxygen	41

Volatile solids = 70% of total solids.
Heating value = 9500 Btu/lb volatile solids.

The sludge has been assumed free of nitrogen, lime, ferric chloride, and other constituents usually present in small amounts, to simplify the calculation. The above analysis is for the solid portion of the sludge only. Different solids contents are assumed for specific examples to illustrate certain points.

Fundamentals of Pyrolysis

By definition, pyrolysis is an irreversible chemical change brought about by the action of heat in an atmosphere devoid of oxygen. Synonymous terms are thermal decomposition, destructive distillation, and carbonization.

The pyrolysis of organic compounds yields the following:

- Char
- Organic liquids (pyroligneous acids)
- Fuel gas
- Water (present in either liquid or gaseous state depending on final pyrolysis conditions).

The char contains any mineral ash or other noncombustible material present in the sludge plus what is termed the "fixed carbon," which represents the carbonaceous fraction of the original material that did not volatilize on heating. The char also usually contains small quantities of hydrogen and oxygen, and nitrogen is sometimes present.

The organic liquids are a complex mixture of chemicals and are often called pyroligneous acids, because they are acidic and were first produced by the destructive distillation of wood. The fuel gas consists of a number of combustible gases, such as carbon monoxide, methane, hydrogen, ethylene, and other higher hydrocarbons in minor quantities. The fuel gas also contains an appreciable quantity of carbon dioxide and may contain water vapor if it has not been previously condensed out of the stream.

The ultimate yield and final composition of the solid, liquid, and gaseous pyrolysis products are determined by a number of variables, such as the chemical composition of the raw material, the heating rate, and the ultimate material temperature. Several investigations [1-4], of these and other process parameters suggest a complexity that makes final product characteristics from pyrolysis impossible to predict.

A pyrolysis process may be endothermic (require heat) or exothermic (give up heat), depending on the ultimate temperature achieved. In most materials, the process is endothermic at lower temperatures and exothermic at higher temperatures. In all cases, *the heating value of the pyrolysis products is the sum of the heating value of the original material and the net energy added during pyrolysis*. In many cellulosic materials, the energy absorbed or liberated by the pyrolysis reaction is very small compared with the heating value of the original material. Unfortunately, in most pyrolysis studies to date, the emphasis has been identification of the many complex chemicals generated by pyrolysis rather than

on heat and material balances for pyrolysis processes, for which very few data are available.

However, since the heating value of the pyrolysis products is always equal to the heating value of the original material plus any heat added, we can perform a heat and material balance based on review of the available data. Details for performing heat and material balances for combustion and pyrolysis processes have been previously described [5,6] and will not be covered here.

Pyrolysis and Incineration Systems— Comparative Thermodynamic Analyses

The first step in any thermodynamic analysis is to draw a Thermodynamic System Boundary around the system to be analyzed. Figure 1 shows a typical thermal processing system for municipal sewage sludge, which can be either a pyrolysis system or an incineration system. The thermodynamic system boundary is indicated for all systems being analyzed (Figures 2-5). In our analyses, we will not consider the heat and mass transfer operations taking place in the scrubbers usually associated with sludge thermal processing systems. For the systems to be analyzed, we will assume zero heat loss. The zero heat loss assumption is very valid for comparative analyses of alternative processes, except in the case of a process with an unusually high heat loss. (Assuming a heat loss of, say, five percent of the sludge heat input would not have served any particular purpose.)

In the systems selected, the only correction to our assumption was made in the analysis of the multiple hearth incinerator, which, in addition to sustaining heat loss through the walls, also exhibits heat loss in the form of heated shaft cooling air discharged to the atmosphere. The values taken for this loss are those reported in the literature [7].

The comparative analyses will be based on a balance of the material and heat inputs and outputs (Heat and Material Balance):

$$\text{Material in} = \text{Material out}$$
$$\text{Heat in} = \text{Heat out}.$$

These balances are a valuable tool that should always be used in the comparative evaluation of sludge thermal processing systems.

In a thermodynamic analysis, *material and heat are accounted for only when they cross the thermodynamic system boundary. Internal recycle loops*, if they are present, *do not affect the overall heat and material balance.*

Sludge Thermal Processing Systems

The four systems selected for analysis are representative of the sludge thermal processing methods currently available or under development:

- Multiple hearth incinerator
- Fluid bed incinerator
- Proprietary pyrolysis reactor
- Multiple hearth pyrolysis reactor

The following selected parameters provide a uniform basis of comparison:

- Minimum afterburner temperature; 1400°F
- Minimum excess air in flue gas; 20 percent

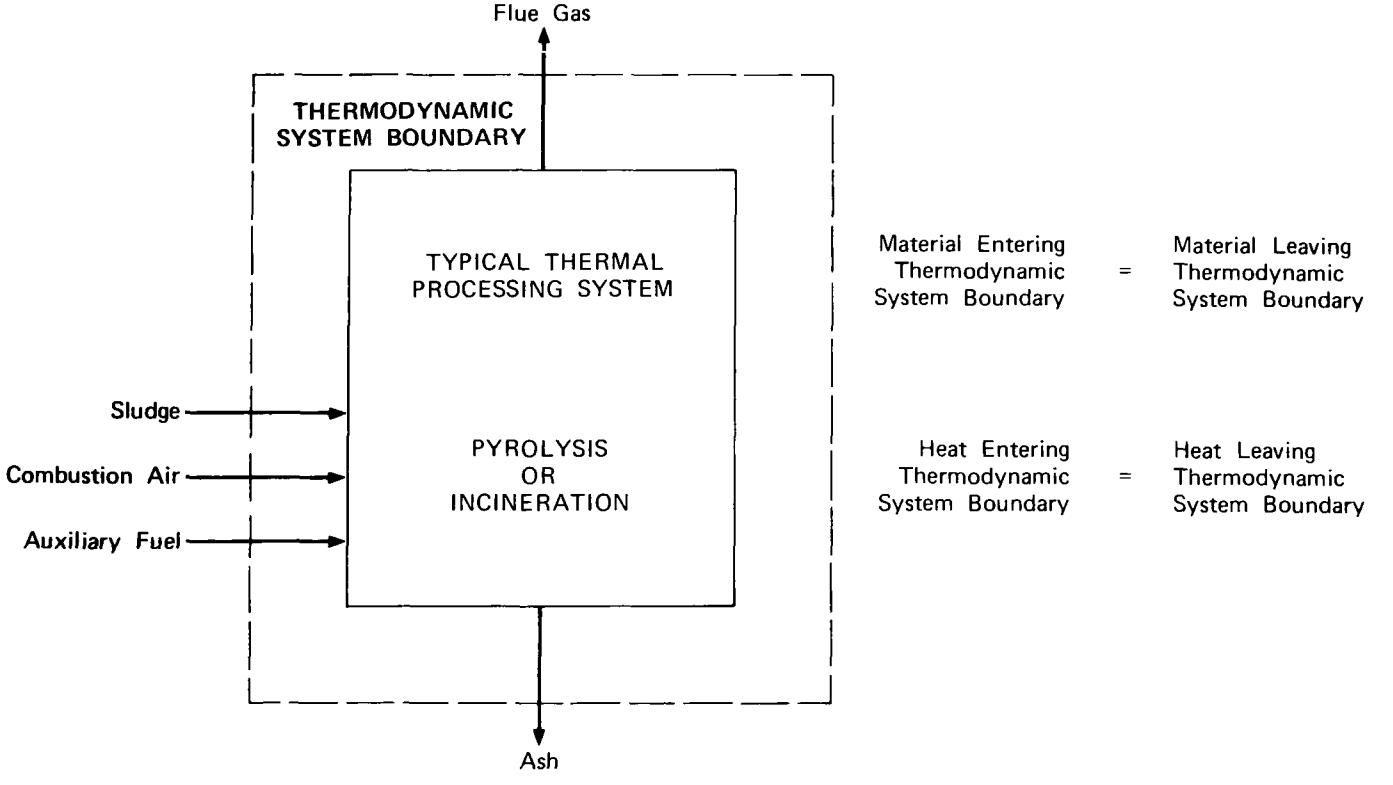

Figure 1: Typical Thermal Processing System.

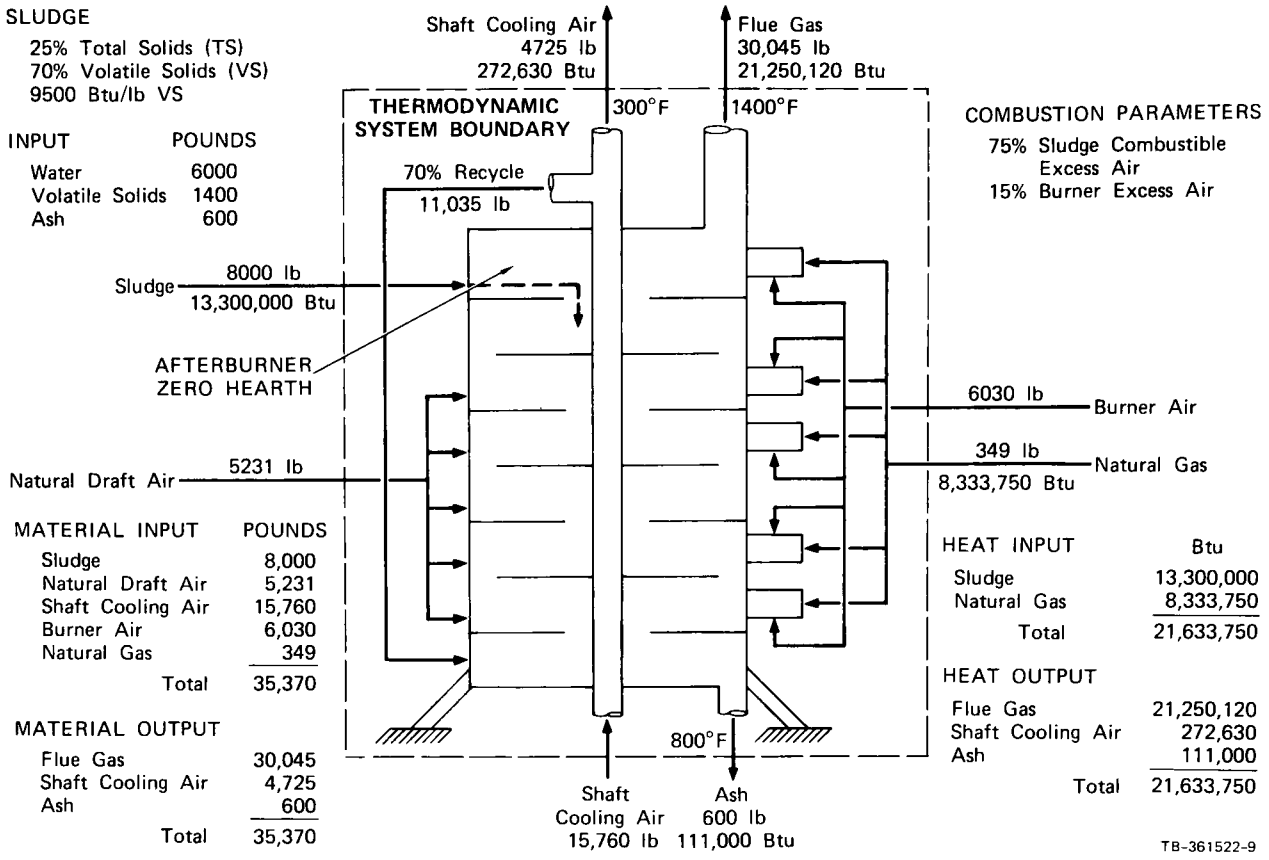

Figure 2: Multiple Hearth Incinerator.

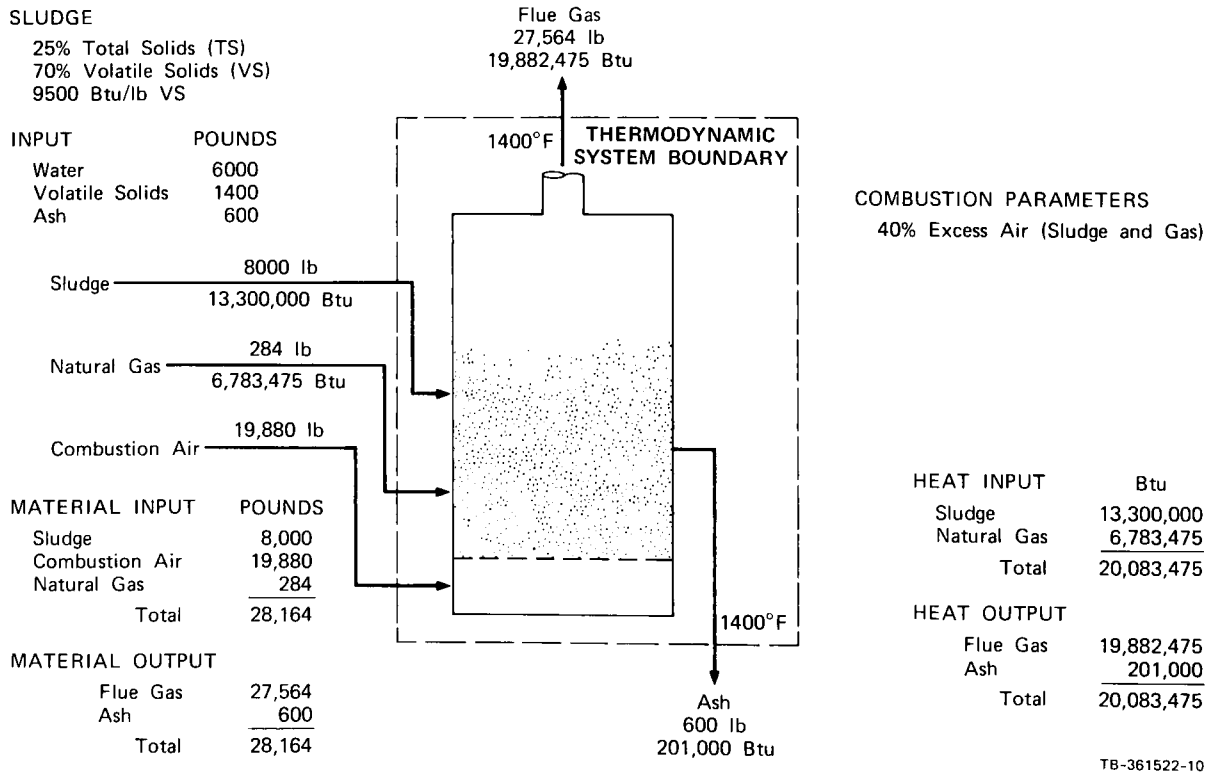

Figure 3: Fluid Bed Incinerator.

- Sludge solids content; 25 percent total solids
- Wall heat loss; none.

When excess air rates higher than the minimum value stated above are necessary for proper operation of a specific reactor, the higher rate has been used.

The four selected processes, briefly described, follow:

Multiple Hearth Incinerator. The multiple hearth incinerator, shown in Figure 2, represents the latest design, and the top (Zero) hearth has been used as an afterburner. In sales literature for this unit, the portion of the heated shaft cooling air recycled back to the bottom hearth for combusion is presented as a heat credit, but when a heat and material balances is performed, the overall effect, as shown in the figure, is actually a heat *loss*.

Fluid Bed Incinerator. The fluid bed incinerator, shown in Figure 3, is conventional except for its excess air rate, which is 40 percent. Sales and advertising literature claim excess air rates of the order of 20 percent, which would represent an oxygen level of approximately 3.5 percent (dry gas-volume percent) in the flue gas, whereas 40 percent excess air represents an oxygen level of approximately six percent. Our experience indicates that most fluid bed incinerators operate near the six percent oxygen level.

Proprietary Pyrolysis Reactor. The proprietary pyrolysis reactor, shown in Figure 4, represents an indirectly heated rotary kiln incorporating specific, patented design features. The application of this reactor for the pyrolysis of sludge is under current development and evaluation. This system has the following unique feature: After burning at temperatures above 1400°F for complete combustion and deodorization, the flue gases are used to evaporate the sludge moisture and pyrolyze the sludge without ever coming in contact with the solid material.

This type of indirectly heated pyrolysis process produces a char consisting of mineral ash and carbonaceous material. Although this char may be used, for example, as activated carbon for water treatment, it is our opinion that the production of char can be used to its best possible advantage in the concentration and retention of heavy metals contained in the sludge (see "Sludge Pyrolysis for Pollution Control").

Multiple Hearth Pyrolysis Reactor. Figure 5 shows a system for pyrolyzing sludge in a multiple hearth furnace. The air and fuel supplied to each hearth have been selected so as to maintain substoichiometric conditions throughout all hearths except the afterburner which is operated at 20 percent excess air. With the 25 percent total solids sludge used in our comparisons, the available heat is not sufficient to recycle a portion back to the furnace to sustain the process. Attempting to use the internal recycle loop, i.e., recycling the 1400°F exhaust gas back to the bottom hearth, would be like trying to lift yourself up by the bootstraps, and would not serve to sustain the process; as mentioned above, heat is gained or lost only as it crosses the thermodynamic system boundary. With a sufficiently high sludge solids content, the process could be made self-sustaining.

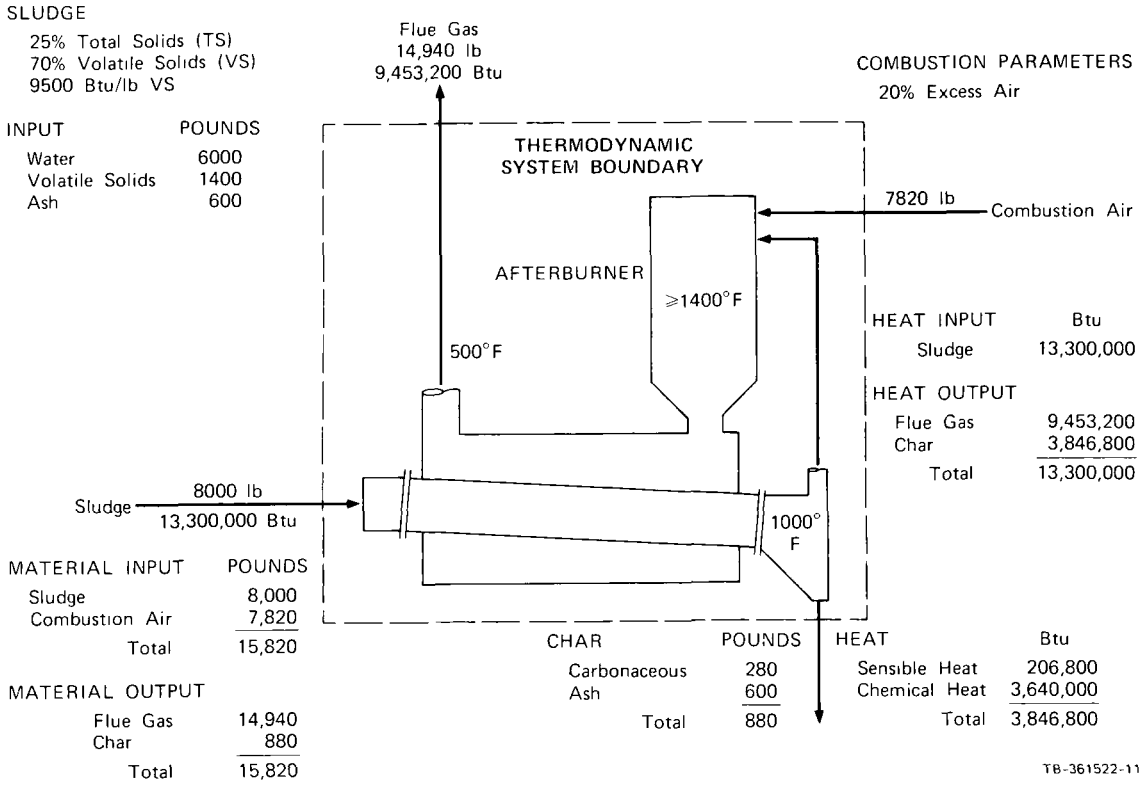

Figure 4: Proprietary Pyrolysis Reactor.

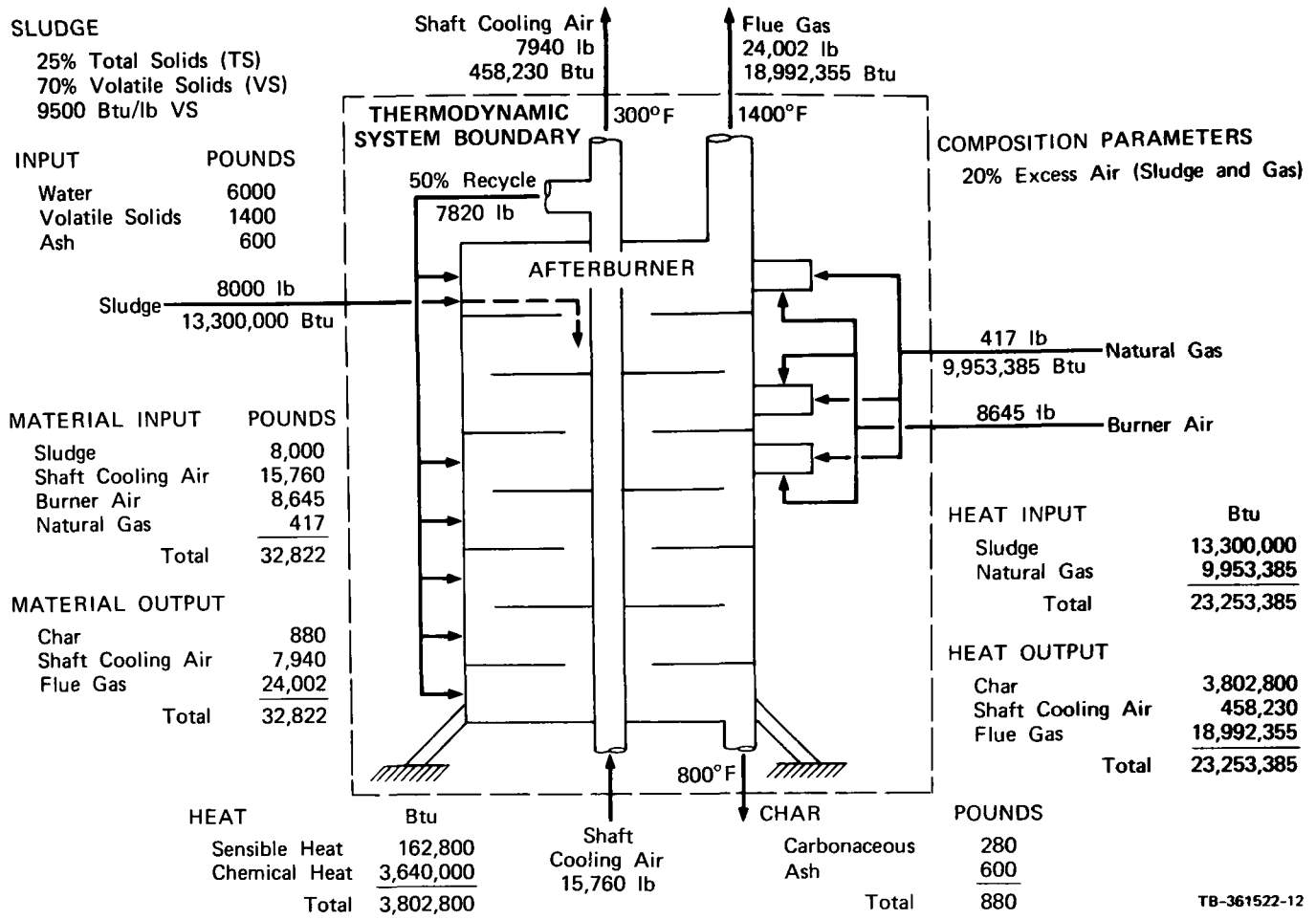

Figure 5: Multiple Hearth Pyrolysis Reactor.

As illustrated by this example, one cannot categorically state that all pyrolysis processes use less fuel and can produce energy. Each process must be carefully evaluated for each thermodynamic condition.

Comparison of Auxiliary Fuel Usage

The auxiliary fuel usage, expressed in pounds and Btu's, for each of the four thermal processes are shown in Table 1, below.

Comparing the fuel usage of the four processes, we find that the fluid bed incinerator uses less fuel than does the multiple hearth incinerator. If the multiple hearth incinerator could operate without an afterburner, so that the incinerator could exit at 800°F, the multiple hearth incinerator could also operate without any auxiliary fuel. However, afterburners operating at 1400°F are now required in New York, California, and several other states, and this requirement is anticipated to be extended to other regions of the country in a governmental effort to prevent the escape of odors and unburned hydrocarbons and to ensure complete destruction of pesticides and polychlorinated biphenyls (PCB).

TABLE 1
Auxiliary Fuel Usage

Process	Natural Gas lb/ton of Total Solids	Btu/ton of Total Solids
Multiple hearth incinerator	349	8,333,750
Fluid bed incinerator	284	6,783,475
Proprietary pyrolysis reactor	0	0
Multiple hearth pyrolysis reactor	417	9,953,385

The multiple hearth pyrolysis reactor shows extremely high auxiliary fuel usage, indicating improper process design and indiscriminate use of pyrolysis.

Sludge Pyrolysis for Pollution Control

When comparing the particulate emissions from a pyrolysis process which uses a high pressure drop venturi scrubber (30 in. w.c.)with those from an incinerator using a low pressure drop (four in. w.c.) spray chamber, obviously, the comparison should be made before the flue gases pass through the scrubber. Unfortunately, very few "hard" data are available on the emissions from pyrolysis process, and information must therefore be extrapolated based on first principles and similar processes.

Sludge pyrolysis systems, in which the combustion process is physically separated from the region where

the solid portion of the sludge is present, offer the potential for a significant reduction in the emission of pollutants. Because of the absence of the combustion air from the region of the solids, entrainment of ash by the flue products is minimized. In fuel gas-producing pyrolysis processes, the combustion can be achieved at a much lower excess air rate, which, in addition to achieving greater thermal efficiency, significantly reduces the volume of flue gases, and therefore, makes possible a greater level of control for the same energy input to the scrubber [8].

Where the combustion is separate from the solid ash-containing portion of the combustion unit, operation at higher, more efficient temperatures is possible because the danger of slagging and clinkering is eliminated.

The presence of heavy metals, primarily lead, zinc, cadmium, and nickel, in sludge and what becomes of them during sludge disposal, is of major concern in current sludge disposal programs. Scientific evidence now supports the hypothesis that low-temperature, char-producing pyrolysis processes may lead to the accomplishment of significant heavy-metal retention in the char. Analysis of coke indicates that heavy metals appear in higher concentrations after pyrolysis of coal than in the original coal sample. Studies of char produced by the pyrolysis of scrap tires [9] provide evidence that many potential pollutants remain chemically bound to the fixed carbon in the char. Unpublished experiments indicate that zinc can be chemically bound to the char when hydrocarbon is pyrolyzed.

In all studies indicating the possibility of heavy metal retention in the carbonaceous portion of char, the material has been indirectly heated in an atmosphere completely devoid of oxygen and at relatively low temperatures, below 1700°F. High-temperature processes or processes where air or oxygen, or both, are introduced, may not offer this advantage.

A program is being developed in which the ability of an indirectly heated sludge pyrolysis system to retain heavy metals in the pyrolysis char will be investigated.

Sludge Pyrolysis for Energy Recovery (Steam Generation)

The four thermodynamic analyses developed here indicate that the combustion of a 25 percent total solids sludge cake offers very little incentive to attempt heat recovery. A measure of heat recovery could be accomplished with those processes exhausting at 1400°F, but a far better alternative would be to change the process to minimize the usage of auxiliary fuel. In any process where heat recovery is contemplated, such recovery must not be accomplished at the expense of auxiliary fuel usage further upstream in the process.

It is quite easy to play a "numbers game" with heat recovery. It can be shown that a sludge incineration process with a 1400°F exhaust temperature can produce more energy (steam) (500°F boiler exit temperature) when a wet sludge and high excess air is used; that is, considering the total amount of steam produced. By examining the ratios, pounds of steam per pound of natural gas, or pounds of steam produced per million Btu of auxiliary fuel input, we arrive at a better appreciation of the process and the proper conclusion: the desirability of high solids content in the sludge cake to be processed and low excess air rate in the process system used.

Techniques are available today, such as heat treatment followed by vacuum filtration or high pressure filtration, which can produce a sludge cake in excess of 40 percent total solids.

To illustrate the principle of energy recovery, we performed a heat and material balance on a 40 percent total solids sludge cake. The proprietary pyrolysis reactor was selected because of the previous comparison, which showed this system to achieve the highest thermal efficiency and to produce a char for the retention of heavy metals. The combustion chamber is separated from the solids region so that the gases can be burned at low excess air and high temperatures without the danger of fusion of the ash. This system is shown in Figure 6.

As shown in the figure, only a portion of the hot flue gases is necessary to sustain the pyrolysis reaction. This analysis does not require accurate prediction of the quantity of heat that must be recycled to the reactor to sustain pyrolysis, because this recycling takes place in an internal (inside the Thermodynamic System Boundary) recycle loop and does not affect the overall heat and material balance. If an actual system were to be put into operation, then this recycle quantity would have to be known accurately.

At a wastewater treatment plant, the steam generated could be used for generation of electricity or for operation of the aerators and pumps, which are large consumers of energy.

SUMMARY AND CONCLUSIONS

In any pyrolysis process, the heating value of the pyrolysis products is equal to the heat of the original material plus any heat added. In our comparative thermodynamic analyses, using the thermodynamic system boundary and a heat and material balance, we have found that not all pyrolysis processes result in a reduction in auxiliary fuel consumption. Our analyses amplify the need to perform a heat and material balance on any proposed sludge thermal processing system before attempting to determine thermal efficiency and auxiliary fuel usage. Our analyses also indicate that, of the four systems evaluated, a proprietary pyrolysis reactor that is indirectly heated by the afterburner flue products requires the least amount of auxiliary fuel.

Indirectly heated, oxygen-free low temperature, char-producing pyrolysis processes have been found to also have the potential for preventing heavy metal emissions into air and water by chemically binding the metal in the

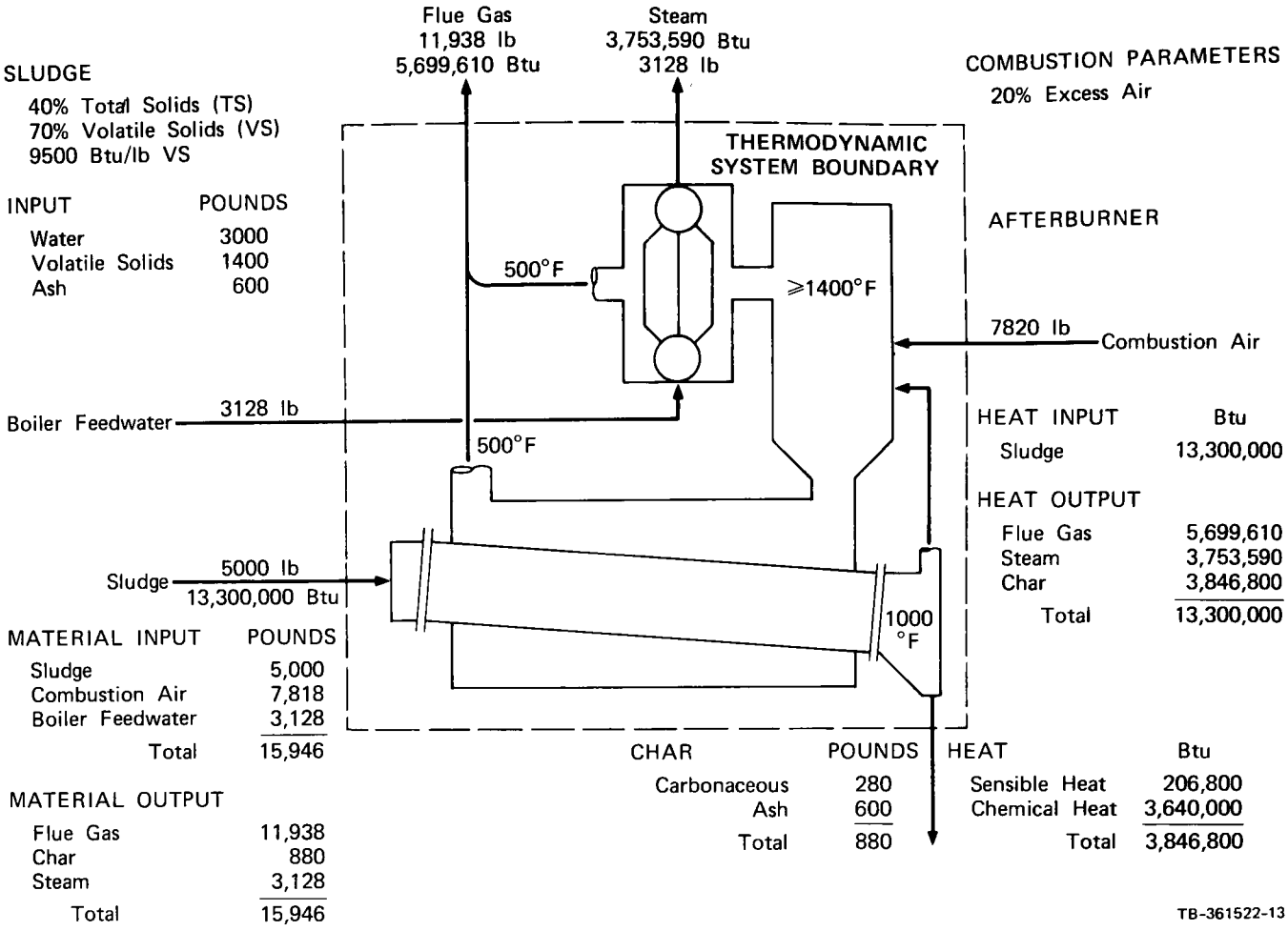

Figure 6: Proprietary Pyrolysis Reactor with Steam Generation.

carbonaceous fraction of the char. A program to study the ability of an indirectly heated sludge pyrolysis reactor to retain heavy metals in the pyrolysis char is under development.

Energy recovery from sludge combustion has been determined to be feasible, but initial efforts should be directed toward eliminating the use of auxiliary fuel during normal operation.

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A SLUDGE POLICY FOR THE 70'S

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I welcome the opportunity to present the views of EPA, Region IX on municipal sludge disposal. Let me begin by discussing EPA and the responsibilities imposed on us by Congress. Then I will mention the key features of environmental law, and add a few observations on the tenor of the times. Against this background, I will present my analysis of implications for municipal sludge management and disposal.

EPA is an independent agency in the executive branch of the Federal government. It is headed by our Administrator, Russell E. Train. He is supported by five Assistant Administrators: Assistant Administrator for Research and Development; Assistant Administrator for Enforcement; Assistant Administrator for Water and Hazardous Materials; Assistant Administrator for Air and Solid Wastes; and Assistant Administrator for Management.

The agency has about 10,000 people, equally divided between headquarters; field laboratories and regional offices. The regional offices, ten in number are responsible for implementing all phases of the agency's programs, except for research, which is handled by the laboratories. Thus, by quick arithmetic, you can conclude that the average regional office has a compliment of about 330 people.

When we were formed by Executive Order, EPA brought together programs from a number of operating agencies:

- Regulation of Pesticides from USDA.
- Water Pollution Control from Interior.
- Air Pollution Control from HEW.
- Solid Waste Management from HEW.
- Regulation of Ambient Radiation Levels from HEW.

Since 1970, we have had two new major programs added to our portfolio by the Congress: Noise Regulation and most recently, Control of Drinking Water Quality.

Thus, under FIFRA, we must classify every pesticide as to degree of hazard; ban those which are too dangerous to the environment; and see that anyone who uses the more hazardous ones are properly trained and regulated. Users of hazardous pesticides, of course, include just about everyone in Agriculture. Under FWPCA, we must license (or permit) every significant discharge to surface waters, and under provisions of the new Safe Drinking Water Act, we will have to regulate discharges to groundwater as well. This, of course, is in addition to insuring that virtually every purveyor of drinking water meets Federal standards. Under the Clean Air Act, we regulate every significant cause of air pollution. Let me skip over noise and radiation, even though they can become extremely important and time consuming concerns under some circumstances. But before going on, I should add, that we manage the largest capital construction programs in the Federal government. In California alone, our office had available on July 1, about 1.2 billion dollars for sewage treatment plant construction grants.

I mention these things to give you some idea of what the 330 people in San Francisco do. It should be clear that we have enough going on to keep busy. It should be even clearer that we are not in the game alone. More about this latter point in a moment.

Let me turn now to a discussion of the general nature of environmental law. Almost all environmental laws have the same general framework. They provide for: the setting of standards; a plan to achieve the standards; research and development; assistance; and enforcement.

The laws also have unique aspects, involving "state primacy" and citizen participation. Let's look at all of the foregoing elements briefly, beginning with standards.

Up until the Clean Air Act of 1970, and the FWPCA Amendment of 1972, the law generally relied upon ambient standards. These are maximum levels of pollution allowed in the ambient air, the open ocean or the flowing streams.

In 1970, Congress turned to emmission and performance standards. Thus under the 1972 amendments to FWPCA, every municipality must meet secondary treatment requirements by 1977. Indeed, such performance requirements have become the foundation of the law, and they reflect a new philosophy which is woven into it. Until 1970, the environment was looked upon as a proper waste disposal sink; provided adequate dilution of the

wastes was achieved. The new philosophy is that each discharger has a responsibility to keep his wastes out of the environment to the maximum extent possible.

Let's examine the next feature of environmental law. While the law generally provides for EPA to establish environmental standards, it provides for state governments to insure that the standards are implemented. This is the principle of primacy mentioned earlier. The state develops basin plans under Title III, and administers the NPDES permit program under Title IV of FWPCA. These are the guiding policy and procedural documents which govern implementation of the law. The law also explicitly provides that Federal effluent limits not diminish any state or local regulation or requirement.

As a corollary to primacy, EPA implements those aspects of the programs which a given state fails to undertake. Our experience has been that the states assumes those responsibilities which they judge to be reasonable and politically viable. Thus, whenever you see EPA out in front on a program, you should *expect* to find that the program is controversial or politically untenable in that State. The only exceptions to this situation are cases where the State is lacking in resources or authority. These exceptional cases generally do not come to the attention of the public. The result of this corollary is that EPA is widely regarded as a controversial and politically naive agency. Given the situation under which we operate, one should expect that we would make a few mistakes. We do make them, and I won't deny it. However, it is important to understand that primacy aspect of the law works to force EPA into the forefront wherever there is controversy or political pressure. These are the situations which everyone hears about because they are news.

Let me skip lightly over the research and assistance provisions of the laws which I am sure you are familiar with. The basic thrusts of research are to provide the data base for environmental standards, and to develop and demonstrate pollution control technology. The assistance programs encompass grants to States to support their environmental programs, as well as the wastewater treatment grant program mentioned earlier.

Let's also review another unique aspect of environmental law. Beginning with the 1972 amendments to FWPCA, local government was given an authorative role in implementation. The section, popularly known as 208, provides for the development of Regional entities to plan and manage pollution abatement. The scope of planning and management required under the law is quite broad. Unlike traditional planning, the institutional, financing, regulatory and enforcement provisions must be detailed. It is clear that Congress intended that 208 plans would be implemented.

Citizen participation is another key element of environmental law. As an aside, let me outline what citizen participation means to me. We begin with the general foundation; the citizen's right to know what government is doing. This right to know applies to all activities of the Federal government, and it is underwritten by the Freedom of Information Act. Then there is the citizen's right to participate in the process of formulating action plans and programs. This right is provided for legally by the Administrative Procedures Act, as well as NEPA. Beginning with the 1970 Clean Air Act, Congress added a new dimension to citizen involvement; the right of a citizen to hold government accountable for it's actions. EPA can be sued for failure to take any action which is not discretionary under post 1970 environmental law. This citizen standing aspect of the law has been tested and the result is a new appreciation of the fact that we must act to carry out the law.

Indeed, we must act even if we feel that all available options are controversial. The new drinking water legislation, passed in late December of last year, has taken citizen involvement a step further. Under its provisions, there is citizen standing to sue EPA, the State, or the water utility to ensure delivery of water meeting Federal primacy drinking water standards. Moreover, the water utility is required to monitor the quality of it's water, and to publicize any incident in which (1) a required measurement is not made; or (2) a standard is exceeded. Thus, the law establishes a mechanism for direct citizen enforcement.

If history is any teacher, a role for local government and stronger citizen involvement will be embodied of all future environmental legislation.

So much for the law, let's look at the "tenor of the times." For the most part, experience in Region IX, and I believe nationally as well, is that basic sewer systems are in place. The task we face is generally to provide treatment, or to upgrade the level of treatment with some provision for expansion of the system. Secondary treatment is the minimum; but in some cases, water quality standards or other conditions will require AWT techniques. Many of the needed system improvements are now under construction, and within the next year or so we expect that almost all of them will be in the design or construction phases. Within another year or so, they will be going into operation. What I am saying, is that the rapid increase in sludge volume discussed in the technical sessions will be here soon. Within the next year or so, all the studies must be done in order to allow time for implementation and for start up of operations of sludge management systems.

That means we don't have time for prolonged research. Results produced two or more years into the future will have to await the next generation of sewage plant construction to be implemented. What we need now are studies leading to immediate implementation. It should be emphasized that Step I grant funds are being used, to fund sludge studies in Region IX, precisely because we expect the studies to be followed by design, construction and operation of the sludge handling systems which the studies recommend. We view sludge management as an integral part of the overall sewerage

system. Where separate design of sludge facilities is undertaken, as a matter of convenience for the parties involved, it is treated as a separate phase-of-construction rather than as a separate project.

The thought that we will actually build what we are now planning leads me to another point that must be emphasized. I fully agree with Congressman Brown that we cannot be satisfied with narrow technical solutions. To be implementable, any sludge study should cover all the aspects mentioned for a 208 study. The division of responsibility between various public and private agencies must be spelled out, revenue and financing must be provided for, institutional arrangements must be provided, and the regulatory and enforcement aspects of the problem should be addressed. These may be more or less important in any given situation. My point, however, is that if we get well down the road toward land disposal at a site in "Outlying County," only to find that the County Commissioners of "Outlying County" (or the local planning and zoning board or whomever) oppose the site, then we have failed just as surely as if we had imporperly designed the sludge thickener.

This brings me to my final observation on the tenor of the times. The social sciences literature, beginning with Vance Packard in the late 1950's and maturing with Kenneth Boulding's monograph on the "SpaceShip Earth" has held that the social and economic system must change. The reality that their thesis was true was brought home to most of us by the energy crisis. It should be noted, however, that energy is not the only thing in short supply (besides money). We have in the recent past seen shortages of lumber, cement, steel alloys, food products, and numerous other commodities.

The philosophy put forward by Boulding is that society should shift from the concept of GNP (or rate of consumption) as the measure of our well-being to the idea that we are better off when we conserve our resources and use them carefully. This principle is gradually becoming generally accepted in society, and the change in philosophy in environmental law is only one aspect of this general trend. My observation is that environmental law is in the fore-front of this trend, however, and this puts us in a position similar to the first year hydraulics student who is about to experience water hammer. We are experiencing as a society, the difficulties associated with trying to change the system by closing the valve at the outlet end. As professionals we know, if my analogy is a good one, the valve must be closed slowly and that the pressure waves back up through the system must be monitored carefully. We also know fundamentally that the right way to deal with the system is from the other end.

What does all this mean from the practical point of view? First, referring back to my comments on the law and its requirements, we cannot use what I have just said as the basis for delay. The arguments that we should continue unregulated dumping sludge in the ocean, the nearest large river, or a nearby gravel quarry have been heard. The decision has been made by Congress. The answer is no. Lingering arguments on behalf of this idea, if there are any, particularly remind me of arguments made a decade ago in favor of continuing raw sewage discharges. Such arguments are not consistent with the emerging philosophy of the 1970's.

Having said that, however, what principles do my observations suggest? Let me state a few of them, although I am sure that the list is not inclusive.

An obvious first step towards the conservation ethic is to reclaim or recycle our waste products. Thus, a preferred option for management of sludge is to utilize it for some beneficial purpose.

Another obvious step is to attempt to reduce the amount of material put into the sewer system, where other more appropriate alternatives are available. Systems analysis of industrial process, where I have seen them done indicate that there is a potential to reduce wastes from this source. Where this is the case, industry should be encouraged to reduce waste volume to the sewers. Such encouragement should automatically result from the implementation of pre-treatment and industrial cost recovery requirements of the law, since those industries which are subject to the highest charges have the greatest incentive to reduce their flows. This aspect of the institutional process should be reinforced (or at least not circumvented) by the sludge management program.

A third point, made previously, is that emphasis should be on implementing existing technology to deal with existing or impending problems.

A fourth point, especially pertinent here in California, is that disposal of sludge to the ocean is not acceptable for the simple reason that it is expedient. In accordance with the principles of Federal law, and the requirements of State/Federal policy, if there are feasible alternatives to ocean disposal (and we believe that there are) these must be pursued.

A last point is that we operate with unique citizen participation requirements. While it is obvious that "you can't please all of the people all of the time," as Congressman Brown quoted yesterday, it is also true that those who dissent have an authoritative way for doing so. The only way to proceed without running into real trouble in this situation is by adhering carefully to the procedural requirements. Our experience has been clear! Good decisions reached in accordance with proper procedures will stand up. Where procedures have not been followed, we encounter delays that have proven to be more costly than any other type of error one can make. Thus, today's manager must understand and carefully follow proper administrative procedures.

While, as I said, it may not be an inclusive list of do's and don'ts, I hope it provides some "food for thought."

ECOLOGICAL IMPACT OF THE DISPOSAL OF MUNICIPAL SLUDGE ONTO THE LAND

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LEGISLATIVE BACKGROUND

The objective of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500, as amended) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." To achieve this objective, the Congress established two goals. The interim goal for 1983 is to assure "fishable and swimmable" water, where attainable. The ultimate goal for 1985 and beyond is to eliminate the discharge of pollutants.

To expedite the achievement of these goals, Congress instituted a two-step process by which publicly owned treatment works are expected to meet the national goals:

- by 1977, they are to produce effluents at least equal to national standards for secondary treatment; and
- not later than 1983, they will provide for the application of the best practicable waste treatment technology (BPT).

During the formulation of the Act, Congress devoted little attention to the matter of the generation and disposal of sludge. In the House-Senate Conference, however, Senator Caleb Boggs noted that larger volumes of by-products would be generated by the advanced treatment processes required by the Act, and that the disposal of sludge could produce serious problems. The Conferees considered that the existing techniques for sludge disposal were unsatisfactory. To provide a regulatory mechanism, they inserted into the Act, Section 405, which is entitled, "Disposal of Sewage Sludge."

Section 405 is designed to prohibit the disposal of sewage sludge in any manner that might affect the inland or coastal navigable waters of the United States. This comprehends the dumping of sludge on land in such a fashion as to run off into the waters. Land disposal sites will be required to obtain a permit subject to "each criterion, factor, procedure, and requirement" applicable to a permit issued under Section 402—the National Pollutant Discharge Elimination System.

The possibility that some "mid-course correction" might be necessary in the requirements also was considered during the House-Senate Conference. The Conferees amended Section 315 of the Act to provide for an independent evaluation of the regulatory aspects of the legislation. This evaluation is to be made by a 15-member National Study Commission that now is designated as the National Commission on Water Quality.

The principal attention of the Committee is addressed to the technological aspects of achieving the effluent limitations and goals set for 1983, but it also is evaluating the impact of the 1985 goal of pollution-free water. The Committee must examine the total economic, social, and environmental impacts associated with the achievement of those goals. The findings of the Commission are intended to serve as the principal data upon which the need for "mid-course corrections" in scheduling or requirements will be based. The report of the Commission, with its recommendations, is to be submitted to Congress not later than 18 October 1975.

PURPOSE AND SCOPE

The National Commission on Water Quality recognized that facilities for the disposal of sludges on land doubtless will be important components of wastewater treatment systems designed to satisfy the 1983 regulations and the 1985 goal set by Congress. Particularly because the environmental consequences of such an intermedia transfer of potential pollutants were considered only peripherally during the formulation of the Act, the potential environmental impacts of land disposal were questioned seriously.

This paper originated when a team formed by Environmental Quality Systems, Inc. (EQSI), Geraghty and Miller, Inc., and Jack McCormick & Associates, Inc. (JMA), was selected by the Commission and contracted to evaluate certain intermedia impacts of residuals disposal. JMA was assigned responsibility for the assessment of the impacts on wildlife and natural vegetation of incineration, ocean dumping, and land disposal of residuals, including both sludge and liquid effluent. The present paper is a summary of our findings on the potential impact of the disposal of municipal sludge onto the land.

Biological Effects of Constituents

The overall investigation was addressed to the volumes and varying composition of sludges to be generated by a wide range of industrial categories, as well as to sludge from municipal treatment works. Because the team members had to work in parallel, rather than in sequence, the JMA ecological assessment needed some standard basis for comparison between this great range of sludges.

One of the first major decisions in the program was to examine the potential biological effects of individual constituents of sludge. Constituents are those components of any type of sludge that potentially are pollutants. They include nutrients, microorganisms, and toxic substances.

In collaboration with EQSI, a considerable amount of information was collected on the composition of sludges. These data were summarized to describe the range of concentrations of various constituents in municipal sludges. Because the ranges are so wide, and because extremely high concentrations of virtually every constituent were reported in sludge from one or more plants, it became apparent that municipal sludges are highly variable, and that they overlap all or most industrial categories.

A substantial proportion of the JMA work effort was devoted to locating information on the biological effects of sludge constituents. A basic resource was the *Blue Book*[1], which was compiled by the Committee on Water Quality Criteria for the US-EPA in 1972. We supplemented the Blue Book data and reassembled the information into a format useful to this study.

Biological Magnification of Pollutants

In the assessment of the potential biological effects of sludge constituents, an important consideration is the tendency of organisms to accumulate metals, certain pesticides, polychlorinated biphenyls (PCB's), and radioisotopes. Through a complex of processes that collectively are known as *biological magnification*, the concentrations of these substances in the tissues of organisms may come to be substantially greater than in the environment. The ratio of the concentration of a pollutant in an organism to that in the environment is termed the *concentration factor.*

An experience at Clear Lake, California, demonstrates biological magnification[2]. The lake was treated with the pesticide DDD to control nuisance hatches of flying insects. After treatment, the concentration of DDD in the water was 0.02 ppm. In the lake plankton, however, the concentration of DDD was five ppm. The fat of fish that fed on the plankton contained more than 2,000 ppm DDD. Grebes ate the fish and died. The tissues of the birds contained 1,600 ppm DDD.

This case illustrates that the concentration of a persistent contaminent generally is greater at successively higher trophic levels. The concentration in the plankton, the minute green plants in the lake, was 250 times as great as the concentration in the water. The concentration in the tissues of the fish that fed on those plants was 100,000 times as great as that in the water.

The grebes, which preyed on the fish, had a concentration that was 80,000 times as great as that in the water, but the concentration was lower than that in the fish. This does not contradict the general rule of "higher concentrations at higher trophic levels." Instead, it demonstrates a second fact, organisms vary in their ability to tolerate the toxic effects of a particular substance. The fish still were alive, even though the concentration of DDD in their fat was 2,000 ppm. In contrast, the birds died when the concentration of DDD in their tissues neared 1,600 ppm.

Through this process of biological magnification, a substance that is sparse in the environment may be concentrated many thousandfold by organisms. This may result in injury or death to sensitive organisms. It also may render fish, shellfish, game, livestock, and crops unfit for human consumption. The only technique that can be used to protect the biota and man is to minimize or prevent the entry of cummulative pollutants into environment.

With a knowledge of potential biological magnification, our consideration of the information assembled on the biological effects of constituents led us to conclude that the criteria previously recommended to protect water quality for various types of uses are reasonable. Because the data base is sparse, however, more intensive investigations may indicate that some criteria are more conservative than is necessary, or they may be too liberal to protect certain uses in some places. At this time, however, no such conclusions are warranted.

A basic assumption of this assessment is that all facilities for the disposal of sludge onto the land will meet all requirements of Section 405. They will satisfy all applicable environmental standards, including standards for surface water quality.

The Existing Conditions of the Nation

To assess the potential environmental impact of a proposed action, one must understand the existing conditions of the site on which the action is to occur. For this investigation, the proposed action is the disposal of sludge onto the land. The site is the entire nation.

The staff of the Commision and the members of the team recognized early during this investigation that some scale of assessment must be established. Very detailed information is available for some areas, but the analyses of other areas can be characterized as "coarse grained." To assure comparability and uniformity, the information in the *National Atlas*[3] was selected as the standard source and scale for the original ecological inventory and assessment.

The basic input data, thus, are at a scale of one inch equals 118.4 miles, or one square inch equals about nine

million acres. At the scale of the final report, one inch on the map is equal to about 150 miles on the ground, so one square inch includes about 14.4 million acres.

To visualize better, imagine that this assessment was made from a space platform. It is an overview of the Nation, and is addressed to major environmental features. It should not be considered to be applicable even at the scale of a single state, and certainly will be too coarse in grain for application to any smaller political subdivision.

Natural Vegetation of the United States

In the background report prepared for this ecological assessment, a detailed description of the vegetation types of the United States is presented. Primarily on the basis of vegetation characteristics, the conterminous United States was separated into three major geographic divisions: the western; the midcontinental; and the eastern United States (Figure 1). Three subdivisions were recognized in the West: The Pacific; the Basin; and the Rocky Mountain Regions. Similarly, a northern region, a central region, and a southern region were recognized in the East.

Endangered and Threatened Species

The inventory of existing conditions included an analysis of the prominant species of wildlife in each of the vegetation regions and in each major vegetation type. As the investigation proceeded, however, it became apparent that the impact of land disposal on wildlife probably will be less significant than the impact of wildlife laws on the availability of sites for land disposal!

The history of wildlife protection is long, and extends back at least to ancient Egypt. Until recently, however, the concern of man largely has been toward those species that he hunts or which are important in various religions or ceremonial rites.

During the twentieth century, attention has been devoted more and more toward vanishing species. Piecemeal approaches that have been implemented in the past, however, have not checked the technological assault on critical habitats or the surges of population growth and sprawl that threaten to sweep many of our co-habitants of the earth to extinction.

A series of international treaties and meetings ultimately led, only a decade ago, to the passage of the first

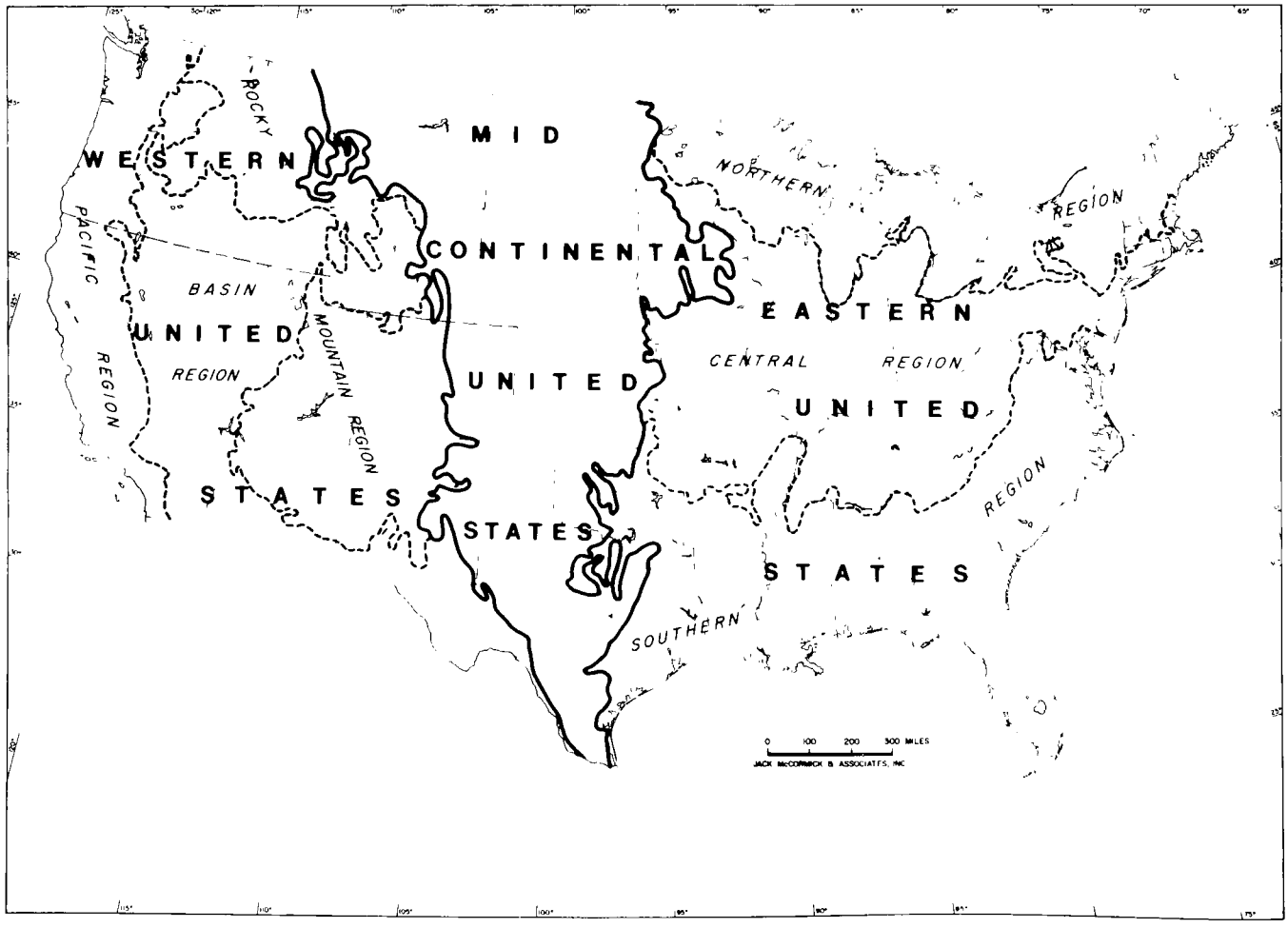

Figure 1: Vegetation Areas.

law in a series of very important Federal wildlife laws. This was the Endangered Species Protection Act of 1966.

The 1966 law was amended by the Endangered Species Conservation Act of 1969. Initially, these laws seemed to have little relevance to land use decisions. The Secretary of the Interior issued lists of endangered species, but few non-biologists seemed to be concerned with them.

As the National Environmental Policy Act of 1969 stimulated a greater attention to environmental concerns, however, the potential impact on endangered species became an important topic in Federal decision-making.

Because the 1969 Act regarded as endangered only those species threatened with extinction throughout the United States, very few project sites conflicted with habitats that support endangered species.

The 1966 and the 1969 Acts were supplanted by the more comprehensive Endangered Species Act of 1973 (Public Law 93-205). A more appropriate name for this 1973 law might be the "Wildlife Habitat Conservation Act." The first purpose listed by Congress in the Act is:

- to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved . . .

The definition of wildlife was broadened to include "any member of the animal kingdom", from elephants to protozoans, and two categories of endangerment were established.

- An endangered species is one that now is in danger of extinction, and
- A threatened species is one that is likely to become an endangered species within the forseeable future if present trends continue.

An equally significant aspect of the Act is that the designation of a species for Federal listing no longer is tied to its nationwide status. Rather, it is to be based on "all or a significant proportion of its range." Section 4(b)(2) of the Act indicates that designations are to consider "any political subdivision of any nation . . ." A recent proposed action to reclassify the American alligator, and to delist the species in three Louisiana parishes, suggests that Federal designations in the future may differentiate categories of endangerment to the county level.

As of 8 July 1975, the Federal list of endangered species included 117 American species. Of these 51 are birds, 31 are fish, 24 are mammals, seven are reptiles, and four are amphibians. Seventy-five occur in the conterminous states, 26 are in Hawaii, four are in Puerto Rico, and one is in the Virgin Islands. Eleven others are oceanic.

The States also have enacted legislation to protect endangered species. To date, 42 states have replied to a JMA qustionnaire. Of these, 38 have endangered species legislation or other laws that enable administrators to promulgate regulations to protect endangered species. Two other states indicated that endangered species bills have been submitted and are expected to be acted upon favorably. Two states reported that no legislation exists and that none is contemplated.

State lists of endangered or threatened species currently include numerous taxa that are not on the Federal list. It appears, however, that within a few years the Federal power may be placed behind each state list by virtue of the 1973 Act. It also is likely that state lists, which now are based largely on statewide status, may be diversified to recognize county-to-county variability.

Major Land Uses and Characteristics

Developed Lands and Undeveloped Lands. To provide a basis for an assessment of the availability of areas suitable for the land disposal of sludges, the United States was subdivided into two general categories of land use—developed or urbanized lands and undeveloped lands (Figure 2).

The largest proportion of the total volume of wastewater treatment residuals will be generated in the urban areas of the United States. Vacant tracts that are large enough to be economical for land disposal are scarce throughout the urban areas. Where they do exist, alternative potential uses, for industry, for commercial development or for residences, will exert strong market pressures, and may bid the price of the land to a point that land disposal would be infeasible. Citizen opposition to disposal sites in densely populated areas also is expected to be strong.

It virtually is certain that the bulk of the sites for the disposal of residuals on land must be sought in the areas characterized as non-urban, or undeveloped. Some of these lands will not be suitable owing to adverse soil conditions, high water tables, inappropriate climatic conditions or other physical characteristics.

Lands that do satisfy the guidelines for the physical quality of the site may be disqualified on other bases. The Endangered Species Act of 1973 and state laws and regulations that are coordinated with the Federal act, in combination with other environmental legislation, soon may exert a strong control over land uses in the United States. Through the environmental assessment process, these recent laws may restrict new development to the existing urban areas and their immediate fringes. Such controls, if they are applied to implement appropriate regional plans, could increase the energy-efficiency of the Nation. They also will increase the competition for sites that are approved for use in the regional plans.

This enumeration, therefore, is addressed to the identification of areas with major natural or institutional limitations on the use of undeveloped land for the disposal of residues.

Critical Areas for Land Disposal of Sludges. Areas that are critical for the disposal of sludges on land exhibit environmental hazards and/or impose other limitations. These lands and the biological communities they support may be affected adversely by the disposal of

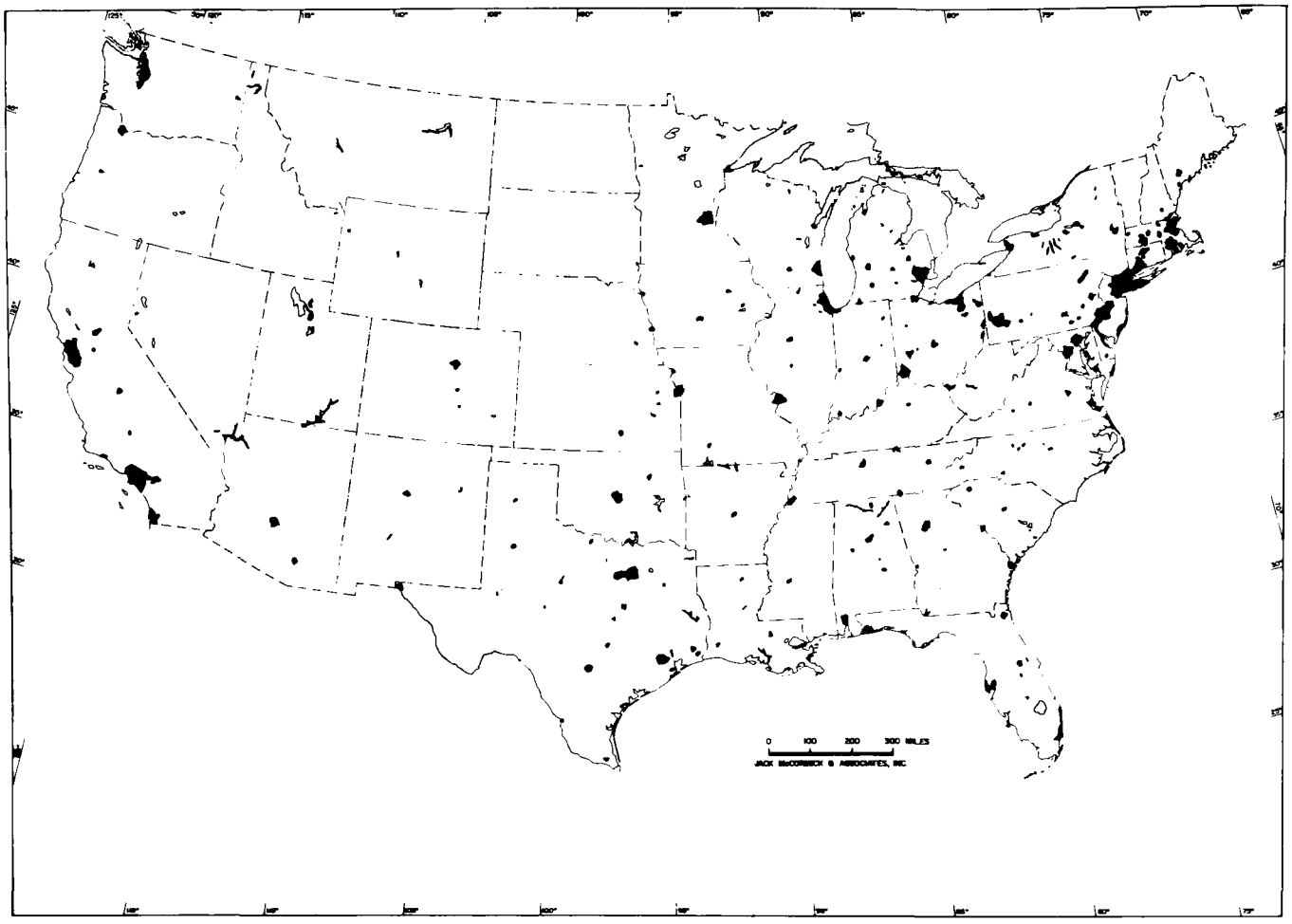

Figure 2: Urban Areas (Adapted from U.S. Dept. of Interior Geological Survey, 1970).

sludges. The potential for the contamination of the environment in most critical areas is intensified by the sensitivity of certain natural processes. Areas of steep slopes, porous or unstable bedrock, or high water table, for example, may be particularly susceptible to degradation. Critical habitats of endangered or threatened animals or plants could be altered to the degree that they no longer function to support viable populations of the imperiled species. Critical areas for the disposal of residues by storage or land application techniques are listed in Table 1.

National Park System [4,5]

Most of the large National Parks are situated in the western United States. A large proportion of the National Historic Sites, National Historical Parks, National Monuments, and National Seashores are in northeastern states. Few properties administered by the National Park Service are located in the midwestern states.

National Forests and National Wildlife Refuges

Most of the National Forest lands are located in the western states, and the largest proportion of the acre-

TABLE 1
Critical Areas for Land Disposal of Sludges

Disposal of Residues by Storage	Land Spreading of Sludge
National Parks	National Parks
National Seashores	National Seashores
National Lakeshores	National Lakeshores
National Historical Parks	National Historical Parks
National Memorial Parks	National Memorial Parks
National Recreation Areas	National Recreation Areas
National Battlefield Sites	National Battlefield Sites
National Monuments	National Monuments
National Wildlife Refuges	National Wildlife Refuges
National Forests	State parks
State parks	State wildlife areas
State wildlife areas	State recreational areas
State forests	Designated or potential natural areas
State recreational areas	Karst topography
Designated or potential natural areas	Wet soils
Floodplains	Land with slopes greater than 8%
Inland and coastal wetlands	Densely populated areas
Wet soils	Critical areas for imperiled species
Karst topography	
Land with slopes greater than 8%	
Densely populated areas	
Critical areas for imperiled species	

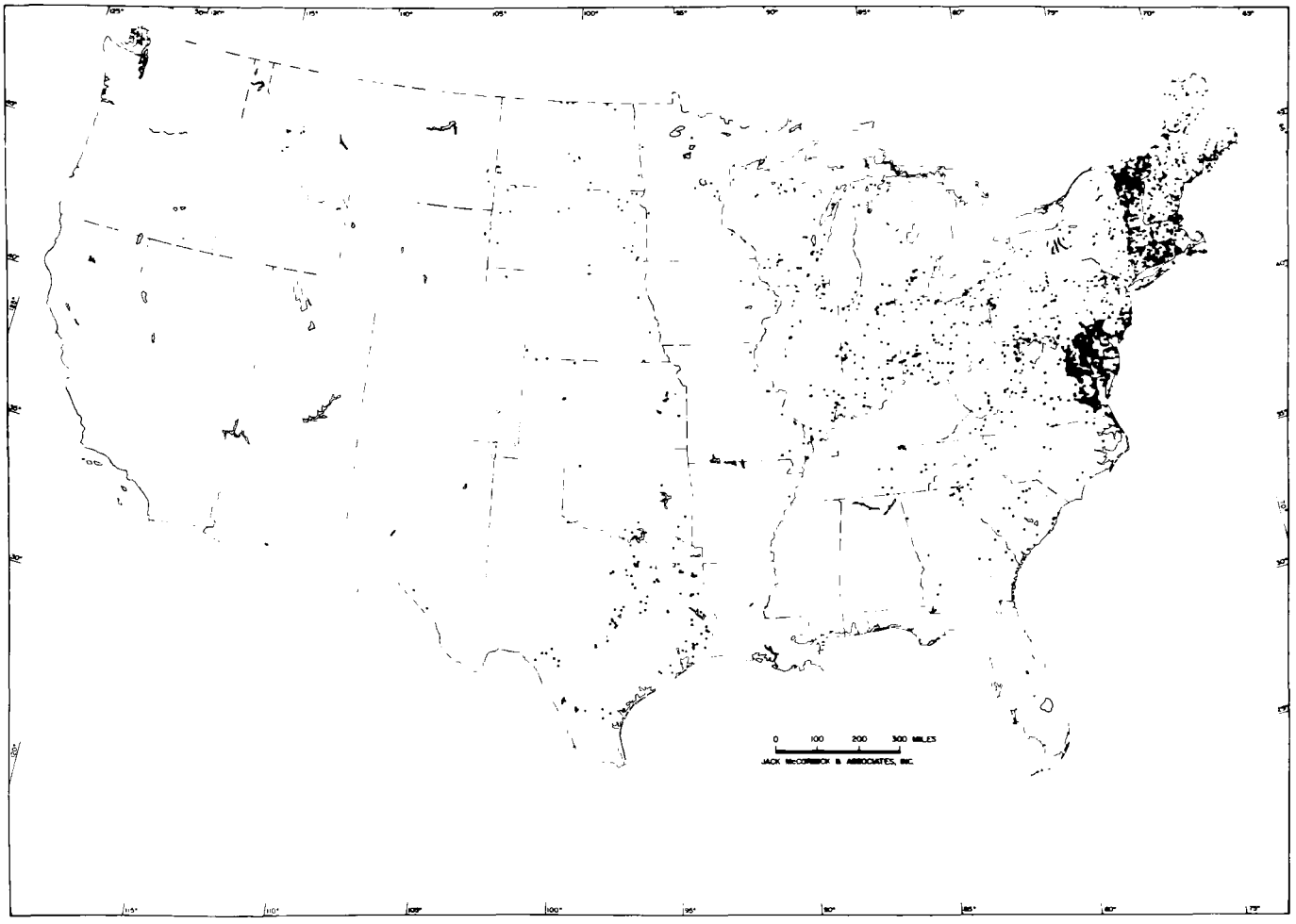

Figure 3: Natural Areas (Adapted from American Institute of Biological Sciences, 1974).

age is in the Rocky Mountains and the mountains of the Pacific states. National Wildlife Refuges are most prominent in the western United States and in Florida.

State Parks

State parks and recreation areas are concentrated in the eastern United States, the Midwest, and California. Some parks, such as the Anza Borrego Desert Park (California) and Baxter State Park (Maine), contain more than 100,000 acres. Most state parks, however, contain fewer than 500 acres.

Natural Areas

Natural areas are lands that are preserved, or which have been recommended for preservation, to protect representative natural ecosystems or populations of endangered plants or animals (Figure 3). Most natural areas have been disturbed only to a very limited degree by human activities, but areas that are recovering from disturbance also may be included.

An inventory of the natural areas of the United States that was conducted by the American Institute of Biological Sciences[6] was the primary source of data. The comprehension of the inventory, however, varies from state to state and no data were obtained from California, Florida, and several other states.

The AIBS investigation identified areas that total 9,636 square miles. A survey conducted by the Nature Conservancy[7] recorded 5,057 square miles of natural areas that currently are administered by state governments in the conterminous United States and 6.9 square miles administered by the government of the State of Hawaii.

Floodplains

The most extensive areas of floodplain land in the United States are located along the Mississippi River. The floodplains shown in Figure 4 are based on the northern and southern floodplain forest types mapped by Kuchler[8]. Other extensive floodplains are situated along the East Coast of the United States and along the tributaries of the Mississippi River.

Steep Slopes

The slope of the land surface is critical to the use of a site for the disposal of sludge. Owing in part to the char-

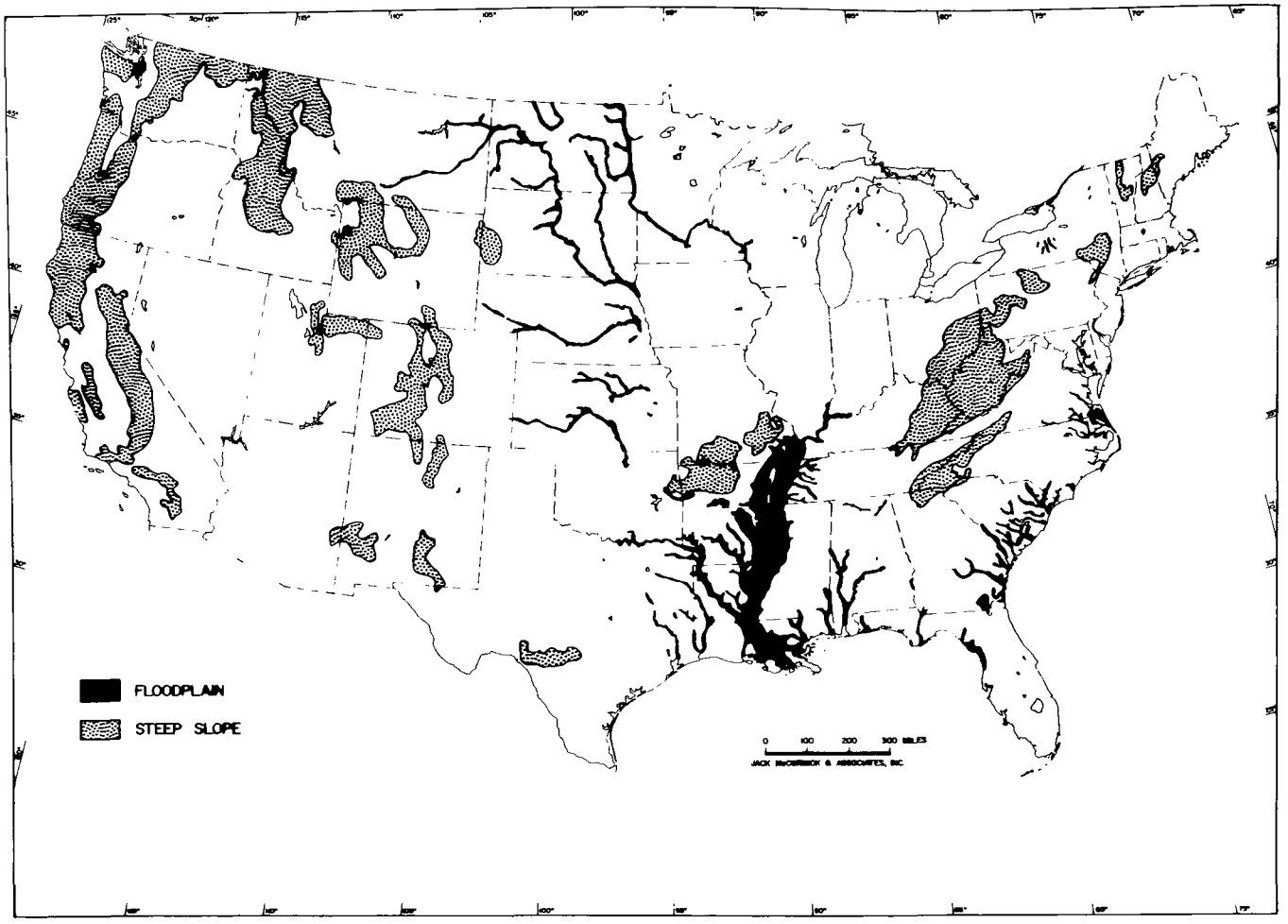

Figure 4: Floodplains and Steep Slopes (Adapted from Kuchler, 1970, Hammond, 1970).

acteristics of the equipment required, slopes of more than eight percent generally are not suitable.

Operations on steep slopes, including the disposal site, areas utilized to store cover materials, access roads, and areas used for supporting services, generally will induce accelerated runoff, will expose soils, will create artificially steep grades, and, consequently, will intensify erosion and sedimentation.

Sections of the nation in which slopes steeper than eight percent occupy at least 80 percent of the surface are identified in Figure 4.

Wetlands

The wetlands of the nation consist of marshes, swamps, open shallow waters, and seasonally flooded lands. Wet soils are prominent in the plains of Minnesota, the Mississippi Valley, Florida, and other parts of the Atlantic and Gulf Coastal Plain (Figure 5). These wet soils are saturated with water either seasonally or permanently. Most wetlands feature organic soils (peat or muck) or recently deposited alluvial soils. The aquatic environment of the wetlands is an essential habitat for waterfowl, many species of fur animals, and some species of farm game, forest game, and warm-water fish [9].

Karst Lands

Karst lands primarily are developed in Texas, Florida, and several Appalachian states (Figure 6). The rocks in these areas predominantly are limestone, dolomite, and/or gypsum. Solution channels and cavities in the rocks act as conduits through which surface water rapidly enters the groundwater system.

SUMMARY OF CRITICAL AREAS

Various kinds of lands that are expected to present major restrictions for the disposal of sludges are listed in Table 2. The gross area of each land type, in square miles, was estimated from the best data available.

No nationwide measurements of the areas of state forests, floodplains, steep slopes, or karst lands were found. The total area of those types of critical sites for which geographically separable, quantitative data were available is 628,954 square miles.

The total of the quantified critical areas in the conterminous states in 547,799 square miles. This is approximately 18 percent of the total land surface of the conterminous states. Of the remaining 2,417,009 square miles, 69 percent (1,660,244 square miles) is categorized

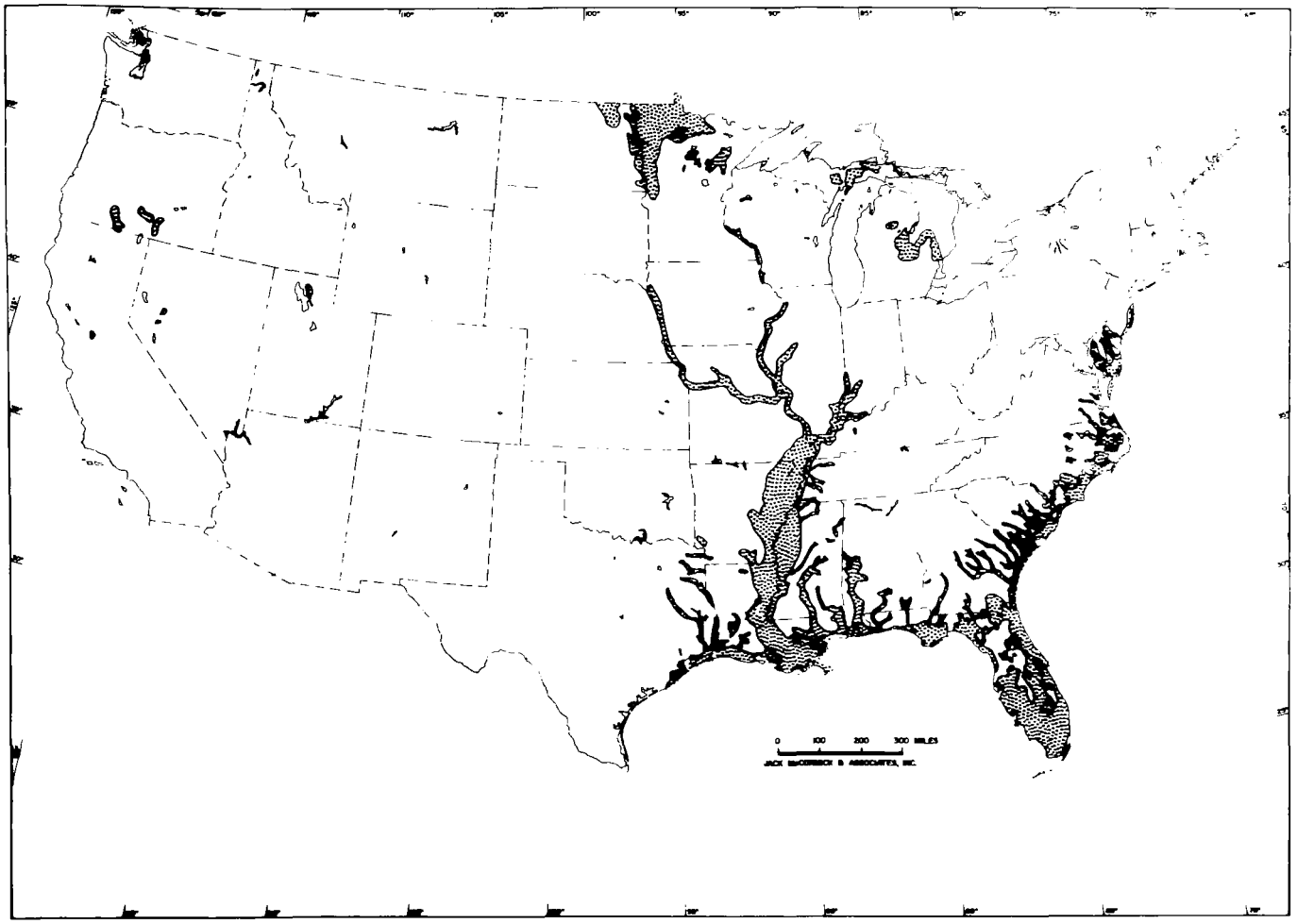

Figure 5: Major Wetlands (Adapted from Soil Conservation Service, 1970, U.S. Dept. of Interior Geological Survey, 1970).

as in farms (Table 2). Unquantified critical areas doubtless account for a substantial proportion of the other 21 percent of the land.

The equivalent figures for the critical areas of Hawaii and Alaska, respectively, are 522 square miles, or eight percent and 80,563 square miles, or 14 percent. Farms occupy about four percent of Alaska and 50 percent of Hawaii.

Approximately 46 square miles, or one percent of the surface area of Puerto Rico is included in National Wildlife Refuges or National Forest Land.

In addition, to the types listed, we obtained bulk measurements for two other Federal agencies. These were not accompanied by geographic breakdowns.

The Energy Research and Development Administration (ERDA), regulates 3,125 square miles of land. This land is contained in twelve major sites. Two sites, which cumulate to 1,206 square miles, have been designated as national environmental research parks. The other areas are being considered for designation.

The largest amount of Federal land, 709,375 square miles, is administered by the Bureau of Land Management (BLM). It is not certain, but can be presumed, that substantial areas that are controlled by BLM will be available for the full range of techniques for disposal of sludge onto the land.

Synthesis and Application to Minimum Geographical Regions

The National Commission on Water Quality segmented the conterminous United States into 13 divisions, or "minimum geographical regions" (Figure 7). The boundaries of these regions are based on various combinations of physical, biological, and water quality features. As a contract requirement, the summary of our study was addressed to these regions.

JMA composited the available maps of individually restricted lands to produce two synthesis maps. The first of these illustrates those lands on which sites for the storage of sludge in landfills, trenches, or lagoons are likely to be prohibited or severely limited (Figure 8). These methods alter the characteristics of the site, and generally are not suited to concurrent multiple uses. They also may restrict the variety of choice for sequential, or future uses. This figure suggests that major difficulties will be experienced in the Appalachian Region,

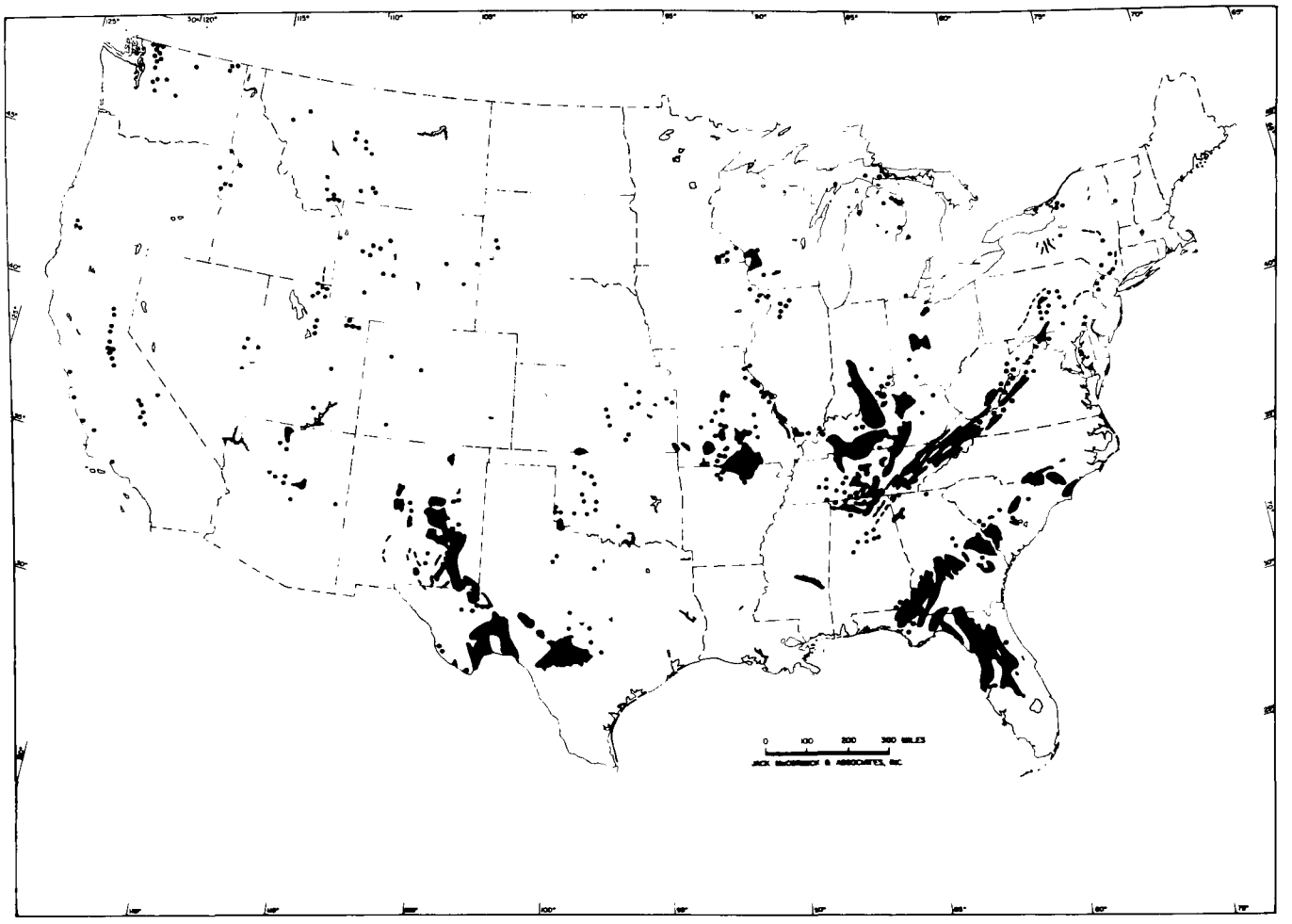

Figure 6: Karst Lands (Adapted from U.S. Dept. of Interior Geological Survey, 1970).

along the Atlantic and Gulf Coastal Plain, in the Mississippi River embayment, in the central and northern Rocky Mountains, and in the Cascades-Sierra-Coastal Ranges section along the Pacific Coast.

The second synthesis map is composed of those lands that are institutionally restricted or physically limited for the application of granular or liquified sludges (Figure 9). The restrictions on the availability of sites for the application of liquid sludge are not expected to be as stringent as those on the availability of sites for the storage of sludge. When properly treated sludges are applied at appropriate rates and with suitable equipment, the land and the biological communities it supports need not be altered significantly. Multiple concurrent use is feasible, and the range of choices for future, sequential uses should not be affected. In point of fact, the use of a site for the land application of residuals is a mechanism by which decisions on the commitment of land can be reserved for future generations.

This figure differs from the preceding figure in that National forest lands, major wetlands, and the floodplains of the Mississippi River and of the rivers in the Midcontinental Division have been subtracted. The limitation on uses of steep slopes also may be relaxed somewhat for granualr and liquified sludges, but the permissable rates of application probably will be relatively low, so that the size of the disposal sites will have to be larger than on unrestricted lands.

Environmental agencies in the United States generally have not yet recognized the suitability of natural wetlands or man made wetlands for the application of effluents or sludges from wastewater treatment processes. Recent studies, however, have indicated that natural wetlands are effective in nutrient removal [10,11]. The biological community near the point of application may be simplified somewhat, but the area that is affected measurably is proportionately small.

Effluents and sludges have been sprayed or flooded on at least 26 sites in National forests and 14 sites in state forests [12]. Numerous tests have determined that forest communities function effectively to assimilate effluents and sludges if the rate of application is appropriate. The growth of trees on inventoried disposal sites was from 27 to 118 percent greater than before residuals were applied [13]. Although short-term results appear to be beneficial, no information is available to evaluate the long-term effects of the application of effluents and sludges to forest lands.

TABLE 2
Geographically Separable Critical Areas
for the Disposal of Sludge

		A. Areas with Severe Restrictions					B. Some Restriction Expected									
	Land Area	State Parks	National Wildlife Refuge	National Park System	Natural Areas[b]	Urban Areas	State Forests	National Forests	Wetlands	Total A	Total A & B	A as % of Area	A & B as % of Area	Land in Farms	Farms as % of Area
Alabama	50,708	22	72	10		714	66	992	2,498	818	4,374	2	9	21,335	42
Alaska	566,432	1,563	34,843	11,777			0	32,380		48,183	80,563	9	14	2,507	4
Arizona	113,417		2,468	4,371		493	0	17,848	44	7,332	25,224	6	22	59,692	53
Arkansas	51,945	43	192	163		266	30	3,840	5,915	664	10,449	1	20	24,523	47
California	156,361	1,130	301	7,037		3,933	110	31,360	874	12,401	44,745	8	29	55,816	36
Colorado	103,766		76	957		429	111	22,440	632	1,462	24,645	1	24	57,339	55
Connecticut	4,862	43	<1	0	69	956	204	<1	37	1,068	1,309	22	27	846	17
Delaware	1,982		34	0	89	55	10	0	205	178	393	10	20	1,053	53
D. C.	61	0	0	(14)		61	0	0		61	61	100	100	0	0
Florida	54,090	269	683	3,335		1,507	479	1,690	26,852	5,794	34,815	11	64	21,925	41
Georgia	58,073	64	689	97	32	729	38,811	1,330	9,249	1,611	51,001	3	88	24,597	43
Hawaii	6,425		5	402		115		0		522	522	8	8	3,216	50
Idaho	82,677	50	103	136		29	1,445	31,800	1,063	318	34,626	<1	42	22,526	27
Illinois	55,748	324	137	<1	33	1,698	27	387	668	2,192	3,274	4	6	46,739	84
Indiana	36,097	120	12	13	54	1,084		263	443	1,283	1,989	4	6	27,458	76
Iowa	55,941	55	104	3	16	436	33	1	216	614	864	1	2	52,453	94
Kansas	81,787	23	80	1	236	331		169	319	671	1,159	1	1	77,172	94
Kentucky	39,650	196	3	101		303	73	964	427	603	2,067	2	5	24,950	63
Louisiana	44,930	27	372	<1		362	13	930	15,074	761	16,778	2	37	15,295	34
Maine	30,920	388	38	58	266	124	33	78	596	874	1,581	3	5	2,750	9
Maryland	9,891	92	29	97	608	527	186	0	453	1,353	1,992	14	20	4,380	44
Massachusetts	7,826	384	18	71	254	1,368	0	0	362	2,095	2,457	27	31	1,095	14
Michigan	56,817	339	164	1,061	298	1,511	5,878	4,199	5,027	3,373	18,477	6	33	18,594	33
Minnesota	79,289	316	289	355	75	847	4,663	4,370	7,883	1,882	18,798	2	24	45,071	57
Mississippi	47,296	25	91	72		214	3	1,776	4,046	402	6,227	1	13	25,062	53
Missouri	68,995	121	67	128	65	734	320	2,252	589	1,115	4,276	2	6	50,657	73
Montana	145,587	31	1,634	1,996	27	49	334	26,100	293	3,737	30,464	3	21	102,813	71
Nebraska	76,483		220	10	109	120	0	548	1,015	459	2,022	1	3	71,616	94
Nevada	109,889	163	3,432	1,222		159	0	7,982	301	4,976	13,259	5	12	16,732	15
New Hampshire	9,027	118	1	<1	167	81	0	1,068	21	367	1,456	4	16	957	11
New Jersey	7,521	61	47	27	513	1,567	261	0	422	2,215	2,898	29	39	1,619	22
New Mexico	121,412	164	585	387		114	1,458	14,370	76	1,250	17,154	1	14	73,113	60
New York	47,831	344	33	73	3,578	2,189	4,146	22	333	6,217	10,718	13	22	15,857	33
North Carolina	48,798	100	172	597	189	468		1,774	6,335	1,526	9,635	3	20	19,896	41
North Dakota	69,273	5	431	112	256	14	0	1,727	2,380	818	4,925	1	7	67,372	97
Ohio	40,975	216	12	46	228	2,109	261	241	153	2,611	3,266	6	8	26,737	65
Oklahoma	68,782	139	213	10	220	605	0	454	437	1,187	2,078	2	3	56,262	82
Oregon	96,184	126	712	274		332	1,227	24,188	738	1,444	27,597	2	29	28,153	29
Pennsylvania	44,966	185	13	81	377	1,590	2,935	775	83	2,246	6,089	5	14	13,907	31
Puerto Rico	3,435		2	<1				44		2	46	<1	1		
Rhode Island	1,049	13	<1	<1	38	211	83	0	40	262	335	25	32	107	10
South Carolina	30,225	91	253	8	436	344	193	935	5,590	1,132	7,850	4	26	10,925	36
South Dakota	75,955	134	66	428	89	27	0	3,103	1,175	744	5,022	1	7	71,225	94
Tennessee	41,328	203	127	401	123	595	213	959	1,294	1,449	3,945	4	10	23,525	57
Texas	262,134		310	1,739		3,073	10	1,213	5,845	5,122	12,190	2	5	222,761	85
Utah	82,906	100	147	3,206		260	0	12,567	1,835	3,713	18,115	4	22	17,677	21
Vermont	9,267	44	7	0	363	0	159	380	60	414	1,013	4	11	2,993	32
Virginia	39,780	67	115	471	646	949	76	2,404	845	2,248	5,573	6	14	16,640	42
Virgin Islands	133		<1	24				<1		24	24	18	18		
Washington	66,570	126	243	3,000		647	2,830	14,168	364	4,016	21,428	6	32	27,436	41
West Virginia	24,070	103	0	1	160	122	130	1,485	6	386	1,997	2	8	6,782	28
Wisconsin	54,464	72	233	165	30	734	679	2,328	4,360	1,234	8,601	5	16	28,281	52
Wyoming	97,203	234	89	3,770		0	0	14,448	47	4,093	18,588	4	19	55,432	57
	3,541,233	8,433	49,967	48,293[a]	9,644	35,185	67,560	292,352	117,520	151,522	628,954	4	18	1,665,967	47

[a] 235 square miles of NPS land is excluded; this includes the Appalachian Trail and water areas in the Gulf Islands.

[b] Environmental Research Parks designated by the Atomic Energy Commission in Idaho (Idaho National Engineering Laboratory, 571,800 acres) and South Carolina (Savannah River Plant, 200,000 acres) are included in this column.

The Potential Impact on Natural Vegetation and Wildlife of the Disposal of Sludge onto the Land

There are two general categories of potential impact insofar as locational aspects are concerned. Site impacts are those that are expected to occur immediately or in the future on the tract that is dedicated to disposal activities. Offsite impacts are those that are expected to occur at any place outside of the boundaries of the disposal site and directly or indirectly as a result of the disposal activities.

Land that is to be utilized in the future for the disposal of sludges that are generated from wastewater treatment facilities will have to satisfy certain guidelines. These guidelines will be based on physical, biological, and sociological criteria. Thus, land that may be suitable from one point of view, may be unsuitable from another point of view. The stringency of these guidelines and the degree to which they are enforced will determine the supply of land that is available for land disposal.

If the disposal facilities are designed, constructed, and operated in a manner that will allow them to satisfy all Federal laws and regulations, offsite impacts will be negligible. "Design," as used here, includes the selection of sites that will meet stringent guidelines.

In large part, the ecological impact of land disposal will be measured by the total amount of land that is preempted for disposal sites. The requirement for land is related, in part, to the volumes of sludges and effluents to be generated and to their qualities. It also is related to the characteristics of the available disposal sites. Each soil, for example, has a specific capacity to adsorb various constituents present in residuals.

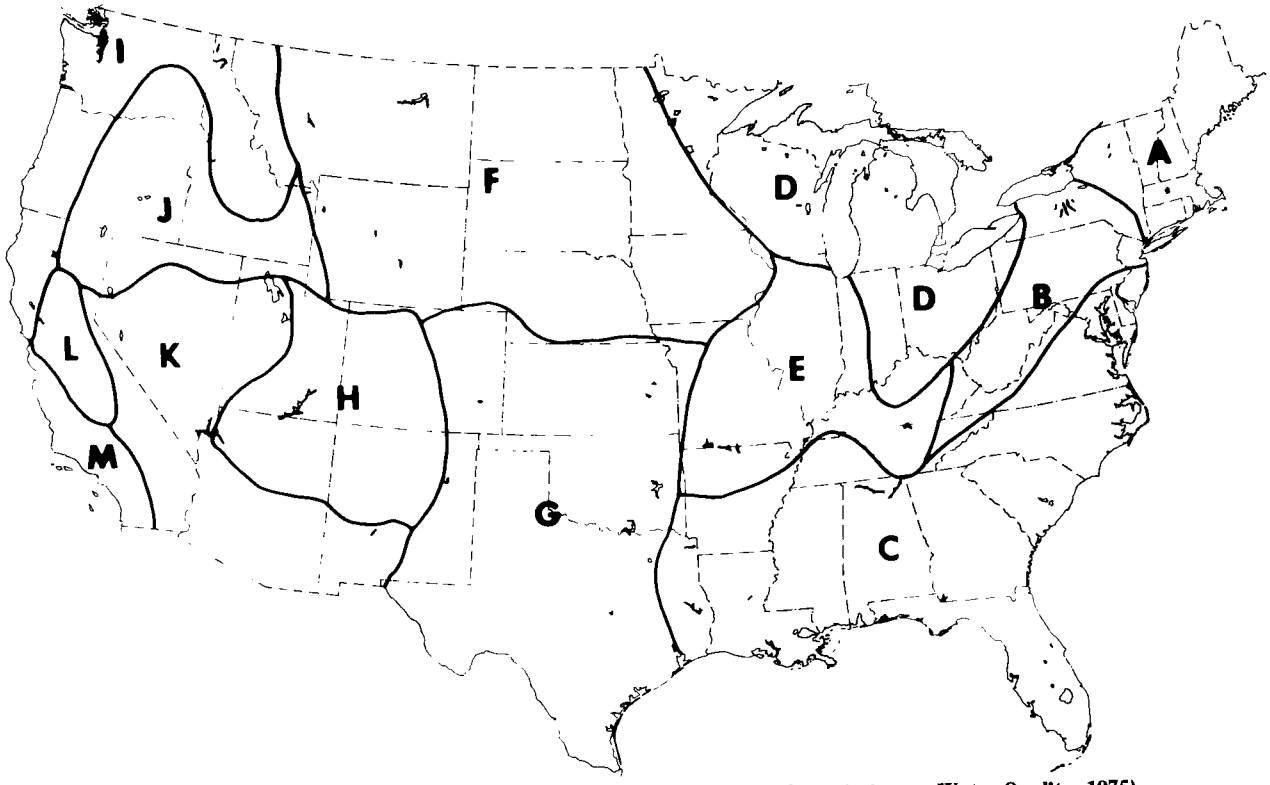

Figure 7: Minimum Geographic Regions (Adapted from National Commission on Water Quality, 1975).

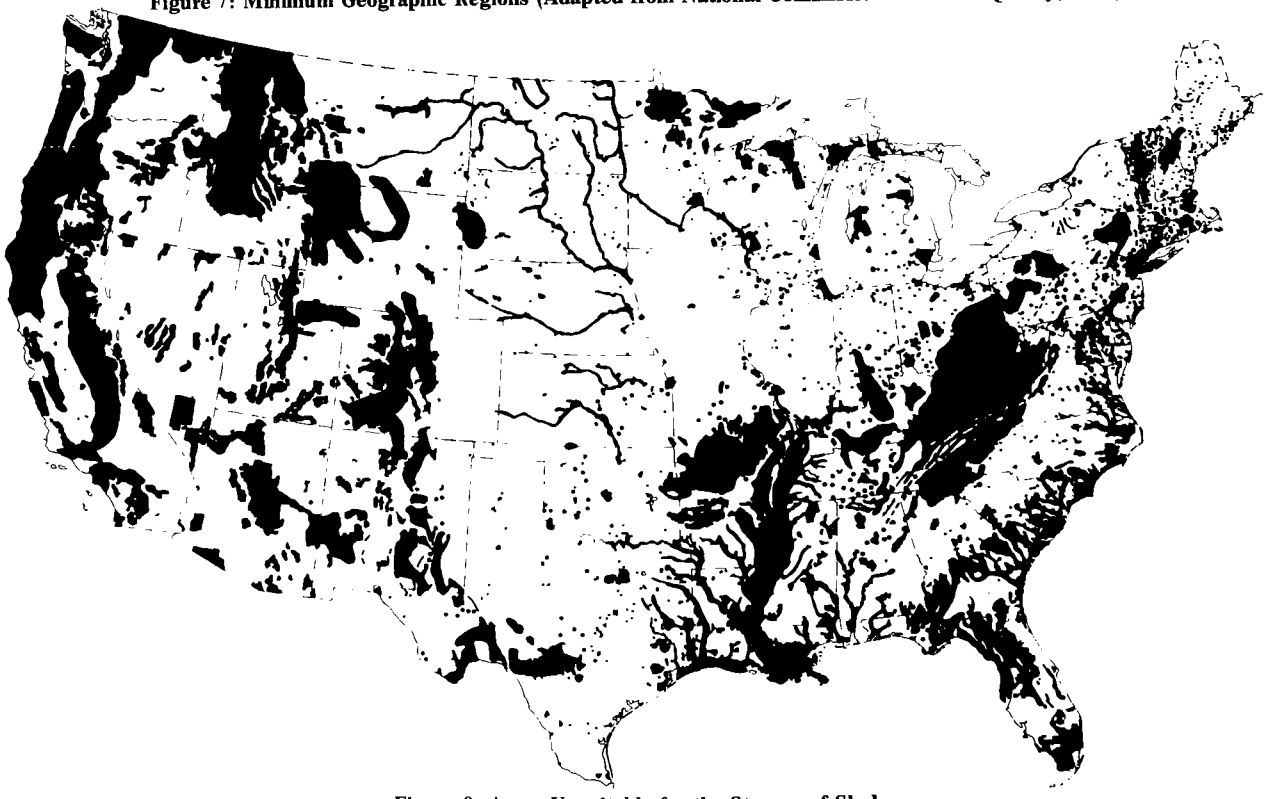

Figure 8: Areas Unsuitable for the Storage of Sludge.

No date that can be applied throughout the nation were available to estimate the region-to-region variability in the expected life of disposal sites. It probably is realistic to assume that the average life expectancy is 20 years. Thus, there will be a regular turn-over in disposal sites. Plans should be drawn not to assure the availability of suitable sites for future use. similarly, the planning should address the future uses of spent sites.

The intensity of site impacts will vary and will be a function of the characteristics of the techniques utilized for disposal and the characteristics of the disposal site. The intensity of impacts generally will be progressively

Figure 9: Areas Unsuitable for the Disposal of Wastewater Effluents.

greater on sites that range from highly disturbed to pristine. Sludge storage facilities generally will alter sites totally. Some techniques for the disposal of liquified sludges may produce only minor changes, whereas other techniques will require drastic alteration of some sites.

The preparation of a site for the storage of sludge will require the removal of all existing vegetation and the termination of any existing activity, such as farming. The removal of vegetation will destroy the value of the site for wildlife. If the recommended guidelines are followed, no endangered or threatened species will be affected. Nevertheless, local populations of breeding wildlife species will be reduced.

The area of impact of landfills will be extended by the need to stockpile excavated material for use later as a cover. Stockpile sites will be cleared of any woody vegetation, land herbaceous plants will be buried. Because a ratio of one volume of sludge to one volume of soil is recommended in sludge landfills, most of the material that is excavated probably will have to be stockpiled.

Most of the common methods that are used to apply liquid or dewatered sludge are practicable only on unobstructed sites. Thus, agricultural land, grazing land, or low-quality land (strip-mined areas, dredged spoils) are suitable, but areas covered by trees or shrubs would have to be cleared. Except for systems which employ partable agricultural irrigation devices that can be placed manually, techniques for spraying also will require unobstructed sites.

If it is necessary to clear natural vegetation from the site that is to be used for the application of sludges to the land, the intensity of impact will vary with the quality of the vegetation and its utility to wildlife. Recent preliminary investigations by the New Jersey Division of Fish, Game, and Shellfisheries [14-16], however, suggest that the productivity and nutritional value of wildlife food plants can be enhanced by the application of sludge. When food patches in a public hunting reserve were treated with sludge, deer grazed most intensively on plots that received the heaviest applications. If disposal sites can be dispersed, therefore, it may be possible to enhance wildlife values even in forested areas.

SUMMARY

This investigation led us to the conclusion that land disposal can be environmentally acceptable. Sludge application, as contrasted to landfilling, is most appropriate.

The supply of suitable sites will be restricted by various natural and institutional limitations. Although sites probably could be found on so-called vacant or natural lands, the most attractive sites seem to be those that already are utilized for crop and livestock production. Multiple use of these lands should be considered to be a national priority. The potential reuse of wastewater by-products to improve soil conditions and add fertility could offset the anticipated substantial rises in the costs of petroleum-derived fertilizers.

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PLANT UPTAKE OF HEAVY METALS FROM SEWAGE SLUDGE APPLIED TO LAND

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INTRODUCTION

Ultimate disposal of sewage sludges by utilization on land is considered by many as the best solution available to the municipal sludge problem. Ocean dumping of sludge will not likely be allowed in the future. Incineration and pyrolysis require expensive fuels and may pollute urban air pollution. Landfills may pollute the groundwater and are difficult to initiate because of public resistance. Although land disposal of sludge presents special problems, many contend that this ultimate disposal route would benefit society.

Sewage sludge appears to be very valuable in revegetation and reclamation of land disturbed by urban development, coal and gravel surface mines, and road construction. If properly used, sludge can transform these disturbed lands into an environment suitable for plant growth.

Many agronomists are concerned that disposal of some sludges on agricultural land may impair crop growth because of their heavy metal contents, or may endanger the food chain through excessive accumulation of these metals in the crop's edible portion. These aspects have been reviewed in depth by Chaney [1,2], Chaney and Giordano[3], Webber[4], and Page[5]. Many researchers have shown that soil properties such as soil organic matter, cation exchange capacity, Fe and Mn oxides, and clay content, as well as crop species can strongly influence the potential for heavy metal problems when sludges are used on land.

It is likely that some sludges which contain high concentrations of certain heavy metals will present problems if used on agricultural lands. To avoid such problems municipalities will have to enforce pretreatment of industrial wastes if land disposal of sewage sludge is to result in long-term benefits to society.

This paper reports preliminary results of field experiments with sludge and composted sludge. One section describes a greenhouse pot experiment showing the effects of soil pH on Zn phytotoxicity and on plant uptake of Zn and Cd. Another describes studies on the disposal and the analyses of sludges currently applied to agricultural land in the Northeast. These studies demonstrate the complexity of heavy metal interactions in the soil-sludge-plant system.

Experimental Results and Discussion

Chard Plots, 1974

Chard was grown on small plots of Woodstown silt loam soil (CEC = 5.9 meq/100g) treated with different sludges for use in feeding trials by our cooperators; chard is noted for its metal accumulation. The sludges used were: (1) anaerobically digested sludge cake from the Blue Plains Water Pollution Control Plant in Washington, D.C. (B.P. sludge); (2) B.P. sludge composted at Beltsville by the windrow method[6] (B.P. compost); (3) B.P. mixed raw sludge heat dried in a torroidal flash drier (B.P. R-HD); (4) an anaerobically digested sludge cake high in Zn and Cu (high metal); and (5) a heat-dried, raw, secondary sludge with a somewhat high Cd/Zn rate (High Cd/Zn).

Table 1 shows sludge metal analyses, Zn (equivalent), the recommended maximum total applications [Zn equivalent addition at ten percent of the C.E.C.], and the actual application rates. The B.P R-HD sludge had higher than expected Cd levels, and subsequently we learned that the High Cd/Zn sludge was used in the start up operations of the torroidal flash drier and comprised over half of the sample. The plots remained fallow for four weeks to avoid initial toxicity, and to leach salts from the seedbed. Dolomitic limestone was added to ad-

TABLE 1
Composition and Application Rates of Sludges Applied in 1974 to Plots of Woodstown Silt Loam Planted to Swiss Chard

Sludge	Zn	Cd	Cd/Zn	Cu	Ni	Zn (eq)*	Max. recommended	Zn applied
	ppm	ppm						
B.P. Sludge	2690	20.2	0.75	670	40	3970	110	0.2
B.P. Compost	930	6.7	0.72	230	370	1530	325	0.1
B.P. R-HD	1290	59	1.6	710	66	1970	220	2
High Metal	5160	14.6	0.27	2120	310	10860	10	56
High Cd/Zn	1420	90	6.3	530	77	2190	197	56

* Zn (eq) [(1 x Zn + 2 x Cu + 4 x Ni) - 200]

just the soil to pH six. Soil pH increased when B.P. compost was added, but declined sharply with the B.P. R-HD and high Cd/Zn sludges (Table 2). While normally 0.5 to 1mt/ha/yr of these raw heat-dried sludges are applied as a N fertilizer, we applied 56 t/ha to provide suitably high metal levels to meet our experimental objectives. This high rate proved to be excessive and caused a rapid pH decrease, initial toxicity, and severe growth inhibition.

TABLE 2
Soil pH and DTPA-TEA Extractable Metals in Plots of Woodstown Silt Loam Amended with Sludges in 1974

Soil Treatment	Soil pH* 4/75	8/75	Zn ppm	Cd ppm	Cu ppm	Ni ppm
Control	6.2	6.6	1.6	0.02	0.8	0.4
B.P. Sludge	6.0	5.7	64.8	0.32	14.6	1.1
B.P. Compost	6.7	6.7	29.4	0.23	11.6	1.7
B.P. R-HD	5.2**	5.2	13.2	0.59	4.5	1.4
High Metal	5.8	5.0	60.6	0.12	26.4	3.4
High Cd/Zn	4.9**	5.5	14.4	0.93	5.2	1.6

* pH adjested to 6.0 in 6/74.

** lime added in 4/75.

Table 3 shows metal analyses of the chard leaves. Chard plants grown on the B.P. R-HD and High Cd/Zn plots were inadvertantly mixed together and are labeled "High Cd's" (Table 3). Sludge applications produced chard higher in Zn, Cd, Cu, and Ni. The most striking increase was that of Cd in chard grown on the "High Cd" plots. Here, the high Cd/Zn ratio in the sludged soil resulted in high chard Cd levels before Zn and other metals began to limit plant growth. The "High Metal" treatment chard, because of the low Cd/Zn ratio of the sludge, resulted in a low chard Cd level when Zn or other metals should have begun to limit growth. Plants readily absorbed Cd in the absence of Zn phytotoxicity, especially at the low pH produced by addition of the R-HD sludges. Chard samples were washed, wilted, freeze-dried, and ground for mixing into a balanced diet for guinea pigs. The feeding trials have been completed and the animal tissues are being analyzed.

Sludge Vs. Sludge Compost Plots, 1973

In June, 1973 plots were amended with Blue Plains anaerobically digested sludge cake, and B.P. sludge composted by the windrow method at Beltsville[6]. These sludge materials were applied at 0, 40, 80, 160, and 240 Mt/ha. Dolomitic limestone was applied to half the plots to establish pH ranges of 5.5 to 6 and 6.5 to 7. Field corn, and many vegetable species and field crops have been grown on these plots. Table 4 shows metal analyses for corn ear leaves, and Table 5 for Swiss chard[7].

TABLE 3
Metals Content of Swiss Chard Grown on Woodstown Silt Loam Amended with Sludges in 1974

Soil Treatment	Zn	Cd	Cu	Ni	Fe	Mn
	μ g/g dry leaves					
Control	70	0.73	11	1.4	94	290
B.P. Sludge	580	4.0	22	3.5	89	1900
B.P. Compost	257	1.7	18	1.7	94	780
High Metal	950	2.0	23	22.3	77	780
High Cd's*	796	24.0	23	6.9	93	2390

* Mixture of chard from B.P. R-HD and High Cd/Zn treatments.

TABLE 4
Heavy Metal Content of Corn Ear Leaves Grown on Woodstown Silt Loam Amended with Sludge and Sludge Compost in 1973

Material	Soil Treatment Rate Mt/ha	pH	Zn	Cd	Mn	Fe
			μ g/g dry leaves			
Control		5.47	35 f*	0.41 e	92 de	112
Sludge	40	5.25	180 ab	1.11 bc	348 a	109
	80	5.65	224 a	1.74 a	299 ab	123
	160	6.48	168 b	1.89 a	331 a	108
	240	6.36	143 bc	1.69 a	219 bc	113
	80	6.35	117 cd	1.48 ab	166 a-d	111
	160	6.29	113 cd	1.82 a	292 ab	145
	240	6.90	148 bc	1.87 a	376 a	81
Compost	40	5.48	84 def	0.58 de	89 de	107
	80	5.99	64 def	0.62 de	57 de	105
	160	6.51	84 def	0.81 ce	89 de	113
	240	6.81	104 cde	1.10 bc	99 de	116
	80	6.85	56 ef	0.41 e	43 e	112
	160	6.90	86 def	0.60 de	74 de	117
	240	6.96	73 def	0.93 cd	90 de	112

* Within column, values followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test.

The following general effects of sludge and soil pH on crop uptake of metals were observed: Zn, Cd, and Ni increased, but Cu, Fe, and Pb were only slightly influenced by sludge application. At the higher soil pH, plant Zn, Cd, and Mn contents decreased. The plants grown on compost plots had significantly lower Zn and Cd contents than those grown on sludge plots. For the crops we have grown, the increase in Cd content was generally not significant from compost, while it was significant from sludge, especially at the lower soil pH.

Several aspects of composting at Beltsville may have influenced our results (Tables 4 and 5): (1) composting generally produces a material which initially raises the soil pH and does not cause as much subsequent slow lowering of soil pH as digested sludge does; (2) composting stabilizes the sludge organic matter, and adds organic matter from composted woodchips; and (3) serpentine rock chips from the composting pad add considerable Mg silicate to the compost and the silicate may reduce metal availability to plants, especially at the higher soil pH. Experiments are now in progress to establish the basis for this apparent reduction in sludge metal availability to plants by composting. Composting of sewage sludge appears to be desirable not only from the standpoint of pathogen reduction, odor control, drying and ease of handling, and lower nitrate levels, but also because of the reduced potential for metal uptake by plants.

Urban Fill-Soil Revegetation Plots, 1971

Our oldest sludge amended plots at Beltsville were established in October, 1971 on an acid, infertile, silt loam fill soil area[8]. The plots were limed to a pH's of

TABLE 5
Heavy Metal Content of Swiss Chard Leaves Grown on Woodstown Silt Loam Amended with Sludge and Sludge Compost in 1973

Treatment									
Material	Rate Mt/ha	pH	Zn	Cd	Cu	Ni	Pb	Mn	Fe
				μ g/g dry leaves					
Control		5.47	133 cd*	2.05 de	7.4 f	2.19	0.81 d	772 b-d	175
Sludge	40	5.25	651 a	5.88 ab	27.7 ab	1.34	3.52 a-d	1683 a	173
	80	5.65	467 b	6.28 a	29.7 a	3.13	4.30 abc	1414 ab	165
	160	6.48	276 bcd	3.84 cd	25.2 bc	1.16	4.22 abc	1417 ab	190
	240	6.36	293 bcd	4.30 bc	24.6 bcd	1.71	4.91 ab	1153 abc	192
	80	6.35	139 cd	2.90 cde	23.4 bcd	0.90	2.10 cd	416 d	171
	160	6.29	205 cd	3.48 cde	22.8 cd	1.10	3.90 a-d	1249 ab	185
	240	6.90	194 cd	3.54 cde	23.1 cd	0.81	4.23 a-c	1442 ab	164
Compost	40	5.84	308 bc	2.93 cde	17.8 e	10.7	0.81 d	793 bcd	209
	80	5.99	247 cd	2.09 de	25.0 bc	3.67	3.93 a-d	380 d	168
	160	6.51	157 cd	2.28 de	23.8 bcd	2.97	4.25 abc	451 d	161
	240	6.81	129 cd	2.27 de	23.8 bcd	2.42	5.34 a	511 cd	180
	80	6.85	123 cd	1.51 e	22.3 cd	1.56	2.41 bcd	292 d	146
	160	6.90	98 d	1.60 e	21.2 cde	2.11	2.42 a-d	340 d	135
	240	6.96	91 d	1.62 e	20.2 de	1.39	4.38 abc	532 cd	140

* Within column, values followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test.

about 5.5 and 7.0, representing poor and good management, respectively. We rototilled B.P. digested sludge into either the surface 15 or 60 cm of the filled area.

In 1972, we grew corn, fescue, and chard, while only fescue was grown in subsequent years. All plots were fertilized with P and K as needed, while the control was also fertilized with N. Table 6 shows the application rates and mixing depths for each treatment. The higher sludge rates provided adequate N for the fescue even during the fourth year (1975). Table 6 shows the Zn, Cd, and Cu contents of fescue forage sampled 3.5 years after the plots were established (May, 1975). The Zn and Cd content increased as application rate increased at both pH's, while Cu content increased little after the lowest sludge rate. The Zn, Cd, and Cu uptake decreased at the higher soil pH; however, Zn uptake decreased more than for either Cd or Cu.

TABLE 6
Heavy Metal Content of Tall Fescue Sampled in May, 1975 Growing on an Urban Fill Soil Amended with Sludge to 15 and 60 cm Depths in October, 1971

Sludge			Zn	Cd		Cu	
Rate	Depth	L*	NL **	L	NL	L	NL
Mt/ha	cm		μ g/g	dry forage			
0	60	13	27	0.24	0.91	3.7	7.3
90	60	25	64	0.83	1.23	7.2	9.8
180	60	32	75	1.15	1.48	7.4	10.3
270	60	42	144	1.04	1.58	8.2	13.0
360	60	49	138	0.91	1.68	8.5	12.0
0	15	15	16	0.20	0.45	3.4	4.1
135	15	50	97	1.56	1.27	7.5	10.3

* L = limed to about 7 pH

** NL not limed, at about 5.5 pH.

Major differences in crop uptake of these metals were found in 1972. For example, at a low pH a plot which had received 360 Mt/ha of sludge to a 60 cm depth, produced chard with 1800 ppm Zn, corn 400 ppm Zn, and fescue only 100 ppm Zn. This study does not indicate rapid reversion of metals to forms unavailable to plants. The fescue Cd levels considerably increased (three to four fold at the low pH), although values were within the observed ranges for normal forage materials.

Corn and Soybean Plots, 1972

In May, 1972, Blue Plains anaerobically digested sludge cake was applied at 0, 56, 112, and 224 dry Mt/ha to plots of Sassafras silt loam in a cooperative study with the University of Maryland Department of Agronomy. Plots were split to compare sludge with sludge plus recommended P and K fertilizer applications. The control-fertilized corn plot also received recommended N fertilizer rates. Both corn (Pioneer 3369A) and soybean (Kent) were grown each year.

Tables 7 and 8 show the heavy metal contents of corn ear leaves and soybean leaves grown in 1974 on Sassafras silt loam amended with sludge in 1972. The Zn and Cd contents of crops grown on sludge amended soil increased as application rates increased. Although Zn and Cu contents did not reach phytotoxic levels, they were considerably higher than the controls (Zn in corn ear leaves increased ten-fold). Sludge amended soils in humid areas may soon decrease to levels at which metals are more available to plants (Tables 5 and 6).

Our corn and soybean results differed greatly from those of Hinesly, Jones, et. al. [9-11], and Bingham, et.

TABLE 7

Heavy Metal Content of Corn Ear Leaves Grown in 1974 on Sassafras Silt Loam Amended with Sludge in 1972

Soil Treatment Sludge Mt/ha	Fert.	Soil pH	Zn	Cd	Cu	Ni	Pb	Mn
				μ g/g dry leaves				
0		5.54 a*	20 f	0.34e	4.4 c	0.48 abc	5.7 b	26 d
0	**	5.15 b	36 ef	0.68e	8.1 ab	0.40 bc	6.8 a	67 ab
56		5.33 ab	79 d	1.93 d	8.0 ab	0.35 c	6.4 ab	41 cd
56	+	5.35 ab	70 de	1.82 d	7.9 ab	0.40 bc	6.2 ab	43 c
112		5.28 b	165 c	3.19 bc	8.1 ab	0.42 bc	4.6 c	63 ab
112	+	5.29 b	135 c	2.73 c	7.5 b	0.65 a	4.6 c	61 b
224		5.25 b	247 a	3.83 a	8.6 a	0.56 ab	4.1 c	76 ab
224	+	5.26 b	210 b	3.62 ab	8.5 ab	0.34 c	4.0 c	79 a

*/ Within-column, values followed by the same letter are not significantly different at the 5% level as according to the Duncan's Multiple Range Test.

* Plots received N-P_2O_5 - K_2O treatment of 180 - 90 - 90 kg/ha

+ Plots received N-P_2O_5 - K_2O treatment of 0 - 90 - 90 kg/ha

TABLE 8

Heavy Metal Content of Soybean Leaves Grown in 1974 on Sassafras Silt Loam Amended with Sludge in 1972

Soil Treatment sludge Mt/ha	Fert.	Soil pH	Zn	Cd	Cu	Ni	Pb	Mn	Fe
					μ g/g dry leaves				
0		5.86 a*	22 c	0.13 c	6.4 d	1.6 b	3.5 b	52 bc	92 ab
0	**	5.74 a	32 c	0.29 b	8.2 c	2.1 b	3.3 ab	57 ab	97 a
56		5.43 b	95 b	0.35 ab	10.1 b	3.3 a	3.4 ab	47 bc	92 ab
56	**	5.43 b	98 b	0.31 b	10.1 b	3.1 b	3.1 b	46 bc	89 abc
112		5.42 b	114 b	0.42 ab	11.0 ab	3.4 a	3.8 a	47 bc	94 ab
112	**	5.42 b	114 b	0.37 ab	10.9 ab	3.7 a	3.3 ab	43 c	84 c
224		5.38 b	151 a	0.51 a	11.6 a	3.5 a	3.4 ab	54 bc	86 abc
224	**	5.41 b	142 a	0.43 ab	11.3 a	3.9 a	3.0 b	58 a	79 c

*/Within-column, values followed by the same letter are not significantly different at the 5% level according to the D Duncan's Multiple Range Test.

** Plots received N - P_2O_5 - K_2O treatment of 0 - 90 - 90 kg/ha

al. [12] We found lower Cd levels in soybean than corn, while they found higher Cd levels in soybean than in corn. Perhaps these differences resulted from Cd/Zn ratios in the soil, and its effect on plant Cd uptake. Further, plant foliar Cd/Zn could have affected the transport of Cd into grains, and the varieties grown could have differed in Cd uptake.

Crops have shown considerable yield increases due to sludge application, although for the first year yield increases were not as great at the higher sludge rates because of "initial toxicity" from salts, ammonia, etc.

In these recently established field plot studies, we have observed that agricultural use of sludge, even from cities without industrial sources of heavy metal, increased crop Cd levels compared with those grown at the same pH on the same soil without sludge. Although others generally confirm these results [13], regional differences may exist, because of different Cd sources in individual sludges, and differences in soil chemical properties, especially soil pH (L.M. Walsh, personal communications).

Old-Sludge Application Site Studies

Another method to assess the effects of land application of sludge on increases in crop metal contents is to test fields which have received large sludge applications over the years. Both crops and soils in these treated areas can be sampled, analyzed, compared with data from adjacent untreated fields to estimate any changes from the long-term use of sludge. The alternative is to study newly established plots for many years.

The long-term sludge plots at Woburn, England, were lost by intermixing because they were small and plowed with a moldboard plow; their earlier results were not readily interpretable and Cd levels were not measured [14]. The 15-year-old, low-rate (seven Mt/ha sludge every second year) plots of Andersson and Nilsson [15] showed significantly higher Zn, Cu, and Ni, but only slightly higher or unchanged Cd, Pb, Hg, Se, Co, Cr, or Mo in rape fodder. Johnson, et. al. [16] reported that the Werribee sewage farm of Melbourne, Australia, had higher Zn levels but not Cd levels in perennial grasses.

Pasture grasses were analyzed by Chaney, et. al. [17] from a 24-year-old sludge-utilization farm at Hagerstown, Maryland (Table 9). Pasture grasses were sampled from control, recently sludged, and previously sludged plots of Hagerstown silt loam. Sludge increased foliar Zn levels, but not Cd levels; Cu and Pb levels increased because of foliar contamination by appplied sludge. The sludge applied at Hagerstown was relatively low in metals, well within the domestic [15] sludge category. (Domestic sludge as defined by Chaney [2], contains less than 2000 mg Zn, 1000 mg Cu, 200 mg Ni, 15 mg Cd, 1000 mg Pb, 10 mg Hg, and 1000 mg Cr/kg dry sludge, with Cd less than or equal to one percent of the Zn content.) Since soil pH had decreased to below 5.5 in several areas, proper pH management would probably have increased pasture yields and decreased the metal contents of the grasses. Some pasture samples contained sufficient Cu (>30 ppm) to possibly injure ruminant animals. Again, this probably resulted from surface contamination of the standing grasses from liquid sludge applications. Studies are in progress to measure the extent of foliar contamination by applying liquid sludge to recently clipped and standing grasses, and to see whether sludge adhering to forages is washed off by rain.

TABLE 9
Heavy Metal Content of Pasture Grasses in Unsludged, Recently Sludged, and Previously Sludged Fields of Hagerstown Silt Loam

Metal	Mean	Range
	μg/g	
Tilled Field Area (previously sludged)		
Zn	33.6	16.9 - 61.0
Cu	8.9	6.9 - 21.0
Cd	0.24	0.10 - 0.41
Pb	1.4	0.4 - 3.3
Untilled Field Area (recently sludged)		
Zn	74.0	18.0 - 134.0
Cu	17.0	7.0 - 33.0
Cd	0.35	0.1 - 0.7
Pb	1.9	0.4 - 7.5
Control Field Areas (unsludged)		
Zn	24.0	14.0 - 32.0
Cu	8.3	3.5 - 10.2
Cd	0.32	0.14 - 0.4
Pb	1.3	0.4 - 3.1

Based on our Hagerstown results, we decided to locate old sludged sites representing a range of soil types and/or sludge metal additions (particularly Cd), and to crop them with chard, soybean, and orchardgrass. We sampled and analyzed over 25 locations. Table 10 shows the metal contents of sludges from some of these locations where sludge is now being applied to agricultural land in the Northeast. Neither Federal nor state governments yet regulate land disposal of these sludges. The Cd level varied from 0.6 ppm in a sludge influenced by food processing wastes to over 1000 ppm in a sludge influenced by a metal-plating industry. Many sludges had less than 15 ppm Cd and Cd/Zn less than or equal to one percent, but most were high in either one or several metals. Very few of these sludges had ever been analyzed for metals or nutrients. Most fields that had sludge applied for many years ranged from pH 5.3 to 5.8, levels conducive to plant uptake of sludge applied metals.

TABLE 10
Heavy Metal Contents of Digested Sewage Sludges Used on Agricultural Land in the Northeast

City	Zn	Cd	Cu	Ni	Cd/Zn
	mg/kg dry sludge				%
20	230	0.6	2600	41	0.26
18	870	7.0	690	37	0.80
19	1390	6.1	570	22	0.44
12	870	5.9	800	36	0.68
15	2380	11.1	680	35	0.47
9	5180	168.0	1450	1140	3.30
13	5800	716.0	1560	590	12.30
22	1520	1230.0	1160	100	81.00

Basic Research on Cd Uptake by Plants

Cd enrichment of crops from ultimate disposal of sludge on agricultural land is one of the primary concerns governing sludge use. (See Braude, et. al. [18] in these proceedings.) Haghiri [19] reported that, at the same soil pH, that as soil cation exchange capacity increased, Cd uptake by oats decreased. He also found that low Zn additions increased soybean Cd uptake, while higher Zn additions reduced Cd uptake (Figure 1). Higher soil temperature increased plant uptake of Cd. In a greenhouse study, Cunningham, Ryan, and Keeney [20], found that as soil Cu levels increased at constant Zn and Cd levels, Cd uptake by corn and rye increased. Bingham, et. al. [12] showed that crops differed markedly in their accumulation of Cd and that graphs of increasing plant Cd vs. added soil Cd could have increasing or decreasing slopes, or be even sigmoidal.

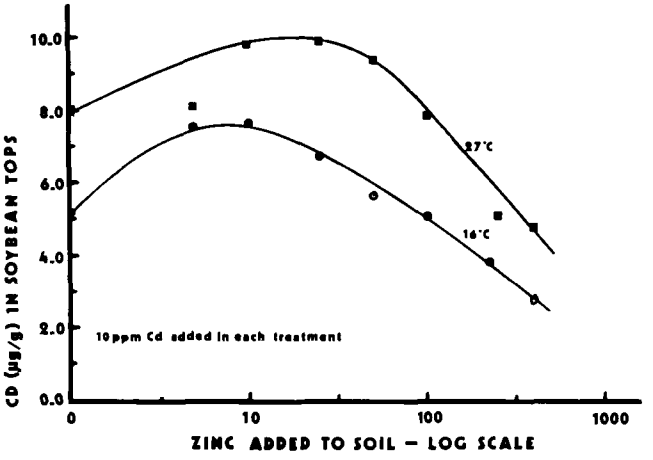

Figure 1: The Effects of Zn Addition and Soil Temperature on Cd Content of Soybean Tops Grown on Soil (pH 6.5) Amended with Ten PPM Cd[19].

We grew "Beeson" soybeans in a pot study to examine the influence of soil pH on Zn phytoxicity and Zn, Cd, Mn, and Fe uptake. Sassafras sandy loam soil was amended with Zn (plus Cd at three percent of the added Zn) at 0, 65, 131, 262, 393, and 524 ppm Zn. Each pot contained two kg of soil. N, P, K, Mg, Zn, Cu, B, and Mo fertilizers were added at 200, 400, 226, 100, 1.31, 0.64, 0.5, and 0.094 mg/kg, respectively, which are high fertility levels appropriate for pot experiments with heavy metals. The soil pH was adjusted from 5.5 to 7.0 using $CaCO_3$; at higher Zn levels the low pH values were omitted because of almost certain phytotoxicity. Three plants per pot were grown for four weeks in a growth chamber. At harvest the plants were separated into roots, stems plus petioles, primary leaves, and trifoliate leaves. Yield, and Zn, Cd, Mn, and Fe content of these tissues were determined. The DTPA-TEA and 0.01 M $CaCl_2$ extractable Zn, Cd, and Mn and soil pH were measured at the start and end of the four week growth period.

No pronounced yield reduction or visual symptom was observed at up to 131 ppm Zn. At lower pH levels and 262 ppm Zn, a severe interveinal chlorosis was observed (Figure 2). When the soil pH was above 6.0 the symptom and yield reduction disappeared. At high soil Zn concentrations, progressively higher pH levels were required to reach normal yields, until, at 524 ppm Zn, increasing the soil pH no longer alleviated Zn phytotoxicity. While the Zn-induced chlorosis symptom resembles interveinal chlorosis caused by Fe deficiency, the Fe in the trifoliate leaves did not fall below 40 ppm. We have observed Zn induced chlorosis in other studies and we think it is a general symptom of Zn toxicity below 6.2 pH. Boawn [21,22] from his studies at pH 6.5-7.5, has suggested that Zn does not cause chlorosis but it is clear from Figure 2 that Zn can cause chlorosis at lower soil pH.

Figure 2: The Effect of Soil pH on Soybean Growth in a Sassafras Sandy Loam Containing 0, 262, or 524 mg Zn/kg. (Soil pH is Indicated on the Pots.)

Figure 3 shows the influence of soil pH on the extractability of soil Zn by DTPA-TEA and 0.01 M $CaCl_2$ at the end of the growth trial. Each plot was generated by 12 to 24 pH levels. Cd extractability was similarly affected by soil pH. The extractable Zn decreased smoothly as the pH increased, with no abrupt decrease in extractable Zn at the critical pH range at which yield reduction or chlorosis were alleviated.

Figure 4 shows the effect of soil pH on trifoliate leaf yield of soybean, and their Zn and Cd content when plants were grown at 262 mg Zn/kg soil (photograph in Figure 2). The leaf content of Zn and Cd decreased as soil Ph increased. Again, there was no abrupt change at the pH at which yield reduction and chlorosis were alleviated.

Figures 5 and 6 show linear regression plots and coefficients of determination (r^2) for the Zn and Cd contents, respectively, or trifoliate leaves. At lower soil Zn additions, where phytotoxicity is not severe, Zn in leaves is correlated highly with soil pH, whereas at higher soil Zn levels the leaf Zn correlations were not as high (Figure 5). Perhaps the Zn phytotoxicity becomes so severe that,

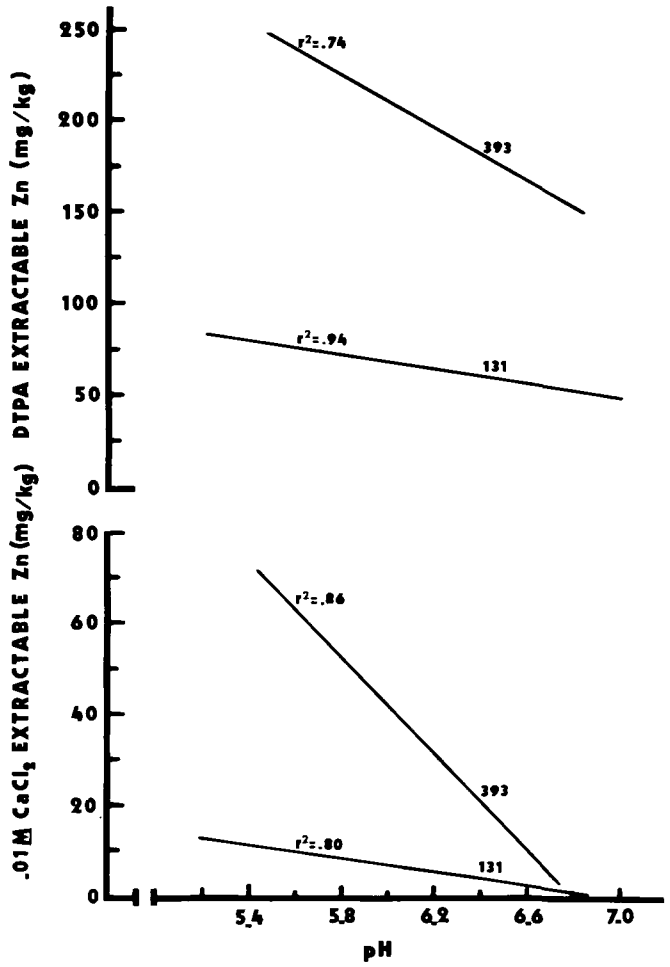

Figure 3: The Effect of Soil pH on DTPA-TEA and 0.01 M $CaCl_2$ Extractable Zn in Sassafras Sandy Loam Amended with 131 and 393 mg Zn/kg.

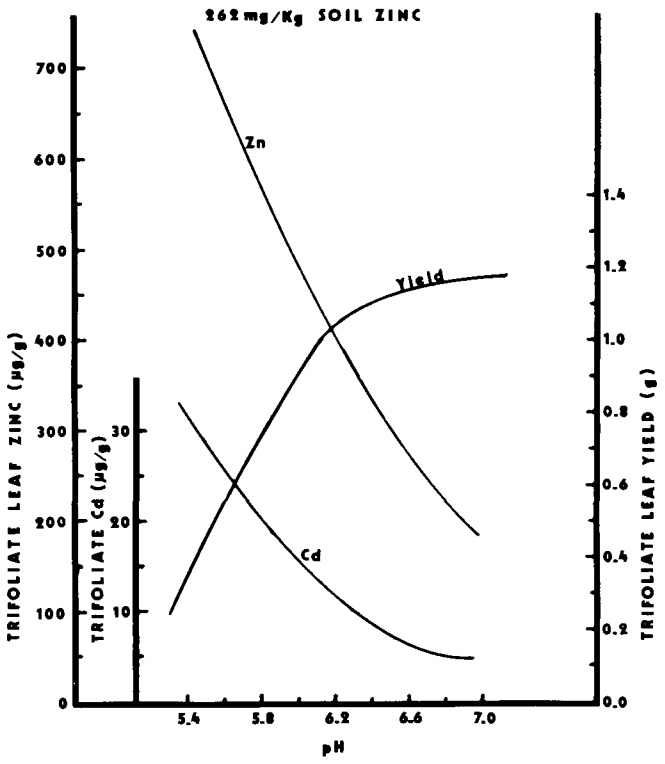

Figure 4: The Effect of Soil pH on Trifoliate Leaf Yield and Zn and Cd Contents of Soybean Grown in a Sassafras Sandy Loam Containing 262 mg Added Zn/kg.

above a certain foliar Zn content, Zn is no longer absorbed or translocated in proportion to available soil Zn. Because Cd phytotoxicity was not the limiting factor in plant growth, Cd translocation continued in proportion to available soil Cd (Figure 6). This led to the Cd/Zn rates shown in Figure 7: where no phytotoxicity was observed, foliar Cd and Zn were similarly influenced by increased soil pH; however, when Zn phytotoxicity was experienced, foliar Zn was limited by the soybean plants' natural mechanisms which limit translocation of Zn to no more than 400 to 700 mg/kg trifoliate leaves. Hence, Cd/Zn ratios increased when the applied Zn (plus three percent Cd of Zn) increased to phytotoxic levels (Figure 7).

Plant Cd uptake is extremely complex. It has been shown that at the same soil Cd level soil pH, C.E.C., Zn, Cu, etc., and temperature, and plant species, variety, age, and part (grain vs. leaves) all affect the Cd content of edible plant parts. We believe that by restricting sludge use on cropland to only those sludges with Cd less than or equal to one percent of their Zn content, the food chain will be adequately protected from sludge-borne Cd.

This, plus a maximum Zn (equivalent) application equal to ten percent of the soil C.E.C. and mandatory initial adjustment of soil pH to 6.5 or higher, will control the increase in crop Cd resulting from sludge use on land. Certainly, no one has yet established an acceptable basis for applying high Cd and high Cd/Zn ratio sludges on agricultural land.

Abatement of Metals at Source to Ensure Safe Sludges

The Environmental Protection Agency advises cities to enforce abatement of metal release to the sewer to protect surface waters and to obtain sludges low in metals to protect: (1) ocean organisms, during ocean disposal of sludge, (2) groundwater, during sanitary landfill disposal of sludge, and (3) air, during incineration of sludge, and groundwater, during disposal of incinerator ash in sanitary landfills. When sludges are applied to land, the metals remain in the topsoil. In order to maintain soil fertility, sludge metals should be minimized, and the maximum amounts of metals which may be applied should be limited tonon-phytotoxiclevels. Chaney[2] and Stewart and Chaney[23] have discussed the need to make the benefits to the farmer and society from sludge use on land worth the risk. Most will agree that if crops are to be grown, a soil should not be amended with more than some maximum Zn, Cu, and Ni levels, based on that soil's properties, e.g., Zn (equivalent) less than or equal to ten percent of C.E.C. or some other maximum.

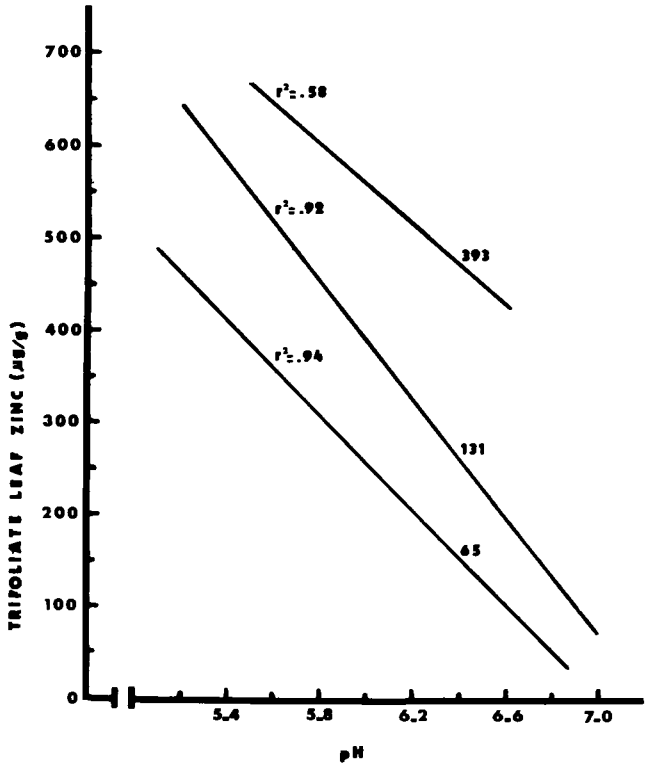

Figure 5: The Effect of Soil pH on Soybean Trifoliate Leaf Zn Content at Several Zn Levels. Zn Added (mg/kg) Is Indicated on Figure.

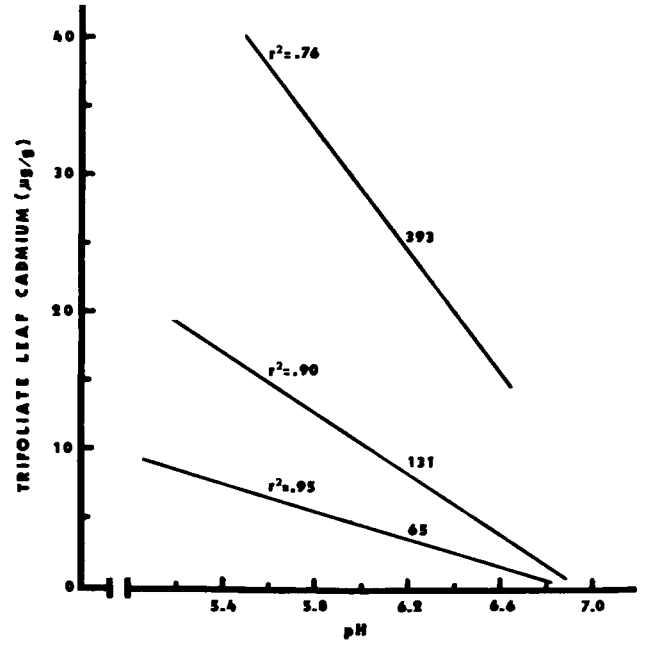

Figure 6: The Effect of Soil pH on Soybean Trifoliate Leaf Cd at Several Zn and Cd Levels. Zn Added (mg/kg) Is Indicated on Figure. Soil Cd Levels Were 2,0, 3.9, and 11.8 mg/kg.

Thus, farmers will not accept high metal sludges which would supply much less N and P than domestic sludges at the same maximum metal application.

To protect the food chain from excessive Cd uptake by plants, Chaney[2] has recommended that only sludges with Cd less than or equal to one percent of Zn should be

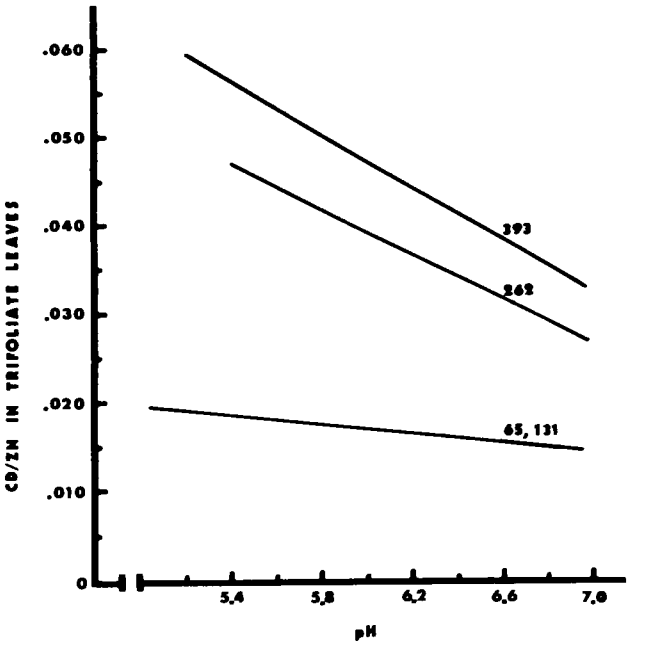

Figure 7: The Effect of Soil pH on Soybean Trifoliate Leaf Cd/Zn Ratios at Several Levels of Added Zn and Cd. Zn Added (mg/kg) Is Indicated on Figure.

allowed on agricultural land. Although high soil pH could be used to limit Cd uptake, there is no guarantee that sludged fields will always be limed. Yield reduction from metal toxicity can be recognized and lime applied the following crop year. However, even this crop should have Cd levels safe for the food chain, or an unacceptable, invisible, risk is being taken. Because Cd less than or equal to one percent of Zn characterizes sludges not impacted by abateable Cd, and this recommendation would lead to a maximum of abut five ppm Cd in plant leaves when phytotoxicity is caused by Zn and the other sludge metals (worst case), Chaney[2] has argued that sludges with Cd less than or equal to one percent of Zn are acceptable for use on land. Under the best management (pH≥6.5) the Cd contents of crop leaves would be considerably lower than 5 ppm at maximum sludge application [Zn (eq.) = ten percent of C.E.C.].

Abatement technology is already available. Lime precipitation [24,25], ion exchange, reverse osmosis [26], liquid-liquid extraction, evaporation, and adsorption on activated carbon, shredded tires [27], peat [28], shredded bark, lignite, starch xanthate [29], and many other materials can lower wastewater Cd to very low levels. In some instances, waste metal recovery has resulted in net savings! The abatement of Cd can be made more by following lime precipitation with filtration through a bed of common peat, Cd abatement can be more nearly failsafe. Cd Values below drinking water standards can be reached with minimum effort and expense.

Cd is a common contaminant of Zn wherever Zn occurs or is used. Most of the Cd is recovered from the Zn during ore processing, and nearly all Zn sold in the United States contains≤0.015 percent Cd of Zn [30]. Thus, industrial use of Zn is not the source of the Cd which becomes

a problem if it reaches sludges. Nor is the problem Cd with the Zn in tires in street runoff. *Rather, it is the specific use of Cd.* Cd pollution can be identified and its abatement enforced. We have analyzed many domestic sludges with Cd/Zn ratios at or below 0.80 percent (e.g., Table 10).

Our findings that many cities have sludges with Cd less than or equal to one pecent of Zn without known Cd sources and the report of Klein, et. al.[31] on sewage-borne metals in New York City conflict which points out the need for objective studies of the Cd sources in urban areas.

Although sludge can be a valuable resource for agriculture, and its land disposal can save cities much money and fuel, each of these benefits is contingent on adequate control of metal release to the sewer and reliable sludge-monitoring programs.

ACKNOWLEDGEMENT

We gratefully acknowledge the cooperation of personnel of the Biological Waste Management and Soil Nitrogen Laboratory, the University of Maryland, the Maryland Environmental Service, and the District of Columbia Department of Environmental Services: E. Epstein, J.M. Walker, J.D. Menzies, J.F. Parr, A.M. Decker, D.S. Fanning, E. Levesque, J.C. Baxter, M.C. Morella, D.C. Mullen, and T. Lathan.

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EFFECTS OF SEWAGE SLUDGE OR EFFLUENT APPLICATION TO SOIL ON THE MOVEMENT OF NITROGEN, PHOSPHORUS, SOLUBLE SALTS AND TRACE ELEMENTS TO GROUNDWATERS

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INTRODUCTION

The downward movement of constituents or decomposition products of organic materials and of reclaimed wastewaters applied to land surfaces is an important factor in groundwater quality. The effect on groundwater quality depends on many parameters including: (1) the nature of the material, (2) its rate of application, (3) management of the land surface, (4) the properties of the soil and the underlying sediments or geological materials, (5) the depth to the saturated zone, (6) the amount of water in the aquifer or aquifers and the recharge rate, and (7) degrees of mixing in the saturated zone. The movement of constituents to the groundwater is of concern in all waste utilization and disposal projects, but is most critical where groundwaters are the major or only source of water for municipal supplies.

When considering the movement of nitrogen, primarily as nitrate, soluble salts, phosphorus and trace elements through soils, one must distinguish between low rates consistent with utilization for crop production and high rates that might be used for disposal of sludges and effluents or for groundwater recharge using reclaimed waters. At low rates of three to five tons dry solids per acre per year to supply the phosphorus needs of crops or 10 to 25 dry tons per acre per year to supply their nitrogen needs most soils, excluding inert sands, have sufficiently large capacities to retain phosphorus and most trace elements that downward movement of these constituents is nil or very slow. At rates of three to five surface feet of effluent waters per year to supply water needs for irrigated lands or at lower rates for supplemental irrigation in humid regions, phosphorus and trace elements added will not move downward to any great extent in most soils. Of course, soluble salts and nitrate will move with drainage waters. At high rates of sludges or effluents adsorptive capacities of soils and sediments can be saturated so that general statements pertaining to low rate systems can not be applied.

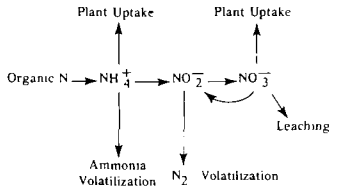
In addition to rate of application the nature of the soil is an extremely important factor in downward movement of constituents. Inert sands and gravels of low organic matter contents have low adsorptive capacities and allow rapid transmission of water whereas the greater the amount of colloidal materials (clays and organic matter) the greater the adsorptive capacity for phosphorus and trace elements. Also, generally, the higher the clay content the slower the water will move. Reactions of constituents with the soil increase with increase in adsorptive capacity and with decrease in rate of movement.

This paper discusses the movement of nitrogen, soluble salts, phosphorus and trace elements through soils in terms of the chemistry of these individual constituents and in relation to low and high rate applications of sludges and effluents and soil properties.

Nitrogen

Nitrogen occurs in muinicipal sewage treatment plant sludges and effluents in organic and inorganic forms. The concentration of nitrogen (N) in effluents normally does not exceed 50 mg N/1, of which approximately 85 to 90 percent is in the form of ammonium, 10 to 15 percent is combined with organic matter, and a small percentage occurs as nitrate[1]. The concentrations of N in liquid sludge varies and depends largely upon percent solids and the type of treatment plant. On a dry weight basis, sludge commonly contains from one to seven percent nitrogen[2]. Liquid sewage sludges containing about five percent solids commonly contain from 1500-2500 mg N/1[3]

The fraction of total N applied in sludges or effluents which may move to underground water supplies depends upon amounts removed by plants and lost through denitrification or ammonia volatilization. The fate of N once it is applied to soil regardless of the source is governed largely by the following reactions (somewhat simplified):



The oxidation of NH_4^+ is a microbial process which proceeds in soil except at extremes in pH (<PH 4.5 and>pH 9), dissolved 0_2 (<0.2 mg/1) and temperature (<5 C and >40 C). The mineralization of organic N to form NH_4^+ proceeds over a wider range of pH and temperature than does the transformation of NH_4^+ to NO_3^-. Hence, mineralization of organic N is not rate limiting in the overall process.

Below pH 4.5, high percentages of inorganic N occur in soils as NH_4^+. The NH_4^+ ion is adsorbed in part by negatively charged surfaces of soil colloids and, as such, its movement is restricted. In soils leaching of NH_4—N and organic N from the root zone is commonly ignored since amounts leached are usually small compared to amounts of NO_3—N leached. At soil pH's greater than nine, sufficient NH_3 forms to inhibit its oxidation to NO_3^- and nitrogen can be lost from the system as NH_3 gas. In the pH range four to nine, under conditions where the dissolved 0_2 exceeds 0.2 mg/1, the NH_4^+ formed by the mineralization of organic N is oxidized to NO_3^-. Nitrate is quite mobile in soil and that which escapes the rooting zone of plants will move with water to lower depths in the soil profile. In soil where regions of low dissolved 0_2 may occur at depths within or below the rooting zone, NO_3^- in the water may be denitrified if the water contains sufficient organic C or reduced forms of S. About one milligram of organic carbon is required for each milligram of nitrate nitrogen to be denitrified (Bower and Chaney).

Once NO_3—N escapes zones in soil where it is removed by plants or denitrified, its movement in soil parallels quite closely the movement of water. Groundwater recharge systems using secondary treated effluent have been designed to minimize the amount of NO_3—N which escapes the zone in soil where it is either removed by plants or denitrified[4, 5]. The systems involve cyclic flooding and drying (anaerobic and aerobic) periods. The aerobic cycle is required to convert NH_4—N to NO_3—N and the anaerobic cycle for the denitrification of NO_3—N. During flooding NH_4—N is adsorbed on the surfaces of soil particles. When the soil is permitted to dry, oxygen enters the soil profile and the NH_4—N is oxidized to NO_3^-. During the next flooding period, anaerobic conditions develop and the NO_3—N is denitrified to N_2 gas. The Flushing Meadows project[6] reported in a ten day flooding period followed by a 10-20 day drying period approximately 30 percent of the N was removed, presumably by denitrification. Somewhat similar results were obtained in the Whittier Narrows project[7] when ten day flooding periods followed by two week dry periods were used.

Effluents or liquid sludges are placed in ponds or lagoons for storage or dewatering by percolation into the soil or evaporation. The purpose of these operations is not necessarily groundwater recharge. There is no plant cover and N loss is exclusively by either denitrification or ammonia volatilization. Lund, et. al.[8] have evaluated nitrogen leaching in soil profiles beneath effluent and sludge lagoons at two locations in California. The soil profiles at both locations were open and coarse textured and conditions were quite conducive to rapid nitrification and subsequent movement to lower depths. Concentrations of NO_3—N in the soil solution at a depth of 12 m beneath sludge ponds which had been used for five or more years were approximately 400 µg NO_3—N/ml. This compared to a concentration of about 30 µg NO_3—N/ml at an offsite location which had not received sludge. The offsite control was an agriculture site and the source of NO_3^- at the lower depths in this profile was nitrogen fertilizers.

Soluble Salts

Concentrations of soluble salts in sewage treatment plant effluents are usually 100-300 mg/1 greater than those of the domestic water supply of the region in question[9]. The percentage increase of soluble salts resulting from wastewater treatment, therefore, depends largely upon the quality of the domestic water supply.

When waters are applied to soils the changes in concentration of soluble salts which occur in the drainage water depend upon the fraction of the water applied which is consumed in evapotranspiration, the extent to which the chemical constituents in the water applied may precipitate in the soil or the extent of dissolution of soluble materials in soil.

In groundwater recharge or wastewater disposal systems where volumes of water applied are large compared to amounts consumed by plants via evapotranspiration, the changes which occur in the composition will be determined almost exclusively by the weathering of soil minerals to produce soluble salts. This weathering process may be enhanced by chemical transformation of constituents in the water which produce acidity, since the solubility of soil minerals increases as the pH of the system decreases. With secondary sewage treatment plant effluents, the main source of acidity arising from biochemical reactions is the oxidations of NH_4^+ to NO_3^-. In the process, two equivalents of hydrogen ion are produced for each equivalent of NH_4^+ oxidized. The extent to which the protons generated react with soil minerals to produce increases in soluble salt is variable. It depends upon other reactions which consume protons but do not increase soluble salts. In systems containing sufficient concentrations of HCO_3^-, for example, the protons produced may react to form carbonic acid or CO_2 and water and the HCO_3^- ion is replaced by NO_3^- ion with no increase in dissolved salt. If, however, the protons generated react with $CaCO_3$, soluble calcium bicarbonate is produced and an increase in soluble salts results.

Field and laboratory studies have demonstrated that effluents applied to soil which contain NH_4^+ produced greater increases in soluble salts than did effluents which contained comparable amounts of NO_3^- but no NH_4^+. Broadbent[10] observed that input water contain-

ing NH_4^+ produced 64 to 128 mg/1 more soluble salts in the drainage waters than did input waters containing an equivalent concentration of NO_3^-. In a groundwater recharge project, McMichael and McKee, using the residue at 100 C as a measure of total dissolved solids (TDS), observed increases of 380 and 160 mg/1 TDS at eight foot depths in two test basins. Bouwer, et. al. passed large volumes (about 100 m) of effluent waters containing 20-40 meq NH_4^+/1 through soil and sediment and observed an increase in TDS of well waters of about two percent.

When waters containing no NH_4^+ and low in dissolved solids are percolated through soils weathering of soil minerals occurs to produce soluble salts. In recent soils (slightly weathered) of arid regions the weathering process is sufficiently rapid to produce concentrations of about 250 mg/1 TDS in the drainage waters[11]. Because of the increment in TDS added in any one cycle of municipal use, most waters from secondary treatment plants contain more than 250 mg/1 TDS even if the TDS of the municipal supply is extremely low. Thus, in groundwater recharge operations involving low NH_4^+ effluent, unless soil materials and sediments have salts which are residual from irrigated agriculture or geological processes, the probability of substantial increases in TDS of percolation water is slight.

In agricultural systems where effluent water is used as a source of irrigation water, concentrations of dissolved salts in the percolation water increase due to the concentrating effect of evapotranspiration. To maintain a proper salt balance for the growth of plants, water in excess of that required by the plants must leach through the root zone. The extent to which dissolved solids increase by plant action depends upon irrigation management. Rhoades, et. al[12] has presented data which show that minimizing the quantity of drainage water results in the smallest possible return of applied salts in the return flow. This occurs because by irrigating with the lowest possible leaching fraction, maximum precipitation of salts in the applied waters occurs, and the weathering of soil minerals to produce salts is minimized.

Data from numerous sources show that NO_3^-, if not lost by biological or chemical processes, will move with water and is a source of NO_3^- contamination of groundwater. The extent of groundwater contamination, however, cannot be assessed from concentrations which occur in soil solution. To evaluate total load of N per unit time, the volume and rate of water movement through the soil above the groundwater table needs to be known.

Transit Time

Free Drainage

The leaching of soluble salts, which consist mainly of the anions NO_3, SO_4, Cl and HCO_3 and of the cations Na, Ca, Mg, through soils is largely dependent on the movement of water through the soil. That is, water movement is so dominant that such factors as ion diffusion, anion exclusion because of the negative charge on clays or organic colloids and temporary trapping or bypassing of salts in micropores or microsites can be ignored for practical purposes.

In the situation where drainage water from the root zone of croplands flows downward through a deep unsaturated zone (where tile lines are not necessary to maintain an aerated root zone), transit time for water and salt to move to a given depth is directly proportional to the water content of the soil material through which the water is moving and inversely proportional to drainage volume. The simple relationship

$$T = \frac{S\theta}{D}$$

where T is the transit time in years, S is the soil depth in cm, θ is the volumetric water content and D is the drainage volume in surface cm, has been found useful in studies of the leaching of NO_3^- through the unsaturated zone in coastal and inland areas of California[13, 14, 15, 16]. The time for water and salts to move 30 m in these irrigated areas is usually 10 to 50 years. In the San Bernadino-Redlands area, for example, fertilization of citrus started about 1900 A.D., whereas NO_3^- started appearing in wells about 1945 and the number of wells that contained water with greater than 10 mg NO_3—N/1 increased as a function of time from 1945 through 1970. Nitrate in these well waters probably comes from various sources but there is sufficient evidence that one of the sources is fertilization of citrus. The time lag is of the correct order of magnitude to be related to transit times for water and salts to be moved through a deep unsaturated zone.

When the drainage water from irrigated fields reaches the saturated zone, it tends to mix very slowly with the water already present and to stay in a surface layer that moves in response to hydraulic pressures. The process of mixing takes place mainly by changes in elevation of the saturated zone in response to recharge or withdrawal of water. For example, the drawn-down cone created around a well that is being pumped promotes mixing of the various layers of water.

In contrast to irrigated fields, the transit of water and salts during groundwater recharge by surface spreading on sandy or gravelly riverbed materials is very rapid. In these cases, the volumes are in the order of magnitude of 100 to 200 surface feet of water per year in comparison to one to two surface feet per year of drainage water from irrigated lands.

The volume of drainage water from croplands cannot be measured directly when this water moves through the unsaturated zone and becomes groundwater. The technology of measuring water flux through the root zone is not yet ready for application in a practical way to field monitoring. Thus, for field studies, estimates of drainage water volume can only be obtained from the dif-

ference between water inputs (infiltration) and evapotranspiration (ET). The problem with this approach is that accurate measurements of ET are difficult to obtain and, for a given field, runoff during rainfall events must be measured directly.

In irrigation agriculture, the chloride balance has been used to estimate drainage volumes from the equation:

$$\frac{\text{Volume of drainage water}}{\text{Volume of irrigation water}} = \frac{\text{Cl}^- \text{ conc. in irrigation water}}{\text{Cl}^- \text{ conc. in drainage water}}$$

In cases where significant amounts of chloride are added in fertilizers or soil amendments such as organic materials, or where harvested crops remove chloride, the concentration of chloride in the water can be adjusted for these quantities.

Increasing irrigation efficiency in irrigated areas or increasing the ET in humid areas will increase the transit time for salts to move through the unsaturated zone. In the case of irrigated agriculture, the mass emission of salts in the drainage water can be decreased by decreasing the drainage volume as a result of increases in on-farm irrigation efficiency. Precipitation of carbonates and silicates are increased by decreases in the drainage volume. However, irrigation agriculture, for the most part, cannot continue without some leaching. Thus, the best that can be done to reduce movement to the groundwater is to reduce mass emissions and increase the transit time.

Tile Drainage

The transit time for water and soluble constituents to move from the land surface into tile lines requires a two-dimensional model whereas in a free-drainage situation a one-dimensional model is sufficient. To get to the tile line the water must move down, and, except in the small area of land over the tile line, it must also move laterally. The transit time is thus a variable depending on the distance from the tile line. Over the line the travel time might be a few weeks or months depending on other factors. At the midpoint between two tile lines the time might be many years.

Recent work by Jury[17, 18] has developed a relatively simple mathematical model dealing with transit times in tile drainage systems. The variables are drain spacing, depth of tile, depth of soil to an impermeable zone, soil porosity and the volume of drainage water. The model has been applied to a number of drainage systems with considerable success. Actually the model predicts the time for a certain fraction of the salt or nitrate from applications of irrigation water or nitrogen fertilizer to be removed in the tile flow. For example, the time required for a 50 percent removal can vary from one or two years to 20 years or more depending on the soil, tile installation parameters and the volume of drainage water.

The model provides mathematical verification and quantifies the concepts that response times to management changes are long. The model also verifies that because of variable transit time, depending on distance from the time line, the total response to changes in management of the land surface will occur over a period of years. The systems are well-buffered because of the amounts of materials in a continuum of transit times from the tile line to the midpoint between tile lines. Because of this slow response there is a potential for misinterpretation of the relationships between surface management and outputs in tile effluents.

Phosphorus

Phosphorus concentrations of sewage treatment plant effluents vary and commonly range from a few to 20 mg P/liter[19]. On a dry weight basis, sewage sludges usually contain from one to six percent phosphorus[20]. Large quantities of phosphorus (P) are precipitated from sewage by lime, aluminum, or iron treatments and generally effluents from sewage treatment plants which employ these processes are lower than other conventional treatment processes. Sludges, from treatment plants employing chemical precipitants (lime, aluminum or iron) on the other hand commonly contain higher concentrations of P than sludges from plants utilizing other types of treatment processes.

In effluents dissolved P occurs as orthophosphates, polyphosphates, and organic phosphates. Orthophosphate is adsorbed or precipitated in acid soils by crystalline and/or amorphous iron and aluminum oxides. In neutral and calcareous soils, orthophosphate reacts with calcium to form, depending upon the ionic composition, a number of slightly soluble or insoluble calcium phosphates.

A number of minerals containing phosphorus occur naturally in soil or have been identified as products of reactions between soil or soil minerals and phosphate salts. Fluorapatite, $Ca_{10}(PO_4)_6F_2$, is the main phosphate mineral in rocks, and probably occurs in most slightly or moderately weathered soils. Other calcium phosphates are hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$; carbonapatite, $Ca_{10}(PO_4)_6CO_3$; octacalcium phosphate, $Ca_4H(PO_4)_3 \cdot 3H_2O$; and dicalcium phosphate, $CaHPO_4 \cdot 2H_2O$. Dicalcium phosphate is the first product of phosphorus fertilizer reaction with soils, octacalcium phosphate, hydroxyapatite, and carbonapatite are thought to form slowly from dicalcium phosphate in slightly acid to alkaline soils. A number of iron and aluminum phosphate minerals have been identified as products of the reaction between concentrated phosphate solutions and clay minerals, and oxides and hydroxides of iron and aluminum; and by inference are thought to occur in soils. Minerals identified include variscite, $Al(OH)_2H_2PO_4$; strengite, $Fe(OH)_2H_2PO_4$; barrancite $(FE,Al)(OH)_2H_2PO_4$; and taranakite, $H_6(NH_4,K)_3Al_5(PO_4)_8 \cdot 18H_2O$.

Concentrations of phosphorus in soil solutions of moderately weathered temperate-region soils are between

0.1 and 1.0 µg/ml. In many highly weathered soils of tropical regions as well as andosols (soils high in oxides of iron and aluminum) and in high pH arid areas (soils high in calcium) phosphorus concentrations are less than 0.1 µg/ml. These solubilities are more or less in keeping with those deduced from solubility product considerations of the mineral forms mentioned.

Phosphate ions are adsorbed on the surface of many substances found in soil. These include the clay minerals or oxide coatings on clay minerals and the same substances which react with phosphorus to form slightly soluble or insoluble compounds. In most cases, it is difficult to distinguish between the formation of new minerals and adsorption on the materials presumed to form to the new minerals. Regardless of the mechanism by which phosphorus is lost from solution (adsorption or precipitation or both) reactions of phosphorus have been reasonably well-described by the Langmuir adsorption isotherm[21, 22]. In the linear form the Langmuir equation has the following form:

$$\frac{c}{\frac{x}{m}} = \frac{1}{kb} + \frac{c}{b}$$

where c= the equilibrium concentration of P in mmoles/1, x/m = mmoles P adsorbed per unit weight, b = the adsorption capacity in mmoles/g, and k is a constant related to the bonding energy. A phosphorus adsorption capacity (b factor) can be obtained from a plot of P adsorption data according to the Langmuir equation. Ellis has used this approach and estimated the adsorption capacity of several soils to range from about 80 to 900 lbs P per acre foot. Adsorption capacities as determined using the Langmuir constants, however, are not permanent and part of the capacity of a soil to sorb phosphorus is restored with time (Ellis). The use of this approach, therefore, underestimates the potential capacity of a soil to attenuate phosphorus in wastewaters or sludges (Bouwer and Chaney). It should serve, however, as a reasonable first approximation.

A number of long-term fertility trials have demonstrated phosphorus mobility, except in all but the most sandy soils, is quite restricted. Pratt, et. al.[23] for example, reported results for phosphorus concentrations in soil treated with treble superphosphate at a rate of 57 lbs P/acre/year for 28 years. More than 80 percent of the P remained in the surface twelve inches and no movement of phosphorus was observed at depths lower than 36 inches. The soil to which the phosphorus was applied had a pH of 7.6, a trace of excess $CaCO_3$, and an exchange capacity of approximately 10 meq/100 g. In Florida, Fiskill and Ballard[24] reported all of the phosphorus from an application of 3200 lbs P per acre applied over a six year period remained in the surface four feet of a Lakeland fine sand.

A number of studies involving land applications of sewage sludges or effluents have demonstrated that phosphorus movement to lower depths in soil profiles is quite restricted. Hook, et. al.[25] observed movement of phosphorus to a depth of approximately 120 cm after six years of irrigation with sewage effluents at rates of five cm per week. The concentrations of phosphorus at the depths sampled were greater for a sandy loam soil than a clay loam soil. Bray extractable phosphorus (0.025N HCl-0.03N NH_4F) increased to a depth of 90 cm in the sandy loam profile, but only to 30 cm in the clay loam profile. In the sewage farm serving Melbourne, Australia (Werribee Farm), Johnson, et. a.[26] reported total concentrations of phosphorus at depths between 25 to 45 cm in soils irrigated with primary effluent for a period of 48 to 73 years which were twice those of the non-effluent treated soils. Most of the phosphorus applied, however, accumulated in the surface 25 cm of soil. Mean concentrations of phosphorus draining from the irrigation paddocks were 2.9 µg P/ml compared to 32.1 µg P/ml for the raw sewage, indicating a soil attenuation of about 90 percent. The soil at the Werribee Farm is acid in the surface and has a CEC which, depending upon the plot, ranged from 15 to 30 meq/100 g.

In systems where sewage effluents or liquid sludges are applied to soils at high rates to recharge groundwaters or dispose of wastewater, phosphorus movement to considerable depths has been observed. Bouwer, Lance and Riggs reported removal of approximately 50 percent of the phosphorus in an effluent containing 10 mg P/1 after passing through 30 feet of soil and sediment (three feet of a fine, loamy sand underlain by coarse sand and gravel layer to a depth of 30 feet). Lund, Page and Nelson (1975) followed the movement of phosphorus in soil beneath lagoons used as percolation or storage ponds for effluents and liquid sludges. In their study phosphorus movement to a depth of at least three meters was observed. The type of soils or sediments involved in the studies of Bouwer, Lance and Riggs and Lund, Page and Nelson (1975) were sands and loamy sands and those most conducive to the rapid movement of phosphorus.

It seems reasonable to conclude the capacity of soils to retain phosphorus is related to their content of reactive colloidal surfaces of clays, clays coated with carbonates and oxides of iron and aluminum, and alkaline earth carbonates. Except for sandy soils, large amounts of phosphorus applied to soil in the form of sludges or effluents will be retained in the surface horizons and consequently restrict their movement to lower depths in the soil profile. The period of time a particular soil can be used as a filter to remove phosphorus will depend on loading rate, rate and volume of water which moves through the soil profile and the capacity of the soil to retain phosphorus. Although methods are available to determine short-term capacities for soils to retain phosphorus, more information is needed on long term effects in relation to loading rate.

Trace Elements

The trace element concentrations of sewage treatment plant sludges and effluents vary widely and depend upon the kinds and percentages of industrial input and the nature of the treatment process. Usually trace element concentrations of sludges increase and effluents decrease in relation to the extent to which sewage waters are treated. Chen, et. al.[27] presents data which show that secondary treatment reduced concentrations of Cd, Cr, Cu, Hg, Pb and Zn in primary effluent by factors which ranged depending on the element from 63 to 80 percent. Suspended particulates were 94 percent less in the secondary effluent than the primary effluent, demonstrating that high concentrations of trace elements in the primary effluent are largely associated with suspended particles.

Page[28] reviewed reported values for concentrations of trace elements in sewage sludges and observed the following ranges to occur (in μg/g dry weight basis): B, 6-1000; Co, 2-260; Cu, 150-11700; Mo, 2-1000; Pb, 10-26,000; Zn, 100-49,000; Cd, 1-1500; Cr, 20-40,000; Hg, 0.1-50; Ni, 10-5300; Se, <0.1-81; and As, 0.5-1800. Concentrations in primary effluent are highly variable and depend upon the percent suspended solids. Secondary effluents almost without exception show lesser concentrations of trace elements than do primary effluents. Ranges for trace element concentrations in secondary effluents reported by Blakeslee[29] for 23 treatment plants in Michigan follow (in mg/1): As, < 0.005-0.23; Cd, < 0.01-0.15; Cu, 0.01-1.3; Cr, < 0.01-1.2; Pb, < 0.02-1.3; Hg, < 0.0002-0.001; and Zn, 0.03-1.2. These concentration ranges of trace elements are more or less comparable to those reported for secondary effluents by others. If secondary effluents were applied to soils at rates of a few surface centimeters per week the potential buildup of trace elements in soil would be low. If one assumes an application of 100 surface cm per year and a concentration of 0.1 mg/1, an amount of trace element equivalent to 1.0 kg/hectare/year would be applied. Since concentrations of trace elements in secondary effluents normally do not exceed 0.1 mg/1, excessive buildup of trace elements resulting from the use of effluents for irrigation would not be expected. However, in long-term, high-rate systems involving groundwater recharge or wastewater disposal operations, accumulation of trace elements in soil with subsequent leaching to lower horizons is possible.

When effluents or liquid sludges are applied to soil, trace elements in the sludges react with the soil and the trace element concentrations in solution are changed. The kinds and extent of chemical reactions which may occur depend largely upon the chemical properties of the soil.

The chemical properties of soil are governed largely by the amount and kind of colloidal clay and organic matter. Waters passing through soils low in organic matter and with high percentages of sand sized particles have a much lower capacity to attenuate the composition of waters passing through them than do soils with high percentages of clay and organic matter. Reactions of constituents in waters with soils under conditions of saturated flow may differ from those under conditions of unsaturated flow. Under anaerobic conditions, solubilities of Cd, Cu, Hg, Ni, Pb, and Zn are usually less than under aerobic conditions.

In general, elements which occur in solution as anions are neutral molecules pass through soils more readily than do elements which occur as cations. The trace elements As, Se, F and Mo in inorganic form occur as anions in aerated soils, while B occurs as a neutral molecule. Although there are exceptions, dissolved Cd, Cu, Cr, Pb, Hg, Ni, and Zn occur in waters and soil solutions in inorganic form as cations. Most trace elements may also occur as either soluble or insoluble organo-metallic complexes in fresh waters and soil solutions. The chemistry of organo-metallic complexes in natural systems is complex and presently not well understood. However, where concentrations of dissolved trace elements in soil solutions and waters exceed those predicted from inorganic solubility product considerations, the element is thought to occur as a soluble organic complex.

There are only limited data available on the movement of trace elements in soils. In a recent study, Boswell[30], observed some movement of Zn to 30 cm depth and Cd, Cr, Cu, and Pb to 15 cm depths in an acid soil which had received a surface application of 16.8 meter tons of sewage sludge per hectare. Data published by Hinesly, et. al.[31] show evidence of movement of Cr, Cu, Cd, Pb, Ni and Zn below 15 cm depth in soil. Page evaluated data reported by Andersson and Nelsson[32] and demonstrated that following annual applications of seven meter tons sludge per year for a twelve year period, essentially all of the applied Mn, Zn, Cu, Ni, Co, Cr, Pb, Cd, Hg, As, and Se were recovered in the surface 20 cm of soil. Only B moved in substantial amounts to depths lower than 20 cm in the soil profile. Kirkham[33] reported no accumulations of Cd, Cu, Pb, and Zn in soil at depths below 61 cm following applications of supernatant liquid from sludge holding lagoons for a three year period.

In systems involving long-term, high-rate volume operations trace element movement to depths of at least three meters has been observed. Kirkham also observed that following applications of approximately 28 meter tons of dry sewage sludge per hectare per year for a 35-year period, concentrations in the depth increment from 30-61 cm of treated soil were increased over those of the control by the following factors: Cd (11.6), Cu (8.4), Ni (4.6), Pb (14.4), and Zn (7.4). In a study at the Werribee Sewage Farm at Melbourne, Australia, Johnson, et. al. observed some movement of Zn, Cu, Ni, and Cd to a depth of at least 45 cm in a field which had been irrigated with raw sewage for 70 years. Lund, Page and Nelson[34] presented data which show movement of Cd, Cu, Ni, and Zn to a depth of at least three meters in soil

beneath a sewage lagoon which had been used to pond secondary sewage sludges for a period of 20 years. With the exception of B, the previously cited references point out that trace element movement (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn) in all but very sandy soils and long-term, high-rate volume operations to depths below one meter in the profile is quite restricted.

In natural soils, concentrations of As in soil solutions are usually less than 0.01 mg/1. Levels, as high as a few mg/1 have been reported in solutions from surface soils where arsenical agricultural chemicals have been applied to control disease or weeds. Where arsenicals have been used for a number of years in orchards to control diseases, movement of As to a depth of two meters in soil profiles has been observed [35]. In acid soils dissolved As probably reacts to form iron or aluminum arsenates which are quite insoluble. In calcareous soils, the formation of calcium arsenate is thought to limit the solubility of As.

The concentrations of cadmium in uncontaminated soil solutions are normally less than 0.005 mg/1. However, concentrations in soil solutions from soils treated with sewage sludges as high as a few mg/1 have been reported [36, 37]. There are not sufficient published data available to critically evaluate Cd movement in soil. Some data are available for high rate and volume systems. Lund, Page and Nelson (1974) observed movement of Cd to a depth of three meters in soil beneath a sludge lagoon. Bouwer, Lance, and Riggs showed that water containing 0.007 mg Cd/1 passed through soil to underground wells with no change in the concentration of Cd. Factors which control the solubility of Cd in natural systems are not well-understood and presently it is not possible to evaluate movement in soils in relation to their chemical properties. Most available information suggests that Cd solubility in soils is controlled by adsorption reactions involving colloidal clays, organic matter, and amorphorus oxides of iron and aluminum.

Concentrations of Zn and Cu in soil solutions are normally in the range of 0.01 to 0.1 mg/1. When sewage treatment plant sludges or effluents containing Zn and Cu are applied to agricultural soils (except for sands) the concentrations of Cu and Zn in the soil solution from the surface horizon may show some increase, but, unless unusually high loading rates are employed movement to depths below one meter are rarely observed. Boswell observed some movement of Cu and Zn to a depth of 30 cm in a soil which was amended with sewage sludge. Lund, Page and Nelson (1974) observed movement to a depth of three meters in soil beneath a sludge lagoon which had received high loading rates for more than 20 years.

Molybdenum and selenium occur in soil solutions as anions. Only limited data are available on concentrations of these elements which may occur in effluents or sludges. Both elements, when dissolved, are thought to react in acid soils with iron and aluminum to form rather insoluble compounds. In neutral and calcareous soils, both elements react with calcium to form rather insoluble compounds. For these reasons movement of either Mo or Se is not expected to occur in agricultural soils receiving either effluent or sludge.

Chromium added to soil in dissolved form is thought to react to form quite insoluble oxides. Unless high loading rates of materials high in Cr are applied to soil, movement of Cr to depths much below the point of application are not anticipated.

The solubility of inorganic Pb in natural systems is probably limited by the formation of sparingly soluble or insoluble compounds such as lead oxide, sulfate, carbonate, and phosphate. Concentrations of Pb in the soil solutions are normally less than 0.01 mg/1; however, higher values have been reported for soil solutions near or derived from parent materials high in lead. Very few data are available for Pb concentrations of soil solutions from soils which have received application of either sewage sludge or effluent. In the groundwater recharge project at Flushing Meadows, Bouwer, Lance and Riggs reported only 20 percent attenuation of Pb in effluent which contained 0.08 mg P/1 after the effluent had passed through three feet of a loamy sand underlain by 27 feet of a sand-gravel mixture.

Concentrations of Hg reported to occur in natural waters and soil solutions are usually less than 0.001 μg/ml [38]. It may occur in solution as a cation, anion, or uncharged molecule. Under reducing conditions Hg may precipitate as HgS which would limit its concentration to <0.002 μg/1. Mercury exhibits high affinity for humic substances and hydrous oxides of iron and aluminum. Because of its high affinity for humic substances and other inorganic constituents in soil, movement of Hg in soil is not expected.

Boron, except in highly alkaline soils (pH <8.5) occurs in soil solutions as undissociated boric acid [$B(OH)_3$]. It is sorbed by active oxides of iron and aluminum in soil, but its affinity for these solid surfaces is low compared to affinities of other trace elements for these surfaces. For these reasons, B is quite mobile in soils. In sandy soils low in organic matter and active iron and aluminum oxides, B in water passes through soils essentially uncharged. Organic matter and active iron and aluminum oxides tend to limit the mobility of B in soils, but generally the equilibrium involved is such that substantial percentages of dissolved B remain in solution and move with percolating water.

SUMMARY

Soils, except for sands, have a high capacity to retain As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn. In situations where sludges of effluents are added to agricultural soils to supplement plant nutrients or as a source of irrigation water, essentially all of the above trace elements applied should remain within the surface meter of soil. In groundwater recharge or disposal operations where

high application rates are involved, movement of trace elements may occur and the extent of movement will depend upon the amount and composition of the waters applied, and the nature of the soil or sediment through which the waters flow.

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ENVIRONMENTAL EFFECTS OF SLUDGE DISPOSAL IN SANITARY LANDFILLS

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INTRODUCTION

The land disposition of sewage sludge is an area of growing controversy. Those who advocate landspreading of sludge on agricultural lands are facing increased opposition from those who point out that insufficient information exists on the health implications to man from the long-term low-level injection of crops grown on sludge amended soil (or animals fed crops grown on sludge amended soil). Further, citizen groups are using our lack of information on pathogen survival and movement in soils and groundwater to "kill" proposed sludge utilization and disposal projects. The problem surrounding the ultimate disposition of sludge is one of the reasons for holding this conference. This paper will address only the small portion of that problem that deals with the environmental effects of the subsurface disposal of municipal wastewater sludges.

Oceanside Demonstration

In particular, this report will discuss two EPA projects, one of which is completed, while the other is ongoing. The first project was an investigation of the environmental and economic effects of disposing liquid sludge and septic tank pumpings into a sanitary landfill. The work on this project was conducted by Ralph Stone, Inc., a consultant located in Los Angeles, through a demonstration grant to the City of Oceanside, California. The objectives of the study were to determine:

- The capacity of solid waste to assimilate the mositure in liquid sludge and septic tank pumpings and the significant factors affecting that capacity.
- The optimum means for nuisance-free admixture of liquid sludge with solid waste in a landfill.
- The effects of combined liquid sludge-solid waste disposal on the environment, landfill operating efficiencies, and personnel performance.
- The effects of liquid sludge on landfill compaction.
- The most economically feasible methods for transporting and disposing of liquid sludge.

Rather than discussing the findings of this project in detail, this report will touch upon the principal conclusions. (Copies of the final report can be obtained by writing to: Solid Waste Information Materials Control Section, U.S. Environmental Protection Agency, Cincinnati, Ohio.)

Significant Findings

A laboratory analysis, based upon the moisture-absorbing capability of the particular components normally found in solid waste, concluded that each pound of solid waste (dry weight) can be expected to absorb 0.6 to 1.8 pounds of water. Table 1 provides a detailed breakdown of the predicted range of absorptive capacity of municipal refuse. The moisture content of Oceanside's solid waste was approximately 25 percent. Therefore, the corrected absorption rate is 0.5 to 1.35 pounds of water per pound of solid waste as received at the landfill. Additional testing, using Oceanside's waste, confirmed that the City's waste fell into the upper half of the expected absorption range.

"The City of Oceanside produces approximately 0.6 lb of sludge (average wet weight from three treatment plants) for every 1.0 lb dry weight of municipal refuse. Theoretically, therefore, the solid waste generated by the city should have adequate capacity to absorb all the water in the liquid sludge. This was verified in a number of field tests at the Oceanside landfill in which sewage sludge was applied to solid waste at a rate of 0.35 to 0.6 lb of sludge per 1.0 lb of solid waste wet weight. A total of 35 applications were made (one day per week for 35 weeks over a ten-month period). No leachate was observed during this period. In cases where minor sludge runoff occurred, it was the result of an inappropriate spreading technique and the runoff was absorbed into the fill cover."

The moisture content of solid waste varies widely depending on seasonal waste characteristics, the weather on the day the waste is collected, etc. If we use an average moisture content of 30 percent, the moisture absorption range changes to 0.42 to 1.25 pounds of water per pound of solid waste.

TABLE 1
Predicted Range of Absorptive Capacity of Municipal Refuse as Received at Oceanside Landfill

Component	Available field absorption capacity of waste components* Maximum	Minimum	Average composition+ (percent)	Field absorptive capacity** Maximum	Minimum
Newsprint	262		7.2	19	
Cardboard	146		8.3	12	
Miscellaneous paper	397	97	23.6	94	23
Leaves and grass	312	92	3.8	12	4
Prunings	207	0	6.3	13	0
Garbage (food waste)	229	0	9.2	21	0
Textiles	284	84	2.3	7	2
Non-absorbents++	0	0	39.3	0	0
Total			100.0	178	60

*The absorptive capacities determined in laboratory tests reduced by the measured moisture contents from Oceanside waste samples, percent dry wt basis.

+Average of year's (four quarters) composition of collected refuse arriving at Oceanside municipal landfill site.

**Pounds water per 100 pounds of average mixed refuse as received at the landfill; derived from product of available absorptive capacity and average composition for each component.

++Includes wood (absorption very slow), foam plastic (insignificant quantity), and dirt, sand, and ashes (which entrain but do not absorb).

Source: Stone, R. Disposal of Sewage Sludge Into a Sanitary Landfill. Environmental Protection Agency Publication SW-71d, Washington, D.C.

TABLE 2
Predicted Average Liquid Sludge and Solid Waste Generation Rates for 1973 and 1985

	Average sludge generation rate (lb/cap/day-dry wt)*	Average sludge generation after digestion (lb/cap/day-dry wt)+	Average liquid sludge generated after digestion (lb/cap/day-5% solids)	Average solid waste generation rate (lb/cap/day)**	Ratio of liquid sludge to solid waste
1975	0.18	0.12	2.34	3.6	.65
1985	0.21	0.14	2.73	3.9	.7

*Based on OSWMP internal calculations.

+Assuming a 50 percent reduction in volatile solids after digestion (the volatile solids content of the sludge is assumed to be 70 percent), the net result is a 35 percent reduction in the total solids digested.

**Based on OSWMP internal calculations for solid waste disposal quantities after resource recovery.

Table 2 shows that any given city, on the average, produced .65 pounds of liquid digested sludge (five percent solids) to each pound of solid waste (wet weight) it generates. It therefore could be concluded that the solid wastes generated by any given city should have adequate capacity to absorb all the water in its liquid digested sludge. However, since the amount of sludge produced will vary greatly, and the population equivalent served by a treatment plant may be greater than that served by the disposal site, it is recommended that site specific calculations be conducted before the disposal of liquid sludge is initiated. Ultimately it is the sludge/solid waste ratio achieved at the working face that determines acceptability.

Since the addition of liquid sludge, if properly managed, should not bring a disposal site to its field capacity (the theoretical point at which leachate will begin to migrate from the disposal site since the waste has reached its moisture retention capacity), the next question the project addressed surrounds the quality of the leachate formed. A comparison of leachate from the Oceanside pilot test drums and field test cells to leachate collected from control drums, control cells at the site, and from other sites in Southern California, showed that addition of sludge to solid waste produced a more acidic leachate (pH 4.65.9 compared to 5.67.8). In addition, the BOD_5 averaged 19,600 mg/1 for the sludge/solid waste leachate as compared to an average of 10,900 mg/1 for the solid waste leachate. No other major differences in leachate quality were reported.

The addition of sludge also resulted in changes in the operational characteristics of the site. "The application of liquid digested sewage sludge by spreading onto the compacted landfill working face proved to be a better methodology than admixing solid waste into a pool of liquid sludge. The landfill dozers experienced no slippage in working the liquid sludge when it was spread and allowed to dry and infiltrate for a few minutes over and into the surface of a working face of less than 30 percent slope. A greater working face slopes and in pooled or fresh liquid sludge, the dozers experienced some slippage."

A double splashplate assembly was used for gravity spreading of the sludge. This configuration distributed the sludge over an estimated area twelve feet wide and six feet deep. In order to avoid channeling and the resultant runoff, the truck (a 3500 gallon tank truck) had to be moved at least three times during unloading. More frequent moves were required in wet weather.

"Qualitatively, addition of liquid sewage sludge to solid waste in the Oceanside landfill was observed to reduce dust and blowing litter due to the increased moisture content of the disposed materials. Further, qualitative observations of odors resulting from admixing normal "well-digested" liquid sludge and solid waste indicated a similarity in strength to typical solid waste landfill odors. The pilot test drums, field test cells, and the demonstration landfill tests indicated that admixture with well-digested primary and secondary sludges produced a mild, earthy, non-noxious odor until the absorbed sludge dried, after which normal landfill odor types prevailed. Undigested raw sewage sludges and septic tank pumpings in the pilot test drums, however, produced moderate to strong noxious septic odors. Such noxious odors can be expected whenever raw sewage is disposed to landfills in cases of digester upsets, treatment plant strikes, natural catastrophes, etc. The septic odors can be controlled by immediate cover with six inches of soil or normal landfill dry solid waste. Even though the Oceanside landfill was located in immediate proximity to an urbanized area including apartments and two schools, very few complaints concerning odors were received."

From a site engineering viewpoint, the addition of sewage sludge resulted in better solid waste fill compaction and density. In a controlled field test, compaction was approximately four percent better following sludge application. (Density averaged 1,120 pounds per cubic yard, which is well into the upper range of "solid waste only" landfills.)

Environmental Effects

The Oceanside project added to our knowledge about sludge disposal, however, it has several weaknesses. Due to the climate in Southern California, it was necessary to spray large quantities of water onto the test cells to produce leachate. Further, while drum tests are valuable, there is a need to determine what happens in a landfill under real-world conditions. Therefore, we awarded a contract to SCS Engineers, in Long Beach, California, to evaluate the environmental impact of mixed sludge/solid waste and "sludge only" disposal sites. These evaluations are being performed at full scale disposal sites rather than in the laboratory or under stringently controlled field test conditions. While we will not be able to explain why groundwater contamination did or did not occur with the same accuracy as we could from a controlled demonstration, we will learn much more about the "real world" impact of nine sludge disposal sites.

Site Selection Criteria

In selecting the nine sites to be investigated, the following criteria were used:

- Subsurface placement of sludge should have been practiced at the site for at least one year.
- The site should not have been closed for more than three years.
- A mixture of sludge only and sludge/solid waste sites must be selected.
- A range of operational practices, geographical, and climatological conditions should be represented.
- Good operational and historical records are preferred.

ANALYSIS

Sites have been selected in New York, New Jersey, Virginia, Illinois, Arkansas, and Nebraska. After each of the sites were selected either two or three wells were drilled. Figure 1 illustrates the procedure used to capture leachate at the bottom of each fill and to measure gas composition (CO_2, CH_4, and air). Each well was drilled down through the buried waste until the subsoil was reached. Core samples of the soil between the bottom of the fill and groundwater were taken every four feet (up to a maximum of four samples). After reaching groundwater, the hole was filled with gravel and cement from the groundwater to a point approximately one foot below the bottom of the fill. As shown in Figure 1, the remainder of the hole was fitted with one leachate and two gas monitoring conduits. A total of three leachate samples will be taken; the first, one month after drilling, and the remaining two will be taken on a monthly basis. Two gas samples will be taken during the four month analysis phase of the project.

Depending on the depth to groundwater and the availability of onsite monitoring wells, either one or two groundwater monitoring wells were drilled. The wells, one in shallow groundwater, while the other was much deeper, were located to capture any contamination moving from the site. Background water quality samples were taken from neighboring wells located upflow from the site. The groundwater from each of these wells, composite samples of sludge collected at the treatment plant, and the soil samples were tested for the constituents listed in Table 3. A similar, but more extensive analysis is being conducted at municipal solid waste sites. The purpose of that analysis is to determine the quantity of leachate produced, the constituents of that leachate, the effectiveness of the soil between the bottom of the fill and groundwater to attenuate the leachate, and to monitor for contaminant movement in groundwater. Of the sixteen sites being examined, some are sanitary landfills, some converted dumps, and some open dumps.

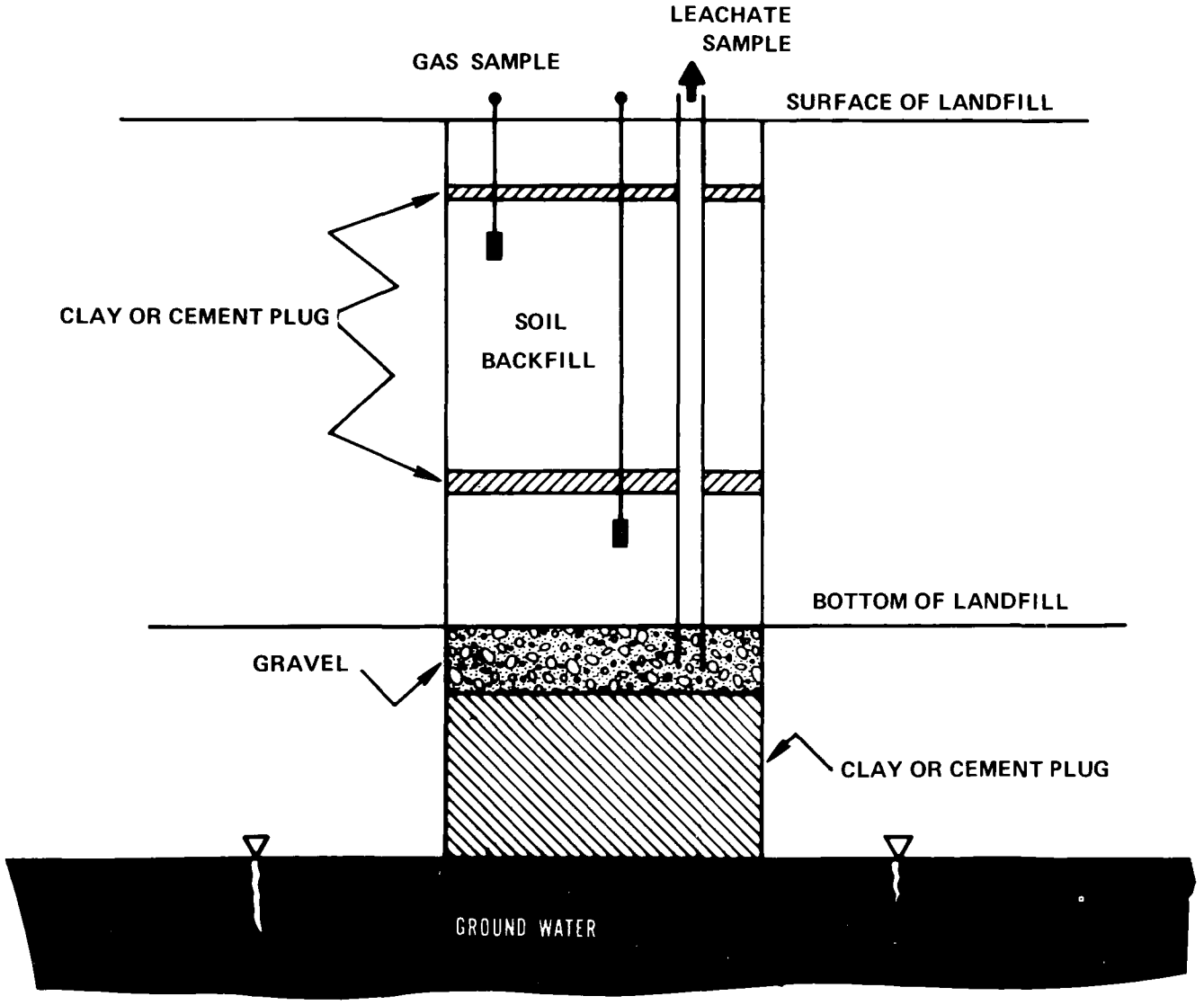

Figure 1: Typical Sampling Well Details.

TABLE 3
Sludge, Leachate, and Groundwater Sample Analysis

NH_4	SO_4	Ca
NO_3	CL	Cd
TKN	Cu	Cr
COD	Fe	Hg
TOC	pH	Pb
Total Coliform	Fecal Strep	

A comparison of the constituents and strengths of leachate produced at sites accepting sludge to those produced at "solid waste only" sites will enable us to better understand the effects of adding sludge to solid waste and their impact on leachate treatment technology. A comparison between contaminant movement will begin to provide the information needed to evaluate the environmental effects of subsurface sludge disposal. We recognize that soil types will vary from site to site, as will leachate quality. This will complicate these comparisons, yet it is our opinion that there will be enough similarity to enable valid comparisons.

Expected Results

Unfortunately, we are only now beginning to receive the data from the first round of sampling. It was hoped to be able to present some preliminary findings, but the data is too sketchy. However, we do expect to find leachate contamination and migration in the groundwater below improperly located and operated sites accepting sludge. This presumption is based on several factors:

1. Approximately 70 percent of the disposal sites in the contiguous United States are located in areas receiving greater than 30 inches of precipitation annually.
2. Most of the 14,000 to 18,500 disposal sites in the United States are dumps rather than sanitary landfills.

Information gathered from state solid waste programs and in-house investigations shows that *dumps* located in areas receiving 30 inches of annual precipitation *will* produce leachate, and in many cases, that leachate will contaminate groundwater beyond drinking water standards. In five groundwater contamination studies recently completed by our office, economic damage averaging over $300,000 per site was incurred. In two of these communities the cost is expected to rise further. In all of these cases, only a small percentage of the groundwater was being utilized, thus minimizing the current economic damage.

The effects of the addition of sludge, whether liquid or dewatered, on the quality of the leachate produced, as well as the effects on the soil's ability to attenuate that leachate and the ability of that leachate to migrate from the site remain to be determined. If the projects proceed as scheduled, we plan to release preliminary findings within the next nine months.

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IMPACT OF LAND DISPOSAL OF SLUDGES ON GROUNDWATER

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INTRODUCTION

This paper deals with the many problems involved in evaluating the impact of land disposal of sludges on groundwater quality, with particular emphasis on the hydrologic aspects. It solves no problems and gives no definitive answers. The purpose, rather, is to direct attention to the complexity of the subject, and to suggest some practical considerations that may be applied in evaluating potential disposal sites.

From the following discussions it is evident that it is possible to draw up guidelines for land disposal of both sludge and effluent, and this of course has been done (particularly for effluent disposal) by numerous agencies (e.g., U.S. EPA[1]). It cannot be emphasized too strongly, however, that these cannot be definitive. Each proposed disposal site must be studied and evaluated according to its own particular characteristics.

The extreme complexity of evaluating the potential impact of land spreading on groundwater resources can be illustrated by the implications of Table 1, which shows 20 principal variables involved. We now assign only three categories to each of these variables (high, medium, low, or good, average, poor), which for many of them is an oversimplification. The number of possible variable combinations that can be encountered is then 3^{20}, or about 3.5 billion. Even if only two categories (good-bad) are assigned, the variable combinations still exceed one million. Obviously, the real-life evaluations are not as appallingly difficult as these figures would indicate. They do demonstrate, however, that there can be no cut-and-dried answers to questions such as "if municipal sludge is applied by spreading, with an application rate of 25 tons per acre per year, what will be the effect on groundwater quality?"

TABLE 1
Principal Variables in Land Disposal

Element	Variables
Sludge	1. Composition 2. Type of treatment
Application	1. Method 2. Loading rate
Soil	1. Texture [a] 2. pH 3. Organic matter content 4. Cation exchange capacity 5. Percent base saturation 6. Depth 7. Slope
Climate	1. Temperature regime 2. Precipitation regime
Crop	1. Uptake 2. Management
Ground Water	1. Depth to zone of saturation 2. Nature of zone of aeration 3. Natural quality of ground water 4. Physical nature of aquifer 5. Chemical nature of aquifer

a) This includes infiltration rate, permeability, and available moisture capacity, each of which could well be considered as a separate variable.

Chemistry

While there is a very large body of data and information on the behavior and fate of contaminants within the zone of biological activity in the soil, there is very little indeed on what occurs within aquifers. Hence the latter must be evaluated almost entirely on theoretical considerations, relating to the mineral composition of the aquifers and the composition of the percolate. This applies to all contaminants, regardless of source.

The percolate concentrations for many sludge constituents vary by two orders of magnitude and the others by one order, depending upon the composition of the sludge and degree of retention in the soil. The constituents whose concentrations may exceed EPA limits for drinking water include: iron, manganese, nitrate, cadmium, lead, silver, and possibly others (based upon percolate data in Table 2 [2-7]. All of the analyses are for percolate at the bottom of the zone of biological activity. Further reduction in contaminants may take place in passage to the water table, depending upon the depth of the latter and the mineral composition of intervening material. However, in the absence of evidence to the contrary, it should be assumed that percolate will not meet drinking water standards. The heavy metals, however, may be removed by ion exchange during passage through the aquifer.

TABLE 2
Constituents of Sludge Percolate[a]

Constituent	Percolate concentration mg/l	
Iron	0.04	- 5.40
Manganese	0.05	- 0.68
Calcium	8	- 107
Magnesium	3	- 152
Sodium	0.90	- 47
Potassium	0.70	- 11
Sulfate	2.4	- 156
Chloride	0.35	- 59
Ammonium	0.40	1.28
Nitrate	8	- 15
Total Nitrogen	8	- 25
Phosphate	0	- 1.2
Organic Carbon	7	- 12
Boron	0.40	- 2.0
Cadmium	0.04	- 1.20
Chromium	0.01	- 0.04
Cobalt	0.02	- 0.04
Copper	0	- 0.25
Lead	0.05	- 0.22
Mercury	0.001	- 0.0014
Molybdenum	0.01	- 0.05
Nickel	0.006	- 2.00
Silver	0.01	- 0.30
Vanadium	0.03	- 0.04
Zinc	0.006	- 0.27
Total Heavy Metals		-

[a]Values reported in References 2-6.

Walker[8] has dealt with the problem of monitoring toxic wastes at land disposal sites. He concludes that practically all such sites are equipped with generally ineffectual monitoring systems, and outlines the measures that would be required for evaluation of the fate of toxic wastes.

The current tendency in predictive chemistry is to combine it with flow and dispersion characteristics of the aquifer, and solve the differential equations involved by use of digital models, as will be discussed later. Of course there is always the problem of just what should be plugged into the equation. Hem[9] points out that the classical adsorption isotherms of Freundlich and Langmuir, while useful for evaluating adsorptive capacities for single ions, have little value in studies of ion-exchange, which is the usual mechanism within aquifers. Back and Langmuir[10] state that the two chemical unknowns that most inhibit the statisfactory formulation of models are the lack of information on chemical reaction rates and the effect of organic ions on the behavior or inorganic ions.

Hydrology

An understanding of the flow pattern of contaminants is of great importance to the understanding of the entire groundwater contamination picture. Figure 1 illustrates an idealized flow pattern. From this it is seen that the sludge-contacted water moves to its discharge area by a definite route, and is not (as is often imagined) subject to dilution by the entire body of groundwater lying between the disposal area and the area of discharge. There is, however, dilution caused by mechanical dispersion, which results from the complexity (on a microscopic level) of the paths followed by the fluid, and (on a macroscopic level) inhomogeneities within the aquifer. Be-

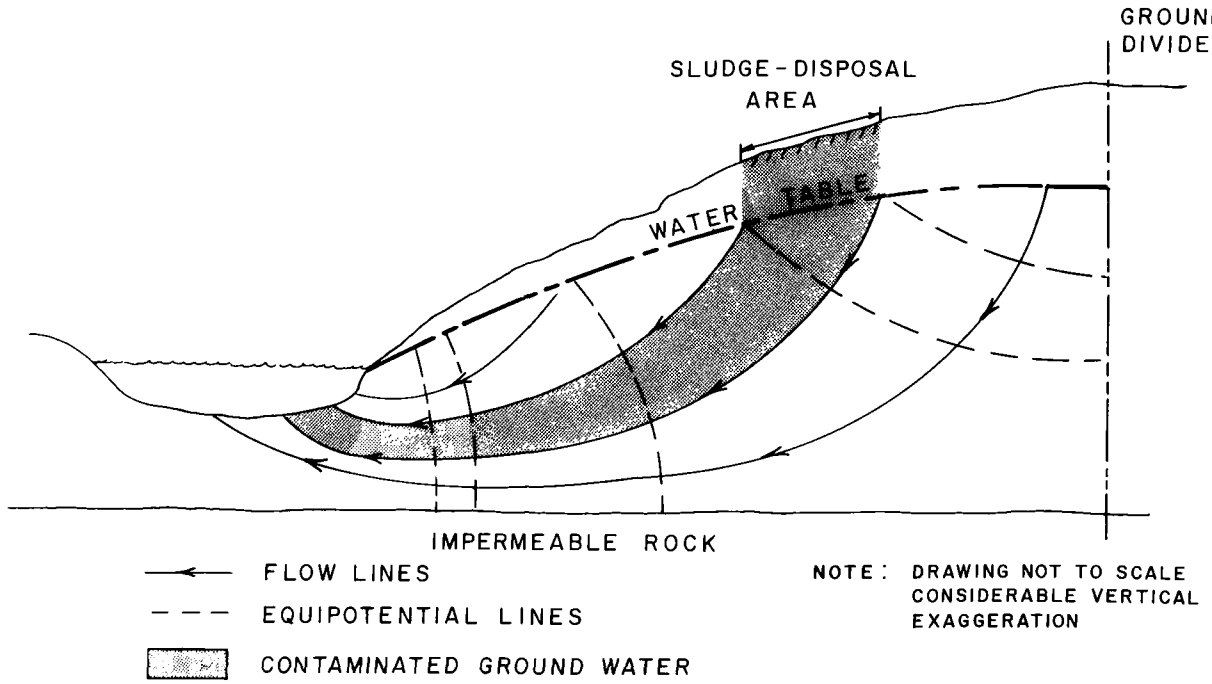

Figure 1: Flow in a Water-Hole Aquifer (Humid Region).

cause of this, the contaminated fluid invades the natural groundwater to some extent and is concurrently invaded by the latter. Molecular diffusion also takes place, but this is relatively unimportant except when the flow rate of groundwater is very low, or the concentration of the contaminant is very high. The latter is associated with high density percolates, which will also distort the idealized pattern by tending to sink to the bottom of the aquifer.

The rate of groundwater movement within an aquifer is obviously of great importance. It is governed by the hydraulic gradient and aquifer permeability, the latter of which varies far more widely than any other physical property encountered in contamination studies. The U.S. Geological Survey [11] has determined permeabilities for a gravel through which, under a gradient of ten feet per mile, water would move at the rate of 60 feet per day, and for a clay through which, under the same gradient, the rate of movement would be one foot in about 30,000 years. The factor is 450 million. Flow rates in most aquifers, however, range from a few feet per day to a few feet per year.

Theoretical solutions, some of them quite elaborate, are available for the expression of all of these phenomena. Unfortunately, these solutions are restricted to relatively uncomplicated systems quite unlike those encountered in actual aquifers. Mechanical dispersion, which is usually predominant in determining the shape of the plume of contamination, is so profoundly affected by heterogeneity that any attempt at detailed prediction is futile. Skibitzke [12] comments that ". . . the nature of the heterogeneous region can hardly be described through reference to the individual geometric discontinuities. Such a description would require an endless compendium of individual descriptions, a device so obviously impractical that it renders the region not amenable to description by measurement of any of the characteristics visible or accessible from the surface of the region."

One of the most informative studies on the spread of groundwater contamination, and the modeling thereof, is the one carried out at the National Reactor Testing Station (NRTS) in Idaho and reported by Robertson and Barraclough [13], with additional background material in a report by Robertson, Schoen, and Barraclough [14]. Their findings show the state-of-the-art of digital modeling for such purposes, and demonstrate clearly both the powers and the limitations of the method. The following discussion is directed to these ends, and technical details are limited to those necessary for a proper understanding.

The NRTS site is on the Snake River Plain in southeast Idaho, overlying an aquifer consisting of thin basaltic flows and interbedded sediments, with a water table about 450 feet below land surface. Industrial and low-level radioactive wastes have been discharged to the aquifer through seepage ponds since 1952, and since 1964 cooling-tower blowdown has been injected directly into the aquifer through an injection well. The U.S. Geological Survey has monitored the facilities since their inception, and has analyzed the fate of the wastes, using data from about 45 observation wells. The complexity of the subsurface regime, however, is such that no explanation could be given for past behavior, and no predictions could be made about the future. To resolve these questions a digital model, simulating the aquifer, was developed. The modeling included a hydrology phase to solve the equation for groundwater flow, and a solute-transport phase to solve the equation for solute movement, both of which were verified on the basis of historical behavior. The verification procedure is used to adiust the values of various parameters, and Robertson and Barraclough note that the most speculative of these are the dispersivities and dispersion coefficient, remarking that "No effective way of measuring coefficients in the field is presently practical because of the large-scale aquifer inhomogeneities. It is therefore invalid to extend ordinary laboratory measurements to field conditions."

Simulations were made for chloride, a conservative ion; tritium, which is subject to radioactive decay; and strontium-90, which was strongly adsorbed. It was concluded that the model is a valid tool for estimating waste distribution in the aquifer. Even so, the authors warn that this is highly dependent upon future hydrologic conditions, which can only be assumed.

The transverse despersivity value (450 feet) required to give the best fit of the theoretical plume to the observed plume is much larger than had been expected from either classic theory or laboratory models. The actual chloride plume after 16 years, extended about five miles downgradient and had a maximum width of almost six miles. In contrast, Pinder [15] found a transverse diffusivity value of only 14 feet in a case of chromium contamination in a glacial aquifer on Long Island. In this particular case, the shape of the plume of contamination could have been predicted with moderate accuracy from the time that contamination commenced, since the aquifer is fairly homogeneous in two dimensions. Drawing a three-degree cone (as suggested by Danel [16]) along the flow lines, using the mound formed under the disposal ponds as an apex, gives nearly as good a fit as does the digital model. This approach does not, of course, involve the element of time. For practical purposes, however, it could be applied to similar aquifers to provide an initial idea of what the area of contamination would be. This by no means eliminates the need for monitoring and periodic analysis of collected data.

Thus far we have been considering natural groundwater flow, disturbed only by mounding effects at the disposal site, which are small for sludge disposal. In practical application, however, there may be existing or potential well fields, relatively nearby, that would utilize the disposal aquifer. The inter-relationship in such cases should be considered, since there is no reason why disposal should preclude utilization, provided that both ac-

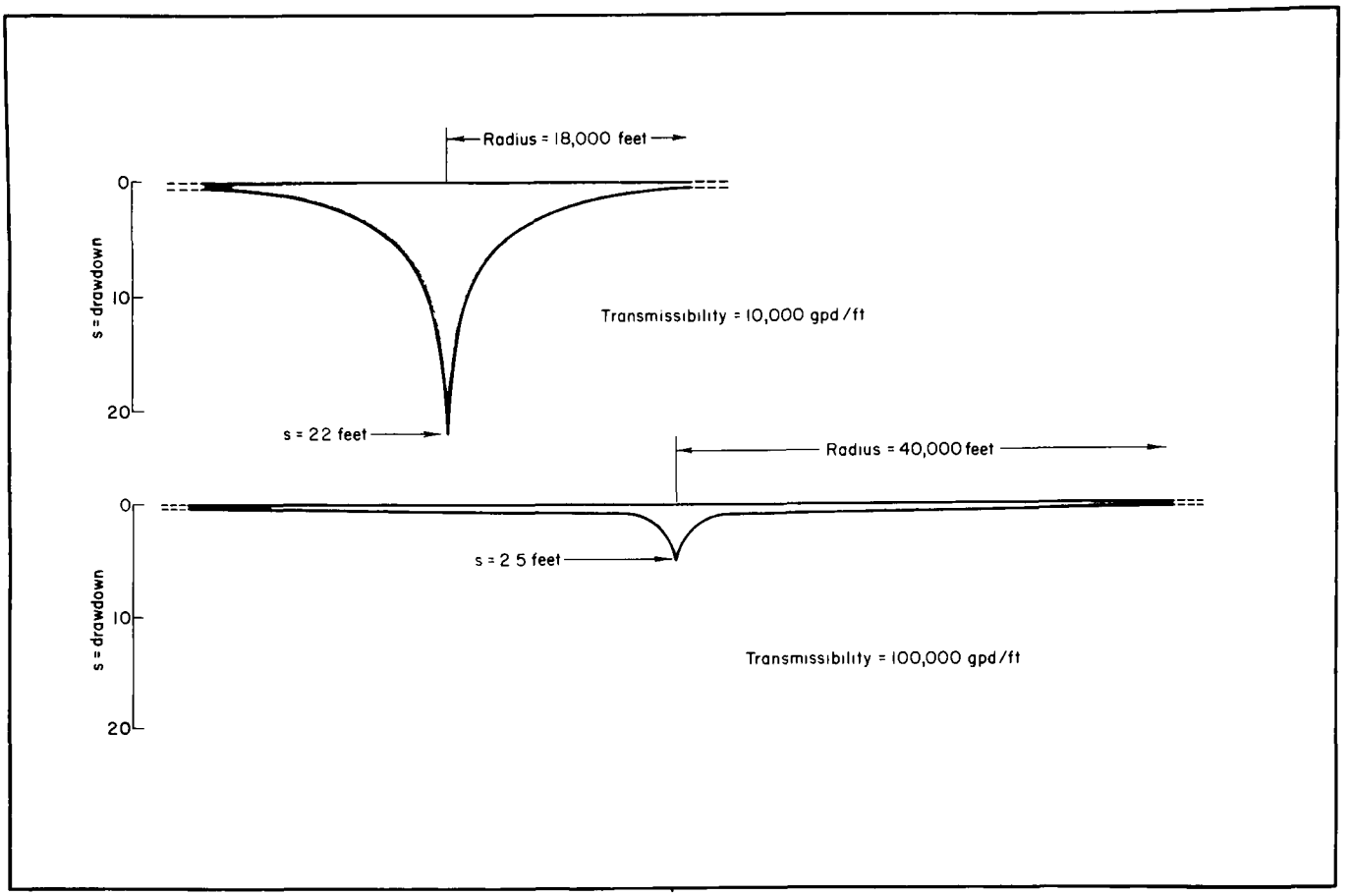

Figure 2: Effect of Differing Coefficients of Transmissibility Upon the Shape, Depth and Extent of the Cone of Depression. Pumping Rate and Other Factors Being the Same in Both Cases.

activities are planned on the basis of an understanding of the hydrologic system.

Pumping from an aquifer alters the natural flow pattern of groundwater, the degree of alteration depending upon the hydraulic characteristics of the aquifer, the rate of pumping, the duration of pumping, and recharge characteristics. This alteration consists of a cone of depression with the well at the center, towards which water flows radially from all directions. Drawdown within the well is required to create a sufficient gradient to move water towards the well at a rate equal to the rate of pumping. Neglecting recharge, the volume of the cone at any given time, multiplied by the storage coefficient, represents the total volume of water extracted from the aquifer since pumping began. The effect of transmissivity on this radius is shown in Figure 2. Since the drawdowns required to move water to the well are less in the more transmissive aquifer, but the volume of water pumped is the same, it is necessary for the radius of influence to be greater. As a corollary, wells in highly transmissive aquifers will capture contaminants at greater distances than those in aquifers of low transmissivity. Because water-table aquifers have higher storage coefficients than do artesian aquifers, the radius of influence and the volume of the cone are smaller in the former, all other conditions being equal.

One effect of this cone of influence on wells pumping in the vicinity of a plume, or of a source, of contamination is shown in Figure 3, which illustrates that undesirable effects cannot be eliminated, necessarily, by locating a well or well field either out of the line of the natural plume or upgradient from the source. On the other hand, Figure 4 illustrates that even in a direct line downgradient from the source, only a portion of the water flowing to the well will consist of contaminated water, and that this portion decreases with increasing distance from the source. Again, however, these are simple cases of perfect radial flow, and the pattern would be distorted by inhomogeneities in the aquifer; by streams, lakes, or impermeable rock barriers within the radius of influence; or by other pumping wells nearby.

Pumping from one aquifer in a series of two or more alters the head relationships among them, and can reverse the naturally occurring interaquifer transfer of water. (This is also true if two or more of the aquifers are pumped, but only the simplest case is considered here since the others differ only in detail, not in principle.)

It is commonly (but not universally) the case that the natural head in an artesian aquifer is higher than that in the overlying water table one. In this case, leakage will occur upwards from the artesian aquifer into the water-table aquifer, the amount per unit area depending upon

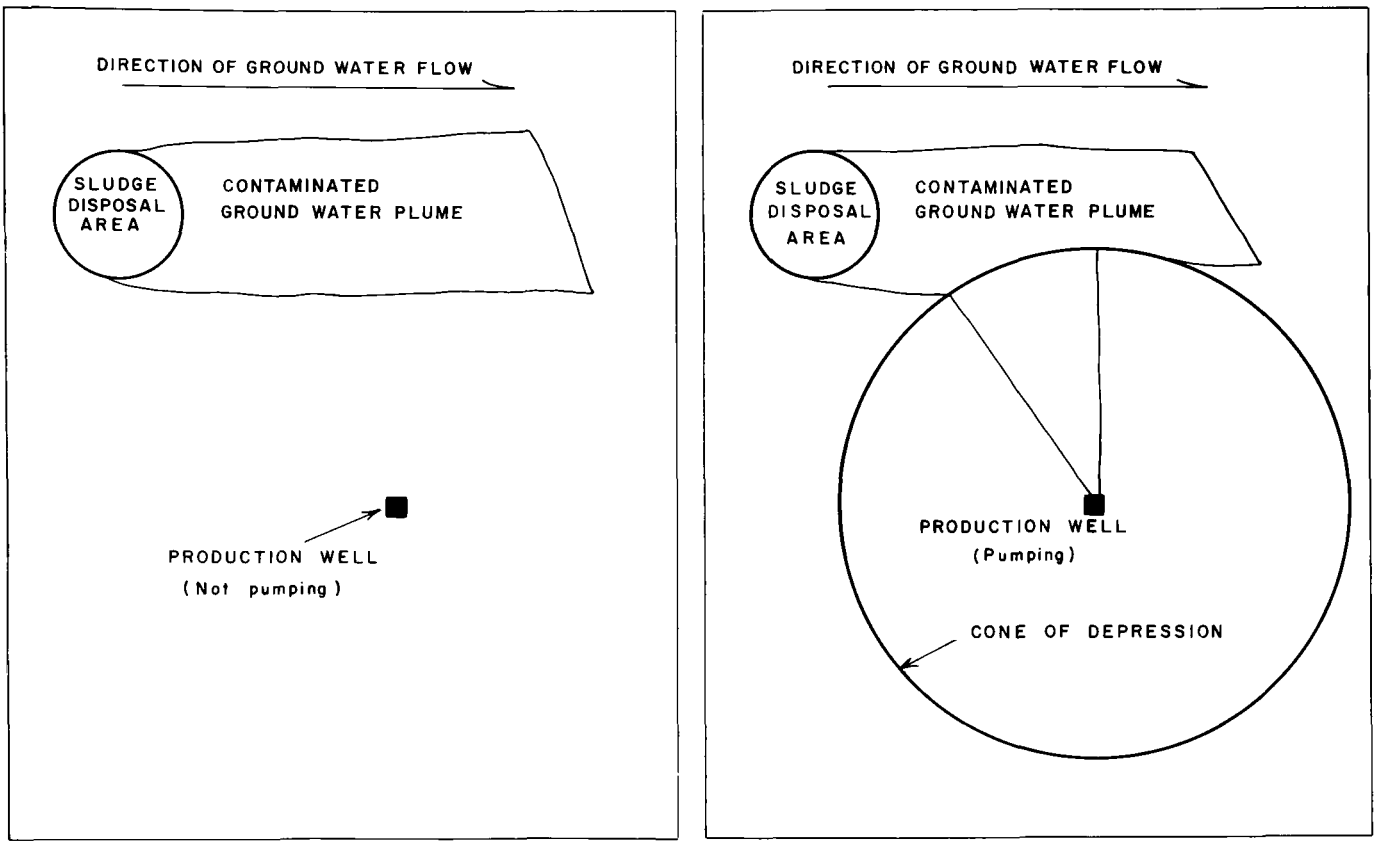

Figure 3: Illustration of Interception of a Contaminated Groundwater Plume by a Pumping Well.

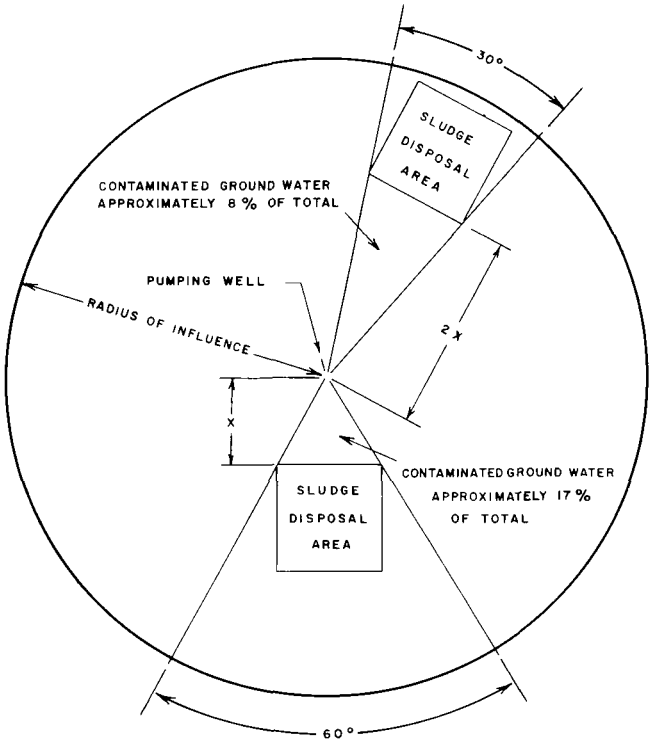

Figure 4: Effect of Distance of Contaminated Source from Pumping Well on Percentage of Contaminated Water Pumped.

the thickness and vertical permeability of the confining bed, and the difference in head between the two aquifers. If the artesian aquifer is pumped, its head within the cone of depression is reduced, as is (consequently) the upward leakage. If the pumping rate is great enough, the artesian head will fall below the water-table head for some distance around the well, and in this area the flow will be reversed and downward leakage will take place (Figure 5).

From the above discussion it is apparent that even a confined aquifer is not necessarily protected from contamination. If the water-table aquifer in the example given is contaminated, some of the contaminants will eventually reach the confined aquifer and thence the pump. The amount of such contaminant transfer will depend upon the same factors that govern leakage, plus the exchange and adsorptive capacities of the confining bed. In some cases, it would be negligible; in others, significant. There is also evidence that clay layers may act as semipermeable membranes, with osmotic effects that may create anomalies in both pressure heads and concentrations of dissolved ions[9].

Obviously, all of these considerations are applicable to cases where natural head in the water-table aquifer is higher than in the artesian one. In this case, the natural leakage would be downwards, and pumping from the artesian aquifer would simply increase the rate of con-

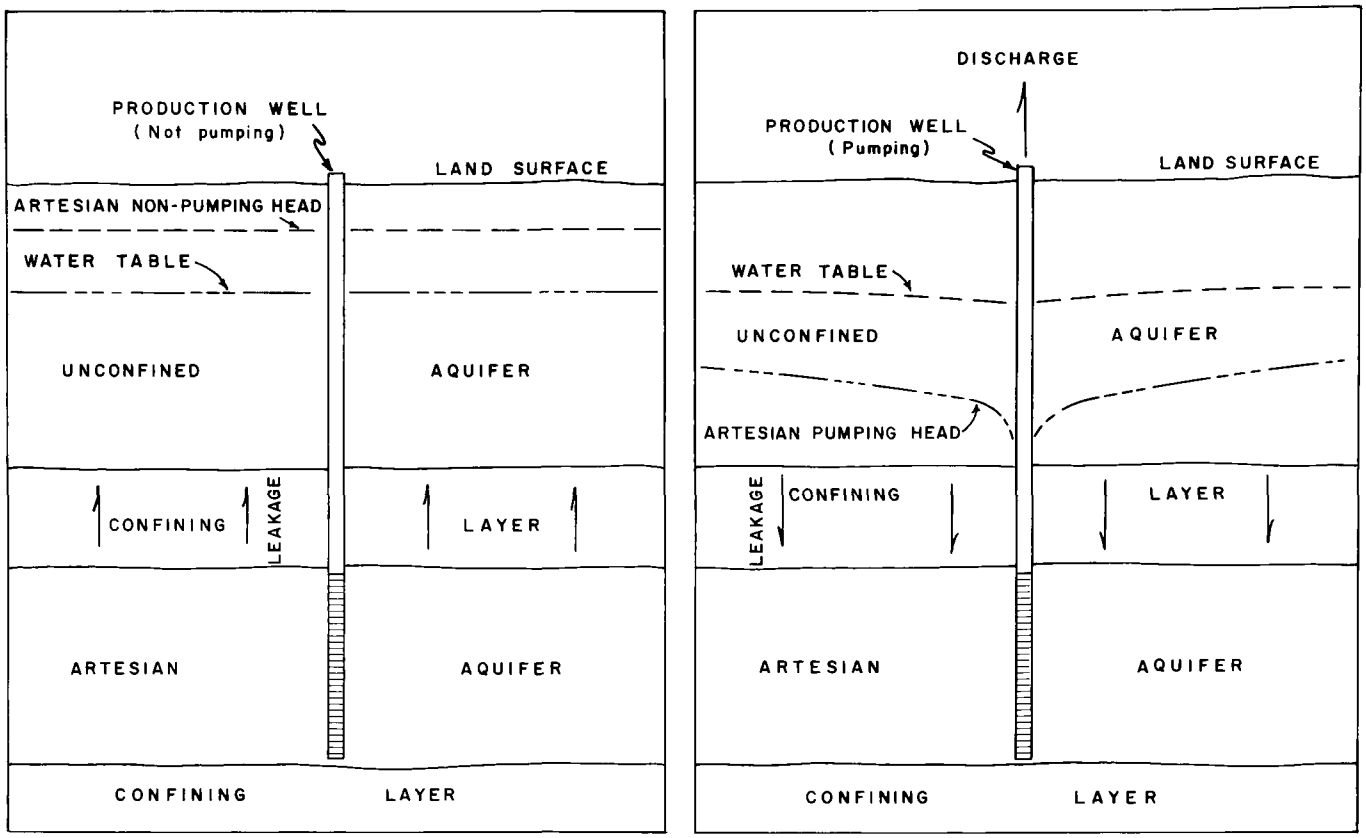

Figure 5: Reversal of Leakage through a Confining Layer by Pumping from an Artesian Aquifer.

taminant transfer. The same is true of the case where an artesian aquifer contaminated by human activities would underlie an uncontaminated water-table aquifer.

SUMMARY

The factors governing the chemical and transport behavior of contaminants through the zone of aeration and in the aquifer are enormously complex, and at present there appears to be little prospect of any accurate prediction of them prior to the emplacement of sludge, or any other potential contaminant source. This may be rectified by the continuation of theoretical and laboratory studies, and in particular by the accumulation of data from field investigations. In the meantime, each proposed disposal site must continue to be evaluated as best as possible for gross effects.

ACKNOWLEDGEMENT

The author wishes to thank Olin C. Braids for the compilation of Table 2, and for his review and suggestions.

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ENGINEERING STUDY AND FIELD DEMONSTRATION TRIALS FOR SAND DUNE STABILIZATION

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INTRODUCTION

The U.S. Navy Weapons System Training Facility is located in the Boardman area of northeast Oregon that is rated by the Columbia-Blue Mountain Resource Conservation & Development Project as a severe wind erosion area. The entire site is within an ancient lake bed making the soil a collection of silt, sand and gravel layers. In addition to moving sand accumulations, concern with dust in the mid-Columbia region has resulted in a request for action by county authorities.

The eastern boundary of the Navy Range is bordered by the Heppener highway. At times during 1971 and 1972 and mid-1974, blowsand has created traffic hazards and a road maintenance problem. In addition, two sandblows along the east boundary have caused some crop damage on adjoining farms.

Along the northern boundary of the Navy Range, sand motion has caused concern since it has crossed the boundary and is moving onto privately owned land. Agricultural land development throughout this windy region of Oregon has caused a high sensitivity to windblown soil erosion.

As a result of numerous requests from county authorities and adjoining neighbors, the U.S. Navy activated two research contracts with the consulting engineering firm of George D. Ward & Associates designed to provide soil stabilization in the critical areas.

The first Navy contract was a soil building program using fiberous wastes. The first trials utilized a variety of solid wastes in varying concentrations which were incorporated into a sandblow (test plot) on the Navy Range. The treated sand was then planted to dryland grasses in November 1972 and evaluated during 1973.

The intent of the second engineering study was to apply on a much larger scale sand control procedures found to be effective during the initial contract. Seeding and physical stabilization procedures were undertaken on the second contract during the fall planting season of 1973 and the early spring planting season of 1974.

The program planned is similar to soil stabilization programs being conducted in Israel, the Isle of Jersey in the English Channel and at the Lowry Bombing Range in Colorado. In Israel, shredded municipal waste is covered with a layer of sand before reseeding with desert vegetation. In Jersey, shredded and composted municipal waste is blended with blowsand for developing turf (and disposing of the solid wastes). At the Lowry Bombing Range the entire production of sewage sludge from Denver is used in a soil building program. The mechanically thickened sludge is deposited in a layer, plowed, disced and seeded. The product is a healthy stand of range grass that is both productive and highly resistant to wind erosion.

RESULTS AND RECOMMENDATIONS

In order to establish adequate vegetative ground cover on the many and widely disbursed areas needing assistance, the careful selection of locally available, lightweight and easily transportable farm equipment plus organic soil additives is quite important. Experience gained in the initial field study clearly demonstrated the high cost of transporting and distributing large quantities of bulky organic materials to remote areas of the range. Consequently, in order to achieve maximum effectiveness at the least possible in-place cost, it is essential that only fast moving, highly mobile equipment plus easily transportable organic and inorganic nutrients be considered. Additionally, the selection of equipment and procedures requiring the smallest number of personnel is important due to high labor costs and seasonal limitations on the availability of local field personnel.

It was found that in order for the project to be economically practical, it must be managed on a highly flexible, seasonal basis. While it is known that planting can occur either in the spring or fall, sudden and unexpected seasonal variations require almost a day to day decision making capability. This flexibility is also necessary in order to assure maximum utilization of available moisture, ground temperature and short wind-free intervals. Therefore, it remains of prime importance that equip-

ment and operating personnel capable of being mobilized quickly should be considered.

When considering the spring and fall planting seasons during which commercial crops are customarily planted, it must be remembered that the farmers basic objective is to allow sufficient growing time to produce a crop of maximum commercial value. This requirement therefore, appreciably shortens the time interval available for commercial planting as compared to that which is available when the objective is to produce any degree of plant growth so long as it is capable of retarding wind velocity along the soil surface. Consequently, maximum advantage should be taken of virtually all opportunities to plant seed when conditions appear suitable to achieve even partial germination and perhaps even stunted plant growth unable to produce seed due to the lateness of planting.

There is obviously an advantage if a seed crop can be produced, since it may make it unnecessary to plant a given area more than once. However, if for any reason no seed stock is produced, even partial growth is advantageous if it slows or stops sand action even in a portion of a problem area. When new plant growth results are marginal, it is recommended that a continuous reseeding program be implemented in an attempt to gain full control of the specific sand area involved before control attempts are withdrawn.

Contrary to conventional farming practices, an area to be seeded should not be plowed and cultivated in the usual fashion which is customarily done to achieve maximum crop uniformity. In the case of soil erosion control, any existing plant growth, whether still living or dead, should be disturbed as little as possible in all reseeding procedures. Where large areas are involved justifying the use of tractor drawn drill seeders, both should be operated in the standing stubble with the seed being planted directly into the existing straw and root clumps. The same is true of hand seeding where wheeled equipment is either not recommended or incapable of operating.

So long as existing plant residues are not disturbed and remain essentially in an upright or leaning position, protection is maximized. Any action, whether it be tillage, grazing, flattening by the wind, or natural decomposition, which either depletes or flattens the residue, reduces its effectiveness to retard wind erosion. The initial increment of residue is normally the most effective with each additional amount increasing the protection in relation to the quantity originally developed.

The physical characteristics of plant residues are also important, and their effect on wind velocity and turbulance at ground level should be considered when selecting plant species. In general, the small finer textured cereal grains and grasses afford greater protection than equal quantities on a total weight basis of coarse stalked plants such as sorghum and maize. Long, small grain stubble, and that in a leaning position, is more effective than if flattened.

Studies conducted by the Food and Agriculture Organization of the United Nations suggest that loamy sands require 1,750 pounds of plant growth per acre to control wind erosion providing the plant stalks remain in an upright or leaning position. If laying flat, the same degree of control would require 3,500 pounds of the same type plant residue.

It is also quite obvious that wherever possible, mechanically planted seed rows should be oriented perpendicular to the wind. Portable wind tunnel tests conducted elsewhere on rows of nine inch high sorghum stubble spaced at 40 inches between rows, showed soil losses three times greater with rows parallel to the wind than with the wind perpendicular to the rows. In the case of Boardman sand, raw spacing over approximately eight inches is not recommended.

Where wide, tractor drawn drill seeders are advantageous in planting long and narrow belts of sand running parallel to the wind, a zig-zag pattern should be followed to prevent an opportunity for wind to line up and run unobstructed down the rows. Such areas should be planted with two passes of the drill seeder. Each should be done in opposing, zig-zag patterns resulting in a "waffle" or "quilted" pattern as the rows cross each other. This same technique is also recommended for cross wind seeding as it affords greater protection than parallel rows of plants. It also compensates for bald spots caused by the occassional failure of planting equipment resulting from clogging of seed chutes that carry the seed from the drill hopper to the individual planting discs.

Another important consideration is the type of seed stock selected. Factors such as cost of seed and the length of time it takes a given species to develop sufficiently are quite important.

Generally speaking, the cereal grains are recommended for the first erosion control seeding attempts due to their ability to establish a maximum amount of vegatative grown in a minimum amount of time. They are annual however, meaning that new growth during the following season is dependent on seed production and survival through the winter. Seed losses due to birds, rodents and drifting sand can, in some cases, destroy nearly the entire crop, and where appreciable loss is suspected, reseeding should be considered.

Slower growing perennials are more desirable over a long period of time. In addition to not requiring reseeding if a seed crop fails, they form very dense and tough root formations having excellent resistance to wind erosion.

Trials were made using individual plantings of Cougar Rye and Nordan Crested Wheatgrass and also plantings utilizing a blend of six parts rye to one part Crested Wheatgrass on a weight basis. Results suggest that Crested Wheatgrass is too costly and too slow to develop

to warrant its use on the first attempts at controlling moving sand. The mix worked reasonably well, but due to the large difference in seed size and the different recommended planting depths, mixed seeding is not considered overly successful.

Small seed such as Crested Wheatgrass should be planted about one fourth inch deep while the larger seed has an optimum planting depth of approximately one inch. When planting in soft sand, these are very difficult dimensions to adhere to, and it is therefore recommended that the larger annual cereal grains be used first to establish some degree of control before the more demanding perennial species are attempted. Costs for these two species in the fall of 1973 were:

	Cost Per lb.	Seeds Per lb.	Pounds Per Acre	Seeds/ Sq. Ft. 1 lb/Acre
Couger Winter Rye	$.10	----	60	----
Nordan Crested Wheatgrass	$.60	175,000	40	4

The seeding rate in pounds per acre was appreciably greater than the normal recommended rate to compensate for the mortality expected as a result of shifting sand. On subsequent reseeding attempts, it is anticipated that the application rate could be dropped to approximately ten pounds to the acre which is still slightly higher than the four to six pound seeding rate for normal soils.

Broadcast seeding was attempted where surface conditions were too irregular to permit the use of conventional farm equipment. Although broadcast seeding is not considered to be nearly as effective as drill seeding, surprisingly good results were achieved in one site. However, it was not until the second season that most of the germination took place. In this instance, hand cranked manually operated seeders were used.

Broadcast seeding utilizing a truck mounted, electrically powered seeder was used in large and open but nearly inaccessible areas during the late spring of 1974. Results as of June, 1974 appeared to be limited. However, as in the previous successful example, it may require two or more seasons before the full results become known.

Areas of natural reseeding should be watched carefully as often the only plant capable of initially establishing itself without help is a very durable and sturdy weed commonly referred to as *Russian Thistle*. The sudden appearance of this annual weed over large areas in as little time as one season can be quite deceiving. While it may appear that the presence of a dense mat of closely spaced Russian Thistle plant starts has stabilized the rapidly moving sand, it must be remembered that freezing kills this species and once the tough, wood like plant stems lose their original strength, sudden winds can tear away entire patches of thistle in the form of tumbleweed. The result is that large areas of unstable sand can be stripped in a matter of hours of all tumbleweed type wind protection, and movement over a wide area can re-occur in a short period of time. Furthermore, during the windy winter months, while plant growth as well as seed germination is dormant, no protective regrowth is possible. Therefore, when zones of "natural healing" are found, they should be hand or broadcast seeded with a mixture of grasses and cereal grains in a manner that does not disturb the frail but protective, naturally occuring, groundcover.

In small areas, hand broadcast seed should be raked to a depth of about one or two inches. The surface of all bare sand should then be covered with loose straw or mulch to prevent loss or gain of sand depth over the seed until germination and regrowth of a new vegetative cover. Nitrogen fertilizer should also be equivalent to a rate of 40 pounds per acre.

It is of fundamental importance that each problem area be evaluated throughout its surface area before major control efforts are started. Control procedures should obviously be started on the upwind side of problem areas wherever possible. Failure to do so exposes unprotected downwind efforts to serious damage or loss resulting from incoming sand. It is therefore far better to start from an area of obvious soil and vegetative stability and move in a series of downwind steps until the full length of each sand formation is secured than it is to attempt to work "into" the prevailing wind and oncoming sand.

In situations where time is critical and it may be necessary to also stop the advancement of sand on the downwind end of a sand formation, it may be necessary to resort to the placement of snow fencing in the path of advancing shallow sand blow type formation.

Snow fencing, although temporarily effective, is not considered a permanent means of erosion control. Nevertheless, its ability to trap sand to nearly the full height of the fence section on the leeward side of the barrier makes it a worthwhile device for retarding movement of sand masses where vegetative cover is not immediately available. This ability is of value in temporarily holding the downwind portions of shallow depth sand blows only. The use of snow fencing on the downwind slopes of high dunes would be totally ineffective and is not recommended.

Where high dunes are to be controlled, it is essential that control procedures be started at ground level on the upwind slope. Work can proceed step by step over several seasons as long as it is done on continuously adjacent horizontal zones. By progressing in this manner up the exposed face of a dune, it is possible to stop the lower portion of a dune and hold it in a fixed position while allowing the wind to continue moving the top downwind. If desired, this process can be used to reduce the height of a dune and to spread its mass out to a more or less predetermined depth and shape.

In general, the most difficult logistical aspect of the project involves the distribution of various forms of or-

ganic nutrients in a thin layer across the sand areas. This must be done concurrent with a carefully selected seeding program utilizing drought resistant cereal grains and grasses. Where moving sand is involved, it is first necessary to physically stabilize the surface of the sand long enough for germination and new plant growth to occur. Otherwise, the higher cost of the initial physical control process could be lost should the entire mass continue to move.

The organic nutrients selected require a variety of techniques for their uniform placement as determined by their quantity, density and other physical characteristics. They may occur in either liquid or bulk form each of which require entirely different types of equipment for their delivery and uniform distribution.

Waste organics, when used, were selected on the basis of their availability, ease of handling, organic value, physical ability to stabilize and their moisture retention characteristics. Waste elements presently able to meet these requirements are:

1. Liquid sewage sludge
2. Baled straw-purchased locally
3. Papermill sludge
4. Shredded bark and woodwastes
5. Feedlot bedding
6. Shredded paper

In remote areas lacking suitable access roads and where planting *may be* effective without the opportunity to first physically stabilize the sand, the use of chemical fertilizers should be investigated. Both cost and availability of chemical fertilizer must be considered and than balanced against the risk of plant growth failure that might result due to the lack of physical stabilization. However, even though more initial expense may be incurred through purchase of chemical fertilizer, their greater nutritional value and reduced bulk warrant their consideration on remote problem areas where access and delivery costs are proportionately high.

Consideration must also be given to the carbon-nitrogen balance of each combination of either fiberous or nutritionally rich waste organics. Papermill sludge, for example, is high in fiber content, but virtually void of measurable nutrients. Additionally, it has a high nitrogen *demand* as the natural decay process proceeds and unless a nitrogen source is provided, it may rob sufficient available nitrogen from the soil to either prevent or greatly reduce germination and a healthy growth response.

To off-set this effect, an available nitrogen source must be provided. This can be in the form of inorganic fertilizer (ammonium sulfate), sewage sludge of feedlot waste. Feedlot bedding normally has enough available nitrogen to be used in combination with either papermill sludge or shredded bark. If used singly, both papermill sludge and shredded bark need about ten pounds of nitrogen per ton of cellulose. Materials of this type are typically applied in dry form.

For situations where liquid application is desired, a blend of papermill "fiber" and nutritionally rich liquid sewage sludge provides an excellent carbon-nitrogen relationship. Additionally, this combination offers a blend in which the fiberous material will concentrate on the surface of the sand where wind resistance is needed, while the nutritionally rich liquid phase soaks into the soil where it is readily available for plant root uptake.

An examination of six month old root growth at the top of a sludge soaked dune revealed an unusually healthy interlocking network of hair-like roots in what had been almost pure sand. In addition to assuring healthier plant growth, the intricate system of roots offers significant resistance to wind erosion of the subsurface zone. This can be quite important where the surface layer of wind protection might be lost due to fire, excessive grazing or wind action.

For areas requiring considerable quantities of fiberous wind stabilization materials, it is essential that the materials be stockpiled in advance. Once the seeding and wind control procedure has been decided upon, ready access to all materials, farm equipment and personnel should be assured before the project is started.

Many of the tools and farm implements necessary to complete a given dune assault can be obtained through rental agreements with the local farming community. Qualified operating personnel can sometimes also be obtained in this same manner. However, it must be remembered that the farmers optimum planting season nearly always coincides with dune seeding schedules and farm hands can be hard to find during these busy seasons.

Besides the farm implements to be used, there may also be the need to assemble portable, engine driven pumps, movable irrigation lines and large bore sludge guns for use in unloading tank trucks and in the aerial application of liquid mixes. Rental charges and the degree of portability for large pumps must be carefully considered.

Other tools needed will be analytical equipment for determining soil moisture and temperature and for charting plant growth and sand movement. Fencing may also be essential, if uncontrolled grazing is permitted in the general vicinity of the control project. Experience has shown that cattle will destroy fences in some instances in order to get at the dense green growth resulting from the use of highly nutritional organic fertilizers. Deep dunes are especially vulnerable due to hoof damage in soft sand.

Fences that are constructed for the protection of controlled or otherwise fragile areas should be equipped with a gate for future access and then left in position if at all possible. It should be remembered that problem areas were generally quite frail to begin with, and when possible, they should be fenced off from grazing and other intrusions for as long as possible in order to permit a full recovery of native range grasses and shrubs.

POTENTIAL HEALTH IMPACTS OF SLUDGE DISPOSAL ON THE LAND

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The potential for adverse human health effects associated with wastewater treatment and disposal systems is related to many pollutants with multiple pathways to man. The pollutants include pathogenic organisms, trace metals, other inorganic materials such as nitrates, and organic toxicants. The pathways include aerosols, surface and groundwaters, direct contact, food chain, and insect and small animal disease vectors.

Although the value of waste treatment, water treatment, sanitation of the environment, and personal hygiene in disease prevention is well established in the United States, insufficient effort has been made to establish the significance of waste treatment systems or receiving sites of the effluent as potential transmitters of pathogenic organisms.

Few studies have addressed this issue in a reasonable manner and yet the devastation in terms of human health that can result from an epidemic of severe enteric illness is well known. Levels of enteric disease and parasitic infections in the human population are generally low, and because the number of carriers in the population is small, it has been suggested that the potential for the spread of infectious agents as a result of the application of fecal wastes to the land is limited[1]. But levels of enteric disease in the United States today are low primarily because we have controlled the spread of enteric pathogens by means of sanitary engineering activities and the practice of good sanitation and personal hygiene. In more recent years the carrier rate has been further limited through immunization and antibiotic therapy, but the major progress in the control of these diseases had been accomplished through environmental sanitation prior to the introduction of measures for reducing susceptibility to disease and prior to the development of the means for controlling clinical disease. Consequently the number of illnesses that presently might be attributable to treatment plants and their discharges is unknown.

Often the lack of epidemiologic observations of disease outbreaks associated with wastewater discharge systems has been cited as evidence that the threat to human health is minimal. It should be recognized however that the reporting of cases of enteric disease is notoriously poor [2,3], and such disease related to the discharge of wastes to waterways or to the land application of wastes very well might not be recognized without intensive surveillance.

That populations in the United States are highly susceptible to enteric disease has been demonstrated repeatedly by the association of human salmonellosis with contaminated food, especially poultry, the association of an estimated 280,000 cases of salmonellosis annually among children with pet turtles raised in contaminated ponds[4-7], and the association of shigellosis and hepatitis in children attending day-care centers[8,9]. Weissman, et. al.[8] have suggested that the community as a whole is at risk from outbreaks of shigellosis at day-care centers and that the increasing incidence of *Shigella sonnei* infections evident in several large cities may reflect the impact of day-care associated shigellosis on urban communities.

The application of wastes to the land could possibly complete other cycles of infection not presently existing, or functioning at low levels. This could lead to the establishment of significant new reservoirs of infection or to increases in the levels of contamination in those already existing, if the practice of applying wastes to land was to be greatly expanded.

The major potential hazard exists where a break occurs in efficiency of the waste treatment process [10,11]. This would be particularly important if epidemic strains of the more serious enteric pathogens were to be imported into the country. Again it is probably due only to the effectiveness of sanitation in the United States that such epidemic strains have not become established. That epidemic cases might arise under relaxed vigilance is suggested by the outbreak of cholera E1 Tor in Jerusalem in 1970 which was attributed to the use of sewage for irrigation of vegetables sold in the city[12].

Pathogens in Wastes

There is a wide variety of pathogenic bacteria, viruses and parasites that occur in sewage (Table 1). However,

TABLE 1
Human Enteric Pathogens Occurring in Wastewater and Sludge and the Diseases Associated With the Pathogens

	Pathogens	Diseases
BACTERIA	Vibrio cholerae	Cholera
	Salmonella typhi	Typhoid and other enteric fevers
	Shigella species	Bacterial dysentery
	Proteus species	Diarrhea
	Coliform species	Diarrhea
	Clostridium species	Botulism
	Pseudomonas species	Local infection
VIRUSES	Infectious hepatitis virus	Hepatitis
	Echoviruses	Enteric and other diseases
	Coxsackie virus	Enteric and other diseases
	Poliovirus	Poliomyletis
	Epidemic gastroenteritis virus	Gastroenteritis
PARASITES	Entamoeba histolytica	Amoebic dysentery
	Balantidium coli	Balantidial dysentery
	Iospora hominis & others	Coccidiosis
	Giardia lamblia	Diarrhea
	Pinworms (eggs)	Ascariasis
	Tapeworms	Tapeworm infestation
	Liver & Intestinal flukes	Liver or intestinal infestation

the types of pathogens present as well as the concentration may vary considerably from community to community. Bacterial pathogens which may be present in wastewater include *Salmonella typhi* [13-16], paratyphoid and other *Salmonella* serotypes [15,17-23], *Pseudomonas aeruginosa* [24], mycobacteria [25-31] and *Clostridium perfringens* [32-34]. Numerous viruses are excreted by man [35,36] including poliovirus (three types), coxsackievirus (25 types), echovirus (25 types), reovisus (three types), and adenovirus (33 types). The only viral disease definitely known to be water-borne and hence possibly associated with wastewater is hepatitis A (infectious hepatitis). Various parasites reported from wastewater include *Entamoeba histolytica* [37], *Entamoeba coli* [38-40], schistosomes [41], *Naegleria* [42], various nematodes [43-47] and fungi [48].

Counts of microbial pathogens in sewage vary considerably, depending upon rates of disease in the contributing population. Organisms, such as *Entamoeba histolytica*, might be expected only in low numbers, if at all [38]. Many parasites and even the cholera vibrio however might be present in the sewage of a community temporarily after a traveler carrying the organisms enters the community. Some bacterial pathogens, including *Pseudomonas aeruginosa*, are consistently present in sewage. Fecal carriage of this organism occurs in approximately 11 percent of healthy adults, and concentrations in excess of 10^5 bacteria per 100 ml are common in raw sewage. Concentrations in excess of 10^6 bacteria per 100 ml have been reported in sewage in Germany and in hospital wastes in South Africa and the United States [49]. Concentrations of other bacterial pathogens, such as salmonellae, fluctuate with rates of disease in the community [17]. Concentrations of non-typhoid salmonellae in raw sewage have been shown to vary from about 110 to 11,000 per 100 ml [50]. Highest numbers occurred during August and September when the reported isolations from human sources normally are greatest [51]. Since the number of isolations of shigellae also varies seasonally, the numbers of shigellae in sewage undoubtedly fluctuate in a similar manner. The numbers of salmonellae or shigellae in sewage are several orders of magnitude less than fecal coliforms and while there is some variability in the ratio of salmonellae to coliforms in the raw sewage of different communities the ratio appears to be quite consistent in a single community. Kehr and Butterfield [52] estimated that about six typhoid organisms were present in sewage for every million coliforms.

Enteric viruses have been demonstrated in raw sewage in various countries in concentrations of one to ten virus particles per ml [53]. The concentrations of virus particles discharged in domestic wastes at any time is determined by the number of cases of viral disease plus the number of carriers in the community [54]. Investigators have reported 4000 virus particles per liter of domestic wastewater during the warmer months of the year and 200 particles per liter during the colder months [55]. In Israel, five cities showed an average of 1050 virus particles per liter, although individual determinations varied from 5 to 11,000 virus units per liter [56]. This latter study demonstrated a ratio of one virus particle per 10^6 to 10^7 coliform organisms. In contrast, however, other studies have demonstrated one virus particle per 65,000 coliforms [57] and a ratio of one virus particle per 50,000 to 100,000 coliforms may not be uncommon in the United States [58].

Because sewage contains pathogenic microorganisms and viruses, it stands to reason that settled sludge should contain large numbers of these pathogens. Primary settled sludges have been shown to contain large populations of microbial pathogens [59,60]. One study [61] demonstrated that concentrations of tubercle bacilli in settled sludge were 13 times greater than in the supernatant liquor. That salmonellae may be present in sludge has been shown also [62]. A mean of 1000 salmonellae have been demonstrated per 100 ml of raw sludge, and 100 per 100 ml of digested sludge. Although less is known about the viruses [63], sludge produced by flocculation of sewage solids [64] and activated sludge may contain large numbers of virus particles. Thus, significant numbers of pathogens can be demonstrated in both primary and secondary sludges.

Effects of Treatment on Pathogens in Effluents and Sludges

Many stuides indicate that bacteria are not removed effectively from wastewater effluent during primary treatment [27,60,61]. On the other hand, primary settling produces sludges which contain significant numbers of pathogenic microorganisms [59]. Apparently, few viruses

are removed from the effluent during primary treatment [65,66].

Alternative means of killing pathogenic organisms in sewage and sludge include ozonation, pasteurization, gamma radiation, and chlorination. Ozone may be a very effective agent against viruses. Shuval [67] and Berg [68] have stressed the potential usefulness of ozone based upon limited reports of research, but each indicates the need for more work on this disinfectant. Hess and Lott [69] and Hess, et. al. [62] reported that populations of Enterobacteriaceae in sludge were reduced by 93 to 99 percent when heated to 70°C for 30 minutes. Limited studies of pasteurization undertaken by the Environmental Protection Agency indicate that heating of digested sludge to 75°C for one hour kills pathogens, and Berg [70] suggested that pasteurization was the only practical method for the control of pathogens where large amounts of solids must be penetrated as is the case with sludges. However, the use of gamma radiation has been considered, and may be useful if radioactive wastes are available as radiation sources. For example, Hess and Lott [69] employing a Cobalt 60 source, achieved 10 to 100,000 fold reductions in numbers of Enterobacteriaceae at 100 krad and up to 100,000,000 fold reductions at 400 to 500 krad in raw and digested sludge. Whatever methods are employed, destruction of nucleic acids of viruses probably is desirable. Melnick [71] has pointed out that viruses presumably inactivated by heat may contain infectious nucleic acids and such virus particles may be activated within macrophages, a phenomenon analogous to the recovery of injured bacteria.

Persistence and Movement of Pathogens in the Environment

Because pathogenic organisms present in sewage and sludges may be transmitted from contaminated environments to man, the persistence of these pathogens in water, soil, sludge, feces and aerosols is of fundamental interest and concern. An understanding of the movement and persistence of pathogens is needed to evaluate potential risks associated with different pathways of transmission.

Aerosols may be produced where sewage or sludge is aerated or sprayed on the land. Randall and Ledbetter [72] found 1170 bacteria per cubic foot (42,000 bacteria per m^3) in samples of air obtained downwind of an activated sludge plant, in contrast to eight organisms per cubic foot (285 organisms per m^3) in samples obtained upwind of the facility. They concluded, furthermore, that in spite of an initial "die-off," the bacteria persisted for a considerable time and distance downwind of the plant. Concentrations in the air were observed to increase with increasing wind velocity. Recently Goff, et. al. [73] published data indicating that survival of bacteria in aerosols were greater at night than during the day. This would suggest that solar radiation causes death either by direct action on aerosolized bacteria or by action on the aerosol particles themselves. Greater aerosol emission occurred at moderate wind speeds than at high or low wind speeds. Poon [74] and Goff, et. al. [73] observed that death rates in aerosols increased with increasing temperature and at relative humidities less than 35 percent. Survival may be reduced also at high relative humidity, which may be attributable to breakdown of RNA [75]. Injury to the cell wall also may occur during aerosolization [76].

Few investigations have been undertaken to explore the dissemination of microorganisms from land application sites. Merz [77] reported that bacterial travel in aerosols was limited to 1,000 to 1,300 feet (300 to 400 meters) in eleven mph (18 km per hr) wind and that most of the mist and bacteria settled within half that distance. Adams and Spendlove [78] were able to recover coliform organisms in the immediate vicinity of a trickling filter plant and as far as 0.8 miles (1.3 km) downwind. Of bacteria isolated 125 feet (38 m) from aeration tanks by Kenline and Scarpino [79], 39 percent were Enterobacteriaceae; of which *Klebsiella, Enterobacter,* and *Escherichia* accounted for 78 percent. Of the remaining isolates, 16 percent consisted of *Citrobacter* and unidentified genera, and six percent consisted of *Shigella, Arizona, Hafnia,* and *Serratia.* No *Salmonella* or *Proteus* were isolated. Few studies have been undertaken to determine the survival of viruses in aerosols. However, Walker [80] reported that poliovirus could survive for as long as 23 hours in aerosols when the relative humidity was high.

The persistence of pathogens in soil or on vegetation has been examined more extensively. Most bacteria appear to be trapped after brief passage through soil [81-90]. Some pathogens can travel for miles through limestone areas, but may be removed near the surface by heavy textured clay soils as a result of adsorption and filtration [91]. Thus the size of an organism and the type of soil affects the distance an organism travels through soil. Although several feet of soil appear necessary for complete removal of bacteria, 92 to 97 percent may be removed in the top 1cm [92]. Mathur, et. al. [93] showed that 99.9 percent of bacteria were removed during passage of sewage through a depth of 17 inches (43 cm) and a horizontal distance of 15 inches (38 cm).

The movement of viruses through soil has not been investigated thoroughly. Results of limited percolation studies [94] suggest that complete virus removal can be achieved by careful application of sewage to land. Jopkiewicz, et. al. [95] reported that concentrations of poliovirus were reduced substantially during passage through irrigation fields. Other viruses were removed less effectively. Removal of viruses in soils is a function of the characteristics of the soil. There is some indication that viruses are removed as effectively as bacteria, principally by adsorption [83,85,86]. According to Drewry and Eliassen [85] virus retention by soils is an adsorptive process that is highly efficient at pH values below 7 to 7.5, but which decreases at higher pH values. Drewry and

Eliassen demonstrated increased adsorption of viruses by increasing clay and silt content, ion exchange capacity, and glycerol retention capacity of soil. Merrell, et. al. [96] reported that viruses injected into percolating water were removed completely in 200 feet (61 m) of horizontal and vertical travel. Robeck, et. al. [97] observed retention of virus particles on sand beds two feet (61 cm) deep when the flow rate was no more than four linear feet (122 cm) per day. They concluded that pre-treatment with alum followed by sand filtration at two to six gpm per square foot (81 to 244 liters per min per m^2) retained 98 percent to 99 percent of virus particles.

Pathogenic organisms may survive in soil and on crops for periods varying from a few hours to several months, depending upon the type of organism, soil moisture, pH, and predation and antagonism from the resident microbial flora [98-102]. Magnusson [103] reported that coliforms remained viable on grass for 15 days in dry weather and for seven days in wet weather. On the other hand, Hess, et. al. [62] reported the survival of salmonellae on grass contaminated with sludge for 40 to 58 weeks in a dry atmosphere. McCarty and King [104] found that enteric pathogens could survive and remain virulent for up to two months. But it has been reported also that coliforms survive longer than *S. typhi* or *M. tuberculosis* [99,105,106]. Kenner, et. al. [107] demonstrated that *E. coli* survived for at least 21 weeks after a single application of sludge to Pennsylvania fields during the spring. Furthermore, E. coli persisted longer than did *P. aeruginosa* (17 weeks) and salmonellae (eight weeks), and both pathogens and indicators survived longest in winter. That indicator organisms survive longer in soil during winter than during summer was demonstrated also by Van Donsel, et. al. [108].

Routes of Infection

In view of the obvious opportunities for contamination of soil, groundwater, surface water, and air with pathogenic microorganisms and viruses in the vicinity of land application sites, there exists a clear need to identify possible routes of infection and to determine their significance.

The contamination of surface waters at land application sites ordinarily would be expected to be less than that expected as a result of the discharge of sewage directly to the surface water. The contamination of groundwaters at land application sites, however, may be a matter of considerable concern in certain areas. While pathogenic microorganisms and viruses may be removed rapidly in many soils, in limestone regions, viruses may reach water supplies. The potential risks associated with contamination of groundwaters are not well defined, and outbreaks of disease related to their contamination are not well documented. Monitoring and epidemiologic surveillance in high risk areas needs to be undertaken to establish, not only travel of pathogens through the ground, but rates of disease in exposed populations.

The significance of aerosols produced at land application sites is not known. Although enteric organisms are transmitted most commonly by contact it has been documented that chimpanzees can become infected with aerosolized typhoid organisms [109]. On the other hand, there is little evidence of higher incidence of disease among workers at sewage treatment plants [110] than among other similar workers but extensive epidemiologic studies have not been undertaken, and there exists little basis upon which to judge the true risk to workers having sporadic exposure to aerosols.

Direct contact with contaminated environments may present a risk to workers and to animals. At some heavily contaminated application sites, workers may be exposed to demonstrable risks. Hookworm and other enteric infections apparently do occur more frequently among farm workers on sewage farms in India than among the farming population in general [111]. Furthermore, Sebastian [112] noted an increased incidence of schistosomiasis in some areas of China where night soil was spread on the land. Obviously these examples represent extreme cases but even where contamination of the environment is not as severe organisms may spread to man and animals.

Animal infections also have been traced to sewage pollution. Schaal [113] demonstrated that the source of an outbreak of salmonellosis in a dairy herd was contaminated stream water. More recently, Bicknell [114] traced an outbreak of *S. aberdeen* in a dairy herd to pasture contaminated with overflows of sewage from a manhole. Salmonellosis in cattle associated with spreading of effluent on pastures was reported by Jack and Hepper [115]. Findlay [116] demonstrated salmonellae in fresh and digested sewage sludges and has suggested that risks to animals may result from use of sewage sludge as fertilizer. Harvey and Price [117] observed that persistence of a *Salmonella* serotype in the sewers of an abattoir providing meat to a community was often followed by human infection.

Risks of infection among animals exposed to sewage are not limited to salmonellae. *Pseudomonas aeruginosa* which may be waterborne [118-123] can be a major cause of mastitis in dairy cows [120,127] and pneumonia in calves. Consequently the application of wastes containing *P. aeruginosa* to pasture, or to streams passing through dairy farms may present a risk to the health of dairy cows and calves.

Grunnett and Brest Neilson [125] suggested that wild animals, especially sea gulls and rats which forage in sewer outfalls and dumps, may transmit salmonellae from sewage to domestic animals. Muller [126] demonstrated a relationship between the proximity to sewage outfalls and the frequency of carriers among gulls in Hamburg, Germany. That salmonellae might be spread similarly from land irrigated with sewage or fertilized with sludge is apparent.

Crops used for human and animal consumption may become contaminated with pathogenic bacteria and viruses present in effluents and sludges applied to the land. In spite of considerable reductions in the numbers of pathogens in the field and on crops as a result of exposure to ultraviolet irradiation, dessication, and competition, sufficient numbers may survive to constitute a health risk. Geldreich and Bordner [127] reviewed sources of contamination of fruits and vegetables and provided support for establishing a limit of 1000 fecal coliforms per 100 ml in irrigation waters.

There have been reported in the literature records of a number of outbreaks of disease attributable to the irrigation of edible crops with wastewater. Gaub [128] reported the isolation of *Shigella flexneri* from cabbage grown in fields irrigated with sewage-contaminated water. *Shigella flexneri* also was the cause of an outbreak of dysentery traced to the irrigation of pasture land with wastewater [22]. Cohen, et. al. [12] reported an outbreak of cholera El Tor in Jerusalem affecting about 250 persons. They demonstrated that vegetables grown on land irrigated with sewage were responsible for the secondary spread of the disease after the introduction of cases and carriers from outside the country. The organisms were recovered from sewage, soil irrigated with sewage, and crops from contaminated fields which were for sale in the market. Shuval [67] cited a similar outbreak of cholera in the City of Gaza. Thus, there may be a substantial risk associated with the consumption of raw vegetables grown on soil irrigated with sewage. Even crops which are eaten only after cooking may represent a risk since they may contaminate working surfaces and utensils in the kitchen, which in turn can lead to contamination of foods in which bacteria multiply. There would appear to be no risk associated with surface irrigation of fruit trees, but if sewage is sprayed, there may be risk both to consumers and to workers.

Bovine tuberculosis can be transmitted on fodder crops irrigated with raw or partially treated wastewater [129]. However, the risk is thought to be minimal if application of wastewater is stopped 14 to 20 days prior to pasturing although there is some controversy on this point. Some workers have reported that the bovine tuberculosis organism can remain viable for three months in wastewater and for six months in soil. Jepsen and Roth [130] found in Denmark that *Corynebacterium bovis* infections in cattle can result from the irrigation of pasture lands with sewage. So the possibility of disease transmission to and through cattle that graze on such pasture lands should be considered.

In general, bacteria appear not to enter healthy and unbroken vegetables. They may, however, penetrate broken, bruised, and unhealthy plants and vegetables [99]. Once vegetables become contaminated, especially if bruised, they cannot easily be decontaminated by rinsing with water or disinfectant. Therefore, germicidal rinses with chlorine are unreliable but pasteurization at 60°C for five minutes is effective [131].

In hot, humid climates where rainfall occurs during the growing season, splashing may cause contamination of plant parts growing above ground and growth of the pathogens might occur during transit. If wastewaters and sludges applied to the soil carry pathogens, the opportunity for contamination of the crops could thus be enhanced.

Viruses also may contaminate vegetables. Christovao, et. al. [132] recovered poliovirus Types I and III from five of eleven samples of irrigation water taken from a vegetable garden in the city of Sao Paulo, Brazil and reported detection of enterovirus in soil, vegetables, and in wastewater used to irrigate the soil in which the vegetables were grown. Viruses were commonly detected on vegetables that grew close to the ground, but not on those that did not grow in contact with soil or wastewater during the growing season. Moreover, viruses may be detected more often in summer and autumn than in other seasons [133]. In extensive experiments, Mazur and Paciorkiewicz [134] detected virus on the green parts of 13 species of plants grown in soil seeded with poliovirus. The virus was isolated from 40.7 percent of ground parts examined and 87.9 percent of samples from the upper exposed parts of roots extending into water containing virus. They also found that ten percent of soil samples contained virus and suggested that virus may have passed from water to soil by external capillaries along the roots.

Infective Doses

Some idea of infective doses is necessary to the establishment of the potential for disease from environmental transmission of infectious agents. Infective doses of most enteric bacterial pathogens are relatively high. For instance, approximately 10^8 enteropathogenic *Escherichia coli* or *V. cholerae* cells must be consumed by healthy male volunteers to produce disease in a "significant" proportion of subjects. Approximately 10^5 *Salmonella* cells (including S. typhi) are required to cause disease, but only 10 to 100 Shigella cells are necessary to cause dysentery [135]. Children, sick people, and old people are more susceptible, however, and fewer cells are needed to produce disease. Thus, only 15,000 *Salmonella cubana* cells caused disease in hospitalized patients [136]. But it must be recognized that cross-contamination by smaller numbers of cells entering the home on food, followed by growth in an appropriate medium may lead to the production of large numbers of cells which can, and frequently do, cause disease.

The infectivity of virus appears to be high, particularly if the small numbers capable of infecting cells in culture can produce infections in man [70]. Such low infective doses, have lead to concern over the significance of low numbers of viruses in drinking water and in contaminated environments.

Other Pollutants in Wastewater

The use of sophisticated analytical techniques has established that virtually all public and private drinking water supplies contain uncharacterized organic compounds. These substances are derived from municipal sewage, industrial waste, agricultural and natural runoff, and from natural sources. There is little information available on the concentrations or toxicities of organic compounds in drinking water and even less is known about organic compounds in sewage. Heavy metals and inorganic compounds are also common constituents of wastewaters. Although serious disease and even death is known to have occurred subsequent to infection of relatively large quantities of some organic and inorganic compounds and heavy metals, little is known about the health effects which might result from chronic ingestion of small quantities of these substances. Exposure to environmental agents has been suspected of producing cancer, birth defects, cardiovascular disease, and other anomolies. However, little evidence exists to causally link a compound or combinations of substances to any specific illness.

CONCLUSION

It is obvious that a potential for producing adverse human health effects is associated with the practice of applying wastewaters or sludge to agricultural lands, and that the risks relates both to toxic chemicals and to pathogenic organisms. The extent of the risk relates to the types of land on which materials are applied, to the treatment the wastes have received and perhaps most importantly to the dedication of individuals involved with the land application or treatment processes, since the greatest hazard probably would develop as a result of disruption of good sanitary or treatment practices at any point in the operation.

The fact that the utilization of wastewaters and sludges to irrigate and fertilize crops is practiced in many parts of the world suggests, in spite of the associated outbreaks of illness recorded, that the practice can function in a safe manner. The fixed nature of quantities of water and essential chemicals available to produce the food vital to the worlds population makes it essential that the means be found to safely use wastewater and sludge in food production. But the uncertainties associated with this practice make it imperative that a continuing research program be vigorously pursued to find the means to minimize the potential hazards associated with the use of wastewater and to demonstrate this fact as quickly as possible and thus help improve the quality of life for all the world's population.

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FDA'S OVERVIEW OF THE POTENTIAL HEALTH HAZARDS ASSOCIATED WITH THE LAND APPLICATION OF MUNICIPAL WASTEWATER SLUDGES

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The responsibilities of the Food and Drug Administration include the protection of the human and animal food chains from contamination by chemicals and pathogenic microorganisms. Such contamination may occur, when polluted sludges from industrial cities are used, or when sludges are improperly processed or applied in an improper fashion on the wrong corps. Such improper practices would clearly be of concern to this Agency, while proper use of good sludge on land and crops would not normally be expected to present a problem.

Several mechanisms can be visualized for the direct or indirect contamination of food and/or domestic animals by sewage sludge. One is direct physical contact, such as by spraying sludge onto growing crops, or by contact between low growing crops (tomatoes, lettuce, etc.) and sludge on or in soil. In such cases food contamination may be microbiological or chemical. Direct absorption of pesticides or persistent organics through plant tissues may also occur. It is less likely for metals. Some heavy metals and organics are taken up from sludge and soil by roots and translocated within the plant. Of most concern is cadmium, as discussed by others at this conference.

Livestock and domestic animals are exposed to these contaminants when grazing on pastures or eating forage. According to one estimate* grazing animals are known to ingest soil (and probably sludge) in amounts ranging from 2 to 14 percent of their total diet. This direct ingestion of sludge contaminants, which are present at higher levels than in crops, could result in increased uptake of heavy metals, such as cadmium, lead and mercury, and of persistent organics (such as PCBs and chlorinated pesticides). The latter may be retained and gradually biomagnified in the fat tissues of the animals. From preliminary data available, cadmium is found predominately in the liver and kidney, and lead in liver, blood and bones. Other tissues and organs may also be contaminated. Research initiated under a joint FDA/EPA agreement with Denver should help clarify this issue.

Complete and precise definitions of safe or unsafe practices are not available at this time due to insufficient data on the transfer of many of these contaminants through the food chain and on the toxicological effects to be expected. Table 1 summarizes information now available on the heavy metals of most concern, some of which has been developed only recently. Tolerable lead levels are for adults and limits have not been suggested for children.

The Total Diet Surveys, also called the Market Basket, have been conducted annually by the Food and Drug Administration since 1965. They are based on food consumption information developed about a decade ago by the U.S. Department of Agriculture and correspond to the diet of a 15 to 20 year old male. A total of 117 foods are included in each total diet sample. The foods are cooked or prepared as normally eaten, and divided into twelve different food class composites which are then analyzed for the various contaminants. The total intake, including water, is about 3,000 grams a day. The average concentration values of Table 1 are calculated on that basis. As these are quite low, they could be greatly affected by a major contaminated food.

Because of the limits of sensitivity of the current analytical methods, "non-detected" and "trace" results are frequently obtained for food composites. The contribution of the total intakes (not included in the data shown in Table 1) has been estimated to be large for lead, possibly tripling or quadrupling the value shown, and for cadmium, increasing the cadmium intake by about 50 percent. The effect on the other elements is small. Comparing these higher cadmium and lead values with the provisional tolerances of the World Health Organization shows that we may have reached the safe upper limits for cadmium intake and may be close for lead also.

Table 2 shows the relative proportion of the diet represented by each of the twelve food classes. The contribution that lead and cadmium containing foods make to the total intake of these metals and the average concentrations in good groups are also presented. Some of the lead

*W.H. Allaway, private communication.

TABLE 1
Heavy Metals in Foods

	CADMIUM	LEAD	MERCURY	SELENIUM	ARSENIC
WHO/FAO, (1972), Provisional Tolerances, (Adult) Converted to µg/Person/Day	57-71	429	43	Not. Establ.	Not Establ.
Total Diet Findings, U.S. Adult µg/Person/Day (1973)	51.2	60.4	2.9	150	10 (As AS_2O_3)
Average Concentration in Entire Diet, Including Drinking Water, PPM	0.018	0.021	0.001	0.05	0.003
Most Prevalent In:	Grains & Cereals, Leafy Vegetables, Fruits, Beverages	Legumes, Fruits	Meats, Fish & Poultry	Grains & Cereals, Meats, Fish & Poultry	Meats, Fish & Poultry

in several groups comes partly from cans (solder), which adds to the level present in the original produce.

In assessing the safety of the sludge use practice, the fact must be considered that not more than about one percent of the total agricultural land in the United States would be treated with sludge if all sludge available were used on land at moderate levels. The resulting impact on selected food commodities and the diet of the overall population can not be clearly estimated at this time. In addition, effects may be much greater on other than the "average person", such as people in localized areas. We should also consider the old, the sick and the very young in these assessments.

More research is obviously needed to assess the magnitude of the problem and to answer questions about background values, toxicological effects, non-dietary routes exposure, and permissible levels. Such information is necessary to determine whether tolerances or guidelines need to be developed for the more important foods or crops we consume.

As discussed by other speakers, the uptake of heavy metals from sludge-treated soil by plants and crops is subject to many complex variables. However, many metals, including cadmium, will be found at higher levels in crops grown on sludged soil than in the controls in the same area. The picture is not so clear for lead, and there is little or no information available on mercury, arsenic and selenium.

An example of the uncertainty regarding sludge use involves mercury. It has been known for some time that mushrooms accumulate metals, and some data were reported to us in 1973 about high levels of mercury and lead in mushrooms grown in sludge/refuse compost. A recent paper from Switzerland* reports data showing that mercury is biomagnified in some mushrooms 2 to 58 times from levels in the soil used. Part of the mercury is methyl mercury.

We analyzed samples of commercial fresh U.S. mushrooms in 1973 and found low levels of mercury (0.03-0.1 ppm) and lead (0.01-0.03 ppm). Mushrooms are, of course, only a small part of the total diet for the average person. However, use of sludge-compost as mushroom soil, as advocated by some, may lead to problems. We expect to be doing a limited amount of work to help resolve this issue.

Sewage sludge is known to contain persistent organic contaminants such as polychlorinated biphenyls and chlorinated pesticides. Uptake studies have shown that edible parts of plants contain these organics, but at levels 5 to 20 percent of the levels in the soils used.

Table 3 lists a number of halogenated chemicals which are likely sludge contaminants. Many municipal sewage systems receive substantial inflow from industrial effluent sources. These may be pretreated, but limitations used are based on COD, BOD, TOC, etc., usually without identification of the specific organic contaminants. In fact, some plant effluents contain a highly diverse range of compounds. These may be the products from manufacturing plants, some auxiliary chemicals, or partial breakdown or reaction products from the effluent treatment. Compositions are often highly complex, as shown by EPA's studies (Athens, Ga.) of the effluents from paper/pulp mills. The widely publicized range of contaminants in drinking water is another indication of the potential for sludge contamination.

As stated, available data are inadequate for a precise hazard assessment of food contamination by organic

*T. Stijve, R. Roschnik, *Trav. Chim. Aliment. Hyg.* 65(1974), 209-220 (English).

TABLE 2
Lead and Cadmium Intake in Total Diet

	FOOD GROUP		LEAD		CADMIUM	
		Intake % of Total Diet	% Of Total Pb Intake	Average PPM	% Of Total Cd Intake	Average PPM
I.	Dairy Products	25.9	0.0	0.0	7.7	0.005
II.	Meat, Fish & Poultry*	9.9	6.6	0.013	4.9	0.0093
III.	Grain & Cereal Products	12.6	6.9	0.010	22.8	0.028
IV.	Potatoes	7.0	1.2	0.0033	17.8	0.046
V.	Leafy Vegetables*	2.0	5.0	0.050	6.2	0.051
VI.	Legume Vegetables*	2.5	31.1	0.26	0.8	0.006
VII.	Root Vegetables*	1.2	6.4	0.11	1.5	0.021
VIII.	Garden Fruits*	3.0	18.8	0.12	3.4	0.019
IX	Fruits*	7.4	15.7	0.043	18.3	0.042
X.	Oils, Fats & Shortenings	1.8	1.1	0.013	2.7	0.027
XI.	Sugar & Adjuncts	2.8	0.9	0.0067	1.3	0.0083
XII.	Beverages (including water)*	23.9	6.3	0.0033	12.7	0.0057

*Includes Canned Foods - Some Metal May Be From Can (Pb)

chemicals in sludge. It is expected that the most likely contamination of foods would be (1) in animals ingesting sludge (grazing, etc.); and (2) following failures of the sewage plant operation with resulting incomplete breakdown of organic chemical contaminants.

The microbiological hazard from use of sewage on land and crops is another problem of great complexity. Microbiologists are concerned about the possibility that increased use of pathogen containing sewage on land and crops may adversely affect public health. For example one concept is the development of a cycle with ascaris eggs (intestinal worms) by: (1) increased intake of these pathogens by, say, a small community ingesting food grown on sludge amended soil in the area, followed by (2) increased pathogen discharge into the sewage system, and (3) increased numbers of pathogens surviving sewage treatment and returning into the food chain, etc. Salmonella, tuberculosis and other bacteria are also of concern in sewage treated crops, and there is the complex question of pathogenic viruses still to be resolved.

For this reason, FDA microbiologists feel that crops which are eaten raw should not be planted within three years after the last sludge application. Crops such as sweet corn, potatoes, etc., which may contaminate other foods in the kitchen, should not be grown unless the sludge used gives a negative test for pathogens. From the microbiological standpoint only industrially heat processed crops would be safe to grow in soil treated with ordinary digested sludge.

To properly define chemical and microbiological hazards requires reliable and extensive scientific data. FDA is conducting programs of its own and collaborative studies with EPA and USDA. FDA activities include: (1) surveys for heavy metals and pesticides in selected raw agricultural commodities grown in different parts of the country; (2) development and improvement of analytical methodology for heavy metals and pesticides; (3) investigations (in our Cincinnati laboratories) on the survival of pathogens on vegetables grown in sludge treated soil, and (4) toxicological studies to determine the effects of

TABLE 3
Potential Organic Contaminants in Sludge (Persistent)

POLYCHLORINATED BIPHENYL AND TERPHENYL

CHLORINATED PESTICIDES

HALOGENATED CYCLODIENE FLAME RETARDANTS

CHLOROBENZENES

CHLOROPHENOLS

CHLORINATED PARAFFINS

MISCELLANEOUS HALOGENATED FLAME RETARDANTS

heavy metals and interaction between elements. These studies should help provide the information needed to establish guidelines and/or tolerances.

As stressed earlier, we have no indication at this time that sludge use on land needs to be limited to crops which are not in the human food chain, or, conversely, that all sludges are suitable for land application. Sludge application should be selective and properly conducted to make it safe. This will eliminate some types of sludges from consideration, while in other cases, land application systems may not be sufficiently cost effective to compete with alternative disposal or use schemes.

A SUMMARY OF OBSERVATIONS ON THERMOPHILIC DIGESTER OPERATIONS

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INTRODUCTION

A summary report is presented on observations made while investigating two applications of thermophilic sludge digestion.

The first concerns the enhancement of the sludge dewatering process under certain conditions when thermophilically digested sludge is used instead of mesophilically digested sludge. The second part concerns the enhancement of methane gas production during thermophilic digestion in comparison to mesophilic digestion.

All of the subject investigations were conducted at the City of Los Angeles' Hyperion Treatment Plant. The investigations on sludge dewatering described herein were initiated in 1972 and continued thru 1973. The investigations on thermophilic operations described herein were also initiated in 1972 and are continuing to date.

These investigations were necessitated by the implementation of state and Federal regulations which essentially prohibited wastewater solids from being discharged into the Pacific Ocean. Consequently, the City of Los Angeles was obligated to seek alternative means of wastewater solids disposal which hopefully would also result in minimum environmental and economic impact. Present investigations indicate that the alternatives to ocean disposal of wastewater solids in the Los Angeles area are limited to land disposal, basically due to the air pollution situation. Unfortunately, chemical conditioning, mechanical dewatering, vehicular transport and disposal of wastewater solids into sanitary landfills will result in an adverse environmental and economic impact in comparison to the present ocean disposal system at the Hyperion Treatment Plant[1]. The thermophilic sludge digestion process was one of the areas investigated in an attempt to reduce chemical conditioning cost and enhance the dewatering process.

The Hyperion Treatment Plant

The Hyperion Treatment Plant, where these studies were conducted is operated by the City of Los Angeles Bureau of Sanitation. The plant serves over three million people in the City of Los Angeles and neighboring communities. The sewage flow comes from as far as 65 miles away.

The plant is located on a 144 acre site in Playa del Rey next to Los Angeles International Airport, on the Santa Monica Bay coast line.

During the 1974-75 fiscal year Hyperion treated 126,916.37 million gallons of wastewater, which averages out to 347.72 million gallons per day (mgd). All of the flow receives preliminary and primary treatment, 100 mgd of the flow receives secondary treatment by the conventional activated sludge process. Primary and secondary effluents are blended and discharged into the ocean five miles off shore at a depth of 220 feet.

Wastewater solids removed in the treatment process are stabilized and reduced in 18 primary anaerobic sludge digesters. Each digester has a capacity of 2.5 million gallons. Presently three of the digesters are being operated at thermophilic temperatures (120°F), the remaining digesters are being operated in the mesophilic range (95°F).

Approximately 4.5 million cubic feet of digester gas is recovered daily from the sludge digestion process. This gas is used as the plants' energy source and presently supplies the air for the activated sludge process and all of the electric power except that used for three large effluent pumps. Excess digester gas is sold to an adjoining thermo-electric power plant which generates electricity.

The residual solids from the digestion process are screened to remove floatables, diluted and pumped to the head of a submarine canyon, seven miles off shore at a depth of 330 feet where the solids are dispersed into deeper waters.

An abridged summary of plant process data pertinent to sludge digestion and handling is shown in Table 1.

An abridged summary of digestion performance parameters is shown in Table 2.

Test Program

The sludge dewatering studies conducted at Hyperion were organized into three progressive phases. The first

TABLE 1
Process Parameters
(1974-75 Averages)

1.	Plant flow	=	347.72 mgd
	Sus Solids in	=	272 mg/l
	BOD in	=	255 mg/l
2.	Raw Sludge	=	547,600 #/d
	Total Solids	=	6.09%
	Vol. Solids	=	77.5%
3.	Digested Sludge	=	220,800 #/d
	Total Solids	=	2.43%
	Vol. Solids	=	61.7%

phase was laboratory testing to select the most promising physical and chemical conditioning processes for anaerobically digested raw sludge. Next, numerous tests were performed on a pilot scale level to verify previous laboratory results. Finally, full scale tests were performed, whenever possible, based on the results of the pilot scale tests. Approximately 18 months of effort was devoted to the dewatering studies. These studies started in 1972 and were concluded in late 1973.

The following parameters were used as criteria in evaluating the sludge dewatering system.

1. Maximum capture of solids, i.e., minimum solids remaining in the liquid fraction.
2. Maximum percent solids in the sludge cake, i.e., minimum moisture in the cake.
3. Maximum operational flexibility and reliability.
4. Minimum pre-conditioning requirements, i.e., minimum polymer or chemical dosage.
5. The most overall cost effective system, i.e., first costs plus operations and maintenance costs.

In addition to the technical considerations above major consideration was given to the environmental impact, energy requirements, resource requirement, and ability to meet legal requirements in the evaluation process.

As an initial goal, the test program established the following specific technical limits:

1. Solids capture (T.S.) 90%
2. Solids in cake (T.S.) 25%
3. Centrate or filtrate quality (S.S.) 1000 mg/1

Limitations

The following observations and discussions are limited to chemically conditioned mesophilic anaerobically digested raw sludge containing approximately five percent waste activated sludge, by weight.

Although other tests were performed without conditioning the sludge or with other conditioning methods, in general, the results were poorer and are not included in this discussion. Only general economic inferences are included due to the fluctuating economic conditions.

TABLE 2
Digestion Performance
(1974-75 Averages)

1.	Gas Production	=	3.63×10^6 ft^3/d
	per Volatile Solids Destroyed		12.82 ft^3/#
	CH_4 quality	=	65%
2.	Volatile Solids Reduction	=	67.8%
3.	Charging Rate	=	0.11 lb. V.S./ft^3
4.	Detention time	=	27.6 days

The basic theories underlying centrifugation and vacuum filtration have been omitted, and only the results obtained from specific equipment are presented.

The percent solids capture (% recovery) is reported in terms of total solids (T.S.). This method was used to facilitate laboratory analyses. Consequently, the actual suspended solids (S.S.) capture is greater than numerical values indicated.

Solid Bowl Centrifuge

In this test series a Kruger Model KDF-500 solid bowl centrifuge was used.

Table 3 indicates the test conditions which were used to obtain the optimum performance from the Kruger centrifuge. The "G" force for these tests was 920 "G's", at a bowl speed of 1860 RPM. The best results were obtained by maintaining maximum pool depth.

Figure 1 illustrates the optimum performance obtained from thermophilic and mesophilic sludges.

Capture of both mesophilic and thermophilic sludges were very good at 88 percent and 92 percent (T.S.) respectively.

Mesophilic sludge resulted in submarginal cake solids content of 18 percent. Thermophilic sludge resulted in an acceptable cake solids content of 30 percent, which was 40 percent drier than mesophilic cake.

The suspended solids content in the mesophilic centrate averaged 1550 mg/1 which was considered over the desirable maximum. The suspended solids content in the thermophilic centrate averaged 1100 mg/1 which was slightly over the desired level, but considered acceptable.

TABLE 3
Optimum Test Parameters
Solid Bowl Centrifuge
Kruger KDF-500

1.	Sludge Feed Rate		
	a) Mesophilic	=	14. GPM
	b) Thermophilic	=	25 GPM
2.	Sludge Feed Concentration		
	a) Mesophilic	=	2.34% T.S.
	b) Thermophilic	=	2.67% T.S.
3.	Polymer Dosage Rate		
	a) Mesophilic	=	11.0 lbs. per ton
	b) Thermophilic	=	8.0 lbs. per ton

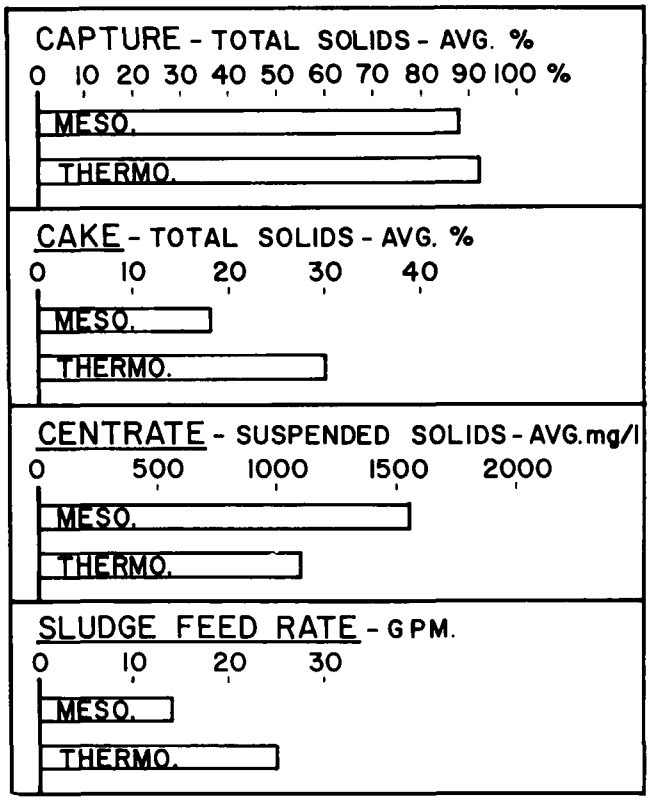

Figure 1: Test Data—Solid Bowl Centrifuge—Kruger KDF-500.

The optimum sludge feed rate for mesophilic sludge was 14 GPM. The optimum sludge feed rate for thermophilic sludge was 25 GPM or 44 percent better than with mesophilic sludge.

Basket Bowl Centrifuge

In this test a full sized 48 inch DeLaval Basket Centrifuge was used. Table 4 indicates the test conditions that provided the optimum performance from the basket centrifuge. The bowl speed was 1400 RPM which resulted in a "G" force of 1330 "G's". The total cycle period averaged 30 minutes.

Figure 2 illustrates the performance between thermophilic and mesophilic sludges in the 48 inch basket centrifuge.

Capture of total solids was very good for mesophilic sludge averaging 90 percent (T.S.). The thermophilic capture was only 38 percent (T.S.) which was considered unacceptable.

With respect to cake solids both mesophilic and thermophilic sludges produced an acceptable 28 percent and 31 percent respectively. Centrate concentration from the mesophilic sludge produced a submarginal 1400 mg/1. The thermophilic sludge centrate was a totally unacceptable 13,800 mg/1.

TABLE 4
Optimum Test Parameters
Basket Bowl Centrifuge
48" DeLaval

1.	Sludge Feed Rate Mesophilic & Thermophilic	= 40 GPM
2.	Sludge Feed Concentration a) Mesophilic b) Thermophilic	= 2.60% T.S. = 2.42% T.S.
3.	Polymer Dosage Rate Mesophilic & Thermophilic	6.0 lbs. per ton

Vacuum Filter

In this test series an Eimco pilot belt vacuum filter was used. The drum diameter was three feet and the belt width one foot.

Table 5 indicates the test conditions under which optimum results were obtained from mesophilic and thermophilic sludges, and Figure 3, the optimum test results.

Mesophilic sludge resulted in an average capture of 91 percent (T.S.) and a thermophilic sludge resulted in a capture of only 56 percent (T.S.). These values represent overall capture percentages including elutriation. The thermophilic sludge lost most of its fine solids in the elutriation process. In the elutriation washwater, thermophilic sludge had a suspended solids concentration of 1,380 mg/1 compared to mesophilic sludge which averaged only 110 mg/1 suspended solids.

The cake solids content in both mesophilic and thermophilic sludges were an acceptable 29 percent and 31 percent respectively.

The filtrate from the mesophilic sludge produced an unacceptable 2500 mg/1 of suspended solids. The thermophilic sludge produced an acceptable 990 mg/1 of

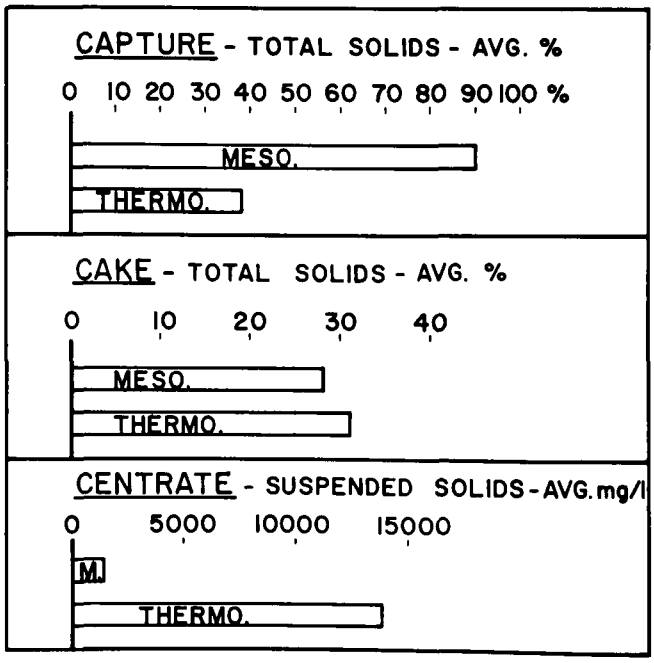

Figure 2: Test Data—Basket Bowl Centrifuge—48" DeLaval.

TABLE 5
Optimum Test Parameters
Vacuum Filter Eimco 1' X 3'

1. Elutriation Rate 1 Sludge and 3 water

2. Elutriation Polymer Dosage Rate
   a) Mesophilic = 0.25%
   b) Thermophilic = 0.50%

3. Elutriate Washwater
   a) Mesophilic = 110 mg/l
   b) Thermophilic = 1,380 mg/l

4. Chemical Conditioning-Elutriated Sludge
   a) Mesophilic = 5% $FeCl_3$ + 10% CaO
   b) Thermophilic = 2.5% $FeCl_3$

5. Feed Sludge Concentration
   a) Mesophilic = 2.90% T.S.
   b) Thermophilic = 2.78% T.S.

suspended solids, however, it already had eliminated most of its fines in the elutriation process.

The yield rate for mesophilic sludge was a low 1.8 lbs. per square foot per hour (lbs./ft.^{2}/hr). Thermophilic sludge averaged a yield of 4.1 lbs./ft.^{2}/hr.

DISCUSSION

Figure 4, summarizes the test data from the systems evaluated. Based solely on the initial technical test goals of "Capture", "Cake Solids" and suspended solids in the "Filtrate-Centrate", the only system qualifying would be the solid bowl centrifuge and thermophilically digested raw sludge.

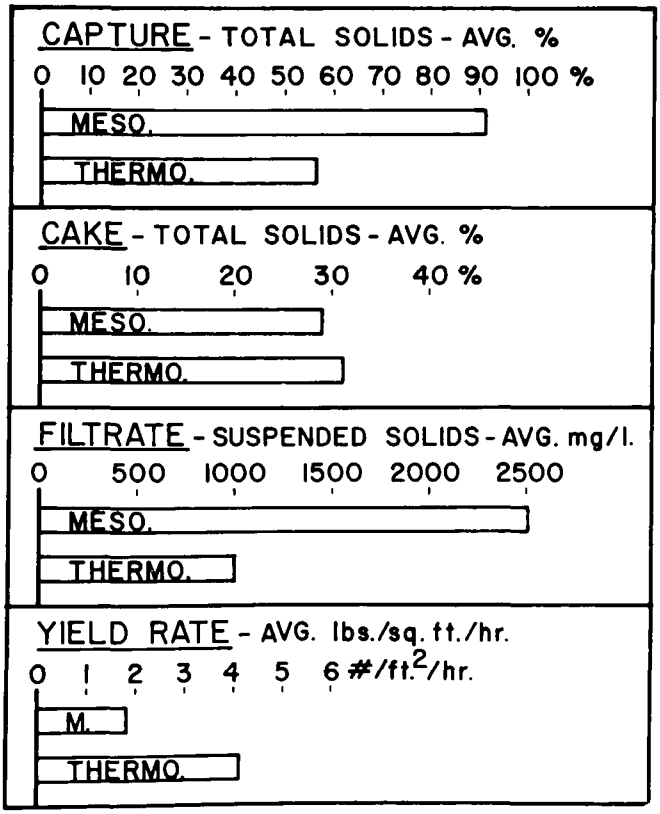

Figure 3: Test Data—Vacuum Filter—Eimco (1' X 3').

EQUIPMENT / SLUDGE TYPE	FEED RATE GPM	CHEMICAL DOSAGE #/TON	CAPTURE %	CAKE %	CENTRATE S.S. mg/l
SOLID BOWL CENTRIFUGE					
meso.	14	11	88	18	1550
thermo.	25	8	92	30	1100
BASKET BOWL CENTRIFUGE					
meso.	40	6	90	28	1400
thermo.	40	6	38	31	13,800
VACUUM FILTER	YIELD #/SF/HR				
meso.	1.8	5% $FeCl_3$ + 10% CaO	91	29	2500
thermo.	4.1	2.5% $FeCl_3$	56	31	1000

Figure 4: Summary of Test Data.

However, Table 6 lists some of the other pertinent factors influencing the selection of a dewatering system. Assuming a system attains or nearly meets the test goals, the next major consideration for ocean dischargers in California would be how to effectively treat the centrate or liquid fraction from the dewatering process, to meet the state of California's Ocean Discharge Plan. Table 7 indicated the proportionate amounts of total chrome and arsenic found in mesophilic and thermophilic sludges. From this preliminary data it could be inferred that thermophilic digestion may solubilize some heavy metals into solution, consequently before any firm evaluation can be made additional analyses must be performed in this area.

In all of the acceptable dewatering processes examined, some forms of sludge conditioning was required. Since this is a continuous expense, careful evaluation and cost comparisons must be made on the unit cost of conditioning chemicals as well as the quantity required. For Hyperion the conditioning by thermophilic

TABLE 6
Evaluation Factors

1. Test Goals
2. Centrate Treatment Expense
3. Sludge Conditioning Expense
4. Cake Transport & Disposal Expense
5. Operational Reliability Flexability
6. Operations & Maintenance Expense
7. First Costs

TABLE 7
Heavy Metal Concentrations

		Total "Cr" mg/l	"As" mg/l
1.	Prim. Sludge		
	dissolved	0.09	0.01
	suspended	45.18	1.00
2.	Mesophilic		
	dissolved	0.06	0.01
	suspended	50.26	0.08
3.	Thermophilic		
	dissolved	0.15	0.04
	suspended	52.52	0.87

TABLE 8
Heat Vs. Chemical Costs

	Meso.	Thermo.
Additional Heat cost $/Ton Avg.	0	$1.66
Chemical costs per ton.	$15.00	$11.00
Total conditioning costs $/ton	$15.00	$12.66

sludge and polymers, Table 8, shows that it was less expensive to operate at the thermophilic temperature range and purchase less polymers, than to depend upon a larger polymer dosage and conventional mesophilic digestion. However, the additional capital expense that may be required for thermophilic operation may modify this conclusion.

The percent solids in the sludge cake dictates the transport and disposal costs. To illustrate this, 100 Tons/day (dry solids) of sludge at 75 percent moisture (25 percent T.S.) will weigh 400 wet tons, whereas, the same amount of sludge at 70 percent moisture (30 percent T.S.) will weigh 333.33 wet tons. Therefore a five percent increase in cake solids will save 67 tons of sludge to be transported and disposed.

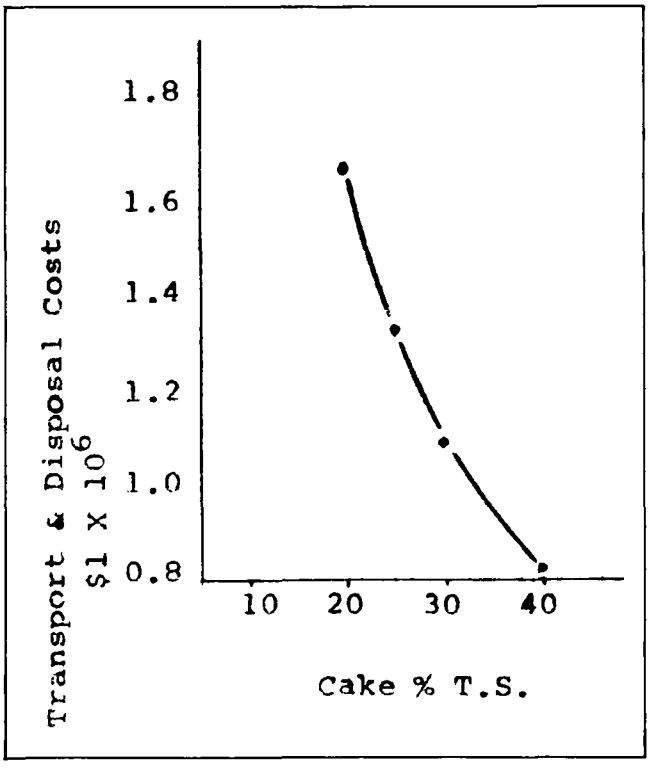

Figure 5: Cake Solids Vs. Disposal Costs (100 T/d at $9.00/T).

Transport and disposal cost estimates have ranged between $6.00 and $12.00 per ton of sludge. Using an average cost of $9.00 per ton, for transport and disposal 25 percent cake will cost $3600/day and 30 percent cake will cost $3000/day, annually this difference amounts to $219,000. Figure 5, illustrates the relationship between cake solids and transport-disposal costs, based on 100 ton per day of solids (dry wt.) and $9.00 per ton transport-disposal costs.

Another of the prime evaluation factors is operational and maintenance requirements of each system. It is difficult to accurately predict the long term situation based on the relatively short term tests performed at Hyperion. Consequently about the only comment that can be made with respect to equipment is that the solid bowl centrifuge was a continuous process, the vacuum filter was semi-continuous, due to the required elutriation process and the basket bowl was a batch process.

Estimates on additional personnel required to operate the complete dewatering operations and sludge transport system indicate 36 personnel. An additional 18 personnel will be required to service and repair the facilities. And an additional five persons will be required for technical and administration support. Therefore, based on an annual average salary of $12,000 per year, salary expenses are estimated to increase by $708,000.

The capital expense associated with each of the systems appears largely related to the sludge feed capacities of the individual dewatering machines, since the conditioning and cake handling systems will be largely similar. Manufacturers are continuously improving their equipment and claim higher capacities for their machines. However, without well established scale up

factors, the capabilities of untried equipment remains uncertain.

The City of Los Angeles is obligated to purchase the low bid on equipment. Consequently, it is difficult to determine what brand or system will be finally installed.

CONCLUSIONS

The following preliminary conclusions were derived from the Hyperion dewatering studies. That thermophilically digested sludge and a solid bowl centrifuge produced a drier sludge cake, contained less suspended material in the centrate, required less chemical conditioning than mesophilic sludge, and permitted a higher sludge feed rate. The thermophilic sludge, solid bowl centrifuge was the only combination to essentially meet all of the dewatering requirements, e.g., solids capture $\geq$ 90 percent (actual 92 percent), centrate suspended solids $\leq$ 1000 mg/1 (actual 1100 mg/1) and a sludge cake solids content $\geq$ 25 percent T.S. (actual 30 percent). The above system also had a higher continuous sludge feed rate when compared to mesophilic sludge, i.e., 14 GPM for mesophilic vs. 25 GPM for thermophilic. Figure 4, summarizes the data.

However, before any final conclusions can be determined the other associated effects of thermophilic digestion must be considered. One of the negative aspects of thermophilic digestion is the large amount of additional heat required, approximately 69 percent more BTU's than mesophilic operations for Hyperions digesters (95°F Meso., 120°F Thermo). This additional heat requirement dictates that additional heating facilities must be constructed for full thermophilic operations.

There is also some evidence that the centrate from thermophilic sludges contains a greater amount of certain dissolved heavy metals, e.g., total chrome. Also, centrate-filtrate from thermophilic sludges were observed to contain higher C.O.D. levels (approximately 30 pecent higher than mesophilic centrate). Since the major reason for limiting the centrate suspended solids concentration to as low a value as possible was to minimize the amount of additional treatment that would be required for the centrate before it could be discharged, any increase in heavy metals or C.O.D. must be considered counterproductive. One major unresolved problem is how to remove relatively small amounts of heavy metals from relatively large flows in a practical manner, so that discharge limits can be reliably met.

Thermophilic digestion also requires more careful operations. Thermophilic bacteria appear more sensitive to loading and temperature changes than the mesophilic bacteria group. This signifies that better process control feed and temperature controls systems be developed (used), to optimize operations and increase reliability.

For Hyperion the long term picture is complicated by the eventual necessity to handle an estimated 4-6 mgd of waste activated sludge (W.A.S.) when full secondary treatment is achieved. The dewatering characteristics of anaerobically digested raw and W.A.S. still remains to be determined. In any case thermophilically digesting the W.A.S. will require substantial amounts of additional heat.

Some preliminary pilot studies have been initiated to determine the compatibility of raw and W.A.S. being combined and anaerobically digested.

The question arises as to why did the thermophically digested sludge dewater better? Several hypotheses have been proposed.

First, sieve analyses (Figure 6) between mesophilic and thermophilic sludges indicate that thermophilic sludge contains a higher percentage of coarser particles which tend to dewater easier. Second, it was observed during laboratory scale dewatering tests (filter leaf tests) that heated sludges tended to dewater easier, reduced liquid viscosity being considered the main factor. Third, the filtrate from thermophilic sludges contained greater quantities of ether solubles, C.O.D. and dissolved solids, consequently, the thermophilic digestion process may have selectively solubilized those compounds or particles which tend to hinder dewatering i.e., grease and oils. However, before any final conclusions can be made, additional investigations must be performed.

The final conclusion concerning dewatering operations at Hyperion is that regardless of whether thermophilic or mesophilic sludge is used or what conditioning agents are applied or what type of equipment is used it will be outrageously expensive.

Thermophilic Digestion

This section of the report will summarize the observations made, while operating three of Hyperion's digesters in the thermophilic temperature range. The first part will discuss the conventional operating parameters of thermophilic digestion. The second part will discuss the apparent enhancement of methane gas pro-

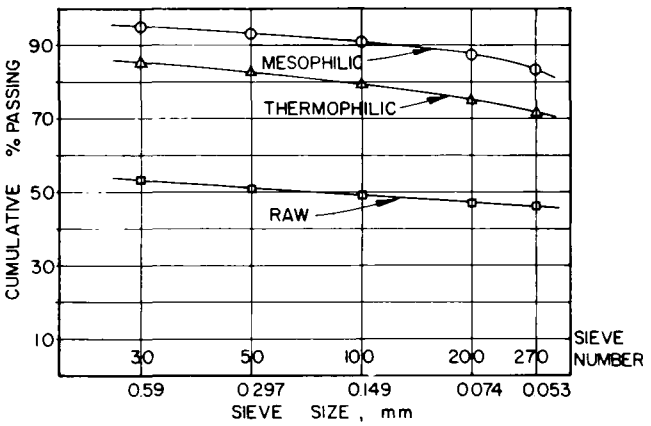

Figure 6: Sludge Particle—Size Distribution.

duction established by a comparison to a mesophilic digester operating under identical conditions.

Full scale thermophilic operation was practiced at Hyperion during the 1953-57 period. The results of this operation were documented by W.F. Garber (1954)[2]. The following are some of the conclusions reached at that time on thermophilic operations:

1. Thermophilic sludge was easier to dewater than mesophilic sludge.
2. Thermophilic sludges had coarser particle sizes.
3. Volatile acids content in thermophilic digesters was higher.
4. The percent volatile solids reduction was greater for thermophilic temperature than for mesophilic temperature at equal detention times.
5. Methane gas production at thermophilic temperatures was lower than that for mesophilic temperatures.
6. Methane gas quality was greater in thermophilic digesters than in mesophilic digesters.

Based on conclusions 1 and 2 above, it was decided to test the dewaterability of thermophilically digested sludge as part of the Hyperion sludge dewatering studies. Consequently, in April of 1972 one of Hyperion's digesters was converted from mesophilic to thermophilic operations. Digester tank 2-A was chosen since it was equipped with a 600 CFM free lift gas mixing system and digester tank profiles indicated excellent uniformity of temperature, alkalinity and volatile acids. The performance history of digester 2-A is depicted by Figures 7, 8 and 9.

As expected the temperature increase from 95°F to a targeted thermophilic temperature of 125°F resulted in much higher levels of volatile acids (V.A.), loss in both methane gas production and quality, a drop in alkalinity, loss in solids reduction, and a drop in pH. The digester was not productive for approximately six months. During this period the volatile solids (V.S.) loading was reduced and the temperature lowered to a new target of 120°F. The digester began to show signs of recovery immediately. From this, it was concluded, that for Hyperion, a thermophilic digestion temperature of about 120°F was desireable.

By late 1972 all processes parameters appeared to be stable, i.e., volatile acids were dropping to 1000 mg/1, alkalinity increased to 5000 mg/1, gas production was near 14 cubic foot per pound of volatile solids added (ft^3/lb. V.S.) and gas quality was near 64 percent methane (CH_4).

With the thermophilic process now reasonably stabilized, a program was initiated to determine the maximum practical loading rate for Hyperion's thermophilic digester. A loading rate of 0.3 pounds of volatile solids per cubic foot of digester capacity was attained by October 1974. All process parameters appeared stable, except for the methane gas production rate (ft^3/lb V.S.). The gas production rate was down to 10 ft^3/lb. V.S., although total gas production was up to 1 X 10^6 $ft.^3$ per

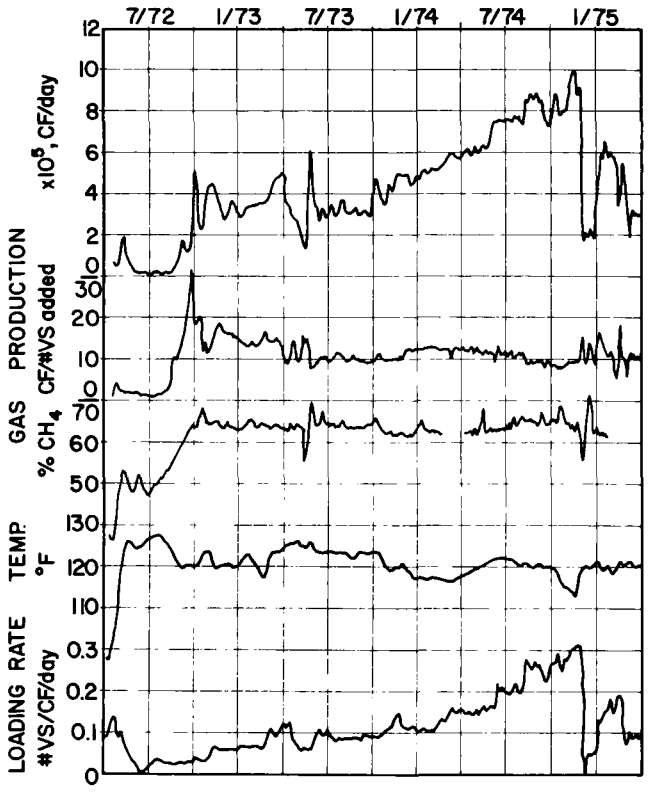

Figure 7: Thermophilic Tank 2-A Data.

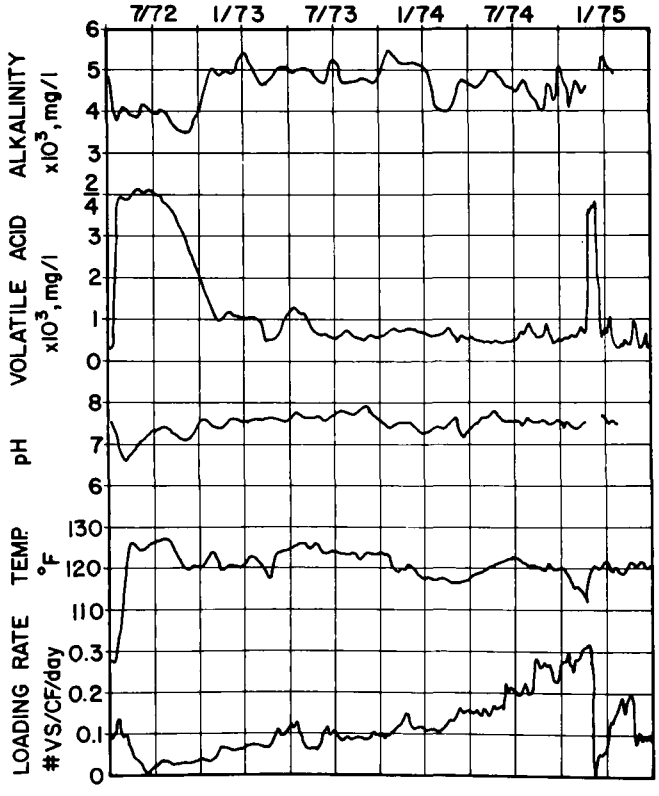

Figure 8: Thermophilic Tank 2-A Data.

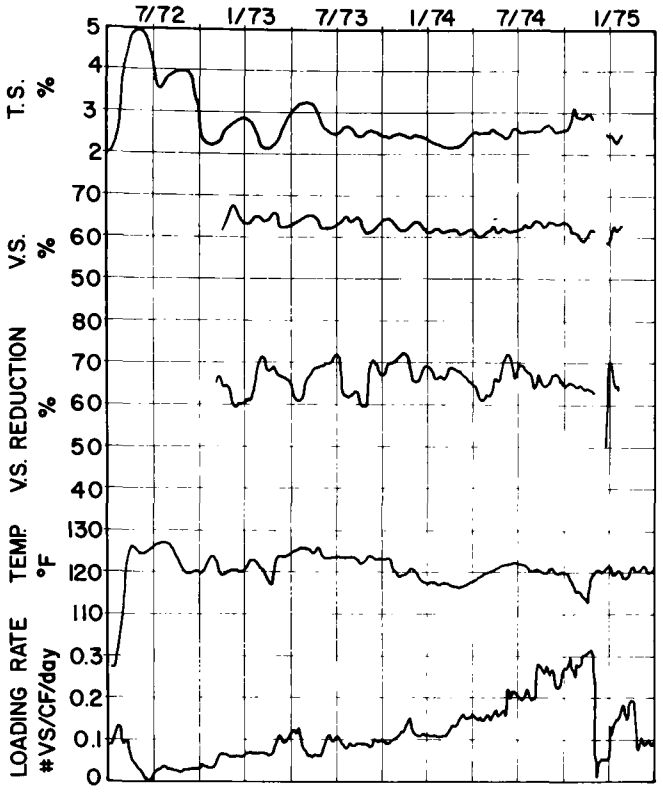

Figure 9: Thermophilic Tank 2-A Data.

day. The loss in gas production rate was later determined as being caused by physical gas leaks in the digester dome. Apparently, the high volume of gas being produced and thermophilic temperatures promoted increased gas leakage in the previously cracked fixed roof concrete domes.

Unfortunately, about this time mechanical difficulties resulted in insufficient heat being available and the digester temperature dropped down near 113°F. This caused an immediate rise in volatile acids and forced a drastic reduction in the loading rate, which in turn resulted in a sharp drop in gas production.

As soon as heat was available, digester 2-A was brought up to 120°F. at a temperature increase of 1°F. per day. The process parameters indicated rapid recovery (≅30 days), from the temperature upset. Unfortunately, the recovery period was during the holiday season and personnel shortages prevented a thorough monitoring of all experimental parameters. Increased regulatory monitoring demands forced further reductions in the comprehensive testing of digester 2-A. The blank portions in Figures 7, 8, and 9 indicate periods when samples were not taken and/or analysed.

At this point in time some of the previous conclusions regarding thermophilic operations at Hyperion were verified and others left in question. The following previous conclusions were verified:

1. In some situations thermophilic sludges are easier to dewater.
2. Thermophilic particles sizes are coarser than mesophilic particles (Figure 5)
3. Volatile acid levels are higher in thermophilic digesters, 400-500 mg/1 vs. 100 to 200 mg/1 for mesophilic digestion.

Contrary to previous conclusions, there is some evidence that methane gas production is higher and gas quality is lower for thermophilic digestion, when compared to mesophilic digestion. The remaining portion of this report will be directed toward these observations.

DISCUSSION

Thermophilic Compared To Mesophilic Digestion

Early in 1975 it was decided to make a direct comparison between mesophilic operations and thermophilic operations. Two secondary digesters which had been cleaned, and modified (gas mixing and heating added) for primary operations were selected for this test. Both digesters are in the same battery adjacent to each other and connected to the same raw sludge feed line. Each digester was(is) gas mixed at a rate of 3000 cfm. The mesophilic temperature was targeted at 95°F and the thermophilic temperature targeted at 120°F. After start up, stabilization occured in the spring of 1975 when both digesters were loaded at 0.16 lb. VS/ft^3. Figure 10 and Table 9 illustrate the results of this test. Digester 3-C

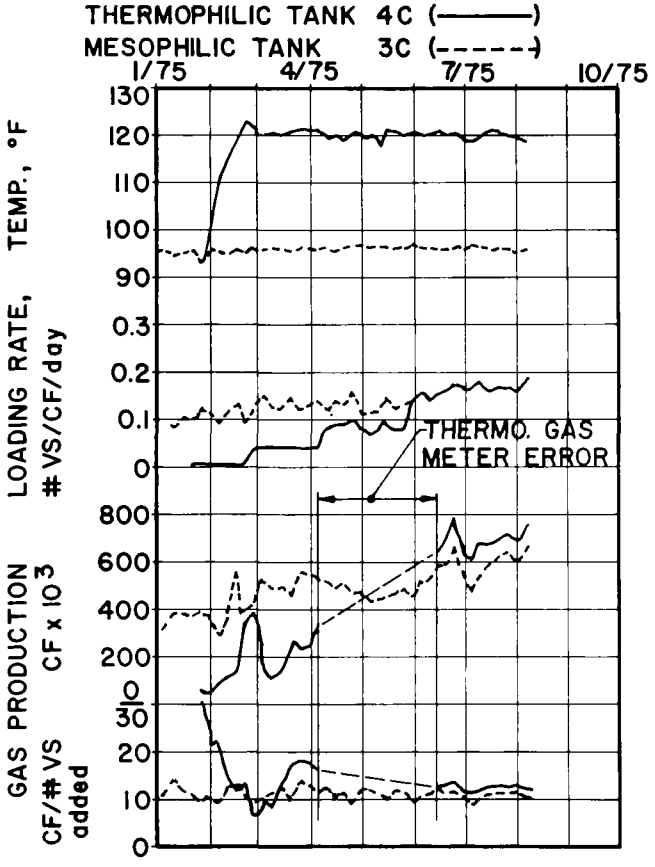

Figure 10: Gas Production.

TABLE 9
Summary of Thermo. Vs. Meso. Tests

Parameter	Raw Sludge	Meso. Sludge	Thermo. Sludge
Temperature, F	77	96	120
Loading Rate,#VS/CF/day		0.16	0.16
Gas Production,CF/day		580,000	680,000
Gas Production,CF/#VS.added		10.9	12.7
Gas Quality,% CH_4		64	63
Volatile Acids,mg/l		300	600
Alkalinity,mg/l	1600	3900	4100
Volatile Acid/Alkalinity Ratio		0.08	0.15
pH	5.1	7.4	7.6
Total Solids,%	6.1	2.5	2.1
Volatile Solids,%	78	60	65
Hydraulic Detention Time,days		18.2	18.2

which was operated at the conventional mesophilic mode typifies Hyperion's sludge digestion operations. Digester 4-C was operated at thermophilic temperatures.

Based on the data from June 1975 to August 1975 the following preliminary conclusions have been reached:

1. Thermophilic digester 4-C is producing more gas (100,000 ft^3/d) than mesophilic digester 3-C under the same loading and detention times.
2. The gas quality of thermophilic digester 4-C is approximately one percent lower than for mesophilic digester 3-C, 63 percent CH_4 vs. 64 percent CH_4 respectively. However, since Hyperion's composite gas quality normally averages close to 65 percent CH_4, the slightly lower values obtained may not be significant.
3. As expected the volatile acid levels (600 mg/1) in thermophilic digester 4-C are twice that of digester 3-C (300 mg/1).
4. The volatile acids alkalinity ratio of thermophilic digester 4-C is 0.15, which indicates less buffering capacity than digester 3-C at 0.08. This would tend to support observations that thermophilic digesters are more sensitive and require closer process controls, e.g., increases in loading or changes in temperature.
5. The total solids and volatile solids percentages shown for mesophilic sludge were Hyperion plant composite averages. Consequently, valid comparisons between digester 4-C and 3-C are not available.
6. Records at Hyperion (1973) indicate that it takes an average of 20,000,000 Btu/day per mesophilic digester for heating[3]. Calculations indicate that approximately 69 percent more heat energy is required to operate at thermophilic temperatures, in this case 0.69 X 20,000,000 Btu/d/digesters = 13,800,000 Btu/day/digester. However assuming that 100,000 ft^3 of methane gas with a heat value of 600 Btu/ft^3 can be obtained from each thermophilic digester (600 Btu/ft^3 X 100,000 ft^3/d = 60,000,000 Btu/d). Then an extra 46,200,000 Btu/d/digester (60,000,000 13,800,000 Btu/d/digester) could be available from thermophilic operations.

ACKNOWLEDGMENTS

The authors express their appreciation and acknowledge the assistance provided by W.F. Garber, S. Raksit, G. Wong, A. Liu, J. Nagano, and others of the Hyperion technical staff who contributed to this paper.

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UTILIZATION OF METHANE FROM SLUDGE DIGESTION

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INTRODUCTION

Utilization of methane from sludge digestion, usually called sludge gas, for in-plant uses has had its ups and downs during the last fifty years. Commercial use of sludge gas had been only occasional and rather experimental in nature. In-plant utilization of sludge gas became fairly well established in the 1930's and 1940's. During the next two decades, the use of sludge gas expanded moderately, inhibited largely by the availability of cheap electrical energy and the effect of union rules in the large plants on engine operating labor costs, but also by the operating and maintenance problems with anaerobic digestion as compared to nonbiological methods. During the last several years, substantial changes in availability and costs of energy have sparked renewed interest in the possibility of in-plant self-sufficiency in energy needs or production of chemicals from sludge gas. The rising costs for power and chemicals and general concern with energy conservation are rapidly changing the economics of inclusion in the waste treatment facilities of methane using processes which were hitherto cost effective only at commercial scales. It is the purpose of this paper to restate numerous conventional uses of sludge gas and to discuss the feasibility of sludge gas utilization for production of chemicals which may be used in the plant or which could be marketed.

Historical Uses of Sludge Gas

Although the use of sludge gas was first demonstrated in 1890's for street lighting in England, widespread use of sludge gas for inplant uses was not established until about 30 years later. While the earlier uses included heating of plant buildings, laboratory uses and incineration of screenings, skimmings, sludge and grit, the utilization of sludge gas got its biggest impetus with the successful use of the gas as a fuel for internal combustion engines in the 1930's. Large municipalities using sludge gas engines currently include New York City, Los Angeles, Cincinnati and Boston. A total of 193,000 installed engine horsepower was reported operating in waste treatment plants in the U.S.A. in 1965[1]. More than half of this installed power was used to run generators which provide a more flexible form of power to meet almost all plant needs. Engines have also been used as direct drives for pumps, air blowers and other equipment. As a secondary advantage, waste heat from engine cooling water can be used for purposes normally requiring hot water or steam boilers. These uses include digester and space heating, air conditioning and other hot water uses. Some generalized modes of sludge gas utilization for various inplant uses are shown on Figure 1.

Historically there has been little or no commercial utilization of sludge gas. In Europe, it was used to a limited extent as a vehicle fuel. In this country, even during the second world war and afterwards, when there was a real shortage of gas for domestic and industrial uses, the matter of sludge gas supply into local distribution networks never received widespread attention. Among various reasons accounting for this are the lower heat value compared to natural gas, variable sludge gas characteristics, purification required to remove carbon dioxide and hydrogen sulfide and additional gas compression to meet the line pressures. In short, so far it has not generally been cost effective to use the sludge gas for commercial purposes compared to the price and availability of natural gas. This situation may change with the rising prices and diminishing supplies of natural gas and the possibilities of sale of sludge gas should be recognized. For example, a study about a year ago for Sacramento indicated a near break-even situation in purifying and selling excess gas to the local utility. At least two large plants do now sell excess gas: Los Angeles County Sanitary District No. 2 delivers about two MCFD to a refinery and the Hyperion Plant of the City of Los Angeles supplies a similar quantity to the City's municipal power system. Gunson[2] reported an average daily sale of 700,000 cubic feet of sludge gas to American Smelting and Refining Company with additional provision that their peak demands would be met on a standby basis.

Recent Developments

During the last 20 years or so, there has been a noticeable decline in the use of anaerobic digestion as a method

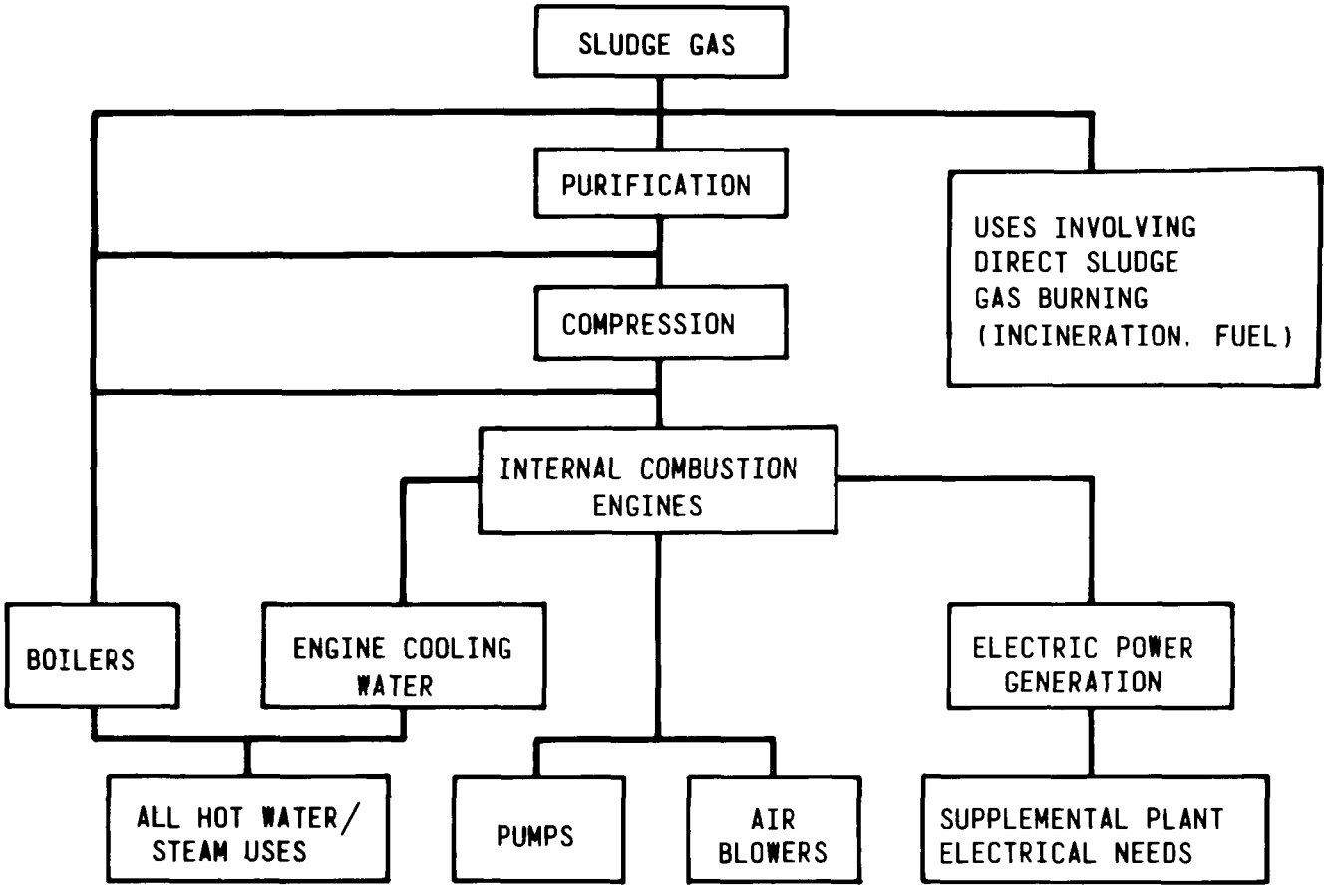

Figure 1: Historical Modes of Sludge Gas Utilization.

for stabilization of sludges. Essentially, this has been because of the low cost and availability of electricity, natural gas or fuel oils for alternative sludge treatment methods. Greater control required for the operation of anaerobic digesters and development of other sludge stabilization processes have also contributed to a shift away from anaerobic digestion. The alternate sludge stabilization and treatment methods, such as aerobic digestion, heat treatment, centrifuging and sludge incineration, have substantially added to the energy requirements at treatment plants, in comparison with the anaerobic digestion which provides net energy for the plant needs.

Another major development which affects the waste treatment energy needs is the adoption of secondary treatment as minimum at all plants and tertiary treatment, to varying degrees, at numerous locations in this country. The Environmental Protection Agency[3] estimates the following energy requirements for different types of treatment plants based on the 1968 inventory of municipal facilities:

Primary - 0.029 Kwh/day/capita
Secondary - 0.113 Kwh/day/capita
Tertiary - 0.226 Kwh/day/capita

These figures or increased needs underscore the concern of plant operators, faced with rising power rates, over the increased operating costs. Because of increased fuel needs and costs, and possible lack of dependability of imported fuels on a national level, the need for re-evaluation of plant energy requirements and sources has never been greater.

Potential Sludge Gas Energy

Sludge gas is obtained as a byproduct during the anaerobic digestion of the sewage treatment plant sludges. Anaerobic digestion is a biological process employed for the stabilization of sludges and essentially consists of 15 to 25 days detention of sludges at elevated temperature and under anaerobic conditions. Optimum operating temperatures vary from 90° to 95° F for mesophilic to 120° to 140° F for thermophilic conditions.

Sludge gas composition varies slightly from one treatment plant to another but is largely a mixture of methane (65 to 70 percent by volume) and carbon dioxide (30 to 35 percent by volume) with smaller quantities of nitrogen, hydrogen, hydrogen sulfide and oxygen. Occasionally, traces of carbon monoxide or other gases may be present.

The average yield of gas in the United States is generally between 10 to 20 cubic feet per pound of volatile solids destroyed with an average of about 17 cubic feet. Existing anaerobic digestion practice commonly

destroys about 50 percent of the volatile solids present in the feed sludge. The solids destruction and gas yield are somewhat influenced by the nature of the volatile material and its susceptibility to biological degradation. Techniques of increasing volatile solids destruction need further investigations.

Recently ICI America (a subsidiary of Imperial Chemical Industries) has claimed that the destruction of volatile matter and the gas yield can be substantially increased (up to two times) by the addition of powdered activated carbon at a dosage of approximately five percent of the sludge solids[4]. A number of treatment plants have been pilot testing during the last year or so to determine the feasibility and the cost effectiveness of this claim, among them being, Cranston, R.I. (seven to eight mgd) and Norristown, Pennsylvania (seven to eight mgd).

The heat value of sludge gas averages about 640 Btu per cubic foot compared to 1,000 Btu per cubic foot for natural gas. These heat values essentially correspond to the percentage of methane in each gas. Theoretically, the electrical equivalent of one cubic foot of sludge gas is 187.52×10^{-3} Kwh. Assuming an average sludge gas yield of 0.8 cubic feet per capita per day for a primary treatment plant and 1.2 cubic feet per capita per day for a secondary plant, the theoretical electric energy yields are 0.150 and 0.225 kwh per capita per day, respectively. Actual electrical power available would be 0.050 and 0.075 kwh per capita per day for primary and secondary plants, respectively when an overall engine-generator efficiency of 33 percent is used. These compare to electrical needs of 0.029 and 0.113 kwh per day per capita for primary and secondary treatment plants respectively[3]. These figures do not include secondary utilization of engine cooling water for digestors, space heating and other hot water requirements of a primary plant and to a substantial degree at a secondary plant can be supplied in-plant from sludge gas utilization. If the sludge gas production can be increased by the use of activated carbon as claimed by ICI America, or by other techniques, it may be possible to meet the total energy requirements of a secondary treatment plant.

At present, power production at sewage treatment plants in this country is usually through the use of gas, dual-fueled, engine-generator systems. It has been suggested by Murphy[5] that the use of fuel cells can substantially increase the energy conversion efficiency from sludge gas to electricity. Fuel cells are relatively simple in construction, create no air pollution, are modular in nature and have no minimum system size. On the other hand, the fuel cell production technology is still in a developmental stage and it will be some time before they can be economically employed for in-plant uses.

New Considerations

There have been numerous happenings in the immediate past as a result of which new alternatives for sludge gas utilization have developed. A number of sewage treatment plant operators all over the country, especially those of large cities or sanitary districts, have chosen to consider these alternatives. A discussion of these alternatives is in order.

Due to recent increases in the cost of petroleum based chemicals, the cost of fertilizers has gone up substantially. More and more farmers and city dwellers are using stabilized dried sludge for fertilizing their lands and lawns. These sludges are deficient in nitrogen, phosphorus and potash and need to be fortified to provide balanced fertilization. Nitrogen required for this purpose could be produced from sludge gas as an alternate to commercially available nitrogen.

Another chemical likely to be in substantial demand at some plants is methanol. Methanol has, so far, been found to be the most cost effective purchased chemical carbon source for the biological denitrification process employed at a number of plants for removal of nitrate-nitrogen. Commercially, methanol like ammonia, is largely made from natural gas. It is believed that methanol production from sludge gas is also a real possibility.

Ammonia Production Technology

It has been reported[6] that approximately 60 to 65 percent of world ammonia production is derived from natural gas. Natural gas reforming and partial combustion are two processes most widely used in the ammonia synthesis. Out of these two, natural gas reforming with steam accounts for 75 to 80 percent of total ammonia production. Application of this process for production of ammonia from sludge gas would employ the same steps as in commercial ammonia production from natural gas. The presence of 30 to 35 percent of carbon dioxide in the sludge gas compared to very little or none in natural gas, should not call for any major process modification as carbon dioxide production and its removal are essential steps in the following process flow scheme.

Steam Reforming Process

A line diagram of this process is shown on Figure 2. Essential steps leading to the production of ammonia from methane in sludge gas are described as follows:

Gas Purification

This consists essentially of desulfurization of the gas to as low sulfur levels as possible. In some sewage treatment plants, using sludge gas as engine fuel, desulfurization is currently practiced using dry gas scrubbers (ferric oxide mixed with hardwood shavings) or wet type bubbling scrubbers. In commercial ammonia plants, natural gas is usually desulfurized by passing over specially prepared activated carbon at ambient temperature and high pressures. Regeneration of the carbon is done with high temperature steam at low pressure.

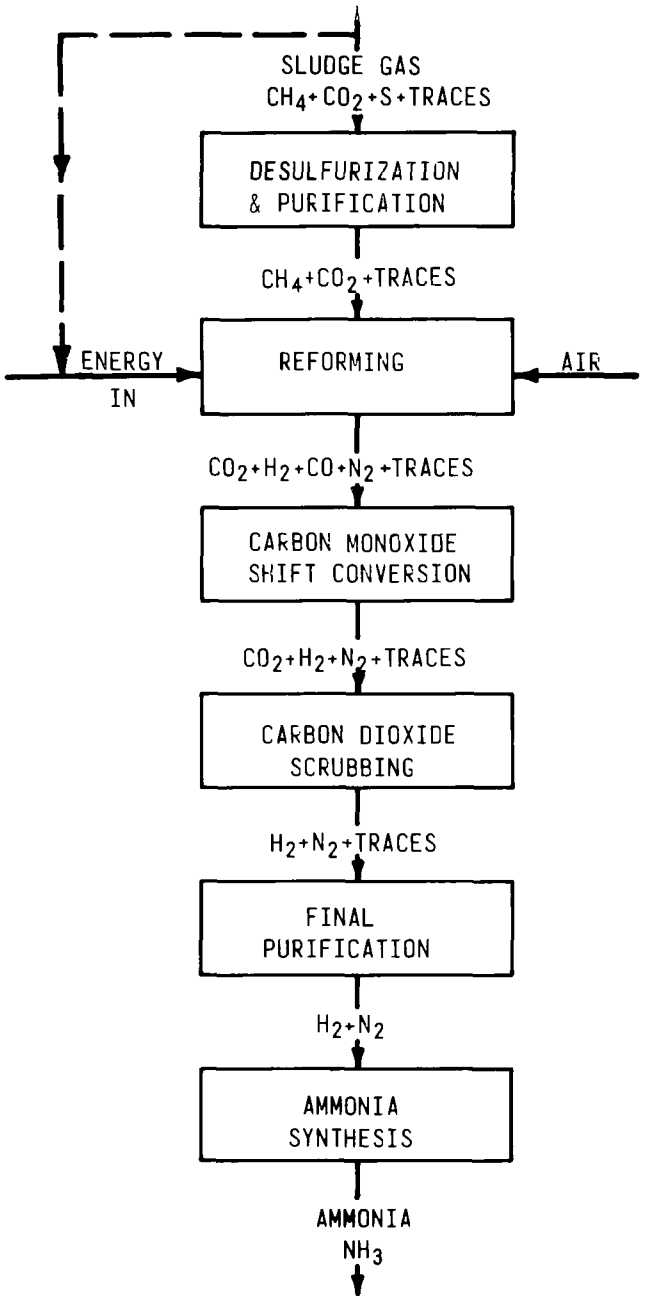

Figure 2: Ammonia Production from Sludge Gas (Simplified Flow Diagram).

Steam Reforming

Steam reforming or synthesis gas production is best described by the following equation:

$$CH_4 + H_2O \xrightarrow{\text{catalyst}} 3H_2 + CO$$
(synthesis gas)

This reaction is endothermic and is carried out at a temperature in the range of 800° C and pressure ranging from atmospheric to 500 psig. A nickel based catalyst is usually employed to assist the completion of this reaction.

The gas reforming is carried out in two stages. In the primary reformer the large endothermic heat is supplied by burning natural gas with air in a furnace. About 40 percent of the methane gas supplied is used to furnish this heat and about 60 percent is converted into synthesis gas.

In the secondary reformer, the primary reformer gases are mixed with air to introduce the nitrogen required for the reaction with hydrogen which results in the production of ammonia. Methane concentration in the synthesis gases at the end of this reaction is reduced to about 0.3 percent.

Heat recovery from the gas combustion for this step provides steam for turbines driving compressors needed later in the production processes and makes the balance of the production steps self-sufficient in energy requirements.

Carbon Monoxide Shift

This step consists of conversion of carbon monoxide to carbon dioxide and hydrogen using steam as per this reaction:

$$CO + H_2O \xrightarrow{\text{catalyst}} CO_2 + H_2$$

This reaction is usually carried out in two steps, one at high temperature 350° to 450° C; and second at low temperature 200° to 300° C. Catalysts are required in both steps. At the end of this reaction, the unreacted carbon monoxide is about 0.3 to 0.5 percent.

Carbon Dioxide Removal

In this step, the bulk of the carbon dioxide is removed by one of the numerous methods available. Among those commonly used are water scrubbing and hot potassium carbonate absorption.

Final Purification or Methanation

This step consists of removal of the remaining carbon monoxide and carbon dioxide since they poison the ammonia catalyst as well as tend to form solid compounds which can damage machinery.

This is essentially the reverse of the methane reforming process and carbon monoxide shift steps, as follows:

$$CO + 3H_2 \xrightarrow{\text{catalyst}} CH4 + H_2O$$
$$CO_2 + 4H_2 \xrightarrow{\text{catalyst}} CH4 + 2H_2O$$

To achieve these reactions, the gases are preheated to about 600° F and then passed over a nickel catalyst.

Ammonia Synthesis

Ammonia synthesis is carried out at pressures ranging from 2,000 to 10,000 psi. Heat recovered from

The synthesis gas after this final purification is essentially hydrogen, about 75 percent, and nitrogen, about 25 percent. The methane formed in the final purification step is only about 0.3 to 0.5 percent, with less than ten ppm of oxides of carbon. Synthesis gas together with all remaining trace gases and inert impurities then pass on to the synthesis step.

the gas reforming step is generally used to produce

steam for turbine driving the compressors. The basic ammonia reaction is given by this chemical equation:

$$N_2 + 3H_2 \xrightarrow{\text{catalyst}} 2NH_3$$

This reaction is exothermic in nature and is sensitive to operating pressures and temperature, ratio of hydrogen to nitrogen and concentration of inert gases. The reaction is usually carried out in the presence of iron oxide which acts as a catalyst.

Methanol Production

Methanol or methyl alcohol synthesis is very similar to that of ammonia. Many ammonia plants are designed so that methanol could also be produced. Like ammonia, most of the commercial methanol production comes from natural gas. A simplified process flow diagram for methanol production from sludge gas is shown on Figure 3. Major differences in methanol production from sludge gas in contrast to that of ammonia are described below:

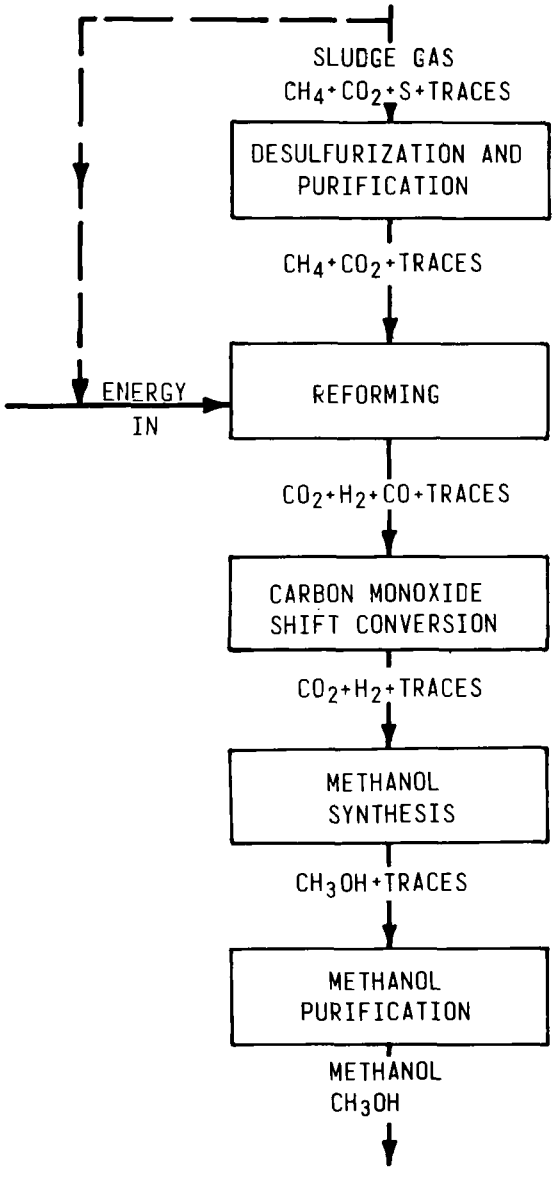

Figure 3: Methanol Production from Sludge Gas (Simplified Flow Diagram).

Stoichiometric Relationship

The basic chemical equation representing overall methanol synthesis is:

$$3CH_4 + CO_2 + 2H_2O \longrightarrow 4CH_3OH$$

Actual sequence of conversion from sludge gas to methanol is essentially the same as described under ammonia synthesis. This includes conversion of methane to synthesis gas (CO_2 + H), carbon monoxide shift conversion to carbon dioxide and methanol synthesis. However, there is no CO_2 scrubbing operation.

Carbon Dioxide Requirements

The stoichiometric equation indicates a net addition of one molecule of carbon dioxide for every three molecules of methane. In commercial production of methanol from natural gas, it is a practice to add make-up carbon dioxide from an external source. This addition may not be required in methanol production from sludge gas, since the latter has approximately the same composition as indicated in the stoichiometric equation.

As seen on Figure 2, for ammonia synthesis, carbon dioxide produced in the process is scrubbed prior to final synthesis. This carbon dioxide scrubbing is not required in methanol production since carbon dioxide is a part of synthesis gases.

Purification

In ammonia production, the synthesis gases are purified of oxides of carbon, prior to ammonia synthesis because the impurities are poisonous to the catalyst employed. In methanol production, the required product purity is obtained by condensation of converted gases and conventional distillation methods after the synthesis has taken place.

Cost Effectiveness of Ammonia and Methanol Production

Recently a preliminary study was undertaken by Greeley and Hansen of the cost of producing ammonia from sludge gas. Production costs were based on production capacities of 50 tons per day and 12.5 tons per day. A summary of the capital and operating costs for these plants are given in Table 1. These costs are based on data by Buividas[6], adjusted to current price levels.

It is estimated that about 80,000 cubic feet of sludge gas will be required to produce one ton of ammonia. Assuming one cubic foot of sludge gas per capita per day and 100 gallons of sewage per capita per day, it will take the entire sludge gas production of a 400 mgd and 100 mgd plant to produce 50 tons and 12.5 tons of ammonia per day, respectively. In other words other energy sources will be required to meet all other in-plant energy requirements. This effect, on the overall plant economics, can be approximated by assuming the purchase of natural gas for chemical production. Assuming

TABLE 1
Ammonia Manufacture from Sludge Gas

Item	50 Ton Plant First Cost	50 Ton Plant Amortized(a) Cost	50 Ton Plant $/Ton of Ammonia	12.5 Ton Plant First Cost	12.5 Ton Plant Amortized(a) Cost	12.5 Ton Plant $/Ton of Ammonia
Capital Cost	$5,000,000	$435,500	$24.00	$2,200,000	$192,000	$42.00
Operation Cost (b)						
Water			1.05			1.05
Catalyst & Chems.			0.60			0.60
Labor			1.25			5.00
Power (c)			7.65			7.65
Total Production Cost			$34.55			$56.30
		Say	$35.00			$57.00

(a) At 6% for 20 years - 8.7% annually.
(b) Sludge gas assumed free of cost.
(c) At 4¢/kwhr. In this case, this power cost is based on feeding liquid nitrogen instead of air in the secondary reforming step. It is further assumed that liquid nitrogen is produced cryogenically.

a natural gas requirement of 50,000 cubic feet per ton of ammonia compared to 80,000 cubic feet for sludge gas, it will mean an additional cost of about $30 per ton of ammonia (assuming natural gas costing $.60 per 1,000 cubic feet). In summary,

	50 Ton Plant	12.5 Ton Plant
Ammonia production cost without cost of gas	$35.00/Ton	$57.00
Cost of natural gas	$30.00	$30.00
Total cost of ammonia production	$65.00	$87.00

Ammonia is commercially available at about $200 to $250 per ton, depending upon the location.

Stoichiometrically, ammonia and methanol production per unit volume of sludge gas are close. Dean[7] estimates that, theoretically, 25,000 cubic feet of sludge gas would be required per ton of methanol produced. His preliminary calculation for Washington, D.C. indicated that sludge gas requirement per ton of methanol produced may be as much as 75,000 cubic feet. This is close to sludge gas requirement of 80,000 cubic feet per ton of ammonia used in the estimated production costs. It is, however, believed that both these numbers represent fairly liberal requirements.

The cost of methanol production from sludge gas would be about the same as for ammonia, since amortized cost forms a major portion of the total costs, and the manufacturing facilities for the two chemicals are essentially the same.

CONCLUSIONS AND RECOMMENDATIONS

Utilization of sludge gas for in-plant uses is receiving renewed interest lately because of rising costs of power and chemicals and general concern for energy conservation. Apparently, both sludge gas utilization and production should be maximized. Recently, it has been claimed that use of activated carbon in the anaerobic sludge digestion process substantially increases production of sludge gas. A number of pilot plants are now being operated at different locations in the United States to test the feasibility of this claim. Studies are continuing at the Hyperion Plant in the City of Los Angeles to see the effects of thermophilic digestion on gas production and sludge dewaterability. Interim results indicate increased sludge gas production but do not outweigh the added costs of energy due to higher operating temperatures. Nevertheless, efforts should be continued to investigate the methods of improving sludge gas production.

It appears that energy requirements at treatment plants are increasing substantially due to proposed secondary treatment at all plants and tertiary treatment expected at many plants. This calls for more intensive

use of sludge gas for plant purposes. It is believed that historical modes of sludge gas utilization are still the most economical methods. Generally speaking, the following order of conventional uses may be considered:

1. Generation of electricity. Engine cooling water should be considered for digestor heating.
2. Direct operation of pumps and blowers.
3. Hot water/steam production for space heating, air-conditioning and digestor heating.
4. Other uses.

In-plant storage will further help in increasing utilization but only in equalizing short term—essentially diurnal-fluctuation in supply and demand. More consideration needs to be given to equalizing seasonal demands such as winter heating and summer air-conditioning loads, both served by gas using systems.

In some places, the utilization of sludge gas for conventional uses may not be feasible. Use of sludge gas for productions of ammonia and/or methanol for in-plant purposes should be investigated. If applicable, ammonia can be used for sludge fortification for using it as soil conditioner or fertilizer. Similarly, methanol can be produced from sludge gas at those plants which employ biological denitrification for nitrate-nitrogen removal.

Commercial utilization of sludge gas has not been a very attractive proposition so far. In exceptional cases, like some plants in the Los Angeles area, sludge gas has been effectively sold to a gas-using industry or utility. Cost effectiveness of sludge gas use for commercial use is likely to improve as natural gas and other energy sources diminish in supply and become more expensive.

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PROCESSING, ECONOMICS AND SALE OF HEAT DRIED SLUDGE

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INTRODUCTION

The heat drying of municipal wastewater sludge for treatment and disposal is an old approach. Between 1916 and 1921, about the same time the activated sludge process was developed, Baltimore, Maryland, entered into a contract with a private contractor to heat dry and dispose of treatment plant sludge[1]. In the 1920's, Houston, Texas, used filter presses to dewater the sludge followed by rotary dryers[2]. In 1950, the sludge treatment system was changed to vacuum drum filters and flash dryers (C-E Raymond Division of Combustion Engineering, Inc.). This system is still in use; in fact, it is being updated and new dryers are being installed to increase the heat dried sludge capacity.

The flash dryer was used even earlier, in 1932 at the Chicago, Illinois, Sanitary District West-Southwest Sewage Treatment Works[3]. These dryers are still being used 43 years later. By 1951 numerous wastewater treatment plants throughout the United States has installed flash dryers[4]. Starting in 1935, units were installed that permitted either incineration or drying or combinations of the two, thus providing flexibility to combat fluctuation in demand for sludge or reduce fuel needs. This flexibility was useful only when a market for heat dried sludge existed. By 1959, approximately 125 municipal sewage treatment plants adopted the heat drying and/or incineration approach for sludge treatment and disposal[5]. With the strong surge of commercial fertilizers, however, the market for heat dried sludge did not develop as hoped. Consequently, both heat drying alone and heat drying and/or incineration options became less popular. Many plants abandoned the heat drying option. Thus, by the early 1970's, there were about 50 heat drying and/or incineration installations in the United States and even these numbers are declining[6].

Milwaukee, Wisconsin is an exception to the general decline in the popularity of heat drying municipal sludge. Its Milorganite production began in the early 1920's and this product is well known and is in strong demand[7]. There have been several new entries into the sludge drying arena. Winston-Salem, North Carolina, dedicated a new heat drying sludge facility in 1974[8]. The heat dried product is produced by a private firm, Orgonics, Inc., Slatersville, R.I., under the trade name of Organiform SS. At the District of Columbia Blue Plains Wastewater Treatment Plant another approach to heat drying wastewater sludges for use as fertilizers is currently being evaluated [3,9]. At Baltimore, a small pilot facility is also evaluating heat drying of sludge [10].

Despite the exceptions cited previously, current literature on the subject of heat drying municipal wastewater sludge emphasizes:

1. Heat drying is about the most expensive process for sludge treatment.
2. The market potential hoped for to utilize heat dried sludge as fertilizer, or soil conditioner, and thereby recover at least part of the treatment cost has not developed.
3. Improper heat drying operations and maintenance could cause problems with heat drying of sludge. Dust and fine sludge particles may be produced, and in the presence of oxygen in the gases, fires or explosions could result. However, it is important to note that proper operations and maintenance will greatly minimize these problems, and safety features on heat drying units virtually eliminate danger to personnel and equipment.
4. Many municipalities that have tried heat drying have abandoned this process, when they can, for other sludge treatment and disposal alternatives. However, there are notable exceptions—Milwaukee, Chicago, Houston, Winston-Salem.
5. Consultants and design engineers today rarely consider heat drying for sludge treatment.

Times are changing in the wastewater treatment field, particularly for sludge treatment and disposal, under the impact of recently enacted wastewater pollution laws and concern for resource conservation. To meet the "Now and Tomorrow" needs, a reassessment of the heat drying approach may be useful, which is the purpose of this presentation.

Overview of Heat Drying of Municipal Wastewater Sludges

Heat Drying of Sludges

Heat Drying is the dehydration of wastewater sludge, that is, most of the water is separated from the sludge as a vapor without combustion of the solid material. In the process air is heated to increase its vapor holding capacity and to provide the latent heat for water evaporation. It is well known that water and sludge are difficult to separate, and it takes a lot of heat energy (1,000 Btu/lb of water at one atm.), to change water from a liquid to a vapor. By the limits of the laws of thermodynamics for irreversible processes, not all of the heat energy can be converted to useful work. The theoretical amount of heat energy needed to evaporate the water divided by the total amount of heat energy input is a measure of the thermal efficiency of the heat drying system. Improving the thermal efficiency is sought because it reduces the heat energy needed to accomplish the same objective.

To lower fuel consumption, as much water as feasible is separated from the wastewater sludge prior to heat drying. Thus, the wastewater sludge may be mechanically filtered, or centrifuges, or pressed out, or squeezed out, or air dried (provided that the sludge is first digested) or any other dewatering method worth trying. These dewatering processes cost money, from about $5 to $35 per dry ton of sludge solids [11].

When wastewater sludge is heat dried to a high solids content, odorous chemicals are volatilized. In the interest of preserving the air quality or maintaining a good neighbor policy, the odorous chemicals must be removed before the gases are released from the heat drying system. Most heat drying systems simply burn (deodorize) these volatiles, which also unfortunately lowers the thermal efficiency of heat drying.

In Table 1 are shown the Btu's required to dry sludges in a flash dryer for various moisture to solid ratios [12]. The dried sludge contains about ten percent moisture. In this table, approximately 2260 Btu* is needed to vaporize one lb** of water. Of course, less fuel and lower costs would result when the thermal efficiency is increased. Several approaches are: (1) reduce the temperature of the stack gases by greater heat recovery; (2) use chemical scrubbers; or (3) add chemicals prior to heat drying. (Reference 5 can be referred to for information on material and energy balances for heat drying sludge treatment.)

Excessive drying may produce a sludge that is dusty or contains many fine particles, which is less acceptable for marketing. A pelletizing or granulation step may be necessary which adds another cost. To meet air quality standards dust or fine particles must be removed, usually by wet scrubbers, before the gases are released from the stacks. The scrubbing water is usually recycled to the treatment plant. As in many other wastewater treatment operations, standby heat drying equipment is desirable for continuous operations. About 25 percent excess capacity seems to be the right amount.

When one takes into account rising fuel costs, capital, maintenance, and labor costs, possible costs for pelletizing or granulating, it is understandable that heat drying of municipal wastewater sludge is about the most expensive of all conventional sludge processing techniques [13].

In Table 2 are shown cost estimates for sludge disposal [11,14] based on 1973 dollars. These cost estimates will vary at different locations. The estimates include preparation costs such as digestion and dewatering, except for composting. Recent composting studies show promise for processing unstabilized sludge. Land costs are not included because they can vary widely. Operating and maintenance cost may account for about two-thirds of the total cost of heat drying [13]. Also, these cost figures *do not* include any credit for sale of products or by-products.

Marketing Heat Dried Sludge

The gold that glitters at the end of the rainbow, left out of the heat drying costs shown in Table 2, is credit for sale of heat dried sludge used as organic soil conditioner, or fertilizer, or for formulation in specialty products. Sale revenues rarely equal the cost for producing the heat dried sludge. However, marketing the product does reduce costs. Sludge contains concentrations of major plant nutrients: nitrogen, phosphorus and potassium that approximate one fifth of those found in chemical fertilizers [15]. Sludge also contains organic matter (humus) that improves the physical properties of the soil. Heat dried sludge for agriculture and horticulture is used mostly for its organic slow release nitrogen and other organic matter. Waste activated sludge is preferred for heat drying because it contains higher concentrations of these nutrients as compared to primary or digested sludges.

Heat drying destroys most of the bacteria in the sludge. However, undigested heat dried sludge is susceptible to putrification if it is allowed to get wet in thick layers on the ground. Heat drying separates most of the water from the sludge solids, but one would not anticipate any significant decrease in the concentration of heavy metals of concern with land application on agricultural soils. Experimental studies, however, are needed to determine whether there is a change in the availability to crops of heavy metals.

In Table 3 are shown the mineral nutrient percents of dried sludge. Chemical fertilizers generally contain much higher nutrient concentrations. It takes about five times as much heat dried sludge as chemical fertilizers to obtain similar responses to nutrients. Therefore,

*To convert Btu to kilocalories, multiply by 0.252
**To convert pounds to kilograms, multiply by 0.454

TABLE 1
Energy Required for Heat Drying Wastewater Sludge

Sludge Moisture/Solids Ratio	Lbs. Water per Ton Dry Solids	Approximate Btu x 10^6 Required for Heat Drying / ton Dry Solids
95/5	38,000	85.3
90/10	18,000	40.1
85/15	11,333	25.1
80/20	8,000	17.6
75/25	6,000	13.0
70/30	4,667	10.0
65/35	3,714	7.9
60/40	3,000	6.3

(1) After Olexsey, Reference 12.
(2) Thermal efficiency, 62 percent.
(3) Stack temperature, 800 F (427 C).
(4) To convert from Btu's to kJ (kilojoules), multiply by 1.054.
(5) To convert from gallons to liters, multiply by 3.785.
(6) To convert Btu/ton (English) to kilocalories/ton (metric) multiply by 0.278.
(7) 10 percent moisture in the heat dried sludge.

about five times as much sludge as chemical fertilizers must be shipped, stored, and spread. This difference gives a decided cost advantage to commercial fertilizers for farming. Consequently, farm use of heat dried sludge has simply not developed to the potential hoped for. Also, selling fertilizer is essentially a seasonal activity with highest sales in the fall and spring months. Storage of about 20 to 25 percent of the heat dried sludge may be needed for off-season demand. This storage adds another cost factor.

Houston, Chicago, Milwaukee, and Winston-Salem are notable exceptions to the adverse marketing trend. Treatment plants in Houston, Chicago, and Milwaukee use waste activated sludge dewatered by vaccuum filtration prior to heat drying. Digested, air-dried sludge is used in the Winston-Salem heat drying facility, and nitrogen compounds are added prior to heat drying.

TABLE 2
Approximate Total Costs for Sludge Disposal

Method	Total Costs ($ / Dry Ton)
Disposal as liquid soil conditioner (or fertilizer)	20
Dewatered sludge as soil conditioner (or fertilizer)	32
Lagooning	15
Landfilling dewatered sludge	32
Barging to sea	15
Pipeline to sea	14
Incineration	32
Composting	30
Heat drying	64

(1) After Olexsey, Reference 11, Page 139 and 140, except see (3).
(2) Based on 1973 dollars, reference 12, except see (3).
(3) Composting cost from reference 14. Cost does not include digestion and dewatering of the sludge.
(4) Cost figures do not include any credit for sale of products or by-products.
(5) Land costs not included.

TABLE 3
Mineral Nutrients Percent of Heat Dried Waste Activated Sludge

NUTRIENT	PERCENT CONCENTRATION	
Total N	3.5	6.4
Organic N	2.0	4.5
P	0.8	3.9
P_2O_5	1.8	8.7
K	0.2	0.7
K_2O	0.24	0.84

(1) After Dean et al, Reference 15.

Houston's dried activated sludge is sold in bulk, via a five year competitive bidding contract, through a broker under the copyrighted trade market name of Hou-Actinite [16]. The total heat drying capacity is utilized, and all of the dried sludge produced is sold. Revenue received is about $21/ton* of sludge solids (1972—FOB-Houston). The cost for heat drying sludge at Houston was not available. However, when the $21 revenue is subtracted from the $64 cost for heat drying (Table 2), the net cost approaches some of the sludge disposal methods shown in Table 2.

The City of Milwaukee sells heat dried sludge through a franchise and also directly to the public in 50 pound bags, under the copyrighted trade market name of Milorganite (Milwaukee-organic-nitrogen) [7]. The total heat drying capacity is utilized. There is no difficulty in selling Milorganite for turfgrass, lawns, golf courses, and to industrial and farm users. Despite a higher unit price for its nitrogen content, Milorganite sells well even at premium prices. Present cost for producing Milorganite is about $90/dry ton and revenue is about $54/dry ton [17]. The net cost is $36 which is less than other sludge disposal alternatives for Milwaukee and also approaches some of the sludge disposal costs shown in Table 2.

The City of Chicago sells heat dried sludge through a broker via competitive bidding. Published figures [18] in 1968 indicate a revenue of $15/ton of sludge solids (FOB-Chicago) and a cost of $60 to produce the heat dried sludge with a net cost of $45/ton. The current revenue from sales of the heat dried sludge is about $17/ton of sludge solids [19] which is only slightly higher than the $15/ton of sludge solids received in 1968. Current cost for producing the heat dried sludge is about $106/ton [20]. Clearly, the net cost has increased. The current output from the Chicago heat drying units is about 165 dry tons/day at 96 percent solids [19]. This amount may be about one half of the rated heat dried sludge production capacity.

The Organiform SS heat dried sludge produced at Winston-Salem differs in that methylolurea and dimethylolurea groups, previously formed by the chemical reaction of urea and formaldehyde, are mixed with digested air-dried sludge from the treatment plant. The nitrogen content of the Organiform SS ranges between 15 and 20 percent by weight. This nitrogen content is three to four times greater than that produced from waste activated sludge only. No difficulty is expected in selling the 10,000 ton/year production capacity. The Organiform SS, because of its higher nitrogen content, may find good entry into the lucrative consumer/retail market.

Thus far, the general tone on heat drying sludge has been somewhat negative. It is time for a look at the "Now and Tomorrow" for the heat drying approach to sludge disposal.

*Ton multiplied by 0.908 = metric ton.

Advantages to Heat Drying Municipal Sludge

The advantages to heat drying municipal sludge are:

1. Undigested sludge can be processed to produce a useful product for agriculture and horticulture. This utilization represents conservation of a natural resource by returning organics and nutrients to the land.
2. Using heat dried sludge for agriculture and horticulture represents a way for ultimate sludge disposal.
3. Processing undigested sludge eliminates digesters which can be troublesome to operate and costly.
4. Heat drying destroys most of the bacteria without lowering the quality or diluting the sludge. The heat dried sludge is readily acceptable from a hygienic viewpoint for land application.
5. The treatment can handle sludges with different moisture contents. However, in the interest of conserving fuel prior dewatering is desirable.
6. The heat drying treatment is positive and consistent, unlike biological sludge digestion which can give below par performance for an extended time.
7. Heat drying units can be operated over a considerable range of fluctuating loadings.
8. Waste heat (e.g., from an incinerator or gas turbines, methane gas from digesters, etc.) can be utilized in the heat drying operation thus reducing, or eliminating, need for auxiliary fuel.
9. The process can be operated on an intermittent basis subject to plant requirements, and standby fuel is not required.
10. Reducing the water content of sludge by heat drying facilitates its transportation and utilization. A wide range of shipping possibilities exists, from barge or rail for bulk amounts down to 5 to 50 pound bags.
11. Heat drying greatly reduces the volume of sludge, permitting a wide range of disposal possibilities (see No. 10 above).
12. Heat drying of sludge reduces odor levels thus permitting storage.

There are other advantages but the twelve cited above are sufficient for our purposes. The heat drying process permits sludge utilization with a wide range of flexibility. What this treatment approach needs most is to sell these advantages to the buying public that is ever becoming more aware of the need to conserve resources.

Processes for Heat Drying Sludges

Theoretically any type of heat drying process is applicable for sludge. In the United States the following types of heat drying units are used, have been used, or are being developed:

- flash dryer
- rotary dryer
- toroidal dryer

- multiple hearth dryer
- atomizing spray dryer

These dryers belong to a class designated as direct heat dryers. Heat transfer is by direct contact of the sludge with preheated gases, and control is achieved by measuring and adjusting the temperature of the heated gases [2]. Costs for direct heat dryers are usually less than for most other types. Organic fouling and inorganic scaling from sludge preclude the use of indirect drying systems. Direct heat dryers can be more easily protected from corrosion.

There are some disadvantages to direct heat dryers. They tend to be thermally inefficient due to the sensible heat loss in the stack gases. Heat losses can be minimized by heat reuse, or keeping the material longer in the dryer, thereby reducing stack temperature. Dust can be cut down by reducing the air velocity or by predrying or pre-forming the sludge into less dust-forming particles.

Figure 1 is a schematic of a flash dryer/incinerator system [11]. Figure 2 is a pictorial flow diagram of the C.E. Raymond Flash Drying System used at Houston [3]. Chicago uses a somewhat similar heat drying system [21]. Both cities feed vacuum filtered, waste activated sludge to the heat dryer.

Flash drying is the instantaneous vaporization of moisture from solids by introducing them into a hot gas stream. The flash dryer system is based on several distinct cycles which can be adjusted for different drying arrangements. The first stage is blending wet filter cake with some previously dried sludge in a mixer to improve pneumatic conveyance. The blended sludge and hot gases from the furnace at about 1200°F to 1400°F (650 to 760°C) are mixed ahead of the cage mill, and flashing of the water vapor begins. The cage mill mechanically agitates the mixture of sludge and gas, thereby providing maximum sludge surfaces for exposure to the hot gases. The residence time in the cage mill is a matter of seconds. Drying is virtually completed by the time the sludge leaves the cage mill. The dry sludge (eight to ten percent moisture) is separated from the spent drying gases in a cyclone. Part of the dried sludge is recycled with incoming wet sludge cake, another part of the dried sludge is screened and sent to fertilizer storage, and what is left can be incinerated in the furnace. From the cyclone, the heat dried sludge solids temperature is around 160°F (71°C) and the exhaust gases temperature is about 220°F to 300°F (104° to 149°C).

The exhaust gases from the cyclone have to be deodorized before release to the atmosphere. The gases are recycled to a deodorizer preheater followed by burning in a furnace or afterburner at temperatures between 1200°to 1400°F (650° to 760°C). The hot deodorized gases are vented at between 600° and 800°F (315° to 427°C) depending on the extent of heat recovery. The lower the stack gas temperature the greater is the thermal efficiency; but a trade-off is made on the capital cost of heat recovery equipment. Unfortunately, the heat remaining in the stack gases is too low for use in a gas turbine, but the hot gases could have other plant uses such as heating buildings. Dust particles in the gases are removed by wet scrubbing or in a dry centrifuge before release to the atmosphere.

Primary combustion air is preheated with the latent heat from spent deodorized gases and introduced a high velocity to promote complete combustion in the incinerator (furnace). In the furnace the fuel used may be gas, oil, coal, previously dried wastewater sludge or waste heat from a solid waste incinerator, gas turbine, etc. Ash is periodically removed from the bottom of the furnace.

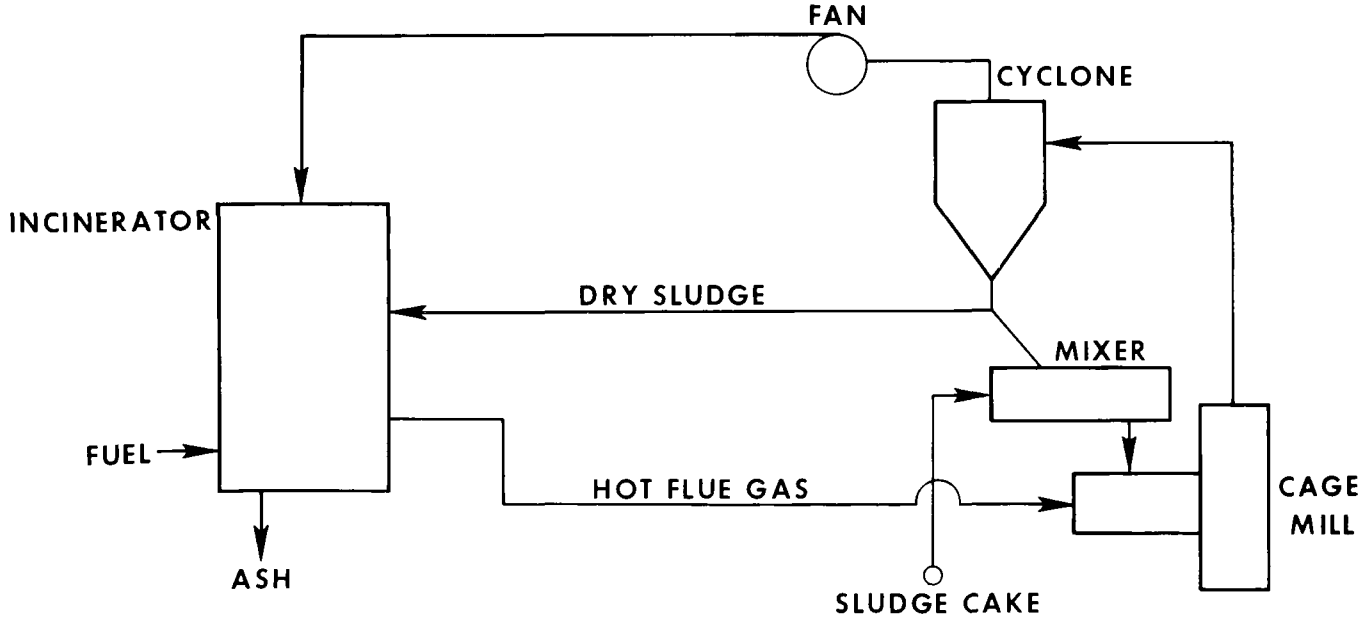

Figure 1: Flash-Dryer-Incinerator (*After Olexsey, Reference 11*).

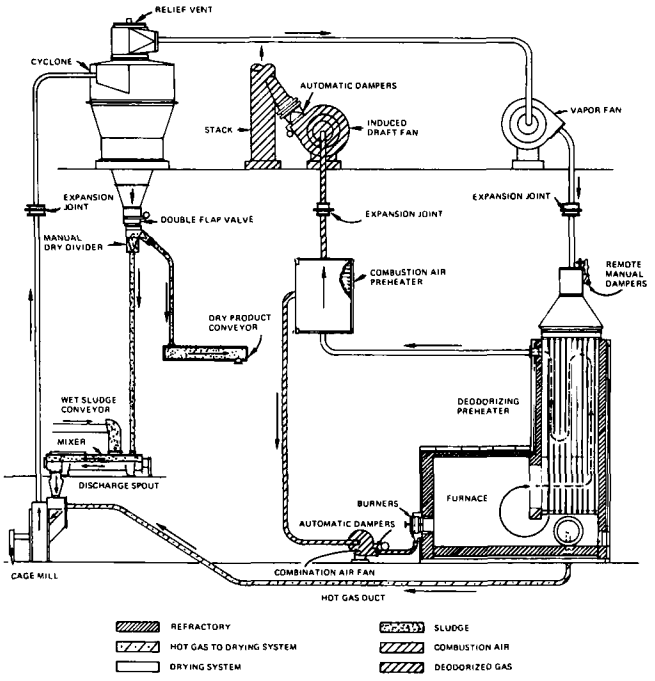

Figure 2: Flash Dryer System (*Reference 3*).

Milwaukee and Winston-Salem use rotary dryers. A rotary dryer consists of a nearly horizontal cylinder through which hot gases flow. The cylinder revolves about five to eight rpm and is usually slightly inclined from the horizontal so that the sludge can be made to flow by gravity [13,22]. To break up the sludge, the inside of the heat dryer cylinder usually is equipped with flights or baffles throughout its length. The direct gas rotary drier may be operated with gas flow parallel to or countercurrent to the sludge flow. Wet filter cake is mixed with previously heat dried sludge in a pug mill for easier conveyance into the dryer. The system may include cyclones for sludge and gas separation, dust collection scrubbers, and a gas incinerating step. The finished product is screened and sent to fertilizer storage. The oversize particles may be crushed and passed through the screen again or recycled to the dryer. Undersize sludge may be pelletized or recycled to the dryer.

The sludge residence time in a rotary dryer is usually longer (e.g., 45 minutes at Milwaukee) than in a flash dryer. Consequently, larger capital equipment is needed. This can be offset because the longer residence time provides an opportunity for deodorization in the dryer, and a separate deodorizing step may not be needed. At Milwaukee, exhaust gases at 900°F (480°C) from gas turbines are supplemented with additional heat from natural gas to raise the temperature to about 1200° to 1250°F (630° to 675°C) [17]. The hot gases enter along the length of the dryer in counter-current flow to the sludge flow. A wet scrubber is used to remove fines from the spent gases.

A block diagram of the Organiform SS process at Winston-Salem is shown in Figure 3 [8]. Urea and formaldehyde, in a 1.5 to 1 mole ratio, are heated to between 86° and 140°F (30° and 60°C) in the reactor. Methylolureas and dimethyl urea groups are produced. The reactor contents are sprayed into the sludge in a paddle mixer. Bacteria cell walls are lysed and sterilization and deodorization occur. The paddle mix is dehydrated in a rotary dryer using co-current, air-sludge flow. The supplemental heat needed is about 950 Btu/lb of water evaporated [23]. Part of the heat was originally furnished by the urea-formaldehyde reaction and reactions with the sludge in the paddle mixer. The Organiform SS is odorless, has a granular consistency, and a nitrogen content between 15 and 20 percent by weight.

Figure 4 is a schematic of the Toroidal Process [3,9] being evaluated at the Washington, D.C., Blue Plains plant. The capacity is about 40 to 54 tons dry sludge daily. The Toroidal dryer uses the jet mill principle, has no moving parts, and dries and classifies solids simultaneously. The dryer may be likened to a 42 inch (1.07 meters) pipe bent into a 16 foot (4.88 meters) diameter doughnut with provisions for inlet of hot air and outlet of moist air plus dried product [24,25]. Dewatered mixed sludge is metered and pumped into a mixer where it is blended with previously dried sludge. The blended material is fed to the doughnut shaped dryer where it comes into contact with heated air at a temperature of 800°F to 1100°F (about 430° to 600°C). At the outlet, those particles which are dry and finely divided follow the air stream out of the unit. The wetter larger particles are retained for additional circuits around the doughnut until drying is complete and they have broken up into fine particles by impacting on one another. About 1180 Btu is used to vaporize one pound of water. The outlet air stream temperature, containing the dry sludge, is about

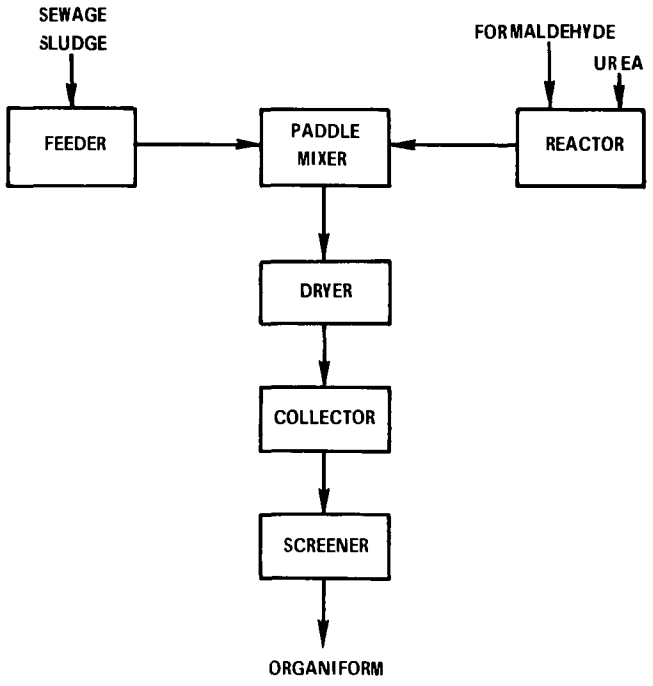

Figure 3: Block Diagram of the Organiform Process (*After Yamamoto, et. al., Reference 8*).

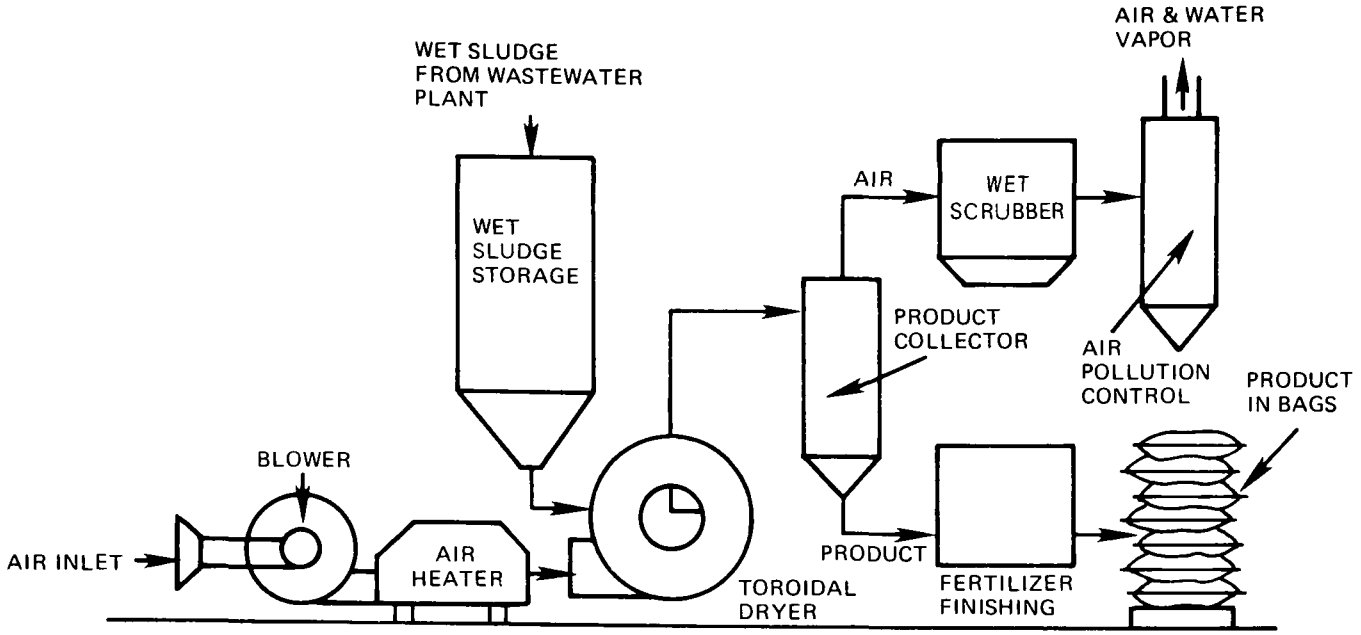

Figure 4: Sludge Drying System Using the Jet Mill Principle - Toroidal Dryer.

200° to 220°F (82°C to 105°C). Cyclone separators remove most of the dried powdered sludge. In a revised system the air stream will pass through a wet scrubber to remove fines. If needed, chemical scrubbers can be utilized for odor removal before the gases are discharged. The dried powdered sludge, after additional nitrogen and phosphorus are added, is formed into briquettes. These briquettes are crushed and screened to produce either bulk or bagged OrganaGro™ (trade market name).

The multiple hearth furnace can be adapted for heat drying [13]. Modifications include fuel burners at the top and bottom hearths plus down draft of the gases. The dewatered sludge cake is mixed in a pug mill with previously dried sludges before entering the dryer. The solids become drier and the gases become cooler as both move downward through the furnace. At the point of exit from the furnace, the solids temperature is about 100°F (38°C) and the gas temperature is about 325°F (160°C).

Atomized drying is spraying liquid sludge in a vertical tower through which hot gases pass downward. Dust carried with hot gases is removed by a wet scrubber or dry dust collector. Another spray dryer system [26] utilizes a high-speed centrifugal bowl. The centrifugal forces atomize the liquid sludge into fine particles and sprays them into the top of the drying chamber where moisture is transferred to hot gases. Nozzles can be used instead of the centrifuge bowl if clogging can be avoided.

Comparison of Fuel Consumption Commercial Fertilizer Versus Heat Dried Sludge

In these days of energy crisis, the amount of fuel required to run a process or produce a product is an important consideration. It is informative to compare the consumption of fuel to produce commercial fertilizer with the fuel needed to produce heat dried sludge. One basis is to compare the two types of material at equivalent nitrogen (N) content.

Two reports [27,28] suggest that about 45 X 10^6/Btu (from natural gas) is needed to produce one ton of N for commercial fertilizers. Another reference [29] indicates that 915 gallons of crude oil are required to produce one ton of N. Because one gallon of crude oil has the equivalent of approximately 146,000 Btu's [30], 915 gallons is about 134 X 10^6 Btu/ton of N. Obviously there is about a 2.7-fold difference, but for comparison with the heat energy required to dry sludge, both energy values will be used.

The N content in waste activated sludge is about 5.7 percent [13], or 114 pounds in one ton of heat dried sludge. About 17.6 tons of heat dried sludge are needed for one ton of N. Referring to Table 1, note the 60/40 moisture/solids ratio which is achievable with a filter press. This sludge cake requires 6.3 X 10^6 Btu/ton of sludge times 17.6 which is 111 X 10^6 Btu/ton N from heat dried sludge. If the 80/20 ratio sludge cake is used, as produced from vacuum filtration or centrifugation, the Btu's needed are about 310 X 10^6 Btu/ton N. The above comparison from Table 1 data implies that 2260 Btu is needed for one pound of water vaporized. However, recent advances in heat drying technology for wastewater sludges suggest that only about 1200 Btu is needed. Using the 1200 Btu figure suggests that for the 60/40 moisture to solid ratio, about 61 X 10^6 Btu is needed for each ton of N produced from heat drying of sludge.

The comparison of the energy requirements for nitrogen from fertilizer or sludge, which is summarized in Table 4, show that the heat energy for equivalent amounts of N from the heat dried sludge at the 60/40

moisture to solids ratio is comparable to the energy requirements for producing N in commercial fertilizers. More heat is needed for the N produced from the 80/20 ratio. If high efficiency is achieved in the sludge dryers and the source of the ammonia in the inorganic fertilizer is crude oil, the commercial inorganic fertilizers and dried sludge are essentially equivalent in fuel consumption per ton of nitrogen.

Production of Heat Dried Sludge for Sale

The approximate yearly production of heat dried sludge sold by wastewater treatment plants is shown in Table 5. Small amounts may be produced by other plants but their contribution appears to be negligible.

In Table 6 are shown the trends in production of municipal wastewater sludge [31]. In 1972, approximately 4.8 X 10^6 dry tons/year sludge was produced. Heat dried sludge represents about 3.3 percent of the total sludge produced.

In Table 7 are shown the trends in disposal of municipal wastewater sludge [31]. Of interest is that about 20 percent (1 x 10^6 dry tons/year) of the sludge is utilized on land. Thus heat dried sludge represents about 16 percent of the total amount of sludge utilized, either directly or in fertilizer mixes on land.

An interesting comparison is the amount of nutrients, specifically nitrogen, available in sludge versus the amount of nitrogen utilized in commercial fertilizers. In 1971, about 10 X 10^6 tons of nitrogen was utilized for fertilizers [32]. In Table 6, sludge production per year (excluding chemical sludge) totals 4.7 X 10^6 tons. Assuming five percent nitrogen content, the total nitrogen is 235,000 tons or about 2.4 percent of the nitrogen used for fertilizers. If all of the sludge generated were used for agricultural purposes, it would make up only a minor portion of the nitrogen used.

SUMMARY "NOW AND TOMORROW"

This presentation has discussed current aspects of heat drying: advantages and disadvantages, processes for producing heat dried sludge, energy relationships,

TABLE 4
Comparison of Energy Needed for Nitrogen Production for Fertilizer

Fertilizer Source	Millions of Btu's/Ton Nitrogen
Commercial fertilizer	50 and 134 (1)
Heat dried sludge (60/40 moisture/solids ratio)	110 (2)
Heat dried sludge (60/40 moisture/solids ratio)	61 (3)
Heat dried sludge (80/20 moisture/solids ratio)	310 (2)
Heat dried sludge (80/20 moisture/solids ratio)	172 (3)

(1) From three different references
(2) 2260 Btu/lb of water evaporated
(3) 1200 Btu/lb of water evaporated

TABLE 5
Production of Heat Dried Sludge for Sales

Location	Approximate average daily production (ton/day)	Approximate quantity sold ton / year
Chicago	165	61,000
Houston	60 (1)	22,000 (1)
Milwaukee	185	67,000
Winston-Salem	27	10,000
Total	437	160,000

(1) Houston's facility is undergoing upgrading of heat drying equipment. Additional heat dryers are also heing added. In 1976, production is expected to increase to about 140 tons/day, 50,000 tons/year.

TABLE 6
Trends in Production of Municipal Wastewater Sludge*

Sludge Type	1972 Population served (millions)	1972 Dry tons per year** X 10^6	1985 Population served (millions)	1985 Dry tons per year X 10^6
Primary (0.12 lb/cap-da)***	145	3.2	170	3.7
Secondary (0.08 lb/cap-da)	101	1.5	170	2.5
Chemical (0.05 lb/cap-da)	10	0.1	50	0.5
Totals		4.8		6.7

* Data taken from a report by Farrell Ref. 31
** ton X 0.908 = metric ton
*** lb X 0.454 kg

TABLE 7
Trends in Disposal of Municipal Wastewater Sludge*

Disposal Methods	1972 Percent	1985 Percent
Landfill	40	40
Utilized on Land	20	25
Incineration	25	35
Ocean (dumping and outfalls)	15	0

* Data taken from a report by Farrell Ref. 31

production for sales and an overview of the process. While heat drying of sludge is expensive, it can be a useful and relatively cheaper alternative to sludge disposal for many municipalities if the final product can be successfully marketed. When one reviews the trends in production of municipal wastewater sludge shown in Table 6, it is noted that over one-third of the sludge to be produced in 1985 will be waste activated sludge. This is precisely the sludge that has been successfully marketed.

Inorganic commercial fertilizers are preferred by farmers because of their higher nutrient content, lower bulk and lower costs. Heat dried sludge sales are directed toward four other major markets: (1) industrial fertilizers compounders; (2) citrus growers; (3) nursery/ horticulture/turf grass markets; and (4) the lucrative consumer/retail market. Thus, rather than competition, it might be better to consider the heat dried sludge as a complement to commercial fertilizers. Heat dried sludge offers the slow-release organic nitrogen, other organics that improve the physical structure of soils, and the availability of trace elements such as zinc (known to be deficient when solely using commercial synthetic fertilizers).

Wastewater treatment authorities are faced with the primary task of treating and disposing of sludge in the most economical manner that least affects the environment. Marketing imposes on municipalities a set of tasks they may find difficult to accomplish because of problems of personnel training, of laws and regulations, and even political restrictions. Therefore, marketing heat dried sludge may best be done by a commercial firm with the skills to handle the marketing and servicing aspects.

The key to heat drying of sludge is the market place, and more information is needed on the acceptability of the product to a public that is becoming increasingly aware of the need to conserve resources. An added incentive to using heat dried sludge is the rapid increase in commercial fertilizer cost. In 1973, the average cost was about $75/ton and by the fall of 1974 it had risen to $140/ton [28]. In today's market the cost of nitrogen per pound from anhydrous ammonia is 11.3 cents, from urea 19.6 cents, and from ammonia nitrate 19.8 cents [33]. Assuming 114 pounds of N from one ton (5.7 percent nitrogen) heat dried sludge, the value of the N is from $13 to $22.50. When value for phosphorus, organics, and minor nutrients also are included, the potential market value for heat dried sludge is even more substantial. Because heat dried sludge is used on turfgrass, citrus crops, tobacco, home gardens and lawns, there is a substantial potential demand. Heat dried sludge may be much too valuable to either burn or bury.

A most lucrative potential market is at the consumer/ retail level. Consideration has to be given to selling small units, e.g., 40 to 50 pound bags. These small units require warehousing, and distribution at the retail point of sale. Distribution, packaging, label definition, brand names, registration, product uniformity, shelf life stability and safety are a few of the considerations a producer must develop for the sludge commodity to reach this premium market. In the Eastern United States, a 40 to 50 pound bag of organic plant nutrients is retailing at $6.50 to $7.00 per bag, or about $260 per ton [34].

The consumer market is a full time effort requiring daily participation. Price fluctuations in the consumer market can vary widely and steeply (Milorganite is an example of franchise and direct marketing). Other municipalities may find it more suitable to establish an outside mechanism to develop and maintain this market potential. It will be most interesting to follow the marketing trends of such products as OrganaGro™ and Organiform SS which are produced from heat dried sludge by commercial firms.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of the following people: R.D. Nickerson and G.C. Simons at the C.E. Raymond/Bartlett-Snow Company; D. Wunderlich, R.R. Rimkus, A. Michuda and D. Zenn at the Metropolitan Sanitary District of Greater Chicago; T. Wolf at the Metropolitan Sewage Commission of the County of Milwaukee; M.T. Garrett at the City of Houston; J.M. O'Donnell at Orgonics, Inc., Slatersville, Rhode Island; W.B. Tarpley at the Organics Recycling Inc., Westchester, Pennsylvania; D.A. Mays, TVA, Muscle Shoals, Alabama; and R.J. Burns, Black, Crow and Eidsness, Inc., Gainesville, Florida.

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COMPOSTING RAW SLUDGE

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INTRODUCTION

Disposal of sewage sludge is a major problem in wastewater treatment. Incineration, ocean dumping, and several land application systems also can present environmental, sociological, and economic difficulties. The environmental problems are primarily associated with air, land and water pollution by inorganic elements and pathogens. Sociological concerns are generally about aesthetics and odors. Transportation of sludge to disposal sites and cost of fossil fuels have resulted in large increases in sludge disposal costs.

In 1972, the Agricultural Research Service, U.S. Department of Agriculture, began investigating the composting of sewage sludge as an alternative to other disposal methods.

Composting is a biological process by which organic matter is decomposed into a relatively stable material. Composted sewage sludge has no objectionable odors. Temperatures generated during composting will greatly reduce or eliminate pathogenic organisms. If composting is done at the wastewater treatment plant, sludge transportation costs are greatly reduced. The final product is aesthetic, dry and easy to handle for use in urban areas or on agricultural land. Although the product contains desirable plant nutrients, it can also contain toxic elements [1,7]. Compost is an excellent soil amendment that enhances the rooting media for plant growth by reducing potential compaction, increasing soil water retention and availability to plants, and providing for better soil water movement and aeration [2,5,6].

The initial studies by the U.S. Department of Agriculture at Beltsville, Maryland, were directed to composting digested sewage sludge in windrows [3,8]. The sludge was obtained from the Blue Plains Wastewater Treatment Plant in the District of Columbia. At present, ten dry metric tons of digested sludge (50 tons, 23 percent filter cake) are being composted daily.

In the fall of 1973, studies were begun on composting raw (primary and secondary activated) dewatered (23 percent filter cake) sludge in the windrows. This procedure was unsatisfactory because obnoxious odors were produced. Several odor-masking or odor-reducing chemicals such as hydrogen peroxide, chlorine dioxide, and gypsum, were tried by either mixing them with the sludge at the treatment plant or applying them during composting. Although odors sometimes were reduced initially, they became strong enough later in the composting process to negate this approach. One of the most effective methods of reducing odors from raw sludge in the windrow was by mixing digested with raw sludge. Even with mixtures of 75 percent raw and 25 percent digested sludge, the odor level was reduced markedly. Since windrow composting of raw sludge proved unsatisfactory, a forced aeration method was developed.

Description of Method

Design of System

The forced aeration system [4] consists of building a pile of raw sludge mixed with woodchips or shredded bark to provide bulk, and using a vacuum to draw air through the pile. Finely screened compost from previous operations is used to cover the pile to prevent odoriferous gases from escaping into the atmosphere (Figure 1). The gases removed from the pile are scrubbed by passing them through another pile of screened compost.

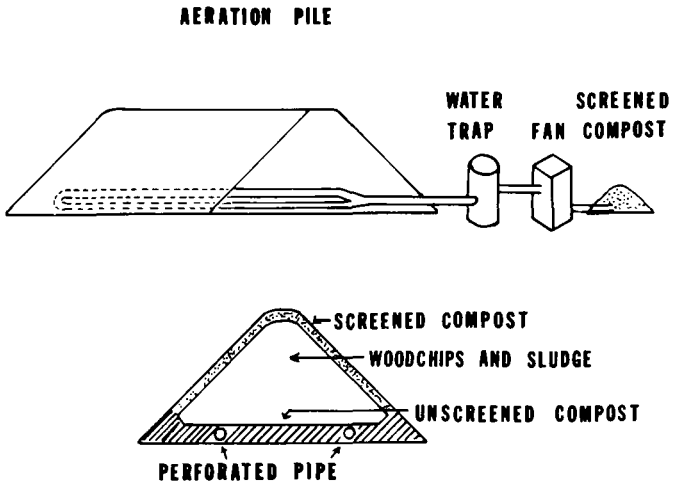

Figure 1: Forced Aeration System.

Procedure

1. A flexible ten cm perforated drainage pipe is laid in a "U" shape on the ground.
2. The pipe is covered by 30 cm of unscreened compost or woodchips. This layer absorbs liquids seeping from the pile and prevents clogging of the pipe.
3. Filter cake raw sludge (23 percent solids) is mixed with woodchips at a ratio of 1:3 on a volume basis. This mixture is placed over the unscreened compost or woodchips covering the pipe. The sludge-woodchips mixture is built up to form a pile approximately six meters wide by 2.5 to three meters high. The length of pile depends on the rate of sludge production and the suction equipment used.
4. The entire pile is covered with a 30 cm layer of screened, cured compost that has passed a 1.0 cm screen. Until screened compost becomes available, woodchips or shredded bark can be used.
5. The perforated pipe is attached by a piece of solid pipe and connectors to a blower. Suction is applied for ten to 14 days; then the blower is reversed and air is conducted into the pile for seven to ten days. By reversing the air flow, temperatures are increased in the cold regions of the pile. Moreover, after the initial period of negative aeration, the concentration of odorous gases discharged from the pile is negligible and presents no problem.
6. The gases removed from the pile during suction are piped into an adjacent small pile of screened ($<$1.0 cm) compost that effectively absorbs the odors.
7. The gases removed during suction are warm and water will condense in the pipe outside the pile. The condensate can be drained and recycled into the sewage system, or a sand filter bed or other disposal system can be used.
8. After 21 days, the compost is moved to a stockpile for curing for about four weeks.
9. The cured compost is screened and the woodchips recovered for reuse.

Before screening, it may be necessary to dry the compost by spreading and periodically turning it with a spike-tooth harrow. Blowing air through the curing pile hastens curing and also produces a drier product.

Monitoring Requirements

Temperature. Temperatures below 45°C indicate improper composting and may be caused by either too low or too high aeration rates.

Oxygen. Oxygen values of gases exhausted and in the pile should range from five to 15 percent. Lower values indicate inadequate aeration and higher values indicate excessive aeration. Proper aeration can be maintained by using a timer to cycle the blower as needed.

Equipment

The following equipment is needed to process a pile containing ten dry metric tons (50 tons 23 percent filter cake):

1. 27 meters (90 ft) of ten cm perforated plastic drainage pipe—cost $24.00.
2. 12 m (40 ft) of ten cm solid plastic pipe—cost $11.00.
3. One 0.33 hp, 5.3 to 6.6 amp motor with blower - similar to Dayton Model 7C504C*—cost $73.37.
4. Two one cm plastic straight connectors—cost $0.70.
5. One ten cm plastic "T" connector—cost $2.65.
6. Timer similar to Dayton four hour cycle timer switch Model No. 2E 131—cost $16.87.

The following monitoring equipment is useful:

1. Temperature probe.
2. Oxygen probe.

A front-end loader is necessary for the construction of the pile. The front-end also can be used to mix the woodchips and sludge; however, better mixing is achieved by spreading the sludge over a bed of woodchips and using a rototiller.

Land Needs

Composting Area. A ten dry metric ton pile (50 ton 23 percent filter cake) is approximately six m wide, 12 m long and 2.5 m high. The composting area would occupy a 72 m square area (approximately 800 sq. ft.). This pile will handle one week's sludge production from a city of approximately 35,000 to 50,000 persons. Additional area is needed for maneuvering equipment and constructing other piles during the three week composting period.

Curing Area. Sufficient space is needed to stockpile the composted material for four weeks after composting. Several piles can be consolidated to save space.

Screening, Drying and Storage Area. An area must be provided to store the final product until distribution. Storage must also be provided for a supply of woodchips.

Administrative Area. Space is needed for an office and for equipment storage.

Miscellaneous. Some land is needed for roadways and parking. Also, a bufferstrip and runoff collection pond are needed if the compost site is not located at a wastewater treatment plant.

The estimated total land area required for composting ten dry metric tons of sludge per week at a wastewater treatment plant is 1.0 hectare (two acres).

Discussion of Method

Figure 2 shows the temperatures reached during composting raw sludge. Measurements were taken at ten locations throughout the pile. These data represent mean temperatures recorded in the center of the pile. Temperatures were lower at the pile edges. During the 26 days of composting, temperatures throughout the pile exceeded 50°C for 15 days. In the coldest locations, temperatures

*Mention of trade name, proprietry product or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may be suitable.

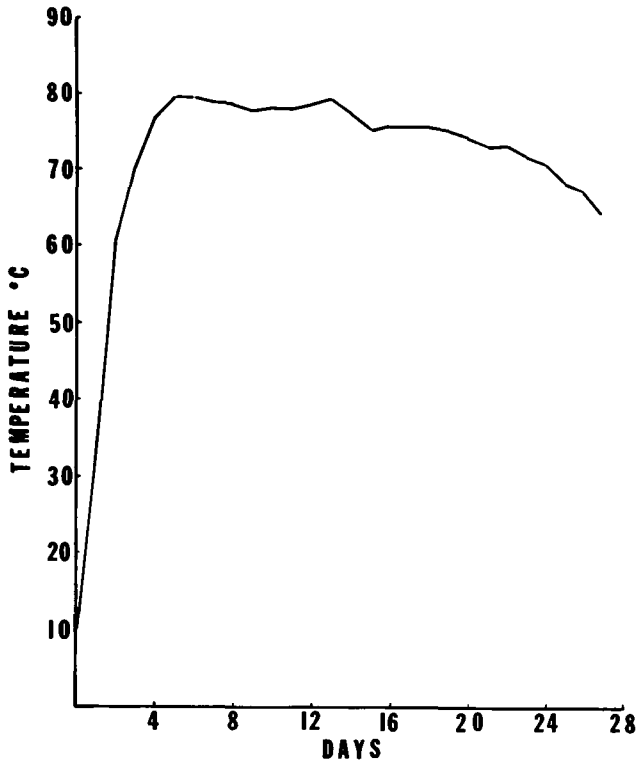

Figure 2: Temperatures Reached During Composting Raw Sludge.

exceeded 60°C for nine days. These temperatures can significantly reduce the pathogen population. Table 1 shows the survival of salmonellae and coliform after composting raw sludge. The number of salmonellae organisms after composting was negligible. Fecal coliform were reduced from 2.7×10^7 to an undetectable level. Further research is being conducted on the survival of these and other pathogens when different composting techniques are used.

Table 2 shows the major components and nutrients of the raw sludge and the compost. Nitrogen, phosphorus, and potassium are three major elements essential for plant growth. Total nitrogen of the composted material was 1.6 percent; phosphorus, 1.0 percent; and potassium, 0.16 percent. Only a small part of the nitrogen is immediately available for plant growth since it is mostly in the organic form. Thus, up to 30 dry metric tons can be applied without overfertilizing plants or releasing nitrate to the groundwater. The organic nitrogen is slowly mineralized so that it is continuously available to plants over several years.

Calcium and magnesium also are essential elements for plant growth. Heavy metals such as zinc, copper, nickel, cadmium, and lead can be toxic to plants and to humans consuming these plants if present in excessive amounts. The compost produced from sludge of the Blue Plains Wastewater Treatment Plant does not contain high levels of toxic elements. Studies at Beltsville, Maryland, showed that the use of this material at recommended rates did not increase the level of undesirable heavy metals in food crops. Considerably more research is being conducted on the use of this product and its effect on soil properties and plant composition.

TABLE 1
Salmonellae and Coliform Populations Before and After Composting Raw Sludge

	Sludge	Compost
	cells/g	
Salmonellae	87	<5
Fecal Coliform	2.7×10^7	<8
Total Coliform	4.4×10^8	<8

1/ Data provided by Dr. W. D. Burge, USDA, Beltsville, Md. 20705.

TABLE 2
Composition of Raw Sludge and Compost

Component	Raw Sludge	Compost
Organic Carbon, %	31	23
Water, %	78	35-58
Potassium, %	.19	.16
Phosphorus, %	1.46	1.0
Calcium, %	1.39	1.42
Magnesium, %	0.41	2.36*
Total Nitrogen, %	3.8	1.6
Ammonia, ppm	1540	235
Nitrate-Nitrite, ppm	1	3
Zinc, ppm	980	770
Copper, ppm	420	300
Nickel, ppm	87	300*
Cadmium, ppm	10	7.6
Lead, ppm	420	290

* Increase in magnesium and nickel due to the serpentine rock used in the compost pad.

CONCLUSIONS

The aerated pile method of composting shows promise for controlling the odors associated with windrow composting of raw sewage sludge. The blanket of screened compost ensures that all of the raw sludge reaches temperatures above the thermal death point of most pathogens. The process can be simply monitored by measuring temperature and oxygen. The method can be adapted readily by either small or large sewage treatment plants and requires only a modest investment in equipment.

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POTPOURRI

INTRODUCTION

In hopes of establishing more feedback and participation by Conference attendees, the agenda was designed with 1½ hours of reserved time set aside on the final day for spontaneous submissions from attendees, who, for any reason whatsoever, wished to contribute an oral mini-paper. An announcement was made at the beginning of the conference for submittal of 8 minute papers which would subsequently be presented and then published in the proceedings. The response was exuberant.

This session illustrated the need for public participation as witnessed by the number of attendees and the vibrant discussions which followed each paper. Had there been more time, this session could easily have continued throughout the day.

Ten papers were presented. The following six papers represent those which were submitted for publication. These compose the session entitled "Potpourri" which terminated the Conference, but opened "lines of communication".

SLUDGE MANAGEMENT AS VIEWED BY AN AGRICULTURAL ECONOMIST

Lee A. Christensen
United States Department of Agriculture
Broomall, Pennsylvania

I'm an agricultural economist with the Economic Research Service, USDA. By way of introduction, ERS is the largest group of agricultural economists in the world. Our tasks are varied, but in general it is to provide economic information to aid USDA in policy formulation and program implementation. You're more familiar with the research of ARS, a companion USDA agency that concentrates on the physical, biological, and engineering aspects of agriculture.

I've attended a number of conferences that have addressed primarily engineers and physical and biological scientists. I've often felt in the minority in terms of background, training, and approach to questions related to sludge management issues. Economists and other social scientists view some of the issues from a different perspective. I would like to share some personal observations with you this morning.

1. We need each other. The solution to wastewater management problems requires a multidisciplinary approach involving engineers, agricultural economists, agronomists, soil scientists, lawyers, and others. Good economic analysis requires valid data on physical and technical relationships and responses. Conversely, the implementation of engineering designs requires the expertise of economists, lawyers, and other social scientists.

2. This leads to a second observation. There are too little data from the multitude of operational systems for sludge management that lends itself to good comparisons. Communities have limited information available to compare costs of land application with incineration and other approaches, especially data generated from a comparable data base. Cost components need better identification so that component costs such as labor, capital, and energy can be readily identified. It seems to be that the sludge treatment cost model discussed in Mr. Smith's presentation is a step in this direction. I hope so, because communities are making major decisions in the allocation of their funds for sludge treatment and need good cost data.

3. I see a need for greater distinctions between waste management alternatives and community size. Land application may have greater potential for small and medium sized communities, which often have the most homogeneous waste product available, open space, and fewer resources to devote to community services. Discussions of treatment alternatives should be more specific in relation to community size.

4. Greater attention needs to be paid to the numerous options that exist for (1) the acquisition of rights to land and (2) the management of farming or treatment operations. Certain functions can best be carried out on lands owned by the wastewater authority, but present landowners can and have cooperated with public manage-

ment systems. Greater attention should be given to developing information systems that will provide farmers incentives to participate in a system, and which will also assure cities adequate management controls.

5. Planning for waste management need not be a single purpose activity. Waste management plans can be incorporated with plans to channel urban growth, to keep lands in open space, and coordinated with other community goals.

6. Related to a total community planning approach is a need to analyze possibilities for reducing the supply of materials entering the waste processing stream. Industry is moving in this direction with increased resource recover and water reuse. However, municipal wastewater management needs to investigate ways to reduce the volume of material entering the treatment system concurrently with treating what comes out of the end of the pipe.

7. Many of you are involved directly in determining the best ways of meeting the wastewater treatment goals specified in the laws. I would raise with you, however, the need to have more discussion of what a clean stream is worth, and in particular, the application of the standards identified in PL 92-500 to all streams. Wastewater treatment is only one of the many demands placed upon the resources of our nation and communities. Estimates prepared in conjunction with the work of the National Water Quality Commission indicate $100 to $300 billion dollars of expenditures over the next ten years. Some communities are faced with making wastewater treatment investments that exceed their entire tax base. Expenditures of this magnitude divert resources from other uses that may be of as great or greater priority, but which don't receive as much attention in public policy debate.

8. Keep in mind that relative prices can play a major role in resource allocation to meet waste management requirements. A price increase in an input, such as electricity, increases interest in processes using lower priced inputs. While it is important to be interested in saving energy in the sludge process, it is more important to provide a specified level of treatment at the lowest *total* cost to the community. Fuel savings are important only as they translate to total dollar savings and not in terms of savings of calories or BTU's. The higher price of natural gas has increased interest in sludge gas generation, just as higher fertilizer prices has increased interest in the value of sludge and effluent as fertilizers.

9. Finally, there is a need to be aware of and consider the impact of land treatment of sludges or wastewater on the agricultural economy, both directly and indirectly. Parties impacted include not only the farmers whose land is used, but also the suppliers of seed, fertilizer, and machinery and the channels for marketing the crops. Possible changes in ownership patterns and land values need evaluation, along with changes in farm and regional production.

COMBINED REFUSE/SLUDGE PYROLYSIS IN THE OAKLAND AREA

N. W. Snyder and B.I. Loran
The Ralph M. Parsons Company,
Pasadena, California

In California, incineration of refuse and sewage sludge is prohibited due to air pollution considerations. Pyrolysis provides a viable alternative because, as stated by Robert Olexsey, of EPA, this process is essentially pollution free.

The Pacific Gas & Electric Company, located in San Francisco, the East Bay Municipal Utility District (EBMUD), Oakland, and the Oakland Scavenger Company commissioned The Ralph M. Parsons Company in July, 1974 to verify the technical and economic feasibility of the Union Carbide "Purox" pyrolysis process and to prepare a preliminary engineering report.

The only data available at the time had been obtained from a Union Carbide pilot plant which could pyrolyze five tons per day of refuse or mixed refuse/municipal sludge. The Parsons Company had developed in the past commercial size plants based on pilot plant data. Additional data for the pyrolysis process became available when the S. Charleston, W. Va. 200 tons per day demonstration plant became operational.

The facility designed would be located in Oakland or San Leandro, California. Its capacity ranges from 1400 to 2100 tons of combined feed, comprising an average of 200 tons per day of digested sludge at 25 percent solids. This is the entire output of the EBMUD District 1 Water Pollution Control Plant; the dewatering is carried out by vacuum filtration. The plant will also receive 125 tons per day of shredded automobile wastes from the Oakland Scavenger Company. This material has a higher heat content, and will help offsetting the negative heat value of the digested sludge at 25 percent solids. Digested sludge is used because anaerobic digestors are already in operation at EMBUD; undigested primary or activated sludge would be otherwise preferable because of the higher energy content.

Figure 1 depicts schematically several aspects of the project. As shown, the main features of the study were (1) receiving, storage, and handling of the shredded municipal refuse, sewage sludge, and other waste; (2) conversion of the waste to a 300 Btu synthetic gas (syngas) using the Purox process; (3) utilization of the syngas in four of the most promising methods including methanation to 1000 Btu synthetic natural gas (SNG), methanol synthesis, distribution of syngas to interruptible customers, and direct production of power with a gas or steam turbine system.

The mixture of municipal refuse, sewage sludge, and shredded auto waste produces a feed which was estimated to have a HHV of 4850 Btu/lb to 5200 Btu/lb. The solid waste is furnished shredded from a separate refuse processing plant where materials such as iron are removed. The shredded refuse is delivered by conveyor or

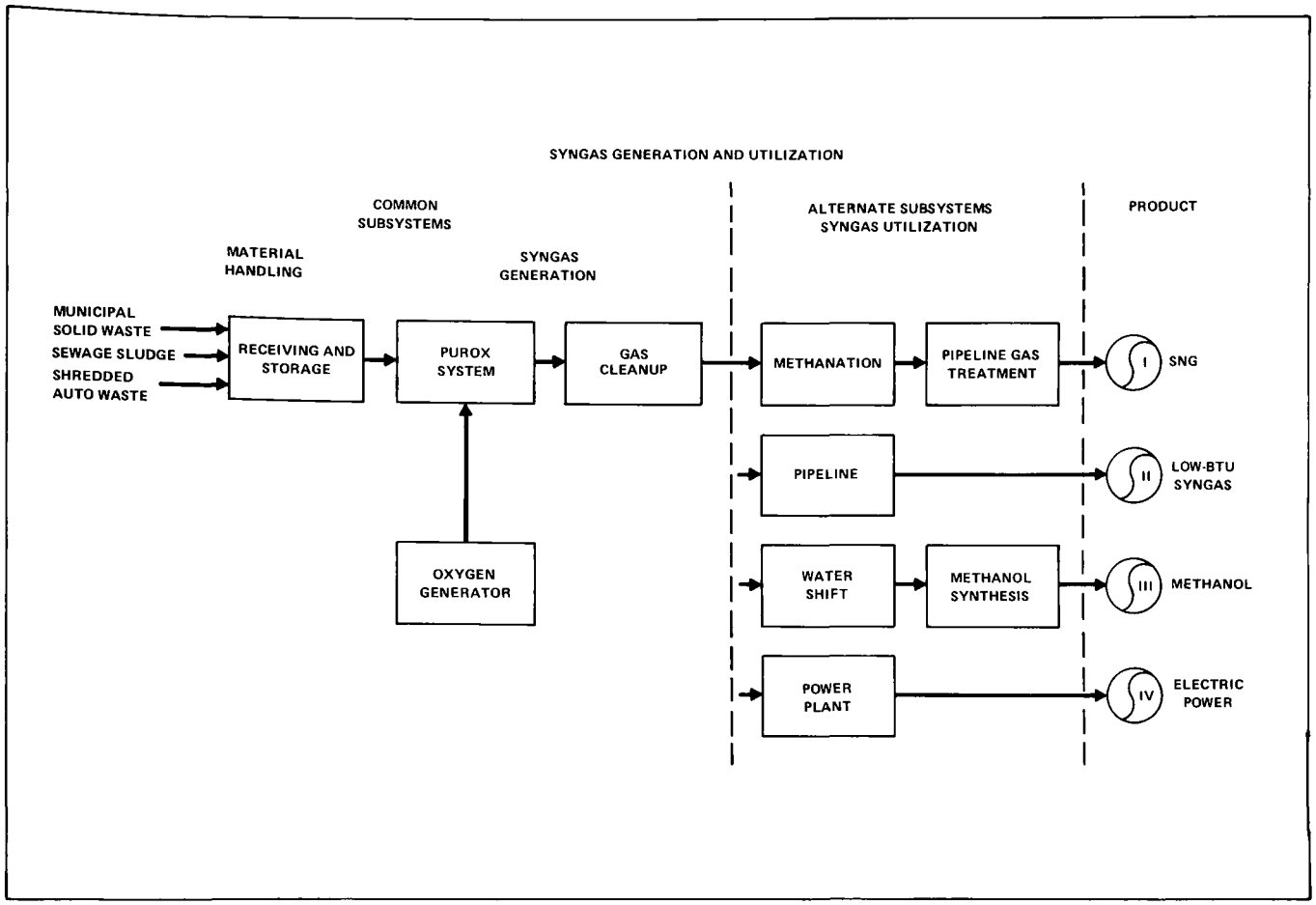

Figure 1: Block Diagram.

transfer truck depending on the location of the fuel conversion plant.

Two of the major problems encountered in pyrolytic processes are the disposition of the char generated in the process and of the large amount of ash. These problems have been overcome in the Purox process by burning the char completely with oxygen, producing the heat required for the pyrolysis process, and by carrying out the pyrolysis at bottom temperatures of 3000°F, sufficient to melt the ash into a low volume glassy frit which can be used for road building and other applications.

The partial oxidation pyrolysis process produces a gas comprised mainly of carbon monoxide and hydrogen with some carbon dioxide and methane. The reactor is a vertical shaft furnace with refuse entering the top and oxygen blown in at the bottom to burn the char. Molten slag leaves at the bottom and the syngas generated passes out at the top.

The waste materials enter at the top as a moist feed and slowly descend. A counterflow of hot gases, starting in the combustion zone at the bottom, dries the wastes which then decompose into synthetic gas, char, and organic liquids in the high temperature pyrolysis zone. Melting of inorganics and combustion of the char occurs in the hearth zone of the reactor producing an ascending gas mixture of CO and CO_2. Oil and tar droplets carried upward by the hot gases are mostly scrubbed out by the descending refuse and thus recycled for cracking to gases and char. Relatively pure O_2 is passed into the hearth to burn all the char.

The heat of combustion is sufficient to maintain a temperature of 3000°F in the hearth, to melt oxides and glasses as well as metals, and to provide the heat for pyrolysis reactions, heat-of-vaporization of water in the entering refuse, and heat losses from the vessel. The syngas produced is cooled to approximately 200°F in drying the refuse.

The product gas is passed through a wet electrostatic precipitator to remove fly ash, oil, and tar mist. Each ton of combined wastes produces approximately 24,000 scf of 300 Btu syngas.

An artist's rendition of the plant is shown in Figure 2. It is seen that a fairly complex facility is required. Plant capital costs for a 1750 tons per day facility are estimated at $38 million for low-Btu syngas production, $42 million if upgrading to 1000 Btu SNG is included, $44 million for production of methanol, and $50 million for generation of electric power (1974 $). Amortization costs range at three to four million dollars per year, with operating costs expected to reach a similar amount. The SNG option would produce ten million scf per day of pipeline-quality gas; at present prices of $1/1000 scf, the product

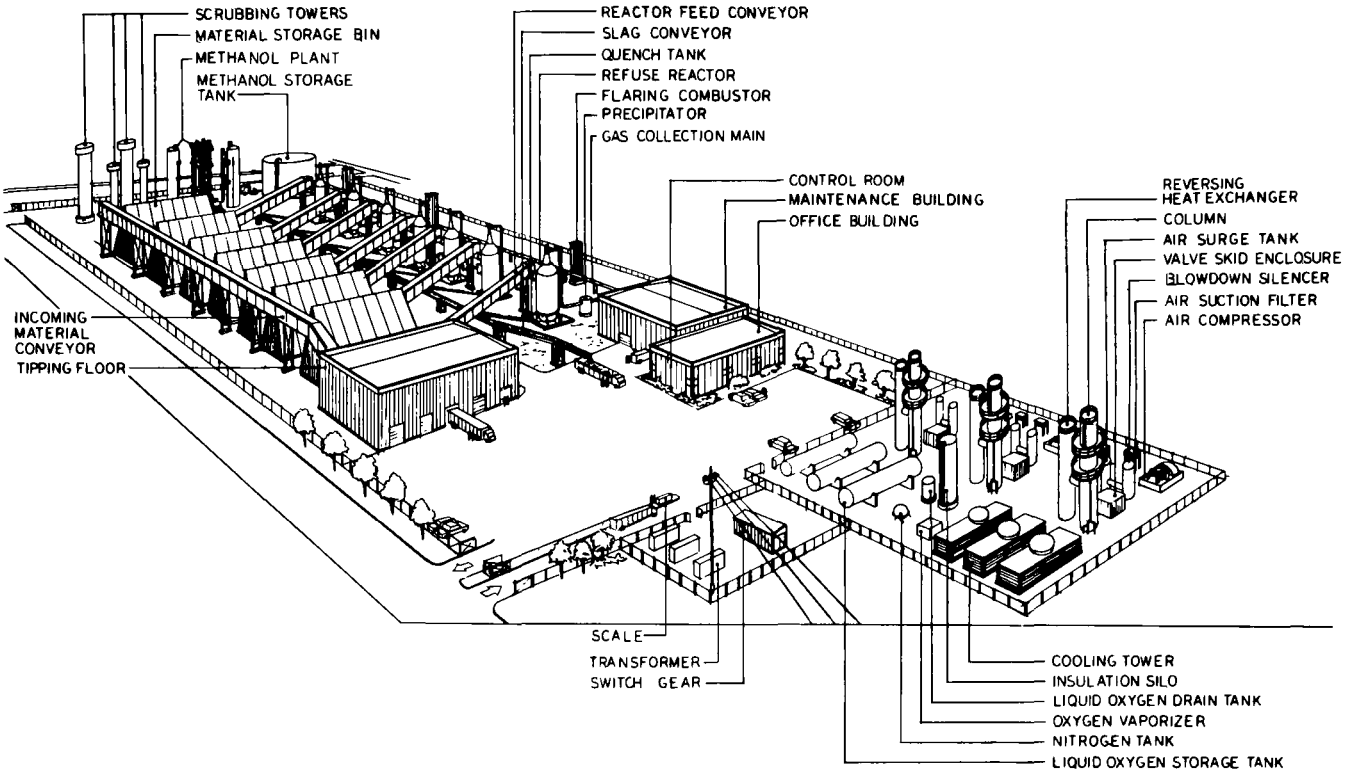

Figure 2: Plant Perspective.

value would offset 50 percent of the costs; with decontrolled natural gas and prices stabilized around new-source levels, both capital and operating costs would be recovered.

ONE COMPANY'S EXPERIENCE

John P. Vircks
AAA Septic Tank Cleaning Co., Inc.
Milwaukee, Wisconsin

The company has been in existence since the early 1940's in the Milwaukee Metropolitan area.

We started with septic tank cleaning along with maintenance and repair of septic tanks, i.e., replacing collapsed tops, repairing outlet baffels, and broken tiles, and attempting to flush sludge out of clogged drain fields when the owners have let the tank go without cleaning far too long. We call it neglect.

Population growth—expansion intensified problems with septic tanks, especially in areas where percolation rates in the soils are low; and, we found a new market developing when holding tanks came into more widespread use.

Before holding tanks were used, the tank size of a septic tank service truck might have been in the area of 1000 to 1600 gallons.

Some surburban schools, country clubs, truck stops, etc., created pressure for more economical equipment, so 3000 gallon and 5000 gallon tank trucks came into use.

Where a residential septic tank might be cleaned on a so called regular basis—once a year with five people without a garbage disposal if the septic tank is 1000 gallons; twice a year with a garbage disposal, a holding tank might need to be emptied any where form once a month to several 5000 gallon loads per day.

We discharge the septage to M.I.S. in the Metro area. Many of our confederates must use land disposal.

Cities in Wisconsin needing to make repairs to heating coils or mixing equipment in their digesters, or where an accumulation of scum created problems, or when the sludge draw off pipe became blocked, or where incineration could not keep up with sludge production, or new construction dictated, complete emptying of the digester became necessary.

The people involved found they needed someone with enough equipment to do the work without stretching the project out all summer.

Along with the need for repairs, etc., phosphorous removal created additional volumes of sludge, and we found people looking for new areas to put sludge. The parks and airports and other places around town did not have enough area for the whole volume.

In some cases, a hole was dug out at the city landfill area. We loaded our trucks at the plant, drove out to the landfill and unloaded into the pit. What happened after that was the city's problem, and, reading between the lines, we assume that these were not really acceptable methods because they are being used less and less.

It is our observation that cities sometimes wait for one reason or another till their back is against the wall before asking for help. And when help is needed you have to do something right away!

We found one situation like this (there have been others). We found a farmer with an acceptable field site (100) acres of alfalfa sod, two thirds of which could be used even though we would stay back 1000 feet from the dwelling.

It rained and snowed and the ground was so wet that farm tractors got stuck just pulling an unloaded farm wagon across the field.

We had to go, so, we purchased 3000 feet of five inch pipe, a rainbird Big Gun with 1.3 nozzle, the wrong kind of pump, and proceeded.

After changing the big gun and the pump and purchasing an additional 4800 feet of pipe with 25 additional gun stands, we have a system, that from an engineering standpoint, works very well but, it turns people off.

The pressure drop at the nozzle, I believe, releases gases into the air, mixes them well with the air, and they drift downwind across the countryside. Also you have this black or brown spray instead of a nice white spray as when regular water irrigation is used. We have been asked to not deliver sludge into that township anymore. One gentleman accused us of almost killing a neighbor of his who had a problem with asthma.

We now use the soil injection method when the ground isn't frozen.

We have surface spread from tank trucks directly to land, then followed immediately with a three bottom moldboard plow.

We still surface spread directly from tank trucks to land in cold weather, or in areas where the local people indicate they can put up with odors, or where the duration of the job is only several days. We have a Big Wheels unit like you see in the hall.

Right now we don't have enough sludge in those areas.

Comments

City's should immediately, even though they don't have a pressing need, should immediately set up a demonstration plot. It takes several crop years sometimes to change farmers ideas—seeing is believing!

When the farmer can look across the fence and see for himself that the crops have not all died and in fact look pretty good, seeing is believing. And you can still drink the water and that the project doesn't have to smell bad, they may come around to your side.

A valid analysis of sludge for nitrogen, phosphorous, and potash trace elements, including heavy metals, should be run immediately. A problem we have is tremendous variability between laboratories and their results. Work with your local County Agricultural Agent.

A heavy metal elimination or reduction program should be initiated so we don't spoil the sludge recyclability.

I sometimes say we have a product that you cannot spoil. It can be spoiled and sometimes is spoiled. Let's not waste our wastes.

VEHICLE CRITERIA FOR LAND APPLICATION AND UTILIZATION OF SLUDGE

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I have run the gamut of feelings while attending, listening and participating at this conference. I have been interested, enlightened, amazed, shocked, frightened and confused. I'm confused because in speaking about agronomic utilization of sewage sludge we have been told how valuable it is. But at the same time we are told that it can't be given away. One person said that he pays a farmer $5.00 a load to put it on his farm. That's in addition to $40.00 per load paid to the hauling contractor.

I don't think the problem is with the material in question as much as it is with the people we're dealing with and the manner in which we're promoting the use of sludge.

Let me ask you a question. What would you think if someone stopped you outside the motel and tried to give you a $100.00 bill? You'd probably think he was some kind of kook or there would be some strings attached. At least I know I'd be skeptical. That's what we seem to be doing with sludge though. We're up to our chin in it, telling people how great it is. And then we say, "Why don't you let me move some of this on you so you can have as much fun as we are?"

If this stuff is really that good, why aren't we marketing it as any salable item should be?

What's the fastest way to promote sales of materials and goods today? We get someone to predict a shortage and the run on sales begins. I think George Ward has the right idea when he entreats you not to waste your sludge because it will one day be in short supply.

We believe that the answer to land application and utilization is *moderation*. Someone said that if a little is good than a lot must be great. But it's not true. Just as eating, drinking, vacationing and other activities are enjoyable in moderation, too much can cause negative reactions. So it is with utilization of sludge.

It would appear that if moderation is the key to utilization of sludge the following items are necessary for proper land application:

1. We must analyze the sludge material so we know what's in it.
2. We must know the soil type, consistency and nutrient requirements for plant utilization.
3. We must spread the material in quantities dictated by #1 and #2.
4. And finally, the material must be spread uniformly on all areas of the acreages designated for utilization.

Senator Muskie, chairman of the Senate subcommittee on Environmental Pollution, said at a recent International Conference of Biological Improvement Alternatives that current methods of treating wastes have been

around for 60 years, without noticable improvement. "As a result," he said, "millions of tons of nutrients such as phosphorus, nitrogen, and potassium are viewed as sludge disposal problems while the costs of fertilizers skyrocket."

If fertilizer is the issue, why don't we handle it like fertilizer. The pictures we saw yesterday of vehicles used for *quote* "Land Application" brought laughter from conference attendees. Don't you think those vehicles affect farmers on whose land you expect to apply your material, in the same way? The inaccuracy, unaccountability and secrecy of those operations can only elicit skepticism and suspicion from proposed recipients, in my opinion.

The company I work with is planning its future on the sincerity and honesty of the American people and more importantly on the intelligence, integrity and abilities of you who design, manufacture, control or operate pollution control systems, wastewater handling programs or sewage treatment plants. Those plans also depend on the foresight and substantial influence of regulatory agencies at the local, state, and national levels. They need to provide guidelines now.

People who have been closely associated with this business, have researched and experimented and actually used this process of land application, have come to us with the determination that any "vehicle" used to accomplish a practical recycling of sewage sludge, lime slurries and sludges, manure slurries and other residual materials on agricultural land must have the following abilities:

1. The vehicle must have flotation abilities so that when the material must be handled, it can be, and farmland will not be adversely affected by travel on it.
2. The vehicle must have a suspension system able to withstand the rigors of travel through fields under the severest of conditions.
3. The vehicle must be able to spread the materials in thin layers over a wide area so that it can dry quickly to prevent runoff and the buildup of odors.
4. The vehicle must be able to spread the material uniformly so that all areas receive equal coverage just as with commercial fertilizer.
5. The vehicle must be able to control the amount of material applied per acre. If this material has valuable fertilizer and soil conditioning characteristics, as Senator Muskie says, than it must be handled in the same manner as any other valuable material. Many systems are selling sludge for agronomic purposes and this obviously limits the application per acre to area and gets a return for any investment. We should stop looking for places to dump sludge and get on with the business of using it properly as a natural resource.
6. The vehicle must be able to spread either dry or dewatered material, material in liquid solution or suspension, or it must be able to incorporate the material below the surface of the ground.
7. The vehicle must have mobility. It must be able to not only work in the fields and do those things suggested, but it must also be able to travel on roads leading to those fields quickly.
8. The vehicle must have a guarantee that is backed by one manufacturer. If good money purchases the equipment, one should not have to go to a variety of places for repairs in the event of a breakdown.
9. And finally, it must have a good looking appearance to lend dignity and good taste to any project.

These are the conditions cited by those who have had the experience and know what is needed. It's not necessary to look any further. Vehicles with all of these abilities and more, are being built by Big Wheels High Flotation Systems of Paxton, Illinois. But the company can only build the machine. *You* have to put them to work in your program to get the job done. Each of us must do our part. Together we can transform the problem of waste material into a valuable recycling of natural resources.

As Big Wheels says in advertising for its new subsurface applicator, "It's and 'open and shut' case for land application."

COMPOSTING SEWAGE SLUDGE IN THE PUGET SOUND AREA

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Two sludge composting facilities are now operating in the Puget Sound area, one in South Tacoma and the other in Bremerton. The original Pilot Plant was constructed in South Tacoma early in 1974 by the inventor of the process, Mr. Willis R. Lebo. At this plant more than three million gallons of septic tank sludge have been aerated and composted to produce a plant food or soil conditioner. The Bremerton facility was constructed in 1975 at the municipal wastewater treatment plant by Mr. Robert Johnson who is in the septic tank pumping business. This plant has been used to aerate and compost not only septic tank waste but also both raw and digested sludge.

The disposal of septic tank waste has been a particularly troublesome problem. The most widely accepted method of disposal has been to discharge it into the municipal sewer system or sewage treatment plant. However, the inflow of this material into the sewage treatment plant is not welcomed by plant operators because of its high level of contamination, and incompatibility with the raw sewage which the treatment plant was designed to handle. Therefore, the septic tank pumpers are generally charged a fee for the privilege of dumping their sludge into the sewer system. By taking advantage of this fact, Mr. Lebo was able to make his Pilot Plant in South Tacoma economically successful by charging a fee

to the septic tank pumpers and then producing a compost which can be marketed in bulk or bagged for sale as a plant food and soil conditioner. In Bremerton, Mr. Robert Johnson obtained the city's permission to construct a Lebo facility rent-free on city-owned land at the Municipal Wastewater Treatment Plant in return for which he has solved the city's problem of sludge disposal by composting their sludge along with his septic tank waste.

DESCRIPTION

The Lebo Process provides a practical method for deodorizing and disinfecting sewage sludge. The material is first deodorized by aeration in the Lebo Aerator. The aerated sludge is discharged onto a compost pile and then covered with a thin layer of sawdust (or compost), and the pile is built up in this manner for composting. Composting temperatures of approximately 150°F develop in the pile, destroying pathogenic bacteria, fly larvae, weed seeds, etc. and making the material safe to use as a plant food and soil conditioner.

DISCUSSION

The technical feasibility and practicality of composting as an effective method of treating sewage sludge has been demonstrated by the U.S. Dept. of Agriculture's sludge composting program at Beltsville, Maryland. At last year's Municipal Sludge Management Conference, Dr. Eliot Epstein presented a paper describing the USDA's method of composting dewatered digested sludge at Beltsville where they use wood chips and spread out the sludge in windrows with frequent turning. Dr. Epstein presented another paper at this year's conference (included herein) describing an experimental program at Beltsville for composting raw dewatered sludge. Since the Beltsville program has been widely recognized and is well documented, it may be used as a basis for comparing the methods used with the Lebo Process for composting sewage sludge in the Puget Sound area. The primary differences are as follows:

1. Lebo Process treats wet sludge (i.e., approx. six percent moisture content) in lieu of dewatered sludge.
2. Lebo Process uses sawdust (or ground bark) in lieu of wood chips, and there is no screening; i.e., all of the material goes into the end product.
3. The Lebo Process aerates the wet sludge in the unique "Lebo Aerator" so as to deodorize it prior to ejecting onto the compost pile.
4. The Lebo Process composts the material in large piles (rather than windrows) and without periodic turning. In this respect it is more like the method used at Beltsville for composting raw sludge (described elsewhere in these proceedings) than the production method used at Beltsville with digested sludge.

CONCLUSION

The Lebo Process is a proprietary method of composting and is in a "patent pending" status. However, the rights to the process (for a specific area) and the Consulting Engineering services of Western Minerals, Inc. are available to implement the Lebo Process for composting septic tank waste and/or municipal sewage sludge to meet particular requirements.

SAFE DISPOSAL AND UTILIZATION OF SLUDGE ON FOREST LANDS

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Disposal of sludge economically and by environmentally acceptable methods is a major problem confronting most of the technically advanced countries of the world, where urban development and living standards are high. This, coupled with intensive development and use of basic resources, high industrial productivity (and therefore waste products), and general non-use of waste by-products, intensifies and magnifies the overall problem. Because of this, providing suitable disposal for sludge may be very costly.

In the United States, about 10,000 metric tons or more of dry sludge solids are produced each day[1]. Sludge currently is disposed of by several methods. Much of it is buried in landfills. A relatively small amount is dried, composted, packaged, and sold as a soil conditioner-fertilizer. About 15 percent is discharged to the oceans, and 25 percent is incinerated[2]. Incineration is an expensive process, however, and without proper treatment can cause serious air pollution. Increasingly, sewage sludge is being spread on land surfaces or incorporated into surface soils for disposal.

Man has disposed of sewage wastes by land application throughout history. So the practice is not new. Because of the increasing waste disposal and pollution problems of today, however, he is now taking a new look at the soil as a treatment and disposal medium. Currently, forest soils are of particular interest.

Land disposal of sewage effluent and sludge has both advantages and disadvantages. Sewage wastes contain valuable nutrient elements useful to plant life. They also help build or restore soil organic matter, and the liquid portions are sources of irrigation water. On the other hand, sewage wastes may include toxic elements or pathogenic organisms which in sufficient amounts potentially can pollute surface or groundwaters or accumulate in soils and produce toxicity and environmental damage along the plant-animal food chain.

Objectives of Waste Disposal Research

Criteria for environmentally safe land disposal of sewage wastes are needed. These criteria must provide protection for:

1. Surface and groundwater supplies. Surface waters may be harmed by enrichment from organics with resultant high biological oxygen demand (BOD) and depletion of dissolved oxygen. Eutrophication of impoundments may result from nitrogen and phosphorus enrichment. Nitrate pollution of groundwater may occur, and pathogens may pollute both surface and groundwater supplies.
2. Soils against excessive nitrogen enrichment, build-up of trace elements or heavy metals, and contamination with pathogens.
3. Vegetation from direct pollution of surface areas and build-up of trace elements or heavy metals into harmful accumulations in plant tissue.
4. Animals feeding in treated land areas. People also should be protected from direct contact with sewage wastes during disposal operations, although documentation of ill effects from contact with digested sludge or chlorinated effluent is scant or unavailable.

Waste Disposal Research

Considerable research is now underway in the U.S. on the effects of applying treated sewage sludges in various amounts and methods, on agricultural lands for the production of agronomic crops.

Research is also underway on the effects of applying sewage sludges to forest lands. Sludge and associated effluent studies are currently underway at six Forest Service (FS) Experiment Stations plus FS-supported cooperative studies at several Universities. The most intensive FS research is at the Michigan-based project. Studies originating here involve:

- Effects of secondary treated sewage effluent on groundwater quality in northern Michigan forests.
- Renovation of sewage lagoon effluents by aerial irrigation on forested land.
- Effects of sewage effluent on growth, product quality, and nutrient recycling capability of several varieties of hybrid poplars and Christmas trees.
- Effects of sewage sludge on the physical and chemical properties of coal-mine spoil and spoil lechates.
- Renovation of strip-mined lands by treatment with sewage sludge.
- Bacteriological and chemical changes in soil and groundwater following incorporation of sealed-vault (untreated) sewage into forest soils.

Other Forest Service sewage and sludge disposal and utilization research include:

- Effects of recycling sewage effluent and sludge on forest soil invertebrate populations (in Pennsylvania).
- Effects of municipal wastewater disposal on the forest ecosystem (at Pennsylvania State University).
- Effects of liquid sludge applications to forested sites (in New Hampshire).
- The influence of ectomycorrhizae and sewage sludge on growth and survival of loblolly pines on kaolin spoils (in Georgia).
- Problems of applying sewage effluent to a forest site in the winter (in Wisconsin).
- Agronomic and economic feasibility of combining wood-processing residues with sewage sludge to produce an acceptable soil amendment (in Colorado).
- Use of sewage effluent on semi-arid chaparral land to provide geeenbelts and fuel breaks and safely dispose sewage wastewater (in sourthern California).

Forests as Disposal Sites

Certain factors and characteristics of forests may limit the use of forests as sewage sludge disposal sites, for example:

- Public acceptance and aesthetics.
- Distribution constraints (steep slopes, physical obstruction of trees).
- Loading and application rate restraints.
- Wildlife implications
- Remoteness (transport distance).

Other characteristics of forests favor their use:

- Abundance and distribution.
- Long cropping periods.
- Relatively low soil fertility status.
- Non-consumptive products for people.
- Remoteness from concentrated human use.
- Opportunity for year-round application in cold climates.

Perhaps an expansion on some of the reasons favoring the use of forests for sewage sludge disposal is in order:

Some commercial forest lands are more suitable than croplands for disposal and utilization of large amounts of heavy metals, trace elements, organic toxicants, and pathogens. With forests, food chain considerations should be of relatively little concern, and prevention of damage to tree crops is the only major concern.

Prolonged overland flow is rare on forested watershed, and soils supporting thickly-forested sites are much better protected from freezing than are open-space croplands of the same general area. Healthy, maturing forests also remove more water from soils through evapo-transpiration than does other vegetation. Consequently, forests may offer greater opportunities than most agronomic crops for safe disposal of certain potentially hazardous sewage sludges and other sewage wastes, and for disposal of large quantities of certain organic and inorganic wastes. Perhaps a key to successful use of forests for the disposal of sludges, or of similarly constituted wastes, is the deliberate and careful selection of tree species (growing on suitable soil types) which are (1) water tolerant, (2) capable of rapid uptake and utilization of nutrients (with concomitant growth), and (3) amenable to harvest operations such as clear cutting

or clean harvesting for maximum use and removal of nutrients.

Significant Findings in Sludge Disposal on Forest Lands

1. Liquid sewage sludge was used to ameliorate extremely acid strip mine spoil in southern Illinois. Application rates of up to 672 metric tons of dry sludge per hectare were more effective in reducing the concentration of A1, S, and H ions in drainage water than agricultural lime at rates up to 44.8 metric tons per hectare. Sludge was far superior to lime in improving the physical properties of the spoil materials.

2. Field tests in the Hiawatha National Forest (northern Michigan) on a Kalkaska sand soil indicate soil incorporation of untreated sewage vault wastes may not pose an environmental hazard in areas protected from public access. The wastes (roughly the consistency of five to ten percent sludge) were mechanically injected under the soil surface. Bacteriological contamination of ground water occurred only at 1.83- to 2.44-meter depths under the treated area when the area was flushed with over 15 cm of water *immediately after treatment*.

3. First year loblolly pine (*Pinus taeda*) seedlings were planted in kaolin spoil material (representative of Georgia and South Carolina kaolin mine spoils) in microplots amended with sewage sludge and grown for six months. Concentrations of sludge were 1, 4, 9, 18, and 36 percent volume to volume. The best growth accurred in four percent sludge which stimulated the seedlings to grow 49 percent more in height, 79 percent more in stem diameter and 126 percent more in fresh weight than the controls. Developments of the ectomycorrhical fungus (*Pisolithus tinctorius*) was better at four percent and nine percent sludge than at zero percent, 18 percent, or 36 percent.

In a concurrent greenhouse pot study, both shortleaf (*P. enchinata*) and loblolly pine seedlings grew better in kaolin spoil with five percent volume to volume sludge than at zero percent or 25 percent, but the improvement of the five percent over the 25 percent was not statistically significant. The five percent sludge level treatment increased foliar-stem fresh weight 148 percent for loblolly pine and 190 percent for shortleaf pine over the controls.

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