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Prepared for international seminar on the environment conducted at the University of North Carolina. A limited number of sets are available for libraries of international organizations.

9. ABSTRACT

This volume of 17 selected papers on the subject of Water Quality Management--Solid Wastes is the second of five volumes prepared as reading references for participants in the IPEAID seminar conducted at the University of North Carolina in March-April, 197 Titles of the other volumes are: (1) Environmental Planning; (3) Air Quality Management; (4) Industrial Pollution; and (5) Resources and the Environment. Authors and titles of papers in this Volume 2:

Barnes, George E. Measuring the monitoring of waste flows.
Illustrated lecture on sewage treatment methods and devices.
Sewage and industrial wastes.

Carroll, John B., and McJunkin, F. Eugene. A collection of source materials on the subject of solid waste management.

Federal Water Pollution Control Administration. A primer on waste water treatment.

Feuerstein, Donald L. Ocean outfall disposal systems.

Kriz, G. J., et al. Beef cattle waste management alternatives.
Dairy waste management alternatives.
Poultry waste mangement alternatives.
Swine waste management alternatives.

Lamb, James C. III. Sources of water, and key factors in selecting water sources.
Stream sampling: location, timing, and types of samples.
Summary of Public Health Service drinking water standards, 1961.

McGauhey, P. H., and Golucke, Clarence G. Control of industrial solid wastes.

Okun, Daniel A. Planning for water management projects.
Sources of water.

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READING REFERENCES

WATER QUALITY MANAGEMENT

SOLID WASTES

VOLUME 2 OF 5

Assembled By

F. Eugene McJunkin

International Program in Environmental

Aspects of Industrial Development

Department of Environmental Sciences and Engineering

University of North Carolina

Chapel Hill, N.C. 27514

U.S.A.

1975 - 1976

INTERNATIONAL ENVIRONMENTAL PROGRAMS AT THE UNIVERSITY OF NORTH CAROLINA

The Department of Environmental Sciences and Engineering at the University of North Carolina has a long standing interest and involvement in international activities and programs concerned with environmental quality and, in particular, with the environmental problems of developing countries. Departmental activities have included special educational programs, on campus and abroad, long and short term technical assistance; research and development; information transfer, including publications; and consulting and service activities by faculty and staff. These programs have included the International Program in Sanitary Engineering Design, the AID Engineers' Environmental Program, the International Program in Environmental Aspects of Industrial Development, the publication series Water Supply and Sanitation in Developing Countries, technical assistance to several overseas universities, and numerous technical studies.

For information on University of North Carolina environmental programs and activities, contact:

Director, International Programs
Department of Environmental Sciences and Engineering
School of Public Health
University of North Carolina
Chapel Hill, N.C. 27514
United States of America

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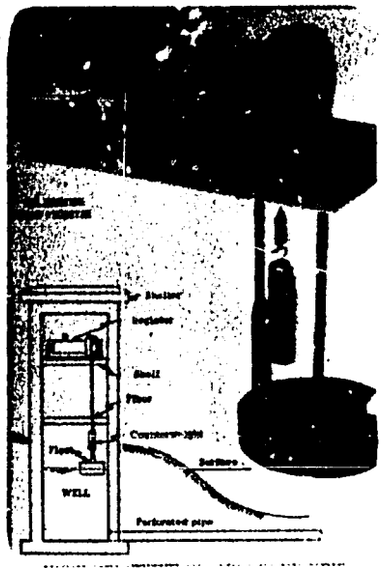
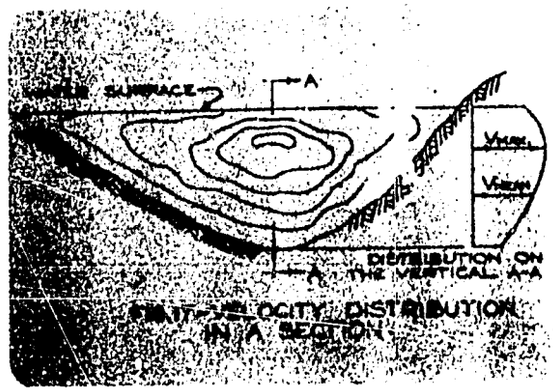
MEASUREMENT AND MONITORING OF WASTE FLOWS

PROFESSOR GEORGE E. BARNES

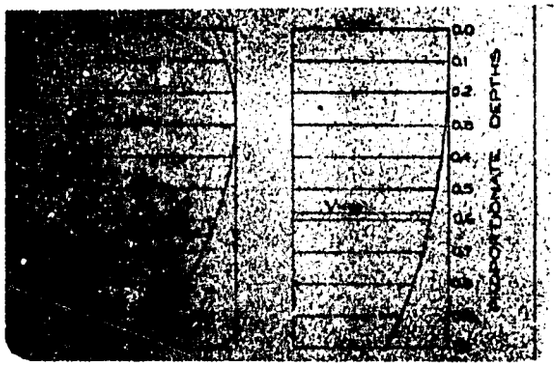
MEASUREMENT AND MONITORING OF WASTE FLOWS
PROFESSOR GEORGE E. BARNES



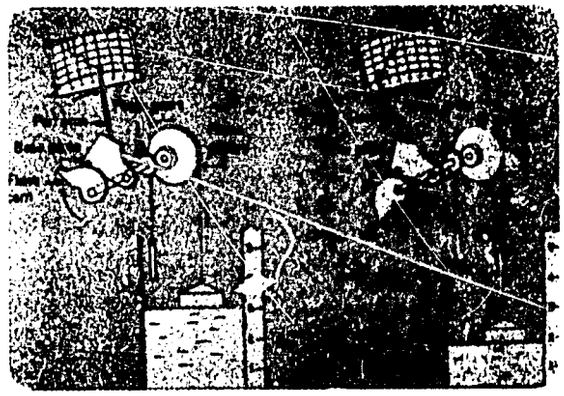
1. Recording stage register & gaging station



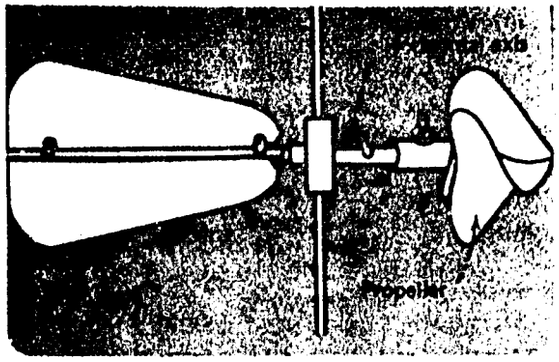
2. Velocity distribution in a section



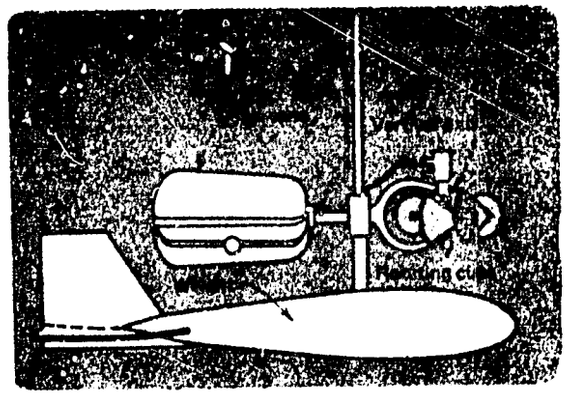
3. Velocity distribution in the vertical



4. Register showing rate of flow directly vs. time



5. Fteley current meter



6. Price current meter

Measurement and Monitoring of Waste Flows
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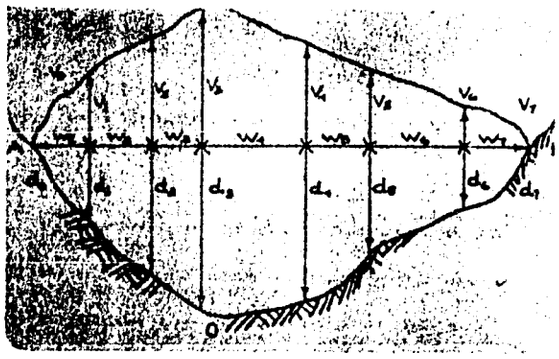

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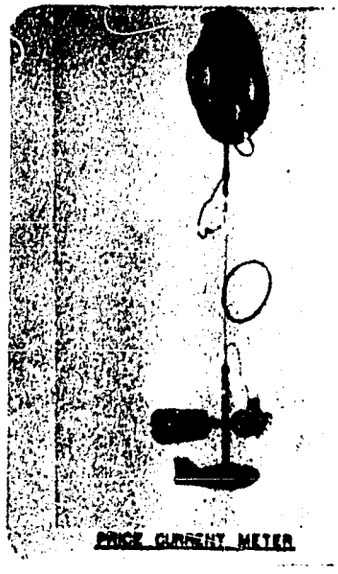

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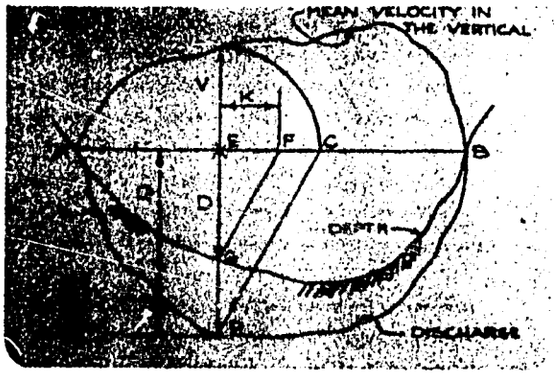

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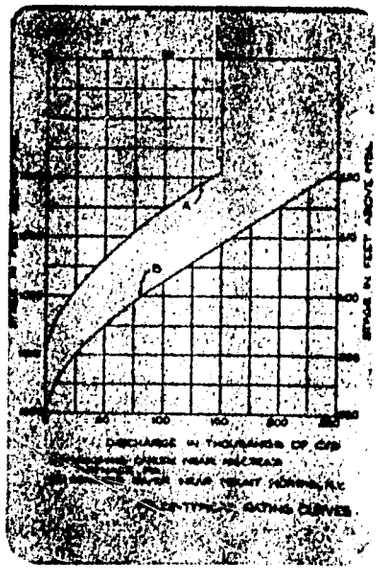

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Measurement and Monitoring of Waste Flow:
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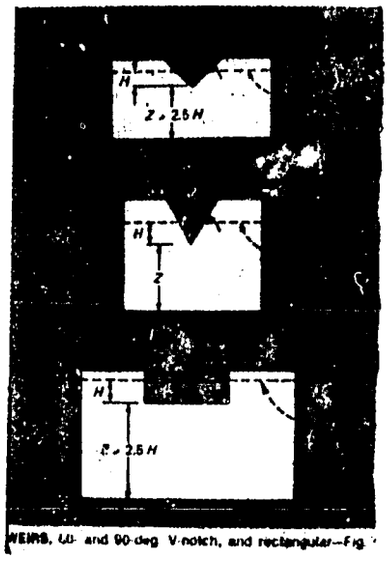

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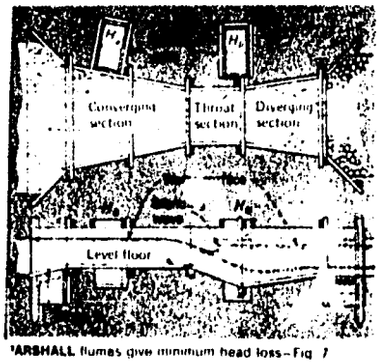

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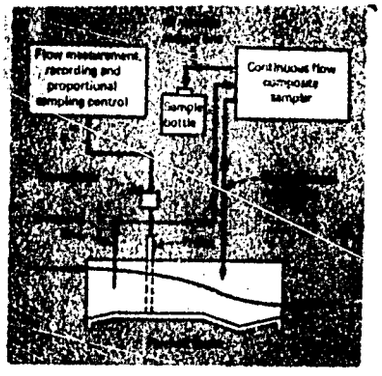
14. Parshall flume



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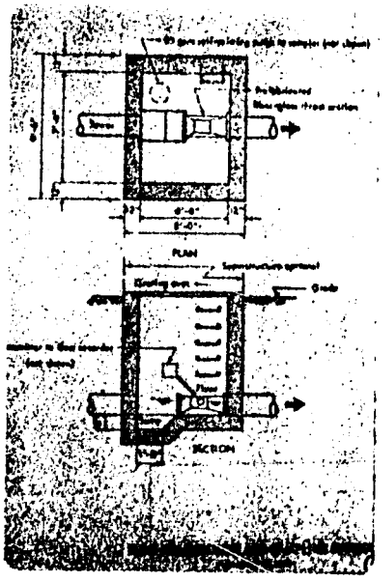

16. Monitoring manhole for stream flow measurement & automatic sampling

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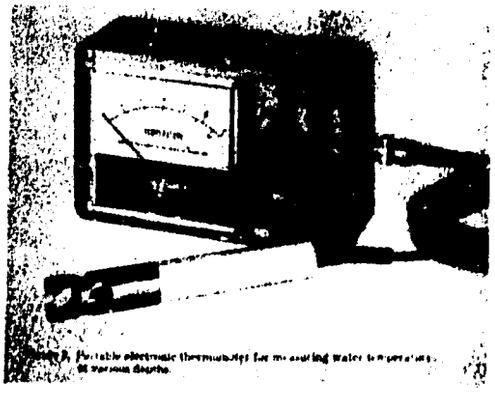

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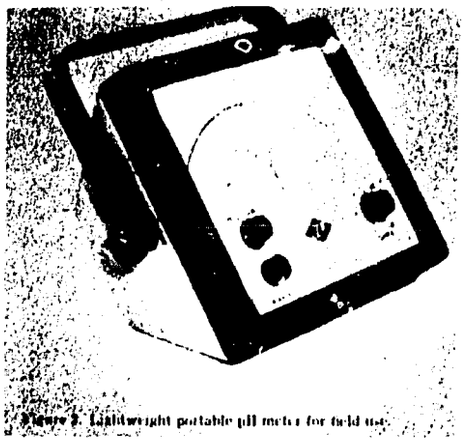

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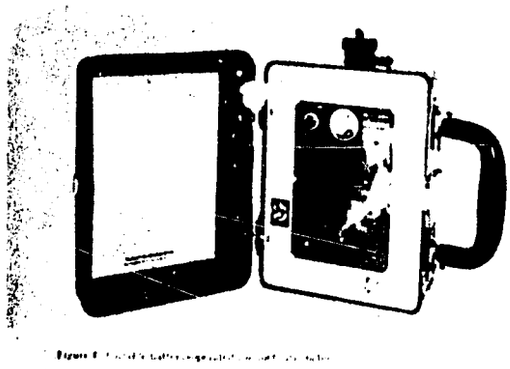

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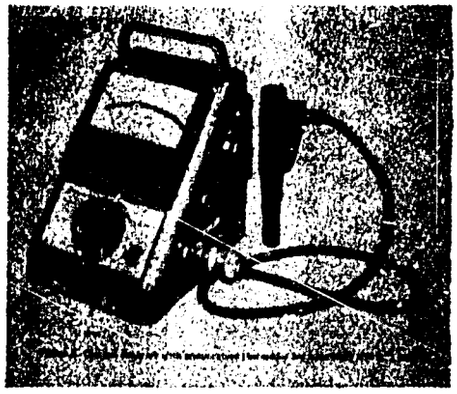

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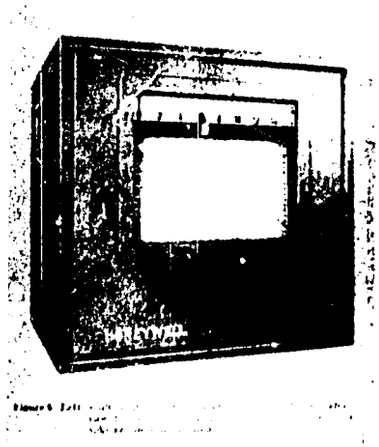

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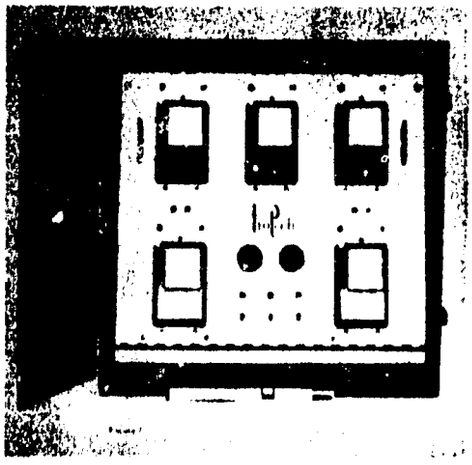
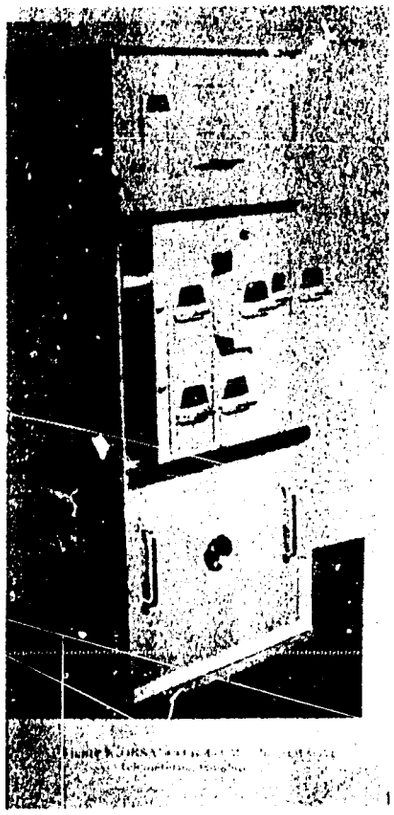


23. (Fig. 7) Semi-portable water quality monitor

Measurement and Monitoring of Waste Flows
Professor George E. Barnes



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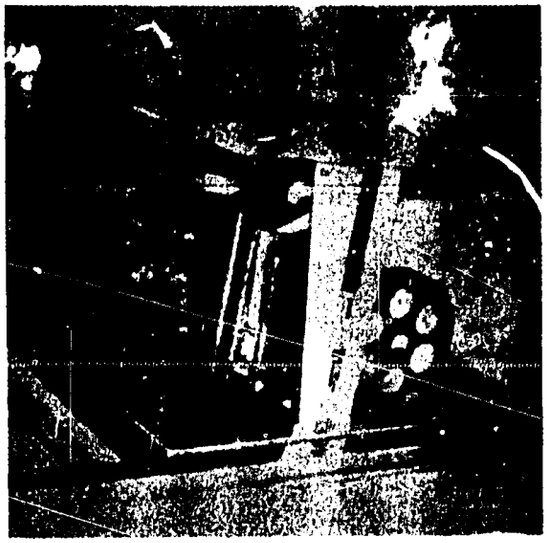

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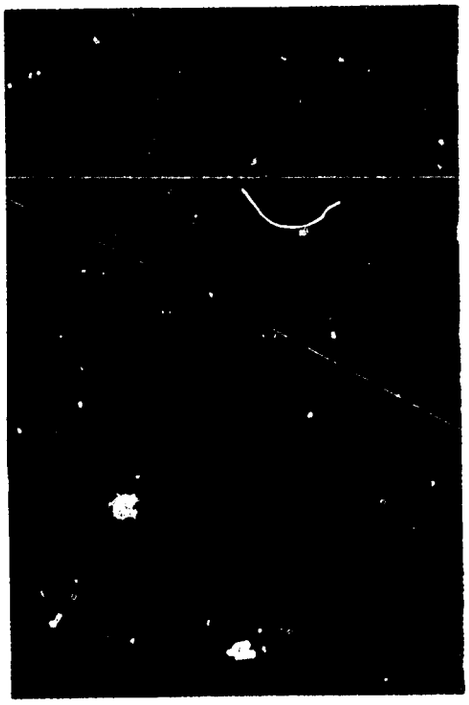

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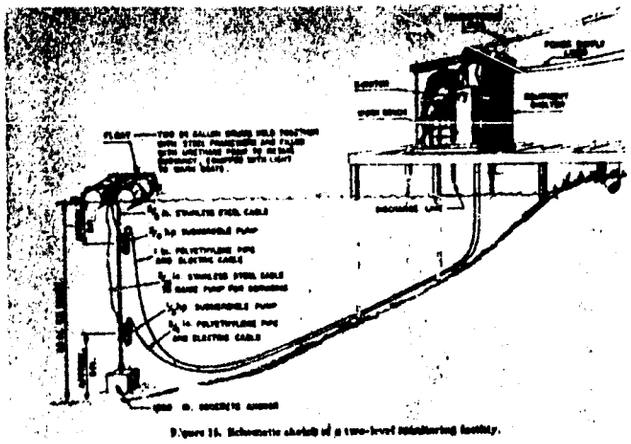


27. (Fig. 15) Two-level intake facility for automatic sampling

ILLUSTRATED LECTURE ON SEWAGE TREATMENT METHODS & DEVICES

BY

PROFESSOR GEORGE E. BARNE

GENERAL SLIDES NOS. 1 - 13:

1. Comminutor: Originally patented by Chicago Pump Co.: Comprises steel cylinder with slotted surface, revolving on vertical axis. Slots engage with vertical comb, in fixed position. provided with cutting teeth. The flow passes through the slots and thence vertically downward to an effluent flume. The flow presses any suspended solids against the slots and holds them, if too large for passage, until the cutting comb reduces them to smaller size , so that they pass with the flow on through. No solids are removed. To save wear from abrasive (inorganic) material, a grit chamber is placed upstream from the comminutor.

1a. Layout for Comminutor: For diversion of the flow around the comminutor, as needed for inspection or repairs, a by-pass is shown. A rack would prevent the passage of solids, when the by-pass is in use.

2. Bar Screen: Originally by Link-Belt: Flat links threaded on horizontal rods, give close clearance to inhibit passage of solids with horizontal flow through the device. The upstream face of the screen is brought to the top of its travel by gearing. Here water sprays flush the solids off into a receiver. Screening of coarse solids is accomplished.

3. Fine Screen: This screen is also by Link-Belt, though competitive makes are available. The major element is a drum with slotted surface. The drum rotates about a horizontal axis. Solids held back by the slots are carried to the top of the drum, and are flushed off with a system of revolving, and travelling, brushes. The screened flow passed through the drum surface to its interior, and thence laterally to an escape channel. Screening, whether by coarse or fine screens, results in the removal of some 10 to 15% of the suspended matter in the raw sewage.

4. Grit Chamber: Link-Belt Type: As the flow passes through the grit chamber, at a velocity of about 1 ft per second, heavier solids settle, and are removed by cross-flights, moving normal to the flow, to be carried up the sloping face of the tank for deposit into a container. These containers must of course be emptied at intervals.

5. Unmechanized Settling Basis: Unmechanized settling basins must be provided in duplicate, to operate on a fill-and-draw sequence. That basin which is not in service must have the deposited solids removed, usually by crude methods, as shown in the figure. For some time now, mechanized basins have been constructed, to minimize space requirements and labor.

6. Primary Settling Tank (rectangular type): Sludge collector mechanism, with cross-flights on endless chains, supported on opposite sides of tank, top and bottom: flights convey settled solids and sludge to sump on inlet end of tank, from which it is removed under gravity head, or by pumps. Flights on return trip act as skimmers for transport of flotable materials and oil to accumulate at outlet end of tank, from which it is removed by squeegees (manually at intervals) to collecting gutter and thence to containers. The same type of tank (without skimming feature) is often used for a final settling tank.

7. Aeration Tanks: Air is supplied by compressors to submerged diffuser tubes or plates alongside one wall of tank. Air rising in bubbles is carried by the flow across the surface and downward against opposite wall, promoting a spiral flow superimposed on the flow along the axis of the tank, thus giving a mixing effect and lengthened contact time with the solids. plus a coagulating effect to enhance settling of aerated solids subsequently, in the final settling tanks. Primary settling, aeration and final settling tanks are included in the activated sludge process.

7a. Trickling Filter: For aeration of pre-settled sewage, the trickling filter is employed. The fixed nozzle type is illustrated. The settled sewage passes through a dosing tank of fixed volume, which discharges under a falling head to distribution piping under the filter surface. and thence with falling pressure during the cycle, to nozzles placed in equilateral fashion. which in turn discharge over a circular ring of diminishing radius, so as to cover the bed once each cycle. There is a resting period while the dosing tank refills.

Today, the fixed nozzle type of filter bed is seldom built. A distributor is employed, revolving about a vertical axis. and having two or more arms extending over and clearing the bed surface. Pressure from the dosing tank causes the arms to rotate and deliver the sewage through orifices under the arms In some installations, there is no resting time. Over a circular bed, the distribution is more uniform, and a smaller head is required to do the work. Filter beds are constructed of coarse stone, to a depth of 7 - 10 feet.

8. Final Settling Tank: The circular type is illustrated. The flow goes to the center vertical column, and radially outward from the distributing head, to the periferal weir, to the effluent channel. Settled solids and sludge are carried to a central sump, by the action of a rotating sludge collector, equipped with radial arms and transverse scrapers, or ploughs. Sludge removal may be by static head, or pumps. Sometimes these tanks are square in plan, with rounded corners that are reached by collector arms which are hinged to the ends of the principal arms.

9. Digester: Liquid sludge from the settling tanks is pumped to digester units, where anaerobic conversion of the solids to gas takes place. Solids content is thereby reduced by some 50% (a highly variable figure when comparing installations). The gas is collected under a floating roof to maintain optimum or uniform pressure: and is delivered to gas burners, or, in some cases, to gas driven engines.

9a. Vacuum Filter: Vacuum filtration is employed for the mechanical dewatering of sewage sludges. The equipment comprises a drum covered with a sheet of porous material. The drum is partially submerged in a sludge bath, and is so designed that the submerged segment is put under vacuum, as are successive segments in turn as the drum is rotated. By vacuum, the water content of the sludge is drawn through the cover and expelled, leaving the solids behind as a thin cake. The cake is scraped off the drum and deposited in a container, or, in some instances, directly into trucks for transport to a dump.

9b. Sludge Drying Bed: In small installations, sludge dewatering is accomplished by gravity flow through beds of sand over gravel, suitably underdrained. Digested (sometimes raw) sludge in poured over the bed to a depth of some 12 inches, and allowed to stand for a month or so, during which time most of the water has drained down to the underdrains, leaving behind a relatively dry cake which can be manually loaded into trucks for disposal elsewhere. Beds may be covered with glass covers to enhance drying during wet periods, and by promoting good circulation of air over the beds.

10. Activated sludge process and by-products treatment: The diagram illustrates activated sludge treatment (primary settling, aeration, and final settling) plus disposition of the by-products of this treatment (skimmings and sludge) In the latter, sludge digestion and incineration are indicated, as representative procedures.

11. Population Equivalent: The population equivalent of an industry is a convenient parameter for the making of comparisons on the pollution potential of various industrial installations, provided that pollution can be measured in terms of volume, suspended solids concentration, and BOD (biochemical oxygen demand).

An industry is said to have a population equivalent of one (1) if it delivers a waste water of 100 gallons per day, having a strength of 240 ppm (parts per million) and a BOD of 200 ppm. Waste waters of different volume and strength would have a population equivalent in proportion to these figures.

For example, the table shows a brewery discharging a waste water whose volume is 300 gallons per day for each barrel of beer produced. The strength of the waste is 650 ppm in suspended solids and 1200 ppm in BOD. If the brewery produces 500 bbls of beer per day, its population equivalent would be calculated as:

500(300/100)(650/240) = 4050 persons (based on suspended solids)

or 500(300/100)(1200/200) = 9000 persons (based on BOD)

12. Industrial Wastes Componants: A number of those components of industrial waste waters are here listed, which are of a character deleterious to the receiving waters, when received in or above critical concentrations. All are of a nature to inhibit the normal biochemical processes that may be expected, whether in a normal aquatic environment. or in those exixting with common sewage treatment processes. Some affect adversely pH, some interfere with proper mixing, and some are toxic in character. They all demand remedy or corrective measures to be taken, over and above those normally supplied.

13. Effect of Some Industrial Wastes on Orthodox Treatment: The toleration limits for certain heavy metals and cyanides encountered in spent rinse waters from electroplating, are indicated in the table. Above the concentrations shown, there may be expected interference with the process. Below these limits, no adverse effects have been observed, in the installation named.

II. FLAMMABLES (Slides 14 - 24:

14. Locality Map, W. 117th St. explosion: Along W. 117th St, which is the boundary between Cleveland and Lakewood, Ohio. some 6000 linear feet of a combined sewer with diameter varying from 4.0 to 7.0 feet, was disrupted from internal explosion with very disastrous consequences, on the afternoon of September 10, 1953. The map shows the location.

15. Plan of W. 117th St. Sewer Line: As shown by the map, the sewer carries combined storm water and sanitary sewage flows to discharge into lake Erie. Low flows are diverted by weirs to sewage treatment plants of the city. The sewer is covered to a depth of about 20 ft. The explosion resulted in a open trench along the line of flow for the full distance, and also opened up similar trenches along the line of branch sewers which are tributary to the W. 117th St. sewer.

16. Trench Opened by Explosion: Ths photo shows the trench opened by the explosion, along W. 117th St. just north of Berea Road.

17. Car Wrecked by Explosion: Here is shown a car which was wrecked by the explosion. One person in the car was killed.

18. Street Wrecked by Explosion: Photo shows disruption of street along the centerline of the sewer, and cars thrown to one side.

19. Variation in pH of sewage owing to presence of industrial wastes: From sewage samples, the charts were prepared to show the hourly variation in pH, as an index to the concentration of industrial wastes present in the flow.

20. Evaporation Rates for Gasoline: Since the presence of gasoline vapors was suspected in the sewer, as a probable cause of the explosion, studies were made to show the liklihood of evaporation of gasoline.

21. House Connections to Sewer: In a typical plumbing system for a house or other structure, traps are provided to prevent foul or hazardous gases from returning to the occupied areas, and vented to permit free access of air to the drains; as shown here for the water closet, lavatory, bath tub, kitchen sink, laundry, etc., In addition, some cities require a main trap on the house connection. Cleanout fixtures are also usually supplied for ready access to clogged pipes . With such an arrangement, there is minimum opportunity for explosion from gas originating in the sewer.

22. Fractional Distillates to Composites, from Sewage Sampling: The more suspect samples from sewage was subjected to fractional distillation to ascertain the more volatile components, as compared with liquids of known volatility. It will be noted that sewage samples 2, 3 and 4, in certain ranges, have a volatility roughly comparable to that of gasoline

23. Auto Equipped for Manhole Sampling: This auto, equipped for sampling of air in manholes, is used Los Angeles, one of many cities who survey the manholes of private and public utilities, to ascertain the presence, if any, of volatiles in the atmosphere of the manhole, for the purpose of remedying any hazardous conditions before explosions would occur. Systematic monitoring pays off.

24. Monitoring Equipment: Monitoring equipment comprises a probe through which samples of atmosphere can be drawn into a container, for analysis.

III. SYNTHETIC RUBBER (Plates 25-31):

25. Copolymer Plants in the United States and Canada: Commencing with World War II. In view of the shortage of raw or natural rubber, the production of synthetic rubber became an important industry in the United States, with the attending problem of the proper disposal of waste waters from the process. The locations for 13 synthetic rubber plants are shown on the map.

26. Copolymer Plant on the Kanawha River: A plant on the Kanawha River was suspect in causing taste and odors in a water treatment plant near Charleston, W.Va, and a study of this and other plants was ordered by the Federal Rubber Director's Office to evaluate pollution problems. Some of the data derived in this and in parallel studies at other plants are illustrated in the following plates. This plate shows the plant and its environs on the Kanawha River near Charleston, W. Va.

27. Flow Sheet of Copolymer Process: This plate shows the blending of butadiene and styrene (the principal ingredients) with additives to form the mix in the reactor, with subsequent stripping and purification to form the latex which is coagulated to raw rubber. then dewatered and pressed into blocks for shipping out to fabricators who make the products. This constitutes one "line" of production. Several lines may be operated in parallel. Each production line has a capacity of 30, 000 tons of synthetic rubber per year.

28. Layout of Copolymer Plant: The copolymer plant at Institude, W.Va., (near Charleston), has a tank farm for the storage of butadiene and styrene, "A" marks the storage units for spent caustic and tertiary butycatachol (inhibiting ingredient) ;"B" source of styrene decanting liquor; "C" point of release for waste wash water (from the vacuum filters), serum, spent brines are rubber fines, and "D" brine softening wastes. Three production lines are indicated, with a total capacity of 90, 000 tons per year of finished rubber.

29. Water Use in Copolymer Plants: The figure indicates the water use in the copolymer process, per line of production; and how it is accounted for, starting with 949000 gallons per day at the start of the process, and terminating with 409000 gallons to the sewer, after meeting several process demands.

30. Model Digesters for Measurement of Toxicity: Sewage sludges, inoculated with various concentrations of toxic ingredients in the wastes from copolymer production. are tested to determine the diminution of the gas produced in digestion. This is taken as a measure of toxicity, since toxicity inhibits gas production during digestion.

31. Toxicity of Various Waste Ingredients: This a plot of test results. The ordinates are cumulative quantities of gas produced; the abscissae at periods of time corresponding, in days. The upper curves show of course those ingredients which have a lower pollution effect, and the lower curves (which include TBC) those of the highest pollution effect; gas production being nil in the presence of these substances in minute quantities.

IV. PICKLE PACKING:

32. Flow Sheet of Process and Packing Procedures: Cucumbers are stored under brine, and after frementation, are processed under steam, freshened by rinsing, and then processed as sweet or dill pickle, for packing and for table use. In the flow sheet, processing sequences are indicated in the upper right hand diagram, for sweet pickles; in the lower right hand diagram, for dill pickles. Waste waters are indicated throughout the flow sheet.

33. Analysis of Sewage and Wastes from Pickle Packing: The high pollutional potential of wastes from various stages of pickle packing as contrasted with ordinary sewages and also wastes from milk product industries and canning are strikingly show in these figures; referring to BOD in particular.

34. Components of Total Wastes Flow: This is a graphical presentation of the separate volumes (shown as cubes) and corresponding BOD values (shown as spheres) It helps to point the way in which remedial measures for the various components, will produce the more beneficial effecta.

35. B.O.D. Reduction by Improved Operating Routines: Principally for BOD reduction, the installation of stainless steel gutters on the packing tables, to collect drip in containers for re-use, saved much money in recycled sugar solutions, and kept the sugar solutions, high in BOD, from escaping to the sewers. Thus, in the general effluent from the plant, BOD was reduced from 754 lbs daily to 150 lbs daily, or by say 604 lbs or 80%.

36. Facilities for Rate of Flow Control and Automatic Sampling: In another plant, it was determined tha the BOD of the wastes sent to the sewers would be within acceptable limits if the flow for a day were delivered uniformly over a twenty-four period, instead if over an eight-hour period. Holding tanks were built with automatic rate controllers, for the purpose, equipped with automatic sampling devices for insuring that the results were properly maintained.

V. OIL SEPARATION: PLATES 37-41:

37. Oil Separation for Soluble Oils: The illustration shows a simple oil separator used in a plant manufacturing aircraft parts, where free-flowing sikuble oil was used as a coolant and lubricant for the cutting tools in lathes and drill presses. Overflowing oils were collected in containers and sent to skimming tanks, where they were mixed with an emulsion breaker, to remain quiescent for several hours and then decanted by introducing water to float off the concentrated excess. The spent oils were then sent to be burned or destroyed in an incinerator.

38. Rise of Oil Globules in Water: Much more ample separators, scientifically designed, are required in large installations, such as one may find at refineries. The basis of design is the rate of rise of oil globules in water, as determined by experiment. The results of such experiments are given in the diagram, for oil globules of given diameter at various temperatures.

39. American Petroleum Institute Separators - Reclangular Type: In many installations, tanks are designed singly or in multiple in accordance with standards of the American Petroleum Institute. The rectangular type, as shown, is commonly employed. The basic equation for design is

$$v_t = C(S_w - S_o)/\mu \quad \text{where:}$$

C is a constant which depends on globular size and on conversion factors such that v_t is expressed in feet per minute rise; S_w and S_o are specific gravities of the mix and of the oil contained in it. and μ is the viscosity of the mix. The reader is referred to API Standards for details. Proper devices for skimming are important, and various types are employed. In the installation shown, the floating oil is pushed along the surface to a slotted pipe, which is in effect a sharp crested weir.

40. Drum Type of Oil Skimmer: The rotary drum skimmer is a more recent type. Skimming is accomplished by a drum that rotates with the flow picking up a thin film of oil which is scraped off and drained into a collecting sump. The drum can be made of carbon steel, stainless steel, aluminum, or plastic. Rotational speed is in the order of 0.5 to 1.5 ft per second. The submergence is 0.5 inches or greater. Practice in this respect depends on the amount of oil to be removed and its viscosity. Advantages are that the oil contains little water and that operation can be made completely automatic.

41. A.P.I. Separators - Circular Type: Circular oil-water separators are designed like a circular clarifier with a central influent stack and a peripheral effluent discharge. One such separator is shown in the figure. The larger unit handles dirty or oily water, whereas the smaller unit is used in clean water service. There has been no rational design method developed for the circular type of clarifier, and one must rely on experience and performance records for projected applications.

VI. NEUTRALIZATION: Plates 42-26:

42. Lime Requirement for pH adjustment : A large rayon manufacturing plant was discharging 2.0 millions of gallons of waste water, containing about 20 tons of sulfuric acid daily into a municipal sewer. Neutralizati by dosing with lime was required to prevent destruction of the sewer itself. The chart shows the lime requirement to adjust pH, in the amoun of say 10 grams of CaO per gallons of waste. This amounts to about 4.0 tons of lime daily, to bring pH of the waste flow to pH 7.0.

43. Lime Storage Bin and Loading Equipment: To handle lime is such quantities, a storage bin with vacuum unloading equipment was installed for the lime, brought in by railroad cars. Under the bins lime feeders were located. Surge tanks were used to keep on hand lime, as milk of lime. Automatically, as the milk of lime supply was depleted, the lime feeder went into action to replenish the supply. From the surge tank, the lime was fed through butterfly valves in proportion to demand, as determined by electrodes submerged in the flow.

44. Automatic Neutralizing Plant (aeration): Treatment of the flow is accomplished in two stages; the first being aeration by means of air diffusers., to degasify the flow to minimize the SO_2 content.

45. Automatic Neutralizing Plant: The second stage of treatment is that of neutralizing; introduction of the lime in proper quantities, plus mixing with under and over baffles, with a flow-through time of some twenty minutes. Milk-of-lime flow is regulated from the surge tank.

46. Effect of pH Control: The chart shows the effect of pH control; it is automatically kept at around 7.0

VII. PICKLE LIQUORS (PLATES 47 - 49):

47. Layout for Treatment Facilities: A major problem in the United States is the disposal of spent pickle liquor. The term pickling is used to denote the cleaning, prior to subsequent processing or forming, of metals such as steel or steel alloys. The cleaning process in most common use is the immersion of the object to be cleaned, in a sulfuric acid bath. After the bath has been depleted of its acid content and fouled l impurities there remains the problem of disposal. The diagram shows schematically the usual steps in treatment with lime used as the neutralizing agent. The sludge resulting from treatment i usually sent to lagoons on waste land.

48. Wire Cleaning House. An actual installation for pickling is shown here. Wire coils are descaled by dipping in a sulfuric acid cleaning bath, and sent to the automatic forming machines to be made into bolts with heads and threads complete.

49. Waste Disposal - Wire Cleaning House: The spent pickle bath and other cleaner baths are drained into a catch-all pit and pumped to a mixing tank. Here it is neutralized (in this instance with soda-ash) and the mix is passed through settling basins before being sent, along with dissolved solids, to the municipal sewer.

VIII. ANODIZING (PLATES 50 - 51):

50. Anodizing baths and rinses: Anodizing is in a sense the reverse of plating, by immersion of the part (usually aluminum) in an acid bath to prepare it, by cleaning, for finishing. The plate shows the sequence of steps for anodizing and finishing, indicating the points at which waste waters originate and are taken off for treatment.

51. Alternate anodizing sequences: This plate is similar to the former, but illustrates alternates sequences for anodizing and finishing, and also the points of take-off for waters which will require treatment.

IX. ACID METAL WASTES (PLATES 52 - 54):

52. Milk of Lime Dosage for Wastes: This and the two following plates show a plant for the treatment of wastes from copper plating. The wastes flow to an accumulation pit. Chemicals are added and sent to mixing tanks. Following mixing, quiescent settling yields a clarified supernatent which goes to the sewer. The sludge is pumped to lagoons.

53. Batch Treatment of Acid Metal Wastes: Here is a plan view of the treatment facilities for wastes from copper plating. From the accumulation pit, the wastes are pumped, with the addition of chemicals, to the treatment tanks. The supernatent goes after settling, to the sewer, and the sludge to the suction pit for the sludge pumps, which, in turn, deliver it to the lagoons for final disposition.

54. Batch Treatment of acid metal wastes - Section Through Facilities: The flow can be followed, in accordance with that previously described, in this sectional view of the receiving and treatment works.

X. RECOVERY OF FLUE DUST (PLATES 55 - 56):

55. Flow Sheet - Recovery of flue dust from wash water: Flue dust originating in blast furnaces is degasified and flushed into a thickener. Milk of lime, prepared from bulk quantities received in car load lots, and transferred to overhead storage by vacuum, is slaked, and fed as a coagulent to the effluent from a clarifier. The resulting sludge is sent to lagoons.

56. Layout of Facilities for Recovery of Flue Dust: A plan view is shown of the facilities for the introduction of lime to the system for flue dust recovery, for its mixing and for the coagulation of the liquor to be treated; indicating the sending of the effluent from the clarifier to waste and the sludge to lagoons.

XI. GENERAL WASTES AT STEEL MILL (PLATES 57 - 58):

57. Layout of Secondary Treatment Units: A comprehensive system for the treatment of water-borne wastes from a steel mill is indicated in the flow sheet. This is one of three identical systems, taking care of a flow of 33, 000 gallons per minute out of a total of 100, 000 gpm. Ferrous sulfate and lime are used as coagulants. These are added in a flash mixer and sent to twin facilities for flocculation, and settling. The clarified effluent is sent to a pumping station, for delivery in part to the river, and in part to re-use. Sludge is sent to vacuum filters for dewatering. The dried sludge is hauled away to a disposal site, by gondola cars on the railroad.

58. Section Through Clarifier Unit: The clarifier unit is shown here, in section and in somewhat greater detail. It will be noted that the outer portion of the tank floor has a somewhat flatter slope than the inner portion. This follows a design based on research and experiment. In the tank, the inflow is directed to the center and then downward. The effluent is sent over a peripheral double weir.

XII ELECTROPLATING WASTES (GENERAL) (PLATES 59 - 64):

Electroplating has in its spent waste waters a number of constituents which are toxic in character and therefor deleterious in streams and in sewage treatment plants.

59. Toxicity of Metals and Cyanides: The plate shows the diminution of gas yield in sludge digestion (one method of determining relative toxicity) from the presence of toxic substances, as determined by experiment. It will be noted that cyanides and hexavalent chromium, have a high degree of toxicity relative to other substances.

60. Alternate Means of Disposal of Wastes: To be illustrated further, here is a list of all the possible means for the disposal of wastes from electroplating.

61. Dilution: Since toxicity is related to the concentration of the deleterious substances, dilution to the point where the concentration of the ingredients is held to innocuous levels, is obviously one means for disposal, wherever this is feasible.

62. Partial Destruction: By partial destruction is meant the destruction of cyanides by the addition of chlorine, and the reduction of the hexavalent chromium to its less toxic tri-valent form, thus cutting down substantially (but not totally) the toxicity of the wastes. No sludge requiring separate disposition, results.

63. Destruction: Destruction is a means for the total removal of all toxic substances from the wastes. Chlorine destroys the cyanides converting them into innocuous nitrogen and carbon compounds. A reducing agent (such as SO_2 for example) converts the hexavalent chromium to the trivalent form, and a coagulent (such as lime) results in precipitating all the metals (including chromium) out of solution to form a sludge. The disposal of this sludge remains a problem.

64. Recovery (of chromium): Spent rinse waters from plating have so much water per pound of solids that to recover these solids by evaporation is prohibitively expensive. However, the concentration can be increased to the point where evaporation is economically feasible, by counter-current rinsing. This is shown in the sketch, where the rinses are progressively returned (rinse 3 to rinse 2, rinse 2 to rinse 1) so that all of the solids are progressively concentrated and the first rinse is correspondingly concentrated; and can be evaporated economically. The solids so recovered are concentrated to a strength of the original plating bath, and can be returned to it as make-up. Thus no solids are lost in the spent rinses. With chromium, that portion of the chromium which has been converted to the trivalent form must be taken out (since it would be an impurity in the bath) by ion-exchange. Cyanides in the form of zinc cyanides can be recovered in the same general fashion.

XIII. DESTRUCTION OF ELECTROPLATING WASTES (PLATES 65 - 75):

65. Flow Sheet: Treatment of Metals-bearing Wastes: This, in schematic form, is a plant for the destruction of the metals-bearing portion of the wastes from electroplating. Lime and Ferrous sulfate are delivered in car lots, and transferred to overhead storage bins by vacuum equipment. By gravity, they are fed to dry feeders, and dissolved to be sent in solutions of known strength to solution tanks, to be pumped in predetermined quantities, as needed, to the mixing tanks. These are equipped with agitators, to secure mixing for a suitable period. This is followed by quiescent settling, producing a clear supernatent which is sent to the sewer. The sludge is drawn from the bottom of the tanks to a sludge pit. Pumps send the sludge to thickener tanks, to reduce water content, from which in turn it goes to overhead storage. By gravity, tank trucks are loaded from the storage bins and the sludge is sent to lagoons. The wastes are delivered from the plating lines to an accumulation tank, and pumped to the treatment tanks for batch treatment. Each batch is analysed for ferrous sulfate and lime requirement.

66. Flow Sheet for Treatment of Cyanide - bearing Wastes: Adjacent to the above units are other units for chlorination and the consequent destruction of the cyanides. Cyanide-bearing wastes are kept separate from the metals-bearing wastes. The flow is collected in a separate accumulation tank, and pumped to the separate treatment tanks. Here the chlorine is added, and mixers are used to get proper distribution of the chlorine solution throughout the mass of liquid wastes. The treated wastes go to the sewer. No sludge is produced.

67. Overall View of Treatment Facilities: In this photograph, one may readily identify the units of the treatment plant just described. To the left are the sludge storage tanks. In the background are the chemical storage bins, and to the right are the treatment tanks.

68. Unloading of ferrous sulfate and lime: Hopper bottom railroad cars bring chemicals to the plant. These are unloaded by vacuum equipment hooked up by hosing to the bottoms of the hoppers.

69. Dehumidifying Equipment: Since ferrous sulfate is hydroscopic, it tends to cake and this interferes with gravity unloading of the storage bins. Therefore dehumidifying equipment was installed to keep the air above the stored chemicals free of moisture.

70. Control Laboratory: Each batch of waste is analysed to determine the ferrous sulfate and lime requirement, prior to treatment. Also, records are kept of the chemicals used and the results of treatment.

71. Chemical Feeders (Dry Feed Type): These feeders receive dry chemicals from above, by gravity and apply it in ribbon form to a belt conveyor, which weighs out the rate of feed. The dry chemical then is dissolved and fed to a solution tank.

72. Distribution of Solutions of Treatment Liquors: A manifold arrangement provides for the delivery of chemical solutions, to the proper treatment tanks.

73. Control Gallery: A pipe gallery provides housing for the piping and valves which control the delivery of untreated waste waters, treated effluents, and sludge to various units of the plant. The very small piping, shown above, is for the delivery of chemical solutions.

74. Pumping of Sludge to Sludge Storage Tanks: Positive displacement pumps are used to pump sludge to the thickener units and storage tanks.

75. Lagooning of Sludge from Tank Trucks: Sludge is delivered by short haul to lagoons located outside the city limits. The accumulation over the years has been considerable.

XIV. RECOVERY OF METALS AND CYANIDES (PLATES 76 - 84):

76. Plans for Multiple Rinsing: Alternate schemes for rinsing are indicated, to reveal (1) how water may be saved and (2) how solids may be concentrated, by several schemes involving one or more rinses in parallel and in series. Minimum water use results from the adoption of scheme F and also maximum concentration of impurities contained in the rinse waters.

77. Rinse Water Requirements in Multiple Rinsing: It is possible to develop formulas which relate the variables (1) chemical concentration in the bath, (2) the volumetric rate of dragout from the bath following immersion of the plated part (3) the volumetric rate of rinse water feed, and (4) the concentration of chemicals in the rinse water overflows. The formulas are developed in a logical sequence and may be used with confidence.

78. Recovery of Chromium: This sketch shows the arrangement of rinse feeds, the provision for trivalent chromium removal by ion-exchange, and evaporator for concentrating the chromium solution to be returned to the plating bath, all in a hypothetical system.

79. Layout of Plating Room: The plating room equipment is arranged in so-called "lines". Each line is devoted to special plating duties.

80. Results of Sampling: Sampling at short intervals over a week's time gave the concentration for various ingredients in the wastes, and frequency of occurrence for each concentration. The curve shown was that pertaining to chromium.

81. Flow Sheet for Disposition of Wastes: The upper diagram shows the disposition of spent rinse waters (whether to sewer, to reclaim by return to plating bath, or recovery by return to bath after evaporation) . The lower diagram shows disposition of periodic dumps from cleaner baths (whether acidic or alkaline) by mixing so as to neutralize one type against the other.

82. Economic Analysis: The total annual cost of any investment is the sum of three terms i.e., interest on the investment, sinking fund for replacement at end of useful life, and annual operating costs.

83. Recovery Factor vs. Interest Rate for 7 yr and 10 yr. Life: These curves are plotted from interest tables, for more ready reference. Note that the so-called recovery factor is the sum of the interest rate and the replacement (or sinking fund factor).

84. Schematic Analysis for Economic Balance: This is a graphical illustration of the fact that the recovery factor is that by which the total annual cost of the investment becomes equal to the annual cost of any other investment to be considered.

NOTES ON STREAM FLOW REGISTRY

Instruments of indicating and recording water condition parameters.

Portable instruments satisfactory for measuring such parameters as temperature, pH, conductivity, and dissolved oxygen are available with probe or electrode sensors and indicating meters. Fig. 2

Fig. 2 shows a battery- operated electric thermometer with a thermister sensing element and marked cable to measure water temperature at various depths.

A light weight portable pH meter with manual adjustment for temperature compensation is illustrated in Fig. 3

Field measurement of conductivity, or of specific conductance, may be performed with a portable meter of the Wheatstone bridge type. The meter shown in Fig. 4 requires manual temperature compensation. Models with built-in thermisters for automatic temperature compensation are available.

A multiple parameter portable instrumentation system for the measurement of dissolved oxygen and temperature is shown in Fig. 5. This system uses a specially designed polarographic probe with semipermeable membrane for fast and accurate sensing of dissolved oxygen. The probe and be obtained with a built-in thermister for convenient temperature measurement; it is also available with automatic temperature compensation for disrect electronic readout of dissolved oxygen in milligrams per liter. Several probe-type sensors may be combined in a submersion assemble and connected by cable to and indicating or recording instrument, or to both.

Fig. 6 shows a four element submersion probe assembly and multipoint strip chart recorder for field measurement of dissolved oxygen, conductivity, temperature and pH. This system requires 120 v. 60 cycle AC power, can be supplied by a portable generator.

Fig. 7 shows a semi-portable water quality monitor which measures water level in addition to dissolved oxygen, conductivity, pH, and temperature. This monitor requires 120 volt, 60 cycle, AC power. Water is pumped from the stream to sensors located in the monitor assembly. The data for each parameter are recorded on separate strip charts.

Continuous surveillance for water pollution in a river, or estuary, requires the sensing of selected water quality parameters at a fixed representative sampling site. Sensors may be placed in the stream for transmitting electrical signals to receiving instruments housed in a nearby shelter. But operation and maintenance are facilitated if the entire instrumentation system is installed in a building where a continuous flow of water is pumped to the sensors. A satisfactory location may be sometimes found at a water treatment plant, and electric power generating station, or an industrial facility using river water. If such facilities do not exist at needed sampling points, a pumping system and an equipment shelter with electrical power must be provided.

In partial summary, we find that practical sensors of the probe type are availably for measurements of temperature, pH, conductivity, dissolved oxygen, and dissolved chlorides. Sensors for toeher water quality parameters are in various stages of reserarch, development, and field evaluat: Also, certain types of automatic systems for chemical analysis can be of service. Analysis for alkalinity, hardness, nitrate, ABS, sulfate, and iron, by colorimetric and potentiometic means, with the results set forth on charts. is possible.

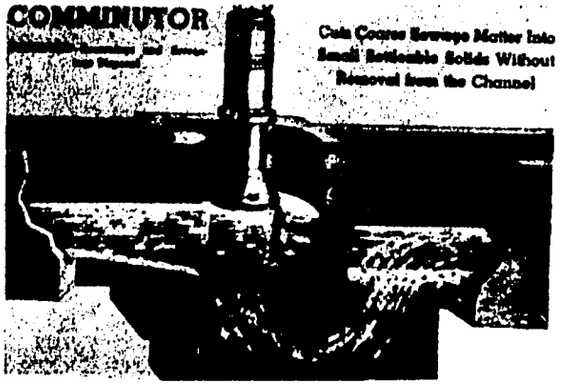
The concept of an integrated automatic instrumentation system was first applied for monitoring water quality in a river basin was first applied by the Ohio River Valley Water Sanitation Commission. The so-called ORSANCO Robot Monitor, first placed in operation in September, 1960, is shwn in Fig. 9. This uses multiple electrode sensors and analysers in modular packages for the integrated recording and transmitting water quality data, and monitored temperature, pH, dissolved oxygen, conductivity, chloride ion, Oxidation-reduction potential, and solar radiation. By June 1962 ORSANCO had six transmitter-type and five strip-chart recorder-type monitors in operation. The signals from the transmitter units were telemetered to Cincinnati for automatic recording on punched paper tape as well as typing on a tabulation sheet.

Some of the components of this monitoring device are shown in a pull-out compartment, in the following illustration. (Fig. 12)

Fig. 13 shows the central logging facility for the Potomac River water pollution surveillance system located at the Federal Water Pollution Control Administration headquarters in Washington, D. C.

Finally in Fig. 15, there is shown a two-level intake facility, where samples are taken automatically at to differect levels, owing to difference in water quality between upper and lower points. Two submersible pumps are supported by an anchor-cable-buoy system at the edge of the river channel. The pumps in this instance are about 5 feet apart. The water is pumped to a small prefabricated housing which shelters the automatic instrumentation system. The pumps and sensors are entirely separate, for more positive response to conditions encountered.

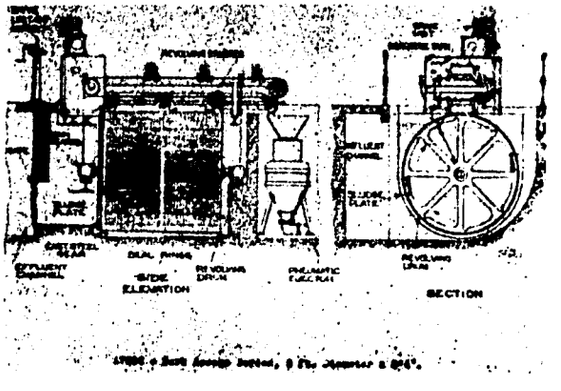
I. GENERAL (slides 1 - 13)



1. Communitor

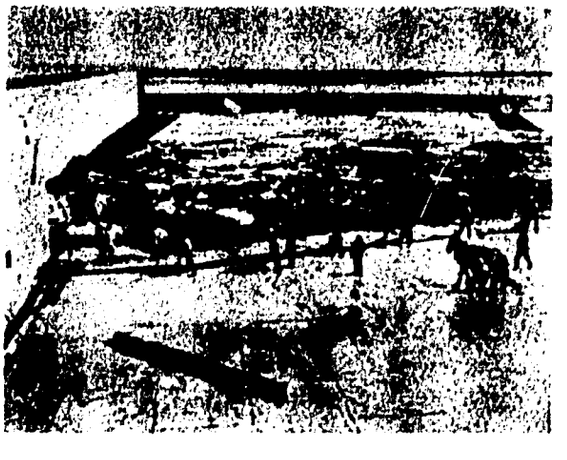
1a. Layout for communitor

2. Bar screen

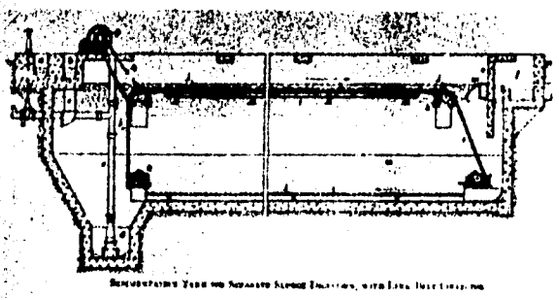


3. Fine screen (drum)

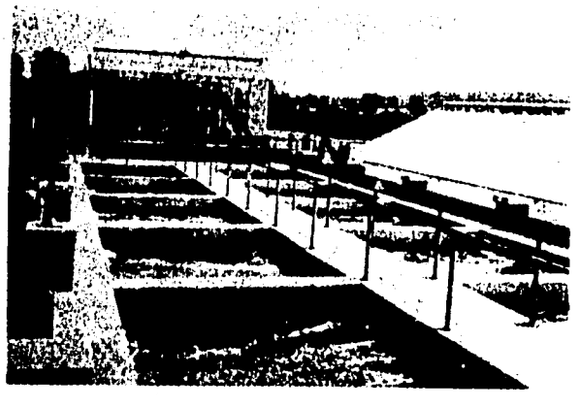
4. Grit chamber



5. Unmechanized settling basin

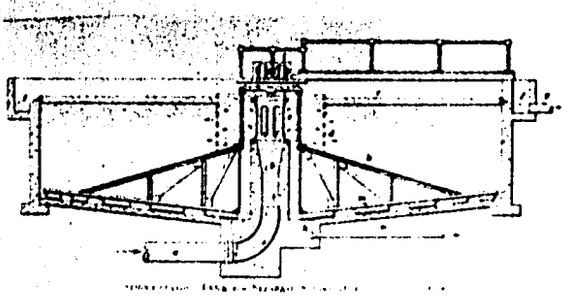


6. Primary settling tank (rectangular)

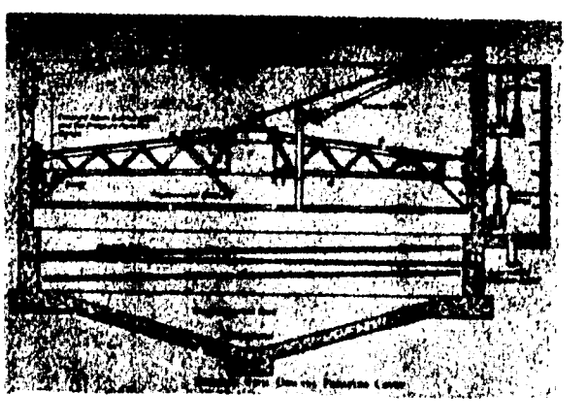


7. Aeration tanks

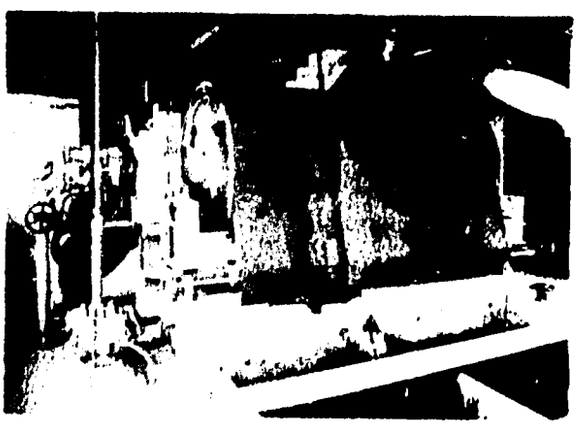
7a. Trickling filter (fixed nozzles)



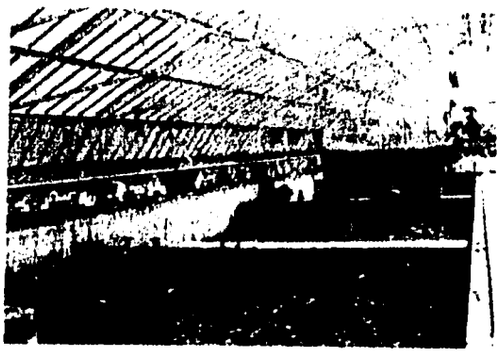
8. Final settling tank (circular)



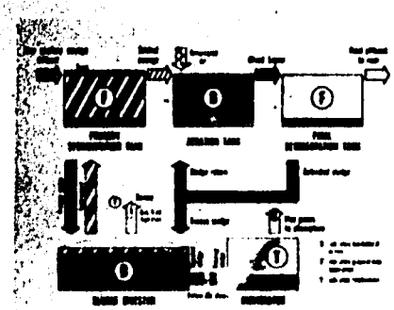
9. Digester



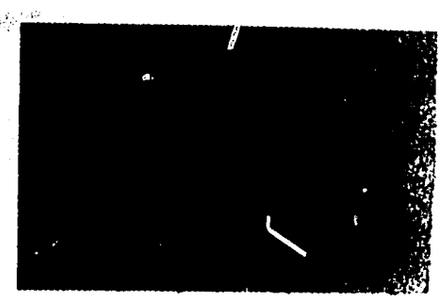
9a. Vacuum filter



9b. Sludge drying bed



10. Activated sludge process and by-product treatment



11. Population equivalent

(a) Acids
(b) Alkalies
(c) Oils and gr
(d) Phenols
(e) Styrene
(f) Tannin
(g) Hot...
(h) Cyanides
(i) Brines
(j) Detergents
(k) Radioactive wastes

12. Industrial waste components

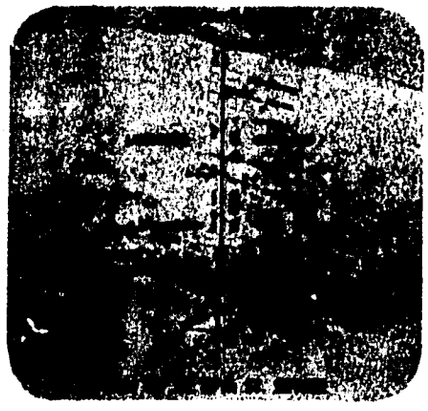
IONS CONCENTRATIONS WITHOUT APPARENT EFFECT ON SEWAGE TREATMENT PROCESSES as observed by Tarvin at Shelby, Ohio

Ion	Concentration in parts per million: Activated sludge	Sludge digestion
Cr	0.85-1.36	215
Cu	0.65-2.2	215
Ni	0.72-0.63	41
Zn	3.0 -8.4	740
CN	1.12-1.87	—

3. Effect of some industrial wastes on orthodox treatment

II. FLAMMABLES (slides 14 - 24)

14. Locality map, 117th St.

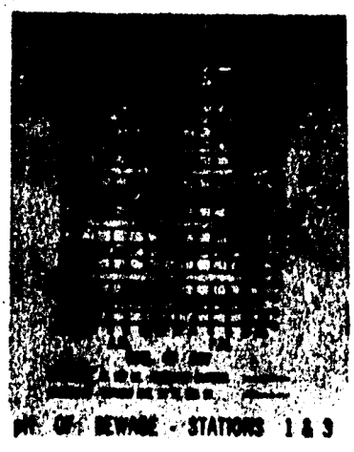


15. Plan of 117th St. Sewer Line

16. Trench opened by explosion

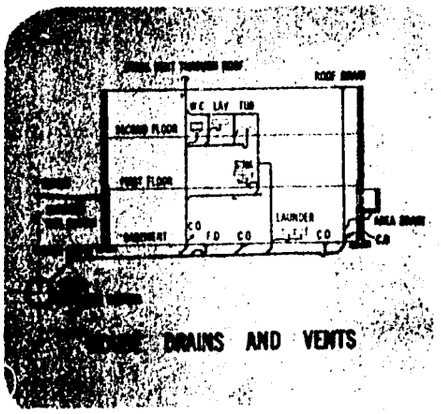
17. Car wrecked by explosion

18. Street wrecked by explosion

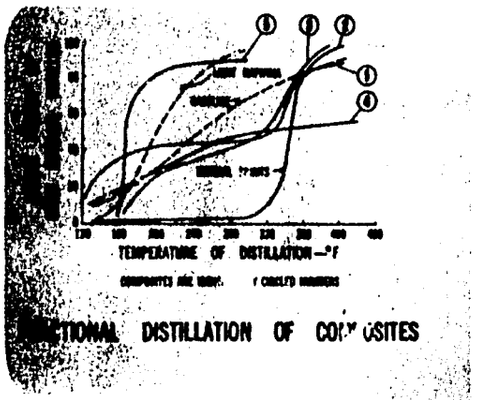


19. Variation in pH of sewage owing to presence of industrial wastes

20. Evaporation rates for gasoline



21. House connections to sewer

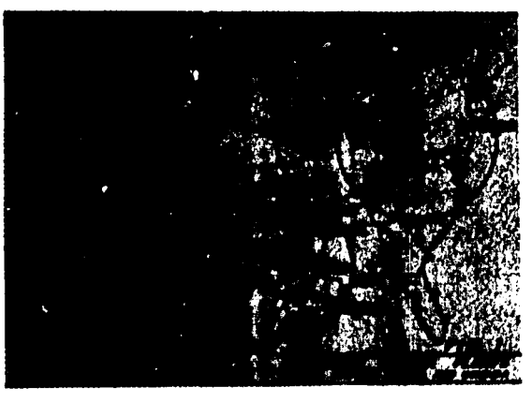


22. Fractional distallates to composites, from sewage sampling

23. Auto equipped for manhole sampling

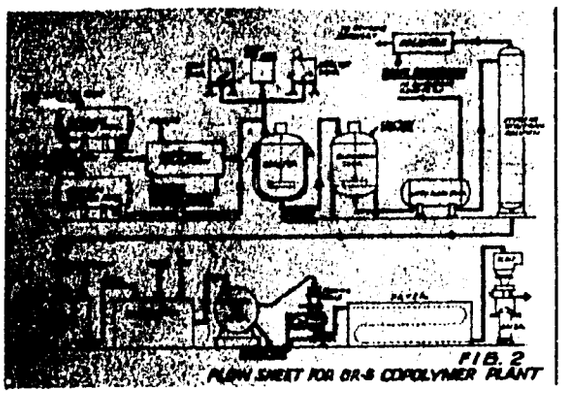
24. Monitoring equipment

III. SYNTHETIC RUBBER (25-31)



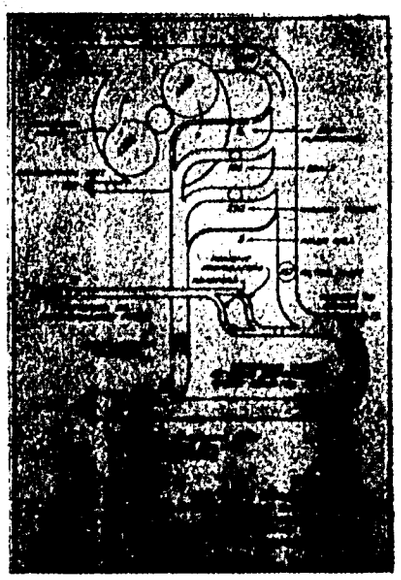
25. Copolymer plants in U. S. and Canada

26. Copolymer plant on Kanawha River



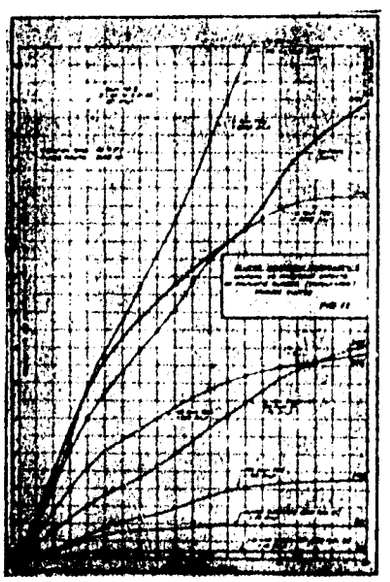
27. Flow sheet of copolymer process

28. Layout of copolymer plant



29. Water use in copolymer process

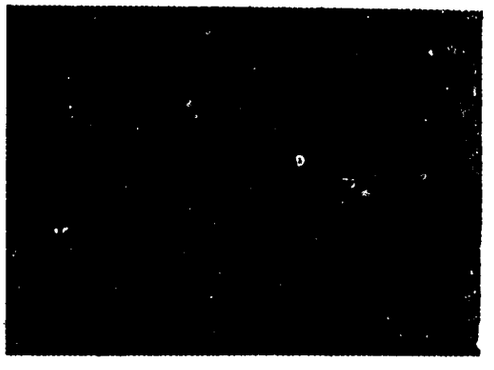
30. Model digesters for measurement of toxicity



31 Toxicity of various wastes ingredients

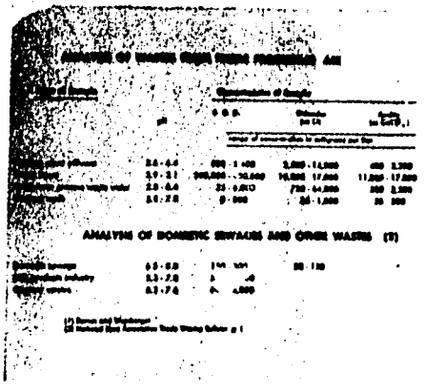
IV. PICKLE PACKING (32-36)

32. Flow sheet of process and packing procedures

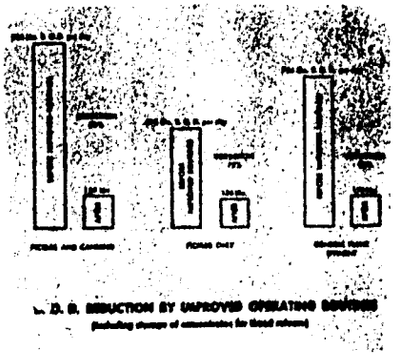


34. Components of total wastes flow

36. Facilities for rate-of-flow control and automatic sampling

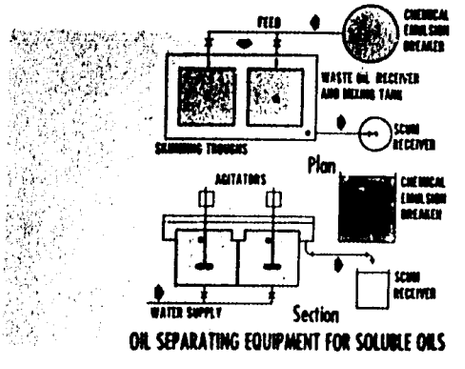


33. Analyses of sewage and of wastes

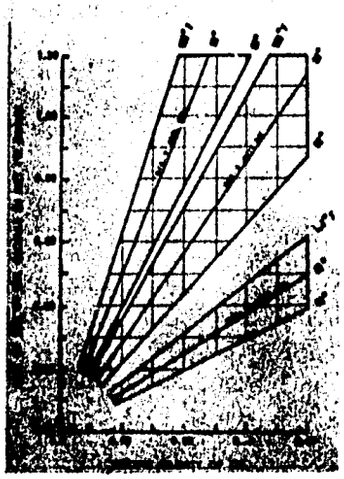


35. BOD reduction by improved operating routines

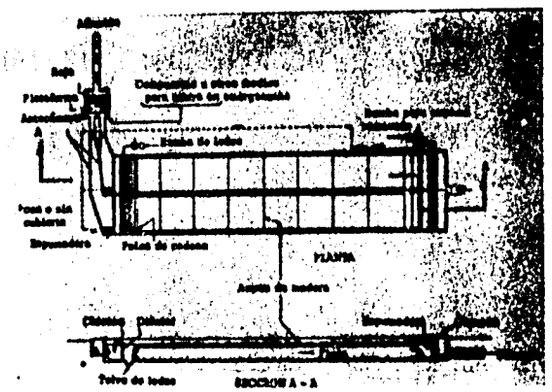
V. OIL SEPARATION (37-41)



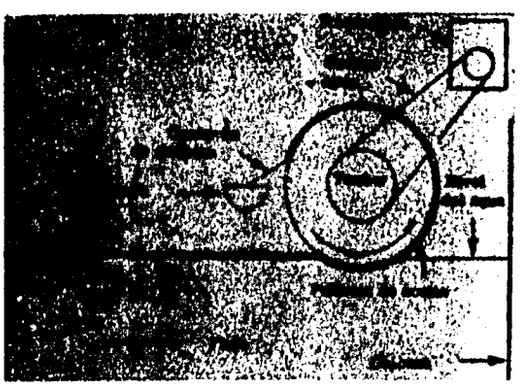
37. Oil separation for soluble oils



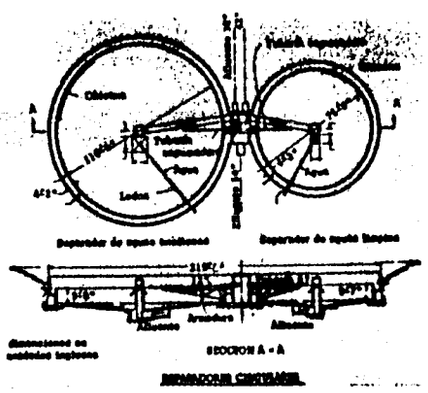
38. Rise of oil globules in water



39. A.P.I. Oil separators - rectangular type

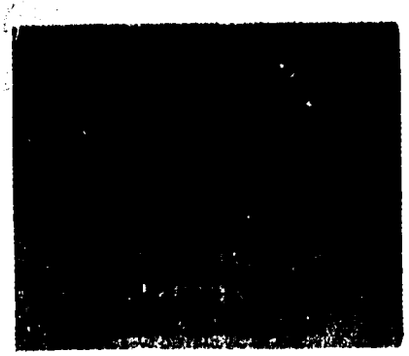


40. Drum type of oil skimmer

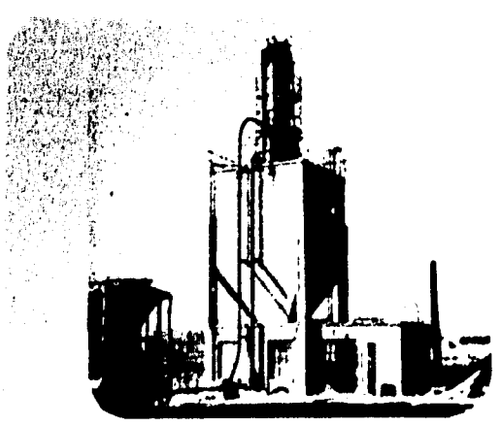


41. A.P.I. oil separators - circular type

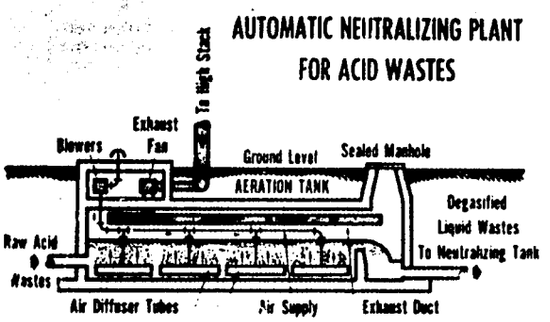
VI. NEUTRALIZATION (42-46)



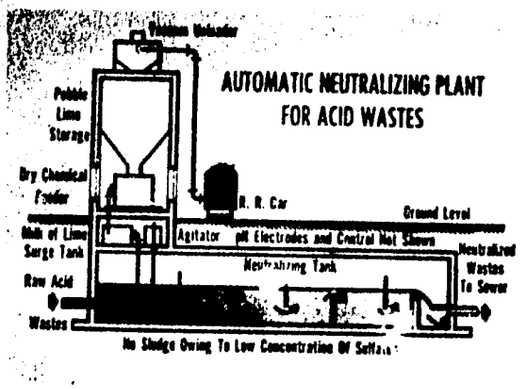
42. Lime requirement for pH adjustment



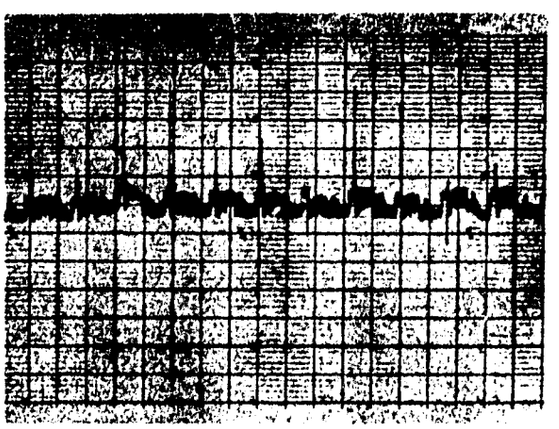
43. Lime storage bin and loading equipment



44. Automatic neutralizing plant (aeration)

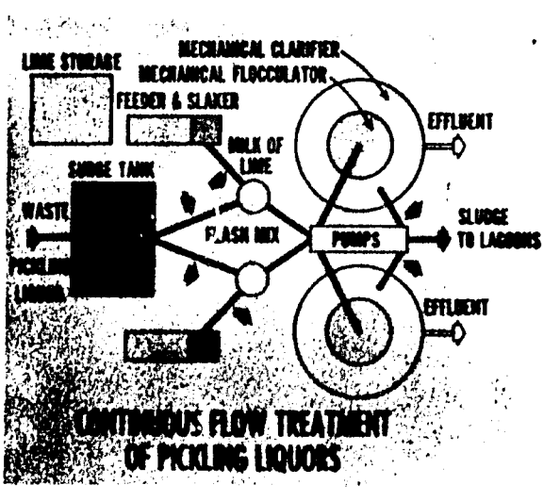


45. Automatic neutralizing plant (neutralization)

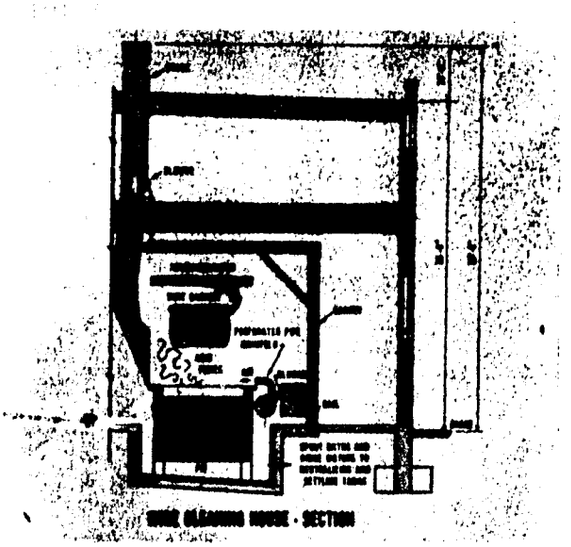


46. Effect of pH control

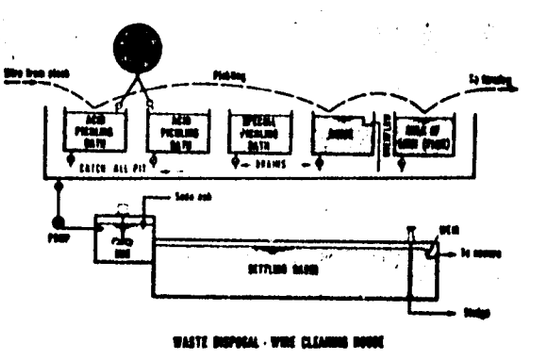
VII. PICKLE LIQUORS (47-49)



47. Layout for treatment facilities

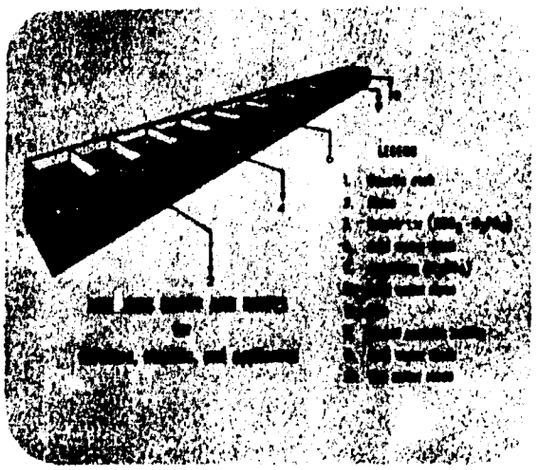


48. Wire cleaning house

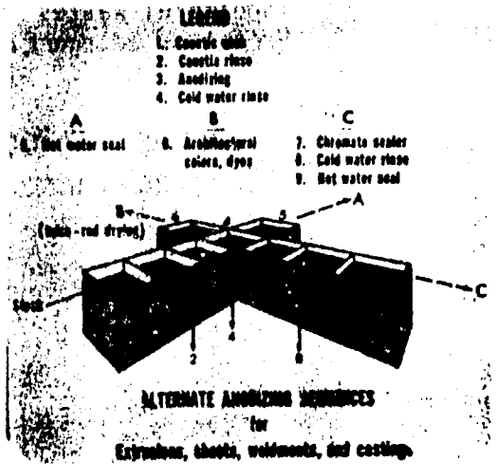


49. Wastes disposal - wire cleaning house

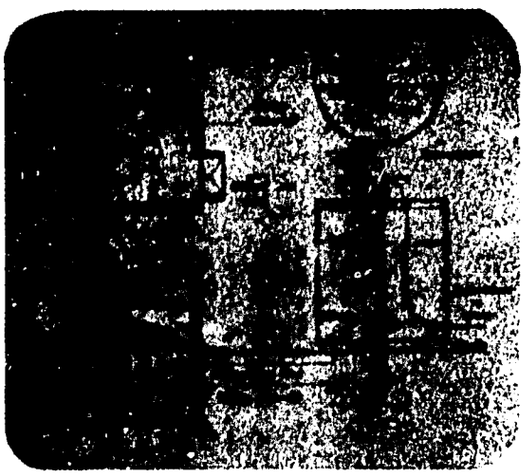
VIII. ANODIZING (50-52)



50: Anodizing baths & rinses

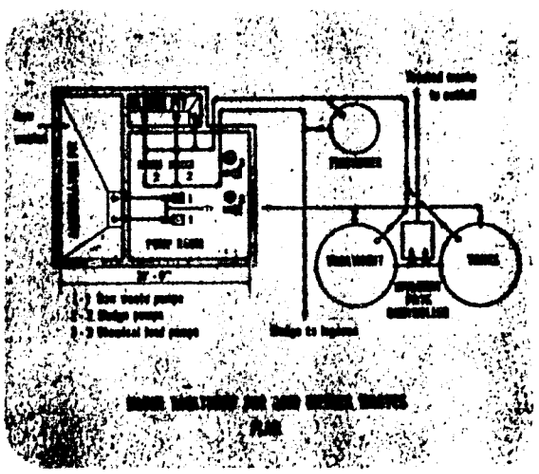


51. Alternate anodizing sequences



52. Milk of lime dosage for wastes

IX. ACID METAL WASTES (53-54)



53. Batch treatment of acid metal wastes -plan of facilities

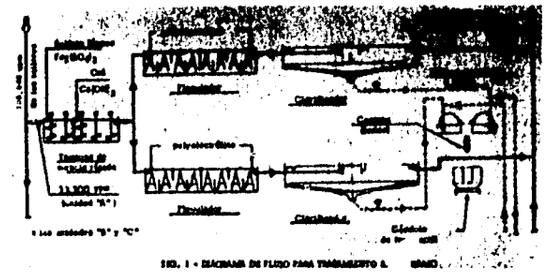
54. Batch treatment of acid metal wastes - Section through facilities

X. RECOVERY OF FLUE DUST 55-56

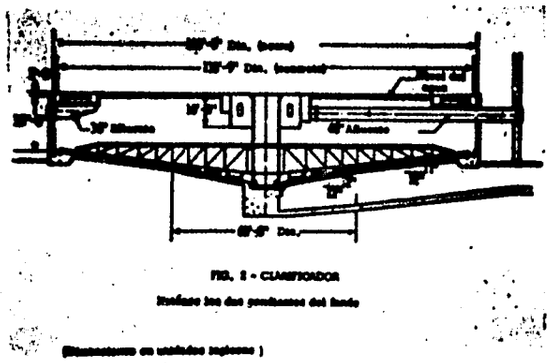
55. Flow sheet - recovery of flue dust from wash water

56. Layout of facilities for recovery of flue dust.

XI. GENERAL WASTES AT STEEL MILL (57-58)

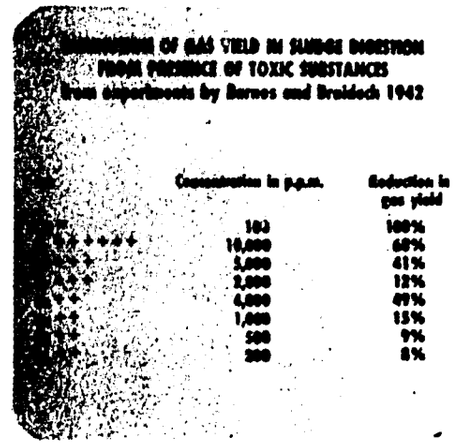


57. Layout of secondary treatment units



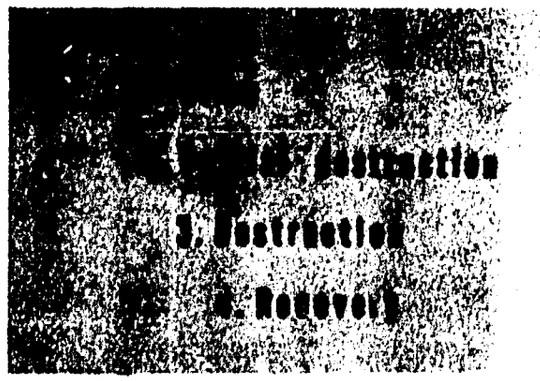
58. Section through clarifier unit

XII. ELECTROPLATING WASTES (GENERAL) (59-64)

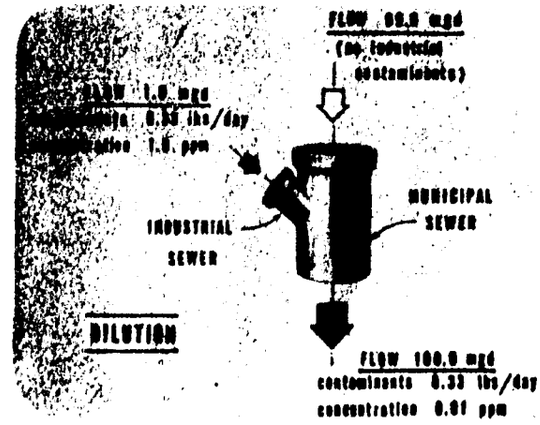


Concentration in p.p.m.	Reduction in gas yield
100	100%
10,000	65%
5,000	41%
2,000	12%
1,000	49%
1,000	15%
500	9%
200	8%

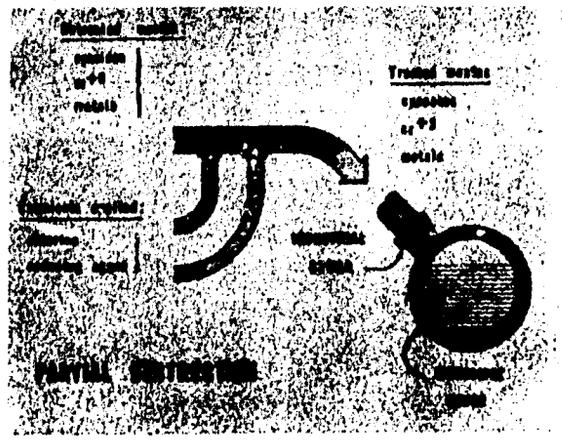
59. Toxicity of metals & cyanides



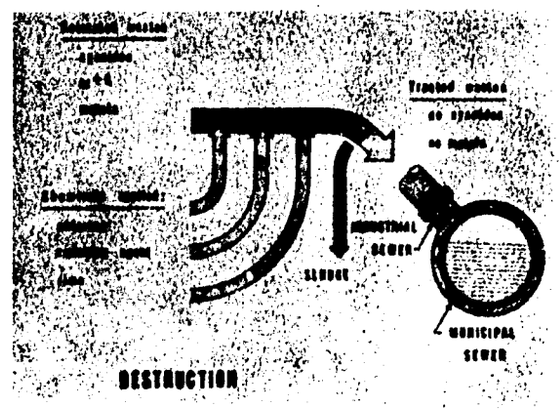
60. Alternate means of disposal of wastes



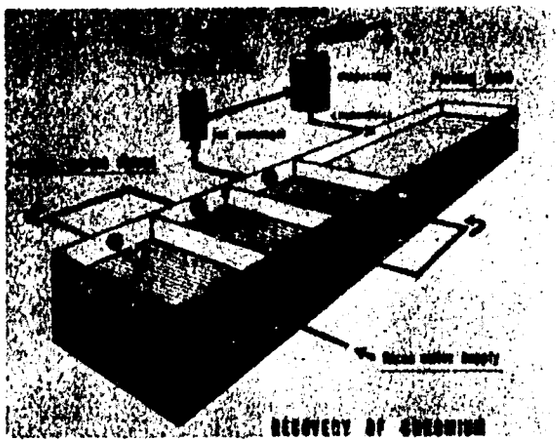
61. Dilution



62. Partial destruction

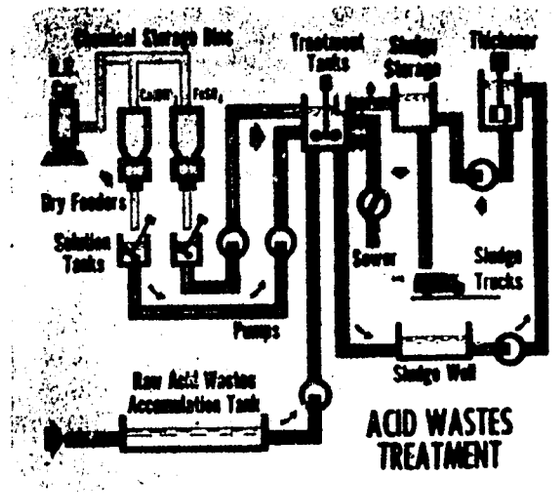


63. Destruction

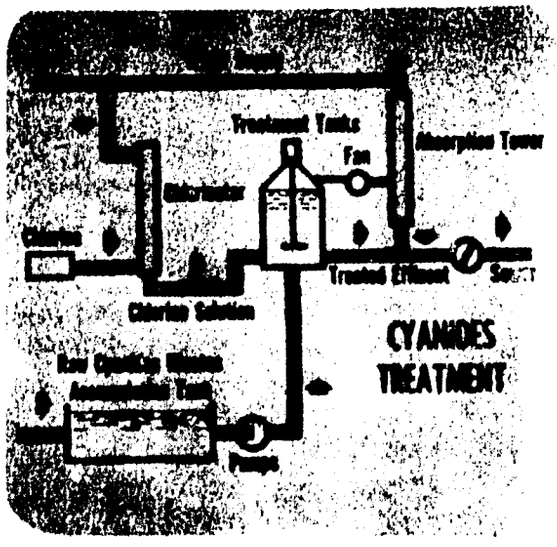


64. Recovery (of chromium)

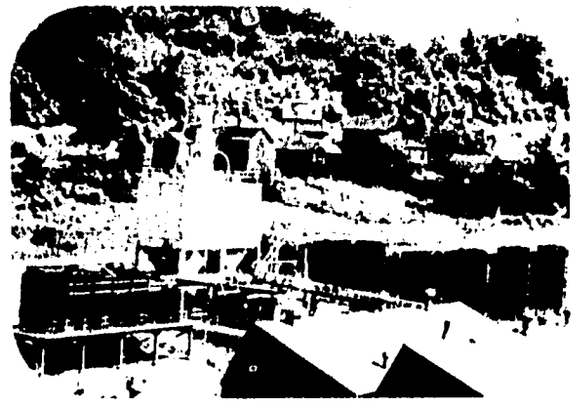
XIII. DESTRUCTION OF ELECTROPLATING WAST
(65-75)



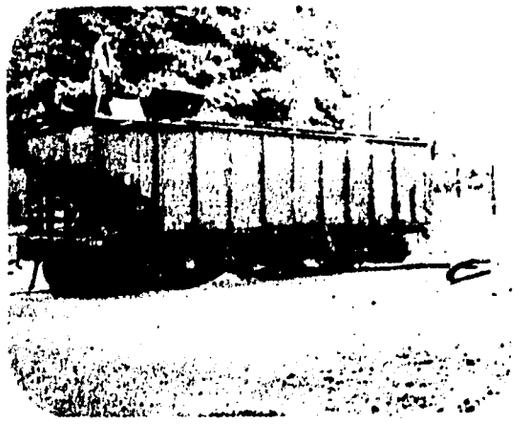
65. Flow sheet, treatment of metals-bearing wastes



66. Flow sheet, treatment of cyanides-bearing wastes



67. Overall view of treatment facilities

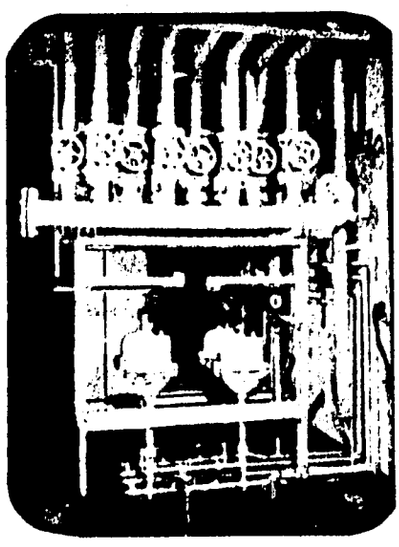


68. Unloading of ferrous sulfate and lime

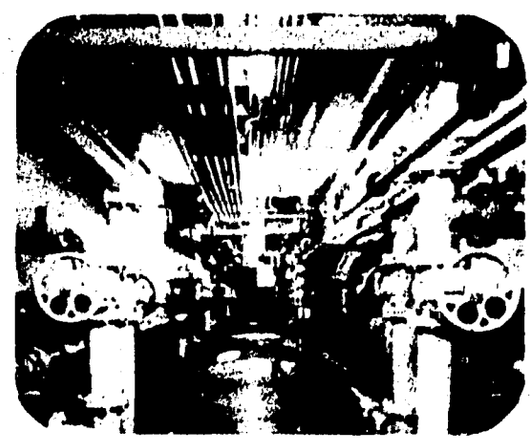
69. Dehumidifying equipment

70. Control laboratory

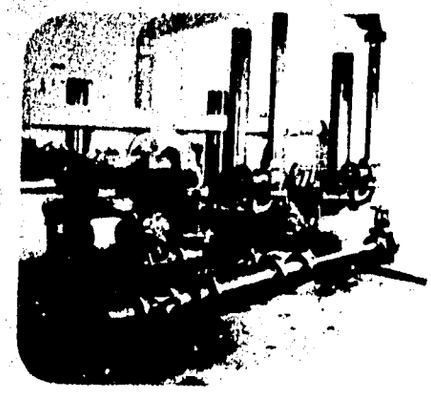
71. Chemical feeders (dry feed type)



72. Distribution of solutions of treatment liquors



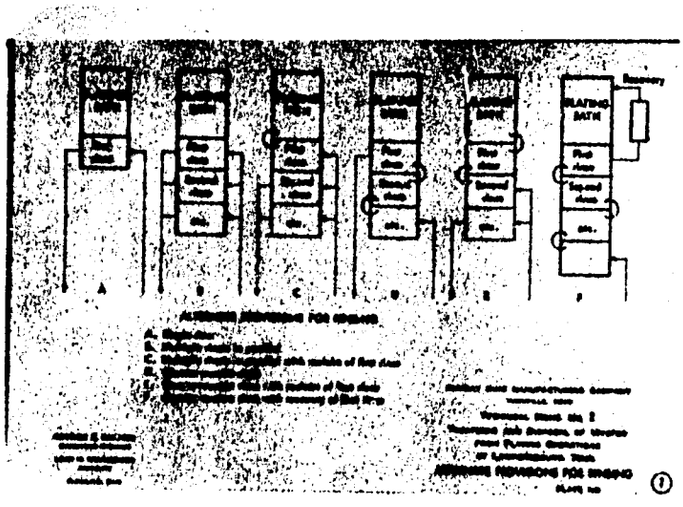
73. Control gallery



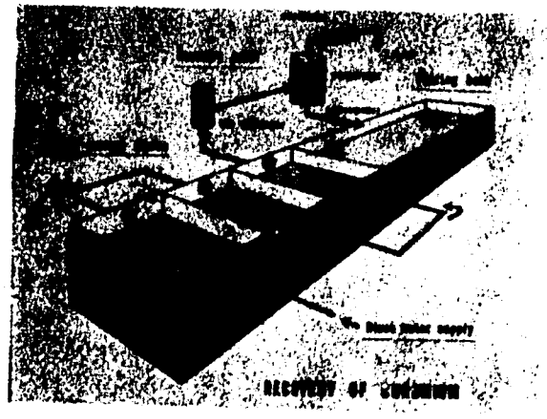
74. Pumping of sludge to storage tanks

75. Lagooning of sludge from tank tru

XIV. RECOVERY OF METALS AND CYANIDES (76-84

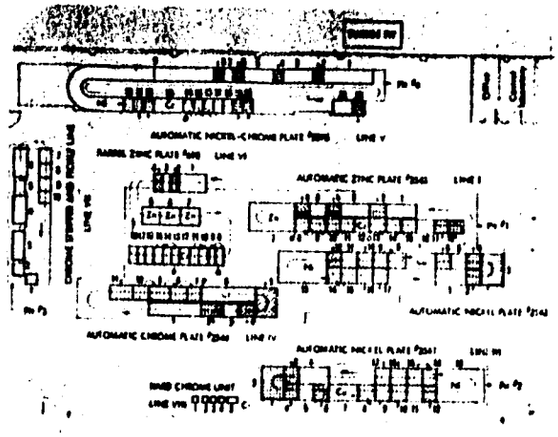


76. Plans fo multiple rinsing

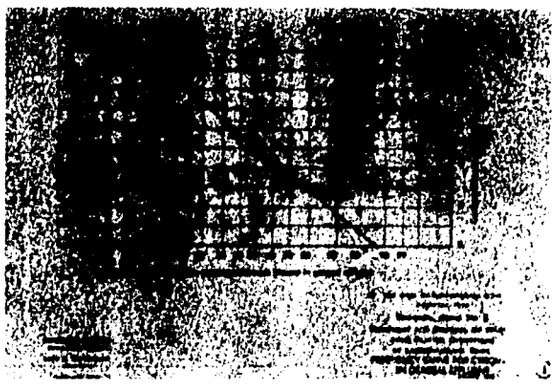


77. Recovery of chromium

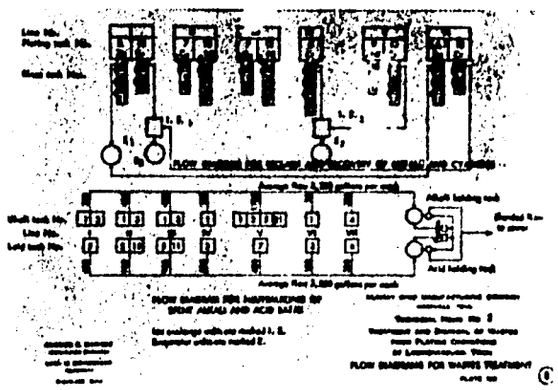
78. Rinse water requirements in multiple rinsing



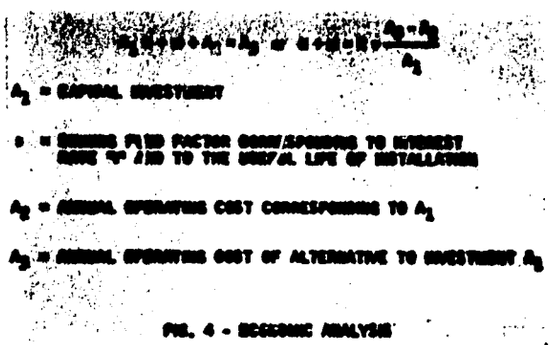
79. Layout of plating room



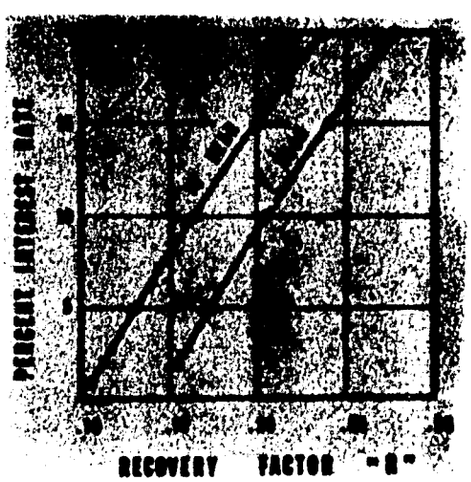
80. Results of sampling



81. Flow diagrams for disposition of wastes



82. Economic analysis



83. Recovery factor vs. interest rate for 7 and 10 year useful life.

84. Schematic analysis for economic balance

A Collection of Source Materials on the Subject of

Solid Waste Management

by: John B. Carroll
F. Eugene McJunkin
Editors

Prepared for the International Program in Environmental Aspects of Industrial Development, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, North Carolina, 17 March 1975.

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INTRODUCTIO

The following discussion is designed to provide the reader with an in depth information base on the subject of solid waste management. It is presented in essentially six parts by subject. Each part contains an in depth discussion of the topic and is generally concluded with an over view of the previous discussion.

The topics included in this discussion in the order of their presentation are:

1. Sanitary Landfill
2. Incineration
3. Composting
4. Dumping
5. Feeding Garbage to Hogs
6. Ocean Disposal

The subject matter has been drawn from American standards and practice, however, it has been edited to reduce the information to a state which can readily be interpreted in relation to other areas of the world. Where possible diagrams, tables, and photographic information has been included to aid in the discussion.

The sanitary landfill is presently the only true disposal method and is basic to any solid wastes program. Incineration is a volume reduction process and produces residues which should be sanitary landfilled. Open burning and open dumping are not solutions to the disposal problem. Feeding hogs garbage is a form of reuse. Compost is a form of processing organic wastes, such as garbage and paper, to form a humus-like soil conditioner. Such a recycling process may be incorporated in the system to handle a small percentage of solid wastes. But local governments should not base any solid wastes management system predominantly on a salvage or compost program.

sanitary landfill

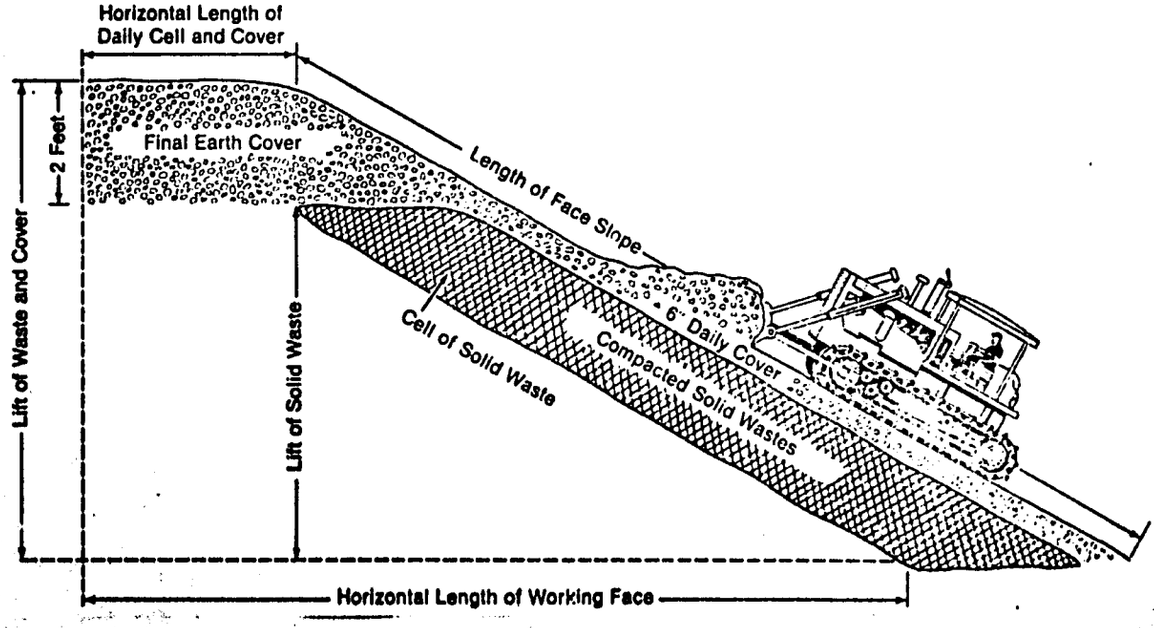
Sanitary landfill frequently is a versatile and economical disposal method. Almost any solid wastes can be disposed of in a sanitary landfill, and otherwise unusable land can often be reclaimed for community use. Major elements in the sanitary landfill process are proper placing of refuse, effective compaction, and adequate cover (see Figure B).

According to the American Society of Civil Engineers:

> Sanitary landfill is a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

No on-site burning should ever be permitted at fill. A sanitary landfill can be made operational in le incinerator or compost plant.

FIGURE B: **sectional view of a sanitary landfill**



*Inoformation taken from (I) in General Bibliography.

soils and geology

A study of the soils and geologic conditions of any area in which a sanitary landfill may be located is essential to understanding how its construction might affect the environment. The study should outline the limitations that soils and geologic conditions impose on safe, efficient design and operation.

A comprehensive study identifies and describes the soils present, their variation, and their distribution. It describes the physical and chemical properties of bedrock, particularly as it may relate to the movement of water and gas (Figure 4). Permeability and workability are essential elements of the soil evaluation, as are stratigraphy and structure of the bedrock.

Rock materials are generally classified as sedimentary, igneous, or metamorphic Sedimentary rocks are formed from the products of erosion of older rocks and from the deposits of organic matter and chemical precipitates. Igneous rocks derive from the molten mass in the depths of the earth. Metamorphic rocks are derived from both igneous and sedimentary rocks that have been altered chemically or physically by intense heat or pressure.

Sands, gravels, and clays are sedimentary in origin. The sedimentary rocks, sometimes called

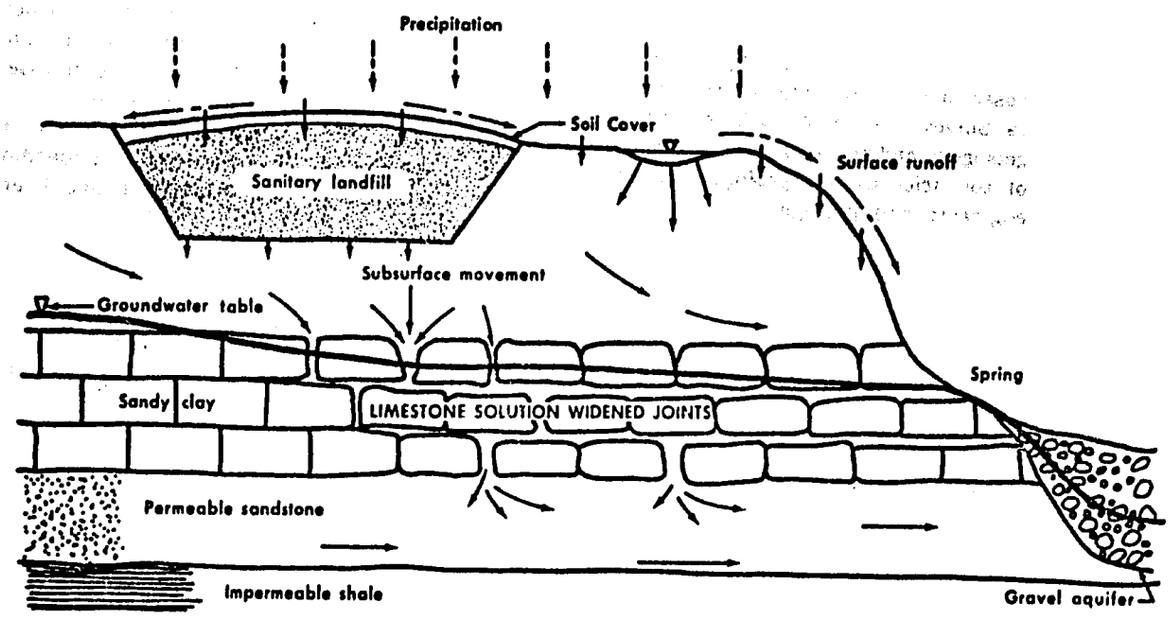


Figure 4. Leachate and infiltration movements are affected by the characteristics of the soil and bedrock.

aqueous rocks, are often very permeable and therefore represent a great potential for the flow of groundwater. If leachate develops and enters the rock strata, contaminant travel will usually be greatest in sedimentary formations. Other rocks commonly classed as sedimentary are limestone, sandstone, and conglomerates. Fracturing and jointing of sedimentary formations are common, and they increase permeability. In fact, the most productive water-bearing strata for wells are formations of porous sandstone, highly fractured limestone, and sand and gravel deposits. Siltstones and shales, which are also of sedimentary origin, usually have a very low permeability unless they have been subjected to jointing and form a series of connected open fractures.

Igneous and metamorphic rocks, such as shist, gneiss, quartzite, obsidian, marble, and granite, generally have a very low permeability. If these rocks are fractured and jointed, however, they can serve as aquifers of limited productivity. Leachate movement through them should not, therefore, be categorically discounted.

Information concerning the geology of a proposed site may be obtained from the U.S. Geological Survey, the U.S. Army Corps of Engineers, State geological and soil agencies, university departments of soil sciences and geology, and consulting soil engineers and geologists.

Soil Cover

The striking visual difference between a dump and a sanitary landfill is the use of soil cover at the latter. Its compacted solid waste is fully enclosed within a compacted earth layer at the end of each operating day, or more often if necessary.

The cover material is intended to perform many functions at a sanitary landfill (Table 4); ideally, the soil available at the site should be capable of performing all of them.

The cover material controls the ingress and egress of flies, discourages the entrance of rodents seeking food, and prevents scavenging birds from feeding on the waste. Tests have demonstrated that 6 in. of compacted sandy loam will prevent fly emergence.[1] Daily or more frequent application of soil cover greatly reduces the attraction of birds to the waste and also discourages rodents from burrowing to get food. The cover material is essential for maintaining a proper appearance of the sanitary landfill.

Many soils, when suitably compacted, have a low permeability, will not shrink, and can be used to control moisture that might otherwise enter the solid waste and produce leachate.

Control of gas movement is also an essential function of the cover material. Depending on anticipated use of the completed landfill and the sur-

TABLE 4

Suitability of General Soil Types as Cover Material*

Function	Clean gravel	Clayey-silty gravel	Clean sand	Clayey-silty sand	Silt	Clay
Prevent rodents from burrowing or tunneling	G	F-G	G	P	P	P
Keep flies from emerging	P	F	P	G	G	E†
Minimize moisture entering fill	P	F-G	P	G-E	G-E	E†
Minimize landfill gas venting through cover	P	F-G	P	G-E	G-E	E†
Provide pleasing appearance and control blowing paper	E	E	E	E	E	E
Grow vegetation	P	G	P-F	E	G-E	F-G
Be permeable for venting decomposition gas‡	E	P	G	P	P	P

* E, excellent; G, good; F, fair; P, poor.
† Except when cracks extend through the entire cover.
‡ Only if well drained.

rounding land, landfill gases can be either blocked by or vented through the cover material. A permeable soil that does not retain much water can serve as a good gas vent. Clean sand, well-graded gravel, or crushed stone are excellent when kept dry. If gases are to be prevented from venting through the cover material, a gas-impermeable soil with high moisture-holding capacity compacted at optimum conditions should be used.

Enclosing the solid waste within a compacted earth shell offers some protection against the spread of fire. Almost all soils are noncombustible, thus the earth side walls and floor help to confine a fire within the cell. Top cover over a burning cell offers less protection because it becomes undermined and caves in, thus exposing the overhead cell to the fire. The use of a compactible soil of low permeability is an excellent fire-control measure, because it minimizes the flow of oxygen into the fill.

To maintain a clean and sightly operation, blowing litter must be controlled. Almost any workable soil satisfies this requirement, but fine sands and silts without sufficient binder and moisture content may create a dust problem.

The soil cover often serves as a road bed for collection vehicles moving to and from the operating area of the fill. When it is, it should be trafficable under all weather conditions. In wet weather, most clay soils are soft and slippery.

In general, soil used to cover the final lift should be capable of growing vegetation. It should, therefore, contain adequate nutrients and have a large moisture-storage capacity. A minimum compacted thickness of 2 ft is recommended.

Comparison of the soil characteristics needed to fulfill all of these functions indicates that some anomalies exist. To serve as a road base, the soil should be well-drained so that loaded collection vehicles do not bog down. On the other hand, it should have a low permeability if water is to be kept out of the fill, fire is to be kept from spreading, and gas is not to be vented through the final cover. These differences can be solved by placing a suitable road base on top of the normally low permeability-type cover material. A reverse situation occurs when landfill gases are to be vented uniformly through the cover material. The soil should then be gas permeable, have a small moisture-storage capacity, and not be highly compacted. As before, the criteria for moisture and fire control require the soil to have a low permeability. Leachate collection and treatment facilities may be required if a highly permeable soil is used to vent gas uniformly through the cover materials; if this is not done, an alternative means of venting gas through the cover material must be sought.

There are many soils capable of fulfilling the functions of cover material. Minor differences in soil grain size or clay mineralogy can make significant differences in the behavior of soils that fall within a given soil group or division. In addition, different methods of placing and compacting the same soil can result in a significantly different behavior. Moisture content during placement, for example, is a critical factor—it influences the soil's density, strength, and porosity.

The soils present at proposed sites should be sampled by augering, coring, or excavating, and then be classified. The volume of suitable soil available for use as cover material can then be estimated and the depth of excavation for waste disposal can be determined. Specific information on the top 5 ft of the soil mantle can often be obtained from the Soil Conservation Service, U.S. Department of Agriculture.

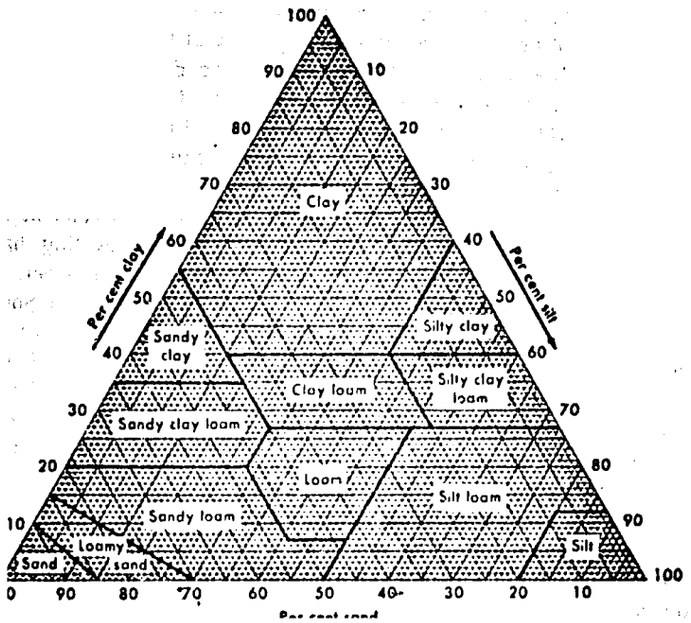
Sanitary landfilling is a carefully engineered process of solid waste disposal that involves appreciable excavating, hauling, spreading, and compacting of earth. When manipulating soils in this manner, the Unified Soil Classification System (USCS) is useful. Although recommendations for soil to be used at a landfill are often expressed in the U.S. Department of Agriculture textural classification system (Figure 5), the USCS is preferred because it relates in more detail the workability of soils from an engineering viewpoint. (Table 5).

Clay soils are very fine in texture even though they commonly contain small to moderate amounts of silt and sand. They vary greatly in their physical properties, which depend not only on the small particle size but on the type of clay minerals and soil water content. When dry, a clay soil can be almost as hard and tough as rock and can support heavy loads. When wet, it often becomes very soft, is sticky or slippery, and is very difficult to handle. A clay soil swells when it becomes wet, and its permeability is very low.

Many clay soils can absorb large amounts of water but, after drying, usually shrink and crack. These characteristics make many clays less desirable than other soils for use as a cover material. The large cracks that usually develop allow water to enter the fill and permit decomposition gases to escape. Rats and insects can also enter or leave the fill through these apertures.

Clay soil can, however, be used for special purposes at a landfill. If it is desirable to construct an impermeable lining or cover to control leachate and gas movement, many clays can be densely compacted at optimum moisture. Once they are in place, it is almost always necessary to keep them moist so they do not crack.

The suitability of coarse grained material (gravel and sand) for cover material depends mostly on grain size distribution (gradation), the shape of grains, and the amount of clay and silt fines present. If gravel, for example, is poorly graded and relatively free of fines, it is not suitable as cover material for moisture, gas, or fly control. It cannot be compacted enough, and the gravel layer will be porous and highly permeable; this would allow water to enter the fill easily. Flies would have little difficulty emerging through the loose particles. On the other hand, a gravel layer no more than 6 in. deep would probably discourage rats and other rodents from burrowing into the fill and would provide good litter control. If gravel is fairly well-graded and contains 10 to 15 percent sand and 5 percent or more



Sand—2.0 to 0.05 mm. diameter
Silt—0.05 to 0.002 mm. diameter
Clay—smaller than 0.002 mm. diameter

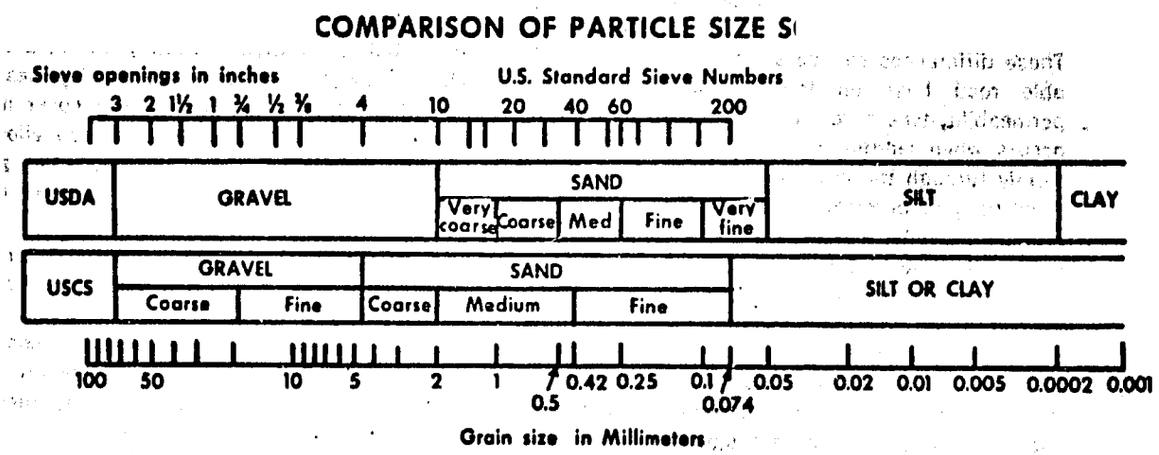


Figure 5. Textural classification chart (U.S. Department of Agriculture) and comparison of particle size scales.

TABLE 5
UNIFIED SOIL CLASSIFICATION SYSTEM AND CHARACTERISTICS PERTINENT TO SANITARY LANDFILLS

Major Divisions		SYMBOL Letter	SYMBOL Hatching	SYMBOL Color	NAME	Potential Frost Action	Drainage Characteristics*	Value for Embankments	Permeability cm per sec	Compaction Characteristics †	Std AASHO Max Unit Dry Weight lb per cu ft ‡	Requirements for Seepage Control
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		RED	Well-graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired steel-wheeled roller	125-135	Positive cutoff
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good,-tractor, rubber-tired steel-wheeled roller	115-125	Positive cutoff
		GM		YELLOW	Silty gravels, gravel-sand-silt mixtures	Slight to medium	Fair to poor Poor to practically impervious	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120 -135	Toe trench to none
		GC			Clayey gravels, gravel-sand-clay mixtures	Slight to medium	Poor to practically impervious	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	None
	SAND AND SANDY SOILS	SW		RED	Well-graded sands or gravelly sands little or no fines	None to very slight	Excellent	Very stable, pervious sections slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Upstream blanket and toe drainage or wells
		SP			Poorly graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Reasonably stable, may be used in dike sections with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Upstream blanket and toe drainage or wells
		SM		YELLOW	Silty sands, sand-silt mixtures	Slight to high	Fair to poor Poor to practically impervious	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Upstream blanket and toe drainage or wells
		SC			Clayey sands, sand-clay mixtures	Slight to high	Poor to practically impervious	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber-tired	105-125	None
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		GREEN	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium to very high	Fair to poor	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Toe trench to none
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	Practically impervious	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired	95-120	None
		OL			Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	None
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		BLUE	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Medium to very high	Fair to poor	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	None
		CH			Inorganic clays of high plasticity, fat clays	Medium	Practically impervious	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	None
		OH			Organic clays of medium to high plasticity, organic silts	Medium	Practically impervious	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	NOT RECOMMENDED FOR SANITARY LANDFILL CONSTRUCTION.						

*Values are for guidance only; design should be based on test results.

†The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled

‡Compacted sl... at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort.

fines, it can make an excellent cover. When compacted, the coarse particles maintain grain-to-grain contact, because they are held in place by the binding action of the sand and fines and cohesion of the clays. The presence of fines greatly decreases a soil's permeability. A well-graded, sandy, clayey gravel does not develop shrinkage cracks. It can control flies and rodents, provide odor control, can be worked in any weather, and supply excellent traction for collection trucks and other vehicles.

Many soils classified as sand (grain size generally in the range of 4.0 to 0.05 mm) contain small amounts of silt and clay and often some gravel-size material as well. A well-graded sand that contains less than 3 percent fines usually has good compaction characteristics. A small increase in fines, particularly silt, usually improves density and allows even better compaction. A poorly graded sand is difficult to compact unless it contains abundant fines. The permeability of clean sand soils is always high, even when compacted, and they are not, therefore, suitable for controlling the infiltration of water. They are also ineffective in constraining flies and gases.

A well-drained sandy soil can be easily worked even if temperatures fall below freezing, while a soil with a large moisture-storage capacity will freeze.

Practically the only soils that can be ruled out for use as cover material are peat and highly organic soils. Peat is an earthy soil (usually brown to black) and is composed largely of partially decomposed plant matter. It usually contains a high amount of voids, and its water content may range from 100 to 400 percent of the weight of dried solids. Peat is virtually impossible to compact, whether wet or dry. Peat deposits are scattered throughout the country but are most abundant in the States bordering the Great Lakes. Highly organic soils include sands, silts, and clays that contain at least 20 percent organic matter. They are usually very dark, have an earthy odor when freshly turned, and often contain fragments of decomposing vegetable matter. They are very difficult to compact, are normally very sticky, and can vary extremely in their moisture content.

Many soils contain stones and boulders of varying sizes, especially those in glaciated areas. The use of soils with boulders that hinder compaction should be avoided.

Soil surveys prepared by the Soil Conservation Service of the U.S. Department of Agriculture are available for a major portion of the country. Local assistance in using and interpreting them is available through soil conservation districts located in some 3,000 county seats throughout the United States. The surveys cover such specific factors as natural drainage, hazard of flooding, permeability, slope, workability, depth to rock, and stoniness. They are commonly used to locate potential areas for sanitary landfills. They also can serve as the basis for designing effective water management systems and selecting suitable plant cover to control runoff and erosion during and after completion of fill operations. Sanitary landfill owners and their consultants can avoid costly investigations of unsuitable sites by using soil surveys to select areas for which detailed investigations appear warranted. Using soil surveys for the foregoing purposes does not, however, eliminate the need for making detailed site investigations.

Land Forms

A sanitary landfill can be constructed on virtually any terrain, but some land forms require that extensive site improvements be made and expensive operational techniques followed. Flat or gently rolling land not subject to flooding is best, but this type is also highly desirable for farming and industrial parks, and this drives up the purchase price.

Depressions, such as canyons and ravines, are more efficient than flat areas from a land use standpoint since they can hold more solid waste per acre. Cover material may, however, have to be hauled in from surrounding areas. Depressions usually result when surface waters run off and erode the soil and rock. By their nature, they require special measures to keep surface waters from inundating the fill. Permeable formations that intersect the side walls or floor of the fill may also have to be lined with an impervious layer of clay or other material to control the movement of fluids.

There are also numerous man-made topographic features scattered over the country—strip mines, worked-out stone and clay quarries, open pit mines, and sand and gravel pits. In most cases, these abandoned depressions are useless, dangerous eyesores. Many of them could be safely and economically reclaimed by utilizing them as sanitary landfills. Clay pits, for example, are located in most impermeable formations, which are natural barriers to gas and water movement. Abandoned strip mines also are naturally suited for use as sanitary landfills. Most coal formations are underlaid by clays, shales, and siltstones that have a very low permeability. When permeable formations, such as sandstones, are encountered near an excavation, impermeable soil layers can be constructed from the nearby abundant spoil. Abandoned limestone, sandstone, siltstone, granite, and traprock quarries and open

pit mines generally require more extensive improvements because they are in permeable or often open-fractured formations. The pollution potential of sand and gravel pits is great, and worked-out pits consequently require extensive investigation and probably expensive improvements to control gas movement and water pollution.

Marsh and tidal lands may also be filled, but they are less desirable from an ecological point of view. They have little value as real estate, but possess considerable ecological value as nesting and feeding grounds for wildlife. Filling of such areas requires, however, the permanent lowering of the groundwater or the raising of the ground surface to keep organic and soluble solid waste from being deposited in standing water. Roads for collection vehicles are also needed, and cover material generally has to be hauled in.

REFERENCE

BLACK, R. J., and A. M. BARNES. Effect of earth cover on fly emergence from sanitary landfills. *Public Works*, 89(2):91–94, Feb. 1958. Condensed and reprinted as Fly emergence control in sanitary landfills. *Refuse Removal Journ*, 1(5):13, 25, May 1958.

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Sanitary Landfill Design

The designing of a sanitary landfill calls for developing a detailed description and plans that outline the steps to be taken to provide for the safe, efficient disposal of the quantities and types of solid wastes that are expected to be received. The designer outlines volume requirements, site improvements (clearing of the land, construction of roadways and buildings, fencing, utilities), and all the equipment necessary for day-to-day operations of the specific landfilling method involved. He also provides for controlling water pollution and the movement of decomposition gas. The sanitary landfill designer should also recommend a specific use of the site after landfilling is completed. Finally, he should determine capital costs and projected operating expenditures for the estimated life of the project.

Volume Requirements

If the rate at which solid wastes are collected and the capacity of the proposed site are known, its useful life can be estimated. The ratio of solid waste to cover material volume usually ranges between 4:1 and 3:1; it is, however, influenced by the thickness of the cover used and cell configuration. If cover material is not excavated from the fill site, this ratio may be compared with the volume of compacted soil waste and the capacity of a site determined (Figure 6). For example, a town having a 10,000 population and a per capita collection rate of 5 lb per day must dispose of, in a year, 11 acre-ft of solid waste if it is compacted to 1,000 lb per cu yd. If it were compacted to only 600 lb per cu yd, the volume disposed of in a year would occupy 19 acre-ft. The volume of soil required for the 1,000-lb density at a solid waste-to-cover ratio of 4:1 would be 2.75 acre-ft; the 600-lb density waste would need 4.75 acre-ft. A density of 800 lb per cu yd is easily achievable if the compacting of a representative municipal waste is involved. A density of 1,000 lb per cu yd can usually be obtained if the waste is spread and compacted according to procedures described in Chapter 6.

The number of tons to be disposed of at a proposed sanitary landfill can be estimated from data

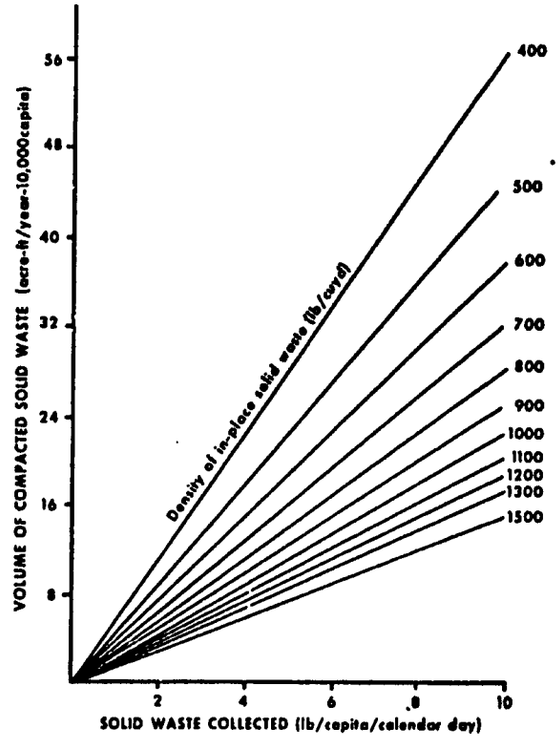

Figure 6. Determining the yearly volume of compacted solid waste generated by a community of 10,000 people.

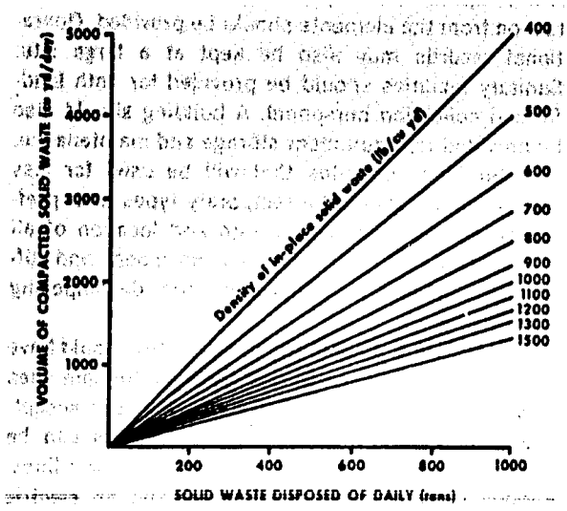

Figure 7. Determining the daily volume of compacted solid waste generated by large communities.

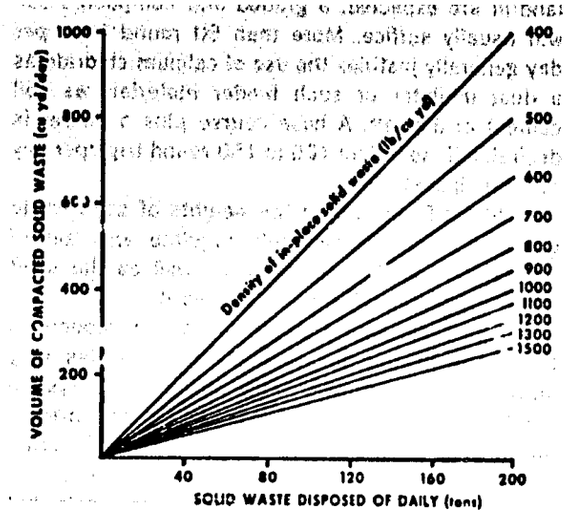

Figure 8. Determining the daily volume of compacted solid waste generated by small communities.

recorded when solid wastes are delivered to disposal sites. The daily volume of compacted solid waste can then be easily determined for a large community (Figure 7) or for a small community (Figure 8). The volume of soil required to cover each day's waste is then estimated by using the appropriate solid waste-to-cover ratio.

The terms used to report densities at landfills can be confusing. Solid waste density (field density) is the weight of a unit volume of solid waste in place. Landfill density is the weight of a unit volume of in-place solid waste divided by the volume of solid waste and its cover material. Both methods of reporting density are usually expressed as pounds per cubic yard, on an in-place weight basis, including moisture, at time of the test, unless otherwise stated.

Site Impovements

The plan for a sanitary landfill should prescribe how the site will be improved to provide an orderly and sanitary operation. This may simply involve the clearing of shrubs, trees, and other obstacles that could hinder vehicle travel and landfilling operations or it could involve the construction of buildings, roads, and utilities.

CLEARING AND GRUBBING. Trees and brush that hinder landfill equipment or collection vehicles must be removed. Trees that cannot be pushed over should be cut as close as possible to the ground so that the stumps do not hinder compaction or obstruct vehicles. Brush and tall grass in working areas can be rolled over or grubbed. A large site should be cleared in increments to avoid erosion and scarring of the land. If possible, natural windbreaks and green belts of trees or brush should be left in strategic areas to improve appearance and operation. Measures for minimizing erosion and sedimentation problems are outlined in the publication Community Action Guidebook for Soil Erosion and Sediment Control.[1]

ROADS. Permanent roads should be provided from the public road system to the site. A large site may have to have permanent roads that lead from its entrance to the vicinity of the working area. They should be designed to support the anticipated volume of truck traffic. In general, the roadway should consist of two lanes (total minimum width, 24 ft), for two-way traffic. Grades should not exceed equipment limitations. For loaded vehicles, most uphill grades should be less than 7 percent and downhill grades less than 10. Road alignments and pavement designs have been adequately discussed elsewhere.[2,3] The initial cost of permanent roads is higher than that of temporary roads, but the savings in equipment repair and maintenance could justify the building of permanent, on-site roads.

Temporary roads are normally used to deliver wastes to the working face from the permanent road system, because the location of the working face is constantly changing. Temporary roads may be constructed by compacting the natural soil present and by controlling drainage or by topping them with a layer of a tractive material, such as gravel, crushed stone, cinders, broken concrete, mortar, or bricks. Lime, cement, or asphalt binders may make such roads more serviceable.

If fewer than 25 round trips per day to the

landfill are expected, a graded and compacted soil will usually suffice. More than 50 round trips per day generally justifies the use of calcium chloride as a dust inhibitor or such binder materials as soil cement or asphalt. A base course plus a binder is desirable if more than 100 to 150 round trips per day are anticipated.

SCALES. Recording the weights of solid waste delivered to a site can help regulate and control the sanitary landfill operation as well as the solid waste collection system that serves it.

The scale type and size used will depend on the scope of the operation. Portable scales may suffice for a small site, while an elaborate system employing load cells, electronic relays, and printed output may be needed at a large sanitary landfill. Highly automated electronic scales and recorders cost more than a portable, simple, beam scale, but their use may often be justified, because they are faster and more accurate. The platform or scale deck may be constructed of wood, steel, or concrete. The first type is the least expensive, but also the least durable.

The scale should be able to weigh the largest vehicle that will use the landfill on a routine basis; 30 tons is usually adequate. Generally, the platform should be long enough to weigh all axles simultaneously. Separate axle-loading scales (portable versions) are the cheapest, but they are less accurate and slower operating. The scale platform should be 10 by 34 ft to weigh most collection vehicles. A 50-ft platform will accommodate most trucks with trailers.

The accuracy and internal mechanism of the scale and the recording device should meet the commercial requirements imposed by the State and any other jurisdiction involved, particularly if user fees are based on weight. Recommended scale requirements have been outlined by the National Bureau of Standards.[4]

Since weights are seldom recorded closer than to the nearest tenth of a ton and most applied loads are between 8 and 14 tons, a scale accuracy of ±1.0 percent is acceptable. All scales should be periodically checked and certified as to standard accuracy.

Both mechanical and electronic scales should be tested quarterly under load. The inspection should include: (1) checking for a change in indicated weight as a heavy load is moved from the front to the back of the scale; (2) observing the action of the dial during weighing for an irregularity or "catch" in its motion; (3) using test weights.

BUILDINGS. A building is needed for office space and employee facilities at all but the smallest landfill; it can also serve as a scale house. Since a landfill operates in wet and cold weather, some protection from the elements should be provided. Operational records may also be kept at a large site. Sanitary facilities should be provided for both landfill and collection personnel. A building should also be provided for equipment storage and maintenance.

Buildings on sites that will be used for less than 10 years should be temporary types and, preferably, be movable. The design and location of all structures should consider gas movement and differential settlement caused by the decomposing solid waste.

UTILITIES. All sanitary landfill sites should have electrical, water, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines, potable water may be trucked in, and an electric generator may be used instead of having power lines run into the site.

Water should be available for drinking, fire fighting, dust control, and employee sanitation. A sewer line may be called for, especially at large sites and at those where leachate is collected and treated with domestic wastewater. Telephone or radio communications are also desirable.

FENCING. Peripheral and litter fences are commonly needed at sanitary landfills. The first type is used to control or limit access, keep out children, dogs, and other large animals, screen the landfill, and delineate the property line. If vandalism and trespassing are to be discouraged, a 6-ft high fence topped with three strands of barbed wire projecting at a 45° angle is desirable. A wooden fence or a hedge may be used to screen the operation from view.

Litter fences are used to control blowing paper in the immediate vicinity of the working face. As a general rule, trench operations require less litter fencing because the solid waste tends to be confined within the walls of the trench. At a very windy trench site, a 4-ft snow fence will usually suffice. Blowing paper is more of a problem in an area operation; 6- to 10-ft litter fences are often needed. Some litter fences have been specially designed and fabricated (Figure 9). Since the location of the working face shifts frequently, litter fences should be movable.

Control of Surface Water

Surface water courses should be diverted from the sanitary landfill. Pipes may be used in gullies, ravines, and canyons that are being filled to transmit upland drainage through the site and open channels employed to divert runoff from surround-

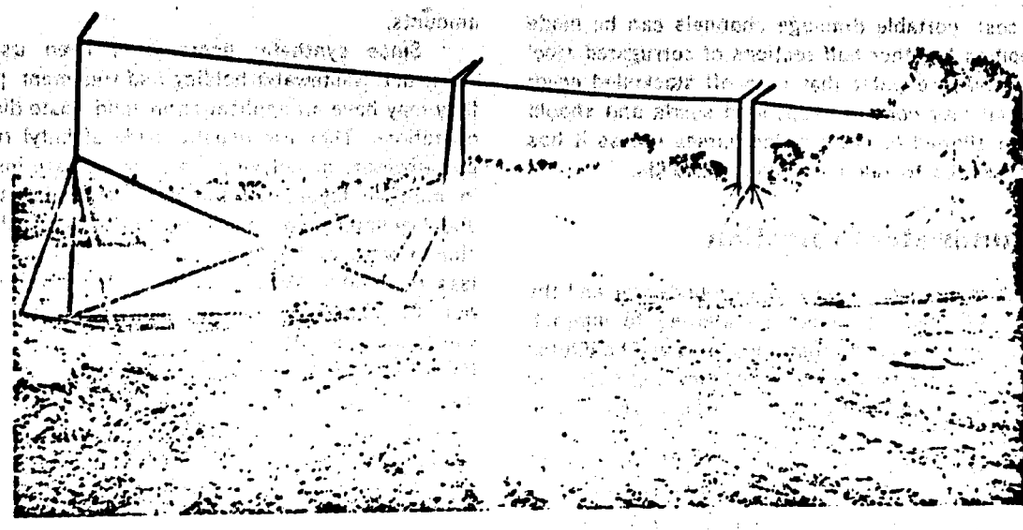

Figure 9. Specially designed and fabricated litter-control fences are often used near the working face of a sanitary landfill.

ing areas (Figure 10). Sump pumps may also be used. Because of operating and maintenance requirements, the use of mechanical equiment for water control is, however, strongly discouraged unless the control is needed only temporarily. If trenches or depressions are being filled, collection sumps and pumps may be used to keep them from flooding. Equipment sizes can be determined by analyzing storm and flood records covering about a 50-year period. Counseling and guidance in planning water management measures are available through local soil conservation districts upon request. A landfill located in a flood plain should be protected by impervious dikes and liners. The top of the dike should be wide enough for maintenance work to be carried out and may be designed for use by collection and landfill vehicles.

The top cover material of a landfill should be graded to allow runoff of rainfall. The grade of the cover will depend on the material's ability to resist erosion and the planned use of the completed site. Portable or permanent drainage channels may be

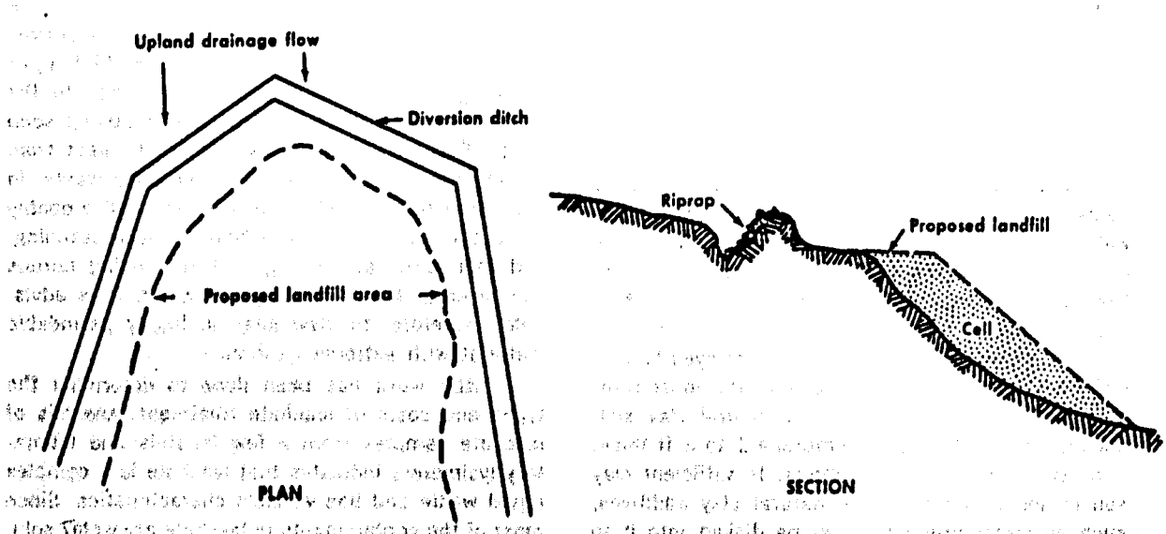

Figure 10. Plan and section views of the use of a diversion ditch to transmit upland drainage around a

constructed to intercept and remove runoff water. Low-cost, portable drainage channels can be made by bolting together half-sections of corrugated steel pipes. Surface water that runs off stockpiled cover material may contain suspended solids and should not be allowed to enter watercourses unless it has been ponded to remove settleable solids.

Groundwater Protection

It is a basic premise that groundwater and the deposited solid waste not be allowed to interact. It is unwise to assume that a leachate will be diluted in groundwater because very little mixing occurs in an aquifer since the groundwater flow there is usually laminar.

When issuing permits or certificates, many States require that groundwater and deposited solid wastes be 2 to 30 ft apart. Generally, a 5-ft separation will remove enough readily decomposed organics and coliform bacteria to make the liquid bacteriologically safe.[5, 6] On the other hand, mineral pollutants can travel long distances through soil or rock formations. In addition to other considerations, the sanitary landfill designer must evaluate the: (1) current and projected use of the water resources of the area; (2) effect of leachate on groundwater quality; (3) direction of groundwater movement; (4) interrelationship of this aquifer with other aquifers and surface waters.

Groundwater mounds, rises in the piezometric level of an aquifer in a recharge area, have been found at several landfills.[7] The mounds are reported to be up to 5 ft above the surrounding groundwater level, and they have intersected deposited solid waste. The investigators believe the water table probably rose because: (1) the permeability of the landfill's soil boundary decreased as a result of excavation and reworking; (2) more water infiltrated through the cover material and solid waste than through the undisturbed soils of the surrounding area.[7]

If a groundwater mound intersects the solid waste, leachate will undoubtedly enter the groundwater and may emerge as a spring around the toe of the fill where the groundwater table intersects the ground surface. Both surface and groundwaters may, therefore, be endangered if a mound forms.

An impermeable liner may be employed to control the movement of fluids. One of the most commonly used is a well-compacted natural clay soil, usually constructed as a membrane 1 to 3 ft thick. It must, however, be kept moist. If sufficient clay soil is not available locally, natural clay additives, such as montmorillonite, may be disked into it to form an effective liner. The use of additives requires evaluation to determine optimum types and amounts.

Since synthetic liners have been used to construct wastewater-holding-and-treatment ponds, they may have an application in solid waste disposal operations. They are usually made of butyl rubber, polyethylene, or polyvinyl chloride and are installed in multiple layers. (If the movement of both gas and leachate is to be controlled, polyvinyl chloride should work better than polyethylene because it is less permeable by gas.) The membranes must be put down carefully to avoid punctures, and layers of soil (usually sand) must be placed on both sides of them. Asphalt liners, which have been used to reduce seepage from canals and ditches, may also have an application in a solid waste disposal operation.

The use of an impermeable barrier requires that some method be provided for removal of the contained fluid. If a natural ravine or canyon is involved, the removal point should be the downstream end of the filled area. The fluid in a bowl-shaped liner could be pumped by a well or series of wells or it could exit through gravity outlets in the bottom of the liner. In the latter case, the pipes should be sloped ⅛ to ¼ in. per ft.

It is often possible to permanently or temporarily lower the groundwater in free-draining, gravelly, and sandy soils. Drains, canals, and ditches are frequently used to intercept the groundwater and channel it to surface water or recharge area at a lower elevation. Doing this generally requires that the designer have a thorough knowledge of the soil permeabilities and the groundwater flow system in the area. It is inadvisable to use temporary methods, such as wells, to lower the water table because it will rise after pumping ceases, and the waste will be inundated. It is well to recognize that highly permeable soils that can be readily drained by ditching or pumping will offer equally little resistance to the movement of leachate from the decomposing solid waste. Even though groundwater can be kept from coming into direct contact with the solid waste, in most climates infiltrated surface water will probably enter the solid waste eventually, cause leaching, and then percolate through the underlying porous soil to enter the lowered groundwater. It is advisable, therefore, to view sites in highly permeable material with extreme caution.

Little work has been done to determine the types and costs of leachate treatment. Analysis of leachate samples from a few landfills and laboratory lysimeters indicates that leachate is a complex liquid waste and has variable characteristics. Since most of the contaminants in leachate are water soluble, conventional biological and chemical treatment

methods are probably required and, hopefully, will prove effective.

To help establish if a landfill is creating a groundwater and surface water pollution problem, a series of observation wells and sampling stations can be used to periodically monitor the water quality. Data on the upstream or uncontaminated water and downstream water quality are necessary to evaluate the pollution potential.

Gas Movement Control

An important part of sanitary landfill design is controlling the movement of decomposition gases, mainly carbon dioxide and methane. Traces of hydrogen sulfide and other odorous gases may also be involved.

Methane (CH_4) is a colorless, odorless gas that is highly explosive in concentrations of 5 to 15 percent when in the presence of oxygen. In a few instances, methane gas has moved from a landfill and accumulated in explosive concentrations in sewer lines and nearby buildings. Gas from landfills has also killed nearby vegetation, presumably by excluding oxygen from the root zone. Carbon dioxide (CO_2) is also a colorless, odorless gas, but it does not support combustion. It is approximately 1.5 times as heavy as air and is soluble in water. The CO_2 reacts to a limited extent to form carbonic acid (H_2CO_3), which can dissolve mineral matter, particularly carbonates, in refuse, soil, and rock. If this occurs, the mineral content or hardness of the water increases, as has been noted at wells located near landfills and dumps.

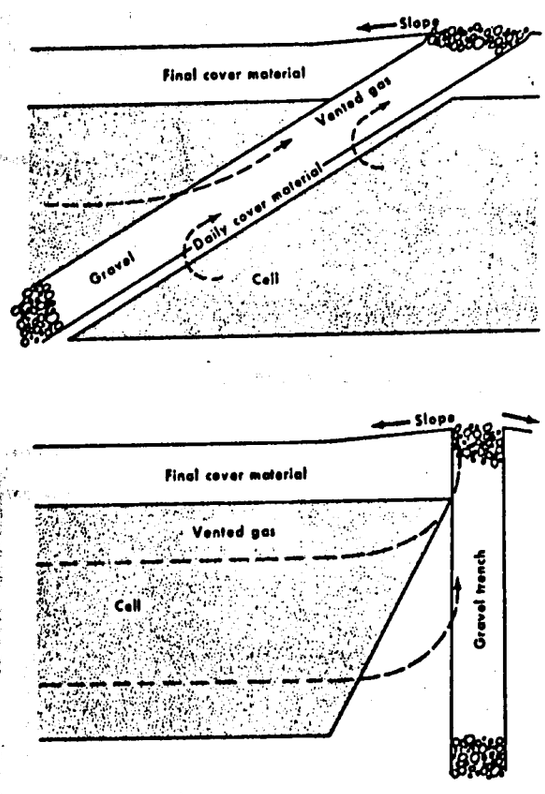

Figure 11. Gravel vents or gravel-filled trenches can be used to control lateral gas movement in a sanitary landfill.

In general, no problems arise when landfill gas can disperse into the atmosphere. If the fill has a relatively impermeable cover, however, the methane will try to vent into the atmosphere by moving laterally through a more permeable material.

The natural soil, hydrologic, and geologic conditions of the site may provide control of gas movement. If not, methods based on controlling gas permeability can be constructed. The following have been used or are considered possible.

PERMEABLE METHODS. Lateral gas movement can be prevented by using a material that is—under all circumstances—more permeable than the surrounding soil; gravel vents or gravel-filled trenches have been employed (Figure 11). Preferably, the trenches should be somewhat deeper than the fill to make sure they intercept all lateral gas flow. The filter material should be graded to avoid infiltration and clogging by adjacent soil carried in by water. If possible, the trench should be built so that it drains naturally; field tile is often placed in the bottom of the trench. The surface of gravel trenches should be kept free of soil and vegetation, because they retain moisture and hinder venting.

In another method, vent pipes are inserted through a relatively impermeable top cover (Figure 12). Collecting laterals placed in shallow gravel trenches within or on top of the waste can be connected to the vertical riser. The sizes and spacings required have not been established, but they depend on the rate of gas production, total weight of solid waste, and the gas permeability of both the cover and the surrounding soil. In some cases, vertical risers have been used to burn off the gas. Pipe vents should not be located near buildings, but if this is unavoidable, they should discharge above the roof line.

Pumped exhaust wells may be used for gas venting. In this method, pipe vents are attached to the line of a suction pump to create differential driving pressure for gas movement. This method is costly and requires frequent maintenance.

IMPERMEABLE METHODS. The movement of gas through soils can be controlled by using materials that are more impermeable to it than the surrounding soil. An impermeable barrier can be used to

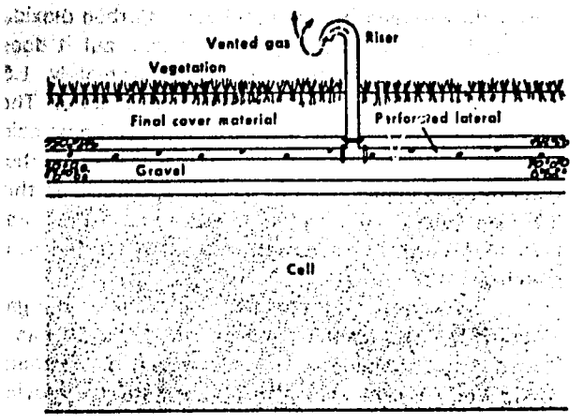

Figure 12. Gases are sometimes vented out of a sanitary landfill via pipes that are inserted through a relatively impermeable top cover and are connected to collecting laterals placed in shallow gravel trenches within or on top of the waste.

contain the gas and vent it through the top cover or simply to block the flow of gas.

The most common method, and possibly the most practical, calls for the use of compacted clay. The material must, however, be kept moist, otherwise it could shrink and crack. (Other fine grained soils may also be used, with the same stipulation.) The clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow (Figure 13). A clay layer 18 to 48 in. thick is probably adequate, but it should be continuous and not be penetrated by solid waste or outcroppings of the surrounding soil or rocks. The liner should be constructed as the fill progresses, because prolonged exposure to air will dry the clay and cause it to shrink and crack.

The use of synthetic membranes was described in the section on Groundwater Protection.

Sanitary Landfilling Methods

The designer of a sanitary landfill should prescribe the method of construction and the procedures to be followed in disposing of the solid waste, because there is no "best method" for all sites. The method selected depends on the physical conditions involved and the amount and types of solid waste to be handled.

The two basic landfilling methods are trench and area; other approaches are only modifications. In general, the trench method is used when the groundwater is low and the soil is more than 6 ft deep. It is best employed on flat or gently rolling land. The area method can be followed on most topographies and is often used if large quantities of solid

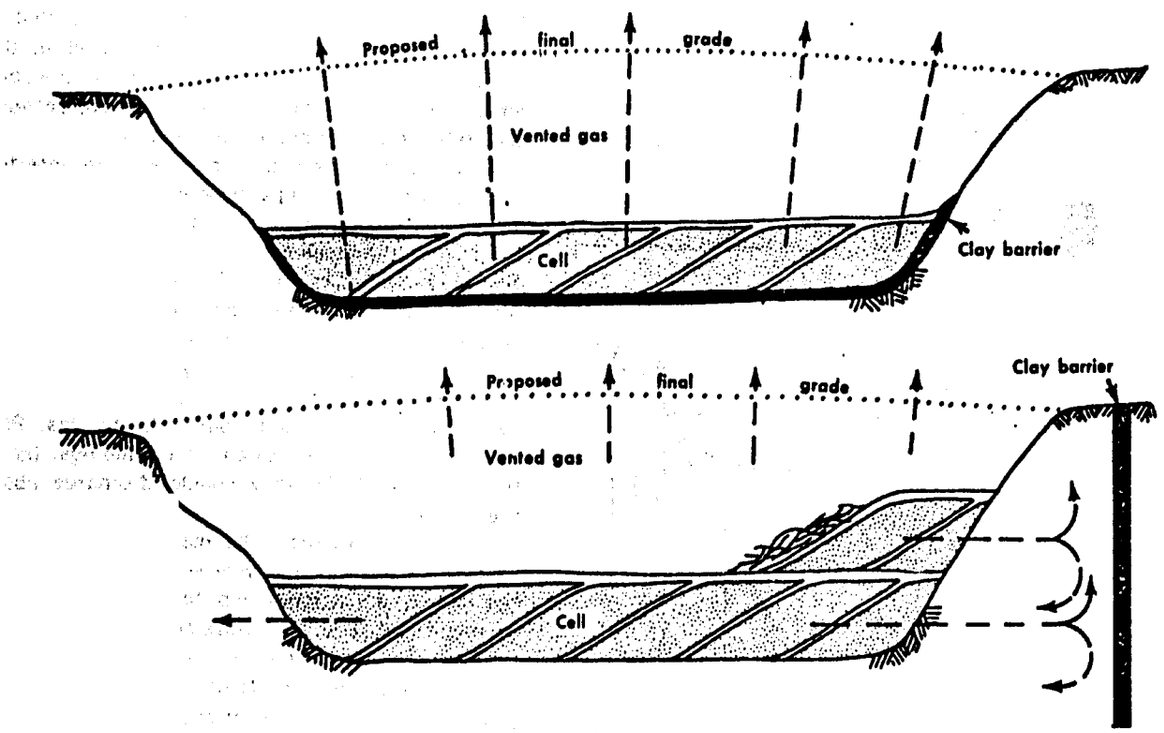

Figure 13. Clay can be placed as a liner in an excavation or installed as a curtain wall to block underground gas flow.

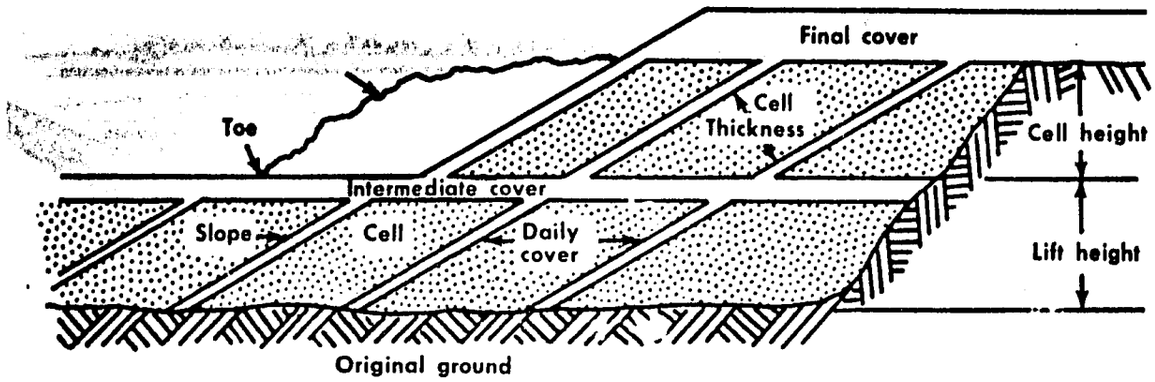

Figure 14. The cell is the common building block in sanitary landfilling. Solid waste is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil constitute a cell. A series of adjoining cells makes up a lift. The completed fill consists of one or more lifts.

waste must be disposed of. At many sites, a combination of the two methods is used.

CELL CONSTRUCTION AND COVER MATERIAL. The building block common to both methods is the cell. All the solid waste received is spread and compacted in layers within a confined area. At the end of each working day, or more frequently, it is covered completely with a thin, continuous layer of soil, which is then also compacted. The compacted waste and soil cover constitute a cell. A series of adjoining cells, all of the same height, makes up a lift (Figure 14). The completed fill consists of one or more lifts.

The dimensions of the cell are determined by the volume of the compacted waste, and this, in turn, depends on the density of the in-place solid waste. The field density of most compacted solid waste within the cell should be at least 800 lb per cu yd. (It should be considerably higher if large amounts of demolition rubble, glass, and well-compacted inorganic materials are present.) The 800-lb figure may be difficult to achieve if brushes from bushes and trees, plastic turnings, synthetic fibers, or rubber powder and trimmings predominate. Because these materials normally tend to rebound when the compacting load is released, they should be spread in layers up to 2 ft thick, then covered with 6 in. of soil. Over this, mixed solid waste should be spread and compacted. The overlying weight keeps the fluffy or elastic materials reasonably compressed.

An orderly operation should be achieved by maintaining a narrow working face (that portion of the uncompleted cell on which additional waste is spread and compacted). It should be wide enough to prevent a backlog of trucks waiting to dump, but not be so wide that it becomes impractical to manage properly—never over 150 ft.

No hard-and-fast rule can be laid down regarding the proper height of a cell. Some designers think it should be 8 ft or less, presumably because this height will not cause severe settlement problems. On the other hand, if a multiple lift operation is involved and all the cellls are built to the same height, whether 8 or 16 ft, total settlement should not differ significantly. If land and cover material are readily available, an 8-ft height restriction might be appropriate, but heights up to 30 ft are common in large operations. Rather than deciding on an arbitrary figure, the designer should attempt to keep cover material volume at a minumum while adequately disposing of as much waste as possible.

Cover material volume requirements are dependent on the surface area of waste to be covered and the thickness of soil needed to perform particular functions. As might be expected, cell configuration can greatly affect the volume of cover material needed. The surface area to be covered should, therefore, be kept minimal.

In general, the cell should be about square, and its sides should be sloped as steeply as practical operation will permit. Side slopes of 20° to 30° will not only keep the surface area, and hence the cover material volume, at a minimum but will also aid in shredding and obtaining good compaction of solid waste, particularly if it is spread in layers not greater than 2 ft thick and worked from the bottom of the slope to the top.

TRENCH METHOD. Waste is spread and compacted in an excavated trench. Cover material, which is taken from the spoil of the excavation, is spread and compacted over the waste to form the basic cell structure (Figure 15). In this method, cover material is readily available as a result of the excavation. Spoil material not needed for daily

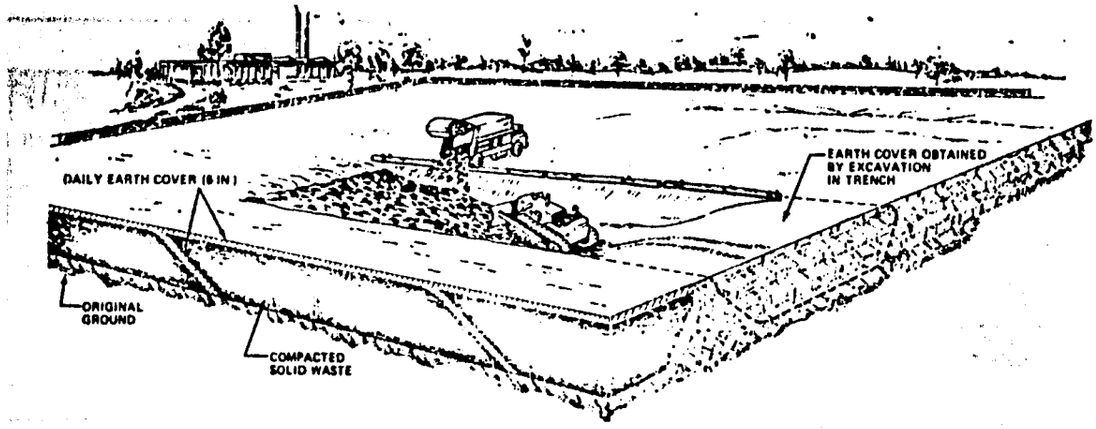

Figure 15. In the trench method of sanitary landfilling, the collection truck deposits its load into a trench where a bulldozer spreads and compacts it. At the end of the day, the trench is extended, and the excavated soil is used as daily cover material.

cover may be stockpiled and later used as a cover for an area fill operation on top of the completed trench fill.

Cohesive soils, such as glacial till or clayey silt, are desirable for use in a trench operation because the walls between the trenches can be thin and nearly vertical. The trenches can, therefore, be spaced very closely. Weather and the length of time the trench is to remain open also affect soil stability and must be considered when the slope of the trench walls is being designed. If the trenches are aligned perpendicularly to the prevailing wind, this can greatly reduce the amount of blowing litter. The bottom of the trench should be slightly sloped for drainage, and provision should be made for surface water to run off at the low end of the trench. Excavated soil can be used to form a temporary berm on the sides of the trench to divert surface water.

The trench can be as deep as soil and groundwater conditions safely allow, and it should be at least twice as wide an any compacting equipment that will work in it. The equipment at the site may excavate the trench continuously at a rate geared

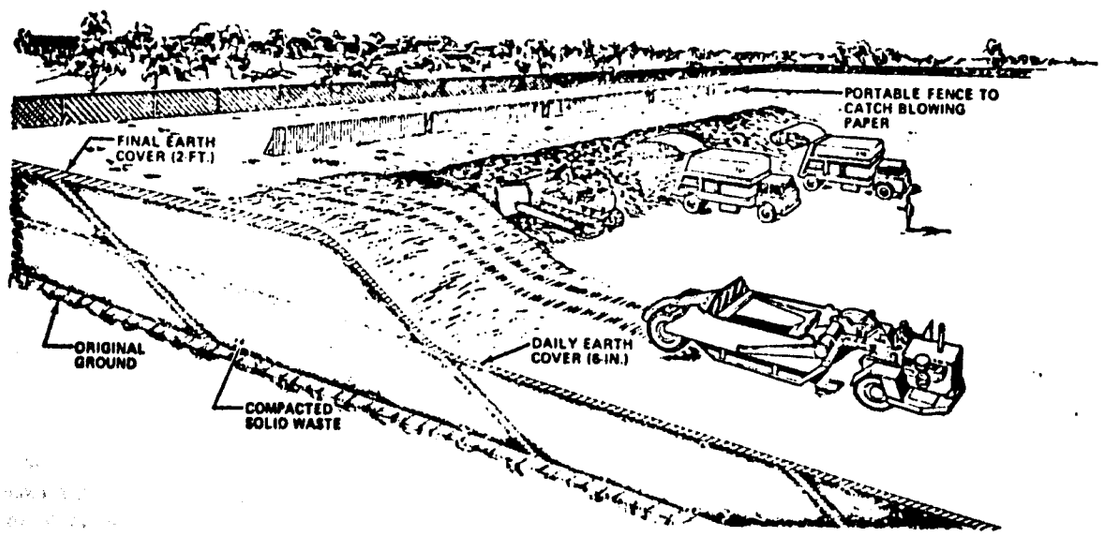

Figure 16. In the area method of sanitary landfilling, a bulldozer spreads and compacts the waste on the natural surface of the ground, and a scraper is used to haul the cover material at the end of the day's operations.

to landfilling requirements. At small sites, excavation may be done on a contract basis.

AREA METHOD. In this method, the waste is spread and compacted on the natural surface of the ground, and cover material is spread and compacted over it (Figure 16). The area method is used on flat or gently sloping land and also in quarries, strip mines, ravines, valleys, or other land depressions.

COMBINATION METHODS. A sanitary landfill does not need to be operated by using only the area or trench method. Combinations of the two are possible, and flexibility is, therefore, one of sanitary landfilling's greatest assets. The methods used can be varied according to the constraints of a particular site.

One common variation is the progressive slope or ramp method, in which the solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste (Figure 17). In this way, a small excavation is made for a portion of the next day's waste. This technique allows for more efficient use of the disposal site when a single lift is constructed than the area method does, because cover does not have to be imported, and a portion of the waste is deposited below the original surface.

Both methods might have to be used at the same site if an extremely large amount of solid waste must be disposed of. For example, at a site with a thick soil zone over much of it but with only a shallow soil over the remainder, the designer would use the trench method in the thick soil zone and use the extra spoil material obtained to carry out the area method over the rest of the site. When a site has been developed by either method, additional lifts can be constructed using the area method by having cover material hauled in.

The final surface of the completed landfill should be so designed that ponding of precipitation does not occur. Settlement must, therefore, be considered. Grading of the final surface should induce drainage but not be so extreme that the cover material is eroded. Side slopes of the completed surface should be 3 to 1 or flatter to minimize maintenance.

Finally, the designer should consider completing the sanitary landfill in phases so that portions of it can be used as parks and playgrounds, while other parts are still accepting solid wastes.

Summary of Design Considerations

The final design of a sanitary landfill should describe in detail: (1) all employee and operational facilities; (2) operational procedures and their sequence, equipment, and manpower requirements; (3) the pollution potential and methods of control-

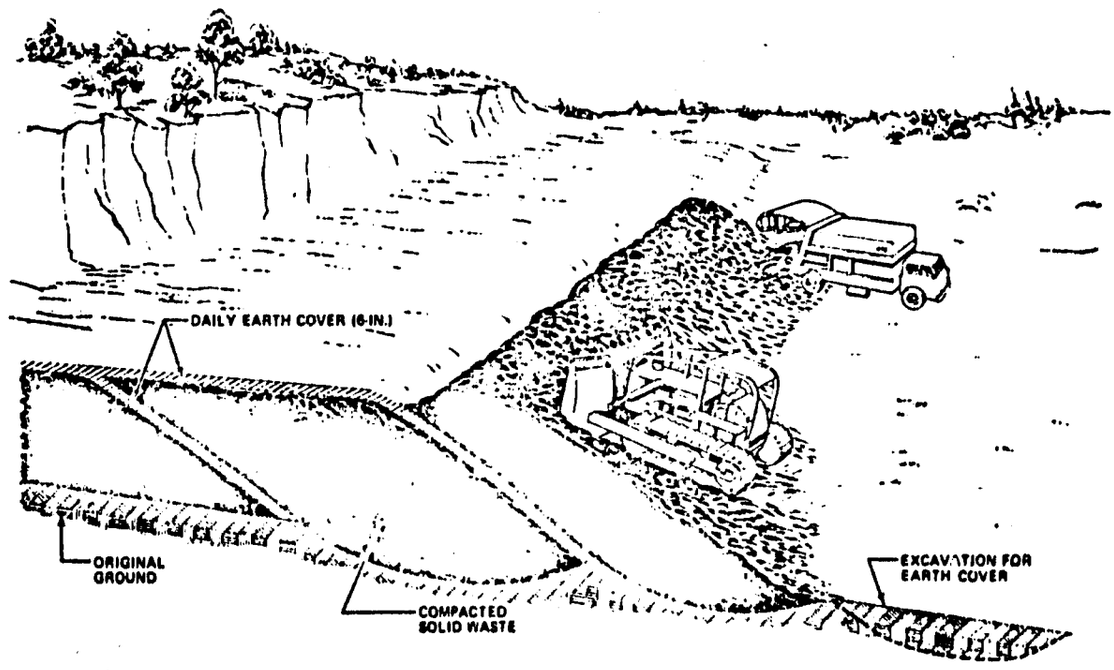

Figure 17. In the progressive slope or ramp method of sanitary landfilling, solid waste is spread and compacted on a slope. Cover material is obtained directly in front of the working face and compacted on the waste.

ling it; (4) the final grade and planned use of the completed fill; (5) cost estimates for acquiring, developing, and operating the proposed site.

The designer should also provide a map that shows the location of the site and the area to be served and a topographic map covering the area out to 1,000 ft from the site. Additional maps and cross-sections should also be included that show the planned stages of filling (startup, intermediate lifts, and completion). They should present the details of:

1. Roads on and off the site;
2. Buildings;
3. Utilities above and below ground;
4. Scales;
5. Fire protection facilities;
6. Surface drainage (natural and constructed) and groundwater;
7. Profiles of soil and bedrock;
8. Leachate collection and treatment facilities;
9. Gas control devices;
10. Buildings within 1,000 ft of property (residential, commercial, agricultural);
11. Streams, lakes, springs, and wells within 1,000 ft;
12. Borrow areas and volume of material available;
13. Direction of prevailing wind;
14. Areas to be landfilled, including special waste areas, and limitations on types of waste that may be disposed of;
15. Sequence of filling;
16. Entrance to facility;
17. Peripheral fencing;
18. Landscaping;
19. Completed use.

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equipment

There is a wide variety of equipment available for sanitary landfill operations. The types selected will depend on the amount and kinds of solid waste to be landfilled each day and on the operational methods to be employed at a particular site. Since money spent on equipment constitutes a large capital investment and accounts for a large portion of operating costs, the selection should be based on a careful evaluation of the functions to be performed and the cost and ability of various machines to meet the needs.

Equipment Functions

Sanitary landfill machines fall into three general functional categories: (1) those directly involved in handling waste; (2) those used to handle cover material; (3) those that perform support functions.

WASTE HANDLING. The practical and safe disposal of solid waste is the primary objective of a sanitary landfill. Although the handling of solid waste at a landfill site resembles an earthmoving operation, differences exist that require special consideration. Solid waste is less dense, more compactible, and more heterogeneous than earth. Spreading a given volume of solid waste requires less energy than an equal amount of soil.

Because of its size, strength, and shape, solid waste is not as conducive as soils to compaction by vibration. In the main, solid waste is compacted by the compressive forces developed by the overall massive loading of a landfill machine. If maximum compaction is desired, a large, heavy machine that is operated in accordance with the recommendations contained in Chapter 6 will give better results than a light machine. Since repeated loading of the solid waste improves its compaction, enough machines should be available that 2 to 5 compaction passes can be made during the operating day. If it is not possible to purchase a large machine, spreading the solid waste into thinner layers and making more passes with a lighter machine may suffice. The optimum number of passes depends on the moisture content and composition of the solid waste. Their exact relationships, as they affect density, have not, however, been determined.

Machines that operate on solid waste, especially during spreading and compaction, are susceptible to overheating because of clogged radiators, to broken fuel and hydraulic lines, to tire punctures, and to damage incurred when waste becomes lodged in the tracks or between the wheels and the machine body. The various accessories that are available to help alleviate these problems are discussed later in this chapter.

COVER MATERIAL HANDLING. The excavating, hauling, spreading, and compacting of cover material are similar to other earthmoving operations, such as highway construction. In landfill operations, however, rigorous control of moisture content to achieve maximum soil density is not usually practiced, although it is desirable to wet a very dry soil somewhat to hold down dust and to improve compaction. The equipment operator who spreads and compacts cover material should be capable of grading it as specified to drain the site. Specific earthmoving requirements vary according to the topographic and soil conditions present. Sand, gravel, and certain loamy clay and loamy silt soils can be excavated with wheeled equipment, but tougher natural soils require tracked machines. If the natural soil cover is thin, underlying formations composed of weathered or partially decomposed bedrock may make

suitable cover material, but they may have to be broken with a crawler equipped with a rock ripper. Rippable materials include most uncemented shale, thinly interbedded limestone and shale, poorly cemented siltstone, and partially decomposed granitic rock types. These are, however, only generalizations, and a particular soil may be easier to excavate or more difficult to work because soil properties may change significantly from season to season. Glacial till can usually be excavated by heavy tracked equipment if the compact clay has a moderate to high moisture content, as in the spring and early summer. In the late summer and fall, when less rain falls, glacial tills or clay soils of similar texture and composition dehydrate and become very hard and difficult to excavate. They must often be ripped first. Freezing weather may also require the use of a rock ripper to remove the frost layer.

SUPPORT FUNCTIONS. A sanitary landfill requires support equipment to perform such tasks as road construction and maintenance, dust control, fire protection, and possibly to provide assistance in unloading operations. Road construction and maintenance must be provided so that the working face can be reached in all types of weather. This often requires the adoption of a dust control program which, in turn, may call for the use of special equipment, such as a water wagon and sprinkler or a salt spreader. Mobile firefighting equipment may be stationed on the site or readily available nearby. Assistance in the unloading operation may include emptying collection trucks equipped with a movable bulkhead and pulling out vehicles that become stuck near the operating face during rainy weather. Unless there are many collection trucks requiring assistance, the spreading and compacting machine can handle the situation.

Equipment Types and Characteristics

A knowledge of the types and characteristics of earthmoving machines is essential if the right selection is to be made, especially since most machines can perform multiple functions.

CRAWLER MACHINES. Crawler machines are of two types: dozer and loader. Other common names for them are: bulldozer, crawler, crawler dozer, track loader, front end loader, and bullclam; many trade names are also used. They all have good flotation and traction capabilities, because their self-laying tracks provide large ground contact areas. The crawler is excellent for excavating work and moving over unstable surfaces, but it can operate approximately only 8 mph, forward or reverse.

The crawler dozer is excellent for grading and

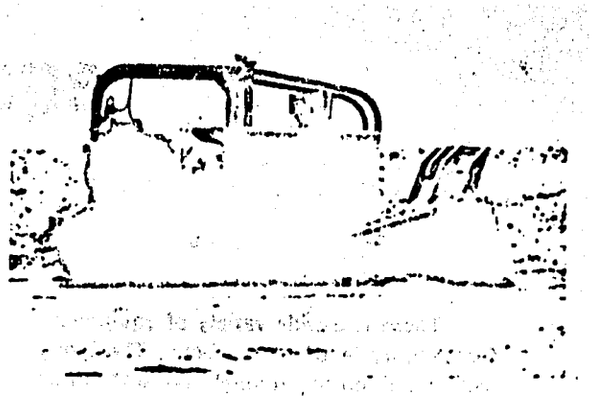

Figure 19. The crawler dozer is excellent for grading and can be economically used for dozing waste for up to 300 ft. It should be equipped with a U-shaped blade that has been fitted with a top extension to increase its pushing area.

can be economically used for dozing waste or earth over distances of up to 300 ft (Figure 19). It is usually fitted with a straight dozer blade for earthwork, but at a sanitary landfill it should be equipped with a U-shaped blade that has been fitted with a top extension (trash or landfill blade) to push more solid waste.

Unlike the crawler dozer, the crawler loader can lift materials off the ground, but its bucket is not as wide, and it is not able, therefore, to spread as much solid waste. The crawler loader is an excellent excavator and can carry soil as much as 300 ft. There are two types of buckets usually used for sanitary landfilling: the general purpose and the multiple purpose (Figures 20-21). The general-purpose bucket is a scoop of one-piece construction. The multiple-purpose bucket, which is also known as a bullclam or 4 in 1, is of two-piece construction, is hinged at the top, and is hydraulically operated. It can thus clamp onto such objects as tree trunks or telephone poles and lift and place them in the fill, or it can crush junked autos or washing machines. It is also useful in spreading cover material. The general-purpose and multiple-purpose buckets come in many sizes. Matching a bucket to a machine should be done with the advice of the machine manufacturer. A landfill blade similar to that used on dozers can also be fitted to loaders.

RUBBER-TIRED MACHINES. Both dozers and loaders are available with rubber-tired wheels. They are generally faster than crawler machines (maximum forward or reverse speed of about 29 mph) but do not excavate as well. The plausible claim has been made that because the weight of rubber-tired machines is transferred to the ground over a much smaller contact area, they provide better compaction, but significant differences of in-place density

Figure 20. Crawler loader with a general-purpose bucket of one-piece construction. The crawler loader is an excellent excavator.

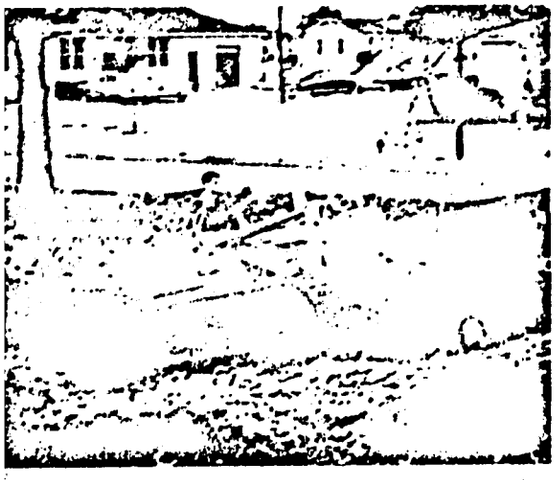

Figure 21. Crawler loader with a multiple-purpose bucket, which is also known as a bullclam or 4 in 1. The bucket can clamp onto such objects as tree trunks and telephone poles and lift and place them in the fill; it can also crush junked cars and washing machines.

Figure 22. The rubber-tired dozer is used only infrequently at sanitary landfills. Because of the rough and spongy surface formed by compacted solid waste, this machine does not grade as well as a crawler dozer.

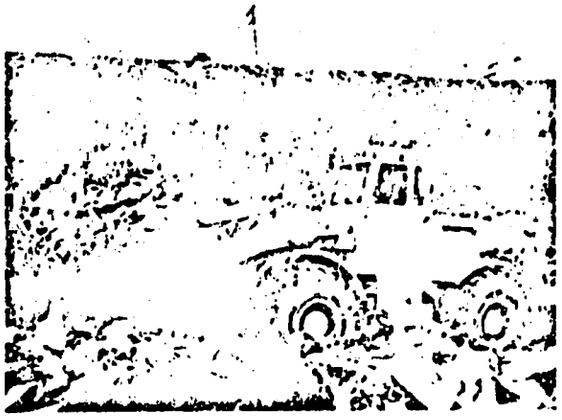

Figure 23. The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket. Because of its high operating speed, this machine is especially suited for putting cover material into haul trucks or carrying it economically for distances of up to 600 ft.

have not been proven. Because their loads are concentrated more, rubber-tired machines have less flotation and traction than crawler machines. Their higher speed, however, allows them to complete more cycles or passes in the same amount of time than a crawler machine. Rubber-tired machines perform satisfactorily on landfill sites if they are equipped with steel guarded tires, called rock tires or landfill tires. Rubber-tired machines can be economically operated at distances of up to 600 ft.

The rubber-tired dozer is not commonly used at a sanitary landfill. Because of the rough and spongy surface formed by compacted solid waste and the concentrated wheel loads, the rubber-tired dozer does not grade as well as a crawler dozer. The flotation of the crawler dozer makes it much more suitable for grading operations. The rubber-tired dozer should be equipped with a landfill or trash blade (Figure 22) similar to that recommended for a track dozer.

The rubber-tired loader is usually equipped with a general-purpose or multiple-purpose bucket (Figure 23). A particular asset of this machine is the high speed and mobility of its operation. When it is only needed part time at a sanitary landfill, it can be driven over public roads to perform other jobs. Because of its high operating speed, the rubber-tired loader is especially suited for putting cover material into haul trucks or carrying it economically over distances of up to 600 ft.

LANDFILL COMPACTORS. Several equipment manufacturers are marketing landfill compactors

equipped with large trash blades. In general, these machines are modifications of road compactors and log skidders. Rubber-tired dozers and loaders have also been modified. The power train and structure of landfill compactors are similar to those of rubber-tired machines, and their major asset is their steel wheels (Figure 24). The wheels are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators (Figure 25).

Steel-wheeled machines probably impart greater crushing and compactive effort than do rubber-tired or crawler machines. A study comparing a 47,000-lb steel-wheeled compactor, the same unit equipped with rubber tires, and a 62,000-lb crawler dozer indicated that under the same set of conditions, the in-place dry density of solid waste compacted by the steel-wheeled compactor was 13 percent greater than that effected by the crawler dozer and the rubber-tired compactor.[1]

The landfill compactor is an excellent machine for spreading and compacting on flat or level surfaces and operates fairly well on moderate slopes, but it lacks traction when operating on steep slopes or when excavating. Its maximum achievable speed while spreading and compacting on a level surface is about 23 mph, forward and reverse. This makes it faster than a crawler but slower than a rubber-tired machine. Since landfill compactors operate at high speeds and produce good in-place densities, they are best applied when they are used only for spreading and compacting solid waste and cover material. When the cover material is a clay, it and some of the solid waste lodge between the load concentrators and must be continually removed by cleaner bars. The surface of a soil layer compacted with a landfill compactor is usually covered by pits or indentations formed by the load concentrators. Numerous passes are needed to minimize the roughness of the surface.

SCRAPERS. Scrapers are available as self-propelled and towed models having a wide range of capacities (Figure 26). This type of earthmoving machine can haul cover material economically over relatively long distances (more than 1,000 ft for the self-propelled versions and 300 to 1,000 ft for towed models). Their prime function is to excavate, haul, and spread cover material. Since they are heavy when loaded, routing them over the fill area will help compact the solid waste. Hauling capacities range from 2 to 40 cu yd.

DRAGLINE. Large excavations can be made economically with a dragline. Its outstanding characteristic is its ability to dig up moderately hard soils and cast or throw them away from the excavation. Because of this feature, it can also be used to spread cover material over compacted solid waste. It is particularly useful in wetland operations. The dragline is most commonly found at large landfills where the trench method is used or where cover material is obtained from a borrow pit. As a rule

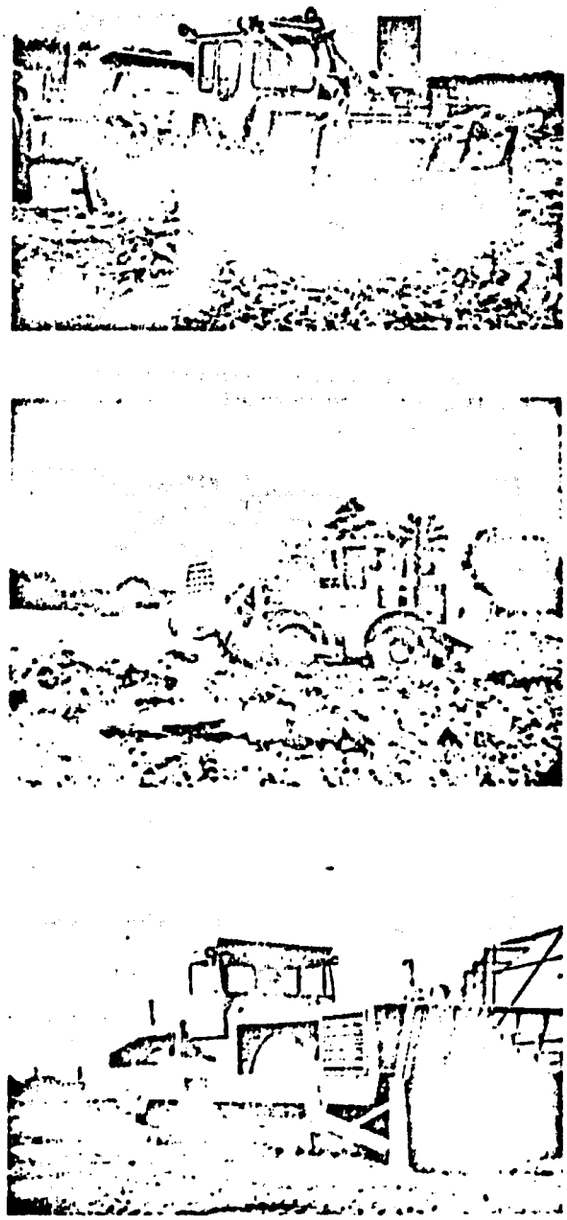

Figure 24. In general, landfill compactors are modifications of road compactors and log skidders. The power train and structure are similar to those of rubber-tired machines. The major asset of the landfill compactor is its steel wheels; it can probably achieve better compaction than a rubber-tired or crawler machine.

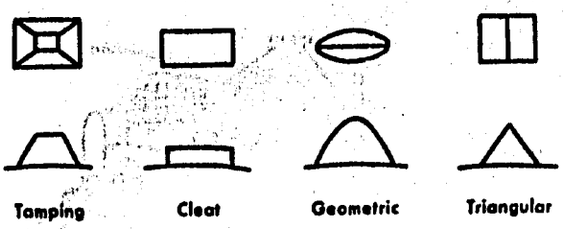

Figure 25. The wheels of a landfill compactor are either rubber tires sheathed in steel or hollow steel cores; both types are studded with load concentrators.

of thumb, the boom length should be two times the trench width. Buckets used at landfills usually range from 1 to 3 cu yd.

SPECIAL-PURPOSE EQUIPMENT. Several pieces of earthmoving and road construction equipment are put to limited use on landfills that dispose of less than 1,000 tons a day. Their purchase may not, therefore, be warranted. When they are needed, they can be borrowed, leased, rented, or the work can be performed under contract.

The road grader can be used to maintain dirt and gravel roads on the site, to grade the intermediate and final cover, and to maintain drainage channels surrounding the fill.

Water is useful in controlling blowing litter at the working face and control of dust from on-site roads. Water wagons range from converted tank trucks to highly specialized, heavy vehicles that are generally used in road construction operations. They can also be used at the landfill to fight fires.

The road sweeper is a real asset at sites where mud is tracked onto the public road system. Its periodic use will encourage local residents to accept the landfill because roadways remain safe.

ACCESSORIES. The equipment used at landfills can be provided with accessories that protect the machine and operator and increase the effectiveness and versatility of the machine (Table 8).

Engine screens and radiator guards keep paper and wire from clogging radiator pores and causing the engine to overheat. A reversible fan can also help alleviate this problem, because the direction of air flow or vane pitch can be changed in less than 5 min. Under-chassis guards can be installed to shield the engine, and hydraulic lines and other essential items of the machine should also be protected if they are susceptible to damage (Figure 27).

The operator's comfort, safety, and efficiency can be increased by providing roll bars, a canopy or cab, cab or helmet air conditioning, and backup warning systems. A canopy is especially desirable for machines that operate in a trench into which

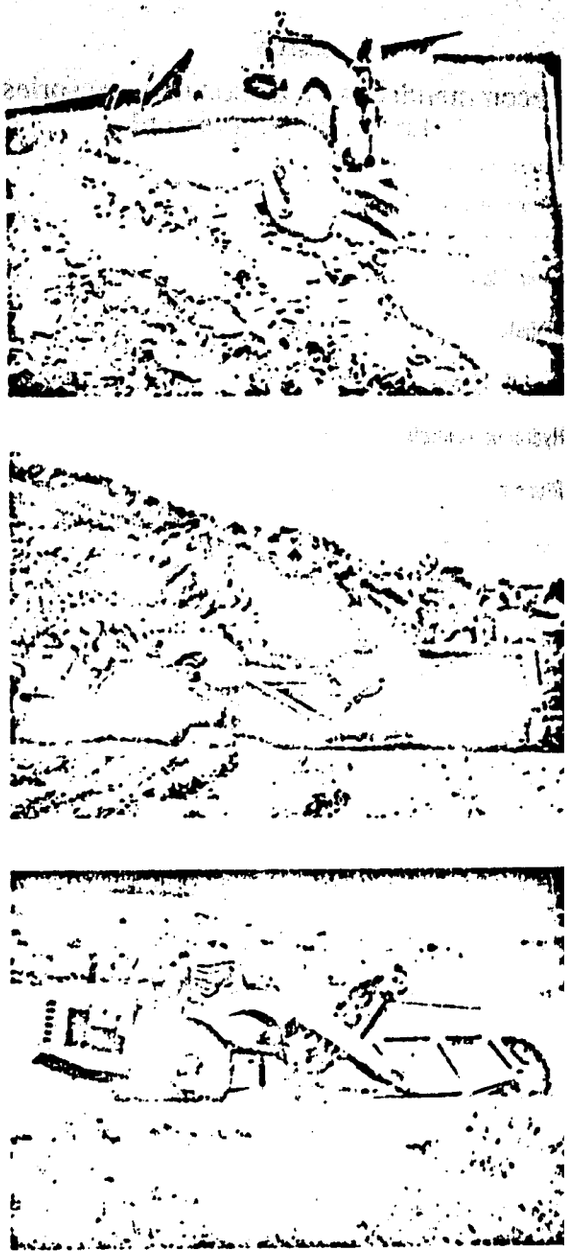

Figure 26. Scrapers are available as self-propelled or towed models; their prime function is to excavate, haul, and spread cover material. Capacities range from 2 to 40 cu yd.

waste is dumped from above. Cabs are particularly useful when the working area is very dusty or the operator must work in very cold weather. Because rubber-tired machines and landfill compactors operate at relatively high speeds, an audible backup warning system should be provided to alert other equipment operators and personnel in the immediate area. This system is also desirable on crawler

TABLE 8

Recommended and Optional Accessories for Landfill Equipment

Accessory	Dozers		Loaders		Landfill
	Crawler	Rubber-Tired	Crawler	Rubber-Tired	compactor
Dozer blade	O*	O	—	—	O
U-blade	O	O	—	—	O
Landfill blade	R†	R	O	O	R
Hydraulic controls	R	R	R	R	R
Rippers	O	—	O	—	—
Engine screens	R	R	R	R	R
Radiator guards-hinged	R	R	R	R	R
Cab or helmet air conditioning	O	O	O	O	O
Ballast weights	O	O	R	R	R
Multiple-purpose bucket	—	—	R	R	—
General-purpose bucket	—	—	O	O	—
Reversible fan	R	R	R	R	R
Steel-guarded tires	—	R	—	R	—
Life-arm extensions	—	—	O	O	—
Cleaner bars	—	—	—	—	R
Roll bars	R	R	R	R	R
Backing warning system	R	R	R	R	R

* O, Optional.
† R, Recommended.

machines, especially when two or more are operating in the same area.

Equipment versatility and effectiveness can be increased by use of a number of accessories. A hydraulically operated ripper is needed when extensive excavation must be carried out in hard soils. It should be mounted on a tracked machine to take advantage of its greater traction. (Back-rippers, hinged teeth attached to buckets or blades that dig into the soil when the machine is reversing, are not as effective as hydraulically operaed rippers.) To give rubber-tired machines and landfill compactors more traction, their wheels can be ballasted with a calcium chloride solution or water, and steel or concrete counterweights can be used on loaders and landfill compactors.

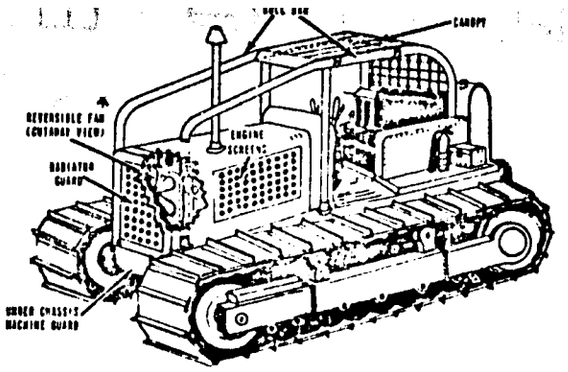

Figure 27. The equipment used at sanitary landfills can be provided with accessories that protect the machine and operator and increase their effectiveness.

Different power trains can be used on many large machines. The power shift and torque converter options are preferable to the dry clutch, direct-drive models because greater speed of operation and less strain on the engine and operator are possible with them.

COMPARISON OF CHARACTERISTICS. The ability of various machines to perform the many functions that must be carried out at a sanitary landfill should be analyzed with respect to the needs and conditions of each site (Table 9). General recommendations regarding the best types and sizes of machines to use at a specific landfill can be misleading. More exhaustive analysis is needed before the final equipment selection is made.

Size of Operation

Definition of functions and evaluation of equipment performance must be matched with the size of the landfill to determine the type, number, and size of the machines needed. No one machine is capable of performing all functions equally well. Neither can it be assumed that equipment effectively used at one site will be the most suitable elsewhere. Unfortunately, production rates expressed in tons of solid waste spread and compacted per hour are not readily available for comparison. Guides that have been proposed by equipment manufacturers and others should be considered only rough estimates of equipment needs for a particular landfill (Table 10).

SINGLE-MACHINE SITES. Particular difficulty is encountered when selecting equipment for a site

TABLE 9

Performance Characteristics of Landfill Equipment*†

Equipment	Solid Waste		Cover Material			
	Spreading	Compacting	Excavating	Spreading	Compacting	Hauling
Crawler dozer	E	G	E	E	G	NA
Carwler loader	G	G	E	G	G	NA
Rubber-tired dozer	E	G	F	G	G	NA
Rubber-tired loader	G	G	F	G	G	NA
Landfill compactor	E	E	P	G	E	NA
Scraper	NA	NA	G	E	NA	E
Dragline	NA	NA	E	F	NA	NA

* Basis of evaluation: Easily workable soil and cover material haul distance greater than 1,000 ft.
† Rating Key: E, excellent; G, good; F, fair; P, poor; NA, not applicable.

TABLE 10

Landfill Equipment Needs[1]

Solid waste handled (tons/8 hr)	Crawler loader		Crawler dozer		Rubber-tired loader	
	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)	Flywheel horsepower	Weight* (lb)
0–20	<70	<20,000	<80	<15,000	<100	<20,000
20–50	70 to 100	20,000 to 25,000	80 to 110	15,000 to 20,000	100 to 120	20,000 to 22,500
50–130	100 to 130	25,000 to 32,500	110 to 130	20,000 to 25,000	120 to 150	22,500 to 27,500
130–250	150 to 190	32,500 to 45,000	150 to 180	30,000 to 35,000	150 to 190	27,500 to 35,000
250–500	combination of machines		250 to 280	47,500 to 52,000	combination of machines	
500–plus	COMBINATION OF MACHINES					

Note: Compiled from assorted promotional material from equipment manufacturers and based on ability of one machine in stated class to spread, compact, and cover within 300 ft of working face.
* Basic weight without bucket, blade, or other accessories.

where only one machine will be used. It must be capable of spreading and compacting both solid waste and cover material, but it may also have to be used to excavate trenches or cover material. In general, the most versatile machine for a small landfill is the tracked or rubber-tired loader. If the machine will not be used full time, a wheeled loader is preferable because of its mobility. If the machine is to stay at the site full time and will not be required to load cover material into trucks, a crawler dozer may be better.

Regardless of the size of a single-machine operation, the dependability of the machine should be high. Arrangements should be made in advance to obtain a replacement if a breakdown occurs, because this development is no excuse for unacceptable disposal. A replacement machine may be made available through the equipment dealer, a local

TABLE 11

Machine Capital Cost

Machine type	Flywheel Horsepower	Weight (lb)	Equipped Machine: Approximate weight* (lb)	Equipped Machine: Approximate cost† ($)	Comment
Crawler dozer	<80	<15,000	19,000	21,000	landfill blade
	110–130	20,000–25,000	32,000	38,000	landfill blade
	250–280	47,500–52,000	67,000	70,000	landfill blade
Crawler loader	<70	<20,000	23,000	21,000	GPB‡—1 cu yd
	100–130	25,000–32,500	31,000	30,000	GPB —2 cu yd
	100–130	25,000–32,500	32,000	32,000	MPB**—1¾ cu yd
	150–190	32,500–45,000	45,000	46,000	GPB—3 cu yd
	150–190	32,500–45,000	47,000	49,000	MPB—2½ cu yd
Rubber-tired loader	<100	<20,000	17,000	21,000	GPB—1¾ cu yd
	<100	<20,000	18,000	23,000	MPB—1½ cu yd
	120–150	22,500–27,500	23,000	33,000	GPB—4 cu yd
	120–150	22,500–27,500	26,000	36,000	MPB—2¼ cu yd

* Basic machine plus engine sidescreens, radiator guards, reversible fan, roll bar, and either a landfill blade, general-purpose bucket, or multiple-purpose bucket as noted.
† June 1970.
‡ General-purpose bucket.
** Multiple-purpose bucket.

contractor, or a municipal public works department.

SMALL SITES. Municipalities disposing of less than 10 tons a day may find the cost of owning a small dozer or loader too high. If excavation and stockpiling of cover material are done on contract, a farm tractor equipped with a blade or bucket may be sufficient for spreading the solid waste. The tractor will not, however, be able to produce much compaction, even if the waste is spread in thin layers. The poor compaction achieved means that a larger fill area will be needed. This requirement, together with the total cost of the contract work, should be compared to the expense of owning and operating a small dozer or loader.

MULTIPLE-MACHINE OPERATION. It is easier to select equipment for a multiple-machine operation than it is for a one-machine operation. Such specialized machines as scrapers and landfill compactors may then be economical to use. If cover material has been stockpiled and more than one machine is available, operations need not be interrupted when an equipment breakdown occurs. As an added precaution, replacement machines should be available through a lease, contract, or borrowing arrangement.

Costs

The equipment selected for a sanitary landfill must not only be able to perform well under conditions present at the site, it must also do so at the least total cost. Equipment costs, both capital and operating, represent a significant portion of the expenses incurred in operating a sanitary landfill.

CAPITAL COSTS. Except for land, the cost of equipment may be the greatest portion of initial expenditures. The sanitary landfill equipment market is very competitive, but rough approximations of costs have been developed (Table 11). A crawler machine weighing 29,000 lb without accessories costs about $29,000. With engine sidescreens, radiator guards, reversible fan, roll bar, and a multiple-purpose bucket, the same machine costs approximately $32,000. A new dragline can cost between $75,000 and $110,000 depending on the length of its boom and cables, and the size of its bucket. In general, most landfill equipment used for excavating, spreading, and compacting has a useful life of 5 years or 10,000 operating hours.

The price of a used machine depends on its type, size, condition, and number of recorded operating hours. Specific resale values are available from auctioneers and manufacturers of earthmoving equipment. The condition and remaining useful life of used equipment should be determined by an expert.

OPERATING AND MAINTENANCE COSTS. Purchases of fuel, oil, tires, lubricants, and filters and

any expenses associated with routine maintenance are considered operating costs. Expenditures on fuel account for approximately 90 percent of operating costs. The expense of operating dozers, loaders, and landfill compactors varies according to type and make; the manufacturer should, therefore, be consulted for specific estimates. Generally speaking, direct operating costs are $3.00 per hour. The skill of the equipment operator, the type of waste handled, topography, and soil conditions also affect operating costs.

Maintenance costs, parts, and labor also vary widely but can be approximated by spreading one-half the initial cost of the machine over its anticipated useful life (10,000 hr). To make these costs more predictable, most equipment dealers offer lease agreements and maintenance contracts. Long downtimes usually associated with major repairs can be reduced by taking advantage of programs offered by most equipment dealers.

High operating costs are frequently associated with low initial costs of the equipment and vice versa. The purchaser should, therefore, require that equipment bids include estimated operating costs.

Actual operating and maintenance expenses should be determined during site operation by use of a cost accounting system.[2] This information can be used to identify areas where costs may be reduced; excessive fuel consumption, for example, may mean the machine needs adjustment or that operating procedures should be modified. Data from the cost accounting system can be used to more accurately predict operating and maintenance costs.

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2. ZAUSNER, E. R. An accounting system for sanitary landfill operations. Public Health Service Publication No. 2007. Washington. U.S. Gov-

General Summary

Determining Land and Equipment Needs. The amount of land needed for sanitary landfill operation is based on the amount of solid wastes to be landfilled. The amount will vary with the seasons, and will be greater when local government disposes of commercial, industrial, or agricultural solid wastes on a regular basis. There are no reliable formulas to determine residential, commercial, agricultural, and industrial waste amounts, so a *careful study must be made* of the solid wastes generated in the area that will be using the sanitary landfill. Weight is the most reliable basis since volume is a relative measure.

Roughly, one acre of land with a 15-ft compacted lift of solid wastes will accommodate a population of 10,000 for a year. If additional lifts can be placed over the initial lift, the land area requirement can be reduced.

Sanitary landfill equipment needs are based primarily on the daily tonnage of wastes to be landfilled. It is best to use scales at the landfill to provide the necessary data to determine daily tonnage. Scales also provide an equitable basis for fees. In a small operation, one tractor with a bucket loader (and a dump truck if cover material must be transported) can operate very well; a large operation may require several pieces of compacting and earth moving equipment. (See Figure C showing equipment needs

FIGURE C: AVERAGE EQUIPMENT REQUIREMENTS

Population	Daily tonnage	Equipment			Accessory*
		No.	Type	Size in lbs.	
0 to 15,000	0 to 40	1	Tractor crawler or rubber-tired	10,000 to 30,000	Dozer blade Front-end loader (1 to 2 yd) Trash blade
15,000 to 50,000	40 to 130	1	Tractor crawler or rubber-tired	30,000 to 60,000	Dozer blade Front-end loader (2 to 4 yd) Bullclam Trash blade
		*	Scrapper Dragline Water truck		
50,000 to 100,000	130 to 260	1 to 2	Tractor crawler or rubber-tired	30,000 or more	Dozer blade Front-end loader (2 to 5 yd) Bullclam Trash blade
		*	Scraper Dragline Water truck		
100,000 or more	260 or more	2 or more	Tractor crawler or rubber-tired	45,000 or more	Dozer blade Front-end loader Bullclam Trash blade
		*	Scraper Dragline Steel wheel compactor Road grader Water truck		

*Optional. Dependent on individual need.

Source: U.S. Department of Health, Education and Welfare, Public Health Service, National Center for Urban and Industrial Health, Solid Wastes Program Publication Number 1792 Sanitary Landfill Facts (Washington: Government Printing Office, 1968), p. 17.

based on tonnage of wastes to be filled and population served

Site Suitability. Selection of a site involves consideration of topography, population, accessibility, hauling distance, cost, time-in-motion, pollution potential, cover material, proximity of residences, citizen reaction, and ultimate usage. Sites should be chosen which will meet anticipated needs for at least the next ten years, but preferably for a 20- to 30-year period. This may mean selection of several sites, each having a life of from three to five years. Sites worth considering for use as sanitary landfills include gullies, ravines, eroded areas, marshlands, strip mines, gravel pits, and flat land.

Generally, the larger the parcel of land, the greater the economies to be gained, presuming the distance to the site is not unreasonably difficult to travel. Where disposal sites are distant, transfer stations may be required. Engineering consultants are usually enlisted to find potential landfill sites, evaluate their suitability, and determine whether transfer station operation would bring economies.

If there is standing or flowing water on the land, it must be permanently diverted before beginning the fill.

A qualified soil specialist or geologist should check the topographic, soil, and geologic conditions to insure protection of the ground water. Subsoil should be impermeable. If not, adequate soil must separate the bottom of the waste fill from the highest known ground-water level. Proper surface drainage should be provided to minimize entry of surface waters into the landfill proper. Surface drainage must be consistent with the surrounding area so the finished construction will neither interfere with proper drainage on adjacent lands nor concentrate run-off water on adjacent areas. To allow normal surface drainage and to minimize erosion, the completed fill should have at least 1 per cent slope, and be seeded to promote stabilization of the cover.

Availability of workable earth is an important factor in operating cost. If it cannot be excavated at the site, or brought in from nearby road construction or other sources, it may have to be purchased. Hauling and purchase can raise costs 25 to 50 per cent or more. The cover material should compact well and be applied thickly enough to prevent cracking and exposure of the filled wastes. In cold climates, cover material must be excavated before the ground freezes. However, freezing can be delayed by adding a mulch covering.

Before implementing a sanitary landfill operation, it is necessary to determine the final use of the land. This affects the final contour and whether all the land will be filled. Maps should be made of the present contour and property lines, and of the projected completed fill.

As wastes decompose, settling occurs. The more wastes were compacted originally, the less settling. Buildings should not be erected on filled land unless proper foundation conditions are provided.

In Waukegan, Illinois, the city's contractor is filling swampland to make it suitable for an athletic field and park. The unfilled high ground will be used to support a school building.

One of the greatest problems in obtaining a site for a sanitary landfill is overcoming public opposition, particularly if a previous landfill has been improperly operated or if dumps exist. Equip-

rent operating noise at a site is comparable to that at any excavation involving heavy equipment. Gases, mostly methane and carbon dioxide, are produced by waste decomposition. Since the sanitary landfill encloses solide wastes in cells, the chance for spontaneous combustion of gas explosion is reduced. If fire should occur, it can be more easily controlled than a fire in an open dump since the oxygen supply in the cell is limited. Moreover, the danger of fire in a sanitary landfill is much

SANITARY LANDFILL DESIGN

Site Location Requirements

The disposal site shall: (1) be easily accessible in any kind of weather to all vehicles expected to use it; (2) safeguard against water pollution originating from the disposed solid waste; (3) safeguard against uncontrolled gas movement originating from the disposed solid waste; (4) have an adequate quantity of earth cover material that is easily workable, compactible, free of large objects that would hinder compaction, and does not contain organic matter of sufficient quantity and distribution conducive to the harborage and breeding of vectors; (5) conform with land use planning of the area.

Site Design

The project plan shall include a general location map and topographic map of the area showing land use and zoning within 1/4 mile of the solid waste disposal site. The topographic map shall be of such a scale that it shows all homes, buildings, wells, watercourses, dry runs, rock outcroppings, roads, and other pertinent details.

The project plan shall also include a plot of the site that shows dimensions, location of soil or rock borings, proposed trenches or original fill face, winter cover stock piles, and fencing. Cross sections shall be included on the plot plan or on separate sheets that illustrate both the original ground and proposed fill elevations. The scale of the plot plan should not be greater than 200 feet per inch.

A report shall accompany the plans regarding; (1) population and area to be served; (2) anticipated types, quantities, and sources of solid wastes to be disposed of; (3) site geology, hydrology, and soil conditions; (4)

source and pertinent engineering properties of cover material and the projected method of protecting it for winter operations; (5) types and numbers of equipment to be used for excavating, earth moving, spreading, compacting and other purposes; (6) persons responsible for the actual operation and maintenance of the site and intended operating procedures; (7) ultimate plan for the completed site.

The design of the sanitary landfill shall include one or more topographic maps at a scale of not over 200 feet to the inch; contour intervals shall not exceed 5 feet. The maps shall show: the proposed fill area; any borrow sections; access roads; grades for proper drainage of each lift required and a typical cross section of a lift; special drainage and gas control devices if necessary; fencing; equipment shelter; existing and proposed utilities; employee facilities; and all other pertinent information to indicate clearly that the sanitary landfill will be developed, operated, and completed in an orderly manner.

The sanitary landfill should be designed by a registered professional engineer.

Operational Design Features

The disposal site shall be provided with operational features and appurtenances necessary to maintain a clean and orderly operation; (1) control of access to the site by fencing or other suitable means; (2) an all-weather access road (if excessively bad weather makes the working face inaccessible, it may be necessary to provide a landfill area near the entrance to the site; (3) suitable devices, such as portable fences, for litter control.

In addition to the required features, there are others that are highly recommended: (1) operational plans to direct and control the use of the site; (2) signs indicating traffic flow, hours of operation, and any charges for disposal; (3) scales for weighing the solid waste received (in a small operation periodic weighing on public or other scales is acceptable; (4) dust control methods (these may require the use of chemicals, oils, or water sprays); (5) communication devices for emergency use and for operational control; (6) electrical service for operations and repairs; (7) fire protection and fire-fighting facilities adequate to ensure the safety of employees and provisions for dealing with accidental burning of solid waste in the landfill; (8) first-aid equipment and training.

Personnel and Personnel Facilities

In order to man and operate the site adequately the following are recommended: (1) a trained supervisor or foreman and trained equipment operators; (2) a shelter for employees to use during inclement weather; (3) a potable water supply for landfill personnel and collection crews; (4) sanitary toilets on or near the site; (5) training in the proper and safe operation of all equipment.

Equipment

To assure safe and efficient operation the following are required: (1) sufficient equipment for spreading, compacting, and covering operations; (2) arrangements whereby alternate equipment is provided within 24 hours following an equipment breakdown.

As a further aid, the following are recommended: (1) safety devices on equipment to shield and protect operators; (2) maintenance and storage shelters.

SANITARY LANDFILL CONSTRUCTION

General

Certain operations must be carried out:

1. Access to the site must be controlled to keep unauthorized persons out and to assist the landfilling operation. (Access shall be allowed only when an attendant is on duty and only to authorized users.)
2. Burning of waste material shall be prohibited.

3. Blowing paper shall be controlled by providing a portable fence near the working area, and the entire area shall be policed at least daily.

4. Salvaging and scavenging shall not be allowed at the working face.

5. Provision shall be made to ensure that no pollution of surface or ground water is created.

6. Provisions shall be made for on-site control of potential gas movement from the landfill.

Other operations are strongly recommended:

1. Operational records should be maintained daily. They should include the type, weight, and volume of solid wastes received; type and volume of cover material used, the portion of the landfill used (determined by cross section and survey); any deviations made from the original plan of operation; and equipment maintenance and cost records. A monthly report should be prepared that describes the amounts of solid waste received, the area of the fill used, the volume of the fill used, and the amount of the cover material used. The report should be submitted to the appropriate governmental agency. Cost records should be maintained and should conform to those recommended by the Solid Waste Management Office in *An Accounting System for Sanitary Landfill Operations*, U.S. Public Health Service Publication No. 2007.

2. Upland surface drainage should be diverted around the site to control infiltration at the fill site and erosion of the in-place cover material.

3. Conditions unfavorable for the habitation and production of insects and rodents should be maintained by carrying out sanitary landfill operations promptly and systematically. It is recommended that the site be inspected regularly by an independent pest control firm and certified reports submitted to the appropriate government agency. Supplemental vector control measures should be instituted when necessary. Domestic animals should be excluded from the site, and proper control measures should be used to control wildlife, when necessary.

4. A detailed description and a plat of the completed fill site (as built) should be recorded with the proper local agency responsible for maintaining titles and records of land to provide notice to future users and owners of the site. The detailed description should include but not be limited to: type and location of pollution controls, and original and final terrain descriptions.

5. Continual training of personnel in the proper operation of a sanitary landfill should be provided.

Landfilling

Certain procedures are required during landfilling:

1. The working face shall be as small an area as the equipment can safely and efficiently operate in.

2. The solid waste shall be spread and compacted in thin layers. In the construction of each cell, it shall be spread into layers that do not exceed 2 feet prior to compaction. The number of layers incorporated into a cell depends on the design and configuration of the site.

3. All solid waste shall be covered daily with at least 6 inches of compacted soil. Daily cover has three main functions: to provide insect and rodent control, to provide fire breaks between cells, and to prevent exposure and blowing of litter and to offer an aesthetically pleasing site at the end of the working day. The in-place cover must be maintained until further filling or the addition of final cover is made.

4. Final cover shall be applied to any surface that represents the final grade of the sanitary landfill; 2 feet of compacted soil is required. Trees, shrubs, and other plants often require more than two feet of soil to grow. Suitable grasses should be planted to prevent erosion and surface deterioration. Final cover shall be placed over any completed section of

the fill within 7 days following the placement of solid waste within that portion.

Other procedures are recommended during landfilling:

1. Supervision should be available to coordinate all unloading activities.

2. Special provisions should be made for vehicles being unloaded by hand so that the flow of mechanically unloading vehicles is not impaired.

3. Final cover should be graded to drain surface run-off water. For this reason, it is best to slightly overdesign initial grades so that when settlement occurs, the surface will be sufficient for good drainage. The top surface should slope 2 to 4 percent, and the side slopes should not be so steep as to cause an erosion problem.

Special Waste Handling

Handling and disposing of waste sludges, waste liquids, and hazardous materials shall be given special consideration with regard to water pollution and the health and safety of employees. Large bulky items should be reduced in volume before daily cover is applied.

Supervision and Inspection

The following recommendations apply:

1. The supervisor of the operation should be an individual who has had experience in earthmoving, waste handling, and disposal.

2. Routine inspection and evaluation of landfill operations should be made by a representative of the appropriate regulatory agency. A notice of any deficiencies, together with any recommendations for their correction, should be provided to the owner or agent responsible for the use of the land and the appropriate individual or firm or governmental agency responsible for the landfill operation.

3. A representative of the appropriate regulatory agency should inspect the completed sanitary landfill before the earth-moving equipment is removed, and any corrective work should be performed before the landfill project is accepted as completed. Arrangements should be made for all cracked, eroded, and uneven areas in the final cover to be repaired as required during the years following completion of the fill.

SANITARY LANDFILL EVALUATION

This evaluation method is intended to measure the level of acceptability of the operations taking place at a disposal site, as well as to provide an overall comparison of its suitability to that of other evaluated sites. The evaluation consists of two subsets of evaluative criteria. The first subset comprises 10 Requirements, all of which must be satisfied if the site is to qualify as a sanitary landfill.

If the operation is a sanitary landfill, the second subset (13 Recommended Items) is provided to achieve a broader evaluation of other features of sanitary landfill design and construction. Operations vary due to size and locality, and certain items may not be required. An exceptional sanitary landfill would meet all Requirements and Items.

Each Requirement and Item in the evaluation is followed by a statement of what is needed to qualify, the reasoning for the statement, and the criteria that must be met. The sanitary landfill should be inspected in detail in order to complete the evaluation. (A suggested check list is included to aid in the evaluation.) Some criteria will require that the operator or supervisor answer certain questions, and precautions should be taken, therefore, to assure that the questions are understood and that the answers are reliable. If possible, written documentation should support the answers.

Sanitary Landfill Requirements

Requirement A: Open Burning Prohibited. No solid waste shall be burned at the sanitary landfill.

Basis: Open burning of solid waste creates odors, air pollution, and fire and safety hazards. It also adversely affects public acceptance of the operation and proper location of future sanitary landfill sites. Local laws that allow or require the open burning of such materials as diseased elm trees and condemned dry foods are outmoded. Such materials can either be incorporated with in the sanitary landfill or disposed of in such a manner as to prevent health hazards or nuisances. Open burning for any reason converts the operation to that of the open dump.

Open burning of solid waste on the site is prohibited at all times. Yes__ No__

Requirement B: Access Limited. Access to a sanitary landfill shall be limited to those times when an attendant is on duty and only to those authorized to dispose of solid waste.

Basis: If public use is allowed when no attendant is on duty, scavenging, burning, and indiscriminate dumping commonly occur. Men and equipment must then be diverted to restore sanitary conditions. When access to the site during operating hours is limited to those authorized, traffic and other accident hazards are minimized.

Access by unauthorized vehicles or pedestrians is controlled. Yes__ No__

Requirement C: Spreading and Compacting. Solid waste shall be spread in uniform layers not over 2 feet thick prior to compaction.

Basis: Successful operation and maximum utilization of a sanitary landfill depend on adequate compaction of the solid waste. In addition, settlement will be excessive and uneven if this is not done. Settlement permits invasion by insects and rodents and severely limits the usefulness of the finished area.

Compaction is best initiated by spreading the solid waste evenly in shallow layers, and better compaction is achieved if the working face is operated on a slope. Further compaction is provided by the repeated travel of equipment over the layer, and, if necessary, by the use of special equipment.

Solid waste is properly spread and compacted. Yes__ No__

Requirement D: Daily Cover. A uniform compacted layer of at least 6 inches of suitable earth cover shall be placed on all exposed solid waste by the end of each working day.

Basis: Daily covering is necessary to prevent insect and rodent infestation, blowing litter, fire hazards, an unsightly appearance, and to control gas and water movement. Fly emergence generally is prevented by 6 inches of compacted soil. Daily covering also divides the fill into "cells" that will limit any underground fires that might occur. The cover material should be easily workable and compactible, should be free of large objects, and should not contain organic matter of sufficient quantity and distribution conducive to the harborage and breeding of vectors.

A uniform, compacted layer of at least 6 inches of suitable earth cover is used for daily cover. Yes__ No__

Requirement E: Final Cover. A uniform layer of earth cover compacted to a minimum depth of 2 feet shall be placed over the entire covered surface of each portion of the final lift. This shall be done not later than one week following the placement of solid waste within that portion.

Basis: A minimum final cover of 2 feet of compacted suitable earth cover will prevent emergence of insects from the compacted solid waste, minimize the excape of odors,

prevent rodents from burrowing, provide for control of gas and water movement, support plant growth, and provide an aesthetically acceptable finished site. This cover also provides an adequate bearing surface for vehicles and is of sufficient thickness for cover integrity in the event of settlement or erosion. Workability and compaction characteristics should at least equal those provided for daily cover.

A minimum final cover of 2 feet of compacted earth cover is used as stated.
Yes__No__

Requirement F: Environmental Protection. The location and the operation must have the approval of the appropriate governmental agency, such as the State Department of Health. There shall be no contamination of ground or surface waters by deposited solid wastes or their products of decomposition, and no hazard or nuisance caused by gases or other products generated by the biologically or chemically active wastes.

Basis: Location, nature of the waste deposited, and substandard operational procedures may lead to pollution of surface waters or underground aquifers. Unless proper standards of location and operations are followed offensive and dangerous concentrations of gases may occur in the soil or above ground and adversely affect the environment. It may be necessary to provide special construction techniques or alter operations to control such conditions.

Solid waste is placed so that the environment is not and will not be adversely affected.
Yes__No__

Requirement G: Blowing Litter Controlled. Blowing litter shall be controlled by fencing placed near the working area or by the use of earth banks or natural barriers. The entire site shall be policed at least daily. Unloading shall be performed so as to minimize the scattering of the solid waste.

Basis: The purpose of the sanitary landfill is to dispose of solid waste in a nuisance-free manner. If papers and other light materials are scattered and the area is not policed, fire hazards, nuisances, and unsightliness result.

Blowing litter is controlled and the site and surrounding area routinely policed.
Yes__No__

Requirement H: Salvage Prohibited. Salvaging shall not be permitted at the working face of the sanitary landfill.*

Basis: Nothing can be tolerated that interferes with the prompt sanitary disposal of solid waste. Salvaging at the working face delays the filling operation and creates unsanitary conditions. The accumulation of salvaged materials also provides harborage for vectors and promotes an unsightliness that can be detrimental to public acceptance of the operation.

Salvaging is never allowed at the working face.
Yes__No__

Requirement I: Operational Considerations. Provision shall be made for all-weather access roads leading to the disposal site, and written provisions and guarantees shall be made for the replacement of operating equipment when it is down for more than 24 hours.

Basis: The purpose of a sanitary landfill is the immediate disposal of solid waste, because this results in the elimination of nuisances and produces an aesthetically acceptable operation. A major breakdown of operating equipment for more than 24 hours reverts the

*Any salvage or reclamation of solid waste materials must take place in a systematic and controlled manner at some site other than the operating area. If such a facility is physically located on the same land plat or nearby, it should *not* be considered part of the sanitary landfill operation.

sanitary landfill operation to an open dump. Access roads that are not negotiable by collection vehicles cause unnecessary delays in the disposal operation.

Sanitary landfills utilizing more than one piece of equipment are normally able to operate efficiently even if one piece of equipment has a major breakdown because it may have sufficient reserve capacity. Smaller operations that involve only one piece of equipment require some type of prior written agreement that guarantees the equivalent of standby equipment within 24 hours after any major breakdown.

Heavy duty use of equipment requires that a schedule of inspection and maintenance be followed to keep it operational under normal conditions (See Recommended Item 5).

Provisions have been made to assure all-weather access roads and to guarantee the equivalent of standby equipment within 24 hours following major breakdown to normal operating equipment. Yes__No__

Requirement J: Special Waste Handling. Toxic, pathogenic, corrosive, flammable, explosive, and other hazardous wastes shall be handled only if special provisions are made.

Basis: Materials such as oil sludges, chemical wastes, magnesium shavings, empty pesticide containers, and contaminated medical wastes can be a special hazard to employees and to the environment if their presence is not known or if they are improperly handled. The site must also have special evaluations to determine that there will be no adverse effects on the environment.

Suitable procedures are established and followed for disposal of special wastes or the wastes are excluded. Yes__No__

Sanitary Landfill Recommended Items

ITEM 1: Instructions for Users. Signs should be posted that clearly indicate the purpose of the operation, the owner or operator of the site, hours of operation, instructions for after-hours delivery, materials accepted or excluded, fees charges, and emergency telephone numbers.

Basis: The site is typically intended to include use by the general public, and guidance must, therefore, be given regarding the location and purpose of the activity and its relationship to the user. Proper use of the site is not guaranteed, but instruction is an essential step in gaining compliance.

A sanitary landfill may sometimes be called a "land reclamation project" or something similar but *never* a "dump," because this term connotes an unacceptable operation. Provision of some method of storage, such as a bulk container near the gate, is an added service for the small hauler or householder who arrives after hours. Persons arriving at the site should quickly be able to determine if their material will be accepted and if so, the cost per unit (ton, cubic yard, etc.). If there should be an emergency such as a fire, either during or after working hours, or a person is injured, clearly posted numbers will expedite obtaining assistance.

Suitable informational and directional signing is provided at the entrance and/or other appropriate locations. Yes__No__

ITEM 2: Measuring Facilities. Provision should be made for weighing or adequately measuring all the solid waste delivered.

Basis: A suitable method of measuring incoming or deposited solid waste is desirable to provide a reliable quantity of data to determine trends and to estimate needs. Estimates of volumes based on truckloads rather than weights are misleading. Weighing is the best basis for establishing fees, and scales should be required as an integral part of the operation. Determination of the volume increments in deposited solid waste may be done

by making periodic volumetric surveys; this permits the use-rate and remaining capacity of the site to be evaluated.

Suitable fixed or portable scales have been installed and are used continuously, or the sanitary landfill is routinely "cross-sectioned" at least every 30 days to determine volumes in place. Yes__No__

ITEM 3: Communications. Telephone or radio communications should be provided.

Basis: Communications are desirable at the generally remote sanitary landfill sites, in case of emergency. If the sanitary landfill is part of a combined collection and disposal system, good communications will result in better performance throughout the system.

Reliable communications are installed at the site. Yes__No__

ITEM 4: Employee Facilities. Suitable shelter and sanitary facilities should be provided for personnel.

Basis: Shelter should be available to employees during inclement weather, and toilet and handwashing facilities are desirable.

Permanent or temporary shelter of adequate size is provided along with safe drinking water, sanitary handwashing and toilet facilities, suitable heating facilities, screens, and electricity (if needed). Yes__No__

ITEM 5: Equipment Maintenance. Provision should be made for routine maintenance of equipment and for prompt repair or replacement.

Basis: Equipment breakdowns of a day or more result in the accumulation of uncovered solid waste (as at an open dump) with all the attendant health hazards and nuisances. Systematic, routine maintenance of equipment reduces repair costs, increases life expectancy, and helps to prevent breakdowns. In the event of a breakdown, prompt repair of equipment will materially shorten down time.

Facilities for routine maintenance are available, and provisions for major maintenance and repair have been made. Yes__No__

ITEM 6: Unloading Area and Working Face. The unloading of the solid waste should be controlled and restricted to an area where the material can easily be incorporated into the working face with the equipment available.

Basis: Proper operation requires systematic placement of the solid waste in a restricted unloading area. Unloading must be coordinated with spreading and compacting. Controlled unloading reduces work, conserves landfill volume, permits better compaction, minimizes scattering of solid waste, and expedites unloading.

The type and size of the unloading area depends on the amount of solid waste received, the type of operation, and the size of the working face. A large working face increases the area to be compacted and covered, with resulting high cost, delays, and unnecessarily exposed solid waste.

Unloading is controlled at all times by signs or a supervisor, and the size of the unloading area is balanced with the size of the working face to allow collection vehicles to unload promptly. Yes__No__

ITEM 7: Fire Protection. Suitable measures should be taken to prevent fires and to control them if they start.

Basis: Fires endanger life and property. Smoke and odors are nuisances to nearby property owners, endanger disposal personnel, and interfere with sanitary landfilling operations. Deliberate burning makes sanitary landfills almost the equivalent of open dumps.

An adequate supply of hoses and of water under suitable pressure is available or a stockpile of earth is maintained reasonably close to the working face of the fill to smother fires; suitable fire extinguishers are on all equipment and in all buildings. Yes __No__

ITEM 8: Bulky Waste Handling. Large or bulky items, sewage solids or liquids (septic tank or cesspool pumpings, sewage sludge, and grit), and other materials that are hard to manage should be disposed of only if special provisions are made.

Basis: Sewage solids or liquids are hard to handle, potentially infectious, and capable of creating health hazards or nuisances if not properly handled. When the sanitary landfill design includes special provisions for the disposal of such large or bulky items as car bodies, refrigerators, water heaters, demolition wastes, tree stumps, logs and branches, they need not be excluded.

Suitable procedures are established and followed for disposal of hard-to-handle materials. Yes__No__

ITEM 9: Vector Control. Conditions unfavorable for the production of insects and rodents should be maintained by carrying out routine operations promptly in a systematic manner. Supplemental vector control measures can be instituted if necessary.

Basis: Proper operation denies insects and rodents food and harborage. Incoming solid waste loads and a rural setting are, however, natural environments for vectors. If any appear, a supplemental vector control program will quickly eliminate them.

Vector control is adequately provided. Yes__No__

ITEM 10: Dust Control. Suitable control measures should be taken wherever dust is a problem.

Basis: Excessive dust at the sanitary landfill can slow down operations, cause accidents, harm equipment, create aesthetic problems, and lead to injuries.

Dust control measures are applied as needed. Yes__No__

ITEM 11: Accident Prevention and Safety. Employees should be instructed in the principles of first aid and safety and in the specific operational procedures necessary to prevent accidents. An adequate stock of first-aid supplies should be on hand.

Basis: The use of heavy earth-moving equipment, the maneuvering of collection trucks and other vehicles, and the infectious, explosive, or flammable items that may be in solid waste can create accident hazards. Since some sites are in remote locations, it is particularly important that personnel be oriented to accident hazards, trained in first aid, and provided first-aid supplies. For reasons of safety, only those authorized to use the site should have access to it.

Employees are given periodic safety training, an adequate first-aid kit and at least one employee trained in first-aid are available at the site at all times. Yes__No__

ITEM 12: Drainage and Grading. The entire site should be graded or provided with drainage facilities to minimize runoff onto the sanitary landfill, to prevent the erosion of earth cover, and to drain rain water from the surface of the sanitary landfill. The final surface of the sanitary landfill should be graded to a slope of at least one percent, but no surface slope should be so steep as to cause erosion of the cover. The surface drainage should be consistent with the surrounding area and should in no way adversely affect proper drainage from adjacent land.

Basis: Runoff from lands adjacent to the site, unless diverted, and rain falling on the surface

of the site may percolate into the sanitary landfill and contaminate either ground or surface waters. Cover material may also be removed by erosion, and standing water may permit mosquitos to breed or interfere with access, unloading, compacting, or placement of cover. To have the sanitary landfill recognized as an acceptable solid waste disposal method, it is important that the complete sanitary landfill blend with its surroundings and not impair adjacent land usage.

The sanitary landfill is properly graded and drained. Yes__No__

ITEM 13: Plan Development and Execution. A sanitary landfill should be planned and designed by a qualified individual. Planned use of the site following construction should be an integral part of the planning, design, and construction. A daily log should be maintained by the supervisor to record such operational information as type and quantity of solid waste received, type and volume of cover material used, the portion of the site used, and deviations made from the plans and specifications. A copy of the original plans and specifications, a copy of the daily log, and a plan of the completed sanitary landfill should be filed with the local governmental agency responsible for maintaining titles to land.

Basis: Completed sanitary landfill sites are ultimately utilized for a variety of purposes. When the ultimate use of the site is known beforehand, the operation can be planned so that suitable building sites, roads, and utilities can be provided. Final grades can be established and allowances made for landscaping and drainage. A record of the construction of the sanitary landfill is necessary for the most efficient utilization of the completed site and for the prevention of health hazards or nuisances.

Plans, record keeping, and reporting are achieved as delineated above. Yes__No__

Evaluation. The following is a summary of the advantages and disadvantages of the sanitary landfill solid wastes disposal method.

Sanitary Landfill

ADVANTAGES	DISADVANTAGES
1. Where land is available, the sanitary landfill is usually the most economical method of acceptable wastes disposal.	1. In highly populated areas, suitable land may not be available within economical hauling distance.
2. The initial investment is low compared to that of other disposal methods.	2. People often confuse sanitary landfills with dumps. Location of sanitary landfills in residential areas can result in extreme public opposition.
3. A sanitary landfill is a complete or final disposal method, compared to incineration and composting where items such as residue and unusable materials require further disposal.	3. A completed landfill will settle and require periodic maintenance.
4. A sanitary landfill can be put into operation within a short period of time.	4. Special design and construction must be utilized for buildings constructed on completed landfill because of the settlement factor.
5. A sanitary landfill can receive most types of solid wastes.	5. Without proper planning, methane, an explosive gas, and the other gases produced from the decomposition of the wastes may become a hazard or nuisance factor and interfere with the use of the completed landfill.
6. A sanitary landfill is flexible: increased quantities of solid wastes can be disposed of with little additional personnel and equipment.	6. Potential for ground-water pollution exists if the landfill is not properly planned, designed, and operated.
7. Submarginal land may be reclaimed for uses such as parking lots, playgrounds, golf courses, and airports.	

Sanitary landfill is the most inexpensive disposal method known today. It is especially suitable for rural areas, mountainous areas, or areas which have an air pollution problem. In communities where land is limited or extremely expensive, this method may not be suitable unless a cooperative agreement can be reached with neighboring jurisdictions. A properly operated sanitary landfill produces no objectionable odors, vector problems, or blight, and is especially suited to the reclamation of marginal land. A sanitary landfill is basic to any other solid wastes processing operation since all produce some materials which must be sanitary landfilled.

Incineration is a controlled process for oxidizing solid, liquid or gaseous combustible wastes to carbon dioxide, water and ash. Sulfur- and nitrogen-containing compounds will produce their corresponding oxides and should not be incinerated without considering their effect on air quality. Halogenated hydrocarbons not only affect the air quality but may corrode the incinerator.

While the incinerated material is largely converted to gases and water, some end-products remain to be disposed of. These include particulate matter carried by the gas stream, ashes, metal, glass, combustibles not completely destroyed, and process water.

Where land for land-disposal is unavailable or too remote for economic hauling, incineration has certain advantages. A properly designed and carefully operated incinerator can be located adjacent to a process plant, thereby reducing hauling time and cost considerably. If the incinerator is properly designed, the operation can be adjusted to handle solid wastes of varying quantity and character. The residue is only a

small fraction of its original weight and volume and is nuisance-free and suitable for fill material.

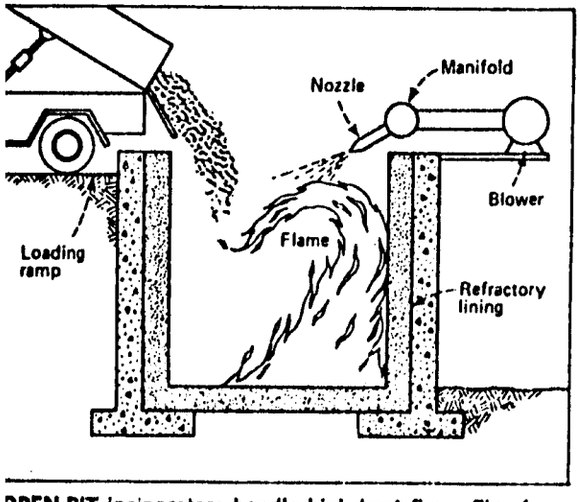
Conventional incinerators are designed for a heat release of 25,000 Btu./cu.ft., but ordinary trash has a lower heating value of 5,000 Btu./lb., while industrial wastes average 15,000 Btu/lb., but may run higher.[30] Rotary kilns and Herreshoff furnaces are the most useful, with open pits being fairly popular. For special wastes such as sludge and tars, vortex furnaces and fluidized beds are used.

Open-Pit Incinerators

Open-pit incinerators vary from the pedestal-mounted oil burner used by Union Carbide[3] to the Du Pont pit.[31] These incinerators solve the problem of high heat flux by eliminating the enclosure. The pedestal-mounted burner handles highly combustible liquid wastes, while the Du Pont pit is better for solid wastes. Their chief drawback is the high particulate concentration at ground level. This requires careful placement of the pit on the plant property.

The Union Carbide installation at Taft, La., burns 600 gal./hr. of organic liquids containing up to 25% water, without visible smoke. The installation consists of two oil burners firing horizontally and mounted about 5½ ft. above grade. The firing area is surrounded by earthworks for personnel protection. Heat is dissipated by direct convection and radiation. By the very nature of the design, there is always excess air.

The open-pit incinerator was originally developed at Du Pont for the safe destruction of nitrocellulose that presents an explosion hazard in a conventional closed incinerator.[32] The incinerator as shown in Fig. 4 has an open top and an array of closely spaced nozzles that create a rolling action of high-velocity air over the burning zone. Very-high burning rates, long residence times leading to complete combustion, and high flame temperatures are achieved. Visible smoke is readily eliminated and smuts are contained



OPEN-PIT incinerators handle high heat flux—Fig. 4

by proper screening. E. S. Monroe, Jr., the inventor, has stated that particulate emissions of less than 0.25 grain/cu.ft. have been achieved for specific industrial wastes. Oversized wastes and plastics that create problems in conventional incinerators are easily destroyed in the open-pit incinerator. It should be noted that the concentration of particulates is slightly higher than conventional incinerators,[33] 0.25 against 0.2 grain /cu.ft. and there is no way to clean the exit gases. Although these pit incinerators are used for liquid wastes, they are more efficient for solid wastes, especially rubber and plastic.

Du Pont has waived proprietary interest in the design, and an undetermined number (probably 100) have been built. A commercial design is marketed by Thermal Research and Engineering Corp. Most of this discussion is based upon their published data.[32]

The incinerator consists of a rigid shell either reinforced-concrete or steel-lined, with refractory on the floor and walls. Empirical and theoretical calculations indicate the optimum width to be 8 ft. between refractory walls. The capacity is determined by length—usually between 8 and 16 ft. The pit is about 10 ft. with cleanout doors located at either end. Normally, a screened enclosure is placed over the pit to contain large airborne particles and for insect and rodent control when burning garbage.

The over-fire air is supplied from a manifold running along one edge of the pit, with alternating 2- and 3-in. nozzles directed downward at an angle of 25 to 35 deg. across the incinerator. Charging is from the opposite side of the nozzles from a loading ramp. The pit should be oriented so that the loading ramp is located upwind. The high-velocity air jets create turbulence in the burning zone, and the excess air aids complete combustion. When the equipment is properly operated, the air pattern creates a sheet of flame under the air manifold on the back wall, rolling the flame across the top of the pit. Particulates and unburned gases are largely returned to the burning zone—more or less eliminating smoke. Smoke intensity rarely exceeds Ringelmann #1 when properly operated.

A variety of wastes have been burned in the pit incinerator. It readily accepts heavy timbers, cable reels and construction wastes. It burns plastics and similar high heat-release materials that might detonate, or erode the refractory in a closed unit. It effectively handles numerous types of manufacturing and process wastes, plant trash, plastics, tires and other rubber wastes. Styrene plastics emit a dense, black smoke and are best handled in a closed incinerator with an afterburner.

Materials that form dangerous products of combustion should be avoided. Wet or dense materials compact in the pit and prevent the penetration of air. Wet bark and sawdust are good examples. Liquid wastes generally present the same problem, although modified versions of the pit have been successfully used to cope with them.

Operating capacity of the pit depends on the lower heating value of the feed, combustion characteristics,

quantity of overfire air, size and configuration of the pit, and method of charging. Not less than 100% excess air is required, and 300% is usual. Du Pont's criteria are: 850 cu.ft./min. of overfire air at 11 in. of water column per foot of length for standard trash (5,000 Btu./lb.).

The incinerators are charged intermittently by dump trucks, although hydraulic rams and skip hoists have been used. The rate of charge depends on the material being burned, in order to meet the heat-release capability of the pit. High-heating-value materials such as plastics are fed in small quantities at frequent intervals. The operator's skill is the major factor in minimizing emissions while maintaining a high burning rate.

Emissions tests are run using a high-volume air sampler both upwind and downwind of the incinerator. A rather high level of particulates will be found within a radius of 200 ft. but beyond this the concentration is well within most air standards.

Direct operating costs are low. Two men can operate two pits. The only other costs are for energy to drive the blower and operate the loader and the clean-out device. No auxiliary fuel is used, as lighting off a small amount of combustible material will ignite the pit. Maintenance is slight and largely consists of repair of the refractory.

Capital cost is low. An average price for a commercial unit 16 ft. long, 8 ft. wide by 10 ft. deep, completely installed, including a covered storage building for the waste and a screened enclosure for the pit is about $65,000. The capacity is 5,000 lb./hr. of low heat-release material, and about half that for high heat-release material.

Closed Incinerators

Incinerators commonly used for industrial wastes include the multiple-chamber, rotary-kiln, Herreshoff, and vortex or suspended-bed. The multiple-chamber is used for commercial and industrial solid wastes usually up to 1 ton/hr. This is the basic design of municipal incinerators, and much larger capacities are possible. The rotary-kiln or Volund furnace is extremely versatile for burning solids, liquids, sludges, and drummed wastes. The Herreshoff or multiple-hearth is also versatile and is largely used for sludges and high-heat-release materials. The vortex furnace is useful for burning sludges, tars and oils. There is also the fluidized bed, which finds specialized applications.

Multiple-Chamber Incinerators

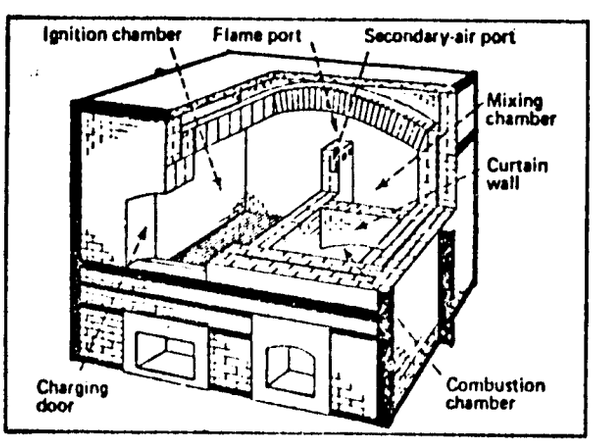
There are two fundamental types of multiple-chamber incinerators: (a) the retort type, so-called from the U-shaped, or return, flow of the combustion gases as shown in Fig. 5; and (b) the inline type, named for the straight-through flow of combustion gases, as shown in Fig. 6. The Federal "Interim Guide"[34] compares these types.

The retort type of design is distinguished by the following features:

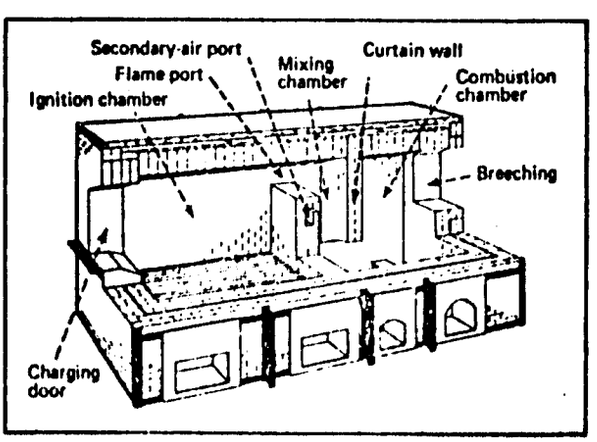
1. Arrangement of the chambers causes the combustion gases to flow through 90-deg. turns in both horizontal and vertical directions.
2. Return flow of the gases permits the use of a common wall between the primary and both secondary chambers.
3. Mixing chambers, flame ports, and curtain-wall ports have length-to-width ratios in the range of 1:1 to 2.4:1.
4. Bridge-wall thickness under the flame port is a function of dimensional requirements in the mixing and combustion chambers. The resulting bridge-wall construction is unwieldy in incinerators in the range of about 500 lb./hr.

Distinguishing features of the inline design are:

1. Flow of the combustion gases is straight-through the incinerator with 90-deg. turns in only the vertical direction.
2. Inline arrangement of the component chambers gives a rectangular plan to the incinerator. This style is readily adaptable to installations that require separated spacing of the chambers for operating, maintenance, or other reasons.
3. All ports and chambers extend across the full width of the incinerator and are as wide as the ignition chamber. Length-to-width ratios of the flame-port,



RETORT type multiple-chamber incinerator—Fig. 5



INLINE type multiple-chamber incinerator—Fig. 6

mixing-chamber and curtain-wall to port-flow cross sections range from 2:1 to 5:1.

A retort incinerator of optimum size offers the advantages of compactness and structural economy due to its cubic shape and reduction in exterior wall length. The retort incinerator performs more efficiently than its inline counterpart in the capacity range of 50 to about 750 lb./hr. The inline incinerator is well suited to high-capacity operation but is not too satisfactory for service in small sizes. The secondary-stage combustion of the smaller inline incinerators is less efficient than that of retort types. The inline incinerator functions best when the unit has a capacity of over 1,000 lb./hr.

Inline and retort incinerators, in the capacity range between 750 and 1,000 lb./hr., are equally efficient. The choice is dictated by personal preference, space limits, nature of the refuse, or charging conditions.

Factors that tend to cause a difference in the performance of the two types are: (1) proportioning of the flame port and mixing chamber, in order to maintain adequate gas velocities within the dimensional limitations imposed by the particular type; (2) maintenance of proper flame distribution over the flame port and across the mixing chamber; and (3) flame travel through the mixing chamber into the combustion chamber.

The additional turbulence and mixing, promoted by the turns in the retort incinerators, allow the nearly square sections of the ports and chambers in small units to function adequately. In the retort sizes, above 1,000 lb./hr., reduced effective turbulence in the mixing chamber that is caused by the increased size of the flow cross-section results in inadequate flame penetration, effluent distribution and secondary-air mixing.

Certain weaknesses of the small inline type are eliminated as the size of the unit is increased. For instance, with an inline incinerator of less than 750-lb./hr. capacity, the shortness of grate length in the ignition chamber tends to inhibit flame propagation across the width of the chamber. This, coupled with thin flame distribution over the bridge wall, may result in smoke (from a smoldering fuel-bed) passing straight through the incinerator and out of the stack without adequate mixing and secondary combustion. Inline models in sizes of 750 lb./hr. or larger have grates long enough to maintain burning across their width to provide flame distribution in the flame port and mixing chamber.

Since smaller inline incinerators have relatively short grates, a problem of construction is added. Usually, the bridge wall is not provided with any structural support or backing; and because secondary-air passages are built into it, the wall is very susceptible to mechanical failure. Careless stoking and grate cleaning in short-chambered inline incinerators can ruin the bridge wall in a short time.

Incinerators under 2,000 lb./hr. may be standardized for construction purposes to a great degree. However, incinerators of larger capacity are not readily standardized because problems of construction, material usage, mechanized operation with stoking grates, induced-draft systems, and other factors make each installation a custom design.

Approximate Costs of Multiple-Chamber Incinerators—Table II

Capacity Lb./Hr.	Incinerator Cost, $	Wet Scrubber Cost, $
100	1,700	3,000
150	2,000	3,600
[illegible]	2,700	4,400
500	5,000	6,200
750	9,500	7,600
1,000	12,500	8,800
1,500	20,000	[illegible],200
2,0[illegible]	25,000	[illegible],200

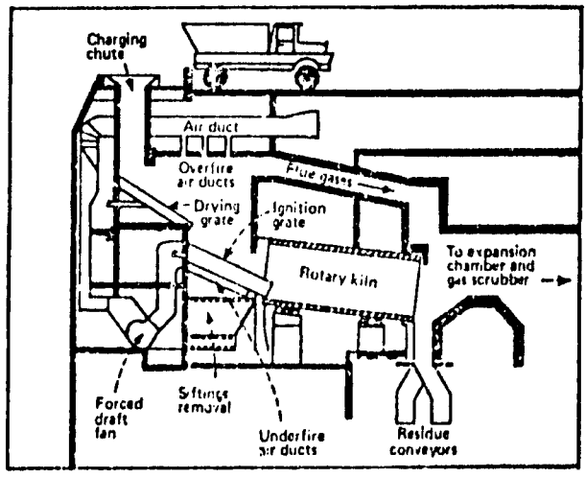
Source is Ref. 34. Cost data are for 1968.

The relative costs in 1968 of incinerator and air-pollution-control equipment of various capacities, exclusive of foundations, are given in Table II. These incinerators can be operated as a part-time assignment for one or two men. The price of power and fuel affects operating costs. Gulf Coast costs have been given as $15 to $16/ton.[35]

Rotary Kiln

The rotary kiln as used by Dow Chemical Co. has previously been described by Novak.[36] This unit is a 65-million-Btu./hr. kiln that disposes low-ash liquid residues and solid chemical wastes such as plastic trimmings, strands, powders, Styrofoam, paper, wood, and other solids with varying heat values. A pack-feed mechanism is used to feed packs and drums filled with waste chemicals into the incinerator.

The rotary kiln as used in municipal installations is shown in Fig. 7.[37] A similar installation in Atlanta is



ROTARY kiln incinerates municipal refuse—Fig. 7

Costs of Multiple-Hearth Incinerators—Table III

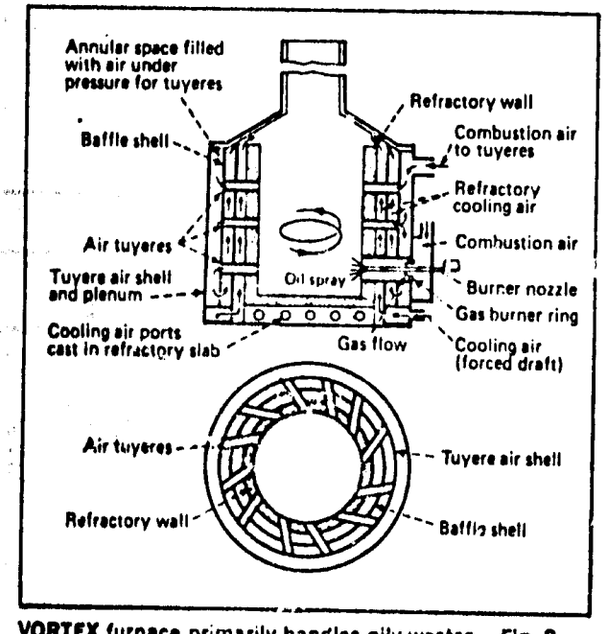
Population	10,000	20,000	50,000	100,000	1,000,000
Sludge incinerated,* (ton/wk., wet basis)	28	56	139	278	2,780
Sludge incinerated, (ton/wk., dry basis)	7	14	35	70	695
Operating schedule, hr./wk.	35	35	70	70	168
Furnace feed, lb./hr.	1,600	3,200	3,960	7,920	33,000
Furnace required, O.D.	10 ft. 9 in.	14 ft. 3 in.	14 ft. 3 in.	18 ft. 9 in.	22 ft. 3 in. (Two)
Hearths	5	5	6	6	8
Installed cost, $	120,000	185,000	200,000	310,000	750,000
Fuel cost, $/wk.	27.50	45	30	45	50
Power cost, $/wk.	9.00	12	13	25	165
Total utility cost, $/wk.	36.50	57	43	70	215
Operating cost, $/ton dry solids	5.20	4.06	1.24	1.01	0.31
Filtration cost, $/ton dry solids	8.00	8.00	8.00	8.00	8.00
Maintenance cost, $/ton dry solids	0.70	0.60	0.60	0.50	0.40
Total disposal cost, $/ton dry solids	13.90	12.66	9.84	9.51	8.71

* Dry solids removed in process = 0.18 lb./(day)(capita); cake moisture = 75%, volatile content = 65%; heating value = 10,000 Btu./lb.
Source: Bartlett-Snow (Div. of Bangor Punta operations). Cost data as of 1967.

connected to a waste-heat boiler and generates steam. Refractory maintenance is a high cost item, with the refractory being replaced about once a year. Cost data are scarce but Atlanta has an installed cost of about $10,000 per daily-ton of feed capacity.

Multiple-Hearth Furnaces

The Herreshoff furnace is the standard multiple hearth used in metallurgical operations and for burning sulfur for acid production, and consists of vertically stacked hearths raked by rabble arms rotated from a common shaft. Waste is discharged from the bottom hearth. This incinerator is almost as versatile as the rotary kiln and is commonly used to incinerate sewage and other sludges as well as regenerate activated carbon. This is one of the few types of incinerators for which detailed operating costs are available. Table III shows installed and operating costs less labor, amortization and overhead. These furnaces can be operated by one man, so actual costs may be estimated.



VORTEX furnace primarily handles oily wastes—Fig. 8

Vortex Furnace

Use of the vortex furnace for chemical wastes has been described by Coleman and Cheek.[38] According to Smith,[39] the unit has proved reliable over a period of time. While this furnace primarily burns oily materials, similar furnaces have been used for burning municipal waste and for calcining lime and phosphate rock.

As shown in Fig. 8, the cylindrical furnace is tangentially fired with a modified oil burner. In operation, the furnace is preheated for 1 hr. to a temperature of 800 to 1,000 F. Operating temperature is 1,200 to 1,600 F., with 20% excess air. Waste oils, fuel gas and primary air pass through a hot ignition tunnel. Tangential firing creates a vortex of hot gas and primary air that flow upward through the hot combustion chamber. As the gases rise, preheated high-velocity secondary air is introduced from tangential tuyeres, maintaining the vortex.

The heat release in this unit is unusually high, about 100,000 Btu./(hr.)(cu.ft.). This has resulted

in slagging of the refractory. As may be expected, some refractory is wasted by erosion.

There are few installations of vortex furnaces, and cost is not readily available. Because of the high maintenance, operating costs will be high. But the high heat-release lowers capital cost.

Fluidized Beds

The fluidized bed is very popular in Europe and is used for sewage sludge in this country. Aside from an oil refinery in Mandan, N.D.,[40] some sulfite paper-mills, and facilities for processing nuclear wastes,[41] fluidized beds are not common in industry other than for recovering lime sludges. The advantages and drawbacks have been well outlined by Bailie.[42]

Sand is commonly used as the heat-transfer agent with consequent disadvantages. The fluidized bed has certain constraints that limit its range of operation. Because the bed is made up of sand particles, the temperature cannot exceed 2,000 F. so as not to approach the softening point of the bed. The gas flowrate at operating conditions cannot exceed the terminal velocity of the sand nor can it be less than the minimum fluidization velocity. These velocities, as well as heat transfer to the cooling surface, depend upon the particle size and the elutriation rate of combustible solids from the bed.

Also, it is necessary to reduce the combustible material in size before it can be fed to the fluidized bed. The bed can accept quite a large range of particle sizes in the feed. The rather violent agitation of the bed helps to suspend large particles that would ordinarily find their way to the bottom, and retains them long enough to allow them to burn.

Violent agitation of the bed particles gives rise to several desirable characteristics. The particles act as a large heat reservoir (16,000 Btu./cu.ft. at 1,400 F.) and their movement throughout the bed keeps it at constant temperature. No hot zone will develop.

The conductive-convective heat-transfer coefficient between the bed particles and foreign material placed in the bed is an order of magnitude higher than that between the gas and the foreign material. The foreign material receives radiation from the bed, which completely surrounds the material. When a combustible particle is added, transfer of energy is rapid, and the particle quickly reaches its ignition temperature. Combustion begins, and its heat is rapidly transferred to the bed.

Because of the violent motion of both the gas and the solid, contact between the burning particle and the oxygen in the gas is excellent. Excess air as low as 5% has been used in the burning of coal in a fluidized bed. The reduction in the excess air required for complete combustion reduces the size and the cost of gas-handling and cleanup equipment required to meet air-pollution standards.

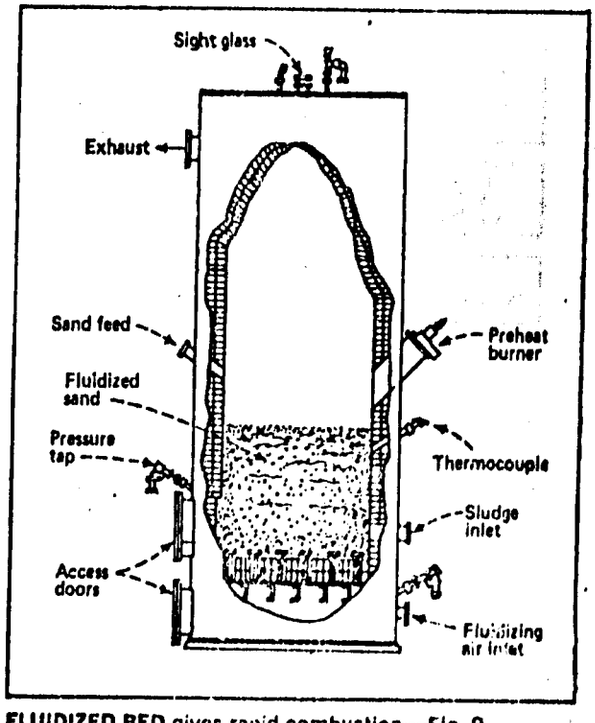
Distillation products are consumed in the fluidized bed before they leave, which reduces the amount of unburned hydrocarbons in the exit gases. This results in cleaner stack emissions, and savings in scrubbing equipment. Because of the strict requirements against atmospheric pollution that may be anticipated in the future, these reductions on scrubbing equipment can result in considerable savings.

In comparing combustion in conventional furnaces and fluidized-bed furnaces, we find that the fluidized-bed furnace operating at a constant temperature of 1,400 F. will have about 90% of the available energy released in the bed, and 50 to 80% of this could be removed to generate steam by placing heat-transfer surfaces in the bed. The maximum temperature developed in a conventional furnace far exceeds that generated in the fluidized-bed furnace. The relatively low-temperature operation of the fluidized bed is less demanding on the materials of construction.

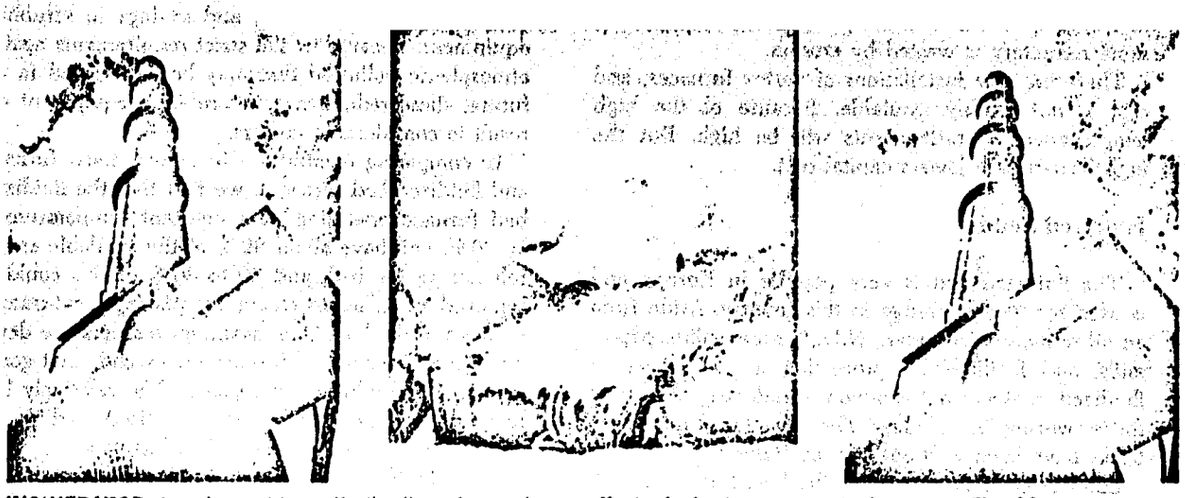
The fluidized bed has a high volumetric heat-generation rate of 100,000 to 200,000 Btu./(hr.)(cu.ft.), leading to compact size. The bed is of simple construction. These factors mean a relatively low capital investment for this furnace.

The removal of heat from the bed may be an economic necessity. Besides the generation of steam, it reduces the amount of gas-handling equipment because excess air is not needed to keep the bed cooled to reasonable temperatures. It also reduces the temperature of exhaust gases, making materials of construction less restrictive and resulting in higher volumetric heat-generation rates.

Because of the widely varying composition of the fuel fed to the incinerator, it is doubtful whether the plant could operate effectively without an auxiliary fuel supply to maintain stable bed-temperatures. Waste low-grade coal, not acceptable for most com-



FLUIDIZED BED gives rapid combustion—Fig. 9



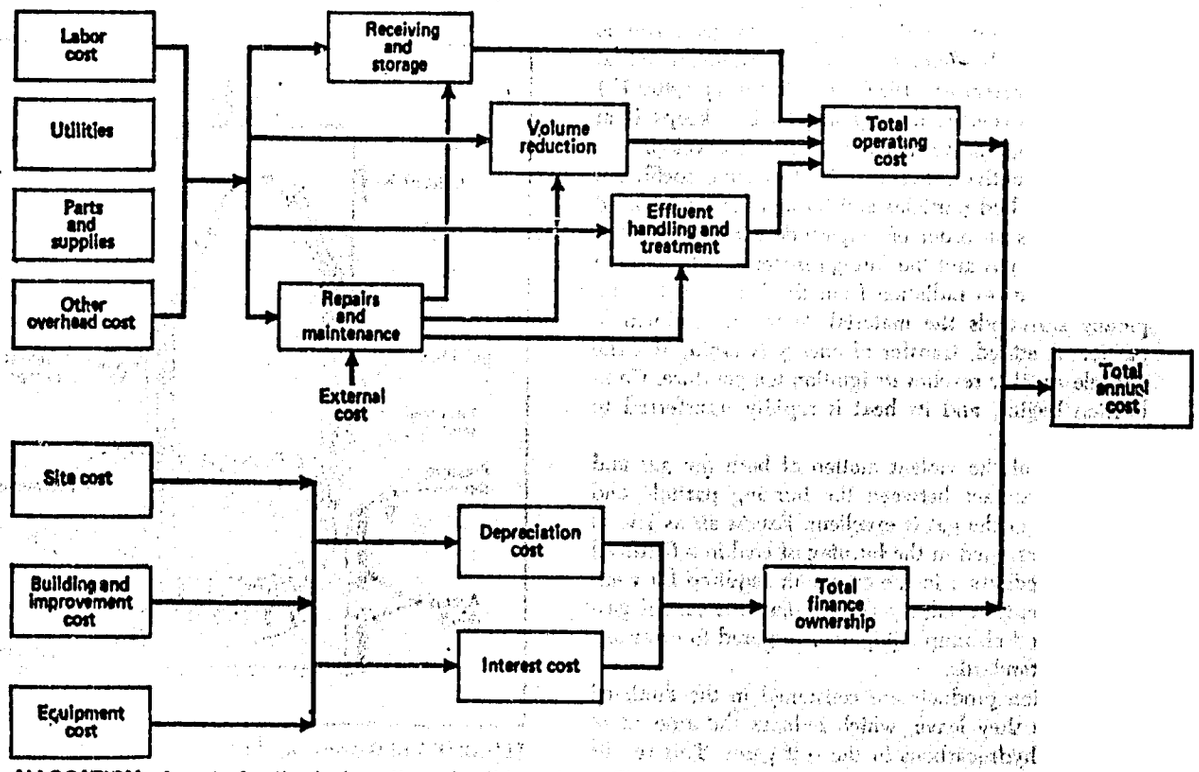
INCINERATOR, burning rubber off oilwell packers, shows effect of afterburner on stack gases—Fig. 10

bustion processes, can be mixed with the solid feed to increase the heating value; fuel oil can be sprayed into the bed to maintain constant-temperature control; the preheat burners may be used to maintain temperature in case of interruption of the amount or quality of the waste. The rate of power generation is controlled by the bed temperature and the air flow-rate that causes the motion of the inert particles in the bed. The fuel used has a relatively minor effect as long as it can burn at a sufficient rate to maintain the bed temperature. Switching from gas to liquid to solid fuel gives the facility great flexibility.

The general design is shown in Fig. 9. Capital costs range slightly higher than a Herreshoff, $60 to $120/(lb.)(hr.) of feed, but overall operating costs are lower when firing sludges.

Afterburners on Incinerator Stacks

Afterburners are used on the stack of incinerators when burning particularly smoky materials such as rubber or polystyrene, or to eliminate noxious odors. These incinerators most commonly strip insulation from cable to recover the metal. Fig. 10 shows a multiple-chamber incinerator that burns rubber rings from oil-well packers. Frequently, the afterburner



ALLOCATION of costs for the incineration of solid wastes—Fig. 11

is used to upgrade inadequate incinerators when the particulates are combustible.

The afterburner is simply an additional combustion chamber inserted in the stack. The residence time for combustion of carbonaceous particulates depends upon particle size, excess air and temperature.[43] Afterburners that provide a residence time of 0.3 sec. with 9.2% oxygen will burn out all particles under 7 microns at 2,000 F.

Operating Costs

Published operating costs vary from as low as $2/ton to several hundred dollars per ton. Actual costs vary significantly with utilization rate, estimated life and interest rate. For industrial use, the best comparison would be cost per pound per hour of feed. This minimizes the effect of utilization rate, although the preheating requirement makes one-shift operation unduly expensive. Because of the relatively small throughput, the average cost of disposal in the CPI exceeds $30/ton when costs are properly allocated. Fig. 11 is adapted from the Bureau of Solid Waste Management and shows allocation of incineration costs.[44]

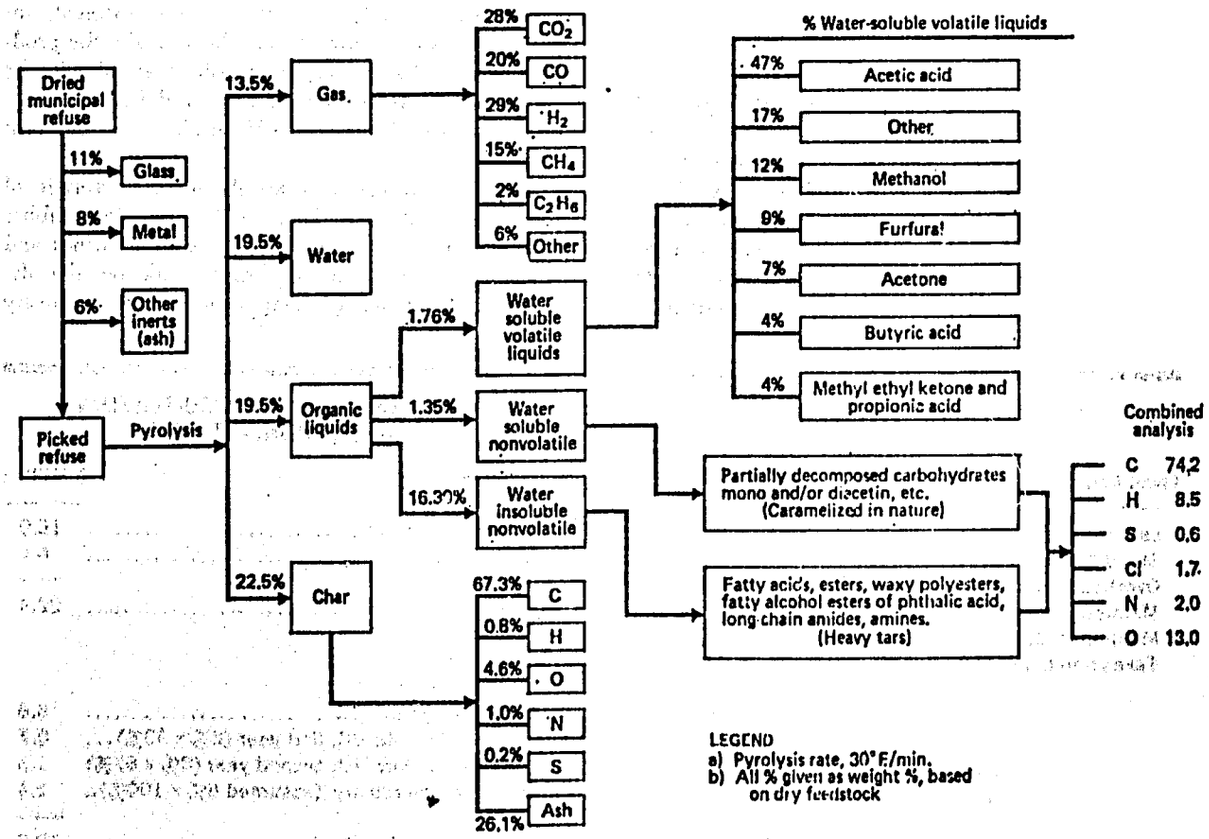
Steam Generation Provides Savings

In an effort to cut such costs, steam is sometimes generated. Because heat recovery and water cooling of incinerators reduces the volume of gas to be treated for pollution control, substantial savings are possible in equipment costs. The increasingly stringent pollution-control regulations increase the economic feasibility of steam generation.

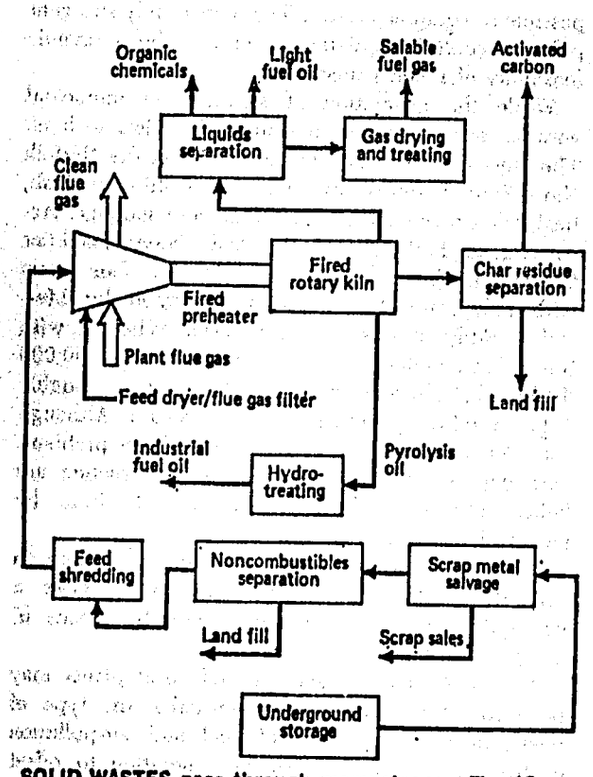
While the generation of steam from municipal waste is fairly common in Europe, it is less so here. The most successful unit in the U.S. is at the Norfolk Navy Yard; it burns 180 tons/day of ships' rubbish, trash from maintenance operations, and garbage. According to Parisius[45] of the U.S. Navy Facilities Command, this unit has operated for four years with only minimum problems. Designed by Metcalf & Eddy, it was built by Foster Wheeler, with the grates supplied by Detroit Stoker. About 50,000 lb./hr. of steam is generated at 275 psig., roughly 1 lb. of refuse produces 1.8 lb. of steam. Although corrosion has been slight, there have been problems with deposits. Various materials of construction are being studied by Battelle Memorial Institute by means of probes in this unit.[46]

Wood wastes and bagasse are commonly used to generate steam.[47] The Merichem Co. operates a packaged boiler that incinerates tars by means of a supersonic burner.

The generation of steam in industrial plants may be accomplished when using virtually any type of incinerator. As the price of fuel and air-pollution control equipment rises, steam generation to offset incinerator costs will increase.



PYROLYSIS of municipal wastes yields products ranging from gases to solids—Fig. 12



SOLID WASTES pass through many stages—Fig. 13

Pyrolysis of Wastes

Only recently has it been realized that pyrolysis has advantages over incineration for carbonaceous wastes. The reaction takes place in a closed system, minimizing air-pollution problems. At larger throughputs capital cost is lower and the system provides its own fuel. Additionally, there is a potential of recovering chemicals or synthesis gas for manufacture of methane or higher hydrocarbons.

The Ford Motor Co. at San Jose, Calif., tested a Lantz converter to pyrolyze 40 to 50 tons/day of industrial waste.[48]

The Lantz converter is a sealed, airtight retort cylinder with an insulated shell. The gas-fired retort, about 20 ft. long, revolves slowly on a slight incline like a rotary kiln. Waste is injected through a star valve. The retort operates at about 1,200 F., and the wastes are pyrolyzed, in the absence of oxygen, to steam, volatile material, carbon dioxide and charcoal. Steam, carbon dioxide and carbon monoxide are trapped and vented. The volatile gases include hydrogen, methane, ethylene and propylene. A 100-ton/day plant is claimed to produce enough gas to generate 400,000 kw./day of electricity. Some 30 to 35% of the input becomes charcoal.

An exhaustive economic analysis of a commercial-size refuse pyrolysis plant was made by Cities Service Oil Co.[49] While this study was for municipal refuse at large tonnages, the economic statements are consistent with practices in the CPI and may be extrapolated for rough estimates of pyrolysis and incineration units. Fig. 12 is a schematic and Fig. 13 a flowsheet of the pyrolysis process. It closely resembles the Lantz and Landgard processes. Table IV gives the total operating cost as $2.14/ton (comparable to $8/ton in a municipal incinerator of similar size). Table V is the total investment, including working capital. While theoretically the products have sales value, practically they should be considered as fuel. The mixture is difficult to separate. Industrial wastes may result in a different product mix.

The main thrust of research in the pyrolysis of industrial waste has been with discarded rubber tires and other polymers. The Bureau of Mines and Firestone[50] have done extensive work on the destructive distillation of scrap rubber. Some recovery

Operating Costs of 5,000-Ton/Day Pyrolysis Plant—Table IV

Fixed Costs	$ Million	
Labor	0.49	
Supervision	0.15	
Overhead	0.64	
Maintenance, onsite	1.00	
Maintenance, offsite	0.24	
Taxes and insurance	0.49	
Total fixed costs	3.01	$1.65/ton
Variable Costs		
Water and power	0.20	
Fuel	0.70	
Total variable costs	0.90	$0.49/ton
Total operating costs	3.91	$2.14/ton

Source: Ref. 49.

Total Investment for 5,000-Ton/Day Pyrolysis Plant—Table V

Investment	$ Million
Inside battery limits	16.0
Offsites	6.4
Total	22.4
Additional Costs	
Contingency (25%)	5.6
Construction interest, first year (8% x 33%)	0.7
Construction interest, second year (8% x 67%)	1.5
Startup extraordinary (assumed 8% x 100%)	2.4
Total additional costs	10.2
Total investment (includes working capital)	32.6

Source: Ref. 49.

of the monomers is possible but the yield resembles that obtained by Cities Service. Conoco has reportedly made carbon black by pyrolyzing scrapped tires.

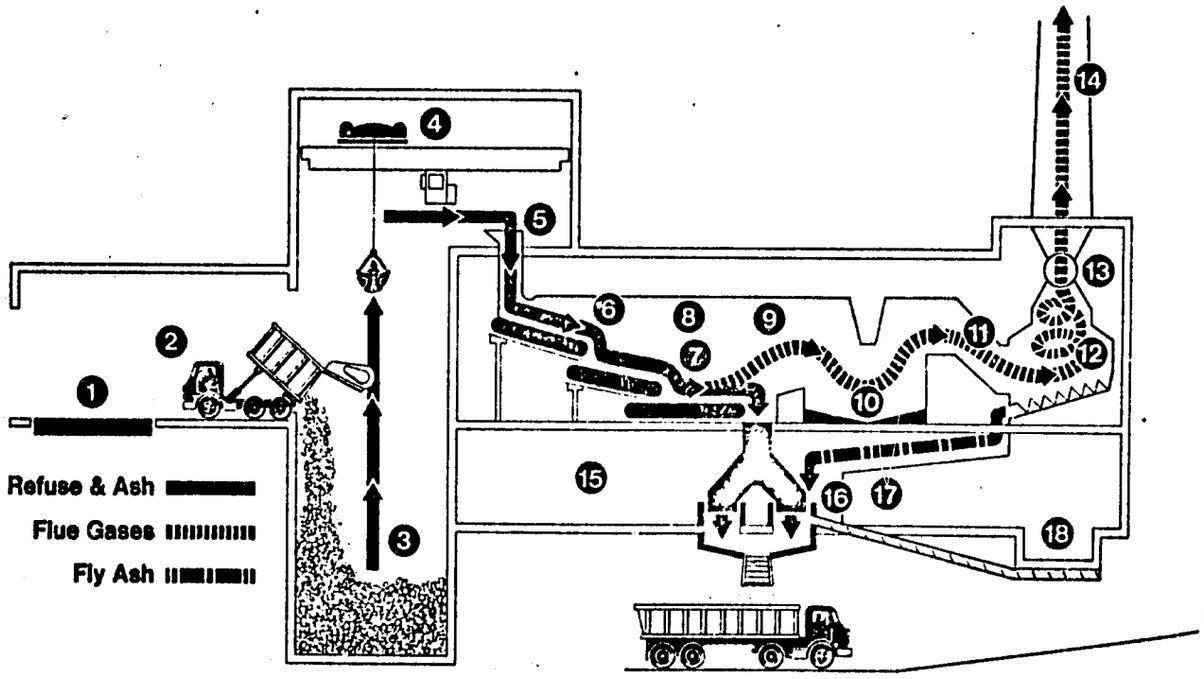
Beyond economic attractiveness, the pyrolysis char is readily converted to activated carbon. A large, cheap source of activated carbon would make it economically feasible to treat large quantities of polluted water. The spent carbon could then be disposed of as a nonpolluting fuel.

Since acetone and methyl alcohol were originally made by the destructive distillation of wood, it is odd that the vast amounts of papermill wastes have not been considered for pyrolysis. The wood bark and fibers could be slurried with a high-sulfur residual fuel oil to a fluid coker, to produce a low-sulfur coke.

Incineration. Incineration is a combustion process by which materials are reduced primarily to carbon dioxide, other gases, and ash. By this method, the volume of solid wastes is reduced, conserving the life of the necessary companion sanitary landfill. Incinerators must be designed and operated to meet stringent air pollution controls. An incinerator is normally rated on the number of tons it has the capacity to burn in a 24-hour period or in tons per hour.

The Plant and the Process. The basic parts of an incinerator plant are the building, scales, storage pit, bucket and crane, charging hopper, furnace (which includes grates, primary and sec-

FIGURE D: **basic incinerator design**



1. Scales
2. Tipping Floor
3. Storage Bin (Pit)
4. Bridge Crane
5. Charging Hopper
6. Drying Grates
7. Burning Grates
8. Primary Combustion Chamber
9. Secondary Combustion Chamber
10. Spray Chamber
11. Breeching
12. Cyclone Dust Collector
13. Induced Draft Fan
14. Stack
15. Garage - Storage
16. Ash Conveyors
17. Forced Draft Fan
18. Fly Ash Settling Chamber

ondary combustion zones, and gas cleaning chamber), residue conveyor, air pollution controls, stack, and quench water controls (see Figure D).

Most solid wastes collection is carried out five or six days a week during daylight hours. It is usually more economical to operate an incinerator on a 24-hour basis or at least until all wastes are burned each day. To permit even operation of the incinerator during the remaining hours of the plant operating day, a solid wastes storage area or pit must be provided at the incinerator plant. Thus, solid wastes can be fed into the charging hopper as needed and vehicles can be emptied conveniently.

For good design, storage of at least 30 hours' capacity should be provided, based on the rated full capacity of the plant. Ideally, the plant should be operated so that the pit is completely emptied daily, and not less than once weekly for safe operation. Plant operating shifts and hours of furnace operation should be planned around this schedule. If the pit is not emptied weekly, material on the bottom will begin to decompose, which produces odors and increases the danger of pit fires by spontaneous combustion.

Because the percentage of garbage in refuse has decreased markedly in recent years, the need for auxiliary fuel to fire an incinerator is minimal or unnecessary.

the importance of temperature

The rate of combustion is directly related to the composition of the solid wastes, the burning surface, and the amount of oxygen supplied both over and under the fire. The temperature of combustion will vary considerably because of the wide range of heat values inherent in the mixture of wastes to be incinerated. To burn the materials thoroughly, furnace temperatures must be maintained between 1500° and 1800° F. Equipment is essential to record temperatures and measure oxygen supplies. When furnace temperature is too high (over 1800°) deposits (called clinker and slag) adhere to grates and refractories (furnace walls and ceiling linings). These deposits can cause serious damage by jamming grates and causing the refractory to wear, melt, and cave in. Periodic maintenance is essential to remove these deposits. (For detailed information on refractory types, see APWA *Municipal Refuse Disposal*, listed in bibliography.)

After combustion, gases and particulate matter pass into an air pollution control device (such as a baffle, wet scrubber, cyclone collector, or electrostatic precipitator) designed to remove them. Any remaining gas, steam, or particulate matter is drawn by induced draft fans or natural ventilation up the refractory-lined stack and into the atmosphere.

After combustion, residue and ash remaining in the primary combustion zone reach the end of the grates, then fall into a water bath to be quenched and cooled. Quench waters contain many dissolved organics and solids, and require treatment prior to reuse or discharge. If not recirculated, waters should be treated and discharged into a sanitary sewer. Residue is then taken to a sanitary landfill.

Consultant Services. An incinerator plant is an extremely complex piece of equipment. Since most local government engineering staff members do not have the specialized knowledge to plan and design an incinerator plant, a consulting engineer is usually retained.

The design should be prepared by one engineering consultant so that all the component parts will be coordinated. The design consultant should be retained from the initial drawing of the plans to the completion of the plant. This means that the consultant should be responsible for seeing that the plant can be and is operated for a continuous period of six months or more at design cacapity by plant personnel trained by equipment manufacturers. (For a detailed discussion of using consultants, see *Guide Number 9, Personnel.)*

Evaluation. An incinerator plant design should be simple, functional, economical, and attractive. This includes the equipment not usually housed within the main building, such as settling and cooling ponds for recirculating water. The plant should operate well at full design capacity with as little maintenance and repair as possible. It should be nuisance free, and it must have a sanitary landfill.

A NACORF survey of cities and counties using incineration uncovered some unacceptable shortcuts which had been "sold" to officials. Many of these shortcuts were part of "package-deal" incinerators offered as turnkey operations. This reinforces the need for public officials to secure competent engineering advice in choosing the incineration system.

Incineration is an effective volume reduction method where land appropriate for sanitary landfill is limited, and money and water are abundant. Incineration can handle about 80 per cent of typical urban solid wastes and reduce weight at least 70 per cent if the plant is operated properly. The remaining residue, along with non-incinerable materials, must be sanitary landfilled. With this system, much less land is needed to sanitary landfill wastes.

The cost of incineration is high. Construction cost (including elaborate air pollution control devices) runs about $7,000 to $12,500 per ton capacity of the plant. Operating costs run about $5 to $9 per ton plus amortization. These high costs are spread among maintenance, power, personnel, and administration. Incineration equipment must be replaced at least every 15 to 20 years.

Skilled operators and continued maintenance are essential. It is foolish to invest a million or more dollars in a plant and then fail to staff it with trained people at adequate salary.

Incineration

ADVANTAGES	DISADVANTAGES
1. Land requirements for the plant are small.	1. The plant is expensive to construct and operate.
2. Operation is not dependent upon weather conditions.	2. Improper operation or inadequate equipment produces air and land pollution.
3. It can be put in urban industrial areas, reducing haul distance.	3. Highly skilled personnel are essential.
4. It provides volume reduction.	4. Continuing maintenance is a necessity.
5. It reduces landfill requirement for solid wastes disposal.	5. Disposal of residue must be provided.
6. It produces a stable, odor free residue.	

Composting

WHILE COMPOSTING is not the universal answer to solid waste management, it does have a place despite the possibility that this place will not become well established in the United States for many more years. There are a variety of uses for compost, but in general its primary use is to supply humus to the soil; and, as yet, humus cannot be artificially produced.

The German farmer has recognized the need to maintain the marginal organic content of his soil by operating a generalized agricultural system that resulted in materials moving from the soil to crops and animals and back to the soil. The efficiency of the system was such that there was a need to supplement the organic content of the soil by a source outside the system. Thus it was found that compost could produce results that were comparable to the results obtained by commercial fertilizers applied to mineral-deficient soils. The comparable results created some confusion as to the role of compost in the soil, but studies have now shown that compost is beneficial to the soil as a source of humus and not of minerals. There is some indication that the reformation now occurring in German agriculture may result in an increasing demand for a ready source of humus as the farms become more mechanized and livestock production becomes a specialized industry.

In the United States the vast land areas available per capita have resulted in single-use or low-level utilization of the land resources. As a result, the soils are considered young and fertile although suffering from poor management in many areas. If the future of the United States is close to what is predicted, the day will possibly come when a greatly decreased land area per capita will require the preservation of our lands for intensive agricultural production by transforming municipal wastes into compost or humus for the soil.

Equipment

Storage Pit. Since composting plants receive only the domestic and some small part of the commercial refuse from a community, we can understand that these plants generally have a small intake of material, ranging from 40 to 200 tons per day. Thus, the storage bunkers (pits) are designed to receive and hold approximately four collection-vehicle loads of refuse. The storage capacity is adequate to maintain plant operations, but when an operational breakdown occurs, an immediate and readily convenient alternate disposal system has to be available. Most of the bunkers are of a trapezoidic design with the two side walls sloping to a conveyor belt along the bunker bottom. The sloping walls help move the refuse onto the conveyor belt but create a problem by allowing the material to bridge-over the conveyor belt. It can be a very difficult job to break this bridge. The best solution to the problem in existing installations has been to construct a vertical falsewall along one side producing one straight and one sloped side. On new installations, a wider conveyor bottom would be recommended (conveyors 6 feet wide or more); however, none of the European installations visited had such wide conveyor bottoms. The Joint U.S. Public Health Service–Tennessee Valley Authority composting plant at Johnson City, Tennessee, uses a wide conveyor, which may be an effective solution to the problem. Most of the installations on the Continent had dust control equipment for the bunker area, but it was either not used, broken, or considered ineffective in operation. In plants where the storage bunker was too small, refuse would be discharged on the ramp and pushed in by a tractor as the bunker was emptied. Gen-

eral design called for a steel conveyor belt at the bottom of the bunker to feed a rubber conveyor belt that moved the refuse to the next processing stage.

Refuse Preparation. As the refuse moved from the storage bunker to the first processing step, some salvage and sorting operations were performed. Most of the plants were doing away with picking or sorting because of increasing labor costs and the small income from salvage. In general, the picking operation was inefficient and greater benefits could have been obtained by better education of the collection crews and the residents. Pickers removed rocks, tires, large pieces of iron, bottles, large sheets of plastic, and other materials considered undesirable for composting. No paper salvage was performed, and in general, the emphasis seemed to be on plastic removal rather than glass. Salvaged wine bottles are still a source of income, but the thrifty European, the increasing use of plastics, and the one-way bottle make bottle salvaging a negligible source of plant income. The nonsalvageable materials removed were placed in large portable containers for transport to the landfill or incinerator.

An over-band magnet, a drum-head magnet, or both, were standard equipment in all compost plants visited. The drum-head magnet is simply an electromagnetic roller at the end of the conveyor belt. The magnetic field places the ferrous material in a different trajectory than the other materials leaving the belt. The over-band magnet is an electromagnet directly over the conveyor belt. An endless belt positioned between the refuse and the magnet sweeps the material out of the magnetic field into a storage container. For greater efficiency two or more magnets might be located at different stations in the process. The iron removed was baled for storage and sale. German scrap iron suffers the same low price as U.S. scrap and was sold for whatever price it would bring, or else given away in exchange for the removal.

Processing: Grinders. Following intake, the refuse could be processed by grinding, rasping, or the Dano drum, depending on the composting system being used. If grinding is used, commercial grinders are supplied by the Buhler Company (double- or single-rotor grinders), the Hazamag Company (double-rotor grinder), or the Gondard Company. Gondard grinders are coming into greater use. The Gondard grinder was discussed previously, but it is worth repeating that the ballistic separation action by this mill actually provides a mechanical sorting or removal of much of the noncompostable material. The Hazamag grinder uses a high-speed double rotor with swinging arms made of flat steel. The Buhler single-rotor grinder uses flat steel arms equipped with a pivoting sledge-hammer-type head at the end. In either grinder, after some wear, the grinding surface can be reversed for additional use. The double-rotor Hazamag and the single-rotor Buhler mill are used for primary grinding; the double-rotor Buhler is generally used for secondary grinding.

As is standard practice for as much European equipment as possible, the grinders are powered by electric motors. It was noted that both grinders were considerably overpowered, but the Buhler mill seemed to be equipped with more excess power than the Hazamag. The excess power is required for starting and for overcoming slugs of material, or materials difficult to grind. Hazamag seemed to be relying on the inertia and grinding action of the double rotor to overcome the hard spots. In addition, the Hazamag mill was more heavily constructed than the Buhler. In the double-rotor Buhler mill used for secondary grinding, the two rotors turn at different speeds, and it was reported that the hammers of the faster rotor had about one-third the life of the slower rotor hammers.

All the grinders are very noisy in operation. None of the mills could grind nylon, especially nylon stockings. The stockings would sometimes accumulate on the rotor until they had to be slashed or burned away with a torch.

Processing: Rasp. Developed by the Vuilafvoer Maatschappij (VAM) firm, the rasp is marketed by the Dorr-Oliver Company. It is a vertical cylinder with a diameter of 15 feet and a total height of 7 feet, containing both a grinding floor and a discharge floor. The grinding floor is formed

from wedge-shaped sections with alternate sections being constructed with round holes (from about 0.5-inch to 1.5-inch diameters) or with 0.5-inch steel pins projecting from the section. The pins also extend part way up the wall all around the inside. There are eight heavy hinged arms that can rotate at various speeds up to 25 rpm. The arms move the material over the floor that serves to alternately screen and rasp the material. The arms can lift up over ungrindable material until such time as a trap door can be opened and the rejects swept out the door by the arms. The material passing through the grinding floor falls on the discharge floor and is moved out a discharge opening by a rotating arm attached to the center spindle. Compared to a grinder, the rasp is physically larger, requires about one-fourth the power, is somewhat quieter in operation, requires less maintenance, and has a higher first cost. The grinding and rasp system of composting appears to be quite competitive in the open market.

Processing: Dano Drum. The Dano drum, usually 9 to 12 feet in diameter and 60 feet or more in length, is rotated at a speed of about 1 rpm during the working day and at about ¼ to ½ rpm at night. The raw refuse is usually given magnetic separation before being discharged into the drum, where a slight inclination of the drum requires about 2 to 5 days for the material to pass through the drum, detention time being a direct function of the speed of rotation. The drum is operated half full, and the slow rotation provides aeration and the self-grinding action that is effective in the reduction of the raw refuse. When the material reaches the end of the drum, a short section of 1.5-inch-diameter screen is used to remove large pieces of reject material. The rejects are periodically discharged from the drum via a trap door in the screen. A characteristic of the drum compost is the presence of small balls of paper. There is some thought that the small, moist, porous ball provides a better microbiological environment than the material produced by a rasp or grinder. Compared to a grinder, the drum has the same advantages as the rasp.

A satisfactory aeration system has not yet been designed for the drum, and, as a result, many operations have been known to have serious odor problems. A recent solution developed for the odor problem has been the use of underground tile fields. The hot, odorous gases are drawn from the drum and forced into a perforated tile distribution network covered by about a meter of soil or compost. The cover material does an excellent job of removing the odors, and the technique is reported to enjoy wide success. When compost is used for the filtering cover material, the hot rising gases create a very fine hotbed, and the compost meisters enjoy performing small-scale growing experiments to demonstrate what their product can do.

Curing

A common method for providing compost curing is the compost windrow. With the practice so widespread, it is noteworthy that no efficient and effective equipment for windrow turning is yet on the market. Windrow turning is accomplished by the use of an end-loader and some type of elevating conveyor that piles the material in the triangle-shaped windrow. The height of the windrows is a function of the amount of compost produced and the storage area available.

At the June 1967 INTAPUC Conference, a model and diagram of a windrow turning machine was on display. The machine looked like a self-propelled stern wheel from a river boat. The wheel was supported by rails on concrete walls on each side of the windrow. As the wheel moved against the windrow, the paddle or cups elevated the compost to an overhead position where it then fell onto a conveyor constructed in the center of the wheel. The conveyor moved the material to the new windrow position. The machine is simple enough and appeared to have the capacity that would be required, but would have the disadvantages of an inability to shred the compost and to clean all of the windrow from the ground. Only one machine of this kind is reported to have been built and it is operating in the Bahama Islands.

No single test has been developed for establishing the frequency of windrow turning. The frequency is usually established by the following variables: the windrow

temperature as measured by a thermometer placed in the windrow, windrow or compost odor, and moisture content as evaluated by the compost meister's nose, sense of touch, and experience. Until effective and reliable test procedures are developed, composting, like brewing, will remain an art dependent on the compost meister to determine how much moisture to add to the raw refuse or compost windrow, the turning frequency for the windrow, and when the compost is ready for sale. This reliance on the compost meister has developed a fraternity of these men, and they circulate from plant to plant as the opportunities develop. A good meister seems to be someone with the ability to work with people, who doesn't mind being in the "garbage business," and is willing to serve time as an apprentice.

Preparation for Sale

At most composting operations visited, when the compost is judged to be finished, it will be screened once before loading. In some operations a final grinding will precede the screening in order to provide an evenly blended and uniform texture of material. Since glass is one of the most objectionable materials in compost, must effort is directed toward its removal. In general the machines used are one of three types. Ballistic separation is one of the most common principles used for glass and other hard particle removal. The first type, known as the ballistic separator, is the largest machine. Compost falling into one end of the machine strikes a high-speed horizontal rotor. The rotor paddles are often short railroad tracks. The paddles or impellers strike the compost and propel it in a horizontal or slightly upward trajectory. Hard, dense, and resilient particles will obtain a high speed and long trajectory, while the soft, light and inelastic particles travel only a short distance. The trajectory paths are confined in a horizontal enclosure, the length and partitioning of which can be adjusted according to the need. The second machine, the secator, is probably the most common device used, mainly because it is cheap and mechanically reliable. Compost falling from the end of a conveyor strikes a shield or bounce plate that directs the material vertically downward onto a revolving drum. The strike plate may direct the material onto the top center of the drum or slightly off center in the direction opposite that of the drum rotation. The heavy and resilient particles will bounce off the drum into a collection bin, while the light and inelastic materials are carried on the drum under the strike plate and into the storage area. The speed of the drum and the position of the strike plate are set in accordance with operating experience. A third machine type used is the inclined plate conveyor. Compost falls onto a steel plate conveyor that moves at an angle upward against the falling compost. Heavy and resilient particles bounce down and off the conveyor while the lighter material is carried upward. This method seems to be the least satisfactory of the three.

Another system observed was a vibrating conveyor belt. The heavier particles and glass would settle downward through the material to the belt. Near the end of the belt a scraper was set and could be moved up or down to remove the upper material from the belt, thus literally scraping the compost from the glass and other materials.

In general, any of these systems alone would be considered satisfactory. For improved quality the compost would sometimes be exposed to two or more of the preceding systems, or the same system twice. This, of course, introduced additional expense. The problem with this equipment is that greater glass removal results in considerable loss of compost and an operational balance between a maximum amount of glass removal and a minimum amount of compost rejection must be attempted.

Screening or sieving of compost is universal at composting plants in order to provide a gradation of the final product. There is, of course, a direct relationship between the amount of screening of the compost and the final cost. Most of the screens were the vibrating type, with a few plants using small drum-type screens. The screening operation was one point in the system where the operator could have a direct influence on the amount of compost produced. The screen openings could be changed to pro-

duce compost in accordance with the greatest sales demands. In the situation where there was no market demand and large stockpiles of material were unwanted, the screen size was sometimes drastically reduced; this greatly increased the reject material and cost per ton of compost produced, although to the untrained eye the plant operation appeared normal.

An experimental sieve for glass removal is being tested. The sieve is an adaptation of a coal sieve that operates on the counter-flow principle. The compost enters the top and falls onto a fine mesh, inclined, vibrating screen. Air, blown at high velocities upward through the screen, suspends the compost a short distance above the screen while at the same time moving the material up the slope of the screen, and eventually out of the machine. The heavier particles remain on the screen and are moved downward and off. Initial tests indicate that the machine works satisfactorily except that some amounts of the heavier compost are removed with the rejects. This may be solved with some modification of the machine or additional processing equipment.

The use of a cross-flow air current for large particle removal was also observed. The air current was directed across the compost falling from a conveyor. The installation did seem effective in removing wine corks, bottle caps, some plastic, and bits and pieces of other material, but the effectiveness is directly related to the preceding operations.

Production Costs

The most frequent questions asked at a composting plant always seem to be how much does it cost to produce the compost, and what is the income from the sales? At most plants these data seem readily available, and the computation (expenses less income) to arrive at the unnecessary operational subsidy seems easy. It usually is not. To attempt to relate economic data from one operation or plant to the same type of plant in a different area, or to a different type of plant, presents an even greater problem. The confusion is compounded when the different economics of two countries enter the picture. Among the many factors that create confusion in economic comparisons are types of refuse received, economics of the area surrounding the plant, plant age, plant mechanization, labor costs, salvage operations, remoteness of plant, and marketability of the compost. The reporting of operational cost data may be confused by the inclusion or exclusion of such things as capital costs, income from salvage, ancillary equipment utilized in the process, taxation or organizational support funds, and so on. Most of the plant operators recognize this problem but for various reasons have no desire to correct the situation. Most operators, however, work toward the goal of keeping the operational subsidy at the minimum level.

It was observed that most of the compost plants were located adjacent to the sewage treatment plants. The sewage sludge was recognized as useful in the composting process, and composting was considered a good method for sludge disposal. The cost accounting system usually included the expense of the equipment needed to transport and incorporate the sludge with the refuse but seldom recognized, by means of charges to the sewage treatment plant or something similar, the benefits of using composting for sludge disposal. The economy of composting could present a different picture if the expense for an alternate means of sewage sludge disposal were recognized. It might be assumed, in general, that if it is necessary to compare economic data for composting operations, an acceptable method of standardized accounting must be developed and utilized.

In most of the operations the "expenses" exceeded the "income," but the necessary subsidy was justified as a reasonable expense for the solution of the solid waste problem. When questioned why composting was the system used, some operators sooner or later admitted that a high-powered salesman had influenced the judgment of the local political body. This is not an uncommon problem. The surprising element was that even though the system didn't prove profitable, as long as the plant subsidy was kept low, the operation was considered acceptable. In most cases composting was justified on the basis

that incineration capital costs were too great, that there was a lack of room for tipping, or that the watershed laws forbade the deposition of any type of raw refuse on the ground. The law, however, was unclear on the difference between "raw" and "treated" refuse. Some serious questions might be raised about a law that forbids depositing "raw" refuse but fails to establish standards for acceptable residues that are deposited on the ground. There are no standards or quality control regulations established for compost produced unless the compost is mistakenly marketed as fertilizer. There are definite quality control standards for fertilizer production.

Compost Sales

Present technology is such that there is no problem connected with producing compost; the problem is what to do after the compost is produced. One of the most effective organizations for the utilization of compost is Vuilafvoer Maatschappij (VAM) of Amsterdam, Holland. One of the largest stockholders in the company is the Dutch government. The company has three major sections: technique, agriculture research, and sales; the operation of one section directly affects the other sections.

The history of VAM illustrates the evolution that has taken place in composting. VAM's first plant was built at Wijster in 1932 when there was a large demand for coarse, low-quality compost to use in land reclamation. At that time about 80 percent of the plant's production went to the land reclamation companies. By 1940, 90 percent of the plant's compost went to farms and only 10 percent to the reclamation companies. This drastic change resulted from the fact that during World War II commercial fertilizers were almost impossible to obtain, and it was necessary to utilize compost to maintain much-needed crop production. The movement to utilize compost carried through to the middle 1950's, and by then the widespread use of compost had resulted in the recognition of several new uses. Cattle were found to prefer grazing on pasture that had been covered with compost rather than stable manure; mixing compost with farm manure increased the organic content of soil; compost could be used as bedding material for chickens and pigs; it was found that compost was effective in curing anemia in pigs. These new uses, of course, increased the demand for compost. In the 20 years between the middle of the 1930's to the 1950's only 1 composting plant was in operation, but since then a total of 15 additional plants have begun to produce compost.

During the 1950's vegetable growing, flower cultivation under glass, and flower bulb cultivation became a large horticultural industry in Holland. This new industry had interesting effects on compost production. A finer quality product was required and the processing of the compost became more complex and expensive. This requirement and ability to produce a finer quality product opened up a new market, a market for what is known as "refuse heating manure"—freshly ground refuse devoid of any sharp particles. This is in great demand by greenhouses. The essential feature of the material is the large amount of heat produced during the decomposition of the organic matter. It is difficult to try to match the supply-and-demand aspects of the product because of the large seasonal demand and the need for the material to be fresh.

Flower bulb cultivation along the sandy North Sea coast created a big compost market when it was found that the use of hand-placed reeds and straw could be replaced by mechanized application of compost. The compost resulted in labor savings and, in addition, had the benefit that it could be left and worked into the soil to become additional organic matter. The ever-increasing population density and demand for recreation areas and parks have created a market for a peat-compost mixture. The peat compost in a 1:1 mixture is said to make the land ready for cultivation quicker and to give the plantings a faster start.

Finally, the changing economy of Holland is resulting in more leisure hours for the city dwellers: hours spent growing flowers in window boxes or on small plots of land. It is more agreeable to apply the compost to the soil than to use animal manures, as there is no relationship between the "power" of

a material and its odor. Thus, while most compost is sold in bulk, there is an increasing demand for small quantities in attractively packaged bags. It is interesting to note that while the compost meister curses plastic as one of the biggest problems in producing quality compost, the sales people find it the most attractive way to market the product.

From the standpoint of total sales, horticultural and recreational uses rank at top, while general agriculture is near the bottom. As a result of the above, the sales demands are met by compost of one of the following classes: (1) horticulture quality; (2) superior quality; (3) peat compost; and (4) town refuse heating manure.

The VAM was established to develop and maintain a market for compost. The government is a strong partner in this organization because it recognized that the proper sale of compost provides a solution to municipal manure (refuse and sewage sludge) disposal problems, as well as maintaining the basic fertility of its limited agricultural land. From its long experience, the VAM company sets forth the following points as being necessary for continued compost sales: (1) a good outlet in the neighborhood of compost producing plants; (2) absence of competitive products such as farm manure, heating manure, etc., unless they have long supply distance; (3) cooperation by a large and well-stocked government information center; (4) the production of exclusive quality products that can be guaranteed completely; (5) favorable trading results with the buyers and no government restrictions; (6) very dry years when crops have had bad yields or died early because of lack of organic matter; (7) the importance of marketing a product with a trademark.

In conclusion, VAM does not hesitate to state that the production of compost is not a money-making proposition. The government is, of course, providing support for the organization, but the amount of the support is undefinable. The important fact is that the compost is sold. Several other countries are faced with problems similar to those in Holland, and some have the federal government involved; yet none has a sales group comparable to VAM and none enjoys the success in compost utilization that Holland does.

Special Systems

A composting system can be considered to have two parts; one part is for the preparation of the material and the other is for providing the required biological environment. Most of the present composting systems can be placed in one of four categories: (1) composting in fermentation cells with prior crushing of the refuse, followed by windrow curing; (2) composting in fermentation cells, followed by windrow curing; (3) composting in windrows without prior preparation, followed by compost product preparation; (4) composting in windrows with prior treatment of refuse without subsequent treatment of compost.

The following is a discussion of several special composting operations observed. While the systems presented are unique and generally the only operations of the kind in the world, the system components still fit the above categories.

Van Maanen System. The operation, first established in 1932, could be nicknamed the "open-dump composter." The majority of the refuse received is railhauled from Den Haag, Holland, about 175 kilometers to the composting plant at Wijster, Holland. The rail cars simply discharge the refuse onto the ground from rail spurs built on viaducts. Immediately after discharge, water sprinkling systems are operated to moisten the refuse. The operations are scheduled to provide up to 7 months' storage in the windrow if possible. After the desired curing time, the compost is transferred via gantry cranes and an endless train of mining cars to the processing building. The material brought to the building is first subjected to a thorough screening by successively coarser screens. The fine material first removed by the screen and given a magnetic separation is nearly free of glass and other undesirable items and makes the best quality compost produced. The material removed by the coarse screens is treated by magnetic separation, then either by a roller crusher or a hammermill. This lower grade compost can then be further re-

fined by ballistic separation and stockpiled for sale. Rejects are used to raise the level of the property adjacent to the windrow area.

The operation is well isolated from nearby farms. As would be expected there are vector and odor problems and a potential groundwater pollution problem connected with the operation. The Dutch government uses the 60-acre site as an experimental laboratory for evaluating vector control programs. Odors are a problem and efforts to use chemical masking agents have not been successful. An underdrain system designed to collect the leachate has been destroyed by corrosion, and some work is now being done to develop a new collection system and provide some measure of treatment for the water collected. A barge canal near the site was used to transport some of the compost to market, but trucks have now replaced the barges. It was reported that the fish in the canal were used as biological monitors for water pollution problems. This may be true, of course, provided that there *are* fish in the canal near the plant and that they are still sensitive to pollution. This is undoubtedly the lowest cost composting system in operation, but not necessarily the most desirable.

Baden-Baden System. The system was developed and is used at the city of Baden-Baden, Germany. It might be nicknamed the "modified tip composter." While being somewhat similar to the Van Maanen system, the operation is on a much smaller scale and provides better environmental control. Refuse is discharged from the collection vehicles into a small storage bunker, then lifted by crane to an overhead receiving hopper. The hopper feeds a rotating drum that was formerly used to screen out ashes but now serves as a flow equalizer for a sorting conveyor where magnetic separation and some hand-picking is performed. The refuse passes from the conveyor into a second drum and is mixed with sewage sludge (from sludge drying beds) until a 50- to 60-percent moisture content is developed, and then the material is discharged into a truck or wagon for transport to the windrow area.

The windrows are constructed on two lines of large-diameter, perforated concrete pipe. In former times air was blown into the pipes and out through the windrow, but odors became a very serious problem. The odor problem has been corrected by drawing air into the pipes through the windrow; the air drawn in is used as the air supply in the bulky waste burner on the site. Water is applied to the windrows and they are turned if necessary. Water pollution problems are handled by discharging drainage into storm drains or to the surrounding marshy area. After an appropriate period of curing, the compost is trucked to the plant, ground, and sieved for sale. The primary purpose of the plant is reported to be the satisfactory disposal of sewage sludge and not the production of compost. The compost that is not sold is used to raise the level of an adjacent marsh.

Caspari-Meyer Brikollare System. This process could be nicknamed the "cookie-cutter composter." The Brikollare system, while being the latest thing in composting, is also probably one of the more highly mechanized and expensive systems developed. The system actually replaces windrow curing with a "block" or "controlled" environment curing.

Refuse delivered to the plant is processed by magnetic separation and some hand sorting before discharge into a Dorr-Oliver rasp. After the rasp, the material is again processed by magnetic separation and ballistic separation. The material is then transferred via conveyor to the "brick" machine. Raw sludge, dewatered by a vacuum filter, is conveyed to a pug mill blending tank where three parts refuse and one part sludge is blended to produce a mixture with about 50 to 60 percent moisture content. After blending, the material is conveyed to a holding or surge tank for the bricking machine. By an elaborate and complex mechanical system, a measured quantity of the material is placed in a mold, vibrated for compaction, extruded from the mold, and stacked on a wooden pallet. The resulting brick, measuring about 15 x 15 x 20 centimeters, has the appearance of dark, raw papier-mâche. A half-moon slot parallel to the long axis, runs along the middle of the bottom of the brick.

When the pallet if full, a fork lift is used to transport the material to the curing shed. While the bricks are stored for about two weeks in the shed, temperatures of about 60° C are obtained and maintained, and large quantities of mold form. No odors were reported to be produced by the bricks.

The curing process was reported as follows. The group of stacked bricks provides a body of heat that maintains the temperature near the optimum for the desired biological activity. Much of the exterior surface of the brick is open to the atmosphere and aerobic decomposition takes place, while inside the brick, anaerobic activity takes place. As the products or byproducts of the anaerobic activity are transferred outward, they encounter the anaerobic-aerobic interface where they are transformed or modified into unobjectionable products. As the curing continues, the brick moisture moves outward and air moves inward and the microorganisms maintain the balance.

Experiments at the plant have shown that when the ground-up bricks are used as insulation material around the brick stockpiles, the stored bricks can still obtain air, and the stockpiles can be stored almost indefinitely. The bricks have the advantages of no odor in long-term storage and a reduction in the size of storage area needed. When the bricks are to be sold, they are passed through a hammermill and the compost is then screened to the desired grade. It is necessary to process only as many bricks as may be needed to produce the quantity of compost desired by the buyer. Although this system is expensive and is vulnerable to mechanical breakdowns, it provides excellent environmental control and produces a desirable product.

Humboldt. The Humboldt system is experimental and is now being developed and tested. The refuse is processed by magnetic separation while being conveyed from the storage bunker to a pug mill for shredding and mixing with sewage sludge. The pug mill has been modified to include shearing knives spaced at intervals along the twin rotors. The homogenized and shredded material discharged from the pug mill is placed in a tall, conical drum that looks very much like an elongated concrete mixer. The material moves downward by gravity and is discharged at the bottom by a scraper system. At the center of the drum are pipes used for the injection of air and moisture when necessary. Hopefully, the system will not require windrow curing and has the advantages of a minimum of mechanization, reduced power requirements, and a controlled environment. Nylon stockings present a problem in the pug mill because they do not shear and then become wrapped about the rotor and entangle pieces of refuse. The result is a huge ball of material that jams the machine. The process is patented and now operating on a pilot scale. When a full-scale plant might be constructed is unknown, and it is still too early to evaluate the potential application of this system.

Research

Soil Effects. Studies carried out to date indicate that compost has definite short- and long-term advantages when added to the soil for crop production. The exact mechanisms that create these benefits are unknown, but seem to be tied into the mysteries that still surround the material known as humus. Compost has been shown to increase the biological activity in the soil; this has been related to the fact that compost-produced crops experience less plant disease. The compost mineral analysis is well known and reveals that the material is definitely not a fertilizer; yet when applied to the soil, the compost produces a crop response that is very similar to that obtained with commercial fertilizer. Compost has been proven to provide a rapid start for plant growth and seems to be able to sustain the quick-start advantage through to the maturity of the plant. One hypothesis is that the dark color of the compost provides a better retention of radiant heat, and the radiant heat aids the growth process. Current experiments at Braunschweig, Germany, are testing this hypothesis.

Dr. Koepf at the Agricultural University at Stuttgart-Mohringen is undertaking studies on the relationship of nitrogen and the soil. The results of this work will certainly have an influence on compost utilization. Dr. Koepf and his colleagues have just completed

work on the background levels of nitrogen present in natural streams, and, in an effort to understand the source of the background levels, Dr. Koepf plans to study the fate of nitrogen applied to the soil. The studies may indicate how much nitrogen goes to the atmosphere, how much nitrogen enters the soil; and of the nitrogen that enters the soil, how much passes through the soil to the water, how much is utilized by plants and microorganisms, how much is retained by the soil, and what forms of nitrogen can best be utilized by the life systems of the soil.

It was noted that when immature compost was being sold, the compost meister usually advised the buyer not to use the material for at least two weeks. The meister had learned by experience that early application of the compost to soil results in adverse effects on crops because the microorganisms extracted nitrogen from the soil in order to complete their actions on the compost. A test for compost maturity in relation to nitrogen was observed. The test apparatus is also used for determining soil moisture *in situ* and consists of a pair of tongs with a wedge-shaped head that clamps about a special piece of porous paper. The instrument is inserted in the soil for a period of time, removed, and a measurement of the penetration of the moisture from the paper edge is referenced to a correlation curve to determine soil moisture. The same procedure is used in a compost sample with specially treated paper. The moisture content of the compost is measured as above, and then chemical additives are placed on the moist area. Color change determines absence or presence of nitrogen, with color intensity providing indication of the quantity. This test can be correlated with the compost maturity and used for guidance in future operations. Test accuracy was not guaranteed and its mechanism was not completely understood.

A test devised for compost utilization was observed and will be mentioned here even though out of context. Plant seedlings or seeds were placed in samples of compost of various ages. The sample with the youngest age that produced the desired plant response was judged to be the material mature enough for sale. The disadvantages of this test were: the large area needed to grow the seedlings; the necessity to keep repeating the entire process; and the need to wait for a period of about five days before results were known. Another study indirectly related to compost and soil effects involved earthworms. Two windrows of ground refuse were placed side-by-side, one as control, the other inoculated with earthworms. After two months it was observed that the control pile was anaerobic at the center and decomposing slowly while the inoculated windrow had decomposed rapidly into compost.

Erosion Control. The high population density of Germany requires maximum production from the agricultural land available, and sustained high-level productivity over a long period of time, so that soil losses must be minimized. One of the prominent German crops with a tremendous erosion potential is grapes grown on hillside vineyards. The grapevine growth is such that there is no ground cover, leaving the soil with a maximum exposure to the erosion-producing elements of nature. In the past, the hillsides were terraced for erosion control, but this is not an efficient utilization of the area available, and gradually the terraces have been replaced by the open mountainside. Both the German government and the Wine Growers Association have recognized the potential problem and have put forth money to determine what control techniques can be utilized.

Compost has been found to be a very effective material for erosion control, and the wine growers are probably the largest group using compost in Germany. Dr. Bosse, at the Bad Kreuznach compost plant, is employed by the Wine Growers Association to study the relationship of compost to erosion control and soil improvement in vineyards. About 90 percent of the plant production was being used on vineyards. On the hillsides where hand labor is necessary, the vineyard rows are planted 1.2 meters apart, while on the flatter areas the rows are 3.2 meters apart to allow the use of machinery. Studies have found that while the method of plowing has some influence, the application of 100 cubic meters of compost per hectare every

three years is effective in erosion control. Based on the fact that compost has been demonstrated to be an excellent material for erosion control, studies were in progress to determine the optimum amount and frequency of application needed to provide long-term benefits and maximum crop production by soil improvement with compost.

An interesting erosion control study has been made by German scientists. The question arose as to how much soil had been lost by erosion over the years. Hundreds of years ago when the land was first being cultivated, the hillside rocks were quite a nuisance. In clearing the fields the rocks were piled along boundary lines or at whatever distance a man could stagger with a large rock or throw a small one. The results of these efforts can be seen today as long rockpiles along the hill slopes. It was agreed that the earth under these piles should be at approximately the original elevation and, therefore, some of the windrows of stone were moved and precise measurements were made of the differences in elevation of the original and the present ground levels. The results indicate that approximately three inches of soil had been lost in several hundred years.

Pathogen Studies. Detailed studies have recently been completed in Germany on the subject of pathogen survival during the composting process. The principal investigator for these studies was Dr. D. Strauch, a doctor of veterinary medicine at the Justus-Liebig University Institute of Human Health Protection and Animal Health at Giessen, Germany. His primary interest was the epidemiologic study of the role of composting in relation to man, animals, and the soil. His studies, quite thorough, were performed on a variety of compost processes, and with a high degree of probability concluded that as long as proper temperatures, humidity, gas exchange, and detention times were maintained in the process, the end product contained no hazards for man or animals. His study procedures and findings have been published in German[7] and summarized in English.[8]

Dr. Strauch developed several interesting techniques during his studies. In one technique he used a Perlon plastic or cloth mesh bag that he named the "inoculation" bag. Two of these bags usually were used in his studies. Both bags were filled with 100 grams compost or ground refuse, and a hypodermic syringe or gelatin capsule was used to inoculate the bag with a known number of the organisms to be studied; a sealed ampoule containing a known quantity of the same organism was placed in the other bag. The two sealed bags were then placed at a desired location in the compost windrow. The ampule provided data as to whether the pathogen destruction was a temperature function alone, while the bag, allowing free exchange of gases, nutrients, and most everything except the test organism, provided data on which microbiological interactions might be operating to destroy the pathogens. The results obtained were considered highly satisfactory. A different technique was required when the composing process included a fermentation cell such as the Dano drum. For this Dr. Strauch developed what he called his "sputniks," hollow, perforated metal spheres that were bolted together. He would place his inoculated bags in these spheres and expose the spheres to the composting process. In the first attempts to use the spheres in the Dano drum, it was found that they very quickly bounced through the drum. In order to closely simulate the movement of the material through the drum, the spheres were wired into place inside the drum and periodically the drum would be entered and the spheres transferred to a new position. Dr. Strauch felt the results obtained were quite reliable. Among the organisms tested by Dr. Strauch were *Bacillus anthrax*, *Salmonella enteritidis*, *Erysipelothrix rhusiopathiae* and Psittaservirus.

Other studies have been carried on by other investigators, but the results obtained

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[7] STRAUCH, D. Veterinärhygienische Untersuchungen bei der Verwertung fester und flüssiger Siedlungsabfälle. Heft 18. In *Schriftenreihe aus dem Gebiete des öffentlichen Gesundheitswesens.* Bundesministerium für Gesundheitswesen, Bad Godesburg, 1964.

[8] BANSE, H. J., and D. STRAUCH. The importance of pre-fermentation in composting. *Compost Science,* 6(3):17–23, Autumn-Winter 1966.

were generally incomplete and nonconclusive. Research work on other aspects of composting had found that the optimum temperature for biological activity in composting is in the range of 40 to 50° C. With a humidity between 40 to 60 percent even the most resistant sporozoa are killed. It was found that antibiotic substances produced under the above conditions operated to control the pathogenic organisms.

In developing controls for the production of hygienic compost, two points must be kept in mind. The necessity for an optimum environment is pointed out above. The second point relates to how compost improves the soil. It is known that the processes occurring in compost enhance the soil biological activity, that needed plant micro- and macronutrients are produced, and that the compost finally becomes humus. The mysteries of humus are still unsolved. In order to produce the preceding benefits, compost must be placed on the soil as soon as possible. Therefore, as soon as the decomposition of the refuse in an optimum biological environment has satisfied the public health requirements, the process should be terminated in order that beneficial continuing actions can take place in the soil.

Reclamation. German studies are being made currently on the use of compost for the reclamation of marginal land. One scientist, Dr. H. Kick, is said to have done considerable work on the utilization of compost in the reclamation of land; however, it was not possible to contact Dr. Kick. From general discussion it was learned that other authorities believed that compost would be an excellent material to use for such activities. Obstacles to the use of compost would be determining: (1) who should pay for the production of the compost, its transportation, and its application; (2) how would the benefits and costs of the reclaimed land be distributed. It seems evident that there would have to be considerable government support for such operations, and at present, there are many other projects marked with high priorities for what German government funds might be available.

General Remarks

At the International Association of Public Cleansing (INTAPUC) conference there was an abundance of composting processes on display. The well-known composting systems were represented as well as several new processes that claimed to be long-awaited answers to problems of composting. It is suggested here that the old and new composting systems are developing in the wrong direction. The quality of compost needed to meet the market demand should be produced as simply and cheaply as possible. Some of the oldest and simplest installations visited produced a quality of compost equal to the product produced by modern, highly mechanized and very expensive systems. Mechanization is, of course, needed to offset increasing labor costs, but, on the other hand, increased mechanization usually has resulted in greater mechanical unreliability. Increased mechanization is also related to the fact that the principal marketing agents for composting systems are equipment or machinery companies that desire inclusion of as many of their products in one system as possible. If composting is to maintain a place as an acceptable technique in the solid waste utilization cycle, the process must be kept as simple as possible to avoid mechanical unreliability and excessive capital costs. Additionally, the composting operation needs access to an efficient sales department that can develop and promote new or existing products and markets.

The Plant and the Process. Composting is a method of handling and processing solid wastes to produce as the end product a humus-like material which may be used as a soil conditioner. The process requires separation of non-compostable materials which must be disposed of by other means. Technically, composting is biological degradation of organic matter under controlled conditions of aeration, temperature, and moisture.

Since the organisms necessary to make compost accompany almost all solid wastes, most materials begin to decompose within a few hours. Garbage degrades quickly; paper, cloth, wood chips, and leather less quickly; most plastics and rubber degrade very slowly if at all.

Composting as generally used in discussions of commercial and municipal processes refers primarily to aerobic decomposition (in the presence of oxygen). However, composting of solid wastes may take place in the absence of oxygen (anaerobically). Odors produced by the aerobic decomposition process are less objectionable. The aerobic process is quicker and achieves higher temperatures, thus guaranteeing a relatively germ-free product, free of live weed seeds and insect larva. The anaerobic process is slow, smelly, and does not achieve temperatures high enough to destroy all pathogens. Anaerobic decomposition also produces noxious gas by-products such as hydrogen sulfide.

In most processes, it is difficult to control the oxygen balance throughout the wastes. Thus, it is possible to have aerobic and anaerobic decomposition taking place simultaneously in different parts of the wastes.

One commercial method is by windrow (pile) composting in which the processed wastes are placed in long rows on concrete, asphalt, or the ground. The rows are mechanically turned about once a day for the first week, then twice a week for about a month.

Some elaborate systems mechanically mix, agitate, and aerate the composting material in enclosed units. This speeds the process so that relatively inert material can be produced in as little as five to seven days.

After conversion into a brown humus-like material, further refining may be necessary to remove undesirable particles (such as metals, glass, ceramics, plastics, rubber, and leather), depending on final use.

Evaluation. The promise that the compost will be sold and thereby pay for the cost of the process is seldom realized. There is no automatic market for compost. The rate of plant failure speaks for itself (see Figure E).

Developing a market may not mean selling compost for profit. may mean finding someone who will take it free in large quanities on a reliable and continuous basis. The local government ay be able to use most of it to maintain grass, trees, and shrubs

FIGURE E: 1968 STATUS OF U.S. COMPOSTING OPERATIONS

Location	Company	Process	Capacity (Tons per day)	Status
Altoona, Pa.	Altoona FAM, Inc. Fairfield Engr. Co.	Fairfield-Hardy	45	Operating
Boulder, Colo.	Rich Land Co.	Windrow	100	Closed
Elmira, N.Y.	National Organic Corp.	Windrow	100	Construction stopped
Gainesville, Fla.	Gainesville Metropolitan Conversion Corp.	Metro	200	Operating for research purposes
Houston, Texas	Biochemical Sales, Inc.	Snell	300	Closed
Houston, Texas	Metropolitan Waste Conversion Corp.	Metro	360	Operating
Houston, Texas	National Organic Corp.	Windrow	300	Construction delayed
Johnson City, Tenn.	PHS-TVA Cooperative Program	Windrow	50	Operating for research purposes
Largo, Fla.	Peninsular Organics, Inc.	Metro	50	Closed
Mobile, Ala.	City of Mobile	Briquetting	300	Operating (with windrows)
Norman, Okla.	International Disposal Corp.	Naturizer	35	Closed
Phoenix, Ariz.	Arizona Biochemical Company	Dano	300	Closed
Sacramento, Calif.	Dano of America, Inc.	Dano	40	Closed
St. Petersburg, Fla.	International Disposal Corp.	Naturizer	105	Closed
San Fernando, Calif.	International Disposal Corp.	Naturizer	70	Closed
Springfield, Mass.	Springfield Organic Fertilizer Co.	Frazer-Eweson	20	Closed
Williamston, Mich.	City of Williamston	Riker	4	Closed
Wilmington, Ohio	Good Riddance, Inc.	Windrow	20	Closed

in city and county parks and along highway median strips and shoulders. Some local governments give it to farmers. In Houston, experiments are underway to determine whether compost can be used for animal feed. Failure to find a reliable end use for the product means that government will have to foot the bill to sanitary landfill the compost as well as its residue.

There is a widely held misconception that compost by itself is a fertilizer. Compost is only a conditioner used to make soil more manageable and increase its ability to hold moisture.

Composting finds its greatest application in agricultural communities. Communities should be careful to avoid the usual pitfalls when considering the compost process. Shysters sell bottled enzymes "to stimulate action to make solid wastes compost." Since bacteria are already present, the action starts whether enzymes are added or not. Glass, metals, tin foil, and other solids will not compost and must be removed; foreign material in the compost will greatly affect the ability to find a use for the end product. Since all wastes cannot be composted, something must be done with the other (inorganic) wastes. They must either be landfilled, sold as salvage, or given away. Sanitary landfilling this material is the only continuously reliable method since the other systems depend heavily on a fluctuating market demand for the used item, and most inorganics do not incinerate well.

Few compost plants operate economically. A private experimental plant in Houston has had a short-term successful record. This plant might be described as a waste utilization plant. Much

commercial composting with salvage

Metropolitan Waste Conversion Corporation, Houston, Texas

In operation since November, 1966, Metropolitan Waste Conversion Corporation converts solid wastes into salvageable items and compost products. The Metro Waste operation consists of removing all salvageable and non-compostible materials, grinding what is left, and then subjecting it to a digesting process which converts it into organic compost.

The process begins when trucks dump waste materials into a continuous conveyor which moves onto a sorting station where such non-compostible materials as ceramics, rubber, glass, and nonferrous metals are removed by hand. Ferrous metals are removed by powerful magnets and sold as scrap metal. Approximately 15 per cent of the material, such as corrugated cardboard, rags, and newsprint, is salvaged, bailed, and sold. The remaining material moves to two sets of grinders and is then mixed with thickened sewage sludge and placed in a specially designed digestor for six days. It is then reground and packaged for distribution.

Since the present market for compost is seasonal (spring and fall) large quantities must be stored at the plant site, usually outdoors. These stock piles have a slightly musty odor that usually cannot be detected more than several hundred feet away. However, some people object, claiming that compost was "garbage" when it entered the plant so it must be "garbage" even after processing. The plant, located in an industrial park and surrounded by residential communities and small businesses, has extended an open invitation to homeowners and businessmen to visit. More than 100 persons have done so. Invariably, they are impressed by its operation and convinced that the plant and process does not constitute a health hazard, as is frequently rumored.

Metro Waste is now working with fertilizer companies to market the product as a blend of organics and chemicals, experimenting with the use of compost instead of wood fibers for hydromulching, and collaborating with a paper company on the use of compost for reforestation programs. To determine proper application amounts and frequency for crops such as cotton, citrus, soybeans, rice, and vegetables, Metro Waste is working with farmers, universities, and county agricultural agents. It also works with a biological laboratory to insure constant quality control and safety of the compost material.

Metro Waste's Houston plant, costing approximately $2 million, has a rated capacity of 360 tons per day. The compost product, after final grinding, sells for about $12 per ton in bulk with no upgrading. The company pays rent on the land and taxes on the building and machinery in Houston, and is treated as any other industry by the city. Original plans for the Houston plant called for a work force of 35 persons including the manager, but Metro Waste found it could conduct an efficient and satisfactory operation with 29 men.

The City of Houston, Texas, has developed a balanced system for wastes disposal by integrating the three acceptable solid wastes processing methods—incineration, composting, and sanitary landfill. The city operates an incinerator and a sanitary landfill. It also contracts with the Metropolitan Waste Conversion Corporation to compost up to 360 tons of solid wastes daily, for which the city pays $3.87 per ton. With these three processing methods, the city has alternatives available in the event that one of the disposal sites must be temporarily closed down.

of the salvage is reprocessed by sister companies and the port provides economical access to overseas markets. The firm sells plastics to Japan; paper for pulp, cans for copper, and glass for reflective paints and for reuse in glassmaking.

Although recycling usable materials should be a national long-range goal, it is unwise to base an entire solid wastes management system on recycling wastes unless a *guaranteed* market is developed in advance. The payment for the recycled goods must be at least sufficient to meet the additional costs of extra manpower for sorting materials and extra time for transporting the material to the user, and for sanitary landfilling the remaining solid wastes. Local governments must consider composting as a treatment or process prior to disposal. They must be prepared to pay a reasonable price for this operation.

Composting

ADVANTAGES	DISADVANTAGES
1. Compost can be used as a soil conditioner.	1. There are presently few outlets for the compost and the salvaged materials.
2. Composting is a recycling method.	2. All wastes will not compost.
3. Composting is a volume reduction method.	3. A sanitary landfill is still needed to dispose of those materials which are not salvaged or will not compost.

checklist for transfer, processing, and disposal operations

- All-weather access and egress roads
- Dust control measures
- Posted regulations
- Employee facilities — washrooms, lunchrooms, lockers
- Scale house and weigh station
- Fenced grounds
- Designated place and container for wastes to be received after hours at the gate
- Landscaping and litter control
- Employee safety program
- Fire fighting equipment available
- No open burning practiced
- Communications
- Adequate screening
- Banning of scavenging
- Efficient recordkeeping

What Constitutes a Dump? The Bureau of Solid Waste Management uses the word "dump" to describe any site where solid wastes are left uncovered for a period of more than a day. Although it is a hazardous and unsatisfactory operation, it is the most widely used practice. A dump also is an accumulation of wastes from one or more sources at a central disposal site under little or no management. **the dump**

Dump operation seems inexpensive; few operators are needed and maintenance costs are low. Actually, the hidden costs of a dump are rodent and insect infestation, poor community relations, excessive demand on health and fire department time, stench, air and water pollution, and land value depreciation.

Cleaning Up an Old Dump. An old dump can be transformed into a sanitary landfill by adopting sanitary landfill operating standards. Before bringing additional solid wastes to the disposal site to be sanitary landfilled, several steps must be taken:

1. Thoroughly extinguish all fires.
2. Exterminate all rats and other vectors. (If this is not done, these vectors and vermin will invade the surrounding community. Residents will believe the new sanitary landfill is the cause.)
3. Compact all solid wastes, and if practical consolidate them into limited areas.
4. Cover the dump with compacted earth.

Kenilworth disposal site in Washington, D.C., once the nation's most notorious open burning dump, ceased burning operations February 15, 1968. After extinguishing all fires, exterminating all vectors, and compacting the wastes, the tons of accumulated charred wastes were covered. By April, a sanitary landfill was in full operation.

progress and problems in cleaning up dumps

City of Beaufort and Beaufort County, South Carolina

"Beaufort has made more progress in taking care of its solid wastes than any other county in the state. It is now correctly disposing of about 50 per cent of it, which puts it a giant step ahead of most counties." This assessment of the situation in Beaufort County, South Carolina, was made by a representative of the Environmental Sanitation Division of the state Board of Health, which has surveyed the status of solid wastes management in all of South Carolina's 46 counties.

The transition from open dumps and burning began in 1956, largely through the efforts of the county health department's chief sanitarian, who was aided by the state health department.

Survey results and recommendations were presented to the city council, which liked the idea of ending open dumping and burning and instead operating a disposal site which could eventually be used for park and recreation purposes. Other economies of the proposal were particularly attractive. It was estimated that $10,000 per year might be saved by eliminating the 8-mile haul to the local dump, and instead landfilling the wastes on property within the city limits. An ordinance regulating the handling and collection of "garbage" and "waste matter" was adopted.

Members of the county Board of Directors (governing board) proved equally receptive to proposals for cleaning up Beaufort County. The board's public service committee prepared guidelines on "Recommended Standards for Sanitary Landfills." Program direction was assigned to the county supervisor of roads and bridges, who gave his full support to the use of county equipment and personnel for the maintenance of disposal sites.

The county now maintains three sites, with long-range plans calling for 11 strategically located sites. A crawler tractor with front-end loader, run by a full-time operator, is transported between the sites to compact wastes in trenches and apply daily cover.

The local terrain is dotted with natural pits and depressions; owners are often anxious to have the land improved. Such land is usually leased to the county for $1 per year to be filled. During the first seven years, two pits were reclaimed through city-county cooperation and are presently being used for ballfields and other recreational activities.

Beaufort County faces special industrial waste problems: pesticide container and wastes disposal; liquid wastes from fertilizer plants; toxic wastes from soybean processing; culls, peels, and seeds from canneries and truck farms; and wastes from local fisheries. Beaufort is currently trying new techniques to improve disposal of these byproducts.

Though solid wastes problems in Beaufort County have by no means been solved, the county finds itself well ahead of most communities its size across the country (population in excess of 45,000). Local officials are actively seeking guidelines and are receptive to suggestions which might provide solutions to their problems. Although limited by inadequate funds and staffing, they are attempting to implement a satisfactory, workable program.

Feeding Garbage to Hogs

Feeding hogs uncooked garbage is prohibited by every state and by federal law. Yet some communities continue to feed hogs raw garbage. A 1967 U.S. Senate Committee on Agriculture Report on the Federal Meat Inspection Act cites a World Health Organization report stating that in the United States one in six persons has trichinosis—this is the highest rate in the world.

To insure necessary and adequate protection of people and hogs, pathogenic organisms must be destroyed. This requires that food wastes be cooked at 212° F for 30 minutes, which is difficult to enforce.

Although it may be convenient for the hog farmer to have a garbage route to get swill for swine, allowing farmers to have their own garbage routes requires the separation of garbage and refuse (which is inconvenient for the homeowner), and in the long run endangers health. As of July 1, 1968, Wisconsin completely outlawed feeding any type of public or commercial garbage to swine. Since most places fail to prepare garbage properly, other states and local governments must enact this prohibition.

General Summary of Foregoing Topics

Every solid wastes management system must be designed to meet the particular needs of the community to be served.

To design a collection system, it is necessary to examine the types of storage containers and collection equipment, route and crew organization arrangements, manpower availability, topographical conditions, degree of homeowner participation feasible, and types and amounts of solid wastes generated.

To design a disposal system, environmental conditions (air, water, and land), cost considerations, and public attitudes must be evaluated to select the method or combination of methods most appropriate. Although the community will need to rely on sanitary landfill for final disposal of solid wastes, incineration and/or composting may be additional processing steps used.

Methods of processing or disposal which cause pollution, such as dumps, open burning, flue-fed burners, and conical burners, are not satisfactory and should not be part of a solid wastes management system. The conditions under which hogs may be fed commercial garbage legally and safely are widely disregarded and difficult to enforce; therefore, local government should not consider feeding hogs garbage to be part of the local solid wastes management system.

Good solid wastes management requires that collection, processing, and disposal be coordinated. In a large solid wastes management system, coordinating collection and disposal operations through the use of transfer stations may bring economies and increased efficiency. Coordination is also essential between public and private operation.

Another area where coordination is necessary is that between local government and the citizen. The citizen must know what is expected of him to make the solid wastes management system effective. In addition, there is a relationship among the amount of citizen participation required, the degree of service provided, and the cost of the service. For example, set-out/set-back collection is more expensive than curb service because the collection crew must do more work. With curb service, the citizen must participate by carrying his solid wastes container to the curb and back on collection days. Another illustration of this relationship is the difference in cost between having local government provide pickup service as opposed to having the citizen bring bulky items directly to the disposal site.

In the operation of a comprehensive solid wastes management system, the management of industrial and agricultural wastes and hard-to-handle items such as abandoned automobiles should not take a back seat to the collection and disposal of residential and commercial solid wastes. In addition, all services should be performed to meet the highest standards of environmental sanitation and personnel safety. Good solid wastes management is an asset to a modern community. The development of solid wastes technology is rapidly expanding just as the types and amounts of solid wastes being produced are changing and increasing. Therefore, the solid wastes management system local government selects today must be flexible enough to adopt tomorrow's technology to meet tomorrow's needs.

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The major objective of this investigation was to inventory major classes of wastes being barged to sea. These findings were summarized in topical discussions of a description of the various major types of waste, a summary of the principal offshore disposal sites; a discussion of disposal methods, amounts, and costs.

DESCRIPTION OF WASTES

Wastes currently being transported aboard barges and ships for disposal at sea from the U.S. coastal cities surveyed have been summarized into seven major categories and ranked according to total volume: (1) dredge spoil, (2) industrial wastes, (3) sewage sludge, (4) refuse, (5) radioactive wastes, (6) construction and demolition debris, (7) military explosives and chemical wastes, and (8) miscellaneous.

For detailed information regarding the characteristics and problems associated with the disposal of these wastes, the reader should consult the following references: American Petroleum Institute, Revelle and Co-Workers, Tarzwell, Moss, U.S. Department of Agriculture, U.S. Coast Guard, Kurak, Sax, California State Department Public Health, Burd, and Sittig, National Academy of Sciences, and American Burd, and Sittig, National Academy of Sciences, and American Chemical Society.[1-15]

Dredge Spoil

Dredge spoil consists of sediments containing various concentrations of alluvial sand, silt, clay, and municipal or industrial waste sludges dredged to improve and maintain navigation channels. It is these sludges which put the Corps of Engineers into the municipal and industrial waste disposal business, giving the Corps a responsibility neither within its charter nor desired by that agency. Most of the dredging operations are conducted by the Corps with seagoing hopper dredges. These spoils are normally disposed of in open coastal waters generally not more than three to four miles from the dredging site.

Industrial Wastes

Industrial wastes originate from a variety of manufacturing and processing operations including petroleum refining, steel and paper production, pigment processing, insecticide-herbicide-fungicide manufacturing, chemical manufacturing, oil-well drilling operations, and metal finishing, cleaning, and plating processes, as well as many others. A brief description of several types of industrial wastes currently being disposed of at sea follows.

Refinery Wastes. Wastes from petroleum refining operations are produced during the chemical refining processing used to extract various products from the crude oil. These include spent caustic solutions, sulfuric acid sludges, dilute process water solutions, spent catalysts, petrochemical wastes, and chemical cleaning wastes. In many cases solid wastes, such as spent clay, catalysts, and sludges are slurried with liquid chemical wastes for disposal at sea.[1-3] The spent caustics and acid sludges also contain varying amounts of contaminants including: sulfides, sulfates, phenolates, napthenates, sulfonates, cyanides, heavy metals, mercaptides, chlorinated or brominated hydrocarbons, and other organic and inorganic compounds.

Spent Acids. Large quantities of spent sulfuric acid and ferrous sulfate are produced by steel mills. The acid, or "pickle liquor," is usually withdrawn from the operation and disposed of when one-half or two-thirds of the acid is converted to ferrous sulfate. Typical wastes contain up to 7 percent free acid and up to 30 percent ferrous sulfate. In recent years some steel mills have converted a portion of their pickling operations to hydrochloric acid which has resulted in reduced volumes containing spent hydrochloric and sulfuric acids.

Another major waste results from titanium pigment manufacturing in which the ore, with iron as a principle impurity, is digested with sulfuric acid. The wastes include the liquor with 7 to 9 percent free sulfuric acid and 8 to 10 percent ferrous sulfate and a mud slurry with 15 to 20 percent inert solids.

Pulp and Paper Mill Wastes. Pulp and paper mill wastes include the organic constituents of wood being pulped, dissolved salts from the digestion process, undigested pulp, and fibers that escaped processing. Depending on the process, the wastes may contain a sulfate cooking solution (calcium, magnesium or ammonia), "black liquor" (sodium hydroxide, sulfide, sulfate) and organic constituents including lignin, hexose and pentose sugars.

Chemical Wastes. Chemical manufacturing, chemical laboratories, metal cleaning finishing and electroplating processes, and a variety of other industrial operations all produce a host of complex waste chemicals. These include murcuric or arsenical compounds, organic acids, pesticide chlorinated hydrocarbons, alkalaes, anilines, cyanides, and other highly toxic substances. Chemical industry wastes are particularly complex in their composition and behavior.

Oil Drilling Wastes. Oil-well drilling wastes disposed of at sea consist primarily of drilling muds containing barite and diatomaceous clays and cuttings (rock chips) from the drill hole. This type of waste is physically similar to dredging spoils.

Waste Oil. These wastes consist principally of oil sludge that remains after any re-refining process. In the case of oil tankers, the wastes are oil residues resulting from tank cleaning operations (butterworthing). Sources of waste oil are numerous, diverse, and include service stations, ship tanks, tank cars, etc. At present, the Oil Pollution Control Act of 1961 restricts the disposal of these wastes at sea to areas beyond the 50-mile limit.

Sewage Sludge. Total solids in sewage include large and small suspended particles as well as matter in true solution. The weight of these solids is usually 0.03 percent or less of the total sewage solution by weight. Solids are removed and treated by screening, grit removal, primary sedimentation, final sedimentation, anaerobic digestion and thickening. Thickened sludges currently being disposed of at sea from barges generally range between 3 to 5 percent solids by weight.

Refuse

The survey revealed that only limited disposal of refuse and garbage at sea occurs. These wastes originate primarily from canneries and from commercial and naval vessels. Cannery wastes consist of ground fruit pits, skins, etc., and are disposed of on a seasonal basis. The composition of vessel refuse depends on the type of vessel, geographic location, and season, and consists of varying amounts of food, paper, plastics, metal, glass, and similar wastes.

Radioactive Wastes

The nuclear energy industry produces high activity, intermediate activity, low activity, and so-called nonactive wastes. Activities range from hundreds of thousands of curies per gallon for high activity wastes to microcuries per gallon for low activity wastes. Solid wastes include contaminated laboratory or process equipment, clothing, and other items. Between 1946 and 1967 the U.S. Atomic Energy Commission (AEC) disposed of limited quantities of solid packaged radioactive waste materials at designated disposal sites in the Atlantic and Pacific Oceans. In most cases these wastes were packaged in weighted 55-gallon drums. Most of these wastes are now disposed of on land. Nuclear vessels regularly discharge low-level liquid coolant wastes at sea under strict AEC regulations.

Construction and Demolition Debris

Typically, these wastes consist of masonary, tile, stone, plastic, wiring, piping, wood, and excavation dirt. At the present time, the only sea disposal of this type of waste is from New York City.

Military Explosives and Chemical Warfare Agents

This category includes unserviceable or obsolete ammunition such as shells, mines, solid rocket fuels, propellents, agents. Until 1964, the disposal of explosives was conducted primarily from barges and ships. Since then, gutted World War II Liberty ships have been utilized, being sunk with the wastes aboard in water depths greater than 6,000 feet.

Miscellaneous

Included in this category are various types of rejected or contaminated products, such as foodstuffs, appliances, small batches of toxic wastes (usually barreled) such as pesticides and complex chemical solutions. Wastes in this category are usually disposed of in small lots, and records regarding their disposal are difficult to obtain as the disposal operations are not often sanctioned by any regulatory agency.

Selection of Disposal Areas

Results of the present study show that past determinations of whether or not a given offshore area was suitable for waste disposal have been based primarily on the following considerations: (1) the disposal area should be far enough away from the coast and/or have an ocean depth deep enough to ensure that no identifiable wastes return to public beaches or interfere with fishing or recreation in coastal areas; (2) the disposal areas should be within a reasonable distance from the coast so that the costs of tug and barge operations are minimized.

In a small number of cases, the potential harm to the environment and the restrictions that the waste disposal operations might place on future exploitation of natural resources (i.e., fishing, minerals, oil research) were taken into consideration. Some studies have been conducted of various environmental aspects of individual disposal operations; these, however, have been limited in both scope and duration and in most cases were conducted after the disposal operations were in progress.

Disposal Methods and Costs

Methods employed for sea disposal of the various wastes consist primarily of transporting the wastes in bulk or containers aboard towed or self-propelled barges. Dredge spoil is handled routinely by U.S. Corps of Engineers aboard their oceangoing hopper dredges. Bulk wastes are normally discharged from tank barges while underway. Containerized wastes might, depending on local practices, be weighted and sunk, or ruptured at the sea surface by axes or rifle fire and allowed to sink. In a few cases highly toxic chemical wastes such as arsenic and cyanide are carried to sea regularly as deck cargo on merchant ships. The containers are then discharged overboard in undetermined areas once the ship is at least 300 miles from shore. In addition, an accepted method of disposal of spent caustics from oil refineries is as ballast on outgoing crude oil tankers that is discharged far at sea.[3]

TABLE 2
AVERAGE AND REPORTED RANGE OF COSTS PER TON FOR MARINE DISPOSAL OF WASTES IN U.S. COASTAL WATERS
1968

Type of Waste	Total U. S.		Pacific Coast		Atlantic Coast		Gulf Coast	
	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton	Average cost/ton	Reported Range $/ton
Dredging spoils	$0.40/ton	$.20 – .55	$0.43/ton	None	$0.54/ton	$.40 – .55	$0.25/ton	$0.20 –.25
Industrial wastes Bulk	$1.70/ton	$0.60-9.50	$1.00/ton	$0.60–9.50	$1.80/ton	$.60–7.00	$2.30/ton	$.75–3.50
Containerized	$24/ton	$5–130	$53/ton	$50 – $130	$7.73/ton	$5 – $17	$28/ton	$10 – $40
Refuse and Garbage	$15/ton	$5 – $60	$15/ton	$5–$60				
Sewage sludge	$1.00/ton	$.80 – 1.20			$1.00/ton	$.80–1.20		
Construction and demolition debris	$0.75/ton	$.70 – 1.35			$0.75/ton	$.70 –1.35		
Explosives	$15/ton	$15 – $90						
Miscellaneous	$15/ton	$5 – $600	$15/ton	$5 – $600				

Little is known about the immediate effects of solid and liquid wastes on the marine environment, even though a number of pioneer studies have been carried out. Even less information is available on long-term or genetic effects.

An adequate understanding of the response of the marine environment to solid and liquid wastes barged to sea requires continuing investigation programs. To date, funds have been available only for short-term studies often directed to specific questions such as maximum permissible barge discharge rates.

More attention has been paid to the disposal of sewage and sewage sludges, both raw and treated, because of the well-known ability of shellfish to concentrate pathogenic bacteria for human consumption. Sludges barged and discharged to the New York Bight have resulted in high levels of fecal coliform contamination in surf clams [1] and the Food and Drug Administration has recently closed affected areas to further harvesting.[40] In contrast, some 400 tons per day of sewage solids, of which approximately one-fourth is organic, have been discharged through submarine outfalls into Santa Monica Bay, California, with no apparent effects on fish abundance.[2,3] Although the fish were able to avoid possibly harmful concentrations, studies of other Southern California receiving waters indicated severe effects on giant kelp (Macrocystis). The discharge attracted scavengers (sea urchins) that grazed on the mature plants and increased turbidity so that the young kelp did not develop.[4]

The great differences in effects of waste disposal at sea underscore the need for broad and critical research. A brief review and discussion of the literature on environmental effects of waste disposal at sea is presented in Appendix D. Information summarized on the following pages summarizes the state of knowledge of the effects of barged wastes and provides a basis for identifying further research needs. [James L. Verber has revised, updated, or compiled several of the tables in this report. He estimates that nearly 78.5 percent of all wastes discharged at sea are polluted.--*Ed.*]

Dredge Spoils

The discharge of dredge spoils at sea results in anomalously rapid sediment build-up at the disposal site, in addition to temporary discoloration of the water by turbidity. The sediment build-up would be expected to have significant effects on bottom-dwelling organisms and the life forms dependent upon them in the food chain. Turbidity may be expected to affect various aspects of the water column and the contained biologic assemblage. Reviews of the literature[5,6] regarding the effects of turbidity on marine fish and crustaceans in coastal waters indicate that, prior to Saila's work on a Narraganset Bay dredge spoil disposal site, there was virtually no information available on the subject. Consequently, much of the following discussion is based on the work by Saila, Polgar, and Rogers.[5]

Bottom Sediment Build-Up. The effects of fish and shellfish of rapid local build-up of sediment as the result of dredge spoil disposal can include destruction of spawning areas, reduction in food supplies and vegetational cover, trapping of organic matter (with resultant development of anaerobic bottom conditions), and the absorption or adsorption of organic matter (including oil).

Turbidity. The effects of turbidity on fish and crustaceans can be direct or indirect. Direct effects

cause an immediate response or even mortality by suffocation; turbidity can also result in reduced growth and decrease survival of larval stages of fish and shellfish. Saila and co-workers summarized the possible indirect effects of turbidity (and siltation) as follows: (1) reduction in light penetration resulting in reduced photosynthesis; (2) reduction of visibility to some feeding organisms; (3) destruction of spawning areas; (4) reduction of food supplies; (5) reduction of vegetational cover; (6) trapping of organic matter, resulting in anaerobic bottom conditions; (7) flocculation of planktonic algae; (8) absorption or adsorption of organic matter (including oil) or inorganic ions.

The effect of dredge spoils depends in large part on the location and characteristics of the disposal site. For example, if dredge spoils are discharged in inshore waters normally quite turbid because of wave action or the tidal flushing of turbid waters out to sea, then the effects of the associated turbidity (but not necessarily the sedimentation) would almost certainly be negligible.

The situation would be significantly different where spoils polluted with oil, sewage, chemicals etc. are dredged from channels and the confines of harbors and transported to sea for disposal. Once these sediments are discharged in other locations, the resulting turbidity (and associated pollution) can be spread extensively by coastal currents. In this regard, Biggs estimated that disposal of spoils from the approaches of Chesapeake Bay increases the turbidity of the water over an area of about 1 to 1.5 square nautical miles around the disposal site, and that discharged solids are dispersed over a bottom area at least five times that of the defined disposal area.[7]

Saila and co-workers investigated the effects on local fishing resources (particularly the northern lobster) of increased turbidity and siltation in relation to the disposal of dredge spoils in 100 feet of water off Narragansett Bay.[5] The results of biological assays and field experiments showed that adult lobsters were able to tolerate, with no adverse effects, turbidities as high or higher than those actually encountered in the disposal area for periods of time equivalent to those during which the spoils seem to remain in suspension. The one case of high mortality observed in the laboratory bioassay tests was believed to be the result of an unidentified toxic substance contained in the dredging spoil, rather than the concentration of suspended particles.

Interpretation of turbidity measurements at the point of discharge by the same investigation revealed that a fraction of the total turbidity cloud consisting of oils and/or light organic material remained near the surface. If present in sufficient quantities for an adequate length of time, this material could pose a possible pollution threat to the adjacent shore area, particularly during the summer season when a drift from the disposal site is predominately shoreward. The dispersion rate of the remaining turbidity cloud was sufficiently rapid that no direct adverse effects to marine resources of economic importance would be expected.

Comparison of the bottom topography before and after the disposal operation indicated that the volume of sediment added to the volume of excess material present in the site was about 2.004,000 cubic yards, which compares favorably with the 1 960.000 cubic yards dredged by the Corps of Engineers; on the basis of this comparison, most of the dredging spoils remained within the designated disposal area. On the basis of the biological and physical data obtained prior to and during the December 1967 to July 1968 Narragansett disposal operation, Saila and co-workers concluded that the spoil disposal site was acceptable from the point of view of minimizing the damage to locally important marine resources.[5]

Another aspect of dredge spoil disposal has been discussed by Gross, who showed that the volumes of dredge spoils and other sediment-like wastes (construction and demolition debris) disposed of in Long Island Sound and the New York Bight disposal areas represent the largest single source of sediment entering directly into the Atlantic Ocean from North America.[8] From Corps of Engineers records, Gross estimated that the mass of waste solids from the New York City area disposed at sea increased from an average of 6.8 million tons per year during 1960 to 1963 to 8.6 million tons per year for the period 1964 to 1968.

Most of the disposal sites referred to by Gross are in areas where there is little natural deposition of sediment to dilute or bury the man-moved solids that in many cases consist of highly polluted harbor sediments. The effect of these sediments on the biota is not well understood at this time. Gross also points out that disposal of spoil from barges or dredges is significantly different from natural processes whereby river borne sediment is deposited on the ocean floor. Disposal operations are highly localized and involve the instantaneous release of several thousand cubic yards of spoil, which produces a thick layer of

sediment that may or may not subsequently be dispersed over a wider area by current action.

Gross emphasized the lack of knowledge regarding the deposits formed by the present disposal operations and the absence of comparative data on existing conditions before disposal operations began. Along these lines, he points out that the present disposal operations are, in effect, gigantic, unplanned experiments and, if treated as such, much could be learned from them.

The Corps of Engineers had earlier recognized the growing need to determine the environmental impact of waste disposal on coastal areas.[9] In 1968, the Chief of Engineers authorized a study of various disposal sites in coastal waters in order to determine the environmental effects produced by the disposal of wastes at sea in these areas. The New York Bight disposal areas were chosen for the initial research because of the large volume of wastes currently being discharged there.

The Coastal Engineering Research Center was responsible for defining the research program. As part of this program, the Sandy Hook Marine Laboratory of the U.S. Bureau of Sport Fisheries and Wildlife has undertaken an intensive two-year biological-chemical field sampling program of the mud, cellar dirt, sewage sludge, and acid disposal grounds in the New York Bight, with the Lamont Geological Observatory of Columbia University carrying out supporting research on water transport and diffusion. [Cooperatively, the Food and Drug Administration has been conducting bacteriological and chemical studies in the same area.--ED.]

Industrial Wastes

The industrial wastes to be discussed below include waste acids, paper mill wastes, chemical wastes, oil drilling wastes, and waste oil. These wastes are typically dissolved or suspended in a water media for bulk discharge at sea from tank barges. In some cases, the material is barreled and dropped over the side.

The majority of studies of the environmental effects of industrial wastes in the sea have been carried out in Gulf of Mexico waters, because the Galveston District of the Corps of Engineers requires filing of laboratory and field studies of the wastes in support of disposal applications. In order to facilitate comparison of the environmental studies of the various types of industrial waste disposal operations, key information from the study results has been summarized (Table 8).

Waste Acid. Studies of the dispersion and environmental effects of acid-iron wastes discharged from barges in the New York Bight disposal area have been investigated by Buelow, Redfield and Walford, Ketchum and Ford, Ketchum, Yentsch, and Corwin, and most recently, by several research workers at the Bureau of Sport Fisheries' Marine Laboratory in Sandy Hook, New Jersey.[1,10-13] These wastes consist of ferrous sulfate and spent sulfuric acid in a freshwater solution, and are the byproducts of a titanium paint pigment manufacturing process.

TABLE 7
DUPLICATE SITES*

Area† Lat. N.	Long. W.	Industrial	Explosive	Radioactive	Dredging	Refuse
Atlantic						
44°26′	67°46′	X			X	
44°24′	68°55′	X			X	
42°25′	70°35′	X	X	X		
38°54′	73°17′	X	X			
38°30′	72°06′	X	X	X		
38°05′	73°24′	X	X			
41°33′	65°33′		X	X		
Pacific						
37°40′	123°25′		X	X		
37°35′	122°50′	X				X

* Compiled by James L. Verber, Food and Drug Administration.

† Sites usually 25 or more square miles.

The studies reported here showed that the toxic effects of these wastes are minimal. Laboratory toxicity tests conducted by Ketchum and co-workers to determine if the acid-iron wastes had any effect on the growth of green plankton algae showed and concentrations of wastes which severely limited growth are found only close to the discharge barge and are diluted rapidly at sea.[12] Zooplankton from samples immediately behind the barge were temporarily immobilized, but recovered rapidly on dilution with unpolluted water a short distance astern of the disposal barge.[10]

Additional findings of the study by Ketchum and co-workers showed that the accumulation of iron hydroxide, resulting from the chemical reaction of the wastes with seawater, was about twice as great in 1957 as that observed in 1948, and 50 percent more

TABLE 8
SUMMARY OF ENVIRONMENTAL STUDIES ON INDUSTRIAL WASTES DISCHARGED AT SEA

Waste Type	Description of Disposal Area				Barging Characteristics				Waste Characteristics	Laboratory Toxicity Studies		
Industrial	Distance from shore (miles)	Water depth (feet)	Latitude	Longitude	Amount of waste/trip	Depth of discharge	Rates of discharge tons/min.	Towing speed (knots)	Given description	Type of test organisms	TLM (range)	Remarks
Spent sulphuric acid	15 from New Jersey coast	80	40°20'N	73°40'W	3200 tons 5000 tons	15 feet	18 70	6 7	Fe_2SO_4 (10%) H_2SO_4 (8.5%)	Marine phytoplankton.	2.7-35.5 mg/l 6-16 day test duration.	Investigated effects of various concentrations of iron on growth of algae.
Chlorinated hydrocarbons	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1200 tons	12 feet	5	6	Beta-chloropropylene (22%), trichloropropane (5%), isopropylchloride (38%), allylchloride (11%), misc. chlorides (33%), heavy ends (3%), pH - 9.8, specific gravity -0.9 - 1.34.	Marine phyto-, and zoo-plankton, anemones, brine shrimp, bacteria, fish.	0.02-2.5% saturated 0.0005-1g/l, 2-24 hr test duration.	Investigated acute toxicity and inhibition to photosynthesis.
Paper mill wastes (black liquor)	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1300 tons	10 feet	5	6	Paper mill wastes, 47% solids, BOD_5-100,000 ppm Na_2CO_3, Na_2SO_4, NaOH etc., pH - 13. Specific gravity 1.27 at 60°C.	Marine phytoplankton zooplankton.	0.001-1.0g/l, 22 hr test duration.	Investigated acute toxicity and inhibition to photosynthesis.
Ammoniasulphate (mother liquor)	100 S of Freeport, Texas	2760	27°35'N	95°20'W	1700 tons		7	4	Ammonium sulfate (23%), nitrogen (8%), carbon (12%), organics (29%) (alcohols, esters, amides), IOD-90 MG/L, BOD_5 57,000 ppm, pH -4.3, S.G. 1.23.	Brineshrimp, top-water minnows.	1.25% by volume 200 ppm, 24 hr test duration.	Acute toxicity.
Waste liquor	70 S of Freeport, Texas	960	27°48'N	94°54'W	2400 tons		5-24	6	Na_2S (Na_2S_2) (6%) (Na_2S_3) NaHS 1% S (total) (6%), NaCl (21%), organic 2%, solids (dissolved and suspended), specific gravity - 1.24 at 60°C.	Marine phytoplankton, top-water minnows, brine shrimp.	0.0005-0.18% by volume, 24 hr test duration.	Acute toxicity.
Chlorinated waste liquor	125 SE of Galveston, Texas	2400	27°36'N	94°36'W	1400 tons (proposed)		13-25 (recommended)	5 (recommended)	(Organic waste) chlorinated organics (10-15%), inorganic salts (Na_2SO_4) (5-6%); (acid) chlorinated organics (1%), sulfuric acid (10-15%), nitric acid (0.1%).	Marine phytoplankton, top-water minnows, brine shrimp.	0.02-0.64% by volume, 24 hr test duration.	Acute toxicity, waste acid more toxic to fish than brine shrimp.
Sodium sludge (containerized)	110 S of Galveston, Texas	2400	27°36'N	94°36'W	15 55-gal. drums (500-570 pounds per drum)	Surface	Variable	10	Metallic sodium (75%), calcium (24%), barium, magnesium, potassium (1%).			
Pesticides	95 SSE of Galveston, Texas	720	27°49'N	94°30'W	50 55-gal. drums per trip	1200 ft	1 barrel/2 mins. (600' intervals on bottom	3	Anilines (chlordaniline, monochlorobenzene), liquid organics (methanol, p-xylene, chlorobenzene), dry chemicals-insoluble (*thiram, thiram-E, thionex, zineb, ferbam, monuron*, carbon disulfate).	Minnows, largemouth bass, salmon, bluegills, mosquito fish, channel catfish, bluegill sunfish.	1-135 mg/l, 48-96 hr test duration.	Toxicity values obtained from literature.
Caprolactam wastes	35 S of Sabine Bank	60	29°10'N	93°40'W								

TABLE 8
SUMMARY OF ENVIRONMENTAL STUDIES ON INDUSTRIAL WASTES DISCHARGED AT SEA—(Continued)

Waste Type	Reported Field Observations			Mixing Characteristics		General study conclusions	References
Industrial	Physical-Chemical	Biological	Observed effects	Initial dilution	Diffusion coefficient $cm^2/sec.$		
Spent sulfuric acid	pH, iron concentration (0-60'), wind, weather, sea state.	Plankton (0-60'), benthic organisms, pelagic fish (30').	Water discoloration, plankton temporarily immobile, iron settled rapidly from surface layer, no appreciable accumulation of iron found in bottom sediments.	1:5,000	2.9×10^4	Mixing and diffusion of wastes occurs rapidly in the wake of the barge. No evidence to indicate adverse effects. Each new proposed waste disposal operation needs careful study prior to allowing ocean disposal.	1, 10, 11, 12, 40
Chlorinated hydrocarbons	Temp. (0-900'), salinity oxygen, waste concentration (0-500'), surface currents, wind, weather, sea state, bottom mud.	Plankton, O_2 evolution, C_{14} uptake, chlorophyll-A, visual inspection of *sargassum* weed.	Water discoloration: fish, plankton killed on direct contact of waste, no harmful effects seen after 2-4 hrs. Bulk of waste sank. Low diffusion of waste at depth.		2.5×10^3 (average)	Disposal of toxic wastes at sea can be accomplished with only a slight effect on organisms in the biomass within a limited oceanic area. Each new waste disposal operation needs careful study prior to sanctioning it.	16, 17, 18, 19
Paper mill wastes (black liquor)	Temp. (0-900'), salinity (0-600'), waste concentration surface samples, pH, oxygen (0-600'), wind, weather, sea state.	Plankton (0-100'), O_2 evolution, C_{14} uptake, chlorophyll-A.	Slight water discoloration. No mortality to marine life. Bulk of waste sank.	1:300,000	2.5×10^3 (average)	Disposal of "black liquor wastes" in the deep sea can be accomplished without determinable effects on marine biota. Ultimate disposal is expected to be accomplished by bacteria. Advisable to monitor each separate load of waste to determine toxicity in laboratory.	15
Ammoniasulphate (mother liquor)	Waste concentration (0-150')		No fish mortality. No floating oil. Bulk of waste sank. Maximum waste concentration at depth.		9×10^2	No undesirable effects were observed. Diffusion great enough to ensure good dispersion to minimize harmful effects to biota.	22
Waste liquor	Waste concentration (0-150'), temp., salinity pH, oxygen, (0-600').	Plankton, pelagic fish, *sargassum* weed communities.	No evidence of subsurface maximum waste concentration.	1:10,000-1:100,000 in 2 hrs		Disposal should produce no significant mortality in the biota, nor any prolonged effects.	21
Chlorinated waste liquor						No significant mortality would be expected from disposal of this waste in the open ocean. It is suggested that a full-scale disposal operation be properly monitored and continued to verify preliminary study results.	20
Sodium sludge (containerized)	pH	Plankton, fish, *sargassum* weed.	No mortality to fish. Flying debris hazardous to disposal personnel. 30% mortality to plankton due to collection methods.			Explosions caused by reaction of sodium with seawater had no significant effects on *sargassum* and zooplankton populations. Absence of fish-kiln was probably due to barrenness of disposal area.	23
Pesticides				100:1	0.002×10^3	Consideration of available toxicity and diffusion data from literature sources indicate that the zone of water containing toxic concentrations of waste surrounding each disposal drum will be limited in extent and duration and will not endanger motile aquatic life in the disposal area to a significant degree.	24
Caprolactam wastes	Temperature (0-60'), salinity (surface), wind, weather, sea state.	Plankton, bottom samples, C_{14}, chlorophyll-A,-B,-C.				Limited scale (one day) of survey precluded any significant results. Recommend future surveys be conducted on 3-day basis for better results.	

than that observed in 1950.[12] This was less than might have been expected, however, from the increase in the discharge rate that had occurred over the same period. No evidence was found to indicate that the general turbidity of the waters caused by the iron precipitate has increased outside the general disposal area. Ketchum[14] and Wuestefeld[9] reported that, since establishment of the acid-iron disposal operation in 1948, a concentration or bluefish has developed on the outer boundaries of the disposal area, thus creating a highly popular sport fishery that did not previously exist.

Paper Mill Wastes. This waste is the so-called 'black liquor' produced by the sulfate process used in paper manufacture; it includes sodium carbonate, sodium sulfate, sodium hydroxide, and other chemicals. The wastes described by Hood and Abbott[15] were discharged off the Texas coast in 1955 and contained about 45 percent solids, were water soluble but quite viscous, and had a pH greater than 13. Laboratory studies using four species of phytoplankton showed the concentration of black liquor affecting photosynthesis (i.e., threshold toxicity) was about 0.05 grams per liter, and the lethal concentration was on the order of 1 gram per liter. Tests on zooplankton produced no acute toxicities in concentrations up to 0.4 grams per liter; greater concentrations were not tested because it was impossible to observe the zooplankton as a result of the opaque characteristics of the wastewater mixture. Visual observations at sea confirmed the non-toxic character of the wastes, as zooplankton in samples taken immediately astern of the discharge barge were observed to be swimming about normally.

Field evidence also showed that the absorbent component of the waste sank almost immediately, leaving only a slight discoloration at the surface that was visible for only 30 to 40 minutes after discharge. A minimum dilution ratio of waste to water immediately behind the barge was calculated to be on the order of 1 to 300,000 or a concentration of 0.03 grams of waste per liter, which is well below the values given previously for threshold and acute toxicity on phytoplankton. Bacterial action should result in the ultimate disintegration of the organic components of the black liquor wastes while the inorganic fraction, principally sodium sulfate, would rapidly lose its identity when mixed with seawater.

Chemical Wastes. For convenience of discussion here, the chemical waste subcategory is divided into chlorinated hydrocarbons, ammonia sulfate, waste liquor, sodium sludge, and pesticides.

Chlorinated Hydrocarbons. The chlorinated hydrocarbon waste category includes betachloropropylene, trichloropropane, isopropylchloride, allychloride, miscellaneous chlorides, and other constituents discharged by chemical and petrochemical plants. The disposal operations discussed here are confined to the Gulf of Mexico. Although wastes containing various percentages of chlorinated hydrocarbons are discharged off the Atlantic and Pacific coasts, their environmental effects have not been investigated primarily because in those areas such studies are not a prerequisite for obtaining a disposal permit.

Four separate chlorinated hydrocarbon disposal operations in Gulf waters have been studied by Hood and his associates[16-18] at the Texas A & M Research Foundation. Their work included field and laboratory investigations of the effects of these wastes on various marine organisms, with emphasis on phytoplankton, zooplankton, and fish. Observed effects at the disposal site included sinking of the bulk of the waste, discoloration of the water, and the death of fish and plankton on direct contact with the undiluted waste. After two to four hours, the surface waste field was found to be sufficiently diluted so that no effect on marine life was observed.

Because the inherent patchy distribution of the microorganisms at sea makes it difficult to obtain statistically significant results, the effects of various toxicity levels on phytoplankton and zooplankton were tested by Hood under controlled laboratory conditions. Inhibition to photosynthesis and respiration caused by the wastes was determined by using standard oceanographic procedures for measuring carbon-14 uptake and oxygen evolution. Comparison of the results with those obtained from uncontaminated control samples maintained under identical laboratory conditions provided an index of inhibition. Acute toxicity tests were also conducted on the plankton and various species of fish. Results of the laboratory toxicity studies showed that the inhibition to photosynthesis and respiration is a much more sensitive and meaningful measure of the toxic effects of organic contaminants in seawater than acute toxicity tests on organisms such as fish.

The effects of wastes on organisms endemic to the disposal sites was assessed in the field by examining the flora and fauna associated with the seaweed, Sargassum, present both within the outside of the disposal area. It was found that direct contact with

the undiluted hydrocarbon wastes at the point of discharge was generally lethal to the small crabs, shrimp, fish, snails, etc., but in most cases samples taken in the disposal area showed conditions had returned to normal within three to eight hours.[15-19]

With regard to diffusion and dispersion of the hydrocarbon wastes, Hood and Stevenson estimated that about seven square miles of surface area would be affected by a single disposal operation.[17] Further their work indicated that within three to nine hours, the wastes in the surface layers were diluted to levels below the limit of detection by the analytical method used.[18,19] In contrast to this, slow dispersion of the wastes occurred at depths from 50 to 500 feet. For example, at one station the waste concentration at 500 feet was roughly equivalent to that observed at the surface in the actual disposal wake 42 hours earlier.[16] Because of the possibility of these waste-laden waters working their way shoreward to bottom fishing areas or regions of upwelling, it was recommended that future disposal areas should be located seaward of the 400 fathom line.

Hood concluded that chlorinated hydrocarbon wastes could be discharged at sea with only minor adverse effects on marine organisms within the dispersal area.[18,19] It should be pointed out, however, that Hood's work did not examine the possible effects of the wastes at depth or of bottom contamination on benthic organisms, even though samples of bottom mud within the disposal area contained from 10 to 100 percent of the original surface concentration of hydrocarbon waste.[16]

Ibert, Wilson, and Harding carried out laboratory tests on the toxicity of two chlorinated hydrocarbon wastes produced by a chemical plant; this study was in preliminary support for an application for marine disposal off the Texas coast.[20] The tests, which used top-water minnows, brine shrimp, and various phytoplankton, measured both the median toxicity level at 24 hours and the critical concentration range, defined as that dilution range between which there is no mortality on the one hand and no survival on the other. In the case of the test plants, 50 percent survived at concentrations of 0.05 to 0.5 percent by volume on 24-hour exposure to the hydrocarbon wastes, and the waste, which included dilute sulfuric acid, was somewhat more toxic, i.e., 50 percent survival at concentrations of 0.02 and 0.05 percent by volume. This greater toxicity should be greatly reduced in a marine disposal operation because of the rapid neutralization of sulfuric acid which occurs in seawater.[10]

Ibert and associates estimated that the waste would be diluted below the 0.006 percent concentration range within an hour by using a pumping rate between 8 and 15 tons per hour while underway at five knots, and concluded that no significant mortality would be expected from the disposal of either waste in the open ocean.

Waste Liquor. Ibert and Harding carried out laboratory and field studies on an industrial waste liquor being discharged off the Texas coast.[21] The waste consisted of various compounds of sodium, hydrogen, and sulfur, along with sodium chloride in an aqueous solution (specific gravity greater than 1.25) that was completely miscible in seawater. On the basis of the laboratory toxicity studies, they concluded marine disposal would produce no significant mortality, nor any prolonged deleterious effects, nor would the concentrations of the waste persist beyond two hours after discharge.

Because the wastes were about 25 percent more dense than seawater, the bulk of the materials sank rapidly from the surface layer, but to the depth covered by sampling (164 feet) there was no evidence of plunging of the wastes in an undiluted stream. Further dilution and dispersion of the wastes were expected to occur on the bottom but sampling was not carried out to confirm this fact.

The reported maximum value of the waste concentration 1.5 miles astern of the barge was less than one in 10^5 (.001%), which was within a factor of two of the minimum value of TL_M reported earlier for the phytoplankton used in the toxicity tests.[21] In spite of these favorable results, it was recommended that future operations use a significantly reduced pumping discharge rate per mile of vessel track in order to insure adequate dispersion under all oceanographic conditions.

Ammonium Sulfate Mother Liquor. MacSmith studied the effects of ammonia sulfate mother liquor on brine shrimp and minnows in the laboratory, as well as the diffusion of these wastes during discharge.[22] This waste material is saturated with ammonium sulfate and contains about 10 percent organic carbon as alcohols, amides, esters, etc.; it is generated in obtaining ammonium sulfate from sulfuric acid in a fertilizer manufacturing process. Smith's work included chemical analyses, biodegradability and toxicity studies, and preliminary diffusion

calculations, as well as sampling at sea to determine actual diffusion.

On the basis of the preliminary diffusion and toxicity studies, it was concluded that the wastes would not produce adverse effects on the environment or organisms within the disposal area. A trial disposal operation verified the predictions that diffusion would be sufficiently rapid to minimize the harmful effects to the biota.

Sodium Sludge. Stein reports a study of the disposal of sodium sludge off the Texas coast.[23] The sludge consisted of approximately 75 percent metallic sodium and 24 percent metallic calcium, and was a waste product from a petrochemical plant. The barreled sodium sludge was punctured and dropped overboard; when seawater made contact with the sodium, the drums exploded (Figure 7). Field observation and sampling indicated that the explosions and elevated pH (resulting from the interaction of the sodium with seawater) had no significant effects on the Sargassum and zooplankton communities as compared to those in the control area. An absence of floating dead fish may have been due to the barrenness of the area.

Corps of Engineers records indicate that on two occasions unpierced barrels loaded with sodium sludge have been retrieved from Gulf waters by fishermen. In these cases, it is almost certain that the disposal operators did not dispose of the barrels in the designated disposal area.

Pesticides. Waller studied the probable environmental effects of the proposed marine disposal of wastes from a Gulf Coast plant that manufactures herbicides and fungicides.[24] The waste included chemicals of the following types: anilines (primarily chloroaniline and aniline with small amounts of monochlorobenzene); liquid organic solvents (methanol, p-xylene and chlorobenzene); and dry chemicals including Thiram, Thiram- E, Thionex, Zineb, Ferbam, Monuron, and carbon disulfate. Because of their toxic nature, these wastes are disposed of in weighted steel drums. To facilitate discharge and dispersal along the bottom, a small air space is left in each drum to ensure deformation and rupture of the drum on the ocean floor.

Waller evaluated toxicity data on these waste materials on the basis of the available literature, and concluded that:

> The herbicides and fungicides are generally more toxic than the liquid organics. These dry chemicals, however, have a very low solubility so that once in solution a relatively low dilution ratio (on the order of 100:1) will reduce the concentration below the median tolerance limits (TL_M). . . . In addition, the susceptibility to biodegradation and chemical instability in an aqueous environment would further reduce localized toxic conditions.[24]

A mathematical model was developed by Waller to consider the dissolution of the slightly soluble solid material with subsequent diffusion into the surrounding seawater and simultaneous chemical degradation. He calculated that, at a discharge rate of one barrel every two minutes from a barge moving at three knots, the drums would be spaced at 600-foot intervals on the ocean floor. In the case of a waste material dissolving over a period of one year, calculations showed that, based on an eddy diffusion coefficient of 2 cm^2/sec, a 100 to 1 dilution is reached at a maximum distance of 54 feet, 30 days after discharge. He considered this approach to be conservative in that no allowance was made for biological degradation or strong currents that could greatly increase the dispersion.

No actual at-sea tests were conducted on this disposal operation. Therefore a follow-on at-sea monitoring program would be highly desirable, particularly in light of potential adverse effects.

Drill Cuttings and Drilling Muds. The rock chips produced by the bit in drilling an oil well are termed drill cuttings. On offshore drilling platforms along the southern California coast, these cuttings are generally washed and discharged below the rig. Although the resulting solid waste accumulation is volumetrically of little significance because of its possible effect on marine life it has been discussed by Turner, Carlisle, and Ebert who reported that the cuttings were found to have no effect, either adverse or beneficial, on the environment.[25,26] Turner and co-workers suggested that, if the cuttings were to be disposed of several hundred feet away from the drilling platform and capped with stones or other rubble, they could provide an artificial habitat for sportfishing.[25]

The disposal of drilling muds and cuttings in deep water from a barge has also received cursory investigation by the THUMS Long Beach Company in cooperation with several Federal and State agencies, including the Corps of Engineers.[27] Observations on the disposal operation consisted of aerial photographs and visual inspection at the sea surface to assesss the extent of surface contamination. On the basis of the

one-day study, it was concluded that the disposal operation posed no threat to the environment.

Waste Oil. Although environmental studies have not been made on the single industrial waste oil disposal operation noted during the survey, some very significant work has been carried out on the wastes from tank cleaning operations conducted by oil tankers at sea. Based on the earlier work of ZoBell regarding the oxidation of hydrocarbons by marine bacteria, Moss has shown the importance of discharging these wastes in a finely divided or atomized form in order to optimize bacterial degradation.[28,29] Moss' calculations show that the full quantity of waste oil (at an average concentration of 0.13 milligrams/liter) resulting from cleaning the tanks of a 45,000 dwt tanker underway at 16 knots would be oxidized by bacteria in 2 to 4.5 days, depending on whether the wastes were discharged continuously over a 24-hour period, or discharged as fast as the tanks were cleaned.[29] The broader aspects of the environmental effects of oil in the marine ecosystem have been summarized recently by Holcomb and Blumer.[30,31] Holcomb concludes that "... little is known about the long-term effects of oil in the marine environment."[30, p. 204]

Discussion. The information indicated in the preceding paragraphs when summarized represents virtually everything we know of the environmental effects of industrial wastes discharged at sea from barges (Table 8). This minute body of information is totally disproportionate with both the amounts of wastes handled and the potential damage that these wastes can do. It should be noted that the limited scope of the work accomplished to date reflects the economic and environmental constraints which have been applied in the past. There is abundant evidence that these constraints are changing so that it is reasonable to assume that future marine disposal of wastes will be limited to those operations which have been shown not to cause damage.

Sewage Sludge

Sewage sludge discharged at sea is the residual from municipal sewage treatment plants and is generally 3 to 10 percent solids by weight. It is discharged from tank barges at one disposal site in the New York Bight and another off Cape May, New Jersey. There are no similar operations on the Gulf or Pacific coasts, although large volumes of sludge are discharged in southern California coastal waters through submarine outfalls.

The effects of sewage sludge on the marine environment have been investigated by Buelow and associates,[1, 32-34] and for the southern California outfalls, by Carlisle, North, Pearson, Rittenburg, Gunnerson, Brooks, and Grigg and Kiwala and many others.[3,4,35-39]

The environmental effects of barge disposal of sludge in the designated sites in the New York Bight and off Cape May, New Jersey (Figure 2) were studied by Buelow and associates at the U.S. Public Health Service's Northeast Technical Services Unit, FDA Laboratory.[40] This study was the outgrowth of the increased concern by Federal and State health agencies and the shellfish industry over the possible contamination of the commercial surf clam beds adjacent to the sewage sludge disposal grounds. Of particular concern was the possibility that the surf clams might accumulate and concentrate bacteria, viruses, and other toxic substances present in the sludge; these substances could, in turn, be transmitted to consumers of the shellfish. Results of this study indicate that sludge settles rapidly to the bottom and that, except in the immediate wake of the barge discharge, the highest coliform contents occurred in the samples from the near-bottom water.

Because of the preliminary nature of their field investigations, Buelow and co-workers were unable either to approve the present disposal sites or to recommend their relocation. Preliminary results, however, of the current Corps of Engineers study of the New York City sludge disposal area indicate that, because of the high bacterial contamination found in surf clams adjacent to the sludge disposal grounds[40] harvesting clams should be prohibited from within a 6 mile radius of the center of the disposal grounds.

Buelow has also concluded that the sludge from the disposal area off Cape May poses a potential threat to existing commercial surf clam beds and shellfish beds located to the south and west of the present disposal site, as they are in a direct line to receive sludge carried by the prevailing tidal currents. In addition, Buelow pointed out that the location of the New York sludge disposal area within a few miles of the head of the Hudson Submarine Canyon, and the apparent southerly drift of the sludge on the bottom towards the head of the canyon, constitute a potential threat to the lobster and red crab populations which may breed in the shallower portions of the canyon.[1]

The work on several major southern California submarine sewage outfalls by the various investigators

cited above demonstrated the presence of coliform concentrations in the upper layer of bottom sediment adjacent to the outfalls. In connection with these studies, Gunnerson has divided the various factors, which are important in reducing bacterial populations in seawater, into three categories[37]: (1) bacteriologic factors endemic to the marine environment—these include competition for food, predation, salinity, sunlight, temperature, pressure, etc. All of these factors may be combined into a single factor—namely, mortality; (2) settling behavior of suspended solids—this is dependent on the size, shape, flocculating characteristics, and density of the sludge particles, which, in turn, are a function of the type of sewage treatment process. Particle characteristics are also important because the bacteria are concentrated within or on the particles; (3) dispersion of the effluent field—this takes place as the sludge field moves downstream from the outfall.

Gunnerson set up a simple mathematical expression relating these three factors.[37] Using this relationship in an investigation of the persistence of coliform bacteria in the primary effluent from the Hyperion Outfall off Los Angeles, he showed that sedimentation is, by far, the most important factor in the disappearance of coliform bacteria from the surface layer of the water column.

The results of work by North and by Grigg and Kiwala to investigate the environmental effects of sewage disposal from the Whites Point outfall in 65 to 195 feet of water off Los Angeles reveal that, shoreward of the 10-fathom curve, large-scale ecological changes have occurred.[4,39] For example, many species that normally occur over rocky substrates at these depths (e.g., kelp, lobster, abalone, and many species of fish) are either rare or no longer present. The length of coastline affected by the sludge deposit has spread from two miles in 1954 to six miles in 1969, at least a three-fold increase in length in 15 years. In contrast, Carlisle reports that sewage sludge disposal from the Hyperion outfall in 320 feet of water in Santa Monica Bay has apparently had no measurable effects on fish abundance.[3]

In summary, studies have indicated that sewage sludge in large concentrations destroys the marine habitat in the immediate vicinity of the sludge field; that the sludge drifts slowly along the bottom because of currents; that coliform and related toxic substances are potential threats to shellfish within a radius of 5 to 10 miles of the site; that the toxic substances and coliform bacteria associated with the sludge are concentrated in bottom sediments; and that a great deal more field and laboratory work is required to accurately predict the detailed behavior of the sludge and the probable environmental response.

Refuse

Although there have been no sizeable municipal refuse disposal operations at sea from the United States in the past 25 years,[41] several U.S. coastal cities (including New York, Oakland, and San Diego) had previously dumped their refuse at sea. These operations were generally unsatisfactory because of the associated fouling of beaches and resultant public disfavor and eventual preventative legal actions. The results of the present survey show, however, that in 1968 there was small-scale disposal at sea of refuse from military installations in Long Beach and San Diego and from a cannery in the San Francisco Bay area (Chapter II). Black also reports that the city of Charlotte Amalis on St. Thomas Island, Virgin Islands, in 1962 began disposing at sea a daily average of 280 cubic yards of refuse.[41]

Studies associated with the past disposal of refuse at sea have been either investigations to establish the sources of wastes found on public beaches, or examinations of the economic and technical feasibility of conducting such disposal operations.

Only in the last two or three years have there been serious attempts to determine the possible environmental effects of disposal of refuse and related solid waste in the ocean. These studies[42-44] are an outgrowth of the several new methods that have been proposed to facilitate effective marine disposal.[45-50] Probably the most comprehensive study to date is that directed by Dr. Melvin W. First and conducted jointly by the Harvard School of Public Health and the University of Rhode Island's Graduate School of Oceanography with funds from the U.S. Public Health Service and the Atomic Energy Commission.[42,51] Systems analysis techniques were employed in this study to evaluate several distinct but interrelated aspects of the feasibility of utilizing shipboard incinerators in connection with marine disposal of refuse from Boston.

Besides defining costs and operating characteristics of the incinerator vessels, the study examined what effects the incinerator residues would have on a variety of marine organisms. Both acute and chronic toxicity tests were carried out on species ranging

from phytoplankton and lobster larval to flounders and clams. Oceanographic studies were made in order to predict the movement of incinerated solid wastes along the bottom under various conditions. Meteorological studies were conducted to determine safe burning sites for every weather pattern likely to be experienced in the general offshore region proposed for the disposal operations.

Oviatt has summarized the studies on the toxic effects of incinerator residue on selected marine species.[43] Short- and long-term toxicity tests were performed on a series of organisms including clams, shrimp, scallop, lobster larvae, and fish. The quahaug (*Mercenaria mercenaria*) was the most resistant; 90-day quahaug bioassays in residue concentrations up to 10 percent by weight failed to produce mortalities or significant changes in growth. The common mummichog survived with no mortalities in 40-day bioassay tests with residue concentrations up to 30 percent by weight. First- and second-stage lobster larvae and the common prawn did not experience significant mortality in residue concentrations of 1 percent or less. Of all the fish species tested, the juvenile menhaden was the most sensitive with less than 50 percent surviving 50 days of exposure to the incinerator residue in concentrations exceeding 1 percent by weight. The sea scallop was the most sensitive bottom organism tested and significant mortality occurred in concentrations greater than 3 percent by weight. Additional work has been described by Rogers.[44]

The toxicity effects reported were not considered a serious drawback to the proposed disposal program because calculations show that about 25 years of daily disposal of 500 tons over a 1-square-mile area would be required to equal the toxic level of one present residue concentration.

Oceanographic studies showed that incinerator residue (including cans) in 50 feet of water would drift under storm conditions with the net movement caused by the combined effects of the wave orbital velocity associated with passing waves and the tidal currents found in the area.[52] Once the cans and other debris begin to rock back and forth as a result of wave orbital motion, weak but steady tidal currents cause a net movement in the direction of the current. Calculations indicate that wave heights greater than 3 feet can move debris down to 50 feet, wave heights above 9 feet can move debris at 100 feet, and wave heights above 12 feet can move debris at 200 feet. On the other hand, burnt cans disintegrate at a fairly rapid rate so that, at depths beyond 100 to 200 feet, disintegration was likely to occur long before the object moved a significant distance.

Observations on a simulated incinerator residue disposal site in 180 feet of water were conducted in 1968 with the aid of a research submarine. Some 25 dives were conducted to observe and photograph marked objects planted on the bottom and the effects of actual incinerator residue deposited earlier in the study area.[53] The general conclusion was that incinerator wastes on bottom in 100 to 200 feet depths off Boston would not drift significantly.

The disposal of municipal refuse and garbage at sea (baled or otherwise caused to sink) has received serious consideration in the past year by such major U.S. coastal cities as New York, Philadelphia, and San Francisco,[49] and increasing pressure for marine disposal is a certainty as the coastal population grows. At present, virtually no information is available on the probable effects on the marine environment of a large- scale disposal operation. Considerable work would be necessary before undertaking such disposal. In this regard, it is worthwhile to note that the results of a recent study on the disposal of solid wastes from Westchester County, New York, conducted for the New York State Pure Waters Authority,[54] showed that barge-haul and disposal of baled refuse at sea was technically feasible and less costly than rail-haul and sanitary landfill or incineration. At-sea disposal was not recommended, however, "...because of the difficulty in proving that it will not unbalance the ecology of the area...".[53] In Philadelphia, a well publicized application for a permit to dispose of refuse at sea was prepared. No action has been taken on this proposal.[54 p. 4]

In considering the uncertainties inherent in evaluating the ecological impact of solid waste disposal at sea, it is important to note that the Bureau of Sport Fisheries and Wildlife (under a cooperative agreement with the Bureau of Solid Waste Management) is investigating the beneficial uses of marine disposal of refuse specifically, the costs and benefits of building artificial fish habitats from wastes such as rubber tires and baled refuse.[56] Such baled refuse might also provide food for fish.

Radioactive Wastes

The environmental effects and dispersion of radioactive wastes in the ocean have been the subject of considerable research over the past 20 years. Al-

though containerized radioactive wastes were not disposed of at sea in 1968, much of the knowledge stemming from previous research is pertinent to an understanding of the environmental effects of present marine solid waste disposal operations. Disposal at sea resumed in 1969, therefore, even though a comprehensive review of the voluminous literature on the subject was beyond the scope of this study, selected basic studies particularly pertinent to other marine disposal operations were reviewed and are discussed in this section. The reader interested in more detailed information is referred to the references cited later in this section.

In 1956, the National Academy of Sciences-National Research Council (NAS-NRC) organized a series of committees to study the various aspects of the biological effects of atomic radiation. In the report of the Committee on Oceanography, Revelle and associates presented a critical evaluation of the state of knowledge available at that time regarding the physical, chemical, biological, and geological processes involved in the interaction of radioactive wastes with the marine environment.[57] On the basis of this evaluation, it was concluded that most of the physical and biological processes in the ocean were too poorly understood to permit precise predictions of the results of the introduction of a given quantity of radioactive materials at a particular location in the sea. The Committee proposed that several basic problem areas should be attacked in the future, in order to obtain the necessary knowledge required for assessing the effects of radioactive waste disposal in the ocean. These include: dispersion in the upper mixed layer of the sea; circulation in the intermediate and deep ocean layers; exchange of water properties between the surface and deeper layers; sedimentation processes; effects of biosphere on the distribution and circulation of elements; uptake and retention of elements by organisms used as food for man; effects of atomic radiation on populations of marine organisms.

In 1958, the U.S. Bureau of Commercial Fisheries, U.S. Atomic Energy Commission, and the Office of Naval Research jointly requested that the NAS-NRC Committee on Oceanography undertake a detailed evaluation of the problems of disposal of both liquid and solid low-level radioactive wastes into the ocean off the Pacific, Atlantic, and Gulf coasts of the United States. The primary objectives of this program were to provide estimates of the level of radioactive wastes that could safely be disposed of at sea, and the most satisfactory locations and methods for disposal to insure that the present or future use and enjoyment of the resources of U.S. coastal areas would not be impaired.[58]

Of the several potential hazards accompanying sea disposal of radioactive wastes, the most critical from the point of view of the NAS-NRC program is the possibility of return of the radioactivity to man. Next in importance is the possible damage to marine organisms from exposure to radioactive wastes. Two avenues through which damage could possibly occur are: (1) transport of the radioactive wastes from the disposal sites to the coastal zone, thereby curtailing the present or future use and enjoyment of the resources of the region; (2) uptake of the radioactive wastes by one or more of the trophic levels in the marine biota, with possible return to man via commercially important fish and shellfish.

Three reports have been published as a result of the NAS-NRC studies.[58-60] Carritt and co-workers studied physical diffusion of low-level radioisotopes from containerized waste disposal areas located in relatively shallow waters on the continental shelf.[58] Pritchard and associates investigated the problem of physical diffusion associated with the disposal of low-level liquid radioactive wastes discharged in the surface layer of the sea from nuclear vessels.[59] The study by Isaacs and co-workers concentrated on the biological aspects of the problem, including the possibility modification of the ecological regimen; in particular they considered the effects of the containerized wastes in attracting fish and other marine organisms, and the subsequent transfer of the wastes from the deeper waters via biological processes.[60]

The Pritchard report summarized the key factors that determine the fate of radioactive material introduced into the marine environment and showed a schematic presentation of the step-by-step considerations that should be made in evaluating the suitability of any marine locale as a receiver of nuclear wastes (Figure 14). The general procedure is the same whether the evaluation concerns containerized wastes or liquid wastes discharged from outfalls and vessels. A similar sequence of considerations is appropriate in the evaluation of potential oceanic sites for non-radioactive solid waste disposal.

In the Carritt study, a series of 28 shallow water disposal sites were proposed for the Atlantic and Gulf coast area.[58] For these sites, the maximum allowable annual rate of disposal for a site two miles in diameter was calculated to be 250 curies of stron-

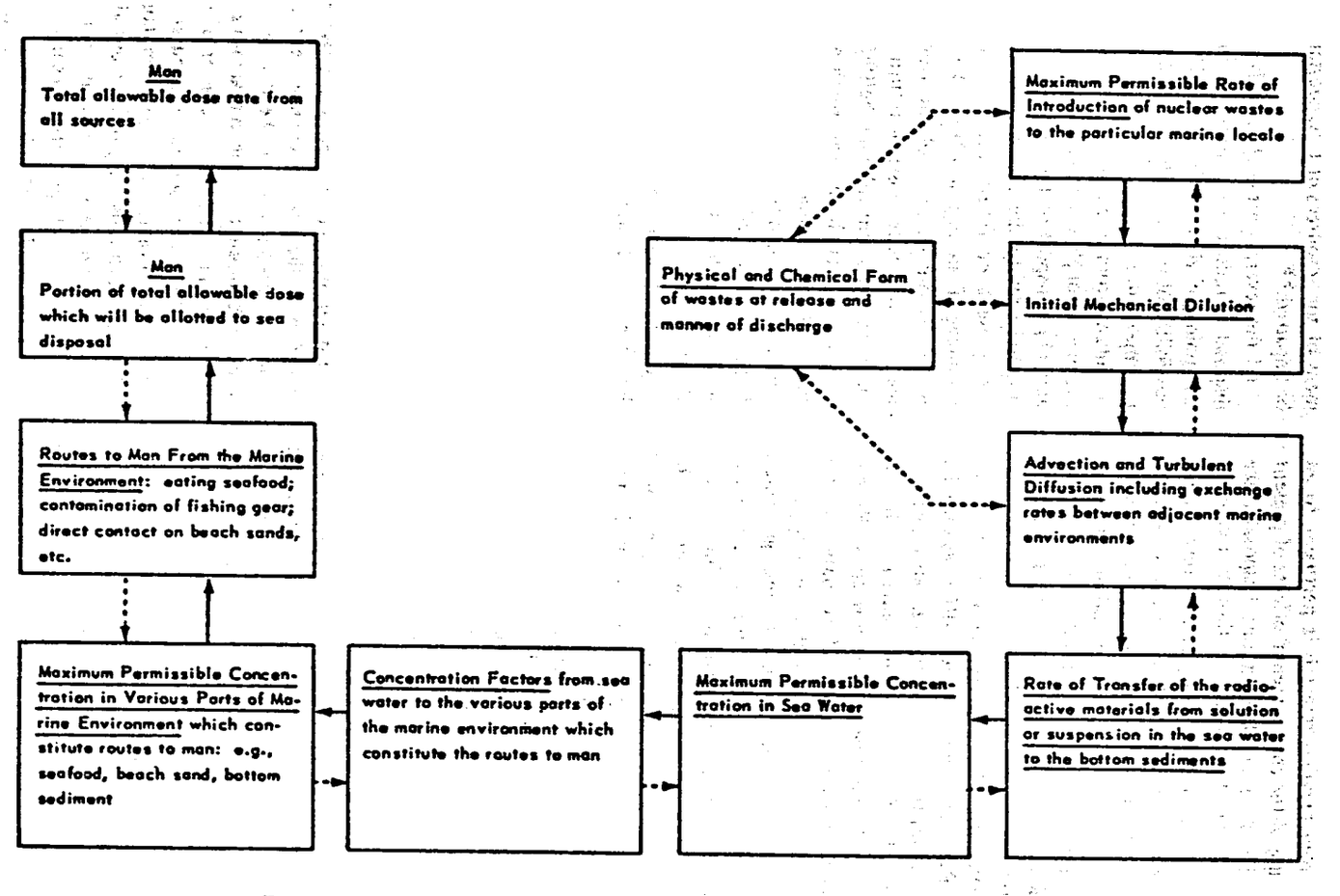

FIGURE 14. Schematic presentation of the step-by-step considerations that should be made in evaluation the suitability of any marine locale as a receiver of nuclear wastes. (From Pritchard *et al.* [59])

tium-90 or its equivalent. This value is based on a modification of the diffusion equation for the continuous release of a contaminant at a known rate, under a steady-state condition of supply from a ruptured container containing not more than two curies of strontium-90 or its equivalent. The effects of adsorption by bottom sediments and uptake by marine organisms are not considered in this equation.

The Isaacs report set the maximum permissible number of disposal sites off the U.S. and Canadian Pacific coast at 40, with a maximum of 20 between the Mexican border and the Columbia River. In determining the allowable rate of disposal for the recommended sites, Isaacs and associates considered two general situations. For each disposal site located below the region of growing marine plants (euphotic zone), yet within the vertical range of human food fish and other human food organisms, they recommended that packaged radioactive wastes (Figure 12) can be disposed of "...at a rate equivalent to 150 curies per year of material that has a maximum permissible concentration in sea water (MPCC) of 1.5×10^{-5} microcuries per kilgram, with soluble isotopes not exceeding 40 millicuries per drum and insoluble isotopes not exceeding 0.5 millicuries per drum on an average basis."[60]

In depths below the vertical limit of human food fish, the annual limit for radioactivity in each disposal area was given as:

$$Q = 5 \times 10^6 \, (\overline{MPCC}) \, (d - b)$$

where Q is the maximum disposal quantity of the isotopes in curies per year, $\overline{MPCC}$ is the weighted mean allowable concentration (in micro curies per kilogram) of the isotopes in seawater, d is the depth of the disposal area in meters, and b is the limiting depth of a human food organism in meters. On the basis of this relationship, a disposal location situated in 4,400 meters (14,436 feet), with b set at 2,400 meters (7,874 feet), would have an allowable disposal of 150,000 curies per year.[60]

From an evaluation of the environmental data associated with the two existing disposal sites (one off San Francisco in the vicinity of the Farallon Islands and one in the Santa Cruz Basin), Isaacs and colleagues recommended that the Santa Cruz basin site should be relocated to the Santa Barbara basin.[60] This change was on the basis of the latter's anaerobic properties, higher rate of sedimentation, bottom characteristics and sparce amount of benthic life, and water circulation. This example points out the fact that the deepest location farthest from shore is not necessarily the best site for disposal of a given waste material.

All of the past efforts to assess the potential hazards of radioactive disposal at sea have been hampered by lack of factual data and the complexity of the physical and biological processes in the ocean. As a result of these limitations, the calculations expressing safe disposal concentrations contain an additional safety factor to allow for the deficit of information on this problem. Each of the NAS-NRC studies cited recommended that further research be conducted in the seven categories cited earlier. Because of the 1963 curtailment of marine discharge of radioactive waste, relatively little of this research has been carried out.

Another recommendation of importance concerns the necessity for monitoring and maintaining records of the amount and location of radioactive waste disposal operations. Both the Carrit and Isaacs studies also pointed out the need for periodic observation of the disposal sites in order to document the distribution of nuclear activity and its effects on the biota, and to provide an indication of whether or not the original assumptions made to determine allowable discharge rates are valid.[58,60] Isaacs and his associates recommended that the monitoring and observation program be conducted by an agency other than the AEC or its contractors.

To the writers' knowledge, only three sites used for disposal of containerized radioactive wastes have actually been resurveyed by the AEC (or with AEC funds). These are: (1) a site off the Farallon Islands near San Francisco;[61] (2) the aforementioned site at the Santa Cruz basin, some 70 miles west of Los Angeles;[60] (3) a site about 130 miles east-southeast off Cape May, New Jersey.[13,58,62] For the two West Coast sites, the results of beta-gamma counting of sediment samples indicated that no radioactivity above natural background levels was present. Similar counts for the site off Cape May, however, produced indications in 1961 of possible leakage of radioactive materials from the containers.[13,62] Despite these findings, no further investigations of the disposal areas have been reported. The need for, and the problems associated with, ongoing environmental monitoring of marine waste disposal operations are discussed in more detail in Chapter IV.

Military Explosives and Chemical Warfare Agents

Surplus or obsolete explosives and chemical and biological warfare agents (CBW) have been disposed of at sea for many years. Summaries by Busby, Hunt, and Rainnie and by Kurak indicate the extent of recent oceanic disposal operations including the Navy's CHASE program (discussed in Chapter IV).[63,64]

Although the environmental effects of explosives disposed in the ocean are probably quite limited, they certainly pose hazards to man and his equipment. Busby and co-workers discussed the hazards that explosive wastes present to operations conducted with research submarines and indicated that, although most of the explosive disposal sites (Figures 1-3) are situated in at least 6,000 feet of water, large amounts of explosive ordnance have come to rest in the shallow waters of the Continental Shelf as a result of combat operations.[63]

CBW agents, on the other hand, because of their inherent toxicity, constitute potential hazards of considerably greater significance. Unfortunately, the nature and scope of these hazards are not well understood. In a recent study by a special panel of the National Academy of Sciences to consider proposed marine disposal of CBW agents by the Army, it was noted that while

> "...various chemical warfare agents have been repeatedly disposed of in the oceans by the United States and other nations...we have no information regarding possible deleterious effects of these operations on the ecosphere of the seas."[65]

According to Boffey and to Ludwigson, on three occasions in the past the U.S. Army had disposed of chemical weapons in the ocean, but had made no effort to determine whether or not there would be harmful effects on the environment.[66,67] These reported instances do not include a 1958 disposal operation in which the Army disposed of 8,000 tons of mustard and lewisite gas by loading it aboard a surplus vessel, towing her to sea, and scuttling her.[64]

The CHASE disposal operation represents a decided improvement over the previous method of barging explosive wastes to sea, but its use for disposal of CBW agents is questionable because of the possibility that detonations of the associated explosives in the cargo after sinking would liberate the CBW material. In this regard, at least two of the vessels sunk in the CHASE program have not detonated according to plan.[67,68]

The National Academy of Sciences' special panel on disposal methods for CBW agents stated that certain CBW agents already embedded in concrete could be disposed of in the sea without serious environmental effects, but specified that this was accepted as a last resort solution in the event land disposal would pose unnecessary hazards to disposal personnel.[65] The panel also recommended that in the future the Army should assume that all chemical weapons will require eventual disposal and should, consequently, build disposal facilities that will not require dumping at sea.

General Considerations. Our present understanding of the short- and long-term responses of the more important marine food chain organisms to various types of waste is extremely limited. For example, wastes may have a detrimental effect through alterations in the natural environmental conditions (i.e., temperature, pH, etc.) or through physiological and other changes resulting from the addition of the wastes, or through both. Thus, in determining the toxic effects of wastes, it is important to consider environmental, physiological, and accumulative effects. Not only are marine organisms directly affected by wastes, but also indirectly through their interaction with other forms of organisms which comprise their food, competition, and predators. The situation is further complicated by the fact that different species and different developmental or life stages of the same species may vary widely in sensitivity or tolerance to different wastes. Thus, unfavorable conditions which may be tolerable for long periods by adults may be entirely unfavorable for spawning, and thus possibly endanger survival of the species.

From the foregoing, it can be seen that a great deal of work remains to be done in order to establish both the short- and long-term environmental effects of various classes of wastes in the marine ecosystem. Laboratory tests on specific organisms, both on a short- and long-term basis, are required in order to establish safe discharge rates of the various wastes. The results of these tests must then be tested in the field to determine their adequacy for protection of marine life in the disposal area.

The latter requirement will involve extensive research, both on the organisms themselves and on effective sampling and bioassay techniques. For example, Hood and co-workers have shown that field sampling utilizing standard oceanographic techniques

was inadequate for the purpose of obtaining test organisms in the Gulf of Mexico. Furthermore, examples collected periodically on this basis reflect only the conditions at the time that they were collected, and there was no way to determine if the organisms were endemic to the disposal area or migratory in nature. Similarly, there is no way to determine whether or not the wastes are responsible for more subtle sublethal effects on the biota as the waste field moves out of the original area under the influence of ocean currents.

PRINCIPAL AREAS OF ENVIRONMENTAL RESEARCH NEEDS

Substantial research efforts related to the environmental effects of waste in the sea are required in three major areas to insure that the ocean environment is not damaged by discharges of waste and that the pollution problems that currently exist in most major U.S. rives, lakes, and estuaries are avoided. These three areas are: development of baseline environmental data, laboratory studies of waste toxicity, and studies of the fate of wastes in the environment and its effects on the biota.

Baseline Environmental Data

In order to properly evaluate the effects of introducing any given foreign substance into the marine environment, it is essential to have an adequate understanding of the various natural fluctuations of the biota and water mass characteristics that are normal for the area in question. Without such an understanding, it is impossible to distinguish between normal variations and those resulting from the presence of the pollutant.

Baseline studies carried out prior to discharging wastes are the most effective means of providing reference data for use as a standard in measuring the effects of introduction of wastes. For an existing discharge, a control study area is set up in the general vicinity of the disposal operation but far enough removed so that it is not affected by the discharged material. In either case, a broad-spectrum study program is required. Physical and chemical studies of the control area serve to identify the natural processes responsible for the observed distributions of oceanographic properties, such as temperature, salinity, etc. Biological studies concentrate on both the quantity and quality of the biota, as well as the natural diversity of the fauna in the area.

Laboratory Studies of Waste Toxicity

The bulk of the toxicity test programs carried out to date on the various wastes being discharged at sea are discussed in Appendix D; they are limited both in scope and number. It is sometimes overlooked in establishing concentration limits based upon deaths of natural organisms that we don't want sick ones either. Substantial additional work is required not only on acute toxicity, but on chronic or sublethal toxicity as well, particularly for industrial wastes.

Nearly all toxicity bioassay experiments performed to date have been acute toxicities (TLM_{50}) which are only 96 hours in duration. Little has been done to observe the survival, reproduction, and behavior of successive generations to determine chronic toxicity levels of various wastes. Data resulting from some acute tests indicate although test animals survived certain concentrations, there was little or no reproductive capability in the first or second generation.

Because of the diversity of the marine fauna and the wide variety in types of wastes disposed at sea, short-cut methods are needed for determining the toxic effects of wastes both on a short- and long-term basis. For example, at the National Marine Water Quality Laboratory in Kingston, Rhode Island, toxicity studies have been centered around those organisms which comprise the largest percentage of the biomass in the marine environment. Another short-cut used at this laboratory is to determine which of the abundant organisms is most sensitive to each particular waste. These organisms are then used in tests to determine the long-term effects of the wastes.

Another important item for research is the development of standard test procedures which can easily be performed without expensive or elaborate instrumentation or highly trained personnel. The Marine Water Quality Laboratory has developed a bioassay technique that uses brine shrimp (Artemia) whose eggs are easily obtainable throughout the country. To further standardize these tests, sea-salts now on the market in convenient packages are recommended for the preparation of artificial seawater.

Research in toxicity effects on the marine environment resulting from barge disposal is nonexistent and urgently needed. Results of investigations around submarine outfalls in 400 feet of water or less over

the past 20 years cannot be extrapolated to the much deeper truly oceanic conditions. Nevertheless, the data from the outfall studies provide useful guidance.

Fate of Wastes and Effects on the Biota

Understanding the fate of the waste after discharge requires an understanding of how the waste physically mixes and disperses in the sea, how the waste degrades chemically and biologically, and what components of the waste tend to concentrate either in the bottom sediments or in various plants and animals in the food chain.

Waste Dispersion. At present, the understanding of how wastes mix and disperse after discharge at sea is limited; generalized theoretical models are too imprecise to allow effective prediction for a specific disposal situation. Environmental studies are required to verify predictive models. Present disposal operations afford excellent opportunities for conducting important full-scale, at-sea experiments on mixing.

Improved sampling methods and equipment should be developed in order to obtain the necessary synoptic data to verify mixing models at all depths in the sea.

Because of the irregular frequency of many discharge operations, and the high costs of ship time for monitoring programs, research is also required to determine the most desirable spatial and temporal at-sea sampling patterns for various types of discharge operations.

Effects on the Biota. The research studies cited in earlier sections of this chapter constitute the bulk of the work on biologic response to barge-discharged wastes carried out to date. Although this work is extremely valuable, the fact remains that it merely scratches the surface of the problem. It is not an exaggeration to state that the environmental effects of past and present discharges are , with essentially no exceptions, not even qualitatively known, let alone measured. It follows that a major research effort in this area is essential.

POSSIBLE BENEFICIAL USES OF SOLID WASTES IN THE MARINE ENVIRONMENT

Although there are severe problems caused by tug and barge disposal of some classes of wastes, a large portion of solid wastes could be disposed of at sea so as to derive benefit. The greatest potential appears to lie in providing artificial habitats for fish.

The coastal zone of the United States is a relatively narrow strip of land bordering our coasts (and the Great Lakes) that contains nearly half of the Nation's population. As our economy and population expand, the coastal zone is becoming increasingly subject to conflicting uses of the relatively limited marine resources available. These uses include fisheries, recreation, fossil fuel and mineral resources development, marine transportation, real estate development, and the disposal of a variety of solid and liquid wastes. Few of these uses are compatible, let alone complimentary. The question of beneficial uses was investigated in the present survey, and results indicate that the only volumetrically significant beneficial use of solid waste in the marine environment is in the construction of artificial reefs for fish habitats. In addition, some suggestions have been made for using selected solid wastes for the construction of breakwaters or islands.

According to current estimates, 82 million persons (12 years of age or older) reside in the marine coastal zone of 23 States.[69] This population is forecast to increase by 17 percent to 96 million by 1980. However, the total number of ocean-oriented recreation "occasions" such as sportfishing, boating, swimming, and surfing are forecast to increase from 1.8 billion in 1965 to 2.4 billion in 1980, a 30 percent increase. Total expenditures associated with these activities are expected to nearly double from $13 billion to $23.6 billion over the same period.

Artificial Habitats for Fish

At present, there are some 104 artificial habitats or reefs along the U.S. coasts (Figures 1 to 3). Most of these are experimental in character and have been established either by research scientists or local sportfishing interests. Typically, they are relatively small features made up of a variety of solid waste materials including cars, tires, etc., often placed near wrecked vessels. A discussion of various aspects of the potential for large-scale use of solid waste for construction of such artificial habitats follows.

Fishing Pressure. As the number of sport fishermen in the United States continues to grow at the rate of ten to fifteen percent annually, it is evident that the fish population that attracts these enthusiasts cannot remain static. According to Winslow and

Bigler in 1965, at least 40 percent of the 80-odd million* coastal zone population participated in sportfishing from the shore and small craft in U.S. coastal waters.[69] The threat of widespread overfishing is significant. In 1965, sportfishing in coastal waters represented a significant fraction of the $108 billion water-oriented recreational industry. Some areas are already heavily overfished. For example, the sheepshead and weakfish have nearly disappeared from the waters off New York and New Jersey.[70] Similarly, populations of black seabass, sheepshead, abalone, and lobster have been seriously reduced as the result of increased fishing pressures off the Southern California coast. It may be that artificial habitats will increase fisheries resources so as to minimize or reverse the effects of overfishing.

Lack of Natural Habitat. Most of the continental shelf within reach of sport fishermen and skin divers operating from small craft is an unproductive, flat, lifeless, sandy desert with very few relief features. Sport and commercial fishermen have known for years that naturally-occurring banks, pinnacles, and hills as well as shipwrecks on an otherwise featureless sea floor attract a variety of fish. These areas of high relief, whether natural or artificial, furnish a firm substrate for the encrustration of organisms, such as barnacles, mussels, and coral, and also provide the necessary protection, food, and spawning areas for fin fish. There is substantial evidence that in nearshore areas where junked cars and rubble have been dumped by man fishing has improved.[26]

Current Status

Recent studies conducted by the California Department of Fish and Game and the Bureau of Sport Fisheries and Wildlife's Sandy Hook Marine Laboratory have shown that properly constructed habitats are a very effective means in congregating the available fish from a given area.[26,71] It has been postulated that the artificial habitats constructed with solid waste serve to increase the populations of other migratory fish by providing additional spawning sites for adults and protection and food for the juveniles.[71]

At the present time, because of the ease in handling, availability, long-life, and low cost, automotive tires are the most attractive material for constructing artificial reefs. Research at the Sandy Hook Marine Laboratory has shown that of several materials tested (wood, glass, concrete, metal, etc.) in the environment, rubber was found to be the most desirable substrate for colonization by the majority of invertebrate organisms in the area.[71] During 1969, over 30,000 tires were implanted on three different experimental reefs. Each reef is being inspected by biologist-divers to assess the effectiveness of the tires in increasing the productivity of the area and to inspect the development of new fish around the habitat. Support for this program has been supplied by the Bureau of Solid Wastes Management. Several types of artificial habitats have been constructed with such wastes as car bodies, tires, and rubble, and the various marine life have been attracted to them (Figures 15 to 20).

A report describing the characteristics of the various existing artificial reefs off the Atlantic and Gulf coasts is currently being prepared by the Bureau of Sport Fisheries and Wildlife's Sandy Hook Marine Laboratory.

It has been suggested that baled refuse would provide both food and habitat as a means of enhancing the production of the environment. The Sandy Hook Marine Laboratory has been carrying on an experimental program to monitor the effects observed in placing baled refuse in shallow water (Figure 20). The initial experiment was inconclusive because of storm damage, but further observations of various types of bales are scheduled.

Availability of Potentially Suitable Solid Waste Material

With regard to the availability of wastes suitable for use in construction of artificial habitats, of the 110 billion tons of solid waste generated annually in the United States, it is estimated that 10 million tons of construction debris, 9 million junked cars, and 100 million old vehicular tires are disposed of annually.[72,73] Although a portion of the cars and tires are reduced and converted into usable scrap, it is likely that a significant fraction of the scrap cars, tires, and debris produced in the populous coastal zone must be disposed of. For example, 20,000 abandoned cars

* This number is significantly higher than the popular often-cited figure of eight million salt water fishermen, but appears to be reasonable and consistent with a national percentage of fishermen compared to total population. Further, these figures do not include the additional population that also participated in sportfishing aboard chartered fishing vessels.

were reported by the city of Philadelphia and over 36,000 by the city of New York in 1968.[74] Sittig reported that 5,000 tons per day of construction demolition waste are deposited in sanitary landfills operated by Los Angeles County.[75] During the present survey, it was determined that New York City annually disposes of over 500,000 tons of demolition and construction debris in landfills and ocean disposal sites.

Estimated Costs

Although evidence gathered over the past 10 years shows that artificial habitats constructed of solid wastes substantially increase sport fishing productivity in local sites, no large-scale program has been undertaken. In examining some of the reasons, it is seen that the cost of preparation and emplacement of the junked cars was relatively high and that the metal was corroded in 3 to 5 years with resulting loss of the reef (see Figure 16). Estimates made by researchers at the Sandy Hook Marine Laboratory indicated that the cars cost from $70 to $100 each because of the cost of handling, barging, and implanting (Figure 21). Although the use of concrete culvert was favorable as a habitat, it too was considered too expensive and heavy to be feasible for reef construction.

Over the last three or four years, experimental work with rubber tires showed these cost less than a

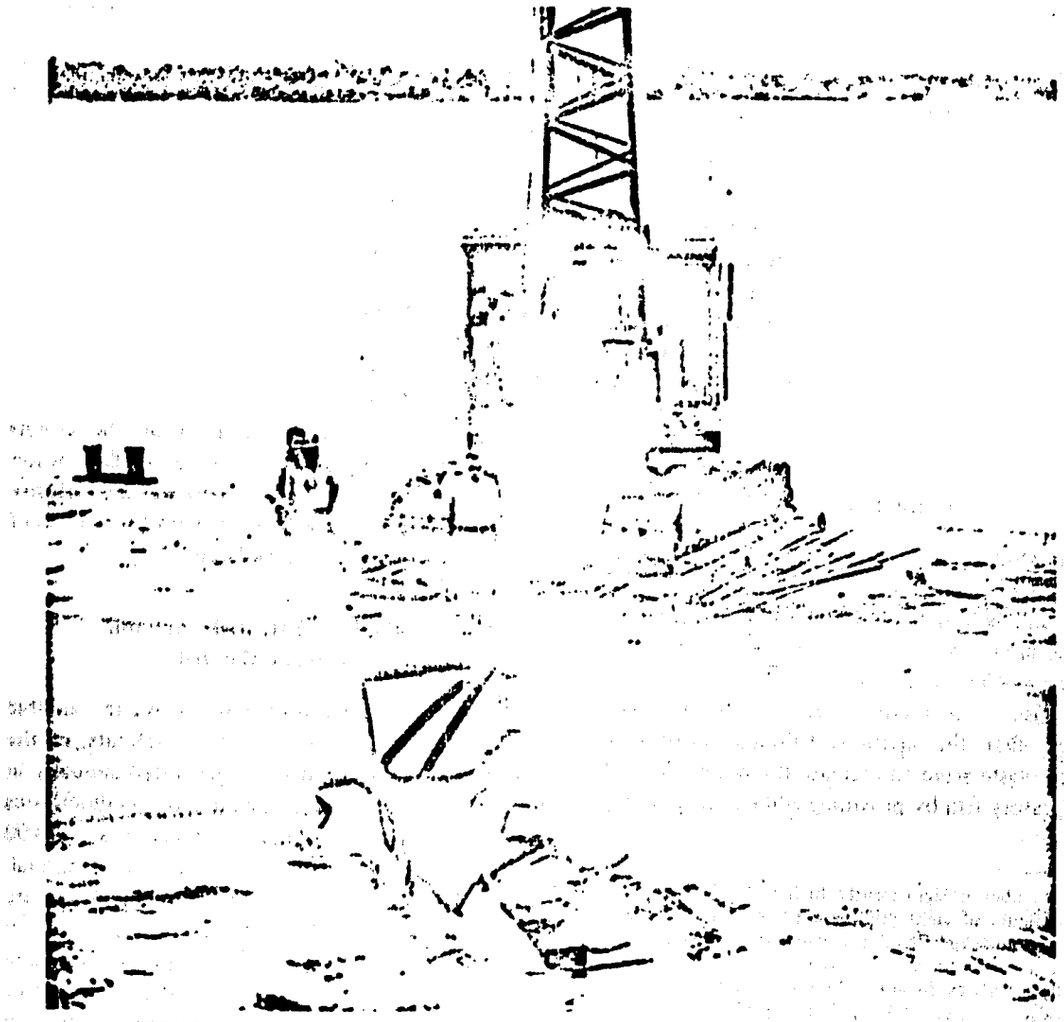

FIGURE 21. Method used to implant junked cars for establishment of an artificial fishing reef in shallow water off the New Jersey coast. (Photograph courtesy of Richard Stone, Sandy Hook Marine Laboratory.)

dollar each, and could be assembled and implanted by local fishing and diving clubs. One method uses four to seven tires joined with steel rodding and weighted with concrete ballast. These units become useful fish habitats after one to two years, when they are thoroughly encrusted with marine growth.

Although it is possible to construct effective artificial fishing reefs from certain types of solid wastes, present practice favors disposal in landfills or recycling as scrap steel. It is conceivable, however, that in only a few years, land values and the volume of solid wastes will make extensive reef construction attractive. In this regard, the controlled building of these reefs in the marine environment for the benefit of sport fishermen would be analogous to the onshore reclamation of canyons and undesirable parcels of land utilizing sanitary landfill techniques for the purpose of creating parks, golf courses, etc. In any event, there is an immediate and continuing need for research and development related to this area.

Other Beneficial Uses of Solid Wastes

Other potential beneficial uses of solid waste materials in the marine environment include its use as a building material in artificial islands, surfing reefs, and floating breakwaters.

Surfing Reefs. Grigg has proposed that demolition rubble be used for constructing artificial surfing reefs off the California coast to supplement the natural reef or shoal areas now heavily congested with an estimated 600,000 surfers.[76] With proper construction, he envisions that these reefs could also serve sport fishermen and skin divers. Grigg estimates that a prototype surfing reef constructed of quarry stone off the coast of Southern California would cost about $150,000. Compared to other environmental improvement projects undertaken by the Corps of Engineers, this figure does not appear excessive. For example, $330,000 was spent on sand dredging last year for beach replenishment in the area of Newport Beach, California.[76] Grigg points out that at present there are no definitive studies to guide the design and construction of multiple-use artificial reefs close to shore, and that further research should be conducted to evaluate their potential.

Floating Breakwaters. Another concept noted during the survey was the proposed use of scrap tires for the construction of a moored, floating offshore breakwater to attenuate wave action.[77] This structure would consist of large truck tires joined to form flexible floating barrier. Related experimental work has been carried out by Uniroyal using a series of baffles to break up the orbital motion of waves, thus dissipating the energy offshore. Costs for the materials for a floating breakwater constructed of used tires are estimated at $600 per 100 lineal feet. Costs for anchors and related mooring tackle, and for installation and maintenance will probably be many times the cost of the basic materials.

Additional research on this concept may find a way to successfully combine the surfing/fishing reef with the breakwater and use both construction rubble and tires.

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WASTE DISPOSAL IN THE MARINE ENVIRONMENT—A LITERATURE REVIEW

Environmental effects of marine disposal of solid and liquid wastes from barges and other vessels may be divided into physical and chemical aspects, biological aspects (including public health) and their interrelationships.

At present, we have a theoretical understanding of mixing and diffusion phenomena which tells us where the waste material should go. In addition, we have a rudimentary understanding of the probable effects of a given waste concentration on certain organisms. By contrast, we have only a very limited understanding of how the waste actually disperses and how the ecosystem actually responds to the presence of the pollutant.

A series of carefully conducted laboratory bioassay tests is generally the first step in defining the level of dilution that is safe for a given set of conditions. Unfortunately, there are significant problems associated with achieving successful test results, and there are more difficult problems associated with effective prediction of the actual mixing or diffusion rate to be expected at the disposal site.

The broader aspects of oceanic circulation were discussed in Appendix C, as are the marine ecological interrelationships generally known as the food chain. More detailed considerations are presented below.

WATER QUALITY REQUIREMENTS

A water quality standard is a plan established by governmental authority as a program for water pollution abatement, and includes water use classifications, water quality criteria necessary to support these uses, and a plan for implementation and enforcement. Water quality criteria are the scientific requirements on which a decision or judgement may be based concerning the suitability of water quality to support a designated use.[1] In essence, water quality criteria are the parameters or measuring sticks used to evaluate whether the specified water quality standards are being met.

The Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965,[2] authorized the States (and the Federal Government) to establish water quality standards for interstate (including coastal) waters. Specific guidelines for the establishment of these standards are contained in the Act. If a given State fails to adopt standards consistent with these guidelines, the Secretary of Interior is authorized to develop the necessary water quality standards for the body of water in question.

Water quality criteria for the coastal waters (extending out to 3 miles) have been established by most coastal states. There are no water quality criteria for waters beyond the 3-mile territorial limit of the United States. Where they exist, these criteria are generally of a descriptive nature, and specific allowable waste concentrations and other quantitative measures are rarely included. Exceptions to this are the several California State Water Quality Board Resolutions which specify limits for such measures as pH, dissolved oxygen, and waste concentration at given distances from the waste disposal barge.

Water quality standards and criteria depend upon the beneficial uses of the water, which for open coastal waters include: (1) propagation of fish, shellfish, and other marine life; (2) boating and navigation; (3) esthetic enjoyment; (4) commercial and sport fishing; (5) skindiving; (6) transport, dispersion, and assimilation of wastes; (7) bathing. The relative importance of these beneficial uses varies geographically and seasonally. In considering the level of water

quality required for the various uses by marine life, man, or industry; water quality criteria are typically defined on the basis of physical, chemical, bacteriological, or biological characteristics or parameters.[3] Many of these same parameters are used in research studies designed to assess the probable effects of waste discharge in marine waters.

PHYSICAL PARAMETERS

The principal physical parameters include color, odor, turbidity, particulate matter (i.e., floatable and suspended solids), transparancy, salinity, temperature, and density of the water column (which is a function of temperature and salinity). Also included are hydrodynamic characteristics such as eddy diffusivity, and geological characteristics such as the composition, grain size, and distribution of bottom sediments.

As McKee has pointed out, physical parameters are most often used to assess the changes that take place in well-defined environmental relationships as a result of the addition of potential pollutants.[3] For example, the addition of waste material contained in large volumes of fresh water media will alter the horizontal and vertical salinity distribution. This will in turn change the existing vertical stability of the water column, which could have a direct effect on the ultimate mixing of the wastes.

There is a substantial body of published work dealing with general problems of mixing, diffusion, and dispersion in marine waters and in related topics (in particular see Orlob, Okubo, and Foxworthy.[4-6]

Numerous factors control the dilution and dispersion of the waste, including such large-scale oceanographic features as density distribution, permanent currents, and tides, as well as local morphology, wind currents, mass transport, and wave action.

In general terms, currents move the water mass containing the waste field away from its point of origin while dilution and dispersion of the waste field take place more or less contemporaneously. When waste material is discharged at sea, components heavier than sea water sink and the lighter fractions float. Dispersion or lateral spreading of the waste is a function of the sinking rate of that waste, and the interaction of forces producing lateral movement. The nature of the sinking action depends on whether or not the waste is a solid or a liquid.

Solids sink (or settle) according to Stokes' law[7] except for modifications introduced by the hydrodynamic shape of the body or particles, and the horizontal forces of currents. The behavior of solids with densities (or bales of solids with composite densities) close to that of sea water is somewhat more complex and need not be discussed here.

Liquid wastes discharged in sea water are diluted and dispersed by the initial dilution of the waste, and subsequent dispersion of the diluted waste field. The denser components of the liquid sink with some attendant dispersion until they encounter a density level in the water column equal to their own. At this depth, a submerged waste field forms with subsequent mixing and lateral dispersion according to isentropic principles.[8] For the components with densities close to sea water, mixing and dispersion take place predominately in the surface water layer under the influence of turbulence produced by winds, waves, currents, and the passage of the disposal tug and barge.

For engineering purposes associated with the disposal of wastes at sea, the turbulent mixing phenomenon or eddy diffusion is best approximated by a modification of Fick's Law,[9,10] which holds that the turbulent mass transfer of a property of a fluid (i.e., temperature, salinity, etc.) per unit of time is proportional to the average concentration gradient. The proportionality constant is called the coefficient of eddy diffusivity; it is not a physical constant but depends on the nature of the turbulent motion.

Since the coefficient of eddy diffusivity is fundamental to an accurate understanding of mixing, considerable attention has been given to the determination of the appropriate value of this coefficient for various mixing situations found in the ocean. Most investigators have limited their studies to the horizontal component of eddy diffusivity in the surface layer of the sea.

Pearson and Orlob each assembled values of the eddy diffusivity coefficient obtained by several investigators;[9,4] the broad range of values (between 10^{-4} and 10^{6}) has caused several investigators to suggest that the Fickian equation may be an inadequate model for completely describing eddy diffusion processes.[5,6]

Although there has been considerable disagreement in the literature on how to formulate a diffusion law adequate to describe oceanic mixing processes, it is generally evident from the values summarized earlier and in more recent work[11] that the magnitude of the eddy diffusion coefficient increases greatly with the scale of the disturbance

being considered. For further discussion, the reader is referred to the references cited.[9,4,11]

Specific studies of the mixing of barge-delivered waste in the sea suggest that mixing and diffusion of wastes generally takes place rapidly in the wake of the disposal barge.[12-14] This mixing is hastened by the added turbulence associated with the passage of the tug and barge and the pumped discharge of the waste. The precision of the diffusion coefficients calculated from studies of various disposal operations is somewhat doubtful because it is difficult to distinguish between the natural diffusion of the waste and that induced by the barge effect just mentioned. From the experimental work at sea, it was estimated that the effect of the barge was to increase average mixing rates by a factor of three,[13] although stirring by the barge produced highly irregular patches of relatively undiluted waste, which is in agreement with the description of the mixing process presented by Eckart. How long these discrete patches may retain their identity is not known, but is is probably on the order of 3 to 4 hours. Hood, Stevenson, and Smith emphasized that the actual pattern of diffusion in the wake of a barge will be understood only through additional experimental work at sea.[15]

In connection with studies of the disposal of paper mill wastes off the Texas coast, Hood and Abbott developed a predictive equation for diffusion.[16] Using this equation, good agreement between the predicted and observed waste concentration in the wake of a chlorinated-hydrocarbon disposal barge 5 minutes after discharge were obtained.[13]

CHEMICAL PARAMETERS

The chemical measures used in defining water quality criteria were summarized by McKee.[3] They include: hydrogen ion concentration (pH); dissolved gases (oxygen, carbon dioxide, etc.); chlorinity; nitrogen analysis (ammonia, nitrites, nitrates); organic carbon (COD) and total carbon; biochemical oxygen demand; nutrients (phosphates, nitrates, silicates, etc.); heavy metals (copper, lead, zinc, etc.); oily substances (hydrocarbons of industrial origin); trace organics (pesticides, detergents, etc.).

In the past, determinations of most of the foregoing chemical measures have resulted in only microquantities for which the effects on beneficial uses are difficult to establish. Chemical analyses of the bottom sediments have, however, often proven useful in assessing the overall impact of pollution, owing to the integrating characteristics of sedimentation and biological accumulation. Generally, the first seven parameters establish the numbers of organisms which are found in the marine environment. The last three may be more critical, for they may either preclude the existence of any life or may so alter the ecosystem that only undesirable forms can survive. It is these compounds whose biological effects must be characterized.

BIOLOGICAL PARAMETERS

In a highly simplified way, the biological assemblage in the sea can be subdivided into three zones: the flora and funa which live in the surface and near surface (euphotic zone) waters; the assemblage living in the mid-water zone; the bottom (or benthic) dwellers.

The surface and near-surface waters are by far the most heavily populated zone; phytoplankton abound and the fauna range from the microscopic zooplankton up through the food web to the large fish and mammals. Within this zone the greatest concentrations occur in relatively shallow coastal waters; these concentrations include our commercial and sport fish as well as sharks, seals, and whales. Also found at the surface are seasonal concentrations of fin fish and shellfish larvae that spawn in open water to return later to near-shore and bottom waters.

The mid-water depths (or mesopelagic zone) are characterized by a low animal population. Nearly all the planktonic forms are absent, which results in attendant limitation of the higher orders in the food web. There is a sparse population of nonfood fish and invertebrates such as giant squid, viper fish, angle fish, and octopus.

The bottom or benthic animals are found in somewhat increased numbers relatively nearshore, since the bottom is able to nourish more life than the water column by accumulating all the debris that falls from the surface. Benthic animals can be divided into two basic groups: the epifauna or animals that live on top of the sediments, such as lobster, shrimp, and flounder; and the in-fauna or those living within the sediments, such as clams, worms, and other burrowing organisms.

The principal biological parameters used in defining water quality criteria so as to protect the biological assemblage include: species diversity indices, median toxicity tolerance (TLM) limits from bioassay tests, fish catch statistics, principal species

tabulations from plankton and trawl hauls, and measures of primary productivity. Species diversity indices and bioassay tests are becoming increasingly important while the other parameters are less useful in marine environmental control.

Species Diversity Indices

Ecologists have long identified polluted environments with a decrease in the number of species, although the total number of organisms of a given species may increase because of reduced competition. Thus, an examination of the diversity of the organisms in an area may provide a measure as to the general health of the environment. Any organism capable of avoiding the waste field, or which spends a limited portion of its life cycle in the test area, is considered of questionable value as a suitable indicator organism. For this reason, sessile forms or organisms that have little motility (such as bi-valves) are generally used. Stein and Denison evaluated the relative merit of "diversity indices" and concluded that the use of biological indicators are superior to chemical and physical measurements used alone. They strongly emphasize, however, the need for quantitative sampling techniques for the proper development of biological indices for evaluating pollution effects.[17]

Bioassays

The bioassay method consists of preparing a series of test solutions of the waste in water at various selected dilution levels, adding the population of test organisms, and observing their reactions and survival for definite time periods. Certain specifications such as temperature control, number and size of test organisms, volume of test solution, and maintenance of dissolved oxygen are usually incorporated in the test procedures.

Although there are several types of bioassays, two are in general use: (1) the acute static bioassay, in which the test solution is not changed during the duration of the experimen; and (2) the flow-through bioassay, in which the test solution is continually renewed. The advantages and disadvantages of these methods have been discussed by McKee, McKee and Wolf, Hueck and Adema, and Hood, Dube, and Stevenson.[3,18-20] It is generally agreed that the flow through bioassay provides a more realistic appraisal of the actual short- and long-term toxicity of a waste in terms of reproduction and growth; however, because of the requirements for complicated equipment, including metering devices and the provision for a large volume of the waste, this method is not as widely used as the acute static bioassay.

Thus, most of the present criteria for the toxicity of wastes are based on static bioassays conducted for each specific situation according to standard procedure establishment by the American Public Health Association.[21] Toxicity data generally are reported as the median tolerance limit (TLM), which is the concentration of waste that kills 50 percent of the test organisms within a specified time span.

It should be noted that the acute TLM value does not represent a "safe" concentration, as believed by manu, but merely the levels at which half the test organisms are killed. In contrast to acute bioassays, some investigators have conducted bioassay experiments on planktonic organisms, which are interpreted in terms of the concentrations of wastes that inhibit physiological processes (photosynthesis or growth) by 50 percent, rather than the concentration required to cause a 50 percent mortality of the test organisms.[3,17,20] In many cases, significant differences have been found between the acute TLM concentrations and those that are low enough to permit normal reproduction and growth.

To allow for these unknown effects of wastes, the National Technical Advisory Committee on Water Quality proposed that, in the absence of toxicity data other than acute TLM values an "application factor" should be applied to the TLM values in order to obtain permissible concentration of wastes that can be discharged at a given location. The application factor is defined as "...the concentration of a material or waste that is not harmful, divided by the 96-hour TLM value for that material."[1] In practice, very few application factors have been determined for the numerous types of wastes and, as a consequence, the Committee has suggested the use of interim application factors until test data become available. These are given as: 1/100 of the 96-hour TLM for pesticides, metals, and other persistent toxicants; 1/20 for ammonia, sulfides, and other unstable or biodegradable materials; and 1/10 for waste materials with noncumulative toxic effects. When two or more toxic materials that have possible additive effects are present in the same waste, a simple additive mathematical relationship is used to determine the permissible concentration.[1]

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INTRODUCTION

WALTER J. HICKEL
Secretary of the Interior

CARL L. KLEIN
Assistant Secretary for Water Quality and Research

DAVID D. DOMINICK
Commissioner, Federal Water Pollution Control Administration

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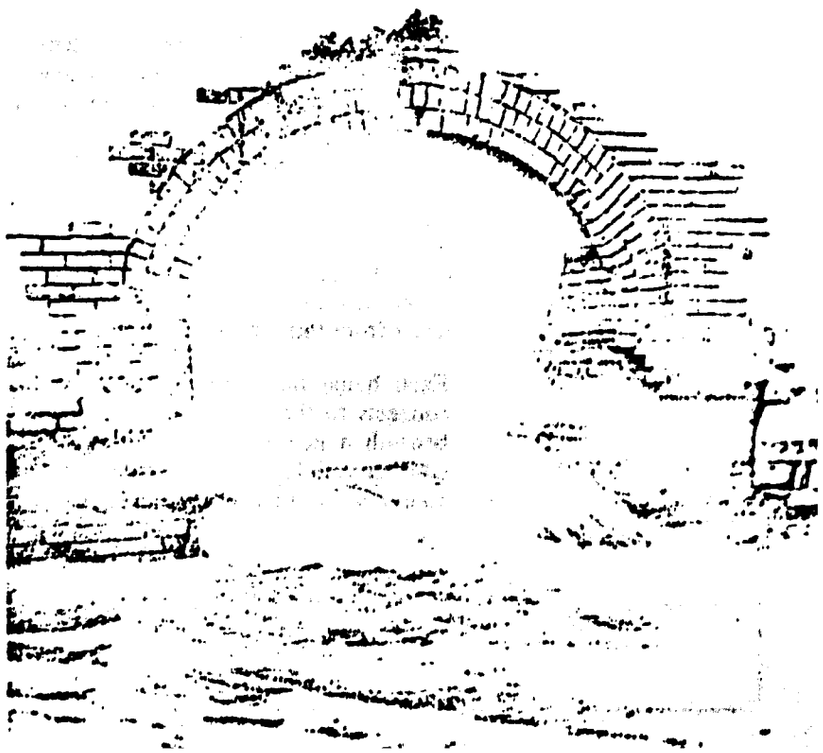
Thousands of waste treatment plants will be constructed or expanded across the Nation during the years ahead to control or prevent water pollution.

This increased construction activity is the result of the passage of the Water Quality Act of 1965 which called for the establishment of water quality standards for all the interstate streams, coastal waters, and lakes, and the Clean Water Restoration Act of 1966 which increased Federal financial aid to cities to help build these needed plants.

Communities across the land will be planning, financing, and building the facilities to meet the water quality standards. Some cities will be constructing plants where none existed before. Others will be expanding inadequate facilities while some communities will be adding more advanced methods to handle new types of wastes.

It won't happen overnight. From drawing board to operation takes time. In some cases, projects will be built in stages. Consequently, more and more people will be watching this developing progress toward cleaner water. They will need to know more about waste treatment.

In this primer, the methods used now and processes being developed for the future to treat wastes are explained.



COLLECTING AND TREATING WASTES

The most common form of pollution control in the United States consists of a system of sewers and waste treatment plants. The sewers collect the waste water from homes, businesses, and many industries and deliver it to the plants for treatment to make it fit for discharge into streams or for reuse.

There are two kinds of sewer systems—combined and separate. Combined sewers carry away both water polluted by human use and water polluted as it drains off homes, streets, or land during a storm.

In a separated system, one system of sewers, usually called sanitary, carries only sewage. Another system of storm sewers takes care of the large volumes of water from rain or melting snow.

Each home has a sewer or pipe which connects to the common or lateral sewer beneath a nearby street. Lateral sewers connect with larger sewers called trunk or main sewers. In a combined sewer system, these trunk or main sewers discharge into a larger sewer called an interceptor. The interceptor is designed to carry several times the dry-weather flow of the system feeding into it.

During dry weather when the sewers are handling only the normal amount of waste water, all of it is carried to the waste treatment plant. During a storm when the amount of water in the sewer system is much greater, part of the water, including varying amounts of raw sewage, is allowed to bypass directly into the receiving streams. The rest of the wastes are sent to the treatment plant. If part of the increased load of water were not diverted, the waste treatment plant would be overloaded and the purifying processes would not function properly. (A special research program is under way on the problem of storm and combined sewers.)

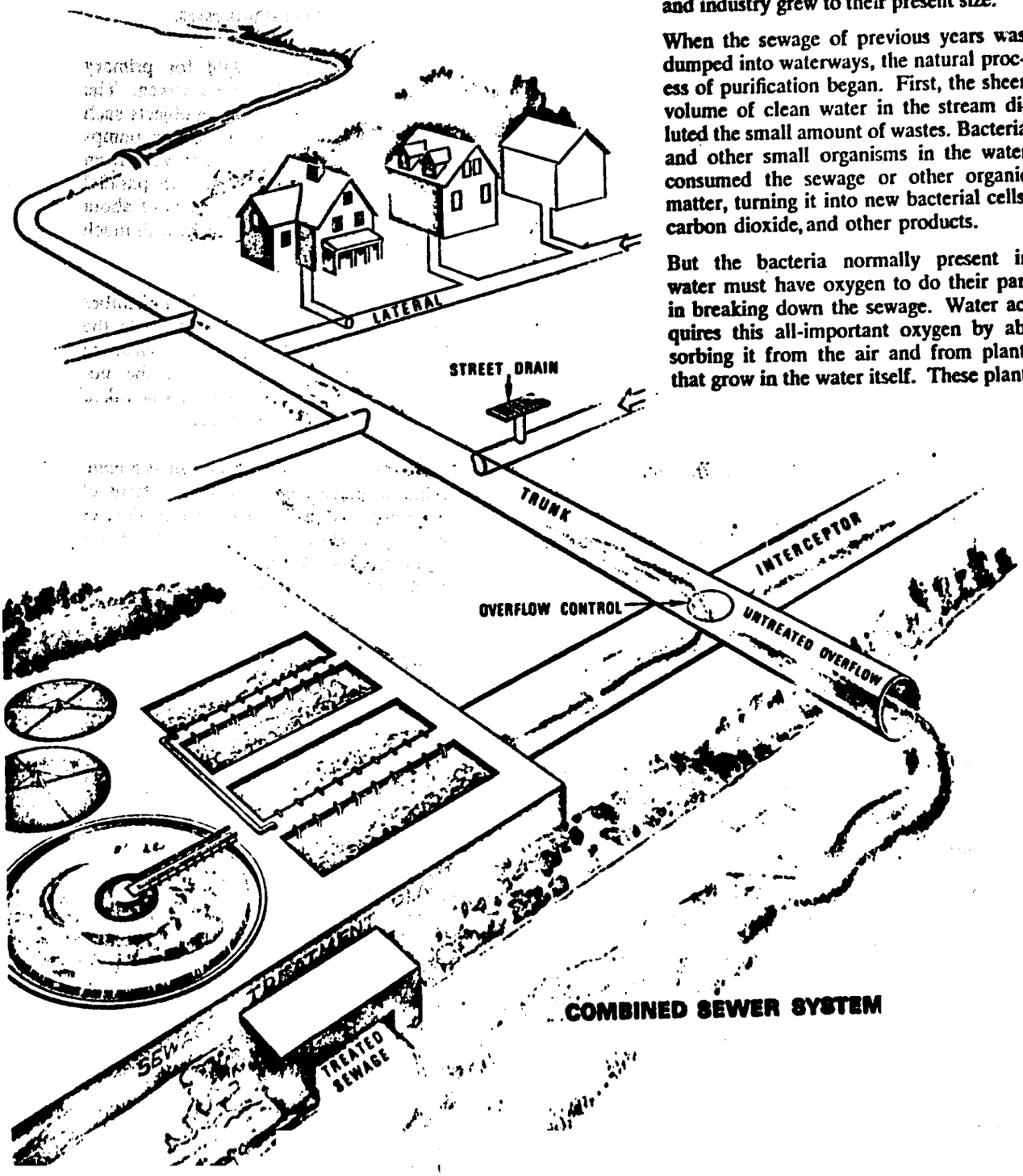
Interceptor sewers are also used in sanitary sewer systems as collectors of flow from main sewers and trunks, but do not normally include provisions for bypassing.

Untreated sewage pours into stream from combined storm-sanitary sewer.

A waste treatment plant's basic function is to speed up the natural processes by which water purifies itself. In many cases, nature's treatment process in streams and lakes was adequate before our population and industry grew to their present size.

When the sewage of previous years was dumped into waterways, the natural process of purification began. First, the sheer volume of clean water in the stream diluted the small amount of wastes. Bacteria and other small organisms in the water consumed the sewage or other organic matter, turning it into new bacterial cells, carbon dioxide, and other products.

But the bacteria normally present in water must have oxygen to do their part in breaking down the sewage. Water acquires this all-important oxygen by absorbing it from the air and from plants that grow in the water itself. These plants



COMBINED SEWER SYSTEM

use sunlight to turn the carbon dioxide present in water into oxygen.

The life and death of any body of water depends mainly upon its ability to maintain a certain amount of dissolved oxygen. This dissolved oxygen—or DO—is what fish breathe. Without it they suffocate. If only a small amount of sewage is dumped into a stream, fish are not affected and the bacteria can do their work and the stream can quickly restore its oxygen loss from the atmosphere and from plants. Trouble begins when the sewage load is excessive. The sewage will decay and the water will begin to give off odors. If carried to the extreme, the water could lose all of its oxygen, resulting in the death of fish and beneficial plant life.

Since dissolved oxygen is the key element in the life of water, the demands on it are used as a measure in telling how well a sewage treatment plant is working. This measuring device is called biochemical oxygen demand, or BOD. If the effluent or the end-product from a treatment plant has a high content of organic pollutants, the effluent will have a high BOD. In other words, it will demand more oxygen from the water to break down the sewage and consequently will leave the water with less oxygen (and also dirtier).

With the growth of the Nation, the problems of pollution have become more complex. The increased amounts of wastes and the larger demands for water have reduced the capacity of running water to purify itself. Consequently, cities and industry have had to begin thinking about removing as much as possible of the oxygen-demanding pollutants from their sewage.

Adequate treatment of wastes along with providing a sufficient supply of clean water has become a major concern.

PRIMARY TREATMENT

At present, there are two basic ways of treating wastes. They are called primary and secondary. In primary treatment, solids are allowed to settle and are removed from the water. Secondary treatment, a further step in purifying waste water, uses biological processes.

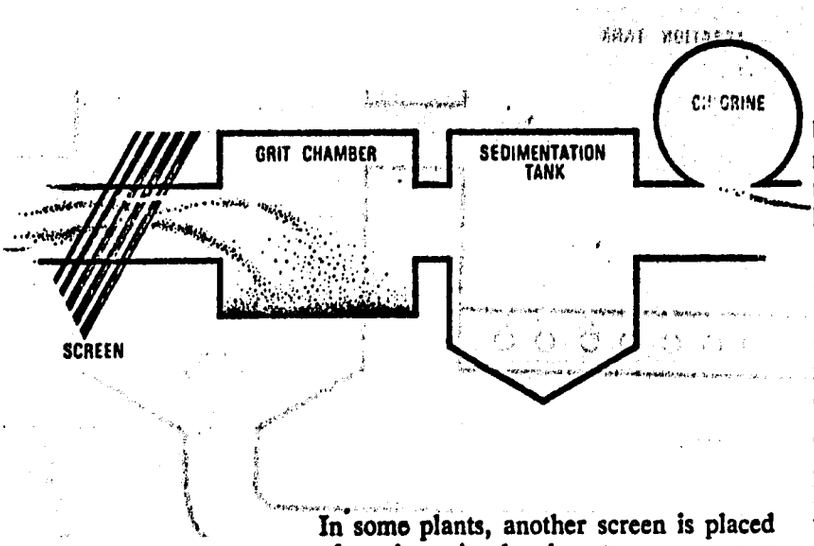
As sewage enters a plant for primary treatment, it flows through a screen. The screen removes large floating objects such as rags and sticks that may clog pumps and small pipes. The screens vary from coarse to fine—from those with parallel steel or iron bars with openings of about half an inch or more to screens with much smaller openings.

Screens are generally placed in a chamber or channel in an inclined position to the flow of the sewage to make cleaning easier. The debris caught on the upstream surface of the screen can be raked off manually or mechanically.

Some plants use a device known as a comminutor which combines the functions of a screen and a grinder. These devices catch and then cut or shred the heavy solid material. In the process, the pulverized matter remains in the sewage flow to be removed later in a settling tank.

After the sewage has been screened, it passes into what is called a grit chamber where sand, grit, cinders, and small stones are allowed to settle to the bottom. A grit chamber is highly important for cities with combined sewer systems because it will remove the grit or gravel that washes off streets or land during a storm and ends up at treatment plants.

The unwanted grit or gravel from this process is usually disposed of by filling land near a treatment plant.



In some plants, another screen is placed after the grit chamber to remove any further material that might damage equipment or interfere with later processes.

With the screening completed and the grit removed, the sewage still contains suspended solids. These are minute particles of matter that can be removed from the sewage by treatment in a sedimentation tank. When the speed of the flow of sewage through one of these tanks is reduced, the suspended solids will gradually sink to the bottom. This mass of solids is called raw sludge.

Various methods have been devised for removing sludge from the tanks.

In older plants, sludge removal was done by hand. After a tank had been in service for several days or weeks, the sewage flow was diverted to another tank. The sludge in the bottom of the out-of-service tank was pushed or flushed with water to a pit near the tank, and then removed, usually by pumping, for further treatment or disposal.

Almost all plants built within the past 30 years have had a mechanical means for removing the sludge from sedimentation tanks. Some plants remove it continuously while others remove it at intervals. To complete the primary treatment, the effluent with the sludge removed leaves the sedimentation tank for chlorination before being discharged into a stream or river. Chlorine gas is fed into the water to kill disease-causing bacteria. It also helps to reduce odors.

Although 30 percent of the municipalities in the United States give only primary treatment to their sewage, this process by itself is considered entirely inadequate for most needs.

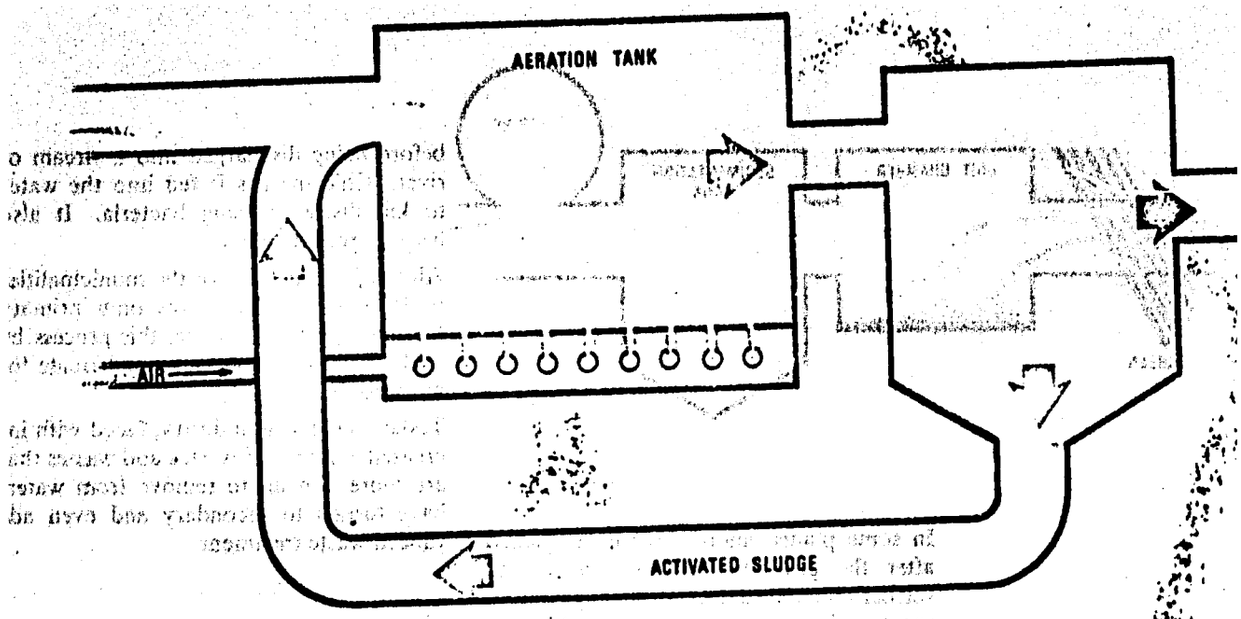
Today's cities and industry, faced with increased amounts of wastes and wastes that are more difficult to remove from water, have turned to secondary and even advanced waste treatment.

SECONDARY TREATMENT

Secondary treatment removes up to 90 percent of the organic matter in sewage by making use of the bacteria in it. The two principal types of secondary treatment are trickling filters and the activated-sludge process.

After the effluent leaves the sedimentation tank in the primary stage of treatment, it flows or is pumped to a facility using one or the other of these processes. A trickling filter is simply a bed of stones from three to ten feet deep through which the sewage passes. Bacteria gather and multiply on these stones until they can consume most of the organic matter in the sewage. The cleaner water trickles out through pipes in the bottom of the filter for further treatment.

The sewage is applied to the bed of stones in two principal ways. One method consists of distributing the effluent intermittently through a network of pipes laid on or beneath the surface of the stones.



Attached to these pipes are smaller, vertical pipes which spray the sewage over the stones.

Another much-used method consists of a vertical pipe in the center of the filter connected to rotating horizontal pipes which spray the sewage continuously upon the stones.

The trend today is toward the use of the activated sludge process instead of trickling filters. This process speeds up the work of the bacteria by bringing air and sludge heavily laden with bacteria into close contact with the sewage.

After the sewage leaves the settling tank in primary treatment, it is pumped to an aeration tank where it is mixed with air and sludge loaded with bacteria and allowed to remain for several hours. During this time, the bacteria break down the organic matter.

From the aeration tank, the sewage, now called mixed liquor, flows to another sedimentation tank to remove the solids. Chlorination of the effluent completes the basic secondary treatment.

The sludge, now activated with additional millions of bacteria and other tiny organisms, can be used again by returning it to an aeration tank for mixing with new sewage and ample amounts of air.

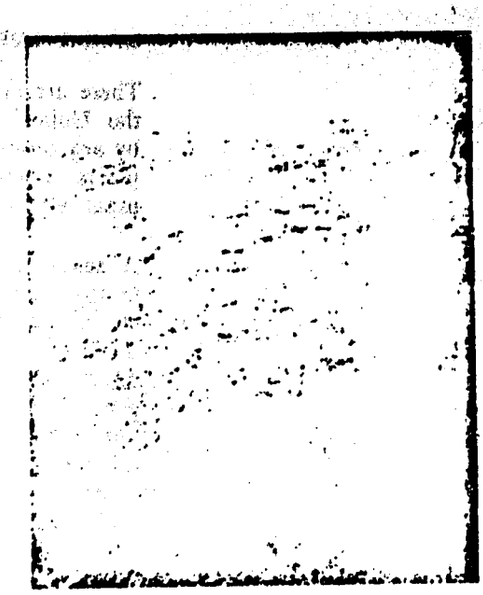
The activated sludge process, like most other techniques, has advantages and limitations. The size of the units necessary for this treatment is small, thereby requiring less land space and the process is free of flies and odors. But it is more costly to operate than the trickling filter, and the activated sludge process sometimes loses its effectiveness when faced with difficult industrial wastes.

An adequate supply of oxygen is necessary for the activated sludge process to be effective. Air is mixed with sewage and biologically active sludge in the aeration tanks by three different methods.

The first, mechanical aeration, is accomplished by drawing the sewage from the bottom of the tank and spraying it over the surface, thus causing the sewage to absorb large amounts of oxygen from the atmosphere.

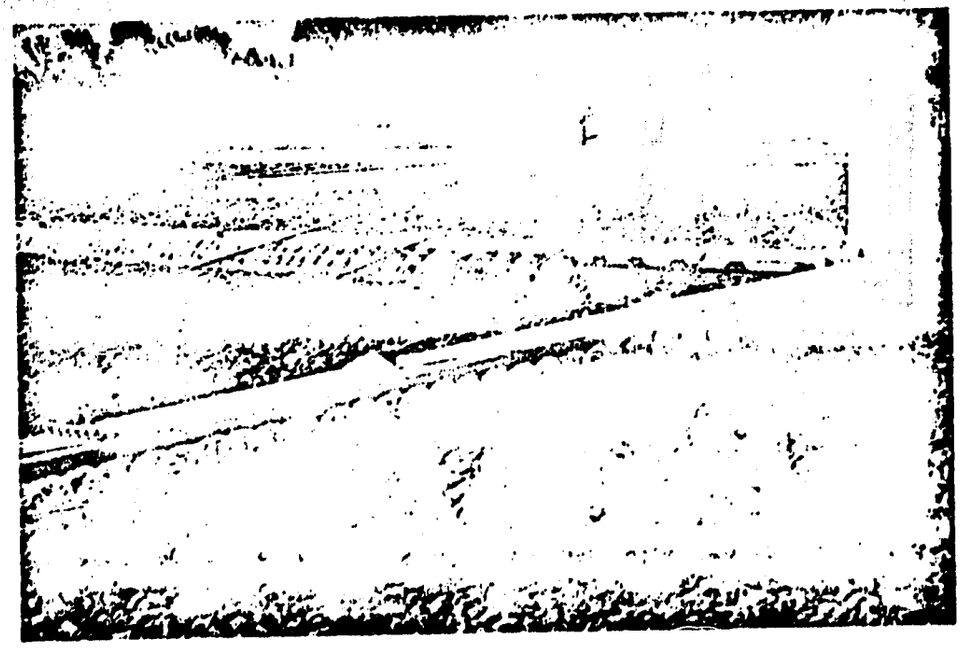
In the second method, large amounts of air under pressure are piped down into the sewage and forced out through openings in the pipe. The third method is a combination of mechanical aeration and the forced air method.

The final phase of the secondary treatment consists of the addition of chlorine to the effluent coming from the trickling filter or the activated sludge process. Chlorine is usually purchased in liquid form, converted to a gas, and injected into the effluent 15 to 30 minutes before the treated water is discharged into a watercourse. If done properly, chlorination will kill more than 99 percent of the harmful bacteria in an effluent.



Aeration unit in sewage treatment plant mixes oxygen from the air with waste water to help bacteria break down organic compounds.

Slowly revolving pipes in trickling filter spray waste water over beds of stones where bacteria consume organic matter.



LAGOONS AND SEPTIC TANKS

There are many well-populated areas in the United States that are not served by any sewer systems or waste treatment plants. Lagoons and septic tanks are the usual alternatives in such situations.

A septic tank is simply a tank buried in the ground to treat the sewage from an individual home. Waste water from the home flows into the tank where bacteria in the sewage break down the organic matter and the cleaner water flows out of the tank into the ground through sub-surface drains. Periodically the sludge or solid matter in the bottom of the tank must be removed and disposed of.

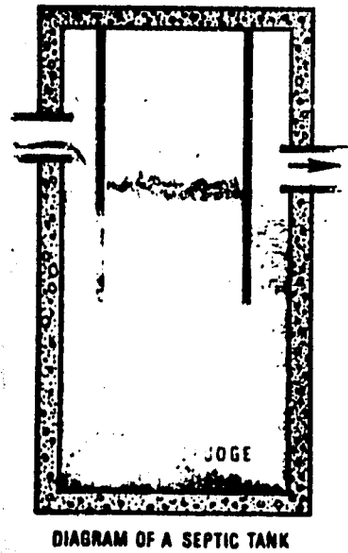


DIAGRAM OF A SEPTIC TANK

In a rural setting, with the right kind of soil and the proper location, the septic tank is a safe and effective means of disposing of strictly domestic wastes. Septic tanks should always be located so that none of the effluent can seep into wells used for drinking.

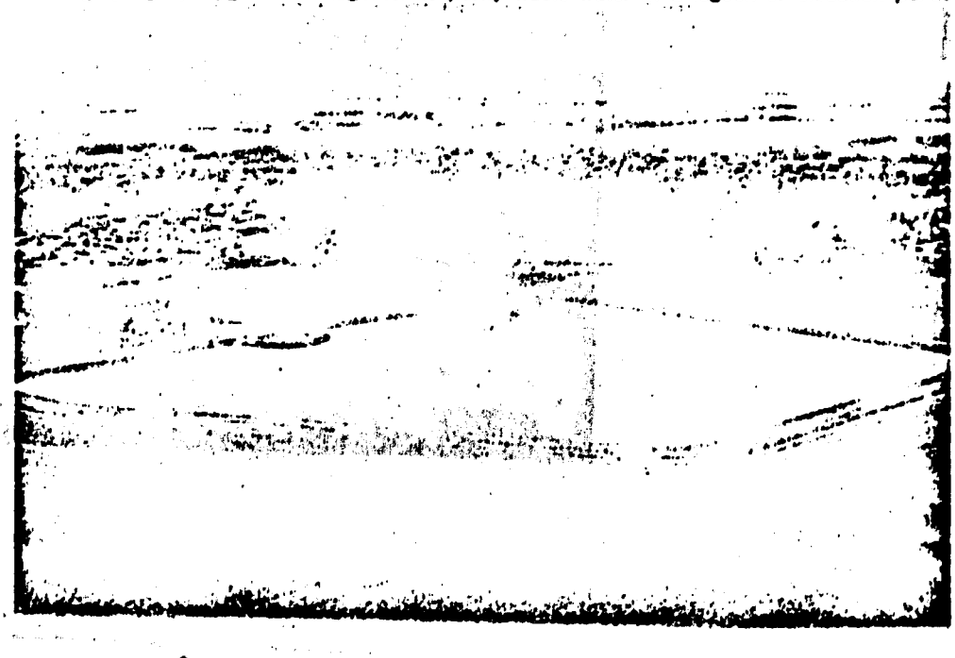
Lagoons or, as they are sometimes called, stabilization or oxidation ponds also have several advantages when used correctly.

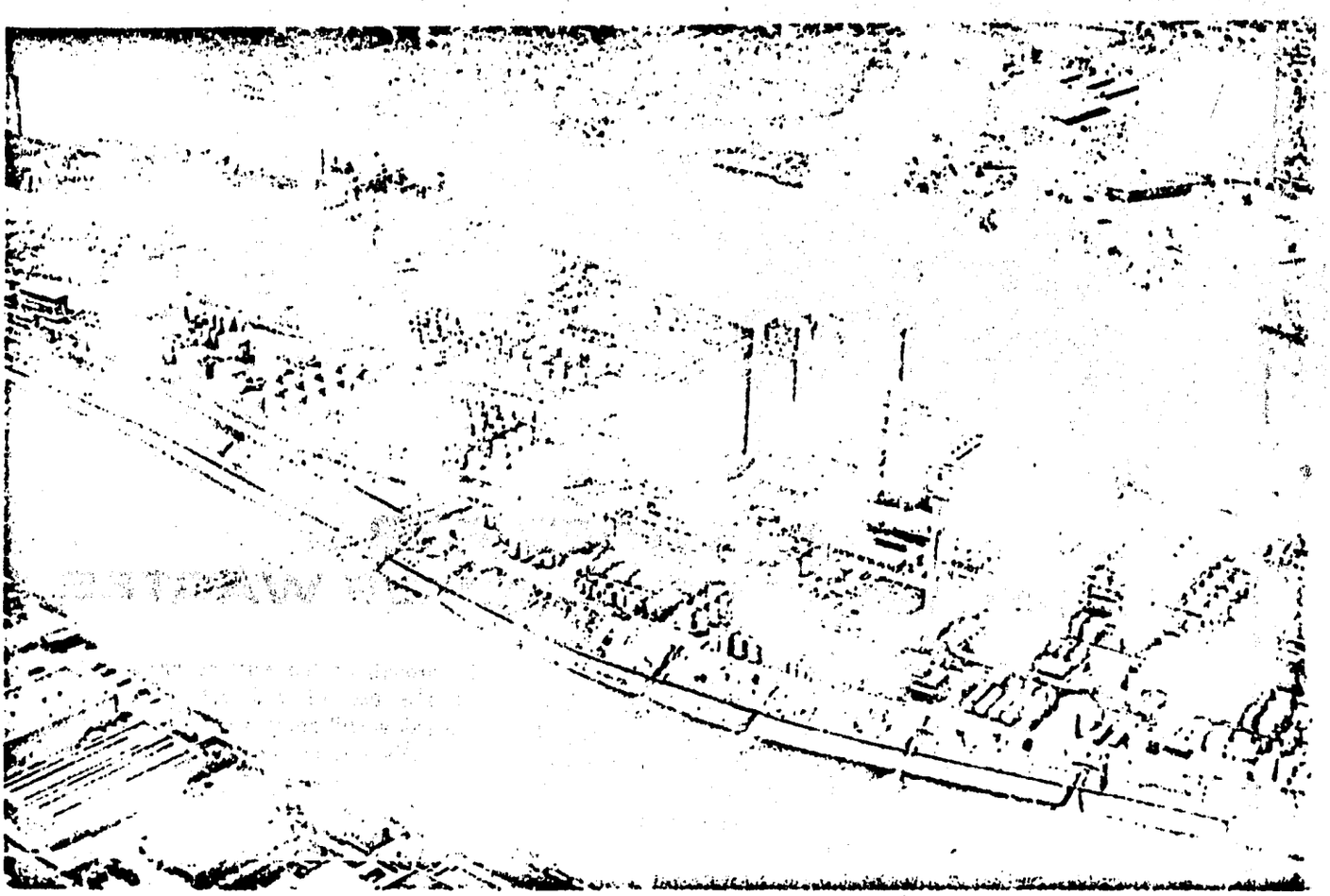
They can give sewage primary and secondary treatment or they can be used to supplement other processes.

A lagoon is a scientifically constructed pond, usually three to five feet deep, in which sunlight, algae, and oxygen interact to restore water to a quality equal to or better than effluent from secondary treatment. Changes in the weather affect how well a lagoon will break down the sewage.

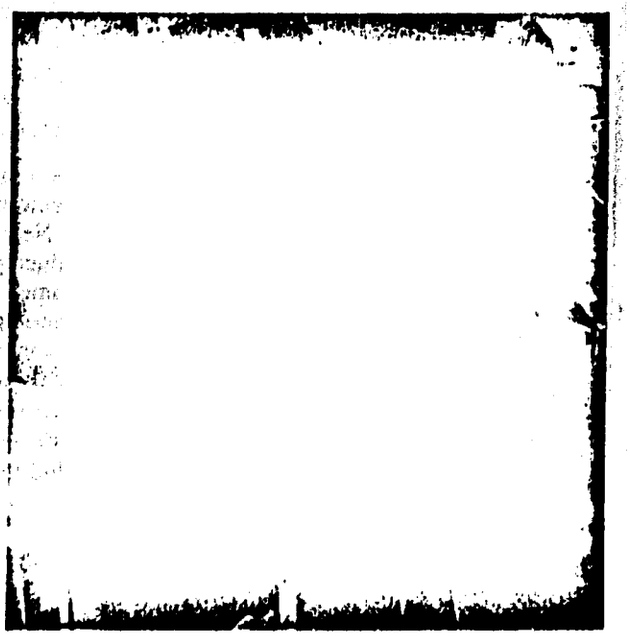
When used with other waste treatment processes, lagoons can be very effective. A good example of this is the Santee, California, water reclamation project. After conventional primary and secondary treatment by activated sludge, the town's waste water is kept in a lagoon for 30 days. Then the effluent, after chlorination, is pumped to land immediately above a series of lakes and allowed to trickle down through sandy soil into the lakes. The resulting water is of such good quality, the residents of the area can swim, boat, and fish in the lake water.

Sunlight, algae, oxygen work together to purify waste water in a lagoon or oxidation pond.





Industrial concentrations can cause gross pollution without adequate treatment. Note sewers dumping wastes.



Activated carbon is tested in tanks as an improved method of removing organic matter by adsorption. Organic compounds cling to carbon and settle out.

THE NEED FOR FURTHER TREATMENT OF WASTES

In the past, pollution control was concerned primarily with problems caused by domestic and the simpler wastes of industry. Control was aimed principally towards protecting downstream public water supplies and stopping or preventing nuisance conditions.

Pollution problems were principally local in extent and their control a local matter.

This is no longer true. National growth and change have altered this picture. Progress in abating pollution has been outdistanced by population growth, the speed of industrial progress and technological developments, changing land practices, and many other factors.

The increased production of goods has greatly increased the amounts of common industrial wastes. New processes in manufacturing are producing new, complex wastes that sometimes defy present pollution control technology. The increased application of commercial fertilizers and the development and widespread use of a vast array of new pesticides are resulting in a host of new pollution problems from water draining off land.

The growth of the nuclear energy field and the use of radioactive materials foreshadow still another complicating and potentially serious water pollution situation.

Long stretches of both interstate and intrastate streams are subjected to pollution which ruins or reduces the use of the water for many purposes. Conventional biological waste treatment processes are hard-pressed to hold the pollution line, and for a growing number of our larger cities, these processes are no longer adequate.

Our growing population not only is packing our central cities but spreading out farther and farther into suburbia and exurbia. Across the country, new satellite communities are being born almost daily. The construction or extension of sewer lines has not matched either the growth rate or its movements. Sea water intrusion is a growing problem in coastal areas. It is usually caused by the excessive pumping of fresh water from the ground which lowers the water level, allowing salt water to flow into the ground water area.

THE TYPES OF POLLUTANTS

Present-day problems that must be met by sewage treatment plants can be summed up in the eight types of pollutants affecting our waters.

The eight general categories are: common sewage and other oxygen-demanding wastes; disease-causing agents; plant nutrients; synthetic organic chemicals; inorganic chemicals and other mineral substances; sediment; radioactive substances; and heat.

Oxygen-demanding wastes— These are the traditional organic wastes contributed by domestic sewage and industrial wastes of plant and animal origin. Besides human sewage, such wastes result from food processing, paper mill production, tanning, and other manufacturing processes. These wastes are usually destroyed by bacteria if there is sufficient oxygen present in the water. Since fish and other aquatic life depend on oxygen for life, the oxygen-demanding wastes must be controlled, or the fish die.

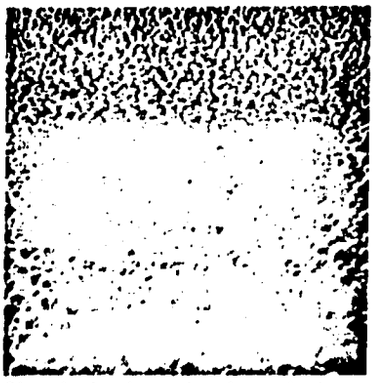
Disease-causing agents—This category includes infectious organisms which are carried into surface and ground water by sewage from cities and institutions, and by certain kinds of industrial wastes, such as tanning and meat packing plants. Man or animals come in contact with these microbes either by drinking the water or through swimming, fishing, or other activities. Although modern disinfection techniques have greatly reduced the danger of this type of pollutant, the problem must be watched constantly.

Plant nutrients—These are the substances in the food chain of aquatic life, such as algae and water weeds, which support and stimulate their growth. Nitrogen and phosphorus are the two chief nutrients present in small amounts in natural water, but much larger amounts are contributed

Common sewage from homes, businesses depletes oxygen supply in the water.

Blood and grease turn water brown at drain from meat packing plant.

Floating algae create unsightly conditions.

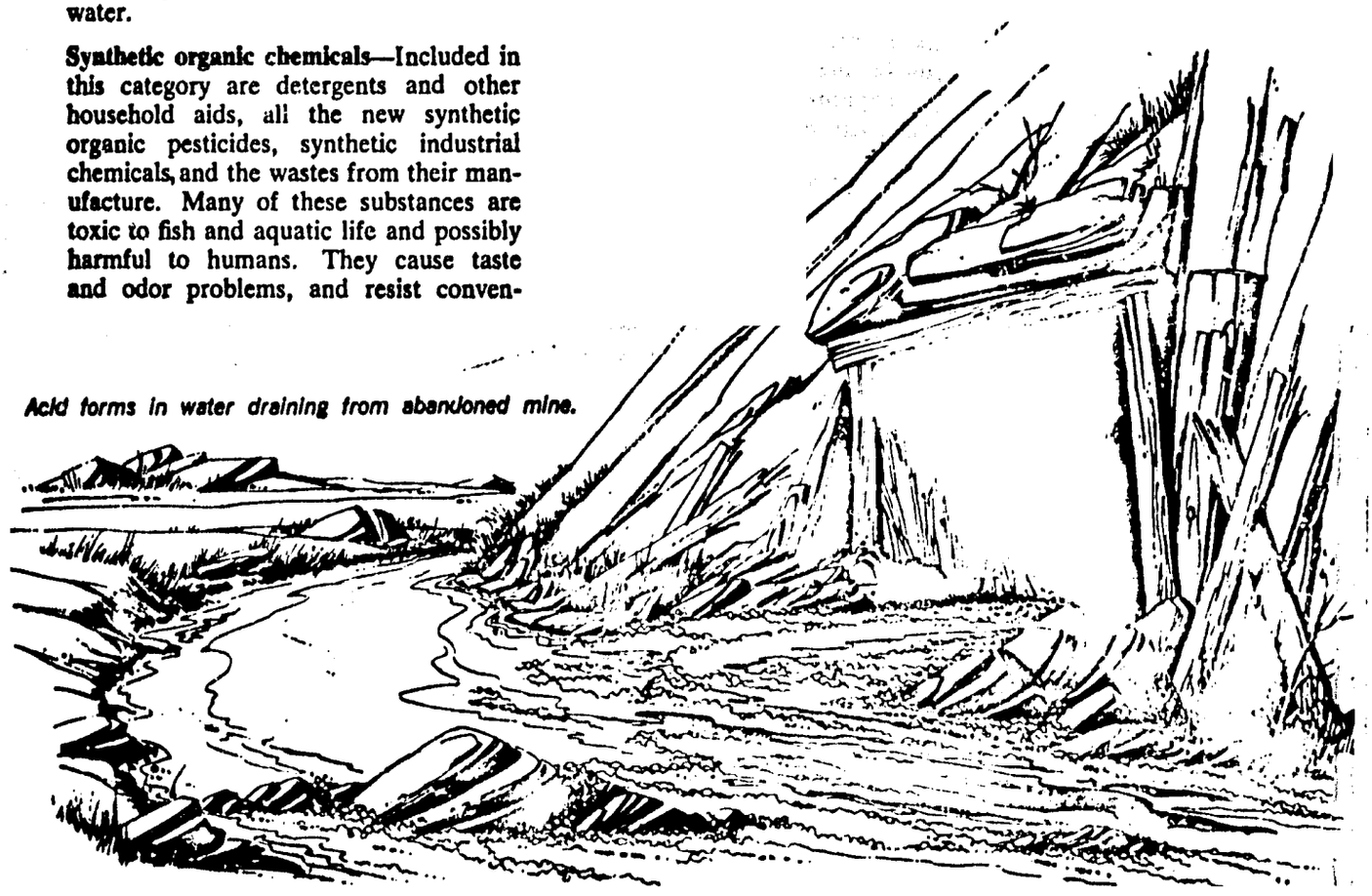


Chemicals in water from factory turn stream into bubbling mess and are difficult to remove.

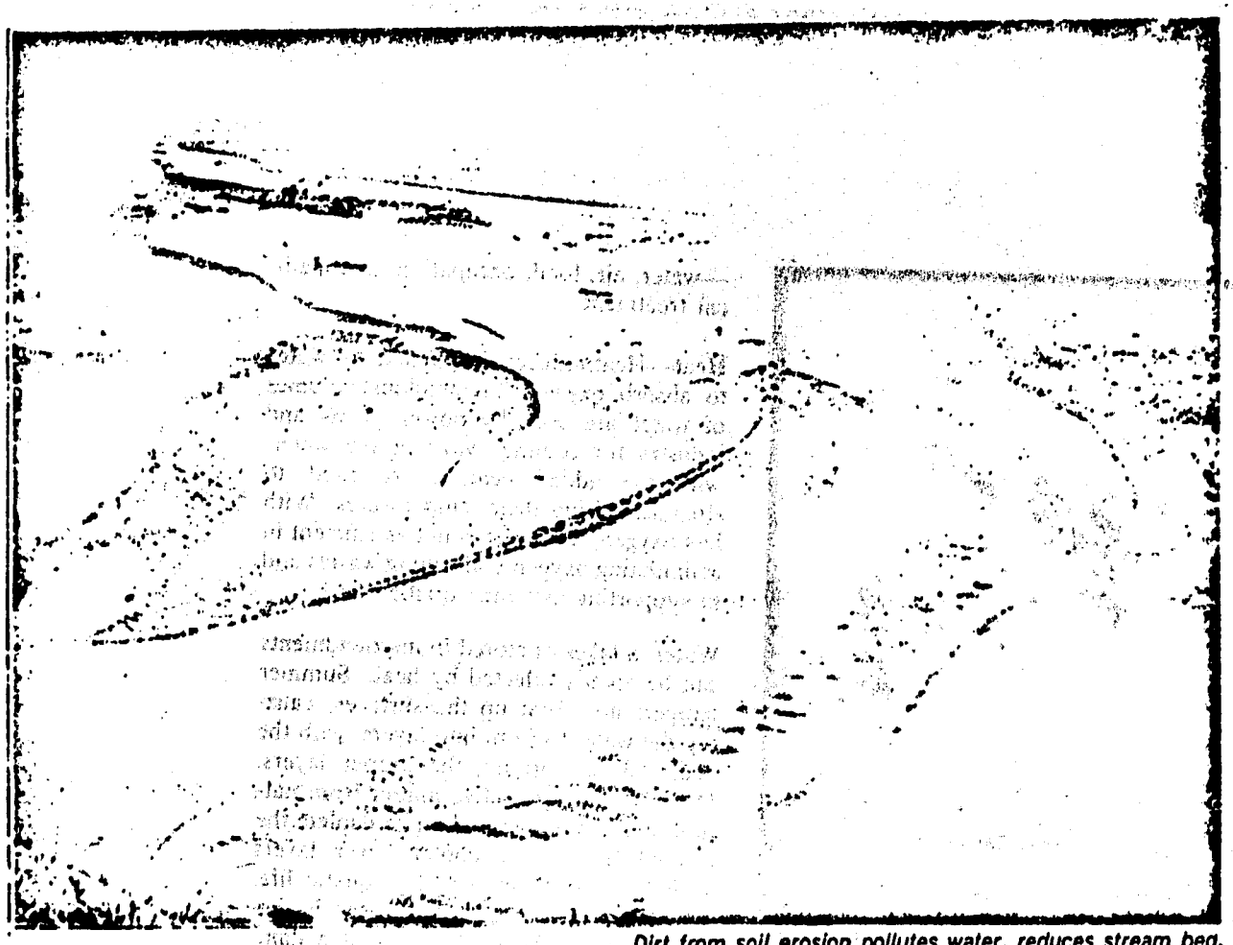
by sewage, certain industrial wastes, and drainage from fertilized lands. Biological waste treatment processes do not remove the nutrients—in fact, they convert the organic forms of these substances into mineral form, making them more usable by plant life. The problem starts when an excess of these nutrients over-stimulates the growth of water plants which cause unsightly conditions, interfere with treatment processes, and cause unpleasant and disagreeable tastes and odors in the water.

Synthetic organic chemicals—Included in this category are detergents and other household aids, all the new synthetic organic pesticides, synthetic industrial chemicals, and the wastes from their manufacture. Many of these substances are toxic to fish and aquatic life and possibly harmful to humans. They cause taste and odor problems, and resist conventional waste treatment. Some are known to be highly poisonous at very low concentrations. What the long-term effects of small doses of toxic substances may be is not yet known.

Inorganic chemicals and mineral substances—A vast array of metal salts, acids, solid matter, and many other chemical compounds are included in this group. They reach our waters from mining and manufacturing processes, oil field operations, agricultural practices, and natural sources. Water used in irrigation picks up large amounts of minerals as it filters down through the soil on its way to the nearest stream. Acids of a wide variety are discharged as wastes by industry, but the largest single source of acid in our water comes from mining operations and mines that have been abandoned.



Acid forms in water draining from abandoned mine.



Dirt from soil erosion pollutes water, reduces stream bed.

Many of these types of chemicals are being created each year. They interfere with natural stream purification; destroy fish and other aquatic life; cause excessive hardness of water supplies; corrode expensive water treatment equipment; increase commercial and recreational boat maintenance costs; and boost the cost of waste treatment.

Thousands of fish are killed each year by wastes in water that reduce oxygen supplies.

Sediments—These are the particles of soils, sands, and minerals washed from the land and paved areas of communities into the water. Construction projects are often large sediment producers. While not as insidious as some other types of pollution, sediments are a major problem because of the sheer magnitude of the amount reaching our waterways. Sediments fill stream channels and harbors, requiring expensive dredging, and they fill reservoirs, reducing their capacities and useful life. They erode power turbines and pumping equipment, and reduce fish and shellfish populations by blanketing fish nests and food supplies.

—water, air, food, occupation, and medical treatment.

Heat—Heat reduces the capacity of water to absorb oxygen. Tremendous volumes of water are used by power plants and industry for cooling. Most of the water, with the added heat, is returned to streams, raising their temperatures. With less oxygen, the water is not as efficient in assimilating oxygen-consuming wastes and in supporting fish and aquatic life.

Water in lakes or stored in impoundments can be greatly affected by heat. Summer temperatures heat up the surfaces, causing the water to form into layers, with the cooler water forming the deeper layers. Decomposing vegetative matter from natural and man-made pollutants deplete the oxygen from these cooler lower layers with harmful effects on the aquatic life. When the oxygen deficient water is discharged from the lower gates of a dam, it may have serious effects on downstream fish life and reduce the ability of the stream to assimilate downstream pollution.

Steaming hot water pollutes river.

More importantly, sediments reduce the amount of sunlight penetrating the water. The sunlight is required by green aquatic plants which produce the oxygen necessary to normal stream balance. Sediments greatly increase the treatment costs for municipal and industrial water supply and for sewage treatment where combined sewers are in use.

Radioactive substances—Radioactive pollution results from the mining and processing of radioactive ores; from the use of refined radioactive materials in power reactors and for industrial, medical, and research purposes; and from fallout following nuclear weapons testing. Increased use of these substances poses a potential public health problem. Since radiation accumulates in humans, control of this type of pollution must take into consideration total exposure in the human environment

To complicate matters, most of our wastes are a mixture of the eight types of pollution, making the problems of treatment and control that much more difficult.

Municipal wastes usually contain oxygen-consuming pollutants, synthetic organic chemicals such as detergents, sediments, and other types of pollutants. The same is true of many industrial wastes which may contain, in addition, substantial amounts of heat from cooling processes. Water that drains off the land usually contains great amounts of organic matter in addition to sediment. Also, land drainage may contain radioactive substances and pollutants washed from the sky, vegetation, buildings, and streets during rainfall.

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ADVANCED METHODS OF TREATING WASTES

These new problems of a modern society have placed additional burdens upon our waste treatment systems. Today's pollutants are more difficult to remove from the water. And increased demands upon our water supply aggravate the problem. During the dry season, the flow of rivers decreases to such an extent that they have difficulty in assimilating the effluent from waste treatment plants.

In the future, these problems will be met through better and more complete methods of removing pollutants from water and better means for preventing some wastes from even reaching our streams in the first place.

The best immediate answer to these problems is the widespread application of existing waste treatment methods. Many cities that have only primary treatment need secondary treatment. Many other cities need enlarged or modernized primary and secondary systems.

But this is only a temporary solution. The discharge of oxygen-consuming wastes will increase despite the universal application of the most efficient waste treatment processes now available. And these are the simplest wastes to dispose of. Conventional treatment processes are already losing the battle against the modern-day, tougher wastes.

The increasing need to reuse water now calls for better and better waste treatment. Every use of water—whether in home, in the factory, or on the farm—results in some change in its quality.

To return water of more usable quality to receiving lakes and streams, new methods for removing pollutants are being developed. The advanced waste treatment techniques under investigation range from extensions of biological treatment capable of removing nitrogen and phosphorus nutrients to physical-chemical separation techniques such as adsorption, distillation, and reverse osmosis.

These new processes can achieve any degree of pollution control desired and, as waste effluents are purified to higher and higher degrees by such treatment, the point is reached where effluents become "too good to throw away."

Such water can be deliberately and directly reused for agricultural, industrial, recreational, or even drinking water supplies. This complete water renovation will mean complete pollution control and at the same time more water for the Nation.

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COAGULATION—SEDIMENTATION

The application of advanced techniques for waste treatment, at least in the next several years, will most likely take up where primary and secondary treatment leave off. Ultimately, entirely new systems will no doubt replace the modern facilities of today.

The process known as coagulation-sedimentation may be used to increase the removal of solids from effluent after primary and secondary treatment. Besides removing essentially all of the settleable solids, this method can, with proper control and sufficient addition of chemicals, reduce the concentration of phosphate by over 90 percent.

In this process, alum or lime is added to effluent as it comes from the secondary treatment. The flow then passes through flocculation tanks where the chemicals cause the smaller particles to floc or bunch together into large masses.

The larger masses of particles or lumps will settle faster when the effluent reaches the next step—the sedimentation tank.

Although used for years in the treatment of industrial wastes and in water treatment, coagulation-sedimentation is classified as an advanced process because it is not usually applied to the treatment of municipal wastes. In many cases, the process is a necessary pre-treatment for some of the other advanced techniques.

ADSORPTION

After the removal of most of the solids, the next problem facing the advanced waste treatment system is to get rid of the dissolved refractory organics. As the word indicates, this is the stubborn organic matter which persists in water and resists normal biological treatment.

The effects of the organics are not too well understood, but taste and odor problems in water, tainting of fish flesh, foaming of water, and fish kills have been attributed to such materials.

Adsorption consists of passing the effluent through a bed of activated carbon granules which will remove more than 98 percent of the organics. To cut down the cost of the procedure, the carbon granules can be cleaned by heat and used again.

An improvement of the process through the use of powdered carbon is under study. Rather than pass the effluent through a bed of granules, the powdered carbon is put directly into the stream. The organics stick to the carbon and then the carbon is removed from the effluent by using coagulating chemicals and allowing the coagulated carbon particles to settle in a tank.

As would be expected, this finely ground carbon will take out even more of the refractory, or stubborn, organics. The potential widespread use of powdered carbon adsorption depends largely on the effectiveness of regenerating the carbon for use again.

Except for the salts added during the use of water, municipal waste water that has gone through the previous advanced processes will be restored to a chemical quality almost the same as before it was used.

When talking of salts in water, salt is not limited to the common kind that is used in the home for seasoning food. In waste treatment language, salts mean the many minerals dissolved by water as it passes through the air as rainfall, as it trickles through the soil and over rocks, and as it is used in the home and factory.

ELECTRODIALYSIS

Electrodialysis is a rather complicated process by which electricity and membranes are used to remove salts from an effluent. A membrane is usually made of chemically treated plastic. The salts are forced out of the water by the action of an electric field. When a mineral salt is placed in water it has a tendency to break down into ions. An ion is an atom or a small group of atoms having an electrical charge.

As an example, the two parts of common table salt are sodium and chlorine. When these two elements separate as salt dissolves in water, the sodium and chlorine particles are called ions. Sodium ions have a positive charge while chlorine ions have a negative charge.

When the effluent passes through the electrodialysis cell, the positive sodium ions are attracted through a membrane to a pole or electrode that is negatively charged. The negatively charged chlorine ions are pulled out of the water through another membrane toward an electrode with a positive charge.

With the salts removed by the action of the two electrodes, the clean water flows out of the electrodialysis cell for reuse or discharge into a river or stream.

When a typical city uses its water the amount of salts in the water doubles. Fortunately, electrodialysis can reduce the amount of salts by about one-half or more. In other words, this process returns the salt content of the water back to where it was or even better than when the city first received the water.

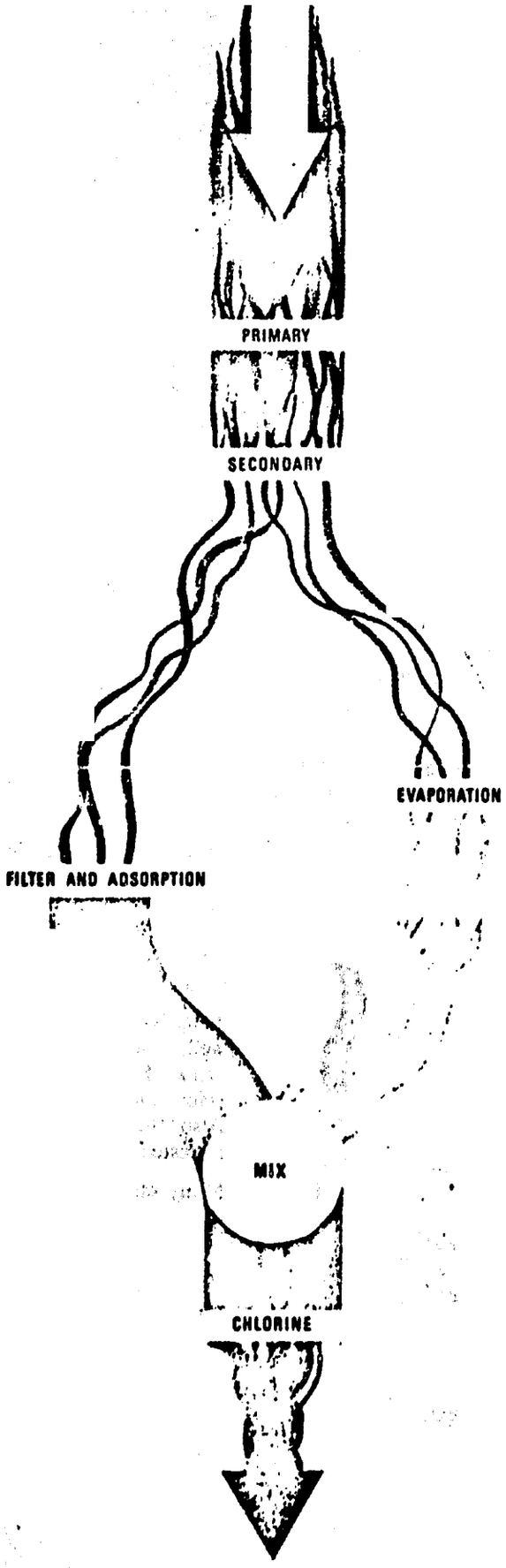
THE BLENDING OF TREATED WATER

Properly designed and applied, the methods that have been explained will be able to supply any quality of water for any reuse.

But none of these processes will stand alone. They must be used in a series or a parallel plan. In a series, all the sewage passes through all the processes, one after another, each process making a particular contribution toward improving the water. For example, the conventional primary treatment removes the material that will readily settle or float; the secondary biological step takes care of the decomposable impurities; coagulation-sedimentation, the third step, eliminates the suspended solids; carbon adsorption removes the remaining dissolved organic matter; electrodialysis returns the level of the salts to what it was before the water was used; and, finally, chlorination provides the health safety barrier against disease carriers.

Basically the same result can be achieved by separating the effluent into two streams. In this instance, all of the waste receives the primary and secondary treatment but then is divided. Part of the effluent passes through the coagulation-sedimentation and adsorption processes which remove the organic matter. The other half of the sewage is treated by evaporation and adsorption to remove all impurities including the minerals.

After going separate ways, the two



streams are mixed together, chlorinated, and then are ready for reuse or discharge into a stream. Splitting the effluent into two streams and then reblending helps reduce the cost of waste treatment for a more expensive process such as distillation.

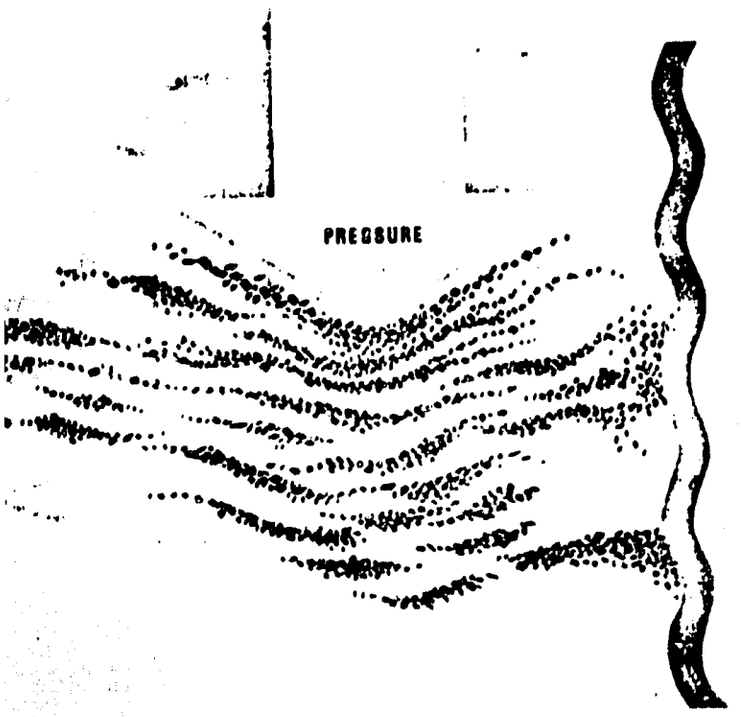
Distillation or evaporation basically consists of bringing the effluent to the boiling point. The steam or vapor produced is piped to another chamber where it is cooled, changing it back to a liquid. The unwanted minerals and other impurities remain in the original chamber.

As most people have discovered, distilled water has a flat, disagreeable taste caused by the absence of minerals and air. But by blending this pure water with water that still contains some minerals, a clean, better tasting water results. And just as importantly, the more expensive distillation process is used on only part of the effluent, and the rest of the waste water is treated by the less costly procedures.

NEW CHALLENGES FOR WASTE TREATMENT

So far, the most readily available processes that will solve most current pollution problems have been covered. But the future holds many new challenges. Scientists are still looking for the ultimate system that will do the complete job of cleaning up water, simply and at a reasonable cost.

One such possible process under study is reverse osmosis. When liquids with different concentrations of mineral salts are separated by a membrane, molecules of pure water tend to pass by osmosis from the more concentrated to the less concentrated side until both liquids have the same mineral content.



Scientists are now exploring ways to take advantage of the natural phenomena of osmosis, but in reverse. When pressure is exerted on the side with the most minerals, this natural force reverses itself, causing the molecules of pure water to flow out of the compartment containing a high salt concentration.

This means that perfectly pure water is being taken out of the waste, rather than taking pollutants out of water as is the traditional way. And this process takes clean water away from everything—bacteria, detergents, nitrates.

Tests have shown that the theory works well, resulting in water good enough to drink. Efforts are now under way to develop large membranes with long life. Also, the process and equipment need to be tested on a large scale.

Many other techniques to improve waste

treatment are under development in laboratories and in the field.

For example, special microscopic organisms are being tested for removing nitrates from waste water by reducing the nitrates to elemental nitrogen.

CHEMICAL OXIDATION

Municipal waste waters contain many organic materials only partially removed by the conventional treatment methods. Detergents are a good example. Oxidants such as ozone and chlorine have been used for many years to improve the taste and odor qualities or to disinfect municipal drinking water. They improve the quality of the water by destroying or altering the structure of the chemicals in the water.

However, the concentration of the organic materials in drinking water supplies is much less than it is in the waste-bearing waters reaching treatment plants. Until recently, the cost of the oxidants has prevented the use of this process in the treating of wastes. Now, improvements in the production and application of ozone and pure oxygen may reduce costs sufficiently to make their use practicable. When operated in conjunction with other processes, oxidation could become an effective weapon in eliminating wastes resistant to other processes.

POLYMERS AND POLLUTION

In discussing the coagulation-sedimentation process, mention was made of the use of alum or lime to force suspended solids into larger masses. The clumping together helps speed up one of the key steps in waste treatment—the separation of solids and liquids.

During the past 10 to 15 years, the chemical industry has been working on synthetic organic chemicals, known as polyelectrolytes or polymers, to further improve the separation step.

Formerly, polymers have proved effective when used at a later stage of treatment—the sludge disposal time. Sludge must be dried so that it can be more easily disposed of. By introducing polymers into the sludge, the physical and chemical bonds between the solids are tightened. When this happens, the water can be extracted more rapidly.

Wider use of polymers is now being investigated. By putting polymers into streams or rivers, it may be possible to capture silt at specified locations so that it can be removed in quantity.

If polymers are put into raw sewage, waste treatment plants may be able to combine a chemical process with the standard primary and secondary stages. And this method of removing solids can be applied immediately without lengthy and expensive addition of buildings or new facilities.

The chemicals also hold promise as a means of speeding the flow of waste waters through sewer systems, thus, in effect, increasing the capacity of existing systems.

THE PROBLEM OF WASTE DISPOSAL

No matter how good the treatment of wastes, there is always something left over. It may be the rags and sticks that were caught on the screens at the very beginning of the primary treatment. It could be brine or it could be sludge—that part of the sewage that settles to the bottom in sedimentation tanks. Whatever it is, there is always something that must be burned, buried, or disposed of in some manner.

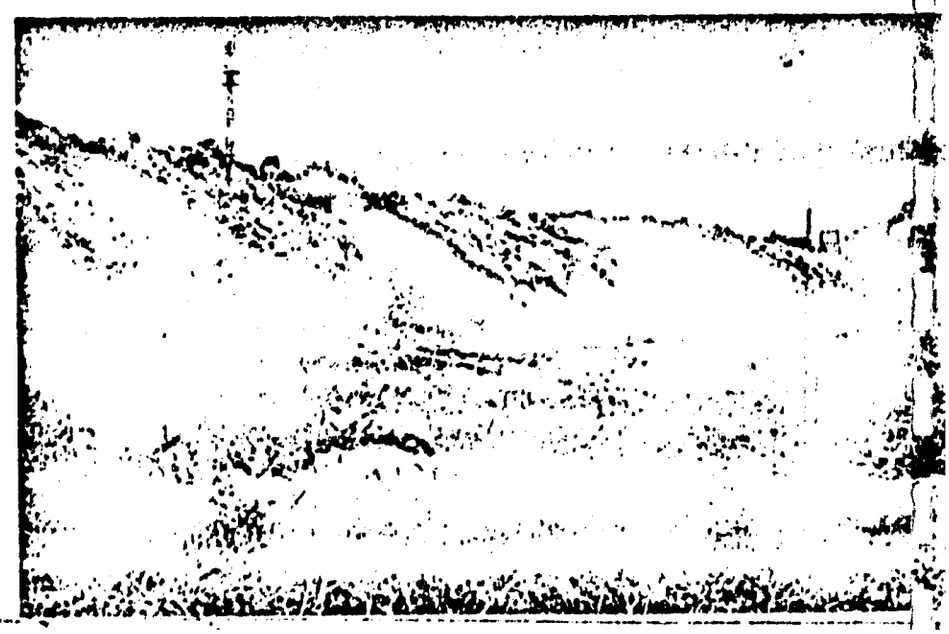
It is a twofold problem. The sludge or other matter must be disposed of to complete a city's or industry's waste treatment. And it must be disposed of in a manner not to add to or upset the rest of the environment.

If it is burned, it must be done in a way not to add to the pollution of the atmosphere. This would only create an additional burden for our already overburdened air to cope with. And air pollutants by the action of rain and wind have a habit of returning to the water, complicating the waste treatment problem rather than helping it.

There are many methods and processes for dealing with the disposal problem, which is sometimes referred to as the problem of ultimate disposal. The most common method for disposing of sludge and other waste concentrates consists of digestion followed by filtration and incineration.

The digestion of sludge takes place in heated tanks where the material can decompose naturally and the odors can be controlled. As digested sludge consists of 90 to 95 percent water, the next step in disposal must be the removal of as much of the water as possible.

Water can be removed from sludge by use of a rotating filter drum and suction. As



Sludge, solid matter left after treatment, is spread over the land to dry.

the drum rotates in the sludge, the water is pulled through the filter and the residues are peeled off for disposal. For more effective dewatering, the sludge can be first treated with a coagulant chemical such as lime or ferric chloride to produce larger solids before the sludge reaches the filter.

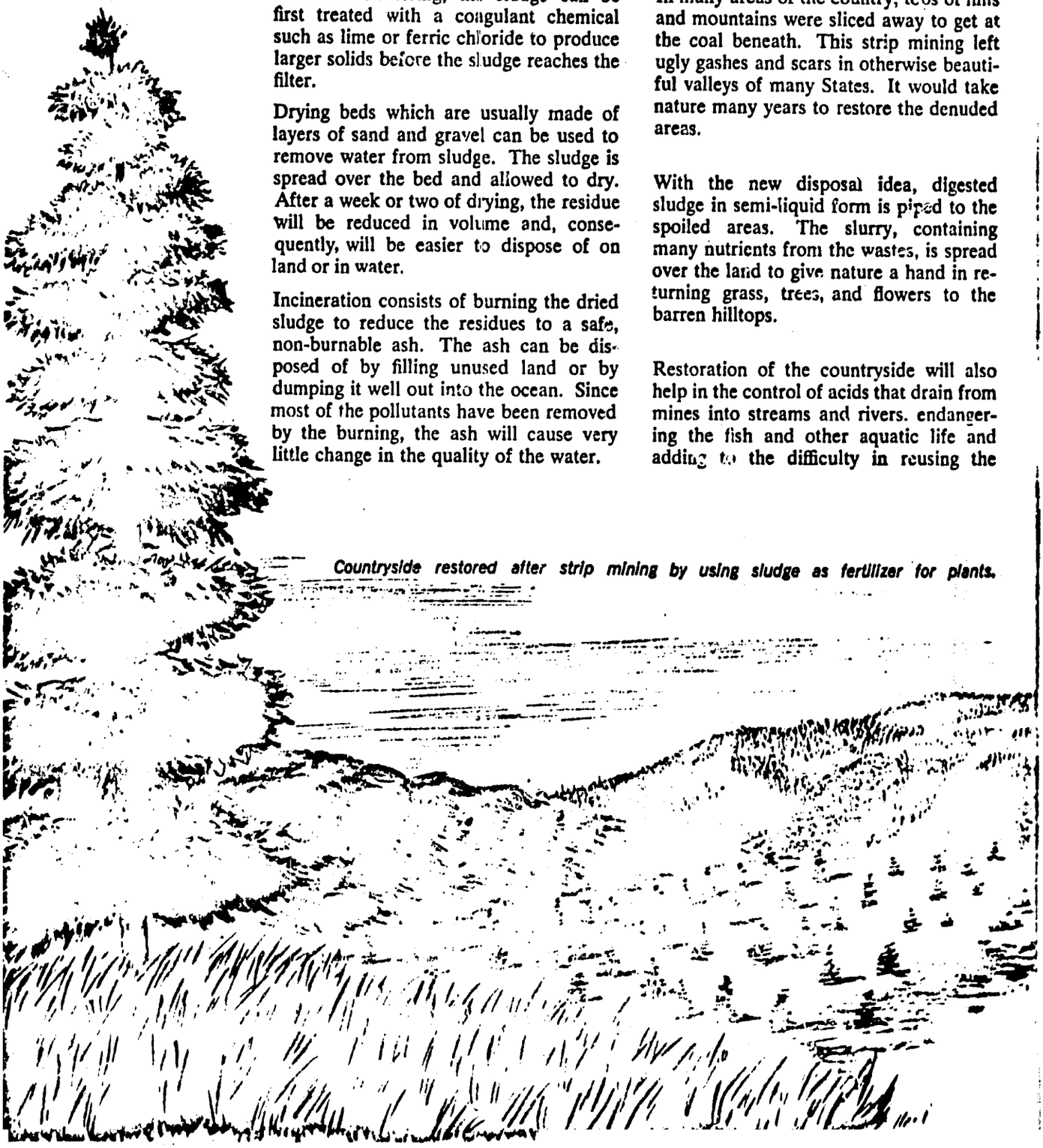
Drying beds which are usually made of layers of sand and gravel can be used to remove water from sludge. The sludge is spread over the bed and allowed to dry. After a week or two of drying, the residue will be reduced in volume and, consequently, will be easier to dispose of on land or in water.

Incineration consists of burning the dried sludge to reduce the residues to a safe, non-burnable ash. The ash can be disposed of by filling unused land or by dumping it well out into the ocean. Since most of the pollutants have been removed by the burning, the ash will cause very little change in the quality of the water.

A very promising new method of sludge disposal gets rid of the unwanted sludge and helps restore a ravaged countryside. In many areas of the country, tops of hills and mountains were sliced away to get at the coal beneath. This strip mining left ugly gashes and scars in otherwise beautiful valleys of many States. It would take nature many years to restore the denuded areas.

With the new disposal idea, digested sludge in semi-liquid form is piped to the spoiled areas. The slurry, containing many nutrients from the wastes, is spread over the land to give nature a hand in returning grass, trees, and flowers to the barren hilltops.

Restoration of the countryside will also help in the control of acids that drain from mines into streams and rivers. endangering the fish and other aquatic life and adding to the difficulty in reusing the



Countryside restored after strip mining by using sludge as fertilizer for plants.

water. Acids are formed when pyrite containing iron and sulfur is exposed to the air.

Sludge or other waste concentrates are not always costly burdens. By drying and other processes, some cities have produced fertilizers that are sold to help pay for part of the cost of treating wastes. If not sold to the public, some municipalities use the soil enrichers on park road parkways, and other public areas.

Some industries have found they can reclaim certain chemicals during waste treatment and reuse them in manufacturing or refining processes. Other firms have developed saleable by-products from residues in waste treatment.

More studies are going on to find greater use for sludge to help solve the disposal problem and to help offset the cost of waste treatment.

Sludge from paper mill removed from waste stream and dried to prevent pollution of nearby river.

Revolving drum filters water from sludge so residues can be disposed of more easily.

Common sewage treatment terminology

Activated Sludge process removes organic matter from sewage by saturating it with air and biologically active sludge.

Adsorption is an advanced way of treating wastes in which carbon removes organic matter not responsive to clarification or biological treatment.

Aeration Tank serves as a chamber for injecting air into water.

Algae are plants which grow in sunlit waters. They are a food for fish and small aquatic animals and, like all plants, put oxygen in the water.

Bacteria are the smallest living organisms which literally eat the organic parts of sewage.

BOD, or biochemical oxygen demand, is the amount of oxygen necessary in the water for bacteria who consume the organic sewage. It is used as a measure in telling how well a sewage treatment plant is working.

Chlorinator is a device for adding chlorine gas to sewage to kill infectious germs.

Coagulation is the clumping together of solids to make them settle out of the sewage faster. Coagulation of solids is brought about with the use of certain chemicals such as lime, alum, or polyelectrolytes.

Combined Sewer carries both sewage and storm water run-off.

Comminutor is a device for the catching and shredding of heavy solid matter in the primary stage of waste treatment.

Diffused Air is a technique by which air under pressure is forced into sewage in an aeration tank. The air is pumped down into the sewage through a pipe and escapes out through holes in the side of the pipe.

Digestion of sludge takes place in heated tanks where the material can decompose naturally and the odors can be controlled.

Distillation in waste treatment consists of heating the effluent and then removing the vapor or steam. When the steam is returned to a liquid it is almost pure water. The pollutants remain in the concentrated residue.

Effluent is the liquid that comes out of a treatment plant after completion of the treatment process.

Electrodialysis is a process by which electricity attracts or draws the mineral salts from sewage.

Floc is a clump of solids formed in sewage when certain chemicals are added.

Flocculation is the process by which certain chemicals form clumps of solids in sewage.

Incineration consists of burning the sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash. The ash can then be disposed of safely on land, in some waters, or into caves or other underground locations.

Interceptor sewers in a combined system control the flow of the sewage to the treatment plant. In a storm, they allow some of the sewage to flow directly into a receiving stream. This protects the treatment plant from being overloaded in case of a sudden surge of water into the sewers. Interceptors are also used in separate sanitation systems to collect the flows from main and trunk sewers and carry them to the points of treatment.

Ion is an electrically charged atom or group of atoms which can be drawn from waste water during the electrodialysis process.

Lateral sewers are the pipes that run under the streets of a city and into which empty the sewers from homes or businesses.

Lagoons are scientifically constructed ponds in which sunlight, algae, and oxygen interact to restore water to a quality equal to effluent from a secondary treatment plant.

Mechanical Aeration begins by forcing the sewage up through a pipe in a tank. Then it is sprayed over the surface of tank, causing the waste stream to absorb oxygen from the atmosphere.

Microbes are minute living things, either plant or animal. In sewage, microbes may be germs that cause disease.

Mixed Liquor is the name given the effluent that comes from the aeration tank after the sewage has been mixed with activated sludge and air.

Molecule is the smallest particle of an element or compound that can remain in a free state and still keep the characteristics of the element or compound.

Organic Matter is the waste from homes or industry of plant or animal origin.

Oxidation is the consuming or breaking down of organic wastes or chemicals in sewage by bacteria and chemical oxidants.

Oxidation Pond is a man-made lake or body of water in which wastes are consumed by bacteria. It is used most frequently with other waste treatment processes. An oxidation pond is basically the same as a sewage lagoon.

Primary Treatment removes the material that floats or will settle in sewage. It is accomplished by using screens to catch the floating objects and tanks for the heavy matter to settle in.

Pollution results when something—animal, vegetable, or mineral—reaches water, making it more difficult or dangerous to use for drinking, recreation, agriculture, industry, or wildlife.

Polyelectrolytes are synthetic chemicals used to speed the removal of solids from sewage. The chemicals cause the solids to coagulate or clump together more rapidly than chemicals like alum or lime.

Receiving Waters are rivers, lakes, oceans, or other water courses that receive treated or untreated waste waters.

Salts are the minerals that water picks up as it passes through the air, over and under the ground, and through household and industrial uses.

Sand Filter removes the organic wastes from sewage. The waste water is trickled over the bed of sand. Air and bacteria decompose the wastes filtering through the sand. The clean water flows out through drains in the bottom of the bed.

The sludge accumulating at the su face must be removed from the b periodically.

Sanitary Sewers, in a separate sy tem, are pipes in a city that car only domestic waste water. Tl storm water runoff is taken ca of by a separate system of pipes

Secondary Treatment is the secor step in most waste treatment sy tems in which bacteria consume tl organic parts of the wastes. It accomplished by bringing the sev age and bacteria together in tric ling filters or in the activat sludge process.

Sedimentation Tanks help remo solids from sewage. The waste w ter is pumped to the tanks whe the solids settle to the bottom float on top as scum. The scum skimmed off the top, and solids c the bottom are pumped out sludge digestion tanks.

Septic Tanks are used to treat d mestic wastes. The undergroun tanks receive the waste water d rectly from the home. The ba teria in the sewage decomposes tl organic waste and the sludge se tles on the bottom of the tan The effluent flows out of the tan into the ground through drains. Tl sludge is pumped out of the tank usually by commercial firms, at re ular intervals.

Sewers are a system of pipes th collect and deliver waste water t treatment plants or receivin streams.

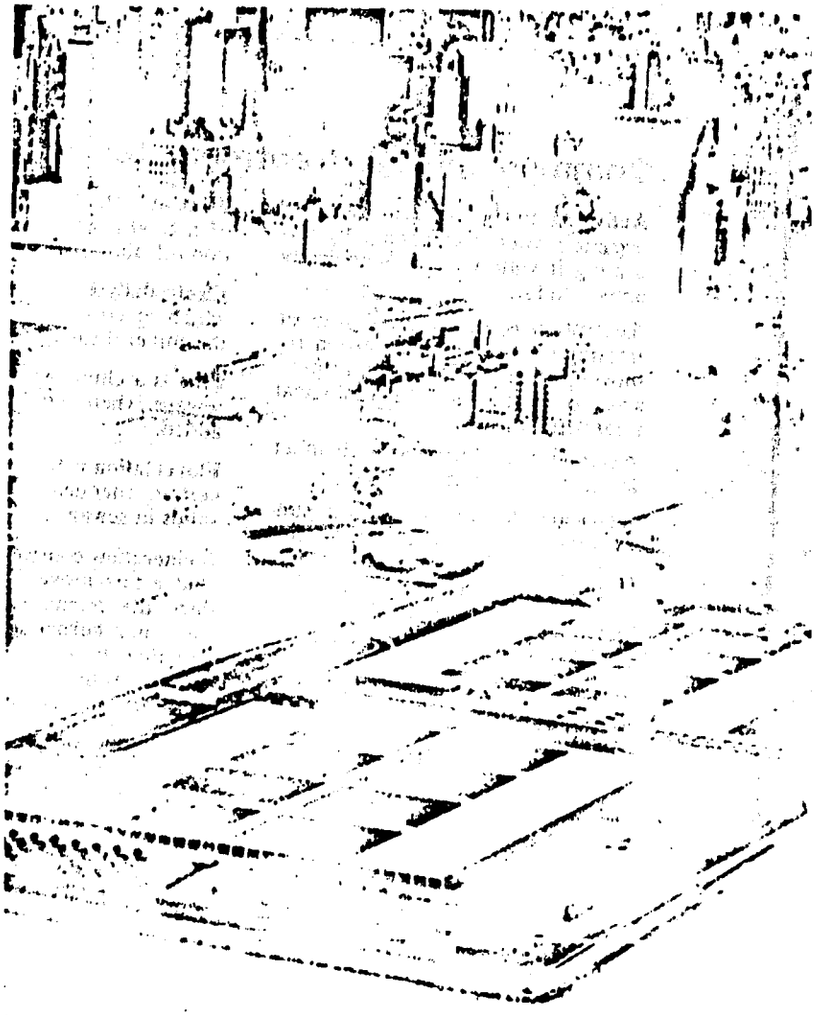
Sludge is the solid matter that se tles to the bottom of sedimentatio tanks and must be disposed of b digestion or other methods to com plete waste treatment.

Storm Sewers are a separate systen of pipes that carry only runoff from buildings and land during storm.

Suspended Solids are the wastes th will not sink or settle in sewag

Trickling Filter is a bed of rock or stones. The sewage is trickle over the bed so the bacteria ca break down the organic waste The bacteria collect on the stone through repeated use of the filte

Waste Treatment Plant is a serie of tanks, screens, filters, and othe processes by which pollutants ar removed from water.



Screening waste treatment plant that serves part of Chicago.

As the Nation's principal conservation agency, the Department of the Interior has responsibilities for water, fish and wildlife, mineral, land, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wise use of all our resources so each can make its full contribution to a better United States—now and in the future.

Prepared by the Office of Public Information
Federal Water Pollution Control Administration

OCEAN OUTFALL DISPOSAL SYSTEMS

Donald L. Feuerstein, Ph.D.*

Submarine outfall disposal systems have been used in a number of areas of the world effectively, and successfully, to dissipate wastewater constituents in a receiving environment. Initial development and use of large submarine outfalls occurred on the West Coast of the United States, particularly in southern California, due propably to a combination of favorable or compelling conditions. Large human populations were concentrated on the coast, the ocean provided the only available receptor for wastewaters, and there was a need to maintain an acceptable bacterial quality of the beach areas.

Because the bathymetry of the West Coast allows attainment of substantial wastewater discharge depths reasonably close to shore (e.g., in Santa Monica Bay, 18 m [60 ft] of depth occurs about one statute mile from shore) that are not equalled on the East Coast (e.g., in Onslow Bay, 18 m of depth occurs more than 13 statute miles from shore), it has been assumed by many that major submarine outfall disposal systems would not be cost-effective on the East Coast, and, as such, few exist. In view, however, of the increasing awareness of the necessity to provide for the most cost-effective and environmentally sound water quality control systems, the efficacy of submarine outfall disposal systems for East Coast conditions requires reexamination.

The objective of an ocean outfall, or for that matter any disposal system, is to reduce or eliminate any adverse effects of wastewater discharges on the receiving environment. This objective is accomplished with a submarine outfall system by effecting the necessary dilution in the immediate vicinity of the discharge with a diffuser section and by locating the diffuser section an appropriate distance from areas of special concern.

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*Associate, Engineering-Science, Inc., 600 Bancroft Way, Berkeley, California 94710

Of the various mechanisms which cause the diminution of discharged wastewater constituents in receiving waters, dilution and disappearance are the two most important ones. Dilution *per se* occurs as a result of two distinct mechanisms. The first is the so-called jet, or initial, dilution which occurs in the immediate vicinity of the diffuser section or point of discharge and which extends to some level in the receiving water above the discharge. The area extending upward to this level is referred to as the initial mixing zone. The second mechanism which causes a dilution of the waste in the receiving water is that which occurs as a result of lateral dispersion, or diffusion. This is a mechanism, very similar to molecular diffusion, which occurs as the wastes are transported away from the initial mixing zone by the receiving water currents.

The second mechanism for diminution of wastewater constituents, at least for the nonconservative wastewater constituents, is disappearance, or decay, whereby the particular nonconservative constituent disappears with time due to any number of factors, such as sedimentation, chemical conversion, or bacterial die-away. These, then are the three principal mechanisms for diminution of the wastes in the environment which must be considered in the rational design of a submarine outfall disposal system.

Because most outfall disposal systems discharge predominantly municipal wastes into the marine environment, which is a salt-water environment, the discharged wastes are generally of lesser salt content than the waters into which they are being discharged. In addition, the municipal wastes are generally warmer than the receiving waters. These two factors cause the discharged waste, upon entering the receiving waters, to rise above the discharge point or diffuser and disperse in the initial mixing zone as a result of buoyant and momentum forces.

A schematic of a rising wastewater plume is shown in Figure 1. At some point in the water column over the port or diffuser, the wastewater-seawater mixture will achieve the same density as the receiving water and thereafter will have no further tendency to rise. Moreover, if the rising wastewater-seawater plume encounters a pycnocline, which is a pronounced density gradient, it will generally rise no further because of insufficient energy in the rising plume to penetrate the pycnocline and because the rising plume would then be surrounded by water of much lesser density.

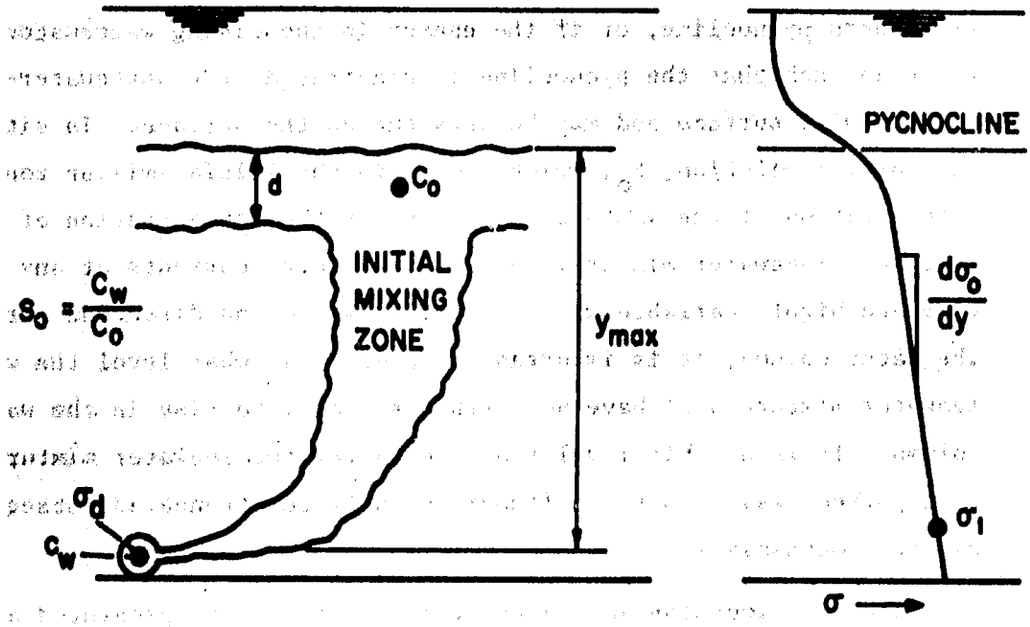

FIGURE 1
DEFINITION SKETCH OF RISING WASTEWATER
SEAWATER PLUME

Pycnoclines, generally about ten meters in depth, are quite common in coastal waters and result from a well-mixed upper layer caused by action of the wind and waves on the ocean surface. Figure 1 represents a situation in which the rising wastewater-seawater plume encounters a pycnocline, resulting in a so-called submerged field. The submerged field is a desirable feature because not only will the discharged wastewater be invisible from a nonsubmerged vantage point but the floatables and other materials in the wastewater which have a tendency to concentrate at the interface, or at the top of this mixed wastewater-seawater zone, will have no tendency to surface and create nuisances. If there is no pronounced pycnocline, or if the energy in the rising wastewater-seawater plume is such that the pycnocline is penetrated, the wastewater-seawater mixture will surface and may be apparent on the surface. In either case, the initial dilution, S_o, which occurs in the initial mixing zone, is the concentration of the wastewater divided by the concentration of the wastewater-seawater mixture. Because the ocean currents at any given time are highly variable with respect to speed and direction throughout the water column, it is important to predict at what level the wastewater-seawater mixture will have no further tendency to rise in the water column. It is at this level that the wastewater-seawater mixture will be transported away from the diffuser and will be attenuated subsequently by other mechanisms.

The relationships and calculations that will be presented are based on the dilution of soluble material and are not applicable to the dilution or dispersion of materials which are only slightly dispersed, such as floatable or particulate matter. It must be emphasized that these relationships do not apply if one is concerned about concentrations of floatable or particulate matter at the surface. Historically, the primary concern has been the resulting concentration of coliform bacteria or pathogens at some point in the receiving water. Because coliform organisms react as a soluble or dissolved substance in the immediate vicinity of the discharge, they can be treated as dissolved substances.

The maximum height, y_{max}, achieved by the rising wastewater-seawater plume above the diffuser can be estimated using the following equation:

$$y_{max} = \left\{ \frac{610\, q_o (\sigma_1 - \sigma_d)}{\sqrt{g} \left[\frac{d\sigma_o}{dy} \right]^{3/2}} \right\}^{1/3} \qquad (1)$$

y_{max} = maximum height of plume above diffuser, m

q_o = discharge per linear meter of diffuser, cu m/sec-m

σ_1 = density of ocean water at level of source

σ_d = density of wastewater

$\frac{d\sigma_o}{dy}$ = density gradient, 1/m

g = acceleration due to gravity, m/sq sec

The appropriate densities and density gradient for use in the expression are shown on Figure 1. Inspection of Equation 1 reveals that the only variable available to the designer of the ocean outfall which influences the maximum height of plume above the diffuser is the term q_o, which is the rate of wastewater discharge per length of diffuser. Thus, within any particular area of wastewater discharge (where seawater densities and density gradients are relatively constant with respect to specific location, and for a specified wastewater flow rate), the maximum height of plume rise is dependent only upon the length of the diffuser section.

The initial dilution, S_o, occurring near the top of the rising wastewater-seawater plume, can be estimated from the relationship shown in the following equation:

$$S_o = \frac{0.41\, g^{1/6} (\sigma_1 - \sigma_d)^{2/3}}{q_o^{1/3} \left[\frac{d\sigma_o}{dy} \right]^{1/2}} \qquad (2)$$

It can be observed that again the only variable available to the designer is q_o, which is the wastewater discharge flow rate per length of diffuser. The other variable factors (density of wastewater, density of ocean water at the level of discharge, and the appropriate density gradient) are generally beyond the control of the designer.

The relationships shown by Equations 1 and 2 were developed for the case of a continuous discharge into a quiescent receiving body of water. As such, they are not exactly applicable to the very dynamic marine environment where there exists a continual mass transport of water past any particular location. On the basis of mass conservation considerations, the maximum initial dilution can be estimated using the following expression:

$$S_o = \frac{u\ b\ d}{Q} \tag{3}$$

u = effective current speed, m/s

b = diffuser length, m

d = mixing depth, m

Q = wastewater discharge rate, cu m/sec

This simple expression indicates that the maximum initial dilution occurring in the initial mixing zone is a function of the effective current speed perpendicular to the diffuser, the length of the diffuser, the mixing depth, and the wastewater discharge rate. Once again, this equation demonstrates that, with the exception of relocating to a point of more favorable current speed or into an area of more favorable mixing depth, the only variable available to the designer is the diffuser length.

Following the initial dilution that occurs in the immediate vicinity of the diffuser, the wastewater-seawater mixture will be transported away from the initial mixing zone by the ocean currents. This transport is accompanied by another dilution mechanism, namely, lateral dispersion. An idealized sketch of a laterally dispersing wastewater plume originating from the diffuser section is shown in Figure 2. As the wastewater of concentration C_o is transported away from the diffuser section, it decreases in concentration due to dilution effected by horizontal dispersion. For the idealized case, the maximum wastewater concentration at any distance from the diffuser will occur at the center-line of the plume, as shown in Figure 2. C_o is the concentration of wastewater over the diffuser following initial dilution, and S_{dif} is the minimum dilution effected by horizontal dispersion at some specified point downstream.

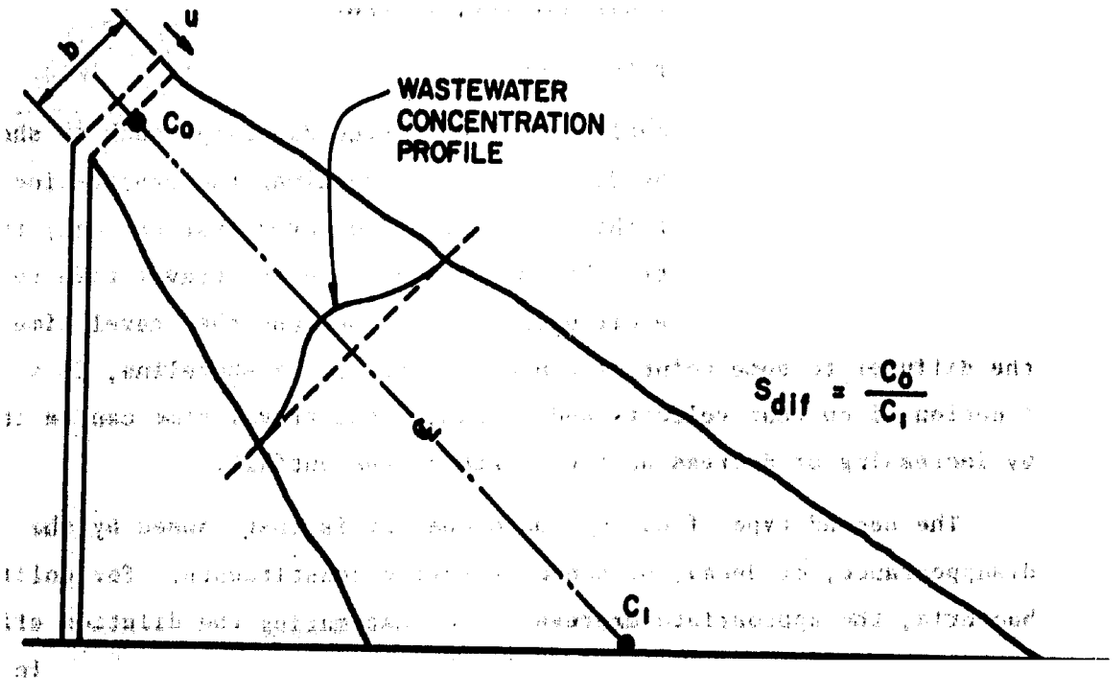

FIGURE 2
DEFINITION SKETCH OF HORIZONTALLY DISPERSING
WASTEWATER - SEAWATER PLUME

The minimum dilution due to horizontal dispersion, S_{dif}, can be determined from the following expression:

$$S_{dif} = \left\{ \text{erf} \sqrt{\frac{1.5}{\left[1 + \frac{8\,a\,t}{b^{2/3}}\right]^3 - 1}} \right\}^{-1} \qquad (4)$$

t = minimum travel time, hr

a = coefficient of diffusivity, $m^{2/3}/hr$

erf = standard error function

This expression is applicable to a line source discharge such as shown in Figure 2. It provides the dilution occurring along the center-line of the plume. Inspection of this expression indicates that the only two variables subject to control by the designer are the travel time to the point of interest and the diffuser length. Because the travel time from the diffuser to some point of concern, such as the shoreline, is a function of current velocity and distance, the travel time can be changed by increasing or decreasing the length of the outfall.

The second type of diminution mechanism is that caused by the disappearance, or decay, of nonconservative constituents. For coliform bacteria, the appropriate expression for estimating the dilution effected by bacterial disappearance, S_{dis}, is the simple expression shown in the following equation:

$$S_{dis} = 10^{t/T_{90}} \qquad (5)$$

T_{90} = time required for 90 percent disappearance of coliform bacteria, hr

From this expression it can be seen that the only variable available to the designer of the disposal system is the minimum travel time, which is a function of the length of the outfall and the appropriate ocean current velocity.

The relative importance of the three diminution mechanisms for various outfall lengths, associated diffuser depths, and T_{90} values is shown in Table 1. These values have been calculated for a wastewater

Table 1

RELATIVE MAGNITUDES OF DIMINUTIONS EFFECTED BY SUBMARINE OUTFALL DIFFUSER SYSTEM[a]

Distance from Diffuser		Depth of Diffuser[b]		Dilution Factor			
				Initial Dilution[c]	Horizontal Dispersion[d]	Disappearance	
km	miles	m	ft			T_{90} = 1 hr	T_{90} = 4 hr
0.5	0.31	5.5	18.0	5.00×10^1	1.98	3.49×10^1	2.40
1.0	0.62	7.3	24.0	6.60×10^1	3.85	1.22×10^3	5.74
2.0	1.24	9.1	29.9	8.30×10^1	8.06	1.49×10^6	3.31×10^1
3.0	1.86	11.0	36.1	9.10×10^1	1.33×10^1	1.82×10^9	1.91×10^2
5.0	3.11	13.7	44.9	1.00×10^2	2.62×10^1	2.71×10^{15}	6.26×10^3
10.0	6.21	16.5	54.1	1.03×10^2	6.90×10^1	7.32×10^{30}	3.94×10^7

[a] Wastewater discharge rate = 0.33 m^3/sec (7.5 mgd); diffuser length = 100 m (328 ft).
[b] Onslow Bay, North Carolina.
[c] Effective current velocity = 3 cm/sec (0.058 knot).
[d] Horizontal current velocity = 9 cm/sec (0.17 knot); horizontal diffusivity = 0.010 $cm^{2/3}$/sec (0.0010 $ft^{2/3}$/sec).

discharge rate of 0.33 m^3/sec (7.5 mgd); a horizontal diffusivity of 0.010 $cm^{2/3}$/sec (0.0010 $ft^{2/3}$/sec), which is a general oceanic average; a diffuser length of 100 m (328 ft); an effective current velocity over the diffuser of 3 cm/sec (0.058 knot); and a transport current velocity of 9 cm/sec (0.17 knot). Looking at the values listed in the column under T_{90} = 1 hour, a relatively small increase in distance results in a very large increase in total dilution. A T_{90} value of one hour is quite typical of values observed in warm waters around the world, such as the waters in the vicinity of Acapulco Bay, Mexico; Rio de Janeiro, Brazil; Puerto Rico; and the Hawaiian Islands. As one proceeds northerly into colder waters, T_{90} values increase. Values along the California coast, for example, are observed to be nearer two to three hours. To consider the relative effect of T_{90} value at a fixed distance of two kilometers, for example, it is apparent from Table 1 that increasing the T_{90} value by a factor of four, from one to four hours, results in a reduction in total dilution of five orders of magnitude, or from a factor of 10^6 to only 10^1. Therefore, the T_{90} value employed in the design of submarine wastewater disposal systems is quite critical in determining the required length and location of the outfall.

It is apparent from Table 1 that the diminution resulting solely from horizontal dispersion is small in relation to other dispersing mechanisms. For example, increasing the distance from the diffuser or the length of outfall from 0.5 km to 10 km results in an increase in total dilution from two to 69. Dilutions on the order of 50 to 100 can be achieved in the initial mixing zone by proper diffuser design.

Although a high dilution of wastewater can be achieved with a submarine outfall disposal system, the other major functional component of the wastewater management system, namely, wastewater treatment, must not be overlooked in determining the most cost-effective system. For a given wastewater characteristic and receiving environment quality objective, there is usually a variety of wastewater treatment and disposal systems that can be integrated to provide comparable results.

In general, an increasing level of treatment or pollutant removal can be matched with a decreasing dilution capacity of the disposal facility to satisfy the same receiving water quality objectives. Because

the costs, as well as the overall environmental effects, of the various candidate systems will differ, a careful consideration and evaluation of the overall wastewater management system must be undertaken if the most economical and environmentally acceptable treatment and disposal system is to be provided.

There is available a fairly large array of processes, representing a wide range of pollutant removal efficiencies, from which to select a treatment process train that can achieve a desired level of treatment or wastewater constituent removal. With respect to disposal of wastewaters into the marine environment, the wastewater parameters of potential concern can be grouped into several generic categories. These are settleable solids, suspended solids, floatables, oxygen-demanding substances, temperature, pH, nutrients, toxic metals, toxic organic compounds, and bacteria or other infectious agents. The magnitude of one or more of these groups of pollutants, depending upon the particular characteristics of the wastewater and the receiving environment, will usually define the necessary design criteria and configuration of the treatment and disposal system.

In addition, other existing and anticipated factors should be taken into account in the functional design of treatment and disposal systems. There appears to be a trend developing for more complete treatment of wastewaters, with little or no subsequent dilution required of the disposal system, because of the increasing desirability and need in many parts of the world for wastewater reuse. Selection of more complete treatment has associated with it, however, several factors which require careful consideration.

One factor is an increase in waste solids requiring disposal due to the use of additive chemicals, such as alum or lime, and to the greater removals of both soluble and insoluble wastewater constituents. The costs of processing and disposing of these waste solids can be large, and the environmental effects of disposing of these materials on land can be quite adverse without proper precautions.

Other factors associated with more complete treatment are increased process unreliability, higher frequency of operational upset, and the need for greater knowledge and sophistication on the part of operating

personnel. As the treatment process train becomes more extensive and complex, its reliability for providing the required level of treatment generally lessens due to a greater need for careful process control and an increase in the number of operations and equipment that can fail or malfunction. An adequate disposal system can provide the necessary immediate dilution to greatly reduce the environmental effects and risks of such occurrences.

Staged implementation is another important factor to be considered in the selection and design of a wastewater treatment and disposal system. Disposal systems, and particularly submarine outfalls, are usually sized for ultimate flow conditions at the end of useful life, which is normally 30 to 50 years. Therefore, the conduit is oversized for most of its useful life, resulting in necessarily high capitalization costs. Treatment plants, however, can be more readily staged to produce an overall higher use factor over the entire planning period, a more equitable distribution of capital costs, and a certain flexibility to respond to unforeseen future changes in wastewater characteristics, water quality objectives, and public attitudes. Disposal systems, on the other hand, have relatively low recurring costs, whereas treatment systems have relatively high recurring costs for labor, power, chemicals, maintenance, and replacement.

In general, treatment and disposal systems that rely primarily on the disposal system for effecting the major diminution or attenuation of controlling pollutants have the relative advantage of possessing high degrees of wastewater dilutions, low recurring costs, and great reliability. Treatment and disposal systems that rely primarily on the treatment system for reducing pollutant concentrations in the environment have the relative advantage of providing specificity of particular pollutant diminution, of reducing the pollutant emission rate, and of providing flexibility to respond to unforeseen future changes.

In conclusion, considerations of the phenomenological aspects of dilution effected by submarine outfall disposal systems, local oceanographic conditions, and an ever increasing demand to lessen the environmental effects of wastewater discharges indicate that submarine outfall disposal systems on the East Coast could be cost-effective and should be given careful evaluation.

BEEF CATTLE WASTE MANAGEMENT ALTERNATIVES

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Prepared by

A. V. Allen, Extension Animal Husbandry
B. L. Carlile, Soil Scientist
S. H. Dobson, Extension Agronomist
L. B. Driggers, Extension Biological and Agricultural Engineer
J. M. Falter, Extension Entomologist
*G. J. Kriz, Extension Biological and Agricultural Engineer
J. F. Lutz, Soil Scientist
J. A. Phillips, Extension Soil Scientist
C. R. Shumway, Extension Economist
R. E. Sneed, Extension Biological and Agricultural Engineer
R. C. Wells, Extension Economist

*Coordinator

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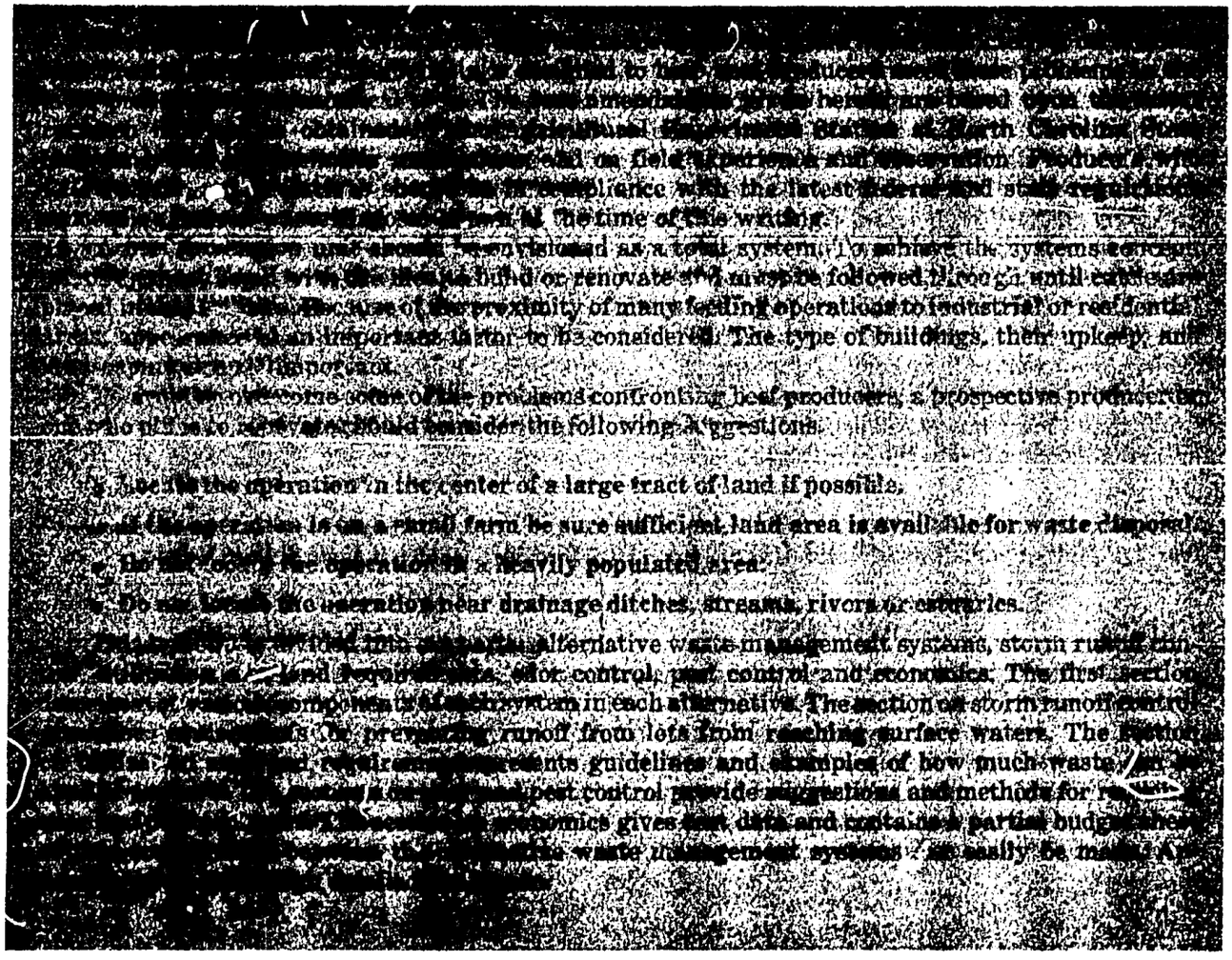
Circular 571 March 1974

Beef Cattle Waste Management Alternatives



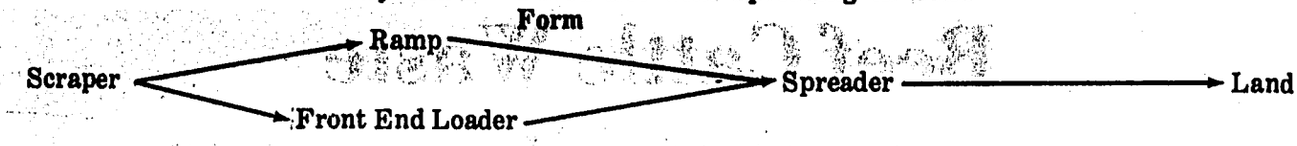
ALTERNATIVE WASTE MANAGEMENT SYSTEMS

Large concentrations of beef cattle in paved or dirt lots is not a common practice in North Carolina but this situation is changing because of feeding practices now employed. Therefore, the producer must be made aware of potential waste management problems associated with the various production schemes.

Removing the manure from the paved area or dirt lot is only a beginning minor step in the total waste management system. Other factors to be considered in the system are collection, storage, treatment and ultimate disposal on the land. Each of these must be done in a manner compatible with good environmental control including pests, odors, soil and water pollution, and good soil and crop management systems.

To date, most waste management systems ultimately return the manure to the land. Depending on the system selected, there may be a storage or detention period between cleaning the lots and land disposal. Care must always be taken to prevent any waste or waste water from [illegible]ching the surface waters of the state and violati[illegible] the water quality standards assigned to those waters.

System I Paved Lot with Spreading in Solid Form



Handling manure in a solid form on a daily basis is not appealing to many beef cattle producers because of frequency of disposal even though there are other considerations such as weather, land availability, odor and proximity of neighbors. Tractor mounted scrapers deposit manure into piles where it is picked up with a tractor mounted loader and deposited in a spreader.

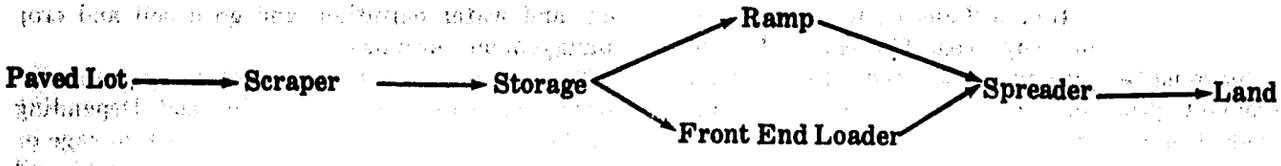
The daily manure production, feces and urine, per 1000 pounds (lb) of body weight is approximately 64 lb or 1 cubic foot (cu ft). Table 1 shows the quantity of manure produced daily by different size herds of 1000-lb cattle and the number of spreader loads required to remove it daily. For 500-lb cattle, the quantity would be approximately one-half that shown in the table. When the waste handling is integrated into the planned production activities, associated problems are minimized with frequent handling. On the other hand, serious problems can arise and the chore becomes disillusioning when manure is allowed to accumulate. This problem is further aggravated as the numbers of animals increase.

Field spreaders are available as tractor drawn or truck mounted units. Flail type tank spreaders will hold either liquids or solids and have either a side or rear discharge. A spreader with beaters should have a rear gate, preferably hydraulically operated, that can be opened and closed from the tractor seat. Select a spreader that will not leak the contents along the road and that will spread the material in small pieces on the land surface so that fly breeding is minimized.

Table 1. Daily Production of Solid Manure from Different Size Herds of 1000-lb Beef Cattle

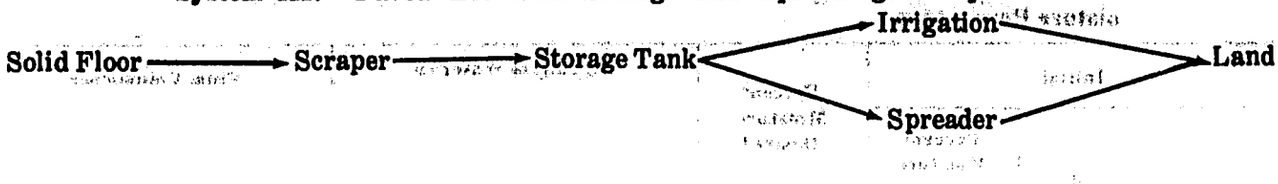
Number of Cattle	Daily Production T	Daily Spreader Loads	
		108 bu spreader	180 bu spreader
10	0.8	0.1	0.1
25	0.8	0.3	0.2
50	1.6	0.6	0.4
100	3.2	1.1	0.7
250	8.0	2.7	1.6
500	16	5.3	3.2
1,000	32	10.6	6.4
2,000	64	21.2	12.8
5,000	160	53.4	32
10,000	320	107	64

System II: Paved Lot with Storage and Spreading in Solid Form



This system usually has short term storage between the time of collection and land spreading. An area with a capacity of 0.8 cubic foot (cu ft) per animal per day located adjacent to the ramp or pick-up area is required for temporary storage. A shelter over the storage area is desirable to keep rain and snow from mixing with the manure.

System III: Paved Lot with Storage and Spreading in Liquid Form



Manure handled by this system is scraped from the paved areas directly into the storage tank. The size of the tank is dependent upon the number of cattle and the frequency of spreading as shown in Table 2. The volume of storage in Table 2 is based on a production rate of 1.5 cu ft per 1000-lb animal per day.

Table 3 gives the storage capacity per foot of length for tanks with different widths and depths. This table along with Table 2 will enable the producer to determine the tank size required to store liquid manure.

Water must be added to the storage tank to bring the waste to a pumpable consistency. Table 4 shows the approximate quantity of water needed to increase the moisture content of the manure. An approximate range of moisture in manures without bedding is as follows:

75-82% moisture—stiff
80-85% moisture—fluid or semi-liquid—quite thick slurry
85-90% moisture—liquid—fairly thin liquid at 90%
93-97% moisture—irrigation consistency

Table 2. Gallons of Storage Required for 1000-lb Beef Cattle by Days of Storage and Herd Size

Number of Beef Cattle	Days of Storage					
	16	30	45	60	75	90
	Gallons					
10	1,125	3,375	5,060	6,750	8,440	10,100
25	2,813	8,450	12,650	16,900	21,100	25,300
50	5,625	16,900	25,300	33,800	42,200	50,600
100	11,250	33,750	50,600	67,500	84,400	101,000
250	28,125	84,500	126,500	169,000	211,000	253,000
500	56,250	169,000	253,000	338,000	422,000	506,000
1,000	112,500	337,500	506,000	675,000	844,000	1,010,000
2,000	225,000	675,000	1,010,000	1,350,000	1,685,000	2,020,000
5,000	562,500	1,690,000	2,530,000	3,380,000	4,220,000	5,060,000

Table 3. Storage Tank Capacity per Foot of Length

Tank Width Ft	Tank Depth Ft		
	6	8	10
	Gal/Ft of Length		
12	540	720	900
14	630	840	1050
16	720	960	1200
18	810	1080	1350
20	900	1200	1500
22	990	1320	1650
24	1080	1440	1800

Table 4. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Initial			Percent Moisture Desired	Amount of Water to be Added to Each Cu Ft to Give the Desired Percent Moisture		Final Volume per Each Original Cu Ft	
Volume		Percent Moisture					
Cu Ft	Gal			Cu Ft	Gal	Cu Ft	Gal
1.0	7.5	85	90	0.50	3.75	1.50	11.25
			95	2.00	15.00	3.00	22.50
1.0	7.5	80	85	0.33	2.50	1.33	10.00
			90	1.00	7.50	2.00	15.00
			95	3.00	22.50	4.00	30.00
1.0	7.5	75	80	0.25	1.88	1.25	9.38
			85	0.67	5.00	1.67	12.50
			90	1.50	11.25	2.50	18.75
			95	4.00	30.00	5.00	37.50
1.0	7.5	70	75	0.20	1.50	1.20	9.00
			80	0.50	3.75	1.50	11.25
			85	1.00	7.50	2.00	15.00
			90	2.00	15.00	3.00	22.50
			95	5.00	37.50	6.00	45.00

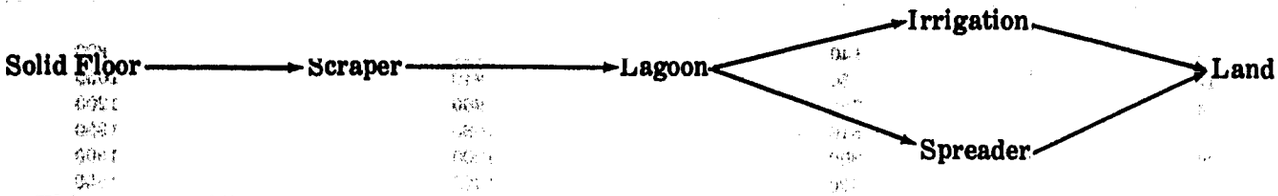
It is evident from Table 4 that the amount of water added to produce a pumpable slurry might be more than the original quantity of manure. For example, the addition of 11.25 gallons (gal) of water to 1 cu ft of fresh manure at 75% moisture raises the moisture content to 90% and changes the volume from 1 cu ft to 2.5 cu ft.

A storage tank requires an agitator or pump-agitator which serves the dual role of agitating and filling the spreader tank. One distinct disadvantage with liquid manure storage is odor while agitating and field spreading. The liquid slurry should not be spread on a hot humid (muggy) day because odors may create a nuisance.

Where odor is a problem, the producer might elect to equip his spreader with a soil injector. This equipment places the liquid slurry 4 to 6 inches (in.) below the ground surface and covers it immediately, drastically reducing odor. Care must be exercised to select a field that is relatively free of large stones, stumps and roots when the injection method is used.

Because of the high cost of a liquid storage tank, this system of waste management will probably not be used extensively. However, it can be combined with a solids handling system with the storage tank being used only when it is not feasible to go directly from the lot to the land.

System IV: Paved Lot with Lagoon and Irrigation



This system differs from System III in that an anaerobic lagoon is used for storage rather than a concrete tank. To meet the design criteria approved by the North Carolina Board of Water and Air Resources, 660 cu ft of water must be provided in the lagoon for each animal.

Lagoons are storage ponds in which the water level must be controlled. There has been very little experience with lagoons for beef cattle waste in North Carolina. Research with swine waste la-

goons in North Carolina indicates explicitly that the effluent cannot be discharged into a watercourse. Therefore, any overflow or discharge must be returned to the land.

The most practical way of controlling the water level in the lagoon is to irrigate the effluent. Caution must be exercised with irrigation to prevent surface runoff. The system should be designed for minimum pipe and sprinkler movement because this is a "nasty" job. Before moving, flush out the irrigation system with clean water. The lagoon effluent should not be spread on a hot humid (muggy) day because odors resulting from the spreading may create a nuisance.

A tank wagon equipped with a vacuum pump might be used with small lagoons, but its volume will limit its use.

Evidence indicates that a lagoon serves as a nitrogen trap by accumulating nitrogen in the sludge build-up on the bottom. This build-up of solids indicates that the sludge must be removed at some future date. However, definite recommended cleaning intervals are not established at this time. Because the decomposition process that takes place in a lagoon reduces the quantity of nutrients, particularly nitrogen, in the effluent, less land area is needed for land spreading.

The greatest use for a lagoon might be in conjunction with a solid manure handling system. Its primary purpose would be to intercept runoff from the feedlot and store manure only when it is impossible to move the manure directly from the lot to the land.

System V: Sheltered Dirt Lot with Spreading in Solid Form

Sheltered Dirt Lot ⟶ Front End Loader ⟶ Spreader ⟶ Land

When this waste management system is used, approximately 50 square feet (sq ft) per animal is recommended. The shelter is bedded as needed with the manure pack building up to several feet while the cattle are on feed. The barn is only cleaned out when the cattle are sold.

A tractor front end loader picks up the manure and deposits it on the spreader for land disposal. Select a spreader that will not leak the contents along the road and that will spread the material in small pieces on the land surface so that fly breeding is minimized.

System VI: Dirt Lot with Limited Shelter with Spreading in Solid Form

Dirt Lot with Limited Shelter ⟶ Scraper ⟶ Front End Loader ⟶ Storage ⟶ Spreader ⟶ Land

This waste management system is sometimes used when cattle are confined at rates up to 200 cattle per acre (A) or 215 sq ft per animal. The lots are scraped periodically and the manure is spread on the land. When the manure cannot be field spread, it is stacked in piles.

Provisions must be made to control runoff from these dirt lots. With repeated scrapings, a large volume of dirt is removed with the manure. In time, this will require replenishing the dirt which is lost in the manure handling process.

System VII: Dirt Lots (Cattle Rotated)

Dirt Lot without Shelter ⟶ Rotate Lots

This system is used in a stocker cattle program. Calves are placed in the lot in early fall at rates up to 100 cattle per A and are sold out the following spring. During the vacated period, a summer annual or silage crop is seeded in the lot to utilize the nutrients and produce a hay or silage crop for feed. When the cattle are rotated from lot to lot other crops may also be planted in the lots to better utilize the nutrients.

System VIII: Pasture (Cattle Rotated)

Pasture ——————→ Rotate Lots

This system uses a stocking density of 4 to 5 cattle per A. The pasture is the prime source or the entire source of feed. The cattle must be rotated in lots in order to allow seasonal growth for efficient nutrient utilization from the pasture crop. No water or air pollution should exist with this arrangement.

Other Alternatives

Recycling. It is a well known fact that beef animals do not extract all the food value from feeds during a single trip through the digestive system. This is expecially true when whole grains are included in the fattening ration. The re-cycling of manure back through the animal to utilize a higher percentage of the nutrients of the original feed has been the subject of considerable research during recent years. Results to date indicate a definite potential in this area. For example:

a. Whole grain has been mechanically separated from an oxidation ditch serving a beef cattle feed lot and stored in an air-tight silo. When mixed back into the cattle ration in amounts less than 21 percent of the total grain, the animals performed in a satisfactory manner. Above that level this recovered grain reduced feed intake and feed efficiency.

b. The entire solid waste from an oxidation ditch serving a beef cattle feed lot was separated, dehydrated, pelleted and fed back to the cattle. When used in amounts less than 37 percent of the total ration, results were generally satisfactory.

c. Processing of solid wastes by aerobic fermentation has given promising results in some tests when used as a protein supplement.

Present results indicate that a minimum capacity of 5,000 head would be needed to make a recycling program economically feasible. Recycling of manure through animals has a potential that may be put into practice in future years. However, as of this date, no feed containing this material has been approved for sale in North Carolina.

Drying. Drying beef cattle manure has received some attention, but at this time must be investigated on an individual enterprise basis. It is closely allied with refeeding. Research at Michigan State University indicates the drying cost to be over $11.00 per T of wet manure.

Composting. Composting has received limited study, but on a large scale does not appear to be practical at this time. To achieve rapid composting, aeration is essential.

Slotted Floors. Slotted floor buildings all under roof in which cattle are housed and fed have limited application at this time in North Carolina. In order to compare favorably with other systems the cost of slats and the convenience and efficiency in storing manure temporarily in pits under the slotted floor must be offset by high bedding and labor costs. Another consideration is the removal of the manure from the pits.

STORM RUNOFF CONTROL

A retention pond should suffice to collect storm runoff from paved areas, dirt lots and drainage areas outside the paved areas that channel runoff through the lots for systems that handle manure in a solid form or use a storage tank. Because the runoff can be diverted to a lagoon it is not necessary to construct a retention pond where a lagoon is used. As of this writing, most pollution control enforcement agencies are proposing storm runoff water retention facilities for a 10-year, 24-hour storm. This means that a beef cattle operation must have an adequate liquid waste retention facility to retain all runoff from areas where manure collects or is deposited for the worst storm likely to occur within a 24-hour period once in 10 years. In North Carolina this storm produces an average of 6 in. of rainfall.

To store 6 in. of rainfall, 3750 gal or 500 cu ft of storage for each 1000 sq ft of area that drains to the retention pond is required. The area includes all paved and dirt lots, roofed areas and areas outside but adjacent to the beef cattle operation that channel runoff water through any area where the manure collects or is deposited.

Figure 1 gives a typical cross-section of a retention pond. The depth of the pond is dependent on site conditions. A good starting depth is about 4 ft. The side slopes should be no less than 1 (rise) to 2 (run). The bottom should slope approximately 1 to 100 toward one end with the last 5 ft having a slope of 1 to 10 in both directions toward the strainer location. This allows the pond to be pumped dry. The strainer should be located about 1 ft above the bottom to prevent clogging and preferably should be fixed.

The retention pond must be kept dry except for the interval between the time that rain is falling and the land is too wet for irrigating the effluent. Normally an irrigation system should be used to spread the effluent. A tank wagon equipped with

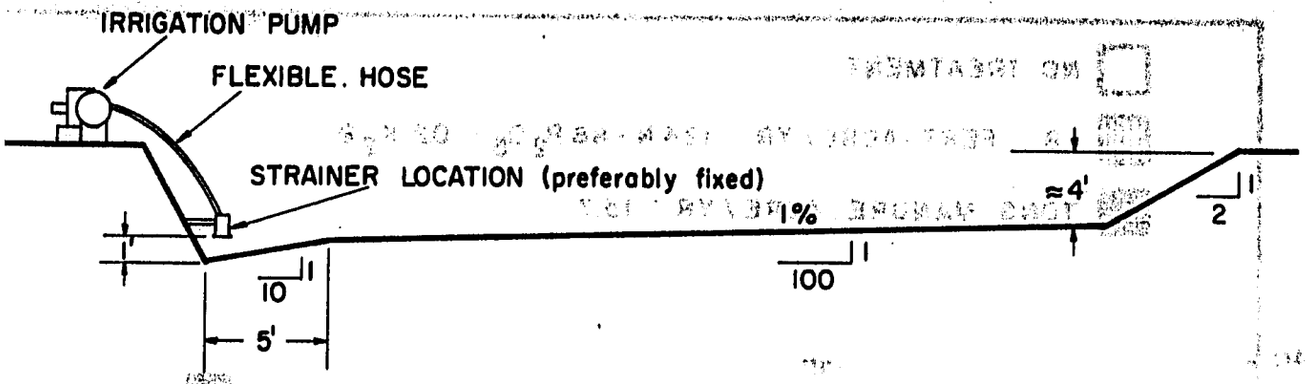


Figure 1. Typical Cross-section of a Retention Pond.

a vacuum pump might be used with small retention ponds, but its volume will limit its use.

UTILIZATION AND LAND REQUIREMENTS

Utilization of beef cattle manure by direct land application is generally recommended. However, because large quantities of manure are generated in concentrated operations, many of which have limited land areas, the manure is often treated as an unwanted commodity to be disposed of by any means that are publicly acceptable or economically feasible. Whenever possible the manure should be treated as a resource and be used as a valuable source of plant nutrients.

Animal manures were one of the earliest sources of plant nutrients. They constituted a major portion of the soil fertility experiments on the first agricultural experiment station, the Rothamsted Station, in England, which was started more than 140 years ago. Likewise, they were used extensively in all of the early soil fertility experiments in the United States. In almost all of those early experiments cattle manures proved equal to or better than commercial fertilizers which at that time were of low quality compared to modern commercial fertilizers. This is well illustrated by some of the Rothamsted data which are presented here for both their historical and technical value (Figure 2).

During the past 40 to 50 years beef cattle manures have been largely replaced by commercial fertilizers as sources of plant nutrients. This may be attributed to: 1) improved physical and chemical quality of commercial fertilizers; 2) improved methods of handling and applying commercial fertilizers; 3) the smaller tonnage of commercial fertilizers required to give the same amount of plant nutrients; and 4) the lower cost per pound of plant nutrients in commercial fertilizers. Beef cattle manure can be used as a source of nutrients for most crops grown in North Carolina except tobacco and certain other crops where nitrogen control is essential.

The principal plant nutrients supplied by both beef cattle manures and commercial fertilizers are nitrogen (N), phosphorus (P) and potassium (K). These nutrients are expressed as percents nitrogen (N), phosphate (P_2O_5) and potash (K_2O). In addition to N, P and K, beef cattle manure usually contains an appreciable amount of calcium, magnesium and sulfur; and traces of manganese, boron, copper and zinc, all of which are essential for plant growth.

Amount and Composition of Beef Cattle Manures

The daily production and the composition of beef cattle manure varies with the size and breed of animal, and the kind and amount of feed consumed. Table 5 presents representative values for the amount and composition of beef cattle manure.

These figures are approximate averages and should be used only as such. The actual composition of any particular batch of manure will be determined by the amount of moisture, the amount of bedding material present, the rations fed, and the way the manure has been handled or stored.

The relative value of cattle manure as compared to commercial fertilizers will be determined by the composition of the manure and by the cost of handling it. This will vary from farm to farm and should be estimated in each individual situation. An important item that should not be overlooked in estimating the value of manure is the fact that it must be disposed of but the cost of disposition is partially offset by its fertilizer value.

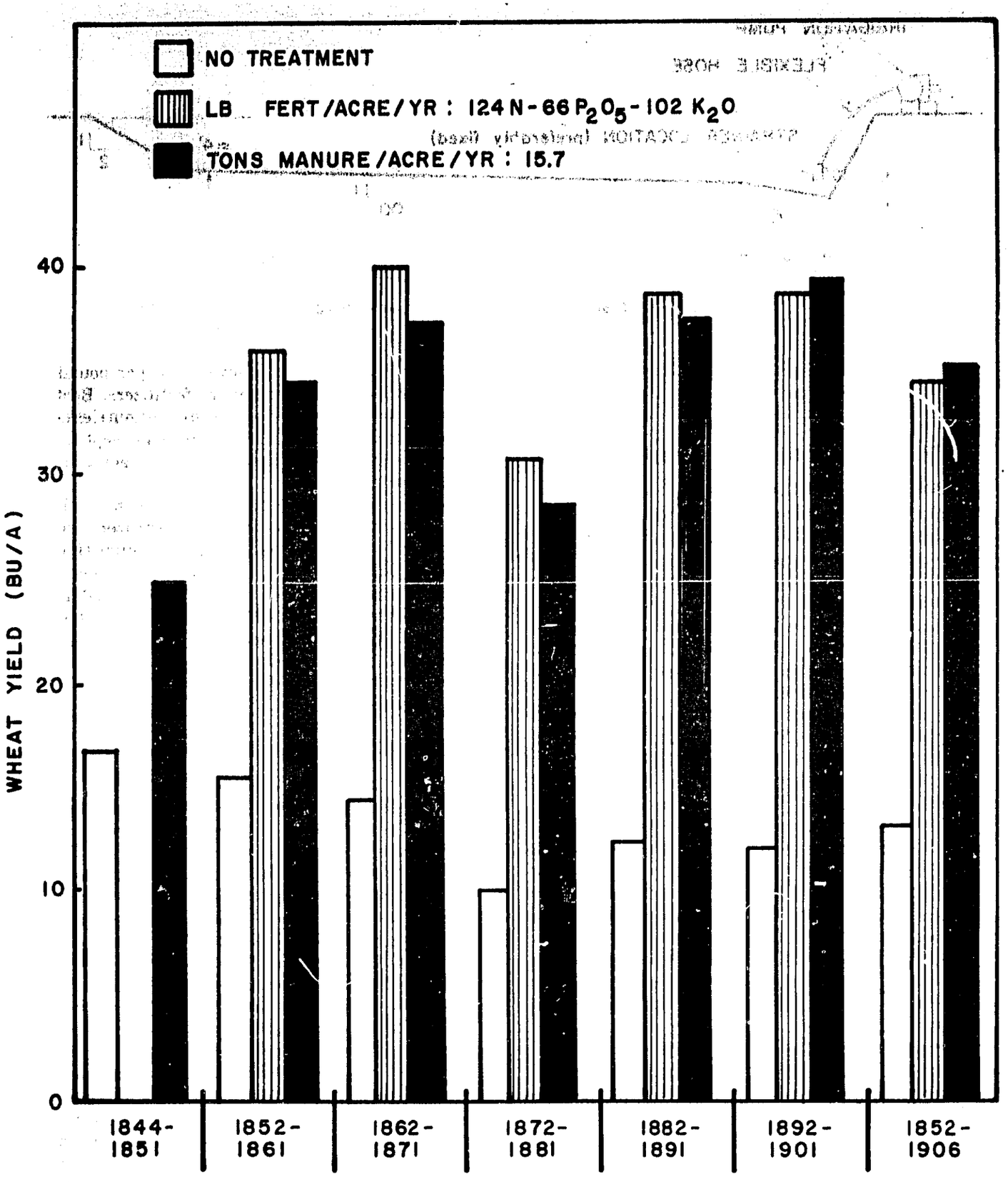


Figure 2. Effect of cattle manure on wheat yields on the oldest agricultural experiment station, at Rothamsted, England. The 10-year periods and the 53-year average (1852-1906) show that yields on the manured plots were about the same as those on the fertilized plots.

Table 5. Average Amount and Composition of Manure Produced by a 1000-lb Beef Animal

Amount Lb/Day/Cow	Composition								
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	Average Percent			Lb/Animal/Day			Lb/T in Fresh Manure		
64	0.90	0.35	0.45	0.36	0.14	0.18	18	7	9

Effects of Beef Cattle Manure on Soils and Crops

Beef cattle manure has several beneficial effects on the chemical, physical and biological properties of soils.

Chemical Effects. The principal chemical effect of manure is the supplying of the major plant nutrients: nitrogen, phosphate, and potash. It also contains a number of other chemical elements necessary for plant growth. The effect of cattle manure on crop yields is shown in Figures 2 and 3. Figure 2 shows that manure was as effective as commercial fertilizers in producing wheat on the Rothamsted Experiment Station. Figure 3 shows that manure produced almost 1900 pounds of seed cotton per acre per year on the Soil Erosion Experiment Station near Statesville, North Carolina. The check plot at the Statesville Station was not fertilized, and, therefore, the yield on it is not comparable to that of the manured plot. In contrast to commercial fertilizers, beef cattle manure supplies organic matter to soils, and this is usually considered beneficial in increasing the nutrient-holding capacity of soils.

Physical Effects. If manure is applied to the surface of the soil, it will help to prevent soil crusting. If mixed with the soil, it will decompose more rapidly and the products of decomposition will improve soil structure and the general physical condition of the soil. Thus, whether applied to the surface or mixed with the soil it will be important in conserving water and soil by reducing runoff and erosion. This is well illustrated by the data in Figure 3. Beef cattle manure frequently is credited with increasing the available water-holding capacity of soils. This is generally not true. If the manured soil contains more water, it very probably is because more soaked in during rainfall or irrigation.

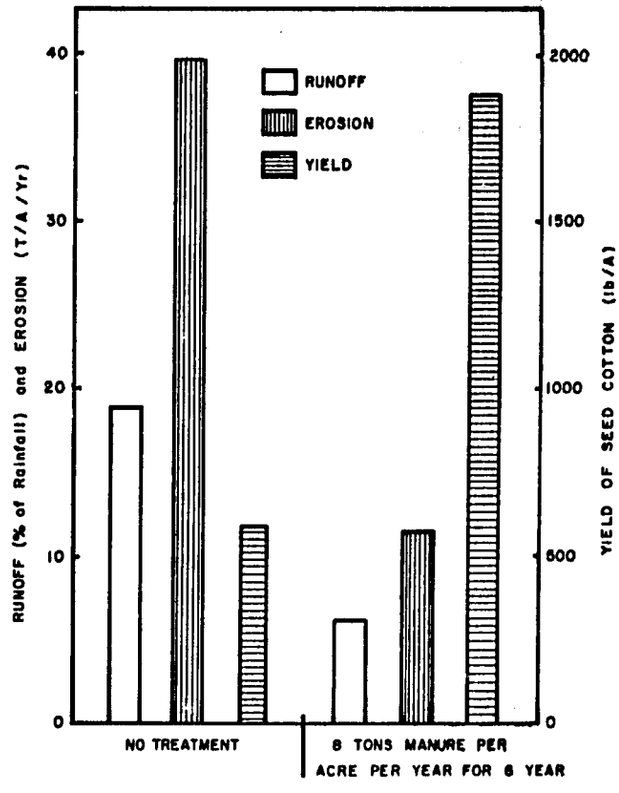


Figure 3. Effect of cattle manure on runoff, erosion and cotton yield at the Statesville Soil Erosion Experiment Station. (The yields are not comparable because the check plots were not fertilized. The good yield on the manured plot is important.)

Biological Effects. Manure is a source of food, and hence energy, for soil microorganisms that decompose it. These soil microorganisms have many very important direct and indirect effects on many physical, chemical, and biological properties of the soil.

Factors Affecting Rates of Application

Several factors affect the amount of manure that might be applied to any given land area. They are: (1) the use to be made of the land—whether it is to be used for crop production or for manure disposal only; (2) if used for crop production, the kind of crop to be grown; (3) the characteristics of the soil including texture, depth and fertility status; (4) topography as it affects runoff and erosion; (5) the season of the year in which the manure is to be applied; and (6) possibility of environmental pollution, particularly the contamination of surface and ground water by excessive leaching or runoff. In this connection care must always be taken to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

From the standpoint of crop production the amount of manure to be applied to any particular crop is determined by the nitrogen content of the manure and the nitrogen requirements of the crop. This will be explained more fully in the following pages.

Crop production is not the only factor to be considered in determining the amount of manure that might be applied to any particular soil. Another very important factor is the possible effect of the manure on environmental pollution, particularly contamination of surface or ground water. The two elements contained in manure which are most likely to cause problems in water are nitrogen, particularly in the nitrate form, and phosphorus. Excessively large amounts of nitrates can be toxic to animals and considerable accumulation of nitrates and phosphate in surface water causes eutrophication (excessive growth of algae and other water-loving plants). When manure decomposes in the soil the nitrogen will ultimately be converted to the nitrate form which is very easily leached. If it leaches downward in the soil to a poorly drained layer, in which there is sufficient organic matter for microorganisms to live on, the nitrate will be converted to the ammonium form which is less easily leached and less toxic to animals, and is likely to be volatilized.

Table 6 gives the relative potential nitrate leaching rates together with some of the soil properties affecting leaching. As a general rule, it would be undesirable to apply heavy applications of manure to soils with a high nitrate-leaching potential. On such soils it would be desirable to use smaller applications distributed throughout the year, making sure that the total application within a year is not excessive.

On fine textured soils infiltration is retarded and surface runoff may contribute to stream pollution. However, as shown in Figure 3 manure is very important in reducing surface runoff.

Table 6 also shows the relative phosphate-fixing capacity of representative soils in North Carolina. Many soils have the capacity to "fix" phosphorus; that is, render it relatively insoluble and on those soils phosphate leaching is usually not a problem. It is a problem, however, on sand and care should be taken not to add large amounts of phosphorus to soils with low phosphate-fixing capacity. As a general rule, the red to reddish-yellow soils with considerable clay in the subsoil have the higher phosphate-fixing capacity. The relative values for some typical soils in the state are given in Table 6.

The leaching of nitrates, phosphates and other plant nutrients is affected by a number of factors such as soil temperature (which affects the rate of decomposition of manure), the kind of crop being grown and, hence, the rate of utilization of the nutrients by the crop, and the soil moisture conditions. Under normal climatic conditions in North Carolina the soils are usually wet during the winter and relatively dry during the summer. "Normal" summer rains penetrate the soil to relatively shallow depths (6 to 10 to 15 inches, depending upon the texture) and under high summertime temperatures the moisture is rapidly lost by evaporation. Under such conditions leaching of nitrates to the water table is improbable, except on extremely coarse-textured soils.

Because only about half of the nitrogen contained in the manure will become available during the first growing season, it might be possible to apply about twice the recommended amount of nitrogen to grain and forage crops without danger of nitrate toxicity or groundwater contamination. However, in succeeding years this carry-over should be taken into account and rates adjusted accordingly. The ratio of N-P_2O_5-K_2O in beef cattle manure is about 2-1-1. (Table 5). Therefore, application of sufficient manure to get the desired amount of nitrogen usually will add sufficient phosphorus and potash. If twice the recommended amount of nitrogen is added (based on 50% availability) it is possible that excessive potash might be added. Some believe that excessive potash in

Table 6. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Texture of Topsoil (6-10 in.)	Texture of Subsoil (6-10 to 20 in.)	Critical Soil Property Affecting Movement of N and P	Relative Potential Nitrate Leaching	Relative Phosphate-Fixing Capacity	Typical Soil Series
Sand	Sand	Low water table, very high permeability	Very high	Very low	Lakeland, Wagram
		High water table	Low	Very low	Bibb, Pelham, Plummer
		Loose to hard, moderately permeable subsoil	Medium to high	Low	Altavista, Durham, Granville, Norfolk
Sandy loam, or Very fine sandy loam	Sandy clay loam, Clay loam, or Clay	Slowly permeable, somewhat plastic subsoil	Medium to low	Medium	Appling, Cecil
		Very slowly permeable, plastic sticky subsoil	Very low	Medium to low	Creedmoor, Enon, Helena, Iredell, Whitestore, Wilkes
		High water table	Low	Medium to low	Lumbee, Rains, Roanoke, Wehadkee, Worsham
Silt loam, or Loam	Silty clay loam, Clay loam, or Clay	Moderately permeable, plastic subsoil	Medium to low	Medium to high	Alamance, Chandler, Chester, Congaree, Fannin, Georgeville, Herndon, Hiwasse, Lloyd, Mecklenburg, Orangeburg, Porters, Ruston
		Slowly permeable, plastic, sticky subsoil	Low	Medium	Bertie, Craven, Dunbar, Nason
		Very slowly permeable, plastic, sticky subsoil	Very low	Low	Lignum, Tatum
		High water table	Low	Medium	Bayboro, Kinkora, Portsmouth, Roanoke
Silty clay loam, or Clay loam	Silty clay, or Clay	Slowly permeable, compact subsoil	Medium to low	High to very high	Caroline (eroded), Cecil (eroded), Davidson, Georgeville (eroded), Hayesville (eroded), Marlboro (eroded)
		Moderately to slowly permeable, granular subsoil	Low	High to very high	Appling (eroded)
		High water table	Very low	Medium	Any low, poorly-drained areas with topsoil removed by burning or stripping
Clay - Eroded or denuded areas, void of topsoil and, thus, with subsoil exposed		Slow to very slowly permeable, compact or granular subsoil	Low to very low	High to very high	Any area with clay exposed by erosion, stripping or burning
		High water table	Very low	Medium	Same as above, but with high water table

forages may cause tetany in animals. If the manure does not supply sufficient phosphorus, superphosphate may be used to supplement that in the manure.

Phosphorus is mainly in the organic form in beef cattle manure. Phosphorus availability is directly related to the rate of manure decomposition and is much slower than that of nitrogen. Potassium in beef cattle manure is an inorganic salt that is easily leached and is readily available for plant use. Most of the other plant nutrients, including the micronutrients, will be released as the manure decomposes.

Losses of nutrients from manure may be by leaching of soluble salts or volatilization. However, these losses can be held to a minimum if the material is applied to the land and incorporated into the soil. Beef cattle manure that is high in nitrogen should be applied to the land at least 2 to 4 weeks prior to planting to prevent ammonia from burning the plants and to reduce possible salt injury. Where available land is required for feed production, management practices must be developed to permit land spreading at suitable times.

How To Determine the Amount to Apply

The nutrient composition of the manure is very dependent on the type of waste management system. Producers, especially those using liquid storage tanks and lagoons, should have the slurry or lagoon liquor analyzed. There are several commercial laboratories in North Carolina that have expressed an interest in analyzing waste samples. For further information, contact your county extension agent or one of the regional offices of the Office of Water and Air Resources of the Department of Natural and Economic Resources located in Greenville, Raleigh, Concord and Asheville.

Estimates of the existing soil nutrient supply can be obtained by soil tests made by the Soil Testing Division of the North Carolina Department of Agriculture. Rates of application should be based on the recommended amount of nitrogen needed to supplement the existing soil nitrogen supply for the particular crop to be grown. Contact your county extension agent for further information on determining the rate of application.

Illustrative examples are shown for handling the waste in solid and slurry forms, and as lagoon effluent. Each example is for a specific set of conditions that may or may not be applicable to your area. Each example is based on the approach that the beef cattle manure is to be a source of fertilizer with the long range objective of optimum crop production.

If the approach is taken whereby the land is to be used for waste disposal without consideration of any crop, higher application rates than given in the examples below could be used. However, the risk of groundwater and surface water contamination is greater, a very good understanding of the characteristics of the soil is essential, and lastly, a resource in the form of fertilizer is being wasted. If this latter approach is used, contact your county extension agent or Soil Conservation Service district conservationist.

Examples

In the examples given below, information on the following will be given based on handling the maure from 500 head of 1000-lb cattle:

—Rate of application.
—Total land area needed per year.
—Land area required for spreading at definite intervals.
—Number of trips required for spreading at definite intervals (except for lagoon example).
—Size of retention pond when needed.

THE EXAMPLES DO NOT TAKE LOCATION, TOPOGRAPHY, SEASON OF YEAR, WEATHER CONDITIONS, STAGE OF CROP GROWTH OR SOIL TYPE INTO ACCOUNT. These factors will be discussed in a subsequent bulletin. The numbers in the parentheses show how the calculations are made.

Solid Form. Assume that the fertilizer recommendations for corn on a particular soil are as follows:

N	P_2O_5	K_2O	Lime
lb/A	lb/A	lb/A	T/A
180	140	160	2

All of the nitrogen (N) is to be supplied by the manure.

1. What is the rate in tons per acre needed to supply the recommended amount of nitrogen?

From Table 5 the average amount of N in fresh beef cattle manure is 18 lb/T. The rate in tons per acre is determined by dividing lbN needed by the lb N/T of manure. The result is 10 T/A (180 lb/A ÷ 18 lb/T).

NOTE! Manure that is stored in a pile or a manure pack will have different amounts of N per ton than fresh manure because of drying and

volatilization. Therefore, the manure should be analyzed to determine the appropriate rate of application.

2. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

From Table 5, a 1000-lb animal produces 64 lb/day of manure. This is equivalent to 11.70 T/yr [(64 lb/day × 365 days/yr) ÷ (2000 lb/T)] or 5850 T/yr from 500 beef cattle. Dividing the total amount of manure by the desired application rate gives the total land area required. The result is 585 A (5850 T ÷ 10 T/A).

Because only 50% of the total N is available the first year, twice the application rate could be made the first year. Thus 293 A of corn could be fertilized in a safe manner for the first year only.

3. How much area is required for daily spreading?

From Table 5, a 1000-lb animal produces 64 lb/day of manure. Thus 500 animals will produce 32,000 lb/day or 16 T/day (32,000 lb/day ÷ 2000 lb/T). From the answer to Question 1, the maximum rate of application is 10T/A. Dividing the daily production rate by the application rate gives the area required. The result is 1.6 A/day (16 T/day ÷ 10 T/A).

4. If the manure is spread daily, how many trips are required with a manure spreader?

There are several sizes and types of manure spreaders. Because the cost of an individual spreader is dependent on the size and type, haul distance may be an important factor to consider. From the answer to Question 3, the daily production rate is 16 T/day. From Table 1, 7 trips with a 180 bu capacity or 11 trips with a 108 bu capacity spreader are required.

5. What size retention pond is required to retain the storm runoff water from a 6-in. rainfall (24-hr 10-yr storm)?

A 500-head beef cattle operation would have approximately 55 sq ft of paved and roof areas per animal Thus the area contributing to the retention pond excluding any area outside the lots that channels runoff water through the lots is 27,500 sq ft (55 sq ft/animal × 500 animals). The volume of run-off water to be stored is 13,750 cu ft (27,500 sq ft ÷ 12 in./ft).

If a 4-ft depth of retention pond can be used, a 50-ft wide 69-ft long pond with vertical walls would be required (50 ft × 69 ft × 4 ft = 13,800 cu ft). Because the slides must have a minimum slope of 1 (rise) to 2 (run), a retention pond with a 42-ft wide by 61-ft long bottom has sufficient size. The top dimensions for the 4-ft deep pond are 58 ft by 77 ft. See Figure 1 for a typical cross-section of a retention pond.

NOTE! If the roofed area is guttered and the water diverted so that it does not come in contact with the manure, the size of the retention pond can be proportionally reduced.

Slurry Form. The manure is scraped into a storage tank and handled in a slurry form. A 30-day clean-out interval is used. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used.

1. What size closed storage tank is required?

A 1000-lb animal will produce approximately 1 cu ft or 7.5 gal of waste per day. The size of storage tank will depend on the clean-out interval. From Table 2 the storage capacity needed for a 30-day clean-out interval is 169,000 gal.

Table 3 gives several combinations of tank sizes. If a 24-ft width and 10-ft depth is selected, the storage capacity per foot of length would be 1800 gal/ft. Thus a tank length of 94 ft (169,000 gal ÷ 1800 gal/ft) is required. Thus, the tank size is 94 ft by 24 ft by 10 ft.

2. What is the rate in tons per acre needed to apply the recommended amount of nitrogen?

Calculations are performed exactly as given in the answer to Question 1 of the *Solid Form Example*. The result is 10 T/A.

3. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

Calculations are performed exactly as given in the answer to Question 2 of the *Solid Form Example*. The result is 585 A.

4. How much land area is required for spreading on a 30-day interval?

A 30-day spreading interval means that the waste will be spread 12 times per year. Thus 48.7 A (585 A ÷ 12) is required.

5. How many trips are required with a liquid manure spreader?

There are several sizes of liquid manure spreaders. Because the cost of an individual spreader is dependent on the size, haul distance may be an important factor to consider. From the answer to Question 1, approximately 169,000 gal will need to be spread every 30 days. If an 800 gal capacity spreader is used, 211 trips (169,000 gal ÷ 800 gal/trip) would be required.

6. What size retention pond is required to retain the storm runoff from a 6-in. rainfall (24-hr 10-yr storm)?

Calculations are performed exactly as given in the answer to Question 5 of the *Solid Form Example*.

The result is a retention pond with a storage capacity of 13,750 cu ft.

Lagoon Effluent. The manure is scraped into one anaerobic lagoon. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used. The terms lagoon liquor and lagoon effluent are used below. Lagoon liquor is the liquid and waste mixture in the lagoon. Lagoon effluent is the lagoon liquor that is discharged or taken from the lagoon.

1. What lagoon volume and surface area are required?

Design criteria approved by the North Carolina Board of Water and Air Resources require 660 cu ft per animal. Storm runoff water was not considered in the design criteria. Therefore the lagoon volume required is 330,000 cu ft (500 animals ÷ 660 cu ft/animal).

The exact surface area of a lagoon depends on the depth and side slopes which in turn are dependent on the site conditions. A first approximation of the surface area can be obtained by dividing the volume by the depth. This approximate surface area provides sufficient accuracy to make the necessary calculations in the remainder of the answers to the questions in this example. If a 6-ft depth is selected, the approximate surface area would be 55,000 sq ft (330,000 cu ft ÷ 6 ft) or 1.26 A (55,000 sq ft ÷ 43,560 sq ft/A). See Appendix I for design details of a lagoon. See Misc. Ext. Publication No. 89 entitled "Tentative Guidelines for the Design, Installation and Operation of Animal Waste Treatment Lagoons in North Carolina" for construction details.

2. How much lagoon liquor needs to be removed each year from the lagoon in order to prevent discharge through the overflow pipe?

When the lagoon is nearly filled to capacity, some lagoon liquor must be removed periodically during the year to prevent discharge through the overflow pipe. This discharge would be caused by manure being added, storm runoff water being diverted to the lagoon, and rain falling directly on the lagoon.

A 1000-lb beef animal produces 1 cu ft/day. Thus, the yearly production from 500 animals is 182,500 cu ft/yr (1 cu ft × 500 animals × 365 days/yr).

The average rainfall in North Carolina is about 50 in./yr. Nearly all of this amount will become storm runoff water if it falls on the paved area or dirt lots. A 500-head operation would have about 55 sq ft of paved and roof area per animal. If this is the only area that contributes to the runoff, the amount of runoff water would be 114,500 cu ft/yr (55 sq ft/animal × 500 animals × 50 in./yr ÷ 12 in./ft).

NOTE! The local average amount of rainfall should be used when making this calculation for your area.

Because the average rainfall per year in North Carolina exceeds the average evaporation by about 15 in. per unit surface area, 68,700 cu ft/yr (55,000 sq ft × 15 in. ÷ 12 in./ft) is assumed to be added by the rain in excess of evaopration that falls directly on the lagoon.

NOTE! The local average amounts of rainfall and evaporation should be used when making this calculation for your area.

Thus, the approximate amount of lagoon liquor to be removed and spread on the land each year is 365,700 cu ft (182,500 cu ft/yr + 114,500 cu ft/yr + 68,700 cu ft/yr) or 8.37 ac ft/yr (365,700 cu ft ÷ 43,560 sq ft/A).

3. What is the nitrogen concentration of the lagoon liquor?

Because the nitrogen concentration of the lagoon liquor will vary according to the amount of water used, a nitrogen analysis of the lagoon liquor should be made by a commercial laboratory. The results will generally be expressed in milligrams N per liter (mgN/1). A rough estimate of the nitrogen concentration of the lagoon liquor can be obtained by dividing the lbN in the liquor by the total amount of waste and water that is added to the lagoon each year.

From Table 5, the mean amount of N in beef cattle manure from a 1000-lb beef animal is about 0.36 lb/day/animal or 65,600 lb/yr (0.36 lb/day/animal × 365 days/yr × 500 animals) from 500 beef cattle. A conservative assumption is that the N concentration of the lagoon liquor in an anaerobic lagoon that has been in operation for more than one year is generally not more than 50% of the N of the fresh waste input. Thus 32,800 lbN are estimated to be in the lagoon liquor.

From the answer to Question 1 the total volume of the lagoon is 330,000 cu ft or 2,465,000 gal (330,000 cu ft × 7.48 gal/cu ft). Therefore a rough estimate of the N concentration of the lagoon liquor is 0.01330 lbN/gal (32,800 lbN ÷ 2,465,000 gal).

NOTE! The nitrogen concentration of the lagoon liquor may increase with the age of the lagoon. Therefore a nitrogen analysis of the lagoon liquor should be made yearly.

4. At what rate can the lagoon effluent be applied to the land?

Table 7 establishes the rate at which lagoon effluent can be applied to the land to achieve a certain nitrogen application rate. Entering Table 7 with an N concentration of 0.01333 lbN/gal and an N requirement of 180 lbN/A, a value of 13,000 gal/A is obtained by estimation. The exact value can be

Table 7. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Gallons per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	240,000	480,000	720,000	960,000	1,200,000	1,440,000
100	0.00083	120,000	240,000	360,000	480,000	600,000	720,000
200	0.00167	60,000	120,000	180,000	240,000	300,000	360,000
300	0.00250	40,000	80,000	120,000	160,000	200,000	240,000
400	0.00333	30,000	60,000	90,000	120,000	150,000	180,000
500	0.00416	24,000	48,000	72,000	96,000	120,000	144,000
600	0.00500	20,000	40,000	60,000	80,000	100,000	120,000
700	0.00583	17,150	34,300	51,500	68,600	85,700	103,000
800	0.00667	15,000	30,000	45,000	60,000	75,000	90,000
900	0.00750	13,300	26,650	40,000	53,300	66,500	80,000
1000	0.00833	12,000	24,000	36,000	48,000	60,000	72,000
1100	0.00917	10,900	21,800	32,700	43,600	54,500	65,400
1200	0.01000	10,000	20,000	30,000	40,000	50,000	60,000
1300	0.01083	9,230	18,460	27,690	36,920	45,150	55,380
1400	0.01168	8,560	17,120	25,680	34,240	42,800	41,360
1500	0.01250	8,000	16,000	24,000	32,000	40,000	48,000
1600	0.01333	7,500	15,000	22,500	30,000	37,500	45,000
1700	0.01417	7,060	14,120	21,180	28,240	35,300	42,360
1800	0.01500	6,660	13,320	19,980	26,640	33,300	39,960
1900	0.01583	6,330	12,660	18,990	25,320	31,650	37,980
2000	0.01667	6,000	12,000	18,000	24,000	30,000	36,000
2100	0.01750	5,710	11,420	17,130	22,840	28,550	34,260
2200	0.01833	5,450	10,900	16,350	21,800	27,250	32,700
2300	0.01917	5,220	10,440	15,660	20,880	26,100	31,320
2400	0.02000	5,000	10,000	15,000	20,000	25,000	30,000
2500	0.02083	4,800	9,600	14,400	19,200	24,000	28,800
2600	0.02165	4,615	9,230	13,845	18,720	23,075	27,690
2700	0.02250	4,450	8,900	13,350	17,800	22,250	26,700
2800	0.02333	4,280	8,560	12,840	17,120	21,400	25,680
2900	0.02415	4,140	8,280	12,420	16,560	20,700	24,840
3000	0.02500	4,000	8,000	12,000	16,000	20,000	24,000

obtained by interpolating as follows:

$$\left[\frac{180\ \text{lbN} - 100\ \text{lbN}}{200\ \text{lbN} - 100\ \text{lbN}}\right] \left[15{,}000\ \text{gal/A} - 7{,}500\ \text{gal/A}\right] + 7{,}500\ \text{gal/A} = 13{,}500\ \text{gal/A}.$$

5. What is the total yearly acreage requirement?

As indicated in the answer to Question 2, 8.37 ac ft of lagoon liquor need to be removed from the lagoon each year. This is equivalent to 2,730,000 gal (8.37 ac ft × 12 in./ft × 27,200 gal/ac in.). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 202 A (2,730,000 gal ÷ 13,500 gal/A).

Because the lagoon will be pumped 4 times per year, 50.5 A (202 A ÷ 4) are required for each pumping.

Because irrigation is generally expressed in terms of acre inches applied to a given area, Table 8 was developed to provide information regarding the number of acre inches per acre of effluent required to give the designated rates of total N per acre for various concentrations in liquid manure or lagoon effluent.

Table 8 could also have been used to determine the acreage requirements for Question 5. Entering Table 8 with an N concentration of 0.01333 lbN/gal and an N requirement of 180 lbN/A, a value of 0.50 ac in./A is obtained by interpolation.

The total amount of lagoon liquor expressed in acre inches per acre to be removed from the lagoon is 100 ac in. (8.37 ac ft × 12 in./ft). Dividing the amount of effluent to be spread by the application

Table 8. Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Acre Inches per Acre Required to Give the Following Pounds of N per Acre					
MgN/1	LbN/gal	100	200	300	400	500	600
50	0.00041	8.82	17.64	26.48	35.28	44.10	52.96
100	0.00083	4.41	8.82	13.24	17.64	22.05	26.48
200	0.00167	2.20	4.40	6.60	8.80	11.00	13.20
300	0.00250	1.47	2.94	4.41	5.88	7.35	8.82
400	0.00333	1.10	2.20	3.30	4.40	5.50	6.60
500	0.00416	0.88	1.76	2.64	3.52	4.40	5.28
600	0.00500	0.74	1.48	2.22	2.96	3.70	4.44
700	0.00583	0.63	1.26	1.89	2.52	3.15	3.78
800	0.00667	0.55	1.10	1.65	2.20	2.74	3.30
900	0.00750	0.49	0.98	1.47	1.96	2.45	2.94
1000	0.00833	0.44	0.88	1.32	1.76	2.20	2.64
1100	0.00917	0.40	0.80	1.20	1.60	2.00	2.40
1200	0.01000	0.37	0.74	1.11	1.48	1.85	2.22
1300	0.01083	0.34	0.68	1.02	1.36	1.70	2.04
1400	0.01168	0.31	0.62	0.93	1.24	1.55	1.86
1500	0.01250	0.29	0.58	0.87	1.16	1.45	1.74
1600	0.01333	0.28	0.56	0.84	1.12	1.38	1.68
1700	0.01417	0.26	0.52	0.78	1.04	1.30	1.56
1800	0.01500	0.25	0.50	0.75	1.00	1.25	1.50
1900	0.01583	0.23	0.46	0.69	0.92	1.16	1.38
2000	0.01667	0.22	0.44	0.66	0.88	1.10	1.32
2100	0.01750	0.21	0.42	0.63	0.84	1.05	1.26
2200	0.01833	0.20	0.40	0.60	0.80	1.00	1.20
2300	0.01917	0.19	0.38	0.57	0.76	0.95	1.14
2400	0.02000	0.18	0.36	0.54	0.72	0.92	1.11
2500	0.02083	0.18	0.35	0.53	0.71	0.88	1.06
2600	0.02165	0.17	0.34	0.51	0.68	0.85	1.02
2700	0.02250	0.16	0.33	0.49	0.65	0.82	0.98
2800	0.02333	0.16	0.31	0.47	0.63	0.79	0.94
2900	0.02415	0.15	0.30	0.46	0.61	0.76	0.91
3000	0.02500	0.15	0.30	0.44	0.59	0.73	0.88

rate gives the acreage required for spreading. The result is 200 A (100 ac in. ÷ 0.50 ac in./A) which is about the same as obtained previously.

One thing is obvious from this example. It is not feasible to use a tank spreader to spread the effluent. A 1400 gal spreader would require 1950 trips (2,730,000 gal ÷ 1400 gal/trip).

6. Is it possible to reduce the land area required for spreading the effluent?

The installation of a second lagoon in series with the existing lagoon will reduce the N concentration of the effluent from the existing lagoon by approximately 50%. Thus the N concentration of the effluent to be spread is about 800 mgN/1. Entering Table 7 with 800 mgN/1 and 180 lbN/A, a value of 27,000 gal/A is obtained by interpolation. The acreage required would be 101 acres (2,730,000 gal ÷ 27,000 gal/A).

If Table 8 were used, a value of 0.99 ac in./A is obtained by interpolation. The required acreage would be 101 A (100 ac in. ÷ 0.99 ac in./A) which is the same as obtained above.

Question 6 points out a problem that can exist when low concentrations are to be spread on fields that require high fertility rates. Assume than an effluent containing 100 mgN/1 is to be spread to satisfy a soil test requirement of 400 lbN/A. From Table 8, 17.6 ac in./A would be required. This extra amount of water over and above the normal rainfall would probably keep the soil too wet, especially in a wet season. This would result in poor soil aeration and in many instances in the growth of slime molds. As a result crop growth would be reduced or destroyed.

Soil Management

For most efficient utilization of nutrients, beef cattle manure should be mixed with the soil either by plowing or disking. If it is left on the surface,

some N will be lost by volatization and perhaps some by surface runoff. Mixing with the soil will essentially eliminate this loss. It will also be very effective in eliminating odors.

The manure must be decomposed before most of the nutrients contained in it become available. Plants cannot use the N, P, K, and other chemical elements contained in the organic manure; they must be released in the inorganic form.

Plowing or disking the manure into the soil will speed its decomposition and will enhance essentially all of the physical, chemical, and biological properties of the soil. However, when applying to pastures, grain and certain other crops, it is not possible to mix it with the soil. If applied to vegetated areas as a slurry irrigation, it is more apt to come into contact with, or perhaps enter, the soil than if applied as dry material.

Some other points to keep in mind include the following:

- Liquid manure should be applied in a manner that will not contaminate surface water. It should not be applied nearer than 50 feet to a stream or other surface water.
- Regardless of the method of application it must be prevented from going directly into waterways or into seepage areas leading directly to a waterway.
- The wind direction and velocity and the proximity of neighbors should always be kept in in mind when applying manure to the land.
- When irrigation is used, it is desirable to follow the application of the effluent with an application of water. This will flush out the irrigation system and will wash the manure off the vegetation and cause more of it to penetrate the soil. However, care should be taken not to add too much water which might result in surface runoff and in poor soil aeration.

ODOR CONTROL

Under ideal conditions in a beef cattle feed lot, bacterial action converts part of the organic materials in manure to nitrate, thus increasing the fertilizer value of the manure. Much of the odor in feed lots is ammonia, resulting from urea being hydrolyzed to ammonia. This represents a loss of plant food and lowers the fertilizer value of the manure. As ammonia becomes more concentrated it reduces the bacterial action. Ammonia is more concentrated when animals are confined to smaller areas, when bedding materials are used and when manure is allowed to accumulate or is stored in an open place.

The following guidelines should be considered in reducing odor:

- Provide more space per animal.
- Allow maximum air movement.
- Locate feed lots so that prevailing wind blows away from population centers.
- Scrape or wash paved surfaces to avoid accumulation of manure.
- If you are surface applying, break the material up so it will dry fast. Apply at a time when the air is dry. Do not apply when the weather is hot and humid. Apply when the humidity is the lowest for your area.
- Use spreaders that do not drip waste material along the road. Tank spreaders are now available with injectors for depositing the manure 4 to 6 in. below the ground surface. With this method the manure is immediately covered which greatly reduces the odor.

Certain chemicals may be sprayed on lots to mask or assist in the control of odors. However, the practical value of this practice is questionable.

Aerators are helpful in reducing odors in lagoons, but no criteria as to the amount of aeration necessary have been established.

PEST CONTROL

Flies

Flies may be reduced in number by a good program of sanitation that limits the incubation areas for hatching eggs. Removal of manure from the feed lot and the drainage of damp areas will help. Sugar baits placed in alley ways, residual sprays on feed bunks, fences, sheds, etc. are valuable in reducing flies. Space sprays can be applied over the entire surface of the feed lot by misting or fogging. Misting is preferred by more operators due to the smaller amount of drift. See the current *N. C. Agricultural Chemicals Manual* for insecticides to use in either space or residue sprays or for baits.

When manure is hauled to the fields it should be spread thin to speed the drying process and eliminate it as a breeding place for flies. When a thick application is made it should be plowed under in a few hours.

Birds, Rats and Mice

These cause problems in feed lots by eating and contaminating feed. The most practical control measures are sanitary practices that eliminate the spillage of feed from bunks or storage areas.

The fencing off of the bunks and buildings to eliminate nesting areas and keeping trained dogs or cats around the feed lot to scare away pests will also help.

N. C. State Statutes prohibit the use of poison baits to control either birds, rats or mice. A chemical repellent bait marketed under the trade name of "Starlicide" has been effective in discouraging visits by birds to feed lots in other states.

For up-to-date legal recommendations on chemicals to use, contact your county extension agent.

Mosquitoes

Heavy populations of mosquitoes sometimes develop in livestock waste lagoons. The mosquito species usually involved needs the protective vegetation along the shoreline for egg laying and survival of its young. To eliminate the mosquito problem remove marginal vegetation, including any flooded plants, and rake dead vegetation and debris away from the edge of the lagoon liquor. Vegetation can be physically removed or killed with an approved herbicide. For emergency control, apply Flit MLO at 5 gal per A or No. 2 fuel oil at 10 gal per A as a spray.

ECONOMICS

If a producer is to make a rational choice among the various waste management systems, he must compare costs of these systems and estimate the value of the waste in a cropping program. In general, systems that handle manure in solid form are less expensive than those using liquid systems. However, because each situation is different, no one "best" system can be suggested—each producer must make his own comparisons.

Each producer must start with his present situation. A producer who is constructing new facilities can simply compare the total annual costs of various waste management systems along with corresponding housing facilities and weigh these costs against the environmental desirability and manure value for each system, realizing the limits upon the capital which he can invest.

Typically, however, a producer with functional existing facilities finds that he may have to change his waste management system because of legislation, labor scarcity, or limited land on which to apply the manure. In this case, the producer will want to look at the net income effect of switching from his present system to another. The calculations involve adding the various additional annual costs associated with the switch.

Two types of costs are involved in any waste management system. They are ownership or fixed costs and variable or operating costs. Both ownership and variable costs should be considered in selecting the waste management system for a specific beef cattle operation. Annual ownership costs are depreciation, interest or investment, repairs, insurance and taxes. Variable costs are for such items as fuel, labor and any other out-of-pocket costs.

In choosing a waste management system, the beef cattle producer should first select the ones that will handle his situation. If only one system is believed suitable, then the only thing to determine is if he can afford to continue in the beef cattle business with the added costs incurred with the waste management system.

Should two or more of the systems be suitable, the farmer should then itemize both the annual fixed costs involved in each system and the annual variable or operating costs. The system with the least annual total cost should be selected assuming that either system being considered will adequately handle the amount of waste produced.

Tables 9-14 present estimates of the investment required for equipment and facilities for each system together with annual power and labor requirements. Optional irrigation systems are included in the footnotes. The data in the tables were obtained from equipment dealers, farm surveys and university research. The annual ownership costs were calculated by multiplying the initial cost of specialized manure facilities and equipment by an ownership cost factor. Table 15 presents the ownership cost calculations for facilities and equipment. The footnotes after Table 15 explains the calculation of the ownership cost factor for specific items. Tractor use, labor and electricity were charged at hourly rates.

Each table is provided with blank spaces to insert those costs, labor and power coefficients which will enable the individual to evaluate alternative systems for his operation.

Table 9. System I Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[1]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Annual ownership cost							
Front end loader (8 ft) and manure bucket (42 in.)	$1,000	.26			$ 260		
Spreader, rear-unload (180 bu)	1,300	.33			429		
Retention Pond (510 cu yd @ 50¢/cu yd)	255	.12			31		
Irrigation system[2]							
Pump (5 hp centrifugal)	550	.17			94		
Sprinklers (24, 7 8 gpm capacity)	180	.23			41		
Pipe (2000 ft - 1¼ in. - 2 in. PVC class 160 w/fittings)	1,270	.13			165		
Gate valves (5 - 2 in.)	50	.21			11		
Total annual ownership cost					$1,031		
Tractor use (60-79 hp)							
Scrape			490	2.90	$1,421		
Clean shelter and spread[3]			153	2.90	444		
Load and spread daily			465	2.90	1,349		
Total tractor					$3,214		
Labor							
Scrape			490	2.50	$1,225		
Clean shelter and spread			153	2.50	383		
Load and spread daily			465	2.50	1,163		
Irrigate (8 irrigations × 0.2 hrs)			2	2.50	5		
Total labor					$2,776		
Electricity for irrigation (680 kwh × 2.5¢/kwh)					$ 17		
Total	$4,605				$7,038		

All footnotes after Table 15.

Table 10. System II Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[1]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Ownership cost							
Scraper, rear mounted (8 ft)	$ 300	.26			$ 78		
Manure bucket, front end mounted (42 in.)	900	.26			234		
Spreader, rear-unload (180 bu)	1,300	.33			429		
Ramp and covered storage area	3,250	.12			390		
Retention Pond (510 cu yd @ 50¢/cu yd)	255	.12			31		
Irrigation system[2]							
Pump (5 hp centrifugal)	550	.17			94		
Sprinklers (24, 7.8 gpm capacity)	180	.23			41		
Pipe (2000 ft - 1¼ in. - 2 in. PVC class 160 w/fittings)	1,270	.13			165		
Gate valves (5 - 2 in.)	50	.21			11		
Total annual ownership cost					$1,473		
Tractor use (60-79 hp)							
Scrape			490	2.90	$1,421		
Clean shelter and spread[3]			153	2.90	444		
Load and spread daily			310	2.90	899		
Total tractor					$2,764		
Labor							
Scrape			490	2.50	$1,225		
Clean shelter and spread			153	2.50	383		
Load and spread daily			310	2.50	775		
Irrigate (8 irrigations × 0.2 hr)			2	2.50	5		
Total labor					$2,388		
Electricity for irrigation (680 kwh × 2.5¢/kwh)					$ 17		
Total	$8,055				$6,632		

All footnotes after Table 15.

Table 11. System III Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[1]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Ownership cost							
Scraper, rear mounted (8 ft)	$ 300	.26			$ 78		
Manure bucket, front end mounted (42 in.)	900	.26			234		
Spreader, rear-unload (180 bu)	1,300	.23			299		
Spreader, liquid manure	2,100	.33			693		
Storage tank (22,560 cu ft @ 65¢/cu ft)	14,640	.12			1,758		
Agitator pump	1,900	.36			684		
Retention pond (510 cu yd @ 50¢/cu yd)	255	.12			31		
Irrigation system[2]							
Pump (5 hp centrifugal)	550	.17			94		
Sprinklers (24, 7.8 gpm capacity	180	.23			41		
Pipe (2000 ft - 1¼ in. - 2 in. PVC class 160 w/fittings)	1,270	.13			165		
Gate valves (5 - 2 in.)	50	.21			11		
Total annual ownership cost					$ 4,088		
Tractor use							
Scrape (60-79 hp)			490	2.90	$ 1,421		
Agitate and pump (60-79 hp)			136	2.90	394		
Clean shelter and spread (60-79 hp)[3]			153	2.90	444		
Spread liquid (90-99 hp)			320	3.52	1,126		
Total tractor					$ 3,385		
Labor							
Scrape			490	2.50	$ 1,225		
Agitate and pump			136	2.50	340		
Clean shelter and spread[3]			153	2.50	383		
Irrigate (8 irrigations × 0.2 hr)			2	2.50	5		
Spread liquid			320	2.50	800		
Total labor					$ 2,753		
Electricity for irrigation (680 kwh × 2.5¢/kwh)					$ 17		
Total	$23,445				$10,243		

All footnotes after Table 15.

Table 12. System IV Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[2]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Ownership cost							
Scraper, rear mounted (8 ft)	$ 300	.26			$ 78		
Manure bucket, front end mounted (42 in.)	900	.26			234		
Spreader, rear-unload (180 bu)	1,300	.23			299		
Lagoon (12,210 cu yd @ 50¢/cu yd)	6,110	.12			733		
Irrigation system[4]							
Pump (30 hp, liquid manure)	2,520	.21			529		
Walkway to mount pump	475	.16			76		
Sprinklers (2, gun type w/trailer)	600	.23			138		
Pipe (4180 ft - 4 in. to 5 in. aluminum w/accessories)	4,540	.17			771		
Total annual ownership cost					$2,858		
Tractor use (60-79 hp)							
Scrape			490	2.90	$1,421		
Clean shelter and spread[3]			153	2.90	444		
Total tractor					$1,865		
Labor							
Scrape			490	2.50	$1,225		
Clean shelter and spread[3]			153	2.50	383		
Irrigate (4 irrigations × 50 hr)			200	2.50	500		
Total labor					$2,108		
Electricity (8100 kwh × 4¢/kwh)					$ 324		
Total	$16,745				$7,155		

All footnotes after Table 15.

Table 13. System V Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[2]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Ownership cost							
Manure bucket, front end mounted (42 in.)	$ 900	.26			$ 234		
Spreader, rear-unload (180 bu)	1,300	.33			429		
Total annual ownership cost					$ 663		
Tractor use (60-79 hp)							
Clean shelter and spread[3]			765	2.90	$2,219		
Labor							
Clean shelter and spread[3]			765	2.50	$1,913		
Haul fill dirt (10 loads @ $5.00/load)					$ 50		
Total	$2,200				$4,845		

All footnotes after Table 15.

Table 14. System VI Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor[2]	Hours	Hourly Rate	Annual Cost	Initial Investment	Annual Cost
Ownership cost							
Front end loader (8 ft) and manure bucket (42 in.)	$1,000	.26			$ 260		
Spreader, rear-unload (180 bu)	1,300	.33			429		
Retention pond (1,990 cu yd @ 50¢/cu yd)	995	.12			120		
Irrigation system[5]							
Pump (30 hp, liquid manure)	2,520	.21			529		
Walkway	135	.16			22		
Sprinklers (2, gun type w/trailer)	600	.23			138		
Pipe (1590 ft - 4 in. aluminum w/accessories)	1,570	.17			267		
Total annual ownership cost					$1,765		
Tractor use (60-79 hp)							
Scrape			98	2.90	$ 284		
Clean shelter and spread[3]			153	2.90	444		
Load and spread from lot			186	2.90	539		
Total tractor					$1,267		
Labor							
Scrape			98	2.50	$ 245		
Clean shelter and spread[3]			153	2.50	383		
Load and spread from lot			186	2.50	465		
Irrigate (8 irrigations × 4 hr)			32	2.50	80		
Total labor					$1,173		
Electricity for irrigation (5680 kwh × 4¢/kwh)					$ 272		
Haul fill dirt (40 loads @ $5.00/load)					$ 200		
Total	$8,120				$4,677		

All footnotes after Table 15.

Table 15. Ownership Cost Factors: Depreciation, Interest, Repairs, Taxes and Insurance, Rounded to Nearest Percent

Item	Life	Depreciation	Interest (7% on ½ initial cost)	Repairs	Taxes and Insurance	Ownership Cost Factor
	(years)		(percent of initial cost)			
Manure facilities	15	6.7	3.5	0.5	1.0	12
Scraper	5	20.0	3.5	1.5	1.0	26
Front end loader	5	20.0	3.5	1.5	1.0	26
Manure bucket	5	20.0	3.5	1.5	1.0	26
Spreaders:						
Rear-unload for all waste	4	25.0	3.5	3.0	1.0	33
Rear-unload for shelter waste only	6	16.7	3.5	2.0	1.0	23
Liquid manure	4	25.0	3.5	3.0	1.0	33
Pumps:						
Agitator	4	25.0	3.5	6.0	1.0	36
Liquid manure	10	10.0	3.5	6.0	1.0	21
Centrifugal	15	6.7	3.5	6.0	1.0	17
Irrigation equipment:						
Self-propelled gun	10	10.0	3.5	6.0	1.0	21
Hand moved sprinklers	8	12.5	3.5	6.0	1.0	23
PVC pipe, hydrants, fittings	40	2.5	3.5	6.0	1.0	13
Aluminum pipe, fittings	15	6.7	3.5	6.0	1.0	17
Gate valves	10	10.0	3.5	6.0	1.0	21
Walkway	20	5.0	3.5	6.0	1.0	16

Source of data: Myron Bennett, "Beef Cattle Waste Disposal Systems," University of Missouri, October, 1972 (mimeographed); Dale Vanderholm, Bruce Berven, and Stewart Melvin, "Cost Data for Alternative Beef Waste Disposal Systems," Iowa State University (mimeographed); Maurice Baker, "Economics of Beef Feedlot Waste Management," paper presented to American Society for Engineering Education, Lubbock, Texas, June, 1972; Purdue University Animal Waste Committee, "Waste Handling and Disposal Guidelines for Indiana Beef Producers," Indiana Agricultural Extension Service, ID-84, 1972; R. C. Wells and G. S. Parsons, "Manure Handling Systems for Free-Stall Dairy Housing, An Economic Appraisal," N. C. Agricultural Extension Service, Circular 480, 1967; O. I. Berge, "Waste Management—What Does It Costs," Hoard's Dairyman, April 10, 1971; Manufacturers catalogs for 1973.

[1] See Table 15.

[2] The assumption is made that there will be some hay, straw, silage, etc., in the retention pond; therefore, the irrigation equipment is designed to handle this material. If provisions can be made to screen all solids from the lagoon, the system cost can be considerably reduced because smaller pumps, pipe and sprinklers can be used. If the roofed area is not guttered, the retention pond must have a capacity of 3.78 ac in. to collect the storm water runoff from a 6 in. rainfall (10-yr, 24-hr storm). If 60% of the average annual rainfall of 50 in. must be pumped each year from the retention pond, 19 ac in. must be land spread. It is assumed that the anticipated 19 ac in. of storm runoff water can be spread on 2 A of land in 8 equal increments. The irrigation system specifications are based on the assumption that 1.2 ac in. per A will be applied at each irrigation on a field of approximately 420 ft × 210 ft with the closest corner 500 ft from the lagoon.

An alternative to the permanent sprinkler system is the hand movable gun type sprinkler system. However, its annual costs are estimated to be $616 greater than the permanent system. The detailed costs associated with that system are as follows:

	Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual Cost
Ownership cost:					
Pump (30 hp, liquid manure)	$2,520	.21			$ 529
Walkway to center of lagoon	70	.16			11
Sprinklers (2, gun type)	600	.23			138
Pipe (1040 ft - 4 in. PVC class 160 w/fittings)	1,480	.18			192
Gate valves (2 - 4 in.)	120	.21			25
Labor (8 irrigations × 0.2 hr)			2	2.50	5
Electricity (1225 kwh × 4¢/kwh)					49
Total					$ 949

[3] Or custom hire a bulldozer to clean shelter.

[4] For design purposes it is assumed that the field is 1500 ft × 1500 ft with the closest corner 700 ft from the lagoon.

An alternative to the hand movable sprinkler system is the self-propelled system. Its annual costs are estimated to be $189 greater. It requires a $3520 larger investment and reduces labor requirements 80%. The detailed costs of that system are:

Self-propelled	Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual Cost
Ownership cost:					
Pump (30 hp, liquid manure)	$2,520	.21			$ 529
Walkway to center of lagoon	475	.16			76
Self-propelled gun traveler	4,600	.21			966
Pipe (2830 ft - 4 in. PVC class 160 w/accessories)	4,060	.13			530
Tractor (30 hp, 4 irrigations × 4 hr per irrigation)			16.0	1.85	30
Labor (4 irrigations × 7.2 hr per irrigation)			28.8	2.50	72
Electricity (8100 kwh × 4¢/kwh)					324
Total					$2,527

[5] It is assumed that some hay, straw, and silage is carried into the retention pond; therefore, the irrigation system is designed accordingly. The retention pond has a capacity of 14.8 ac in. to handle all runoff from the lot for a 10 yr, 24 hr storm (6 in. of rainfall). If 60% of the average annual rainfall of 50 in. must be pumped each year from the retention pond, 74 ac in. must be land spread. It is assumed that the anticipated 74 ac in. of storm runoff water can be spread on 8 A of land in 8 equal increments. For design purposes it is assumed that the field is 630 ft × 550 ft with the closest corner 500 ft from the lagoon.

Permanent alternatives to the hand movable sprinkler systems include the big gun and small sprinkler systems. The investment costs are $4055 and annual costs $588 greater for the big gun system compared to the hand movable system. The investment costs are $1500 greater but the annual costs are $281 less for the permanent small sprinkler system compared to the hand movable system.

Permanent big gun system	Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual Cost
Ownership cost:					
Pump (30 hp, liquid manure)	$2,520	.21			$ 529
Walkway	135	.16			22
Sprinklers (9, gun type)	2,250	.23			518
Pipe (2480 ft - 4 in. PVC class 160, w/fittings)	3,480	.13			431
Gate valves (9 - 3 in.)	495	.21			104
Labor (8 irrigations × 1.0 hr/irrigation)			8.0	2.50	20
Electricity (5680 kwh × 4¢/kwh)					272
Total					$1,896

Permanent small sprinkler system	Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual Cost
Ownership cost:					
Pump (5 hp centrifugal)	$ 550	.17			$ 94
Sprinklers (99, 7.8 gpm capacity)	720	.23			166
Pipe (6720 ft - 1 in. - 2½ in. class 160 w/fittings)	4,780	.13			615
Gate valves (11 - 2½ in.)	275	.21			58
Labor (8 irrigations × 2 hr/irrigation)			16	2.50	40
Electricity (2139 kwh × 2.5¢/kwh)					54
Total					$1,027

Comparison of Systems

Table 16 presents a summary of the estimated initial investment and annual costs of six alternative waste management systems. The systems with cattle in dirt lots without shelter or on pasture are not included because the nutrients in the manure are directly utilized by crops or grasses planted or growing in the lots. In addition the stocking rates are such that pollution due to surface runoff is negligible.

Table 16. Estimated Initial Investment, Annual Costs and Labor Requirements for Six Alternative Waste Management Systems for a 500 Head 1000-lb Beef Cattle Operation

Waste Management System	Initial Investment	Annual Ownership Cost[1]	Annual Labor Requirement	Total Annual Cost
System I —Paved Lot with Spreading in Solid Form[2]	$ 4,605	$1,031	1,110 hr	$ 7,038
System II —Paved Lot with Storage and Spreading in Solid Form[2]	8,055	1,473	955	6,632
System III —Paved Lot with Storage and Spreading in Liquid Form[2]	23,445	4,088	1,101	10,243
System IV —Paved Lot with Lagoon and Irrigation[1]	16,745	2,858	843	7,155
System V —Sheltered Dirt Lot with Spreading in Solid Form[3]	2,200	663	765	4,845
System VI —Dirt Lot with Limited Shelter with Spreading in Solid Form[4]	8,120	1,765	469	4,677

[1] Does not include tractor ownership cost.
[2] 55 sq ft per animal—20 sq ft under shelter, 35 sq ft outside; 80% of waste dropped outside, 20% inside; bedding = 2 lb/day; lot scraped daily; shelter cleaned twice per year.
[3] Confinement—50 sq ft per animal under shelter; bedding = 10 lb/day; cleaned twice per year.
[4] 215 sq ft per animal—20 sq ft under shelter, 195 sq ft outside; 80% of waste dropped outside; bedding = 2 lb/day; lot scraped 6 times per year; shelter cleaned twice.

APPENDIX I

Lagoon Design for 200 Beef Cattle

The tentative guidelines approved by the North Carolina Board of Water and Air Resources set the minimum volume per cow at 660 cu ft. For 200 cattle, 132,000 cu ft of storage must be provided in the lagoon. If a depth of 10 ft is selected, the *average* area (area at one-half the depth) would be 13,200 sq ft (132,000 cu ft ÷ 10 ft). To get the waste into the lagoon as well as physically construct the structure, an average width of 50 ft will be selected. The average length will then be 264 ft (13,200 sq ft ÷ 50 ft). Therefore, a lagoon with 1:1 side and end slopes will have the dimensions as shown in Figure 4.

For other depths and widths, the procedure for sizing would be the same as outlined in this example.

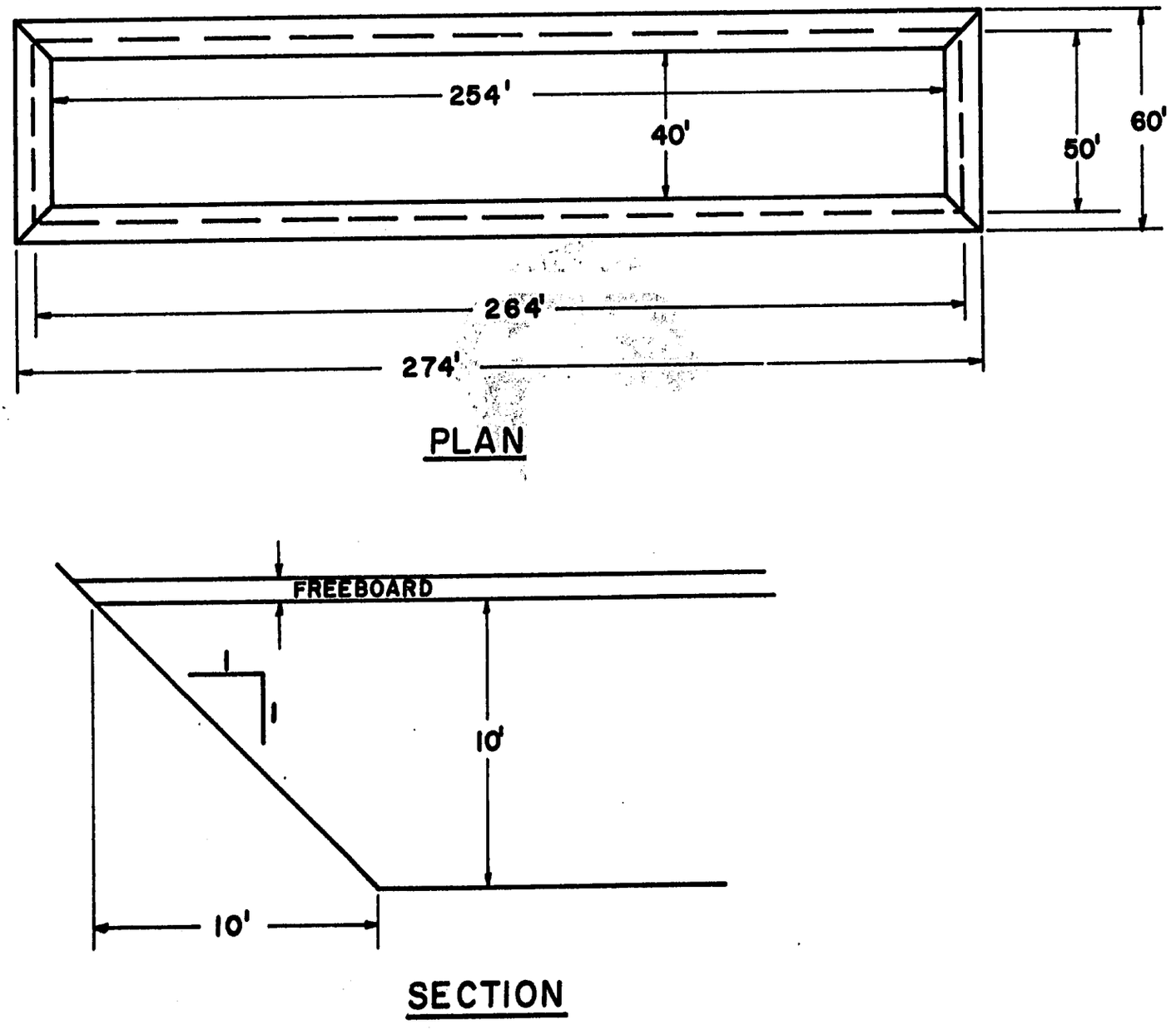


Figure 4. Plan and Section View of a Lagoon.

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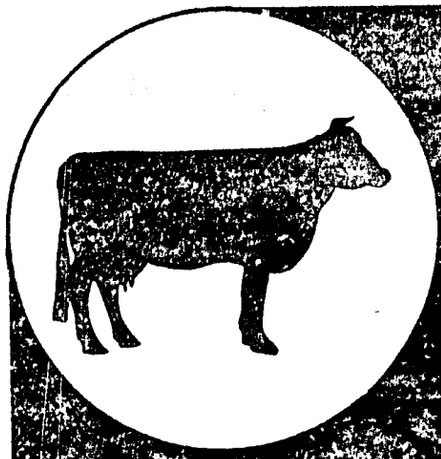

DAIRY WASTE MANAGEMENT ALTERNATIVES

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Prepared by

B. L. Carlile, Soil Scientist
S. H. Dobson, Extension Agronomist
L. B. Driggers, Extension Biological and Agricultural Engineer
J. M. Falter, Extension Entomologist
*G. J. Kriz, Extension Biological and Agricultural Engineer
J. L. Lutz, Soil Scientist
M. R. Overcash, Biological and Agricultural Engineer
G. S. Parsons, Extension Dairy Husbandry Specialist
J. A. Phillips, Extension Soil Scientist
R. E. Sneed, Extension Biological and Agricultural Engineer
R. C. Wells, Extension Economist

* Coordinator

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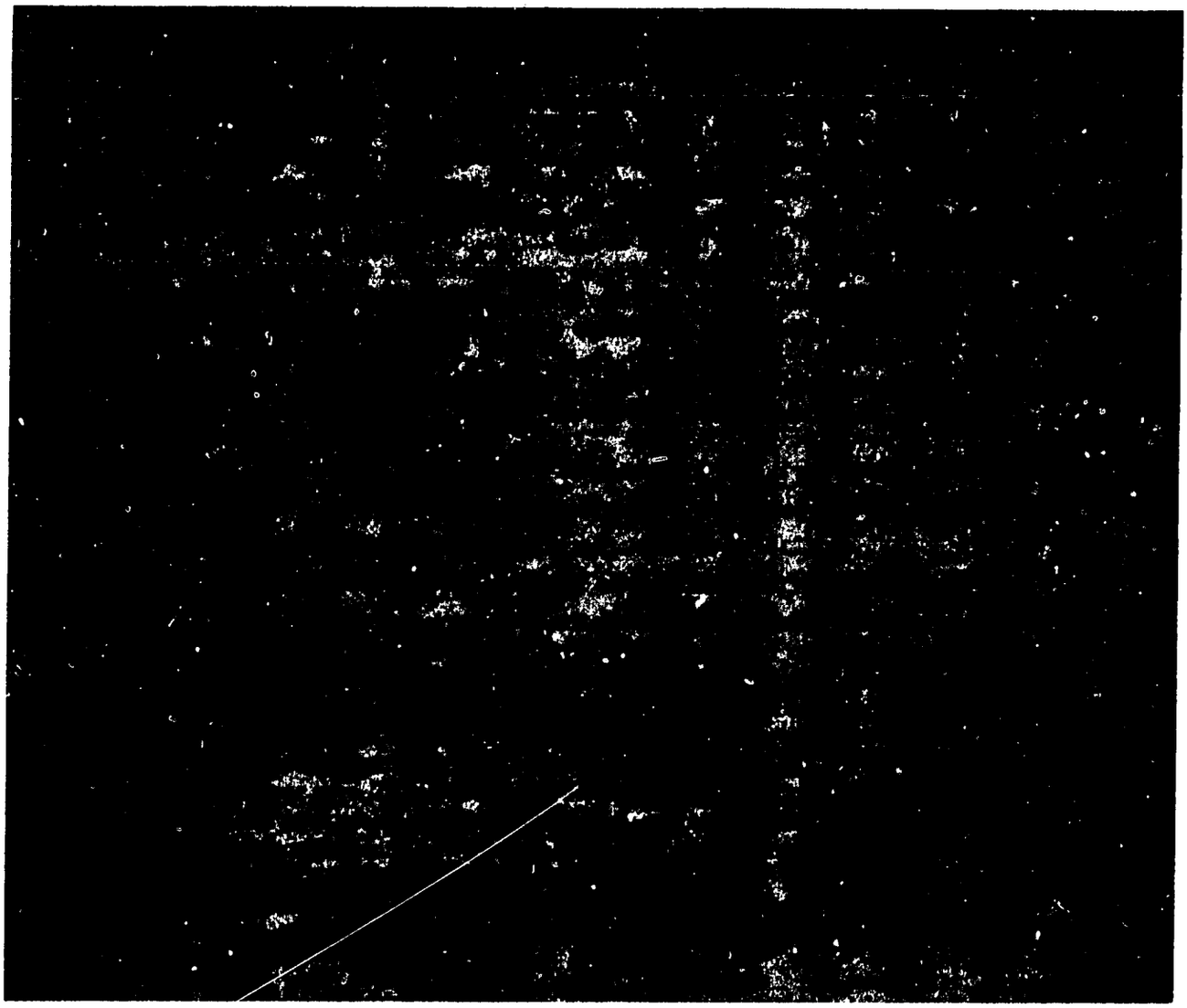
Dairy Waste Management Alternatives



ALTERNATIVE WASTE MANAGEMENT SYSTEMS

Disposal of dairy manure represents one of the most difficult materials handling jobs. The daily manure production, feces and urine, per 1,000 pounds (lb) of body weight is approximately 75 lb, of which about 70% or 53 lb is solids, and 30% or 22 lb is liquid. On this basis, the daily manure production of a mature Holstein cow weighing 1400 lb is about 105 lb or 1.6 cubic feet (cu ft).

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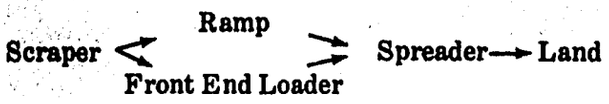
Studies show that approximately 2 cu ft per cow per day are handled when manure is stored in a tank in the liquid form from a non water-flush cleaning system. When manure is flushed from a paved lot, considerably more volume must be handled.

To date, most waste management systems ultimately return the manure to the land. Depending on the system selected, there may be a storage or detention period between cleaning the paved areas and land disposal. Care must always be taken to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

System I: Direct Spreading in Solid Form

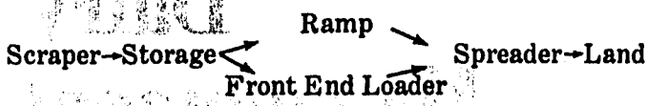


Handling manure in a solid form is not appealing to many dairymen primarily because of frequency of disposal even though there are other considerations such as weather, land availability, odor and proximity of neighbors. Tractor mounted scrapers deposit manure into piles where it is picked up with a tractor mounted loader and deposited in a spreader or onto a ramp where it is pushed off into a spreader.

Table 1 shows the quantity of manure produced daily by different size herds and the number of spreader loads required to remove it daily.

Field spreaders are available as tractor drawn or truck mounted units. Flail type tank spreaders will hold either liquids or solids and have either a side or rear discharge. A spreader with beaters should have a rear gate, preferably hydraulically operated, that can be opened and closed from the tractor seat. Select a spreader that will not leak the contents along the road and that will spread the material in small pieces on the land surface so as to minimize fly breeding.

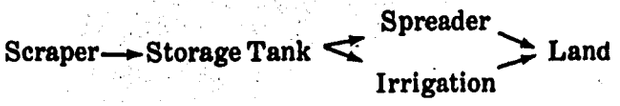
System II: Storage and Spreading in Solid Form



This system usually has short term storage between the time of collection and land spreading. An area with a capacity of 1.2 cu ft per cow per day located adjacent to the ramp or pick-up area is required for temporary storage. During fly season manure piles must be removed and spread at least every 4 days in order to break the life cycle of the fly.

If long term storage is required, the manure must be stored in a tight-screened and trapped manure shed. Consult your local sanitarian before making such an installation.

System III: Storage and Spreading in Liquid Form



Some producers have felt that a liquid system is best, but interest has drastically declined in the installation of liquid systems requiring a concrete storage tank. Land spreading of liquid waste is not as simple as many pictured. Two major disadvantages are the cost of the system and odors associated with agitating and field spreading partially decomposed manure. In addition, a greater volume of manure is handled in a liquid system than a solid system.

Manure handled by this system is scraped from the paved areas directly into the storage tank. The size of the tank is dependent upon the number of cows in the herd and the frequency of spreading as shown in Table 2.

Table 1. Daily Production of Solid Manure from Different Size Herds of 1400-lb Cows

Number of Cows	Daily Production T	Daily Spreader Loads	
		108 bu Spreader	100 bu Spreader
10	0.5	0.2	0.1
25	1.3	0.4	0.3
50	2.6	0.9	0.5
75	3.9	1.3	0.8
100	5.0	1.8	1.0
125	6.5	2.2	1.3
150	7.9	2.6	1.6

Table 2. Gallons of Storage Required for 1400-lb Cows by Days of Storage and Herd Size

Number of Cows	Days of Storage					
	10	30	45	60	75	90
	Gallons					
10	1,500	4,500	6,750	9,000	11,250	13,500
25	3,750	11,250	16,850	22,500	28,100	33,750
50	7,500	22,500	33,750	45,000	56,250	67,500
75	11,250	33,800	50,700	67,500	84,500	101,300
100	15,000	45,000	67,500	90,000	112,500	135,000
125	13,750	56,250	84,450	112,500	140,750	169,000
150	22,500	67,500	101,000	135,000	169,000	207,000

Table 3 gives the storage capacity per foot of length for tanks with different widths and depths. This table along with Table 2 will enable the producer to determine the tank size required to store liquid manure.

Table 3. Storage Tank Capacity per Foot of Length

Tank Width Ft	Tank Depth Ft		
	6	8	10
	Gal/Ft of Length		
12	540	720	900
14	630	840	1050
16	720	960	1200
18	810	1080	1350
20	900	1200	1500
22	990	1320	1650
24	1080	1440	1800

Water must be added to the storage tank to bring the waste to a pumpable consistency. Table 4 shows the approximate quantity of water needed to increase the moisture content of the manure. An approximate range of moisture in manures without bedding is as follows:

- 75-82% moisture - stiff
- 80-85% moisture - fluid or semi-liquid—quite thick slurry
- 83-90% moisture - liquid—fairly thin liquid at 90%
- 93-97% moisture - irrigation consistency

It is evident from Table 4 that the amount of water added to produce a pumpable slurry might be more than the original quantity of manure. For example, the addition of 11.25 gallons (gal) of water to 1 cu ft of fresh manure at 75% moisture raises the moisture content to 90% and changes the volume from 1 cu ft to 2.5 cu ft.

A storage tank requires an agitator or pump-agitator which serves the dual role of agitating and filling the spreader tank. One distinct disadvantage with liquid manure storage is odor while agitating and field spreading. The liquid slurry should not be spread on a hot humid (muggy) day because odors may create a nuisance.

Where odor is a problem, the producer might elect to equip his spreader with a soil injector. This equipment places the liquid slurry 4 to 6 inches (in.) below the ground surface and covers it immediately, drastically reducing odor. Be careful to select a field that is relatively free of large stones, stumps and roots when using the injection method.

System IV: Lagoon and Irrigation

Anaerobic lagoons are being looked upon with favor by some producers. To meet the design criteria approved by the North Carolina Board of Water and Air Resources, a volume of 660 cu ft must be provided in the lagoon for each cow.

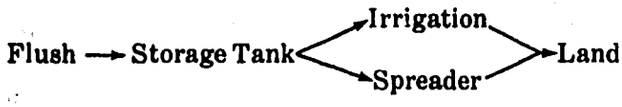
Lagoons are storage ponds in which the water level must be controlled. There has been very little experience with lagoons for dairy waste in North Carolina. Research with swine waste lagoons in North Carolina indicates explicitly that the effluent cannot be discharged into a watercourse. Research in Florida on dairy waste lagoons produces the same evidence. Therefore, any overflow or discharge must be returned to the land.

The most practical way to control the water level in the lagoon is to irrigate the effluent. Caution must be exercised to prevent surface runoff. The system should be designed for minimum pipe and sprinkler movement because this is a "nasty" job. Before moving, flush out the irrigation system with clean water. The lagoon effluent should not be spread on a hot humid (muggy) day because odors resulting from the spreading operation may create a nuisance.

A tank wagon equipped with a vacuum pump might be used with small lagoons, but its volume will limit its use.

Evidence indicates that a lagoon serves as a nitrogen trap by accumulating nitrogen in the sludge build-up on the bottom. This build-up of solids indicates that the sludge must be removed at some future date. However, definite recommended cleaning intervals are not established at this time. Because the decomposition process that takes place in a lagoon reduces the quantity of nutrients, particularly nitrogen, in the effluent, less land area is needed for land spreading.

System V: Flush, Storage and Irrigation



The water flush system of cleaning the paved lot has generated tremendous interest among producers, but it has some serious disadvantages. The real problem is disposing of all the dirty water as it leaves the paved lot. If a storage tank is used with this system, only short term storage is feasible because of the large volume of waste and water that must be handled. The waste load is upwards from 100 gal per cow per day. This is a minimum of 7 times the daily load of a conventional liquid manure system as outlined under System III.

System VI: Flush, Lagoon and Irrigation

Dairies that use large quantities of water for cleaning the paved lot, washing udders and cleaning the facilities and equipment require large liquid storage areas. Storage areas that have to be emptied very infrequently are preferred and thus producers who use the flush technique are centering on lagoons for manure storage. The lagoon capacity must be designed on the basis of the total amount of water to be stored and not on the design criteria of 660 cu ft per cow that is approved by the North Carolina Board of Water and Air Resources. The latter does not provide sufficient lagoon capacity.

Provisions must be made to control the water level in the lagoon. Because of the volume, land spreading with irrigation equipment will generally be more feasible than with a tank spreader.

Other Alternatives

Drying. Drying is a method receiving consideration. Michigan State University has pioneered in this work, and their research indicates a total drying cost of over $11 per T of wet manure. At this time, drying must be investigated on an individual enterprise basis.

Refeeding. Refeeding by formulation of diets to include animal waste as an ingredient is being studied. Before being incorporated into feed, it is generally agreed that some type of processing is needed. Drying has been closely allied with refeeding. Before refeeding can be practiced, it must be proven that no detrimental effects will result from toxic hazards caused by feed additives, pesticides or pathogenic microorganisms, and also the practice will require approval by the Food and Drug Administration.

Composting. Composting has received limited study, but on a large scale does not appear to be practical at this time. To achieve rapid composting, aeration is essential.

STORM RUNOFF CONTROL

A retention pond should suffice to collect storm runoff from paved areas, dirt lots and drainage areas outside the paved areas that channel runoff through the lots for systems that handle manure in a solid form or use a storage tank. Because the runoff can be diverted to a lagoon it is not necessary to construct a retention pond where a lagoon is used. As of this writing, most pollution control enforcement agencies are proposing storm runoff water retention facilities for a 10-year, 24-hour storm. This means that a dairy must have an ade-

quate liquid waste retention facility to retain all runoff from areas where manure collects or is deposited for the worst storm likely to occur within a 24-hour period once in 10 years. In North Carolina this storm produces an average of 6 in. of rainfall. If the amount of rainfall from a 10-year, 24-hour storm is known for your local area, this value should be used to determine the volume of the retention pond.

To store 6 in. of rainfall, 3750 gal or 500 cu ft of storage for each 1000 sq ft of area that drains to the retention pond is required. The area includes all paved and dirt lots, roofed areas and areas outhel runoff water through any area where the manure collects or is deposited.

Figure 1 gives a typical cross-section of a retention pond. The depth of the pond is dependent on site conditions. A good starting depth is about 4 ft. The side slopes should be no less than 1 (rise) to 2 (run). The bottom should slope approximately 1 to 100 toward one end with the last 5 ft having a slope of 1 to 10 in both directions toward the strainer location. This allows the pond to be pumped dry. The strainer should be located about 1 ft above the bottom to prevent clogging and preferably should be fixed.

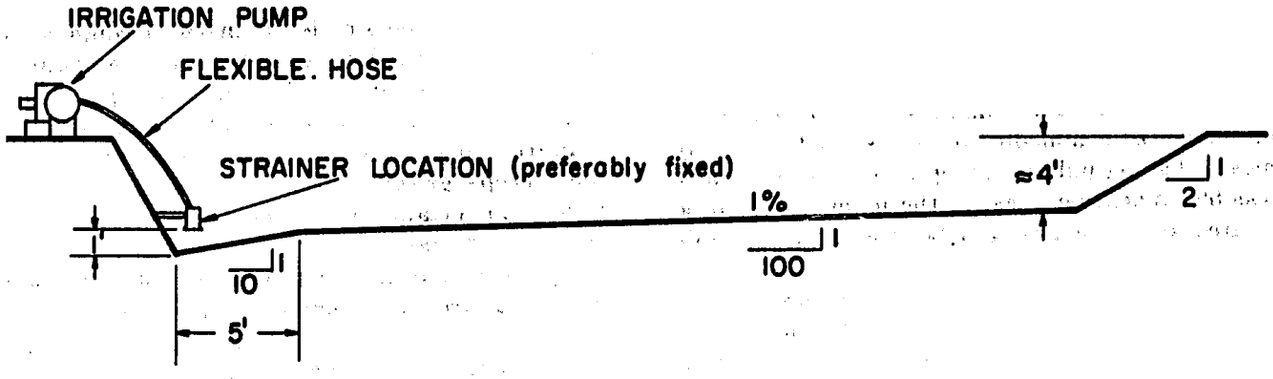


Figure 1. Typical Cross-section of a Retention Pond.

The retention pond must be kept dry except for the interval between the time that rain is falling and the land is too wet for irrigating the effluent. Normally an irrigation system should be used to spread the effluent. A tank wagon equipped with a vacuum pump might be used with small retention ponds, but its volume will limit its use.

PARLOR AND MILKHOUSE WASTE WATER

Wash water from the parlor and milkhouse must be collected to prevent it from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

When the manure is handled in a solid form, provisions must be made to collect the waste water separately in a storage tank, retention pond, or septic tank.

When the manure is scraped into a storage tank, it is better to collect the waste water separately in a retention pond or septic tank than to divert it into the manure storage tank. If the waste water is diverted to the manure storage tank, the capacity of the storage tank needs to be increased by 20% for the given clean-out interval shown in Table 2.

With a lagoon system, all waste waters from the parlor and milkhouse can be piped into a lagoon.

UTILIZATION AND LAND REQUIREMENTS

Utilization of dairy manure by direct land appli-

Table 4. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Initial			Percent Moisture Desired	Amount of Water to be Added to Each Cu Ft to Give the Desired Percent Moisture		Final Volume per Each Original Cu Ft	
Volume		Percent Moisture					
Cu Ft	Gal			Cu Ft	Gals	Cu Ft	Gals
1.0	7.5	85	90	0.50	3.75	1.50	11.25
			95	2.00	15.00	3.00	22.50
1.0	7.5	80	85	0.33	2.50	1.33	10.00
			90	1.00	7.50	2.00	15.00
			95	3.00	22.50	4.00	30.00
1.0	7.5	75	80	0.25	1.88	1.25	9.38
			85	0.67	5.00	1.67	12.50
			90	1.50	11.25	2.50	18.75
			95	4.00	30.00	5.00	37.50
1.0	7.5	70	75	0.20	1.50	1.20	9.00
			80	0.50	3.75	1.50	11.25
			85	1.00	7.50	2.00	15.00
			90	2.00	15.00	3.00	22.50
			95	5.00	37.50	6.00	45.00

cation is generally recommended. However, because large quantities of manure are generated in concentrated operations, many of which have limited land areas, the manure is often treated as an unwanted commodity to be disposed of by any means that are publicly acceptable or economically feasible. Whenever possible the manure should be treated as a resource and be used as a valuable source of plant nutrients.

Animal manures were one of the earliest sources of plant nutrients. They constituted a major portion of the soil fertility experiments on the first agricultural experiment station, the Rothamsted Station, in England, which was started more than 140 years ago. Likewise, they were used extensively in all of the early soil fertility experiments in the United States. In almost all of those early experiments cattle manures proved equal to or better than commercial fertilizers which at that time were of low quality compared to modern commercial fertilizers. This is well illustrated by some of the Rothamsted data which are presented here for both their historical and technical value (Figure 2).

During the past 40 to 50 years dairy manures have been largely replaced by commercial fertilizers as sources of plant nutrients. This may be attributed to: 1) improved physical and chemical quality of commercial fertilizers; 2) improved methods of handling and applying commerical fertilizers; 3) the smaller tonnage of commerical fertilizers required to give the same amount of plant nutrients; and 4) the lower cost per pound of plant nutrients in commercial fertilizers. Dairy manure can be used as a source of nutrients for most crops grown in North Carolina except tobacco and certain other crops where nitrogen control is essential.

The principal plant nutrients supplied by both dairy manures and commercial fertilizers are nitrogen (N), phosphorus (P) and potassium (K). These nutrients are expressed as percents nitrogen (N), phosphate (P_2O_5) and potash (K_2O). In addition to N, P and K, dairy manure usually contains an appreciable amount of calcium, magnesium and sulfur; and traces of manganese, boron, copper and zinc, all of which are essential for plant growth.

Amount and Composition of Dairy Manures

The daily production and the composition of dairy cattle manure varies with the size and breed of animal, and the kind and amount of feed consumed. Table 5 presents representative values for the amount and composition of dairy manure.

These figures are approximate averages and should be used only as such. The actual composition of any particular batch of manure will be determined by the amount of moisture, the amount of bedding material present, the rations fed, and

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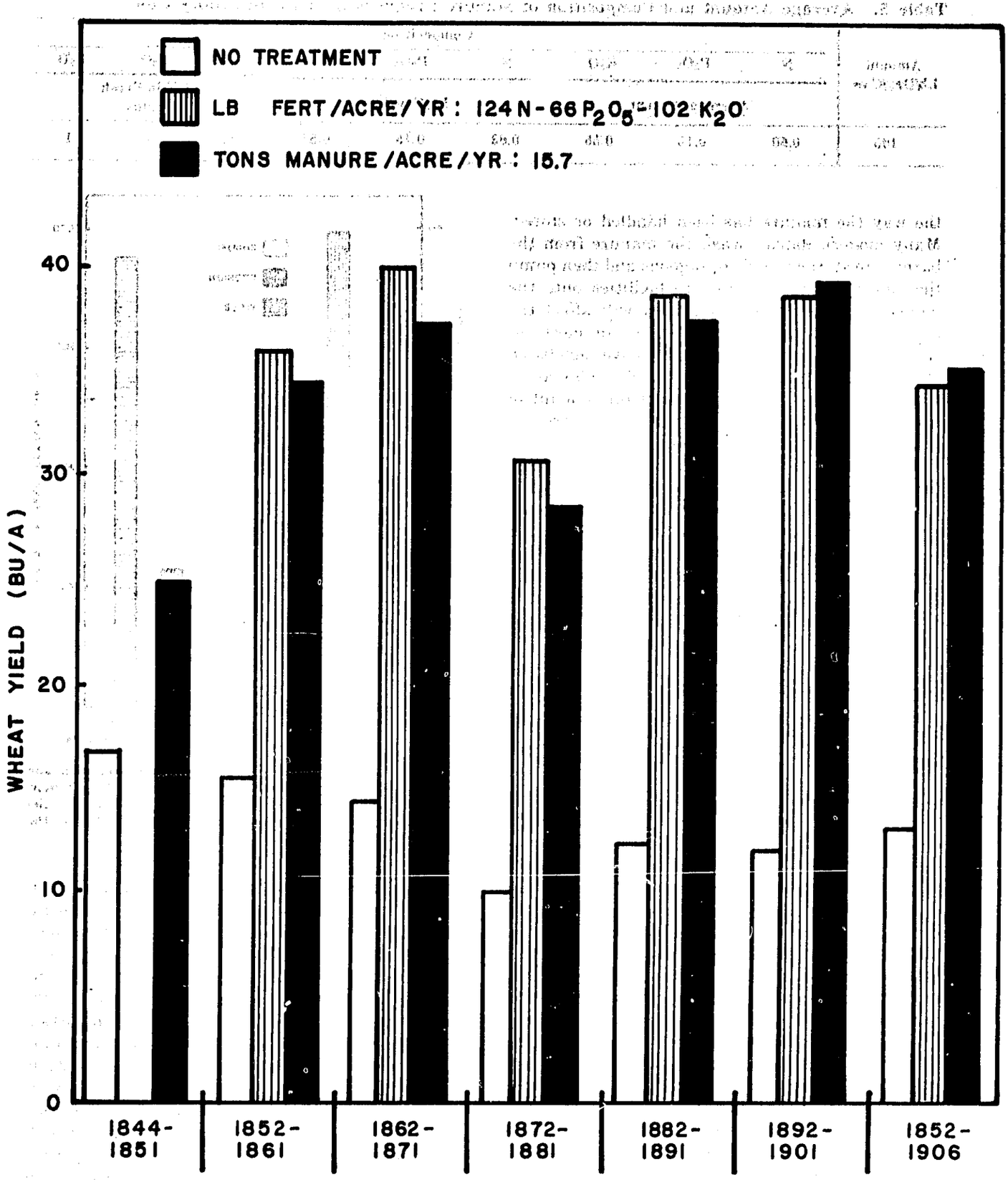

Figure 2. Effect of cattle manure on wheat yields on the oldest agricultural experiment station, at Rothamsted, England. The 10-year periods and the 53-year average (1852-1906) show that yields on the manured plots were about the same as those on the fertilized plots.

Table 5. Average Amount and Composition of Manure Produced by a 1400-lb Dairy Cow

Amount Lb/Day/Cow	Composition								
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	Average Percent			Lb/Cow/Day			Lb/T in Fresh Manure		
105	0.60	0.15	0.55	0.63	0.15	0.57	12	3	11

the way the manure has been handled or stored. Many modern dairies wash the manure from the barns into storage tanks or lagoons and then pump the slurry from those storage facilities onto the fields. The amount of water used will affect the composition of the slurry. Because in most instances it would not be practical to have each batch of manure analyzed, the figures in Table 5 may be used to get approximate values of the amount of manure in the slurry and the amount of nitrogen, phosphate and potash contained in it.

The relative value of cattle manure as compared to commercial fertilizers will be determined by the composition of the manure and by the cost of handling it. This will vary from farm to farm and should be estimated in each individual situation. An important item that should not be overlooked in estimating the value of manure is the fact that it must be disposed of but the cost of disposition is partially offset by its fertilizer value.

Effects of Dairy Cattle Manure on Soils and Crops

Dairy cattle manure has several beneficial effects on the chemical, physical and biological properties of soils.

Chemical Effects. The principal chemical effect of manure is the supplying of the major plant nutrients: nitrogen, phosphate, and potash. It also contains a number of other chemical elements necessary for plant growth. The effect of cattle manure on crop yields is shown in Figures 2 and 3. Figure 2 shows that manure was as effective as commercial fertilizers in producing wheat on the Rothamsted Experiment Station. Figure 3 shows that manure produced almost 1900 pounds of seed cotton per acre per year on the Soil Erosion Experiment Station near Statesville, North Carolina. The check plot at the Statesville Station was not fertilized, and, therefore, the yield on it is not comparable to that of the manured plot. In contrast to commercial fertilizers, dairy cattle manure supplies organic matter to soils, and this is usually considered beneficial in increasing the nutrient-holding capacity of soils.

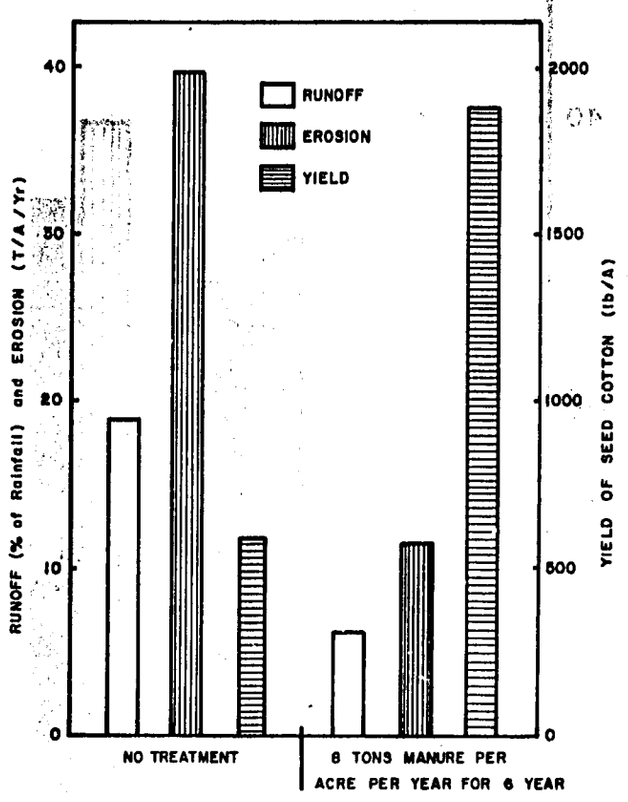

Figure 3. Effect of cattle manure on runoff, erosion and cotton yield at the Statesville Soil Erosion Experiment Station. (The yields are not comparable because the check plots were not fertilized. The good yield on the manured plot is important.)

Physical Effects. If manure is applied to the surface of the soil, it will help to prevent soil crusting. If mixed with the soil, it will decompose more rapidly and the products of decomposition will improve soil structure and the general physical condition of the soil. Thus, whether applied to the surface or mixed with the soil it will be important in conserving water and soil by reducing runoff and erosion. This is well illustrated by the data in Figure 3. Dairy cattle manure frequently is credited with increasing the available water-holding capacity of soils. This is generally not true. If the manured soil contains more water, it very probably is because more soaked in during rainfall or irrigation.

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Biological Effects. Manure is a source of food, and hence energy, for soil microorganisms that decompose it. These soil microorganisms have many very important direct and indirect effects on many physical, chemical, and biological properties of the soil.

Factors Affecting Rates of Application

Several factors affect the amount of manure that might be applied to any given land area. They are: (1) the use to be made of the land—whether it is to be used for crop production or for manure disposal only; (2) if used for crop production, the kind of crop to be grown; (3) the characteristics of the soil including texture, depth and fertility status; (4) topography as it affects runoff and erosion; (5) the season of the year in which the manure is to be applied; and (6) possibility of environmental pollution, particularly the contamination of surface and ground water by excessive leaching or runoff. In this connection care must always be taken to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

From the standpoint of crop production the amount of manure to be applied to any particular crop is determined by the nitrogen content of the manure and the nitrogen requirements of the crop. This will be explained more fully in the following pages.

Crop production is not the only factor to be considered in determining the amount of manure that might be applied to any particular soil. Another very important factor is the possible effect of the manure on environmental pollution, particularly contamination of surface or ground water. The two elements contained in manure which are most likely to cause problems in water are nitrogen, particularly in the nitrate form, and phosphorus. Excessively large amounts of nitrates can be toxic to animals and considerable accumulation of nitrates and phosphate in surface water causes eutrophication (excessive growth of algae and other (water-loving plants). When manure decomposes in the soil the nitrogen will ultimately be converted to the nitrate form which is very easily leached. If it leaches downward in the soil to a poorly drained layer, in which there is sufficient organic matter for microorganisms to live on, the nitrate will be converted to the ammonium form which is less easily leached and less toxic to animals, and is likely to be volatilized.

Table 6 gives the relative potential nitrate leaching rates together with some of the soil properties affecting leaching. As a general rule, it would be undesirable to apply heavy applications of manure to soils with a high nitrate-leaching potential. On such soils it would be desirable to use smaller applications distributed throughout the year, making sure that the total application within a year is not excessive.

On fine textured soils infiltration is retarded and surface runoff may contribute to stream pollution. However, as shown in Figure 3 manure is very important in reducing surface runoff.

Table 6 also shows the relative phosphate-fixing capacity of representative soils in North Carolina. Many soils have the capacity to "fix" phosphorus; that is, render it relatively insoluble and on those soils phosphate leaching is usually not a problem. It is a problem, however, on sand and care should be taken not to add large amounts of phosphorus to soils with low phosphate-fixing capacity. As a general rule, the red to reddish-yellow soils with considerable clay in the subsoil have the higher phosphate-fixing capacity. The relative values for some typical soils in the state are given in Table 6.

The leaching of nitrates, phosphates and other plant nutrients is affected by a number of factors such as soil temperature (which affects the rate of decomposition of manure), the kind of crop being grown and, hence, the rate of utilization of the nutrients by the crop, and the soil moisture conditions. Under normal climatic conditions in North Carolina the soils are usually wet during the winter and relatively dry during the summer. "Normal" summer rains penetrate the soil to relatively shallow depths (6 to 10 to 15 inches, depending upon the texture) and under high summertime temperatures the moisture is rapidly lost by evaporation. Under such conditions leaching of nitrates to the water table is improbable, except on extremely coarse-textured soils.

Because only about half of the nitrogen contained in the manure will become available during the first growing season, it might be possible to apply about twice the recommended amount of nitrogen to grain and forage crops without danger of nitrate toxicity or groundwater contamination. However, in succeeding years this carry-over should be taken into account and rates adjusted accordingly. Though data are not available, it is generally believed that more than 50 percent of the N in a slurry will become available the first year. The ratio of N-P_2O_5-K_2O in dairy cattle manure is about 4-1-4 (Table 5). Therefore, application of sufficient manure to get the desired amount of nitrogen usually will add sufficient phosphorus and potash. If twice the recommended amount of

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Table 6. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Texture of Topsoil (6-10 in.)	Texture of Subsoil (6-10 to 20 in.)	Critical Soil Property Affecting Movement of N and P	Relative Potential Nitrate Leaching	Relative Phosphate-Fixing Capacity	Typical Soil Series
Sand	Sand	Low water table, very high permeability	Very high	Very low	Lakeland, Wagram
		High water table	Low	Very low	Bibb, Pelham, Plummer
Sandy loam, or Very fine sandy loam	Sandy clay loam, Clay loam, or Clay	Loose to hard, moderately permeable subsoil	Medium to high	Low	Altavista, Durham, Granville, Norfolk
		Slowly permeable, somewhat plastic subsoil	Medium to low	Medium	Appling, Cecil
		Very slowly permeable, plastic sticky subsoil	Very low	Medium to low	Creedmoor, Enon, Helena, Iredell, Whitestore, Wilkes
		High water table	Low	Medium to low	Lumbee, Rains, Roanoke, Wehadkee, Worsham
Silt loam, or Loam	Silty clay loam, Clay loam, or Clay	Moderately permeable, plastic subsoil	Medium to low	Medium to high	Alamance, Chandler, Chester, Congaree, Fannin, Georgeville, Herndon, Hiwasse, Lloyd, Mecklenburg, Orangeburg, Porters, Ruston
		Slowly permeable, plastic, sticky subsoil	Low	Medium	Bertie, Craven, Dunbar, Nason
		Very slowly permeable, plastic, sticky subsoil	Very low	Low	Lignum, Tatum
		High water table	Low	Medium	Bayboro, Kinkora, Portsmouth, Roanoke
Silty clay loam, or Clay loam	Silty clay, or Clay	Slowly permeable, compact subsoil	Medium to low	High to very high	Caroline (eroded), Cecil (eroded), Davidson, Georgeville (eroded), Hayesville (eroded), Marlboro (eroded)
		Moderately to slowly permeable, granular subsoil	Low	High to very high	Appling (eroded)
		High water table	Very low	Medium	Any low, poorly-drained areas with topsoil removed by burning or stripping
Clay - Eroded or denuded areas, void of topsoil and, thus, with subsoil exposed		Slow to very slowly permeable, compact or granular subsoil	Low to very low	High to very high	Any area with clay exposed by erosion, stripping or burning
		High water table	Very low	Medium	Same as above, but with high water table

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nitrogen is added (based on 50% availability) it is possible that excessive potash might be added. Some believe that excessive potash in forages may cause tetany in animals. If the manure does not supply sufficient phosphorus, superphosphate may be used to supplement that in the manure.

Phosphorus is mainly in the organic form in dairy cattle manure. Phosphorus availability is directly related to the rate of manure decomposition and is much slower than that of nitrogen. Potassium in dairy cattle manure is an inorganic salt that is easily leached and is readily available for plant use. Most of the other plant nutrients, including the micronutrients, will be released as the manure decomposes.

Losses of nutrients from manure may be by leaching of soluble salts or volatilization. However, these losses can be held to a minimum if the material is applied to the land and incorporated into the soil. Dairy cattle manure that is high in nitrogen should be applied to the land at least 2 to 4 weeks prior to planting to prevent ammonia from burning the plants and to reduce possible salt injury. Where available land is required for feed production, management practices must be developed to permit land spreading at suitable times.

How To Determine the Amount to Apply

The nutrient composition of the manure is very dependent on the type of waste management system. Producers, especially those using liquid storage tanks and lagoons, should have the slurry or lagoon liquor analyzed. There are several commercial laboratories in North Carolina that have expressed an interest in analyzing waste samples. For further information, contact your county extension agent or one of the regional offices of the Office of Water and Air Resources of the Department of Natural and Economic Resources located in Greenville, Raleigh, Concord and Asheville.

Estimates of the existing soil nutrient supply can be obtained by soil tests made by the Soil Testing Division of the North Carolina Department of Agriculture. Rates of application should be based on the recommended amount of nitrogen needed to supplement the existing soil nitrogen supply for the particular crop to be grown. Contact your county extension agent for further information on determining the rate of application.

Illustrative examples are shown for handling the waste in solid and slurry forms, and as lagoon effluent. Each example is for a specific set of conditions that may or may not be applicable to your area. Each example is based on the approach that the dairy manure is to be a source of fertilizer with the long range objective of optimum crop production.

If the approach is taken whereby the land is to be used for waste disposal without consideration of any crop, higher application rates than given in the examples below could be used. However, the risk of groundwater and surface water contamination is greater, a very good understanding of the characteristics of the soil is essential, and lastly, a resource in the form of fertilizer is being wasted. If this latter approach is used, contact your county extension agent or Soil Conservation Service district conservationist.

Examples

In the examples given below, information on the following will be given based on handling the manure from a 100-cow herd of 1400-lb cows:

—Rate of application.
—Total land area needed per year.
—Land area required for spreading at definite intervals.
—Number of trips required for spreading at definite intervals (except for lagoon example).
—Size of retention pond when needed.

THE EXAMPLES DO NOT TAKE LOCATION, TOPOGRAPHY, SEASON OF YEAR, WEATHER CONDITIONS, STAGE OF CROP GROWTH OR SOIL TYPE INTO ACCOUNT. These factors will be discussed in a subsequent bulletin. The numbers in the parentheses show how the calculations are made.

Solid Form. Assume that the fertilizer recommendations for corn on a particular soil are as follows:

N	P_2O_5	K_2O	Lime
lb/A	lb/A	lb/A	T/A
180	140	160	2

All of the nitrogen (N) is to be supplied to the manure.

1. What is the rate in tons per acre needed to supply the recommended amount of nitrogen?

From Table 5 the average amount of N in fresh cattle manure is 12 lbN/T. The rate in tons per acre is determined by dividing lbN needed by the lbN/T of manure. The result is 15 T/A (180 lb/A ÷ 12 lb/T).

2. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

From Table 5, a 1400-lb dairy cow produces 105 lb/day of manure. This is equivalent to 19.15 T/yr [(105 lb/day x 365 days/yr) ÷ (2000 lb/T)] or 1915 T/yr from a 100-cow dairy herd. Dividing the total amount of manure by the desired application rate gives the total land area required. The result is 128 A (1915 T ÷ 15 T/A).

Because only 50% of the total N is available the first year, twice the application rate could be made the first year. Thus 64 A of corn could be fertilized in a safe manner for the first year only.

3. How much area is required for daily spreading?

From Table 5, a 1400-lb dairy cow produces 105 lb/day of manure. Thus a 100-cow herd will produce 10,500 lb/day or approximately 5 T/day (10,500 lb/day ÷ 2000 lb/T). From the answer to Question 1, the maximum rate of application is 15 T/A. Dividing the daily production rate by the application rate gives the area required. The result is 0.33 A/day ÷ 15 T/A).

4. If the manure is spread daily, how many trips are required with a manure spreader?

There are several sizes and types of manure spreaders. Because the cost of an individual spreader is dependent on the size and type, haul distance may be an important factor to consider. From the answer to Question 3, the daily production rate is 5 T/day. From Table 1, one trip with a 180 bu capacity or two trips with a 108 bu capacity spreader are required.

5. What size retention pond is required to retain the storm runoff water from a 6-in. rainfall (24-hr 10-yr storm) and the parlor and milkhouse waste water?

A 100-cow operation would have approximately 150 sq ft of paved and roof areas per cow. Thus the area contributing to the retention pond excluding any area outside the lots that channels runoff water through the lots is 15,000 sq ft (150 sq ft/cow x 100 cows). The volume of runoff water to be stored is 7,500 cu ft (15,000 sq ft x 6 in. ÷ 12 in. /ft).

The amount of milkhouse waste water and cleanup water is negligible compared to the amount of storm runoff water. The former amount is about 4 gal/cow/day. For a 100-cow herd the amount is 400 gal/day or 53.5 cu ft/day.

If a 4-ft depth of retention pond can be used, a 32-ft wide, 60-ft long pond with vertical walls would be required (32 ft x 60 ft x 4 ft = 7680 cu ft). Because the sides must have a minimum slope of 1 (rise) to 2 (run), a retention pond with a 24-ft wide by 52-ft long bottom has sufficient size. The top dimensions for the 4-ft deep pond are 40 ft by 68 ft. See Figure 1 for a typical cross-section of a retention pond.

Slurry Form. The manure is scraped into a storage tank and handled in a slurry form. A 30-day cleanout interval is used. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used.

1. What size closed storage tank is required?

The size of storage tank will depend on the cleanout interval. From Table 2 the storage capacity needed for a 30-day cleanout interval is 45,000 gal. Table 3 gives several combinations of tank sizes. If a 20-ft width and 10-ft depth is selected, the storage capacity per foot of length would be 1500 gal/ft. Thus a tank length of 30 ft (45,000 gal ÷ 1500 gal/ft) is required. Thus, the tank size is 30 ft by 20 ft by 10 ft.

If the milking parlor and clean-up waste water is diverted to the manure storage tank, the tank capacity must be increased 20% for the same cleanout interval.

2. What is the rate in tons per acre needed to apply the recommended amount of nitrogen?

Calculations are performed exactly as given in the answer to Question 1 of the *Solid Form Example.* The result is 15 T/A.

3. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

Calculations are performed exactly as given in the answer to Question 2 of the *Solid Form Example.* The result is 128 A.

4. How much land area is required for spreading on a 30-day interval?

A 30-day spreading interval means that the waste will be spread 12 times per year. Thus 10.7 A (128 A ÷ 12) is required.

5. How many trips are required with a liquid manure spreader?

There are several sizes of liquid manure spreaders. Because the cost of an individual spreader is dependent on the size, haul distance may be an important factor to consider. From the answer to Question 1, approximately 45,000 gal will need to be spread every 30 days. If an 800 gal capacity spreader is used, 57 trips (45,000 gal ÷ 800 gal/trip) would be required.

6. What size retention pond is required to retain the milkhouse waste water and the storm runoff from a 6-in. rainfall (24-hr 10-yr storm)?

Calculations are performed exactly as given in the

answer to Question 5 of the *Solid Form Example.* The result is a retention pond with a storage capacity of 7,500 cu ft.

Lagoon Effluent—Non-flush System. The manure is scraped into one anaerobic lagoon. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used. The terms lagoon liquor and lagoon effluent are used below. Lagoon liquor is the liquid and waste mixture in the lagoon. Lagoon effluent is the lagoon liquor that is discharged or taken from the lagoon.

1. What lagoon volume and surface area are required when the storm runoff water is *not* diverted into the lagoon?

Design criteria approved by the North Carolina Board of Water and Air Resources require 660 cu ft per cow. Storm runoff water was not considered in the design criteria. Therefore, the lagoon volume required is 66,000 cu ft (100 cows x 660 cu ft/cow).

The exact surface area of a lagoon depends on the depth and side slopes which in turn are dependent on the site conditions. A first approximation of the surface area can be obtained by dividing the volume by the depth. This approximate surface area provides sufficient accuracy to make the necessary calculations in the remainder of the answers to the questions in this example. If a 6-ft depth is selected, the approximate surface area would be 11,000 sq ft (66,000 cu ft ÷ 6 ft) or 0.25 A (11,000 sq ft ÷ 43,560 sq ft/A). See Appendix I for design details of a lagoon. See Misc. Ext. Publication No. 89 entitled "Tentative Guidelines for the Design, Installation and Operation of Animal Waste Treatment Lagoons in North Carolina" for construction details.

2. What lagoon volume and size are required when the storm runoff water is diverted into the lagoon?

If the lagoon is also used to collect storm runoff water that falls on paved and roofed areas as well as any area outside the lots that channels runoff water through the lots, the lagoon must have the capacity to store the manure, the milking parlor waste water and clean-up water, the storm runoff water and the rainfall that falls directly on the lagoon for the time interval between pumpings to lower the water level in the lagoon in order to prevent discharge through the overflow pipe.

A 1400-lb cow produces 1.6 cu ft/day. Thus, the yearly manure production from a 100-cow herd is 58,500 cu ft/yr (1.6 cu ft x 100 cows x 365 days/yr). The milking parlor waste water and clean-up water is about 4 gal/cow/day. This amounts to 19,450 cu ft/yr (4 gal/cow/day x 100 cows x 365 days ÷ 7.5 gal/cu ft).

The average rainfall in North Carolina is about 50 in./yr. Nearly all of this amount will become storm runoff water if it falls on the paved or dirt lots. A 100-cow operation would have about 150 sq ft of paved and roof area per cow. If this is the only area that contributes to the runoff, the amount of runoff water would be 62,500 cu ft/yr (150 sq ft/cow x 100 cows x 50 in./yr ÷ 12 in./ft).

NOTE! The local average amount of rainfall should be used when making this calculation for your area.

Because the average rainfall per year in North Carolina exceeds the average evaporation by about 15 in. per unit surface area, some lagoon capacity must be added for this 15 in. of rainfall that falls directly on the lagoon. Suggested amounts are 10% for a 6 ft deep and 5% for a 12 ft deep lagoon of the summation of the yearly amount of manure production, milking parlor waste water and clean-up water, and storm runoff water. Amounts for other lagoon depths can be obtained by interpolating between these two suggested amounts. If the lagoon is chosen to be 6 ft deep the storage volume needed for the rain in excess of evaporation that falls directly on the lagoon is 14,045 cu ft.

NOTE! The local average amounts of rainfall and evaporation should be used when making this calculation for your area.

If one-half of the lagoon capacity is removed 4 times per year (which is equivalent to pumping the lagoon empty twice per year), the required capacity would be 77,248 cu ft [(58,500 cu ft + 19,450 cu ft + 62,500 cu ft + 14,045 cu ft) ÷ 2]. If the lagoon is to be 6 ft deep, the approximate surface area would be 12, 875 sq ft (77,248 cu ft ÷ 6 ft) or 0.30 A (12,875 sq ft ÷ 43,560 sq ft/A).

3. How much lagoon liquor needs to be removed each year from the lagoon of Question 1 in order to prevent discharge through the overflow pipe?

When the lagoon is nearly filled to capacity, some lagoon liquor must be removed periodically during the year to prevent discharge through the overflow pipe. This discharge would be caused by manure being added, waste water and clean-up being diverted to the lagoon, and rain falling directly on the lagoon. From the answer to Question 2, the yearly manure production is 58,500 cu ft and the amount of waste water and clean-up water is 19,450 cu ft. Using the approximate surface area of 11,000 sq ft and 15 in./yr of rain in excess of evaporation, 13,750 cu ft/yr (11,000 sq ft x 15 in./ft) of water is added due to the rain that falls directly on the lagoon. Thus, the total amount of lagoon

liquor to be removed is 81,700 cu ft/yr (58,500 cu ft/yr + 19,450 cu ft/yr + 13,750 cu ft/yr) or 1.87 ac ft/yr (81,700 cu ft/yr ÷ 43,560 sq ft/A) and spread on the land.

4. How much lagoon liquor needs to be removed each year from the lagoon of Question 2 to prevent discharge through the overflow pipe?

As stated in the answer to Question 2, 77,248 cu ft needs to be removed 2 times per year. This amounts to 3.54 ac ft (77,248 cu ft x 2 ÷ 43,560 sq ft/A).

Although the difference between the surface areas of lagoons in the answer to Questions 1 and 2 is only 1,248 sq ft, there is a difference of 1.67 ac ft (3.54 ac ft − 1.87 ac ft) of lagoon liquor that must be pumped each year. Much of this latter difference is due to storm water runoff. Therefore, gutters should be installed on all roofed areas and all drainage from areas outside the lot that normally would channel runoff water through the lots should be diverted away from the lots. It is recom mended, however, that the storm runoff water b diverted to the lagoon rather than constructin both a lagoon and a retention pond.

5. What is the nitrogen concentration of the la goon liquor in the answer to Question 4?

Because the nitrogen concentration of the lagoo liquor will vary according to the amount of wate used, a nitrogen analysis of the lagoon liquo should be made by a commercial laboratory. Th results will generally be expressed in milligram N per liter (mgN/1). A rough estimate of the nitro gen concentration of the lagoon liquor can be ob tained by dividing the lbN in the liquor by th total amount of waste and water that is added t the lagoon each year.

From Table 5, the mean amount of N in dair manure from a 1400-lb cow is about 0.63 lb/day cow or 23,000 lb/yr (0.63 lb/day/cow x 365 days

Table 7. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Gallons per Acre Required to Give the Following Pounds of N per Acre					
MgN/1	LbN/gal	100	200	300	400	500	600
50	0.00041	240,000	480,000	720,000	960,000	1,200,000	1,440,000
100	0.00083	120,000	240,000	360,000	480,000	600,000	720,000
200	0.00167	60,000	120,000	180,000	240,000	300,000	360,000
300	0.00250	40,000	80,000	120,000	160,000	200,000	240,000
400	0.00333	30,000	60,000	90,000	120,000	150,000	180,000
500	0.00416	24,000	48,000	72,000	96,000	120,000	144,000
600	0.00500	20,000	40,000	60,000	80,000	100,000	120,000
700	0.00583	17,150	34,300	51,500	68,600	85,700	103,000
800	0.00667	15,000	30,000	45,000	60,000	75,000	90,000
900	0.00750	13,300	26,650	40,000	53,300	66,500	80,000
1000	0.00833	12,000	24,000	36,000	48,000	60,000	72,000
1100	0.00917	10,900	21,800	32,700	43,600	54,500	65,400
1200	0.01000	10,000	20,000	30,000	40,000	50,000	60,000
1300	0.01083	9,230	18,460	27,690	36,920	45,150	55,380
1400	0.01168	8,560	17,120	25,680	34,240	42,800	41,360
1500	0.01250	8,000	16,000	24,000	32,000	40,000	48,000
1600	0.01333	7,500	15,000	22,500	30,000	37,500	45,000
1700	0.01417	7,060	14,120	21,180	28,240	35,300	42,360
1800	0.01500	6,660	13,320	19,980	26,640	33,300	39,960
1900	0.01583	6,330	12,660	18,990	25,320	31,650	37,980
2000	0.01667	6,000	12,000	18,000	24,000	30,000	36,000
2100	0.01750	5,710	11,420	17,130	22,840	28,550	34,260
2200	0.01833	5,450	10,900	16,350	21,800	27,250	32,700
2300	0.01917	5,220	10,440	15,660	20,880	26,100	31,320
2400	0.02000	5,000	10,000	15,000	20,000	25,000	30,000
2500	0.02083	4,800	9,600	14,400	19,200	24,000	28,800
2600	0.02165	4,615	9,230	13,845	18,720	23,075	27,690
2700	0.02250	4,450	8,900	13,350	17,800	22,250	26,700
2800	0.02333	4,280	8,560	12,840	17,120	21,400	25,680
2900	0.02415	4,140	8,280	12,420	16,560	20,700	24,840
3000	0.02500	4,000	8,000	12,000	16,000	20,000	24,000

yr x 100 cows) from a 100-cow herd. A conservative assumption is that the N concentration of the lagoon liquor in an anaerobic lagoon that has been in operation for more than one year is generally not more than 50% of the N of fresh waste input. Thus 11,500 lbN are estimated to be in the lagoon liquor.

From the answer to Question 2, the total yearly amount of manure, waste water, storm runoff water and rain in excess of evaporation that flows into or falls onto the lagoon is 154,496 cu ft (58,500 cu ft + 19,450 cu ft + 62,500 cu ft + 14,045 cu ft) or 1,155,000 gal (154,496 cu ft x 7.48 gal/cu ft). Therefore the nitrogen concentration is 0.00996 lbN ÷ 1,155,000 gal).

6. At what rate can the lagoon effluent be applied to the land?

Table 7 establishes the rate at which lagoon effluent can be applied to the land to achieve a certain nitrogen application rate. Entering Table 7 with an N concentration of 0.01000 lbN/gal and an N requirement of 180 lbN/A, a value of 18,000 gal/A is obtained by estimation. The exact value can be obtained by interpolating as follows.

$$\left[\frac{180\ \text{lbN}-100\ \text{lbN}}{200\ \text{lbN}-100\ \text{lbN}}\right]\left[20{,}000\ \text{gal/A}-10{,}000\ \text{gal/A}\right]$$

$$+\ 10{,}000\ \text{gal/A} = 18{,}000\ \text{gal/A}.$$

7. What is the total yearly acreage requirement?

As indicated in the answer to Question 4, 3.54 ac ft of lagoon liquor need to be removed from the lagoon each year. This is equivalent to 1,155,000 gal (3.54 ac ft x 12 in./ft x 27,200 gal/ac in.). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 64.2 A (1,155,000 gal ÷ 18,000 gal/A).

Because the lagoon will be pumped 4 times per year, 16.1 (64.2 A ÷ 4) are required for each pumping.

Because irrigation is generally expressed in terms of acre inches applied to a given area, Table 8 was developed to provide information regarding the number of inches per acre of effluent required to give the designated rates of total N per acre for various concentrations in liquid manure or lagoon effluent.

Table 8 could also have been used to determine the acreage requirements for Question 7. Entering Table 8 with an N concentration of 0.01000 lbN/gal and an N requirement of 180 lbN/A, a value of 0.67 ac in./A is obtained by interpolation.

The total amount of lagoon liquor expressed in acre inches per acre to be removed from the lagoon is 42.5 ac in (3.54 ac ft x 12 in./ft). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 63.5 A (42.5 ac in. ÷ 0.67 ac in./A) which is about the same as obtained previously.

One thing is obvious from this example. It is not feasible to use a tank spreader to spread the effluent. A 1400 gal spreader would require 825 trips (1,155,000 gal ÷ 1400 gal/trip).

8. Is it possible to reduce the land area required for spreading the effluent?

The installation of a second lagoon in series with the existing lagoon will reduce the N concentration of the effluent from the existing lagoon by approximately 50%. Thus the N concentration of the effluent to be spread is about 600 mgN/l. Entering Table 7 with 600 mgN/l and 180 lbN/A, a value of 36,000 gal/A is obtained by interpolation. The acreage required would be 32.1 acres (1,155,000 gal ÷ 36,000 gal/A).

If Table 8 were used, a value of 1.23 ac in./A is obtained by interpolation. The required acreage would be 34.5 A (42.5 ac in. ÷ 1.23 ac in./A) which is about the same as obtained above.

Lagoon Effluent—Flush System. A flush system is used to move the manure into one anaerobic lagoon. The storm runoff water will be diverted into the lagoon. The same fertilizer recommendations as assumed in the *Solid Form Example* will be use.

1. What lagoon volume and surface area are required?

The lagoon must have the capacity to hold the flush water, the manure, the milking parlor waste water and clean-up water, the storm runoff water, and the rainfall that falls directly on the lagoon.

A flush system has a minimum water requirement of 100 gal/cow/day. Therefore, a 100-cow dairy uses about 3,650,000 gal/yr (100 gal/cow/day x 100 cows x 365 days/yr) or 486,000 cu ft/yr (3,650,000 gal/yr ÷ 7.5 gal/cu ft) to flush the lots. From calculations in the answer to Question 2 of the *Lagoon Effluent—Non-flush System* the yearly amount of manure production is 58,500 cu ft/yr, milking parlor waste water and clean-up water is 19,450 cu ft/yr, and the storm runoff water is 62,500 cu ft/yr.

If the lagoon in this example is chosen to be 12 ft deep, the capacity needed for the rain in excess of evaporation that falls directly on the lagoon is 31,300 cu ft/yr. See the answer to Question 2 of the *Lagoon Effluent—Non-flush System* for details of

Table 8. Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Acre Inches per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	8.82	17.64	26.48	35.28	44.10	52.96
100	0.00083	4.41	8.82	13.24	17.64	22.05	26.48
200	0.00167	2.20	4.40	6.60	8.80	11.00	13.20
300	0.00250	1.47	2.94	4.41	5.88	7.35	8.82
400	0.00333	1.10	2.20	3.30	4.40	5.50	6.60
500	0.00416	0.88	1.76	2.64	3.52	4.40	5.28
600	0.00500	0.74	1.48	2.22	2.96	3.70	4.44
700	0.00583	0.63	1.26	1.89	2.52	3.15	3.78
800	0.00667	0.55	1.10	1.65	2.20	2.74	3.30
900	0.00750	0.49	0.98	1.47	1.96	2.45	2.94
1000	0.00833	0.44	0.88	1.32	1.76	2.20	2.64
1100	0.00917	0.40	0.80	1.20	1.60	2.00	2.40
1200	0.01000	0.37	0.74	1.11	1.48	1.85	2.22
1300	0.01083	0.34	0.68	1.02	1.36	1.70	2.04
1400	0.01168	0.31	0.62	0.93	1.24	1.55	1.86
1500	0.01250	0.29	0.58	0.87	1.16	1.45	1.74
1600	0.01333	0.28	0.56	0.84	1.12	1.38	1.68
1700	0.01417	0.26	0.52	0.78	1.04	1.30	1.56
1800	0.01500	0.25	0.50	0.75	1.00	1.25	1.50
1900	0.01583	0.23	0.46	0.69	0.92	1.16	1.38
2000	0.01667	0.22	0.44	0.66	0.88	1.10	1.32
2100	0.01750	0.21	0.42	0.63	0.84	1.05	1.26
2200	0.01833	0.20	0.40	0.60	0.80	1.00	1.20
2300	0.01917	0.19	0.38	0.57	0.76	0.95	1.14
2400	0.02000	0.18	0.36	0.54	0.72	0.92	1.11
2500	0.02083	0.18	0.35	0.53	0.71	0.88	1.06
2600	0.02165	0.17	0.34	0.51	0.68	0.85	1.02
2700	0.02250	0.16	0.33	0.49	0.65	0.82	0.98
2800	0.02333	0.16	0.31	0.47	0.63	0.79	0.94
2900	0.02415	0.15	0.30	0.46	0.61	0.76	0.91
3000	0.02500	0.15	0.30	0.44	0.59	0.73	0.88

this calculation.

If one half of the lagoon volume is removed 4 times per year (which is equivalent to pumping the lagoon empty twice per year), the volume required is 328,875 cu ft/yr [(486,000 cu ft/yr + 58,500 cu ft/yr + 19,450 cu ft/yr + 62,500 cu ft/yr + 31,300 cu ft/yr) ÷ 2].

If a depth of 12 ft is selected, the surface area would be approximately 27,400 sq ft (328,875 cu ft ÷ 12 ft) or 0.63 A (27,400 sq ft ÷ 43,560 sq ft/A). See Appendix I for design details of a lagoon. See Misc. Ext. Publication No. 89 entitled "Tentative Guidelines for the Design, Installation and Operation of Animal Waste Treatment Lagoons in North Carolina" for construction details.

2. How much lagoon liquor needs to be removed in order to prevent discharge through the overflow pipe?

As stated in the answer to Question 1, 328,875 cu ft/yr need to be removed 2 times per year. This amounts to 15 ac ft (328,875 cu ft x 2 ÷ 43,560 sq ft/A).

3. What is the nitrogen concentration of the lagoon liquor?

Using calculations similar to those in the answer to Question 5 of the *Lagoon Effluent—Non-flush System* example, the nitrogen concentration of the lagoon liquor is 0.00233 lbN/gal [11,500 lbN ÷ (657,750 cu ft x 7.5 gal/cu ft)]. Research results from waste management studies conducted at the Randleigh Dairy Farm by the Department of Biological and Agricultural Engineering, NCSU, give approximately the same nitrogen concentration.

4. At what rate can the lagoon effluent be applied to the land?

Using calculations similar to those in the answer

to Question 6 of the *Lagoon Effluent—Non-flush System* example, the rate of application is 79,200 gal/A.

5. What is the total yearly acreage requirement?

Using calculations similar to those in the answer to Question 7 of the *Lagoon Effluent—Non-flush System* example, the acreage requirement is 62.4 A.

Because the lagoon will be pumped 4 times per year, 15.6 A are required for each pumping.

Question 4 points out a problem that can exist when low concentrations are to be spread on fields that require high fertility rates. Assume that an effluent containing 100 mgN/1 is to be spread to satisfy a soil test requirement of 400 lbN/A. From Table 8, 17.6 ac in/A would be required. This extra amount of water over and above the normal rainfall would probably keep the soil too wet, especially in a wet season. This would result in poor soil aeration and in many instances in the growth of slime molds. As a result crop growth would be reduced or destroyed.

Soil Management

For most efficient utilization of nutrients, cattle manure should be mixed with the soil either by plowing or disking. If it is left on the surface, some N will be lost by volatilization and perhaps some by surface runoff. Mixing with the soil will essentially eliminate this loss. It will also be very effective in eliminating odors.

The manure must be decomposed before most of the nutrients contained in it become available. Plants cannot use the N, P, K, and other chemical elements contained in the organic manure; they must be released in the inorganic form.

Plowing or disking the manure into the soil will speed its decomposition and will enhance essentially all of the physical, chemical, and biological properties of the soil. However, when applying to pastures, grain and certain other crops, it is not possible to mix it with the soil. If applied to vegetated areas as a slurry irrigation, it is more apt to come into contact with, or perhaps enter, the soil than if applied as dry material.

Some other points to keep in mind include the following:

- Liquid manure should be applied in a manner that will not contaminate surface water. It should not be applied nearer than 50 feet to a stream or other surface water.
- Regardless of the method of application it must be prevented from going directly into waterways or into seepage areas leading directly to a waterway.
- The wind direction and velocity and the proximity of neighbors should always be kept in in mind when applying manure to the land.
- When irrigation is used, it is desirable to follow the application of the effluent with an application of water. This will flush out the irrigation system and will wash the manure off the vegetation and cause more of it to penetrate the soil. However, care should be taken not to add too much water which might result in surface runoff and in poor soil aeration.

ODOR CONTROL

Dairy producers can do much to minimize criticism from neighbors and the general public by following management practices which minimize potential environmental problems associated with farming. Waste management methods which minimize the release of offensive odors should be utilized, particularly if an adequate buffer zone is not available for the dispersion of these odors. Attention needs to be given to timing in spreading the manure and location of fields.

The following guidelines should be considered in reducing odors:

- Locate the facility where pollution and objections of neighbors are minimized.
- Select a waste management system that would be compatible with the farm location.
- If you are surface spreading, break the material up so it will dry fast. Apply at a time when the air is dry. Do not apply when the weather is hot and humid. Apply when the humidity is the lowest for your area.
- Use spreaders that do not drip waste material along the road. Tank spreaders are now available with injectors for depositing the manure 4 to 6 in. below the ground surface. With this method the manure is immediately covered, which greatly reduces the odor.
- In an anaerobic lagoon the microorganisms live without oxygen. Decomposition of the organic materials is relatively slow and sometimes odors are released which are very objectionable. Most structures for treatment of animal wastes are of this type due to the volume of material to be handled. Aerators are helpful in reducing odors in lagoons, but no criteria as to the amount of aeration necessary have been established. Some research is underway to establish these criteria.

PEST CONTROL

Flies. An effective pest control program requires

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both the elimination of breeding areas and the use of insecticides. There are no chemical materials which can be substituted for good sanitation practices. Flies breed most frequently in places that are unclean and moist. Infrequent disposal of manure is one of the most common offenses in this respect.

Milking parlors should be cleaned daily. Spilled feed or anything which will attract flies should be cleaned up promptly.

Pay particular attention to the places around the barnyard where flies may breed such as manure pits, trash heaps, and the areas around the base of silos where drainage and plant material provide breeding places. These areas should receive special attention. Clean up or remove these materials at least weekly.

CLEAN UP FIRST—THEN LOOK TO INSECTICIDES FOR ADDITIONAL FLY CONTROL.

For the safe use of insecticides always do the following:

- Use currently recommended insecticides.
- Read the label carefully and follow instructions.
- Use exactly the dosage and time indicated.
- Keep records on insecticide use—what, when, where.
- Use properly maintained and calibrated equipment.
- Observe cautions on the label. Do not contaminate feed, water, milk and milking equipment.
- Always store insecticides in original containers and keep tightly closed. STORE AWAY FROM CHILDREN AND UNDER LOCK AND KEY.
- Make proper disposal of all empty insecticide containers.

For up-to-date legal recommendations on chemicals to use, contact your local agricultural extension agent.

Lagoon Mosquitoes

Heavy populations of mosquitoes sometimes develop in animal waste lagoons. These mosquitoes need the protective vegetation along the shoreline for egg laying and survival of their young.

To help eliminate mosquito problems, remove the marginal vegetation including any flooded plants. Rake dead vegetation and debris away from the edge of the lagoon. Vegetation can be physically removed or killed with an approved herbicide. For emergency control, apply sprays of Flit MLO at 5 gallons per acre or Number 2 fuel oil at 10 gallons per acre.

ECONOMICS

If a producer is to make a rational choice among the various waste management systems, he must compare costs of these systems and estimate the value of the waste in a cropping program. Because each situation is different, no one "best" system can be suggested. Each producer must make his own comparisons.

Each producer must start with his present situation. A producer who is constructing new facilities can simply compare the total annual costs of various waste management systems and weigh these costs against the environmental desirability and manure value for each system, realizing the limits upon the capital which he can invest.

Typically, however, a producer with functional existing facilities finds that he may have to change his waste management system because of legislation, labor scarcity, or limited land on which to apply the manure. In this case, the producer will want to look at the net income effect of switching from his present system to another. The calculations involve adding the various additional annual costs associated with the switch.

Two types of costs are involved in any waste management system. They are ownership or fixed costs and variable or operating costs. Both fixed and variable costs should be considered in selecting the waste management system for a specific dairy operation. Annual ownership costs are depreciation, interest on investment, repairs, insurance and taxes. Variable costs are for such items as fuel, labor and any other out-of-pocket costs.

In choosing a waste management system, the dairy producer should first select the ones that will handle his situation. If only one system is believed suitable, then the only thing to determine is if he can afford to continue in the dairy business with the added cost incurred with the waste management system.

Should two or more of the systems be suitable, the farmer should then itemize both the annual fixed costs involved in each system and the annual variable or operating costs. The system with the least annual total cost should be selected assuming that either system being considered will adequately handle the amount of waste produced.

Tables 9-14 present estimates of the investment required for equipment and facilities for each system together with annual power and labor requirements. The data in the tables were obtained from equipment dealers, farm surveys and university research. The annual ownership costs were calculated by multiplying the initial cost of specialized manure facilities and equipment by an ownership cost factor. The footnotes explain the calculation of the ownership cost factor for specific items. Tractor use, labor and electricity were charged at hourly rates.

Each table is provided with blank spaces to insert those costs, labor and power coefficients which will enable the individual to evaluate alternative systems for his operation.

Table 9. System I Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Initial	Annual
Scraper, rear mounted	$ 300	.18[1]			$ 54		
Ramp	750	.12[2]			90		
Spreader, side-unload	1,500	.23[3]			345		
Tractor use, 50-59 hp for scraping, 60-79 hp for spreading			470	$2.26	1,062		
Retention Pond	150	.12[2]			18		
Pump, 2 hp, 20 gpm	500	.27[4]			135		
Irrigation equipment for 1170 ft of line	1,215	.19[5]			231		
Electricity, 2 kw/hr @ 3¢/hr			188	.06	11		
Labor			504	2.50	1,260		
Total	$4,415				$3,206		

[1] 8 years of life; 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost
[4] 6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost
[5] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

Table 10. System II Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Initial	Annual
Scraper, rear mounted	$ 300	.18[1]			$ 54		
Ramp and storage area	1,500	.12[2]			180		
Spreader, side-unload	1,500	.23[3]			345		
Tractor use, 50-59 hp for scraping, 60-79 hp for spreading			470	$2.26	1,062		
Retention Pond	150	.12[2]			18		
Pump, 2 hp, 20 gpm	500	.27[4]			135		
Irrigation equipment for 1170 ft of line	1,215	.19[5]			231		
Electricity, 2 kw/hr @3¢/hr			188	.06	11		
Labor			504	2.50	1,260		
Total	$5,165				$3,396		

[1] 8 years of life; 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost
[4] 6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost
[5] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

Table 11. System III Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System with a 30-day Storage Period

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Initial	Annual
Scraper, rear mounted	$ 300	.18[1]			$ 54		
Tractor use, 50-59 hp for scraping			280	$2.26	633		
Storage tank (6,000 cu ft @ 65¢/cu ft)	3,900	.12[2]			468		
Agitator pump	1,900	.27[3]			513		
Tractor, 60-79 hp for agitating and pumping			45	2.90	131		
Spreader, liquid manure	2,100	.23[4]			483		
Tractor, 90-99 hp for hauling and spreading			105	3.52	370		
Retention Pond	150	.12[2]			18		
Pump, 2 hp, 20 gpm	500	.27[3]			135		
Irrigation equipment for 1170 ft of line	1,215	.19[5]			231		
Electricity, 2 kw/hr @3¢/hr			188	.06	11		
Labor			440	2.50	1,100		
Total	$10,065				$4,147		

[1] 8 years of life; 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost
[4] 6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost
[5] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

Table 12. System IV Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Initial	Annual
Scraper, rear mounted	$ 300	.18[1]			$ 54		
Tractor, 50-59 hp, for scraping			280	$2.26	633		
Lagoon	2,000	.12[2]			240		
Walkway pump in lagoon	750	.12[2]			90		
Irrigation pump, 30 hp, 200 gpm	2,200	.27[3]			594		
Irrigation equipment for 2340 ft of line	2,430	.17[4]			413		
Labor			325	2.50	813		
Electricity, 30 kw/hr @ 3¢/hr			97	.90	87		
Total	$7,680				$2,924		

[1] 8 years of life, 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost
[4] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

Table 13. System V Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Item	Estimated Cost					Your Cost	
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Initial	Annual
Pump, 2 hp, 20 gpm for flush water	$ 500	.27[1]			$ 135		
Well	1,350	.12[2]			162		
Flush tanks, 10,000 gal	1,600	.19[3]			304		
Dam and diversion gates	1,125	.19[3]			214		
Slurry ditch covers	1,140	.19[3]			217		
Storage tank, 20,000 gal	1,950	.12[2]			234		
Irrigation pump, 30 hp, 200 gpm	2,200	.27[1]			594		
Irrigation equipment for 2340 ft of line	2,430	.19[3]			462		
Retention Pond	150	.12[2]			18		
Pump, 2 hp, 20 gpm	500	.27[1]			135		
Labor, 35 min/day			223	$2.50	558		
Electricity, irrigation pump, 30 kw/hr @ @ 3¢/hr			304	.90	274		
Electricity, water pumps 2 kw/hr @ 3¢/hr			3,228	.06	194		
Total	$12,945				$3,501		

[1] 6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

Table 14. System VI Estimated Initial Investment and Annual Costs of Dispo stall System

Item	Estimated Cost					
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	
Pump, 2 hp, 20 gpm for flush water	$ 500	.27[1]			$ 135	
Well	1,350	.12[2]			162	
Flush tanks, 10,000 gal	1,600	.19[3]			304	
Dam and diversion gates	1,125	.19[3]			214	
Slurry ditch covers	1,140	.19[3]			217	
Lagoon	6,000	.12[2]			720	
Slurry pump, 30 hp, 200 gpm	2,200	.27[1]			594	
Walkway pump in lagoon	750	.12[2]			90	
Irrigation equipment for 2340 ft of line	2,430	.19[3]			462	
Labor, 35 min/day			213	$2.50	533	
Electricity, slurry pump, 30 kw/hr @ 3¢/hr			410	.90	369	
Electricity, water pump, 2 kw/hr @ 3¢/hr			3,040	.06	182	
Total	$17,095				$3,982	

[1] 6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost
[2] 15 years of life; 7% interest on ½ initial cost; repairs, .5% of initial cost; taxes and insurance, 1% of initial cost
[3] 8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

The sources of data for Tables 9-14 were:

1. Berge, O. I., Waste Disposal . . . What Does It Cost, Hoards Dairyman, April 10, 1971.

2. Jacobs, J. J. and G. L. Casler, Economic and Environmental Considerations in Dairy Manure Management Systems, A. E. Res. 72-18, Department of Agricultural Economics, Cornell University, December 1972.

3. Wells, R. C and G. S. Parsons, Manure Handling Systems for Free-Stall Dairy Housing, Extension Circular 480, N. C. Agricultural Extension Service, June 1967.

Comparison of Systems

Table 15 presents a summary of the estimated initial and annual costs of the six alternative systems.

Table 15. Estimated Initial Investment, Annual Costs and Labor Requirements for Six Alternative Waste Management Systems for a 100-Cow Free-Stall Dairy

Waste Management System	Initial Investment	Annual[1] Ownership Cost	Annual Labor Requirement	Total Annual Cost
System I —Ramp	$ 4,415	$1,873	504 hr	$3,206
System II —Ramp and storage area	5,165	1,963	504	3,326
System III —Liquid manure, 30-day storage	10,065	1,902	440	4,147
System IV —Lagoon and irrigation	7,680	1,891	325	2,924
System V —Flush, storage tank, and irrigation	12,945	2,475	223	3,501
System V —Flush, lagoon and irrigation	17,095	2,898	213	3,982

[1] Does not include tractor ownership cost.

The two manure ramp systems require the lowest initial investment. Solid waste handling has the highest power and labor costs, but the lowest ownership costs. Thus, the solid waste handling systems have two of the lowest estimated total annual costs. The liquid manure system with 30-day storage has the highest annual cost. The system employing a mechanical scraper, lagoon and irrigation requires a larger initial investment than solid waste handling systems, but also requires less outlay for power and labor. This system has the lowest estimated total annual cost. The water flush systems require substantial investments, but the savings in labor and power that the flush systems offer tend to offset the ownership costs associated with the large investment.

The engineering aspects of lagoons and irrigation of dairy waste are still being investigated. The systems presented in this publication may be modified further in an effort to reduce costs and to satisfy environmental requirements. *Financial planning should play an important role in selecting a manure disposal system.* Many dairymen are likely to borrow funds to finance a new waste disposal system. The repayment terms of the loan must be carefully evaluated. For example, a 10-year loan at 8% interest will require annual payments of about $715 for a ramp system, $1500 for a liquid manure system and a range of $1940-2530 for flush irrigation systems. The ability to repay the loan must be considered. When savings in labor and power or convenience are studied, the dairy producer must decide which system gives the best chance to pay off the loan with the least jeopardy to his cash flow position, his net worth and his credit rating.

APPENDIX I

Lagoon Design for 100 Cows

The tentative guidelines approved by the North Carolina Board of Water and Air Resources set the minimum volume per cow at 660 cu ft. For 100 cows, 66,000 cu ft of storage must be provided in the lagoon. If a depth of 10 ft is selected, the *average* area (area at one-half the depth) would be 6,600 sq ft (66,000 cu ft ÷ 10 ft). To get the waste into the lagoon as well as physically construct the structure, an *average* width of 50 ft will be selected. The average length will then be 132 ft (6,600 sq ft ÷ 50 ft). Therefore, a lagoon with 3:1 side and end slopes will have the dimensions as shown in Figure 4.

For other depths and widths, the procedure for sizing would be the same as outlined in this example.

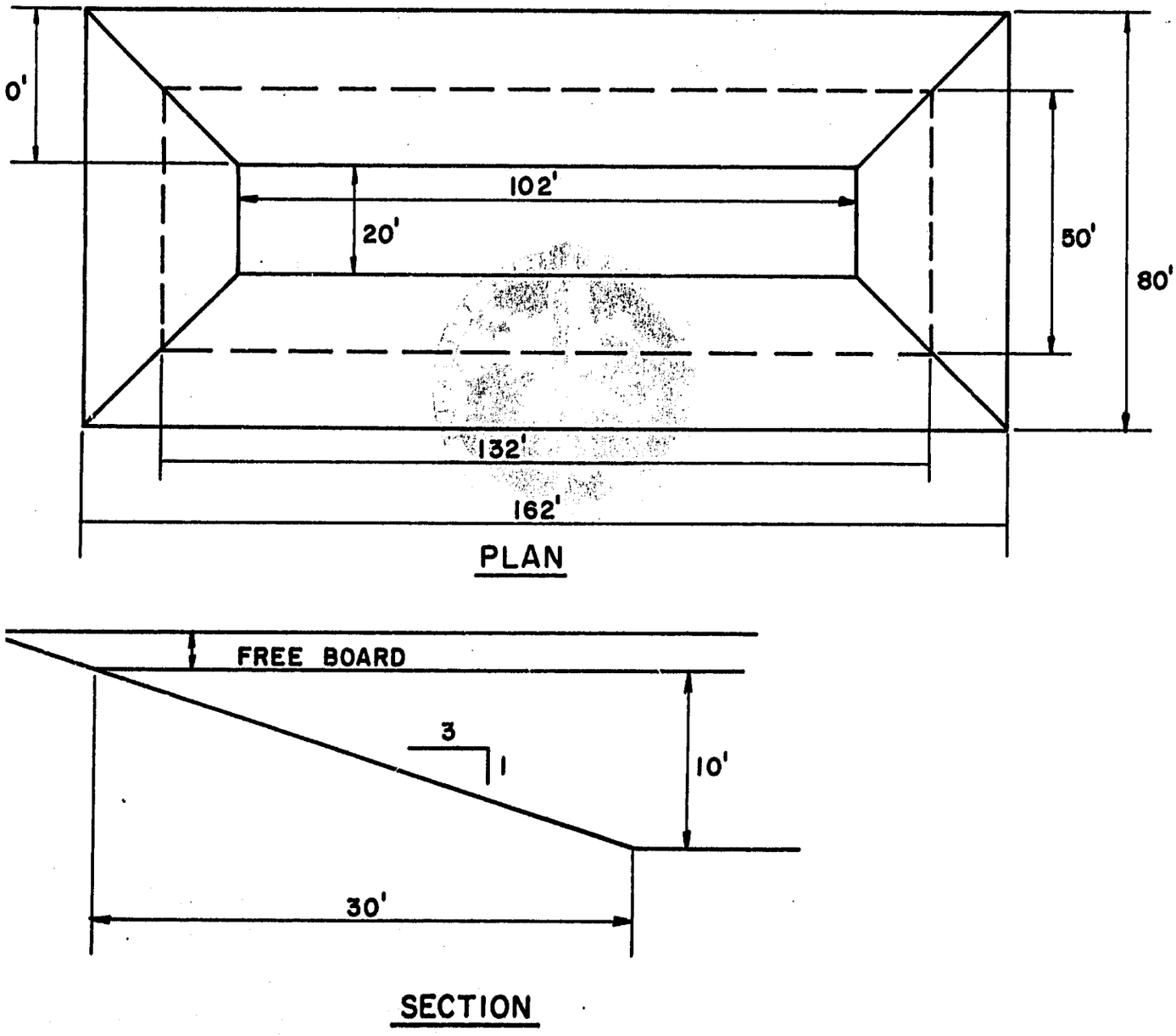

Figure 4. Plan and Section View of a Lagoon.

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POULTRY WASTE MANAGEMENT ALTERNATIVES

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L. B. Driggers, Extension Biological and Agricultural Engineer
J. M. Falter, Extension Entomologist
D. G. Harwood, Extension Economist
*G. J. Kriz, Extension Biological and Agricultural Engineer
J. F. Lutz, Soil Scientist
W. C. Mills, Extension Poultry Scientist
J. A. Phillips, Extension Soil Scientist

* Coordinator

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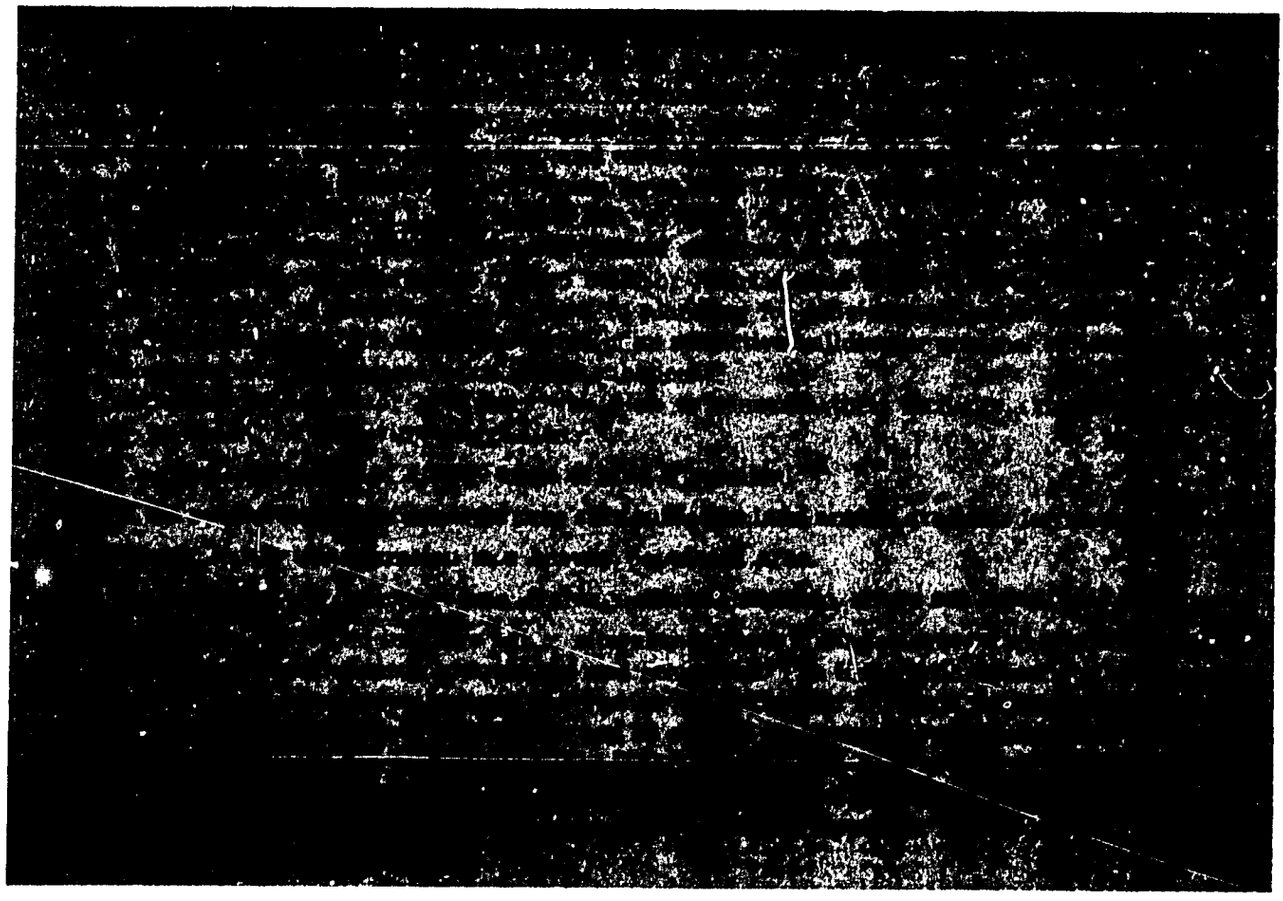
Poultry Waste Management Alternatives



ALTERNATIVE WASTE MANAGEMENT SYSTEMS

With an increase in size of layer, broiler and turkey production units and more concern for a cleaner environment, more attention must be given to methods of poultry waste disposal. Higher bird densities and larger production units yield large quantities of manure daily. A 5-pound laying hen produces about 0.04 gallons (gal) or 0.005 cubic feet (cu ft) per day of manure on a wet basis. As shown in Table 1, the quantity becomes astronomical as flock sizes increase. Consequently, the producer must select a method that will allow him to properly treat, utilize or dispose of this by-product.

Waste from caged layers is handled either as solid or liquid material. However, from broilers and turkeys, it is most often handled as a solid because these birds when confined are housed on litter on an open floor. Consequently at cleaning time, the waste and litter are scraped into piles and loaded onto a spreader for direct land disposal. Tables 2 and 3 show the manure production from varying flock sizes of broilers and turkeys, respectively.

Table 1. Manure Production from Caged Layers

Flock Size Number of Birds	Daily Manure Production		Monthly Manure Production		Yearly Manure Production	
	Gal	Cu Ft	Gal	Cu Ft	Cu Ft	T
1,000	40	5	1,200	150	1,800	56
5,000	200	25	6,000	750	9,100	280
10,000	400	50	12,000	1,500	18,000	560
15,000	600	75	18,000	2,500	27,000	840
25,000	1,000	125	30,000	3,750	45,000	1,400
50,000	2,000	250	60,000	7,500	91,000	2,800
75,000	3,000	375	90,000	11,250	133,000	4,200
100,000	4,000	500	120,000	15,000	182,000	5,600
200,000	8,000	1,000	240,000	30,000	365,000	11,200
500,000	20,000	2,500	600,000	75,000	914,000	28,000

Table 2. Manure Production from Broilers

Flock Size Number of Birds	Daily Manure Production	Monthly Manure Production	Yearly Manure Production	
	Cu Ft	Cu Ft	Cu Ft	T
1,000	2	60	720	12.6
5,000	10	300	3,600	63
10,000	20	600	7,200	126
15,000	30	900	10,800	189
25,000	50	1,500	18,000	315
50,000	100	3,000	36,000	630
75,000	150	4,500	54,000	945
100,000	200	6,000	72,000	1,260
200,000	400	12,000	144,000	2,520
500,000	1,000	30,000	360,000	6,300

Table 3. Manure Production from Turkeys

Flock Size Number of Birds	Daily Manure Production	Monthly Manure Production	Yearly Manure Production	
	Cu Ft	Cu Ft	Cu Ft	T
1,000	5.5	165	1,980	34.6
5,000	27.5	825	9,900	173
10,000	55	1,650	19,800	346
15,000	82.5	2,490	29,900	524
25,000	137.5	4,140	49,700	865
50,000	275	8,250	99,000	1,730
75,000	412.5	12,400	149,000	2,610
100,000	550	16,500	198,000	3,460
200,000	1,100	33,000	396,000	6,920
500,000	2,750	82,500	990,000	17,300

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Waste Management System for Broilers and Turkeys

When broilers and turkeys are raised in confinement on litter on an open floor, it is best to handle the manure in a solid form. The following flow diagram schematically illustrates the system.

Scraper→Front End Loader→Spreader→Land

The usual cleanout procedure as illustrated above moves the manure directly from the broiler or turkey house to the land for spreading. This eliminates any other storage between cleanout and spreading, thus reducing cost. With a planned cleanout and cleanup interval between flocks of birds no problems are usually encountered.

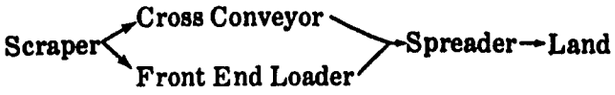
Be sure to select a spreader that will not leak the contents along the road but will spread the material in small pieces on the land surface so as to minimize fly breeding. If the material is very dry, exercise care on windy days to prevent dust and feathers from creating a nuisance.

Sometimes the litter is treated and used for more than one flock of birds. When this procedure is followed, the major cleanout and cleanup intervals are more infrequent.

Alternative Waste Management Systems for Caged Layers

To date, all management or disposal methods ultimately return the manure to the land. Depending upon the method selected, there may be a storage or detention period between cleaning a caged layer house and land disposal. Always be careful to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

System I: Direct Spreading in Solid Form

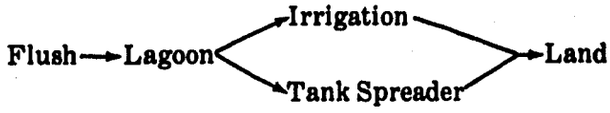


Mechanical pit scrapers are generally used in conjunction with a cross conveyor at one end of the poultry house. The two units operate simultaneously with the pit scraper depositing manure onto the cross conveyor which discharges the manure directly into a spreader for land disposal. This mechanized method requires daily pit cleaning and manure removal from the house. In addition, ample land must be available to receive the manure.

Small tractors can also be used to scrape the pits in lieu of the mechanical pit scraper, but the tractor must move through the aisles and requires an operator. This unit will deposit manure on a cross conveyor or in a pile where it can be picked up with a tractor front end loader. Usually, these pieces of equipment are used where the house is not cleaned daily.

Field spreaders are available as tractor drawn or truck mounted units. Flail type tank spreaders will hold either liquids or solids and have either a side or rear discharge. A spreader with beaters should have a rear gate, preferably hydraulically operated, that can be opened and closed from the tractor seat. Be sure to select a spreader that will not leak the contents along the road and will spread the material in small pieces on the land surface so that fly breeding is minimized.

System II: Flush with Lagoon



A hydraulic water flush system of pit cleaning is being used successfully in conjunction with a lagoon. Water from the lagoon is recirculated through the pits generally twice each day and moves the droppings from under the cages into the lagoon.

To meet the design criteria approved by the North Carolina Board of Water and Air Resources, 30 cubic feet of water must be provided in the lagoon for each laying hen. No overflow or discharge from the lagoon is permitted. Therefore, provisions must be made to control the water level in the lagoon.

Irrigating lagoon effluent is probably the most practical way to control the water level in the lagoon because of the quantity. When using irrigation, care must be exercised to prevent surface runoff. The system should be designed for minimum pipe and sprinkler movement because this is a "nasty" job. Before moving, flush out the irrigation system with clean water.

A tank wagon equipped with a vacuum pump might be used with small lagoons, but its volume will limit its use.

The lagoon effluent should not be spread on a hot humid (muggy) day because odors from the spreading operation may create a nuisance.

Evidence indicates that the lagoon serves as a

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nitrogen trap by accumulating nitrogen in the sludge build-up on the bottom. This build-up of solids indicates that the sludge must be removed at some future date, but definite recommended cleaning intervals are not established at this time. By reducing the quantity of nutrients through the decomposition process that takes place in a lagoon, less land area is needed for land spreading because of nutrient reduction, particularly nitrogen, in the effluent.

System III: Storage and Spreading in Liquid Form

Liquid handling of manure on a frequent basis can be accomplished by pit scrapers moving the manure directly to a concrete storage tank. The size of the tank is dependent upon the number of birds, the moisture content of the manure, and the frequency of spreading. Water must be added to the storage tank to bring the waste to a pumpable consistency. Table 4 shows the approximate quantity of water needed to increase the moisture content of the manure. A general range of moisture content for manures without bedding would be as follows:

75—82% moisture - stiff
80—85% mositure - fluid or semi-liquid—quite thick slurry
83—90% moisture - liquid—fairly thin liquid at 90%
93—97% moisture - irrigation consistency

It is evident from Table 4 that the amount of water added to produce a pumpable slurry might be more than the quantity of manure initially. For example, the addition of 11.25 gal of water to 1 cu ft of fresh manure at 75% moisture raises the moisture content to 90% and changes the volume from 1 cu ft to 2.5 cu ft.

A storage tank requires an agitator or pump-agitator which serves the dual role of agitating and filling the spreader tank. One distinct disadvantage with liquid manure storage is odors while agitating and field spreading. The liquid slurry should not be spread on a hot humid (muggy) day because odors resulting from the agitating and spreading operations may create a nuisance.

Where odor is a problem, the producer might elect to equip his spreader with a soil injector. This equipment places the liquid slurry 4 to 6 inches (in.) below the ground surface and covers it immediately, drastically reducing odor. Care must be exercised to select a field that is relatively free of large stones, stumps and roots when the injection method is used.

Table 4. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Initial			Percent Moisture Desired	Amount of Water to be Added to Each Cu Ft to Give the Desired Percent Moisture		Final Volume per Each Original Cu Ft	
Volume		Percent Moisture					
Cu Ft	Gal			Cu Ft	Gal	Cu Ft	Gal
1.0	7.5	85	90	0.50	3.75	1.50	11.25
			95	2.00	15.00	3.00	22.50
1.0	7.5	80	85	0.33	2.50	1.33	10.00
			90	1.00	7.50	2.00	15.00
			95	3.00	22.50	4.00	30.00
1.0	7.5	75	80	0.25	1.88	1.25	9.38
			85	0.67	5.00	1.67	12.50
			90	1.50	11.25	2.50	18.75
			95	4.00	30.00	5.00	37.50
1.0	7.5	70	75	0.20	1.50	1.20	9.00
			80	0.50	3.75	1.50	11.25
			85	1.00	7.50	2.00	15.00
			90	2.00	15.00	3.00	22.50
			95	5.00	37.50	6.00	45.00

Table 5. Storage Tank Capacity per Foot of Length

Tank Width Ft	Tank Depth Ft		
	6	8	10
	Gal/Ft of Length		
8	360	480	600
10	450	600	750
12	540	720	900
14	630	840	1050
16	720	960	1200
18	810	1080	1350
20	900	1200	1500
22	990	1320	1650
24	1080	1440	1800

Table 5 gives the storage capacity per foot of length for tanks with different widths and depths. This table along with Table 1 will enable the producer to determine the tank size required to store liquid manure.

System IV: Flush with Aerated Lagoon

Flush → Aerated Lagoon → Irrigation → Land

This system is similar to System II except that the lagoon is aerated. Aeration serves two important functions. Firstly, it reduces the odor from the lagoon. Secondly, it increases the quality of effluent or reduces the nutrient content of the effluent because of degradation. This results in less land area for disposal. Aeration is currently being studied and complete design criteria are not available at this time.

Other Alternatives

The following alternatives have been studied or tried in various locations in the United States. They do not appear to be economical at the present time in comparison to the previously described alternatives unless one has a sale or use for the dried product.

Drying. Drying is a method that has received considerable attention. Michigan State University has pioneered in this work, and their research indicates a total drying cost of $8.00 plus per ton (T) of wet manure. At this time, drying must be investigated on an individual enterprise basis.

Deep Pit Houses. Deep pit houses for layers have received acclaim by some, but this is a relatively new method with some serious disadvantages. The manure is allowed to build up in an 8-ft pit under the cages until cleanout. As long as the manure is kept dry, the system appears to offer advantages, but overflowing and leaky waterers or an ingress of groundwater or surface runoff necessitates cleanout and causes odor problems. To prevent the addition of water from ground or surface runoff, the pit should be constructed above ground. Also, mechanical ventilation must be employed to facilitate drying of the manure in the pit.

Composting. Composting has received limited study. A combination of drying and composting takes place in a properly operating deep pit house and possibly explains the success and acceptance by some producers. Aeration is essential for rapid composting. Composting on a large scale has not become practical.

Refeeding. Refeeding by formulation of diets to include animal waste as an ingredient is being studied. Before being incorporated into feed, it is generally agreed that some type of processing is needed. Drying has been closely allied with refeeding. Before refeeding can be practiced, it must be proven that no detrimental effects will result from feed additives, pesticides or pathogenic microorganisms and also the practice will require approval by the Food and Drug Administration.

UTILIZATION AND LAND REQUIREMENTS

Utilization of poultry manure by direct land application is generally recommended. However, because large quantities of manure are generated in concentrated operations, many of which have limited land areas, the manure is often treated as an unwanted commodity to be disposed of by any

means that are publicly acceptable or economically feasible. Whenever possible, the manure should be treated as a resource and be used as a valuable source of plant nutrients.

During the past 40 to 50 years poultry manures have been largely replaced by commercial fertilizers as sources of plant nutrients. This may be attributed to: 1) improved physical and chemical quality of commerical fertilizers; 2) improved methods of handling and applying commerical fertilizers; 3) the smaller tonnage of commerical fertilizers required to give the same amount of plant nutrients; and 4) the lower cost per pound of plant nutrients in commercial fertilizers. Poultry manure can be used as a source of nutrients for most crops grown in North Carolina except tobacco and certain other crops where nitrogen control is essential. The efficiency of properly applied manure as a source of nutrients is comparable to that of commercial fertilizers, and the crop recovery values of the nutrients from manure are quite comparable to those from commerical fertilizer.

The principal plant nutrients supplied by both poultry manures and commercial fertilizers are nitrogen (N), phosphorus (P) and potassium (K). In fertilizers the nutrients are expressed as percents nitrogen (N), phosphate (P_2O_5) and potash (K_2O). In addition to N, P and K, poultry manure usually contains an appreciable amount of calcium, magnesium and sulfur, and traces of manganese, iron, boron, copper, zinc and molybdenum, all of which are essential for plant growth. Care should be taken to monitor the levels of trace elements in the soil in order to avoid excessive or toxic amounts.

Nutrient Composition of Poultry Manures

The daily production of poultry manure and its composition varies with the type of fowl, whether broilers, layers or turkeys, and the kind and amount of feed consumed.

Table 6 gives representative values of the nutrient composition of oven dried poultry manure. The actual composition of any particular batch of manure will be determined by the amount of moisture, the amount of litter present, the rations fed, and the way that the manure was handled or stored. Because in most instances it would not be practical to have each batch of manure analyzed, the figures in Table 6 may be used to get approximate values of the amount of nutrients in the manure.

Table 7 shows the effect of moisture content on the average nutrient composition of caged layer manure.

The relative value of poultry manure as compared to commercial fertilizer will be determined by the composition of the manure and by the cost of handling it. This will vary from farm to farm and should be estimated in each individual situation. An important item that should not be overlooked in estimating the value of manure is the fact that the manure must be disposed of but the

Table 6. Nutrient Composition of Oven Dried Poultry Manure*

Plant Nutrient	Type of Manure (oven dried)					
	Broiler		Caged Layer		Turkey	
	Mean Lb/T	Range Lb/T	Mean Lb/T	Range Lb/T	Mean Lb/T	Range Lb/T
Nitrogen (N)	45.4	29.8 - 52.9	39.8	25.6 - 117.6	94.0	62 - 126
Phosphorus (P_2O_5)	49.0	17.4 - 48.2	38.4	28.5 - 59.2	45.0	44 - 46
Potassium (K_2O)	40.7	30.1 - 44.9	44.9	17.6 - 81.5	38.7	31 - 45
Calcium (Ca)	39.4	12.4 - 70.9	68.1	32.2 - 110.0		
Magnesium (Mg)	7.3	1.2 - 15.9	10.4	6.2 - 16.9		
Sulfur (S)	7.6	2.0 - 16.0	9.5	3.9 - 15.8		
Manganese (Mn)	0.55	0.27 - 1.05	0.66	0.33 - 1.04		
Iron (Fe)	2.45	1.37 - 3.34	2.69	0.99 - 4.72		
Boron (B)	0.07	0.04 - 0.12	0.06	0.03 - 0.08		
Copper (Cu)	0.05	0.03 - 0.11	0.06	0.03 - 0.08		
Zinc (Zn)	0.25	0.17 - 0.51	0.24	0.13 - 0.51		
Molybdenum (Mo)	0.03	0.01 - 0.07	0.03	0.02 - 0.06		

*Data derived from
1. North Carolina State University.
2. Dyal, R. S. Agricultural values of poultry manure. ARS, USDA, Beltsville, Maryland.
3. Perkins, H. F. and M. B. Parker. 1971. Chemical composition of broiler and hen manures. Research Bulletin 90. University of Georgia, Athens, Georgia.
4. Papanos, Stanley and B. A. Brown. 1950. Poultry manure: Its nature, care and use. Storrs Agricultural Experiment Station, Storrs, Connecticut.

Table 7. Effect of Moisture Content on the Average Nutrient Composition of Caged Layer Manure

Type of Manure	Moisture Content	Solid Matter	Average Nutrient Composition					
			N		P_2O_5		K_2O	
	%	%	%	Lb/T	%	Lb/T	%	Lb/T
Fresh droppings	75	25	0.5	10	0.47	9	0.57	11
Partially dried	50	50	1.0	20	0.95	19	1.15	23
Nearly dry	25	75	1.5	30	1.42	28	1.72	34
Dry	0	100	2.0	40	1.90	38	2.30	45

cost of disposal is partially offset by its fertilizer value.

Effects of Poultry Manure on Soils and Crops

Poultry manure has several beneficial effects on the chemical, physical and biological properties of soils.

Chemical Effects. The principal chemical effect of manure is the supplying of the major plant nutrients: nitrogen, phosphate and potash. It also contains a number of other chemical elements necessary for plant growth. In contrast to commercial fertilizers, poultry manure supplies organic matter to soils. This is usually considered beneficial in increasing the nutrient-holding capacity of soils.

Physical Effects. If manure is applied to the surface of the soil, it will aid in preventing soil crusting. If mixed with the soil, it will decompose more rapidly and the products of decomposition will improve soil structure and the general physical condition of the soil. Thus, whether applied to the surface or mixed with the soil, it will be important in conserving water and soil by reducing runoff and erosion. Poultry manure is frequently credited with increasing the available water-holding capacity of soils. This is generally not true. If the manured soil contains more water, it is probably because more soaked in during rainfall or irrigation.

Biological Effects. Manure is a source of food, and hence energy, for soil microorganisms that decompose it. These soil micoorganisms have many very important direct and indirect effects on many physical, chemical and biological properties of the soil. It should be noted that some adverse effects may be caused by pesticide residues in the manure.

Factors Affecting Rates of Application

Several factors affect the amount of manure that might be applied to any given land area. They are: (1) the use to be made of the land—whether it is to be used for crop production or for manure disposal only; (2) if used for crop production, the kind of crop to be grown; (3) the characteristics of the soil including texture, depth and fertility status; (4) topography as it affects runoff and erosion; (5) the season of the year in which the manure is to be applied; and (6) possibility of environmental pollution, particularly the contamination of surface and ground water by excessive leaching or runoff. In this connection care must always be taken to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

From the standpoint of crop production the amount to be applied to any particular crop is determined by the nitrogen content of the manure and the nitrogen requirements of the crop. This will be explained more fully in the following pages.

Crop production is not the only factor to be considered in determining the amount of manure that might be applied to any particular soil. Another very important factor is the possible effect of the manure on environmental pollution, particularly contamination of surface or ground water. The two elements contained in manure which are most likely to cause problems in water are nitrogen, particularly in the nitrate form, and phosphorus. Excessively large amounts of nitrates can be toxic to animals and considerable accumulation of nitrates and phosphate in surface water causes eutrophication (excessive growth of algae and other water-loving plants). When manure decomposes in the soil the nitrogen will ultimately be converted to the nitrate form which is very easily leached. If it leaches downward in the soil to a poorly drained layer, in which there is sufficient organic matter for microorganisms to live on, the nitrate will be converted to the ammonium form which is less easily leached and less toxic to animals, and is likely to be volatilized.

Table 8 gives the relative potential nitrate leaching rates together with some of the soil properties

Table 8. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Texture of Topsoil (6-10 in.)	Texture of Subsoil (6-10 to 20 in.)	Critical Soil Property Affecting Movement of N and P	Relative Potential Nitrate Leaching	Relative Phosphate-Fixing Capacity	Typical Soil Series
Sand	Sand	Low water table, very high permeability	Very high	Very low	Lakeland, Wagram
		High water table	Low	Very low	Bibb, Pelham, Plummer
Sandy loam, or Very fine sandy loam	Sandy clay loam, Clay loam, or Clay	Loose to hard, moderately permeable subsoil	Medium to high	Low	Altavista, Durham, Granville, Norfolk
		Slowly permeable, somewhat plastic subsoil	Medium to low	Medium	Appling, Cecil
		Very slowly permeable, plastic sticky subsoil	Very low	Medium to low	Creedmoor, Enon, Helena, Iredell, Whitestore, Wilkes
		High water table	Low	Medium to low	Lumbee, Rains, Roanoke, Wehadkee, Worsham
Silt loam, or Loam	Silty clay loam, Clay loam, or Clay	Moderately permeable, plastic subsoil	Medium to low	Medium to high	Alamance, Chandler, Chester, Congaree, Fannin, Georgeville, Herndon, Hiwasse, Lloyd, Mecklenburg, Orangeburg, Porters, Ruston
		Slowly permeable, plastic, sticky subsoil	Low	Medium	Bertie, Craven, Dunbar, Nason
		Very slowly permeable, plastic, sticky subsoil	Very low	Low	Lignum, Tatum
		High water table	Low	Medium	Bayboro, Kinkora, Portsmouth, Roanoke
Silty clay loam, or Clay loam	Silty clay, or Clay	Slowly permeable, compact subsoil	Medium to low	High to very high	Caroline (eroded), Cecil (eroded), Davidson, Georgeville (eroded), Hayesville (eroded), Marlboro (eroded)
		Moderately to slowly permeable, granular subsoil	Low	High to very high	Appling (eroded)
		High water table	Very low	Medium	Any low, poorly-drained areas with topsoil removed by burning or stripping
Clay - Eroded or denuded areas, void of topsoil and, thus, with subsoil exposed		Slow to very slowly permeable, compact or granular subsoil	Low to very low	High to very high	Any area with clay exposed by erosion, stripping or burning
		High water table	Very low	Medium	Same as above, but with high water table

affecting leaching. As a general rule, it would be undesirable to apply heavy applications of manure to soils with a high nitrate-leaching potential. On such soils it would be desirable to use smaller applications distributed throughout the year, making sure that the total application within the year is not excessive. On fine textured soils infiltration is retarded and surface runoff may contribute to stream pollution.

Table 8 also shows the relative phosphate-fixing capacity of representative soils in North Carolina. Many soils have the capacity to "fix" phosphorus; that is, render it relatively insoluble and on those soils phosphate leaching is usually not a problem. It is a problem, however, on sand and care should be taken not to add large amounts of phosphorus to soils with low phosphate-fixing capacity. As a general rule, the red to reddish-yellow soils with considerable clay in the subsoil have the higher phosphate-fixing capacity. The relative values for some typical soils in the state are given in Table 8.

The leaching of nitrates, phosphates and other plant nutrients is affected by a number of factors such as soil temperature (which affects the rate of decomposition of manure), the kind of crop being grown and, hence, the rate of utilization of the nutrients by the crop, and the soil moisture conditions. Under normal climatic conditions in North Carolina the soils are usually wet during the winter and relatively dry during the summer. "Normal" summer rains penetrate the soil to relatively shallow depths (6 to 10 to 15 inches, depending upon the texture) and under high summertime temperatures the moisture is rapidly lost by evaporation. Under such conditions leaching of nitrates to the water table is improbable, except on extremely coarse-textured soils.

When high quality fresh poultry droppings are added to a warm moist soil, ammonia production is rapid during the first few days. Generally the maximum levels occur in the first two weeks. The production of nitrate from ammonia is slow the first week but reaches a maximum after 4 weeks. Research has shown that 30 to 60 percent of the total nitrogen of the droppings will become available during the first six weeks. If, however, the poultry manure contains a lot of litter (shavings, sawdust, etc.), the release of nitrogen will be retarded due to its wide carbon-nitrogen ratio; therefore, the release of all the nitrogen may take more than one season. Because only about half of the nitrogen contained in the manure will generally become available during the first growing season, it is possible to apply about twice the recommended amount of nitrogen to grain and forage crops without the danger of nitrate toxicity or groundwater contamination. However, in succeeding years this carry-over should be taken into account and rates adjusted accordingly.

Phosphorus is mainly in the organic form in poultry manure. Phosphorus availability is directly related to the rate of manure decomposition and is much slower than that of nitrogen. Potassium in poultry manure is an inorganic salt that is easily leached and is readily available for plant use. Poultry manure also contains many minor elements in very small quantities that are released as the manure decomposes.

Losses of nutrients from manure either occur from leaching of soluble salts or volatilization. However, these losses can be held to a minimum if the material is applied to the land and incorporated into the soil. Manure that is high in nitrogen (pure droppings) should be applied to the land at least 2 to 4 weeks prior to planting to prevent ammonia from burning the plants and to reduce possible salt injury. Where available land is required for feed production, management practices must be developed to permit land spreading at suitable times.

How To Determine the Amount to Apply

The nutrient composition of the manure is very dependent on the type of waste management system. Producers, especially those using liquid storage tanks and lagoons, should have the slurry or lagoon liquor analyzed. There are several commercial laboratories in North Carolina that have expressed an interest in analyzing waste samples. For further information, contact your county extension agent or one of the regional offices of the Office of Water and Air Resources of the Department of Natural and Economic. Resources located in Greenville, Raleigh, Concord and Asheville.

Estimates of the existing soil nutrient supply can be obtained by soil tests made by the Soil Testing Division of the North Carolina Department of Agriculture. Rates of application should be based on the recommended amount of nitrogen needed to supplement the existing soil nitrogen supply for the particular crop to be grown. Contact your county extension agent for further information on determining the rate of application.

Illustrative examples are shown below for handling the waste in solid and slurry forms, and as lagoon effluent. Each example is for a specific set of conditions that may or may not be applicable to your area. Each example is based on the approach that the poultry manure is to be a source of fertilizer with the long range objective of optimum crop production.

If the approach is taken whereby the land is to be used for waste disposal without consideration of any crop, higher application rates than given in the examples below could be used. However, the risk of groundwater and surface water contamination is greater, a very good understanding of the characteristics of the soil is essential, and lastly, a resource in the form of fertilizer is being wasted. If this latter approach is used, contact your county extension agent or Soil Conservation Service district conservationist.

Examples

In the examples given below information on the following will be given based on handling the manure from a caged layer house containing 25,000 birds:

—Rate of application.
—Total land area needed per year.
—Land area required for spreading at definite intervals.
—Number of trips required for spreading at definite intervals (except for lagoon example).

THE EXAMPLES DO NOT TAKE LOCATION, TOPOGRAPHY, SEASON OF YEAR, WEATHER CONDITIONS, STAGE OF CROP GROWTH OR SOIL TYPE INTO ACCOUNT. These factors will be discussed in a subsequent bulletin. The numbers in the parentheses show how the calculations are made.

Solid Form. The manure is scraped from the houses on a daily basis. Assume that the fertilizer recommendations for fescue pasture on a particular soil are as follows:

N	P_2O_5	K_2O	Lime
lb/A	lb/A	lb/A	T/A
200	140	150	2

All of the nitrogen (N) is to be supplied by the manure.

1. What is the rate in tons per acre (T/A) needed to supply the recommended amount of nitrogen?

From Table 7, the average amount of N in fresh caged layer manure is 10 lbN/T. The rate in tons per acre is determined by dividing lbN needed by the lbN/T of manure. The result is 20 T/A (200 lb/A ÷ 10 lb/T).

2. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

From Table 1, a 25,000 bird caged layer flock produces 1400 T of manure per year (yr). Dividing the total amount of manure by the desired application rate gives the total land area required. The result is 70 A (1400 T ÷ 20 T/A).

3. How much land area is required for daily spreading?

The daily manure production rate is 3.84 T (1400 T/yr ÷ 365 days/yr). From the answer to Question 1, the maximum rate of application is 20 T/A. Dividing the daily production rate by the application rate gives the area required. The result is 0.19 A (3:84 T ÷ 20 T/A).

4. If the manure is spread daily, how many trips are required with a manure spreader?

There are several sizes and types of manure spreaders. Because the cost is dependent on the size and type, haul distance may be an important factor to consider. From the answer to Question 3, the daily production rate is 3.84 T/day. One trip with a 5 T (180 bu) capacity or two trips with a 3 T (108 bu) capacity is required.

Slurry Form. The manure is scraped into a storage tank and handled in a slurry form. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used.

1. What size closed storage tank is required?

It is advisable to clean the closed storage tank a minimum of twice per week. From Table 1, a 25,000 bird flock produces 1000 gal of manure daily or 4000 gal every 4 days. Because the weather or land may not be suitable for spreading on the regularly scheduled cleaning days, the capacity of the storage tank should be increased by at least 50%. Thus a storage tank of 6000 gal (4000 gal x 1.5) is required.

Table 5 gives several combinations of tank sizes. If a 10-ft width and 6-ft depth is selected, the storage capacity per foot of length would be 450 gal/ft. Thus a tank length of approximately 13.5 ft (6000 gal ÷ 450 gal/ft) is required. The tank size is 13.5 ft by 10 ft by 6 ft.

2. What is the rate in tons per acre needed to apply the recommended amount of nitrogen?

Calculations are performed exactly as given in the answer to Question 1 of the *Solid Form Example*. The result is 20 T/A.

3. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

Calculations are performed exactly as given in the answer to Question 2 of the *Solid Form Example*. The result is 70 A.

4. How much land area is required for semi-weekly spreading?

A semi-weekly spreading interval means that the

waste will be spread 104 times per year. Thus 0.67 A (70 A ÷ 104) is required for each semi-weekly spreading.

5. How many trips are required with a liquid manure spreader?

There are several sizes of liquid manure spreaders. Because the cost of an individual spreader is dependent on the size, haul distance may be an important factor to consider. From the answer to Question 1, approximately 4000 gal will need to be spread every 4 days. If an 800 gal capacity spreader is used, 5 trips (4000 gal ÷ 800 gal/trip) are required.

Lagoon Effluent. A flush system and one anaerobic lagoon are used. The same fertilizer recommendations as assumed in the *Solid Form Example* will be used. The terms lagoon liquor and lagoon effluent are used below. Lagoon liquor is the liquid and waste mixture in the lagoon. Lagoon effluent is the lagoon liquor that is discharged or taken from the lagoon.

1. What lagoon volume and surface area are required?

Design criteria approved by the North Carolina Board of Water and Air Resources require 30 cu ft per laying hen. Therefore the lagoon volume required is 75,000 cu ft (25,000 birds x 30 cu ft/bird).

The exact surface area of a lagoon depends on the depth and side slopes which in turn are dependent on the site conditions. A first approximation of the surface area can be obtained by dividing the volume by the depth. This approximate surface area provides sufficient accuracy to make the necessary calculations in the remainder of the answers to the questions in this example. If a 6 ft depth is selected, the approximate surface area would be 125,000 sq ft (750,000 cu ft ÷ 6 ft) or 2.86 A (125,000 sq ft ÷ 43,560 sq ft/A). See Appendix I for design details of a lagoon. See Misc. Ext. Publication No. 89 entitled "Tentative Guidelines for the Design, Installation and Operation of Animal Waste Treatment Lagoons in North Carolina" for construction details.

2. How much lagoon liquor needs to be removed each year from the lagoon in order to prevent discharge through the overflow pipe?

When the lagoon is nearly filled to capacity some lagoon liquor must be removed periodically during the year to prevent discharge through the overflow pipe. This discharge would be caused by manure being added and by rain falling directly on the lagoon. Table 1 shows that 45,000 cu ft of manure would be added each year for a 25,000 bird flock. Because the average rainfall per year in North Carolina exceeds the average evaporation per year by 15 in. per unit surface area, 156,200 cu ft/yr (125,000 sq ft x 15 in. ÷ 12 in./ft) is assumed to be added by the rain in excess of evaporation that falls directly on the lagoon. Thus, the approximate amount of lagoon liquor to be removed each year is 4.60 ac ft [(45,000 cu ft + 156,200 cu ft) ÷ 43,560 sq ft/A].

NOTE! The local average amounts of rainfall and evaporation should be used when making this calculation for your area.

3. What is the nitrogen concentration of the lagoon liquor?

Because the nitrogen concentration of the lagoon liquor will vary according to the amount of water used, a nitrogen analysis of the lagoon liquor should be made by a commercial laboratory. The results will generally be expressed in milligrams N per liter (mgN/1). A rough estimate of the nitrogen concentration of the lagoon liquor can be obtained by dividing the lbN in the liquor by the total amount of waste and water that is added to the lagoon each year. However, because the current recommended volume for a poultry lagoon appears to be excessively large, the total volume of the lagoon rather than the total amount of waste and water added each year will be used to determine the nitrogen concentration.

From Table 6, the mean amount of N in caged layer manure is about 40 lbN/T. From Table 1, the yearly manure production for 25,000 caged layers is 1400 T of manure. Thus 56,000 lbN (1400 T x 40 lbN/T) is discharged into the lagoon. A conservative assumption is that the N concentration of the lagoon liquor in an anaerobic lagoon that has been in operation for more than one year is about 50% of the N of fresh waste input. Thus 28,000 lbN are estimated to be in the lagoon liquor.

From the answer to Question 1, the total volume of the lagoon is 750,000 cu ft or 5,625,000 gal (750,000 cu ft x 7.48 gal/cu ft). Therefore, a rough estimate of the N concentration of the lagoon liquor is 0.00498 lb/gal (28,000 lbN ÷ 5,625,000 gal).

NOTE! The nitrogen concentration of the lagoon liquor may increase with the age of the lagoon. Therefore a nitrogen analysis of the lagoon liquor should be made yearly.

4. At what rate can the lagoon effluent be applied to the land?

Table 9 establishes the rate at which lagoon effluent can be applied to the land to achieve a certain nitrogen application rate. Entering Table 9 with 0.00498 lbN/gal and 200 lbN/A, a value of 40,000 gal/A is obtained.

5. What is the total acreage requirement?
As indicated in Question 2, 4.60 ac ft of lagoon liquor need to be removed from the lagoon. This is equivalent to 1,502,000 gal (4.60 ac ft x 12 in./ft x 27,200 gal/ac in.). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 37.6 A (1,502,000 gal ÷ 40,000 gal/A).

Because irrigation amounts are generally expressed in terms of acre inches applied to a given area, Table 10 was developed to provide information regarding the number of acre inches per acre of effluent required to give the designated rates of total N per acre for various N concentrations in liquid manure or lagoon effluent.

Table 10 could also have been used to determine the acreage requirements for Question 5. Entering Table 10 with 0.00498 lbN/gal and 200 lbN/A, a value of 1.48 ac in./A is obtained. The total amount of effluent expressed in acre inches per acre to be removed from the lagoon and spread on the land is 55.2 ac in. (4.60 ac ft x 12 in./ft). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 37.3 A (55.2 ac in. ÷ 1.48 ac in./A) which is approximately the same as obtained previously.

Several things are obvious from this example. Firstly, it would be sheer nonsense to use a tank spreader to spread the effluent. A 1400 gal spreader would require 1073 trips (1,502,000 gal ÷ 1400 gal/trip).

Secondly, the amount of acreage necessary at one time is considerably lessened if smaller amounts are taken out more frequently. For instance, if the lagoon effluent is spread 4 times per year, only 9.4 A would be required for each spreading.

Thirdly, an application of 1.48 ac in./ac could be excessive at certain times of the year. If the soil cannot absorb this amount, a larger area may be required and a lesser total application be used.

Table 9. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Gallons per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	240,000	480,000	720,000	960,000	1,200,000	1,440,000
100	0.00083	120,000	240,000	360,000	480,000	600,000	720,000
200	0.00167	60,000	120,000	180,000	240,000	300,000	360,000
300	0.00250	40,000	80,000	120,000	160,000	200,000	240,000
400	0.00333	30,000	60,000	90,000	120,000	150,000	180,000
500	0.00416	24,000	48,000	72,000	96,000	120,000	144,000
600	0.00500	20,000	40,000	60,000	80,000	100,000	120,000
700	0.00583	17,150	34,300	51,500	68,600	85,700	103,000
800	0.00667	15,000	30,000	45,000	60,000	75,000	90,000
900	0.00750	13,300	26,650	40,000	53,300	66,500	80,000
1000	0.00833	12,000	24,000	36,000	48,000	60,000	72,000
1100	0.00917	10,900	21,800	32,700	43,600	54,500	65,400
1200	0.01000	10,000	20,000	30,000	40,000	50,000	60,000
1300	0.01083	9,230	18,460	27,690	36,920	45,150	55,380
1400	0.01168	8,560	17,120	25,680	34,240	42,800	41,360
1500	0.01250	8,000	16,000	24,000	32,000	40,000	48,000
1600	0.01333	7,500	15,000	22,500	30,000	37,500	45,000
1700	0.01417	7,060	14,120	21,180	28,240	35,300	42,360
1800	0.01500	6,660	13,320	19,980	26,640	33,300	39,960
1900	0.01583	6,330	12,660	18,990	25,320	31,650	37,980
2000	0.01667	6,000	12,000	18,000	24,000	30,000	36,000
2100	0.01750	5,710	11,420	17,130	22,840	28,550	34,260
2200	0.01833	5,450	10,900	16,350	21,800	27,250	32,700
2300	0.01917	5,220	10,440	15,660	20,880	26,100	31,320
2400	0.02000	5,000	10,000	15,000	20,000	25,000	30,000
2500	0.02083	4,800	9,600	14,400	19,200	24,000	28,800
2600	0.02165	4,615	9,230	13,845	18,720	23,075	27,690
2700	0.02250	4,450	8,900	13,350	17,800	22,250	26,700
2800	0.02333	4,280	8,560	12,840	17,120	21,400	25,680
2900	0.02415	4,140	8,280	12,420	16,560	20,700	24,840
3000	0.02500	4,000	8,000	12,000	16,000	20,000	24,000

Table 10. Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Acre Inches per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	8.82	17.64	26.48	35.28	44.10	52.96
100	0.00083	4.41	8.82	13.24	17.64	22.05	26.48
200	0.00167	2.20	4.40	6.60	8.80	11.00	13.20
300	0.00250	1.47	2.94	4.41	5.88	7.35	8.82
400	0.00333	1.10	2.20	3.30	4.40	5.50	6.60
500	0.00416	0.88	1.76	2.64	3.52	4.40	5.28
600	0.00500	0.74	1.48	2.22	2.96	3.70	4.44
700	0.00583	0.63	1.26	1.89	2.52	3.15	3.78
800	0.00667	0.55	1.10	1.65	2.20	2.74	3.30
900	0.00750	0.49	0.98	1.47	1.96	2.45	2.94
1000	0.00833	0.44	0.88	1.32	1.76	2.20	2.64
1100	0.00917	0.40	0.80	1.20	1.60	2.00	2.40
1200	0.01000	0.37	0.74	1.11	1.48	1.85	2.22
1300	0.01083	0.34	0.68	1.02	1.36	1.70	2.04
1400	0.01168	0.31	0.62	0.93	1.24	1.55	1.86
1500	0.01250	0.29	0.58	0.87	1.16	1.45	1.74
1600	0.01333	0.28	0.56	0.84	1.12	1.38	1.68
1700	0.01417	0.26	0.52	0.78	1.04	1.30	1.56
1800	0.01500	0.25	0.50	0.75	1.00	1.25	1.50
1900	0.01583	0.23	0.46	0.69	0.92	1.16	1.38
2000	0.01667	0.22	0.44	0.66	0.88	1.10	1.32
2100	0.01750	0.21	0.42	0.63	0.84	1.05	1.26
2200	0.01833	0.20	0.40	0.60	0.80	1.00	1.20
2300	0.01917	0.19	0.38	0.57	0.76	0.95	1.14
2400	0.02000	0.18	0.36	0.54	0.72	0.92	1.11
2500	0.02083	0.18	0.35	0.53	0.71	0.88	1.06
2600	0.02165	0.17	0.34	0.51	0.68	0.85	1.02
2700	0.02250	0.16	0.33	0.49	0.65	0.82	0.98
2800	0.02333	0.16	0.31	0.47	0.63	0.79	0.94
2900	0.02415	0.15	0.30	0.46	0.61	0.76	0.91
3000	0.02500	0.15	0.30	0.44	0.59	0.73	0.88

6. Is it possible to reduce the land area required for spreading the effluent?

The installation of a second lagoon in series with the existing lagoon will reduce the N concentration of the effluent from the existing lagoon by approximately 50%. Thus the N concentration of the effluent to be spread would be about 0.00249 lbN/gal. Entering Table 9 with 0.00249 lbN/gal and 200 lbN/A, a value of 80,000 gal/A is obtained. The acreage required would be 18.8 A (1,502,000 gal ÷ 80,000 gal/A).

If Table 10 were used, a value of 2.94 ac in./A is obtained. The required acreage would be 18.8 A (55.2 ac in. ÷ 2.94 ac in./A).

Question 6 points out a problem that can exist when low concentrations are to be spread on fields that require high fertility rates. Assume that an effluent containing 100 mgN/l is to be spread to satisfy a soil test recommendation of 400 lbN/A. From Table 10, 17.64 ac in./A would be required. This extra amount of water over and above the normal rainfall would probably keep the soil too wet, especially in a wet season. This would result in poor soil aeration and in many instances in the growth of slime molds. As a result crop growth would be reduced or destroyed.

Soil Management

For most efficient utilization of nutrients, poultry manure should be mixed with the soil either by plowing or disking. If it is left on the surface, some N will be lost by volatilization and perhaps some by surface runoff. Mixing with the soil will essentially eliminate this loss. It will also be very effective in eliminating odors.

The manure must be decomposed before most of the nutrients contained in it become available. Plants cannot use the N, P, K, and other chemical elements contained in the organic manure; they must be released in the inorganic form.

Plowing or disking the manure into the soil will speed its decomposition and will enhance essentially all of the physical, chemical, and biological properties of the soil. However, when applying to pastures, grain, and certain other crops, it is not possible to mix it with the soil. If applied to vegetated areas as a slurry irrigation it is more apt to come into contact with, or perhaps enter, the soil than if applied as dry material.

Some other points to keep in mind include the following:

- Liquid manure should be applied in a manner that will not contaminate surface waters. It should not be applied nearer than 50 feet to a stream or other surface water.
- Regardless of the method of application it must be prevented from going directly into waterways or into seepage areas leading directly to a waterway.
- The wind direction and velocity and the proximity of neighbors should always be kept in mind when applying manure to the land.
- When irrigation is used, it is desirable to follow the application of the effluent with an application of water. This will flush out the irrigation system and will wash the manure off the vegetation and cause more of it to penetrate the soil. However, care should be taken not to add too much water which might result in surface runoff and in poor soil aeration.

ODOR CONTROL

Odor control is a very difficult problem. Some research has been conducted on odors, but no definite statements can be made regarding odor control. Controlling odors around the poultry operation is still largely dependent upon good housekeeping and satisfactory manure handling.

Steps in controlling odors include:

- Properly disposing of dead birds.
- Keeping broken eggs out of manure.
- Keeping manure as dry as possible.
- Avoiding moving manure on hot, damp still days.
- Providing good drainage around houses.
- Providing sufficient size lagoons.
- Diluting odor by adequate ventilation.

Aerators are helpful in reducing odors in lagoons, but no criteria as to the amount of aeration necessary have been established. Some research is underway to establish this criteria.

PEST CONTROL

Flies. Successful fly control begins with good sanitation practices. Fly breeding areas should be eliminated as much as possible. Broken eggs, decaying vegetable matter, waste feed, and manure are probably the most common materials used by flies for breeding. Keeping the moisture in manures as low as possible, removing broken eggs from manure, and keeping areas around the poultry house clean and neat will discourage fly breeding. "Dry" is the word if you can manage it. If not, then chemicals will help you.

Less fly problems are encountered when flush systems with lagoons are properly used because the fly's life cycle is effectively broken.

Using residual sprays for adult fly control by spraying all walls, rafters, ceilings and other surfaces where adult flies tend to rest is an effective means of control. Spraying should be repeated at 2- to 3-week intervals or as needed to control adult flies.

When a rapid kill is desired, a space spray such as dichlorvos (Vapona), naled (Dibrom) or Pyrethrins should be used. This may be applied as a fog or mist with birds present.

Poison baits have been used successfully by many poultry producers to control adult house flies in and around buildings. Normally, the baits are used with other chemical treatments such as residual surface sprays, but occasionally they bring satisfactory results when used alone. As with all chemical controls, the poison baits should be used in combination with good sanitation and manure management practices if best results are to be obtained.

The success of baits against the house fly depends on their proper use. Dry baits should be scattered in dry places where flies rest, such as aisles, floors and window sills. It is best to make daily applications of 3 to 4 oz dry and 1 to 3 gal liquid per 1,000 sq ft until fly population are reduced. Then weekly applications are made as needed. Liquids can be applied by brush or a sprinkling can to fly resting sites. The baits should be applied to clean surfaces such as sheets of metal, wood or burlap sacks rather than directly onto manure or debris. Liquids can be dispensed effectively with a chicken watering device modified by inserting a cellulose sponge in the trough to prevent clogging by dead flies.

Best pest control is usually obtained when residual sprays and dry baits are used at the same time. Sprays and baits should be used all year

round as needed to prevent heavy buildup in the spring.

It is preferable to use larvicides as *spot treatments only* to kill fly larvae that develop in wet areas of the droppings. Overall treatment with liquid larvicides on a regular schedule is not recommended because they are of questionable effectiveness, increase chemical resistance, destroy beneficial mites and insects in manure, add moisture to the manure, and are costly.

DO NOT USE LARVICIDE IN MANURE WHEN A LAGOON IS A PART OF THE WASTE MANAGEMENT SYSTEM.

The insecticides used in baits are poisonous to both man and animals. Protect your hands with rubber gloves when mixing and applying the baits. Be sure the baits are placed where the birds cannot reach them and equipment, feed and water are not contaminated. STORE ALL INSECTICIDES UNDER LOCK AND KEY.

For up-to-date legal recommendations on chemicals to use, contact your county extension agent.

Lagoon Mosquitoes

Heavy populations of mosquitoes sometimes develop in animal waste lagoons. These mosquitoes need the protective vegetation along the shoreline for egg laying and survival of their young.

To help eliminate mosquito problems, remove the marginal vegetation including any flooded plants. Rake dead vegetation and debris away from the edge of the lagoon. Vegetation can be physically removed or killed with an approved herbicide. For emergency control, apply sprays of Flit MLO at 5 gallons per acre or Number 2 fuel oil at 10 gallons per acre.

ECONOMICS

If a producer is to make a rational choice among the various waste management systems, he must compare costs of these systems and estimate the value of the waste in a cropping program. Because each situation is different, no one "best" system can be suggested. Each producer must make his own comparisons.

Each producer must start with his present situation. A producer who is constructing new housing can simply compare the total annual costs of various waste management systems and weigh these costs against the environmental desirability and manure value for each system, realizing the limits upon the capital which he can invest.

Typically, however, a producer with functional existing houses finds that he may have to change his waste management system because of legislation, labor scarcity, or limited land on which to apply the manure. In this case, the producer will want to look at the net income effect of switching from his present system to another. The calculations involve adding the various additional annual costs associated with the switch.

Two types of costs are involved in any waste management system. They are ownership or fixed costs and variable or operating costs. Both fixed and variable costs should be considered in selecting the waste management system for a specific poultry operation. Annual ownership costs are depreciation, interest on investment, insurance and taxes. Variable costs are for such items as fuel, labor, repairs and any other out-of-pocket costs.

Annual depreciation is determined by dividing the original cost of the waste disposal system by the expected years of life for that system. Interest is computed at one-half the rate of interest paid. This is for intermediate (up to seven years) or long-term credit. If a person is paying 8 percent interest on an investment that is repaid over several years, on the average he will pay approximately 4 percent per year on the original investment. Insurance should be shown at its actual cost. Taxes will vary among counties depending on the tax rate and value for tax evaluation.

In choosing a waste management system, the poultry producer should first select the ones that will handle his situation. If only one system is belived suitable, then the only thing to determine is can he afford to continue producing poultry with the added costs incurred in the waste management system.

Should two or more of the systems be suitable, the producer should then itemize both the annual fixed costs involved in each system and the annual variable or operating costs. The system with the least annual total cost should be selected assuming that either system being considered will ade-

Table 11. Estimated Cost of Poultry Waste Management Systems Based on a Flock Size of 25,000 Caged Layers

	Estimated Cost (Spring 1973)		Your Cost	
	Initial	Annual	Initial	Annual
System I				
Concrete manure pits	4,000	392.00		
Pit scraper, conveyor	6,084	900.48		
Tractor scraper, 12 hp gas	1,200	177.60		
Front end loader	500	74.00		
Spreader, 180 bu	1,400	207.20		
Tractor, 55 hp diesel	6,200	917.60		
Truck spreader, 2 ton	5,450	806.60		
Labor		1,000.00		
Repairs				
Fuel and Electricity				
System II				
Concrete manure pits	4,000	392.00		
Lagoon, 750,000 cu ft	8,000	784.00		
Farm wagon	350	51.80		
Irrigation system	6,000	888.00		
Tractor, 35 hp gas	4,300	636.40		
Agitator pump	1,900	281.20		
Tank spreader	2,100	310.80		
Tractor, 55 hp diesel	6,200	917.60		
Labor		450.00		
Repairs				
Fuel and Electricity				
System III				
Pit scraper	6,084	900.48		
Storage tank, 4800 gals	640	62.72		
Agitator pump	1,900	281.20		
Tank spreader	2,100	310.80		
Tractor, 55 hp diesel	6,200	917.60		
Tank and soil injector (800 gals)	2,555	378.14		
Labor		550.00		
Repairs				
Fuel and Electricity				
System IV				
Concrete manure pits	4,000	392.00		
Lagoon, 750,000 cu ft	8,000	784.00		
Aerator				
Farm wagon	350	51.80		
Tractor, 35 hp gas	4,300	636.40		
Irrigation system	6,000	888.00		
Labor		450.00		
Repairs				
Fuel and Electricity				

quately handle the amount of waste produced.

The value of poultry manure has been reported to range from $5 to $26 per ton, depending upon handling practices and other factors. This value and the cost of fertilizer to replace the manure must also be considered in selecting a waste management system.

Table 11 lists the estimated initial investment and annual costs for each alternative waste management system. It is based on a flock size of 25,000 caged layers. The depreciation is 10 years for equipment and 20 years for structures. The interest is the initial cost times 4 percent; the insurance, initial cost times 0.5 percent; and taxes, initial cost times 0.3 percent. Only those components that comprise a system under each alternative should be used when making comparisons.

APPENDIX I

Lagoon Design for 25,000 Birds

The tentative guidelines approved by the North Carolina Board of Water and Air Resources set the minimum volume per bird at 30 cu ft. For 25,000 birds, 750,000 cu ft of storage must be provided in the lagoon. If the depth is 10 ft, the *average* area (area at one-half the depth) is 75,000 sq ft (750,000 cu ft ÷ 10 ft). If the average width is chosen to be 150 ft the average length would be 500 ft (75,000 sq ft ÷ 150 ft). Therefore a lagoon with 3:1 side and end slopes will have the dimensions as shown in Figure 1.

For other depths and widths, the procedure for sizing would be the same as outlined in this example.

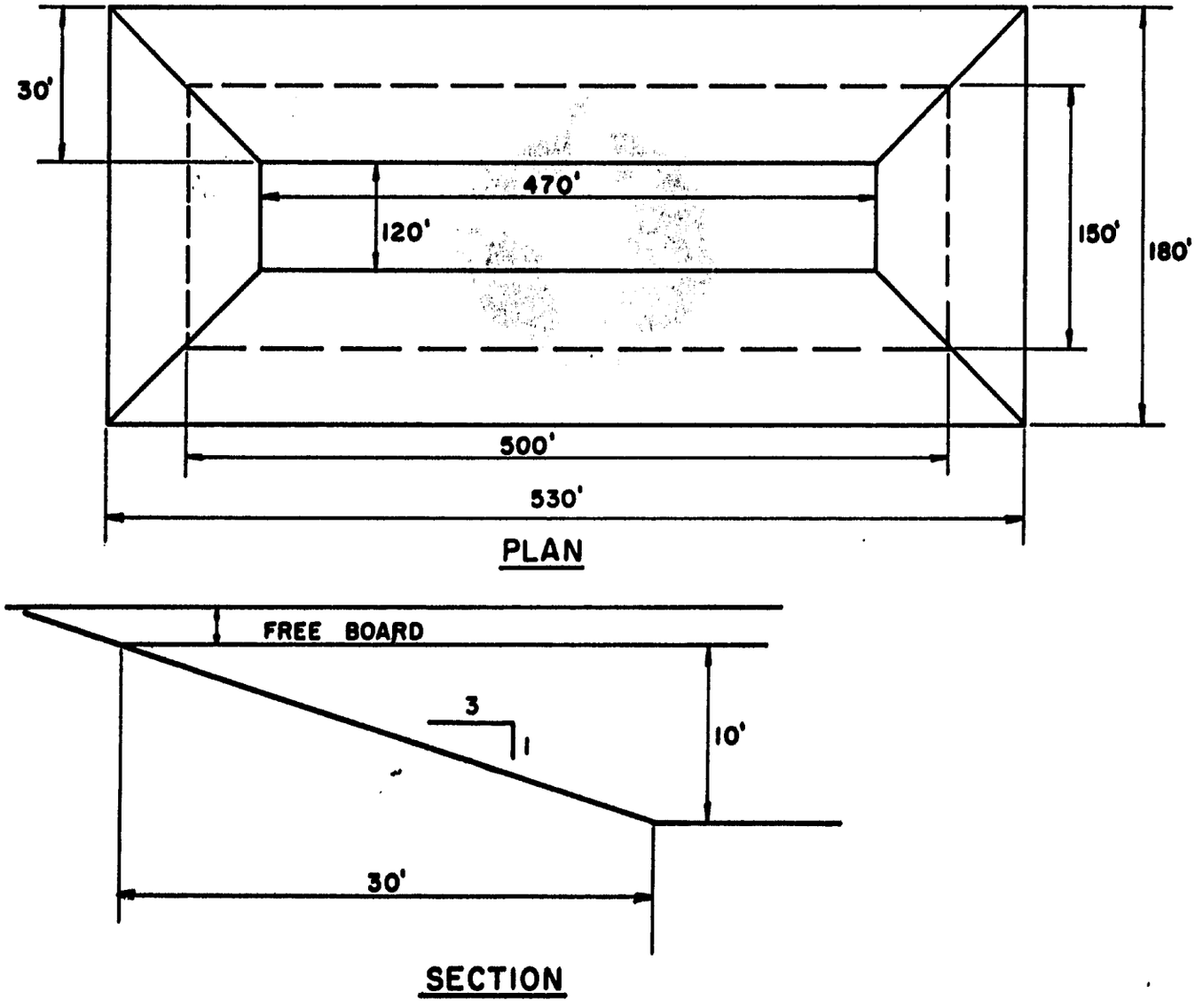

Figure 1. Plan and Section Views of a Lagoon.

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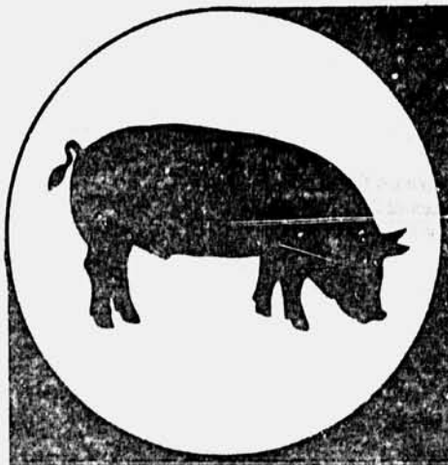

SWINE WASTE MANAGEMENT ALTERNATIVES

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Prepared by

L. B. Driggers, Extension Biological and Agricultural Engineer
J. M. Falter, Extension Entomologist
J. R. Jones, Extension Animal Scientist
*G. J. Kriz, Extension Biological and Agricultural Engineer
J. F. Lutz, Soil Scientist
J. A. Phillips, Extension Soil Scientist
C. R. Weathers, Extension Economist

* Coordinator

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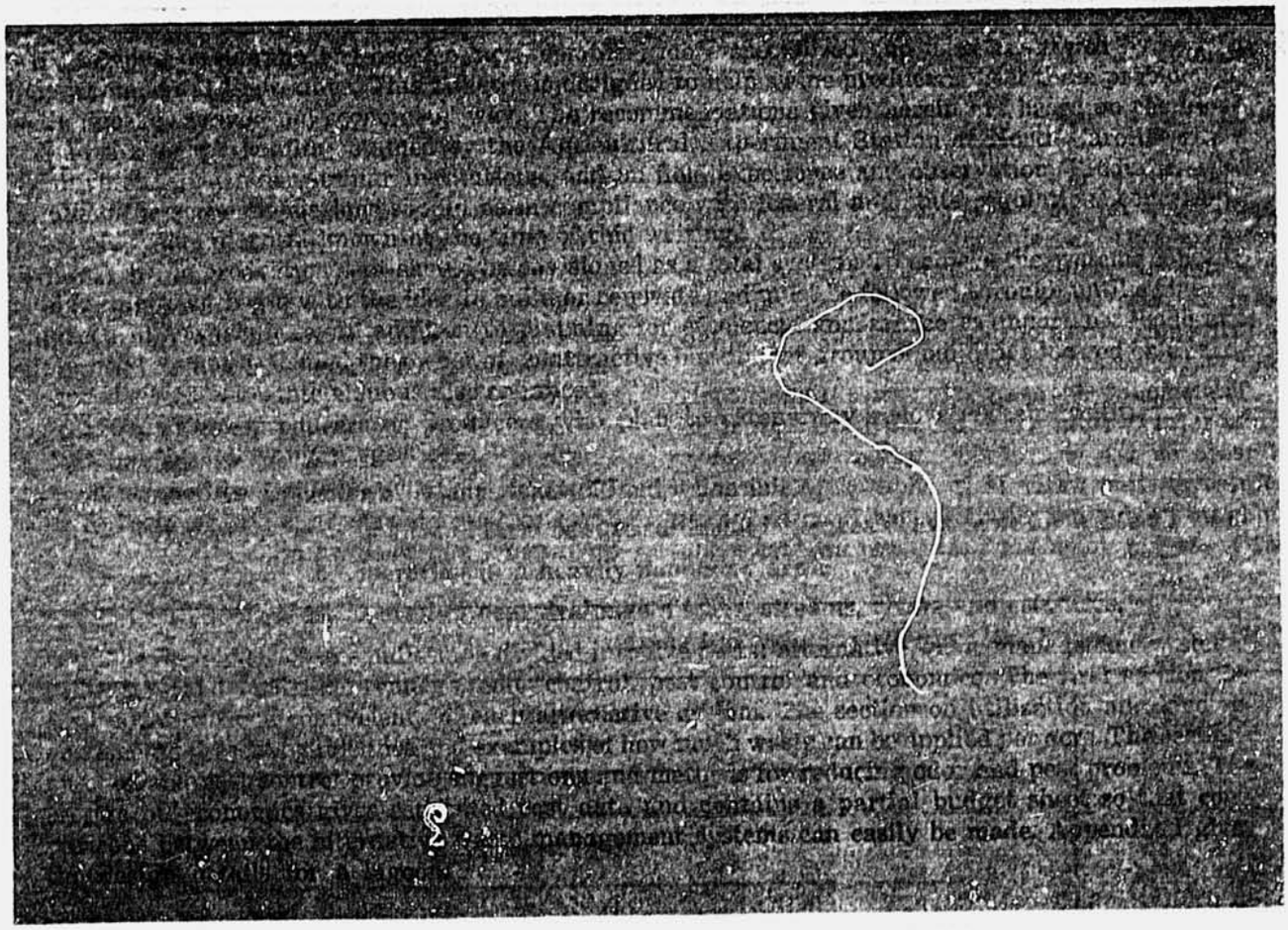
Swine Waste Management Alternatives



ALTERNATIVE WASTE MANAGEMENT SYSTEMS

Manure management is an important aspect of a complete swine production system. Collection, storage, treatment and disposal must be compatible to effect pollution control.

The manure production of growing and finishing pigs is given in Table 1. These figures provide the basis for determining the daily manure production which is paramount in the selection of a disposal system.

Research and experience to date suggest that manure be returned to the land. The quantity or application rate depends primarily upon methods of pretreatment and the utilization capacity of the soil and growing plants.

Careful analysis of waste management alternatives will enable a producer to select the system most applicable. Care must be taken to prevent any waste or waste waters from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

Table 1. Manure Production of Growing and Finishing Pigs

Pig Weight Lb	Age Weeks	Manure Production				
		Feces	Urine	Total	Daily Volume Gal/Day/Lb of Animal	Average Daily Volume Gal
		Lb/Day/Lb of Animal				
19 - 40	3 - 8	0.027	0.058	0.085	0.0102	0.27
40 - 80	8 - 12	0.043	0.048	0.091	0.0109	0.65
80 - 120	12 - 16	0.054	0.061	0.115	0.0138	1.3
120 - 160	16 - 20	0.046	0.058	0.104	0.0125	1.8
160 - 200	20 - 23	0.047	0.051	0.098	0.0117	2.1

System I: Solid Floor and Storage Tank

Solid Floor→Wash→Storage Tank→Spreader→Land

This system is not widely used but does have application for some producers. Manure from a solid concrete floor should generally be scraped to a gutter for washing or scraping into the storage tank because washing the entire floor can have detrimental effects on pigs depending upon their age and the season of the year.

The amount of wash water varies tremendously from farm to farm and thus will have a great influence on the size of the storage tank needed. Moreover, this water is in addition to the daily manure production. Studies show that the lowest daily average volume of wash water used for cleaning solid floor pens is 2 gallons (gal) per 100-pound (lb) pig. Some of the high volume users average 10 gal/100-lb pig. This is a wide range, but more important it is adding to the daily volume of animal waste.

A storage tank of reinforced concrete should be sized on the basis of numbers of pigs, weight of pigs, moisture content of the manure and frequency of spreading. It requires an agitator or a pump-agitator which serves the dual role of mixing the contents into a pumpable slurry and filling the spreader tank.

Table 2 gives the storage capacity per foot of length for tanks with different widths and depths. This table along with Table 1 will enable the producer to determine the tank size required to store the manure and wash water.

Table 2. Storage Tank Capacity per Foot of Length

Tank Width Ft	Tank Depth Ft		
	6	8	10
	Gal/Ft of Length		
10	450	600	750
12	540	720	900
14	630	840	1050
16	720	960	1200
18	810	1080	1350
20	900	1200	1500
22	990	1320	1650
24	1080	1440	1800

Sometimes, water must be added to the storage tank to bring the contents to a pumpable consistency. Table 3 shows the approximate quantity of water needed to increase the moisture content of the manure. A general range of moisture content for manures without bedding would be as follows:

75—82% moisture - stiff
80—85% moisture - fluid or semi-liquid—quite thick slurry
83—90% moisture - liquid—fairly thin liquid at 90%
93—97% moisture - irrigation consistency

Table 3. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Initial			Percent Moisture Desired	Amount of Water to be Added to Each Cu Ft to Give the Desired Percent Moisture		Final Volume per Each Original Cu Ft	
Volume		Percent Moisture					
Cu Ft	Gal			Cu Ft	Gals	Cu Ft	Gals
1.0	7.5	85	90	0.50	3.75	1.50	11.25
			95	2.00	15.00	3.00	22.50
1.0	7.5	80	85	0.33	2.50	1.33	10.00
			90	1.00	7.50	2.00	15.00
			95	3.00	22.50	4.00	30.00
1.0	7.5	75	80	0.25	1.88	1.25	9.38
			85	0.67	5.00	1.67	12.50
			90	1.50	11.25	2.50	18.75
			95	4.00	30.00	5.00	37.50
1.0	7.5	70	75	0.20	1.50	1.20	9.00
			80	0.50	3.75	1.50	11.25
			85	1.00	7.50	2.00	15.00
			90	2.00	15.00	3.00	22.50
			95	5.00	37.50	6.00	45.00

It is evident from Table 3 that the amount of water added to produce a pumpable slurry might be more than the quantity of manure initially. For example, the addition of 11.25 gal of water to 1 cubic foot (cu ft) of fresh manure at 75% moisture raises the moisture content to 90% and changes the volume from 1 cu ft to 2.5 cu ft.

Field spreaders are available as tractor drawn or truck mounted units. Select a spreader that does not leak the contents along the road. A tank wagon equipped with a vacuum pump is frequently used for this purpose. An irrigation system for land spreading may be used instead of a spreader.

One distinct disadvantage with liquid manure storage is odors while agitating and field spreading. The liquid slurry should not be spread on a hot humid (muggy) day because odors resulting from the agitating and spreading operation may create a nuisance.

Where odor is a problem, the producer might elect to equip his spreader with a soil injector. This equipment places the liquid slurry 4 to 6 inches (in.) below the ground surface and covers it immediately, drastically reducing odor. Care must be exercised to select a field that is relatively free of large stones, stumps and roots when the injection method is used.

System II: Solid Floor and Lagoon

Solid Floor → Wash → Lagoon → Irrigation / Spreader → Land

This method of disposal has more appeal than System I. It differs in that a lagoon is used as the storage unit. To meet the design criteria approved by the North Carolina Board of Water and Air Resources, 150 cu ft of water must be provided in the lagoon for each hog.

Lagoons are storage ponds in which the water level must be controlled. Research with swine waste lagoons in North Carolina indicates ex-

plicitly that the effluent cannot be discharged into a water course. Therefore, any overflow or discharge must be returned to the land.

Irrigating lagoon effluent is probably the most practical way of controlling the water level in the lagoon because of the quantity. When using irrigation care must be exercised to prevent surface runoff. The system should be designed for minimum pipe and sprinkler movement because this is a "nasty" job. Before moving, flush out the irrigation system with clean water.

A tank wagon equipped with a vacuum pump might be used with small lagoons, but its volume will limit its use.

The lagoon effluent should not be spread on a hot humid (muggy) day because odors resulting from the spreading operation may create a nuisance.

Evidence indicates that the lagoon serves as a nitrogen trap by accumulating nitrogen in the sludge build-up on the bottom. This build-up of solids indicates that the sludge must be removed at some future date, but definite recommended cleaning intervals have not been established at this time. By reducing the quantity of nutrients through the decomposition process that takes place in a lagoon, less land area is needed for land spreading because of nutrient reduction, particularly nitrogen, in the effluent.

System III: Slotted Floor and Lagoon

Slotted Floor → Lagoon → Irrigation / Spreader → Land

Slotted floor swine buildings are rapidly becoming the rule rather than the exception. Pits under the slats allow temporary manure storage until emptied into the lagoon. Final disposal from this point would be the same as in System II.

System IV: Slotted Floor with Direct Spreading

Slotted Floor → Spreader → Land

This method can be employed particularly with small producers who have land readily available onto which the manure can be applied. The pit under the slats serves as a storage area.

A tank wagon equipped with a vacuum pump is most often used to empty the pit. One distinct disadvantage in handling liquid manure is odors while field spreading. The liquid slurry should not be spread on a hot humid (muggy) day because odors resulting from the spreading operation may create a nuisance.

Where odors are a problem when field spreading, the producer may equip the spreader with an injector. This equipment places the liquid slurry 4 to 6 in. below the ground surface and covers it immediately, greatly reducing odor. Be careful to select a field that is relatively free of large stones, stumps and roots when using the injection method.

Other Alternatives

Drying. Drying at this time does not offer much promise because most of the manure is handled as a liquid.

Composting. Like drying, this method holds little promise because the solids would have to be separated from the liquids. Then too, aeration is essential to achieve rapid compositng.

Mechanical Aeration. Aeration of lagoons or holding tanks will eliminate odors and upgrade lagoon performance. This increased degree of pretreatment prior to terminal land disposal will eliminate odors arising from land irrigation and surface spreading as well as reduce the amount of land required for disposal. A floating aerator can easily be placed in an existing lagoon.

Mechanical aeration must be investigated on an individual enterprise basis as a component in the waste treatment system.

UTILIZATION AND LAND REQUIREMENTS

Utilization of swine manure by ultimate disposal on land is generally recommended. However, because large quantities of manure are generated in concentrated operations, many of which have limited land areas, the manure is often treated as an unwanted commodity to be disposed of by any means that are publicly acceptable or economically feasible. Whenever possible, the manure should be treated as a resource and used as a valuable source of plant nutrients.

During the past 40 to 50 years swine manures have been largely replaced by commercial fertilizers as sources of plant nutrients. This may be attributed to: 1) improved physical and chemical quality of commercial fertilizers; 2) improved method of handling and applying commercial fertilizers; 3) the smaller tonnage of commercial fertilizers required to give the same amount of plant nutrients; and 4) the lower cost per pound of plant nutrients in commercial fertilizers. Swine manure can be used as a source of nutrients for most crops grown in North Carolina except to-

bacco and certain crops where nitrogen control is essential. The efficiency of properly applied manure as a source of nutrients is comparable to that of commercial fertilizers, and the crop recovery values of the nutrients from manure are quite comparable to those from commercial fertilizer.

The principal plant nutrients supplied by both swine manures and commercial fertilizers are nitrogen (N), phosphorus (P) and potassium (K). In fertilizers the nutrients are expressed as percents nitrogen (N), phosphate (P_2O_5) and potash (K_2O). In addition to N, P and K, swine manure usually contains an appreciable amount of calcium, magnesium and sulfur and traces of manganese, iron, boron, copper, and zinc, all of which are essential for plant growth. Care should be taken to monitor the levels of trace elements in the soil in order to avoid excessive or toxic amounts.

Nutrient Composition of Swine Manures

The daily production and the composition of swine manures varies with the size of animal and the kind and amount of feed consumed. Table 4 gives representative values of the major plant nutrient composition of raw swine manure including urine expressed in pounds per day per 100-lb hog (lb/day/100-lb hog).

Table 4. Major Plant Nutrient Composition of Raw Swine Manure Including Urine*

Plant Nutrient	Mean Lb/Day/100-Lb Hog	Range Lb/Day/100-Lb Hog
Nitrogen (N)	0.048	0.019 - 0.070
Phosphorus (P_2O_5)	0.014	0.011 - 0.020
Potassium (K_2O)	0.021	0.008 - 0.050

* Data derived from
Humenik, F. J., M. R. Overcash and L. B. Driggers. Swine Production Industry Waste Characterization and Management. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, N. C.

Table 5 gives representative values of the trace-element composition of oven dried swine manure.

Table 5. Trace-Element Composition of Oven Dried Swine Manure*

Trace Element	Mean Lb/T	Range Lb/T
Calcium (Ca)	58	48 - 72
Magnesium (Mg)	14	6.6 - 24
Sulfur (S)	14	5.8 - 18.4
Iron (Fe)	2.4	1.2 - 3.6
Zinc (Zn)	1.0	0.76 - 3.6
Boron (B)	0.27	—
Copper (Cu)	0.20	0.20 - 1.0
Manganese (Mn)	0.20	—

* Data derived from
Humenik, F. J., M. R. Overcash and L. B. Driggers. Swine Production Industry Waste Characterization and Management. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, N. C.

The actual amount of the major plant nutrients and trace elements present in the manure is dependent on the rations fed and the way that the manure is handled or stored. Because in most instances it would not be practical to have each batch of manure analyzed, the numbers in Tables 4 and 5

may be used to get approximate values of the amount of nitrogen, phosphorus, potassium, and trace elements contained in it.

The relative value of swine manure as compared to commercial fertilizer will be determined by the composition of the manure and by the cost of handling it. This will vary from farm to farm and should be estimated in each individual situation. An important item that should not be overlooked in estimating the value of manure is the fact that the manure must be disposed of but the cost of disposal is partially offset by its fertilizer value.

Effects of Swine Manure on Soils and Crops

Swine manure has several beneficial effects on the chemical, physical and biological properties of soils.

Chemical Effects. The principal chemical effect of manure is the supplying of the major plant nutrients: nitrogen, phosphate and potash. It also contains a number of other chemical elements necessary for plant growth. In contrast to commerical fertilizers, swine manure supplies organic matter to soils. This is usually considered beneficial in increasing the nutrient-holding capacity of soils.

Physical Effects. If manure is applied to the surface of the soil, it will aid in preventing soil crusting. If mixed with the soil, it will decompose more rapidly and the products of decomposition will improve soil structure and the general physical condition of the soil. Thus, whether applied to the surface or mixed with the soil, it will be important in conserving water and soil by reducing runoff and erosion. Swine manure is frequently credited with increasing the available water-holding capacity of soils. This is generally not true. If the manured soil contains more water, it is probably because more soaked in during rainfall or irrigation.

Biological Effects. Manure is a source of food, and hence energy, for soil microorganisms that decompose it. These soil microorganisms have many very important direct and indirect effects on many physical, chemical and biological properties of the soil.

Factors Affecting Rates of Application

Several factors affect the amount of manure that might be applied to any given land area. They are: (1) the use to be made of the land—whether it is to be used for crop production or for manure disposal only; (2) if used for crop production, the kind of crop to be grown; (3) the characteristics of the soil including texture, depth and fertility status; (4) topography as it affects runoff and erosion; (5) the season of the year in which the manure is to be applied; and (6) possibility of environmental pollution, particularly the contamination of surface and ground water by excessive leaching or runoff. In this connection care must always be taken to prevent any waste or waste water from reaching the surface waters of the state and violating the water quality standards assigned to those waters.

From the standpoint of crop production the amount of manure to be applied to any particular crop is determined by the nitrogen content of the manure and the nitrogen requirements of the crop. This will be explained more fully in the following pages.

Crop production is not the only factor to be considered in determining the amount of manure that might be applied to any particular soil. Another very important factor is the possible effect of the manure on environmental pollution, particularly contamination of surface or ground water. The two elements contained in manure which are most likely to cause problems in water are nitrogen, particularly in the nitrate form, and phosphorus. Excessively large amounts of nitrates can be toxic to animals and considerable accumulation of nitrates and phosphate in surface water causes eutrophication (excessive growth of algae and other water-loving plants). When manure decomposes in the soil the nitrogen will ultimately be converted to the nitrate form which is very easily leached. If it leaches downward in the soil to a poorly drained layer, in which there is sufficient organic matter for microorganisms to live on, the nitrate will be converted to the ammonium form which is less easily leached and less toxic to animals, and is likely to be volatilized.

Table 6 gives the relative potential nitrate leaching rates together with some of the soil properties affecting leaching. As a general rule it would be undesirable to apply heavy applications of manure to soils with a high nitrate-leaching potential. On such soils, it would be desirable to use smaller applications [illegible] throughout the year, making [illegible] total application within a year is [illegible] fine textured soils [illegible] runoff may contribute to [illegible]

[illegible] the relative phosphate-fixing capacity of representative soils in North Carolina. Many soils have the capacity to "fix" phosphorus; that [illegible] relatively insoluble and on those soils phosphate leaching is usually not a problem. It is a problem, however, on sand and care should be taken not to add large amounts of phosphorus

Table 6. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Texture of Topsoil (6-10 in.)	Texture of Subsoil (6-10 to 20 in.)	Critical Soil Property Affecting Movement of N and P	Relative Potential Nitrate Leaching	Relative Phosphate-Fixing Capacity	Typical Soil Series
Sand	Sand	Low water table, very high permeability	Very high	Very low	Lakeland, Wagram
		High water table	Low	Very low	Bibb, Pelham, Plummer
Sandy loam, or Very fine sandy loam	Sandy clay loam, Clay loam, or Clay	Loose to hard, moderately permeable subsoil	Medium to high	Low	Altavista, Durham, Granville, Norfolk
		Slowly permeable, somewhat plastic subsoil	Medium to low	Medium	Appling, Cecil
		Very slowly permeable, plastic sticky subsoil	Very low	Medium to low	Creedmoor, Enon, Helena, Iredell, Whitestore, Wilkes
		High water table	Low	Medium to low	Lumbee, Rains, Roanoke, Wehadkee, Worsham
Silt loam, or Loam	Silty clay loam, Clay loam, or Clay	Moderately permeable, plastic subsoil	Medium to low	Medium to high	Alamance, Chandler, Chester, Congaree, Fannin, Georgeville, Herndon, Hiwassee, Lloyd, Mecklenburg, Orangeburg, Porters, Ruston
		Slowly permeable, plastic, sticky subsoil	Low	Medium	Bertie, Craven, Dunbar, Nason
		Very slowly permeable, plastic, sticky subsoil	Very low	Low	Lignum, Tatum
		High water table	Low	Medium	Bayboro, Kinkora, Portsmouth, Roanoke
Silty clay loam, or Clay loam	Silty clay, or Clay	Slowly permeable, compact subsoil	Medium to low	High to very high	Caroline (eroded), Cecil (eroded), Davidson, Georgeville (eroded), Hayesville (eroded), Marlboro (eroded)
		Moderately to slowly permeable, granular subsoil	Low	High to very high	Appling (eroded)
		High water table	Very low	Medium	Any low, poorly-drained areas with topsoil removed by burning or stripping
Clay - Eroded or denuded areas, void of topsoil and, thus, with subsoil exposed		Slow to very slowly permeable, compact or granular subsoil	Low to very low	High to very high	Any area with clay exposed by erosion, stripping or burning
		High water table	Very low	Medium	Same as above, but with high water table

to soils with low phosphate-fixing capacity. As a general rule the red to reddish-yellow soils with considerable clay in the subsoil have the higher phosphate-fixing capacity. The relative values for some typical soils in the state are given in Table 6.

The leaching of nitrates, phosphates and other plant nutrients is affected by a number of factors such as soil temperature (which affects the rate of decomposition of manure), the kind of crop being grown and, hence, the rate of utilization of the nutrients by the crop, and the soil moisture conditions. Under normal climatic conditions in North Carolina the soils are usually wet during the winter and relatively dry during the summer. "Normal" summer rains penetrate the soil to relatively shallow depths (6 to 10 to 15 inches, depending upon the texture) and under high summertime temperatures the moisture is rapidly lost by evaporation. Under such conditions leaching of nitrates to the water table is improbable, except on extremely coarse-textured soils.

Because only about half of the nitrogen contained in the manure will generally become available during the first nitrogen season, it is possible to apply about twice the recommended amount of nitrogen to grain and forage crops without the danger of nitrate toxicity or groundwater contamination. However, in succeeding years this carry-over should be taken into account and rates adjusted accordingly.

Phosphorus is mainly in the organic form in swine manure. Phosphorus availability is directly related to the rate of manure decomposition and is much slower than that of nitrogen. Potassium in swine manure is an inorganic salt that is easily leached and is readily available for plant use. Swine manure also contains many minor elements in very small quantities that are released as the manure decomposes.

Losses of nutrients from manure either occur from leaching of soluble salts or volatilization. However, these losses can be held to a minimum if the material is applied to the land and incorporated into the soil. Swine manure that is high in nitrogen should be applied to the land at least 2 to 4 weeks prior to planting to prevent ammonia from burning the plants and to reduce salt injury. Where available land is required for feed production, management practices must be developed to permit land spreading at suitable times.

How to Determine the Amount to Apply

The nutrient composition of the manure is very dependent on the type of waste management system. Producers should have the slurry or lagoon liquid analyzed. There are several commercial laboratories in North Carolina that have expressed an interest in analyzing waste samples. For further information, contact your county extension agent or one of the regional offices of the Office of Water and Air Resources of the Department of Natural and Economic Resources located in Greenville, Raleigh, Concord and Asheville.

Estimates of the existing soil nutrient supply can be obtained by soil tests made by the Soil Testing Division of the North Carolina Department of Agriculture. Rates of application should be based on the recommended amount of nitrogen needed to supplement the existing soil nitrogen supply for the particular crop to be grown. Contact your county extension agent for further information on determining the rate of application.

Illustrative examples are shown below for handling the waste in slurry form and as lagoon effluent. Each example is for a specific set of conditions that may or may not be applicable to your area. Each example is based on the approach that the swine manure is to be a source of fertilizer with the long range objective of optimum crop production.

If the approach is taken whereby the land is to be used for waste disposal without consideration of any crop, higher application rates than given in the examples below could be used. However, the risk of groundwater and surface water contamination is greater, a very good understanding of the characteristics of the soil is essential, and lastly, a resource in the form of fertilizer is being wasted. If this latter approach is used, contact your county extension agent or Soil Conservation Service district conservationist.

Examples

In the examples given below, information on the following will be given based on handling the manure from typical swine operations:

—Rates of application.
—Total land area needed per year.
—Land area required for spreading at definite intervals.
—Number of trips required for spreading at definite intervals (except for lagoon example).

THE EXAMPLES DO NOT TAKE LOCATION, TOPOGRAPHY, SEASON OF YEAR, WEATHER CONDITIONS, STAGE OF CROP GROWTH OR SOIL TYPE INTO ACCOUNT. These factors will be discussed in a subsequent bulletin. The numbers in the parentheses show how the calculations are made.

Slurry Form. A swine operation has 300 hogs on a solid concrete floor. The manure is scraped into a gutter and washed into a storage tank. A 30-day clean-out interval is used. Assume that the fertilizer recommendations for corn on a particular soil are as follows:

N	P_2O_5	K_2O	Lime
lb/A	lb/A	lb/A	T/A
180	140	160	2

All of the nitrogen (N) is to be supplied by the manure.

1. What size closed storage tank is required?

Because the storage tank must be sized for the maximum size hogs that will be in the production unit, the average daily volume per hog of 2.1 gal per day is selected from Table 1. For this example, assume that 3.9 gal/hog of wash water is used daily. Thus the total daily volume of waste output is 1800 gal ((2.1 + 3.9) gal/day/hog x 300 hogs). During a 30-day period the total volume of waste output is 54,000 gal (1800 gal/day x 30 days).

Table 2 gives several combinations of tank sizes. If a 20-ft width and 8-ft depth are selected, the storage capacity per foot of length would be 1200 gal/ft. Thus a tank length of 45 ft (54,000 gal ÷ 12 gal/ft) is required. Thus, the tank size is 45 ft by 20 ft by 8 ft.

2. What is the rate in tons per acre needed to supply the recommended amount of nitrogen?

From Table 4, the average amount of N in swine manure is 0.048 lb/day/100 lb hog. From Table 1, the total manure production for a 160-200 lb pig is 0.098 lb/day/lb of animal. The average percent of nitrogen in the manure is 0.49% [(0.048 lb/day/100 lb hog) ÷ (0.098 lb/day/lb of animal)]. The amount of nitrogen per ton of manure is 9.8 lbN/T (2000 lb/T x 0.0049 N). The rate in tons per acre is determined by dividing lbN needed by the lbN/T of manure. The result is 18.4 T/A (180 lb/A ÷ 9.8 lb/T).

3. What is the total land area needed in order that the application rate for nitrogen is not exceeded?

From Table 1, the total manure production for a 160-200 lb pig is 0.098 lb/day/lb of animal. Thus 300 pigs averaging 180 lb produce 1050 T of manure per year (0.098 lb/day/lb of animal x 180 lb animal x 300 animals x 365 days/yr ÷ 2000 lb/T). Dividing the total amount of manure by the desired application rate gives the total land area required. The result is 57 A (1050 T ÷ 18.4 T/A).

4. How much land area is required for spreading on a 30-day interval?

A 30-day spreading interval means that the slurry will be spread 12 times per year. Thus 4.75 A (57 A ÷ 12) are required.

5. How many trips are required with a liquid manure spreader?

There are several sizes of liquid manure spreaders. Because the cost of an individual spreader is dependent on the size, haul distance may be an important factor to consider. From the answer to Question 1, approximately 54,000 gal will need to be spread every 30 days. If an 800 gal capacity spreader is used, 68 trips (54,000 gal ÷ 800 gal/trip) would be required.

Lagoon Effluent. A swine operation has 500 hogs on a totally slotted floor. The waste is discharged into an anaerobic lagoon. No wash water is used. The same fertilizer recommendations as assumed in the *Slurry Form Example* will be used. The terms lagoon liquor and lagoon effluent are used below. Lagoon liquor is the liquid and waste mixture in the lagoon. Lagoon effluent is the lagoon liquor that is discharged or taken from the lagoon.

1. What lagoon volume and surface area are required?

Design criteria approved by the North Carolina Board of Water and Air Resources require 150 cu ft per hog. Therefore the lagoon volume required is 75,000 cu ft (500 hogs x 150 cu ft/hog).

The exact surface area of a lagoon depends on the depth and side slopes which in turn are dependent on the site conditions. A first approximation of the surface area can be obtained by dividing the volume by the depth. This approximate surface area provides sufficient accuracy to make the necessary calculations in the remainder of the answers to the questions in this example. If a 6-ft depth is selected, the approximate surface area would be 12,500 sq ft (75,000 cu ft ÷ 6 ft) or 0.29 A (12,500 sq ft ÷ 43,560 sq ft/A). See Appendix I for design details of a lagoon. See Misc. Ext. Publication No. 89 entitled "Tentative Guidelines for the Design, Installation and Operation of Animal Waste Treatment Lagoons in North Carolina" for construction details.

2. How much lagoon liquor needs to be removed each year from the lagoon in order to prevent discharge through the overflow pipe?

When the lagoon is nearly filled to capacity, some lagoon liquor must be removed periodically during the year to prevent discharge through the overflow pipe. This discharge would be caused by manure being added and rain falling directly on the lagoon. From Table 1, the average daily volume of manure produced by a 160-200 lb hog is 2.1 gal/

day/hog. Thus 500 hogs averaging 180 lb produce 51,000 cu ft/yr (2.1 gal/day/hog x 500 hogs x 365 days/yr ÷ 7.5 gal/cu ft) of manure. Because the average rainfall per year in North Carolina exceeds the average evaporation per year by 15 in. per unit surface area, 15,600 cu ft/yr (12,500 sq ft x 15 in. ÷ 12 in./ft) is assumed to be added by the rain in excess of evaporation that falls directly on the lagoon. Thus, the approximate amount of lagoon liquor to be removed each year is 1.53 ac ft [(51,000 cu ft/yr + 15,600 cu ft/yr) ÷ 43,560 sq ft/A].

NOTE! The local average amounts of rainfall and evaporation should be used when making this calculation for your area.

3. What is nitrogen concentration of the lagoon liquor?

Because the nitrogen concentration of the lagoon liquor will vary according to the amount of water used, a nitrogen analysis of the lagoon liquor should be made by a commercial laboratory. The results will generally be expressed in milligrams N per liter (mgN|1). A rough estimate of the nitrogen concentration of the lagoon liquor can be obtained by dividing the lbN in the liquor by the total amount of waste and water that is added to the lagoon each year.

From Table 4, the mean amount of N produced by swine is 0.048 lb/day/100-lb hog. Thus the yearly amount of N produced by 500 hogs weighing 200 lb is 17,500 lbN (0.048 lb/day/100-lb hog x 200-lb hog x 365 days/yr x 500 hogs). A conservative assumption is that the N concentration of the lagoon liquor in an anaerobic lagoon that has been in operation for more than one year is about 50% of the N of fresh waste input. Thus 8,750 lbN are estimated to be in the lagoon liquor.

From the answer to Question 2, the total yearly amount of manure that is discharged into the lagoon is 51,000 cu ft or 381,000 gal (51,000 cu ft x 7.48 gal/cu ft) and rain in excess of evaporation that falls onto the lagoon is 15,600 cu ft or 116,500 gal (15,600 cu ft x 7.48 gal/cu ft). Therefore, the nitrogen concentration is 0.01760 lbN/gal [8,750 lbN ÷ (381,000 gal + 116,500 gal)].

NOTE! If 4 gal/day/hog are used for wash water for a partially slotted floor, the total yearly amount is 730,000 gal (4 gal/day/hog x 500 hogs x 365 days/yr). The nitrogen concentration would then be 0.00714 [8,750 lbN ÷ (381,000 gal + 116,500 gal + 730,000 gal)]. Research results from studies conducted on lagoons by the Department of Biological and Agricultural Engineering, NCSU, give approximately the same nitrogen concentration.

4. At what rate can the effluent be applied to the land?

Table 7 establishes the rate at which lagoon effluent can be applied to the land to achieve a certain nitrogen application rate. Entering Table 7 with 0.01760 lbN/gal and 180 lbN/A, a value of 10,500 gal/A is obtained by estimation. The exact value can be obtained by interpolating as follows. The gal/A for N concentrations of 0.01750 and 0.01883 lbN/A lbN/gal and 180 are determined first.

For 0.01750 lbN/gal

$$\left[\frac{(180\ \text{lbN} - 100\ \text{lbN})}{(200\ \text{lbN} - 100\ \text{lbN})}\right] [11{,}420\ \text{gal/A} - 5{,}710\ \text{gal/A}]$$

$$+ 5{,}710\ \text{gal/A} = 10{,}278\ \text{gal/A}.$$

For 0.01883 lbN/gal

$$\left[\frac{(180\ \text{lbN} - 100\ \text{lbN})}{(200\ \text{lbN} - 100\ \text{lbN})}\right] [10{,}900\ \text{gal/A} - 5{,}450\ \text{gal/A}]$$

$$+ 5{,}450\ \text{gal/A} = 9{,}810\ \text{gal/A}.$$

Using the results of the above calculations, the gal/A for an N concentration of 0.01760 lbN/gal is determined.

$$\left[\frac{(0.01760\ \text{lbN/gal} - 0.01750\ \text{lbN/gal})}{(0.01883\ \text{lbN/gal} - 0.01750\ \text{lbN/gal})}\right]$$

$$[9{,}810\ \text{gal/A} - 10{,}278\ \text{gal/A}]$$

$$+ 10{,}278 = 10{,}243\ \text{gal/A}.$$

If 600 mg/l (the research result) is used for the nitrogen concentration, a value of 36,000 gal/A is obtained.

5. What is the total yearly acreage requirement?

As indicated in the answer to Question 2, 1.53 ac ft of lagoon liquor need to be removed from the lagoon each year. This is equivalent to 500,000 gal (1.53 ac ft x 12 in./ft x 27,200 gal/ac in.). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 48.8A (500,000 gal ÷ 10,243 gal/A).

Because irrigation is generally expressed in terms of acre inches applied to a given area, Table 8 was developed to provide information regarding number of inches of effluent required to give the designated rates of total N per acre for various effluent concentrations in liquid manure or lagoon effluent.

Table 8 could also have been used to determine the acreage requirements for Question 5. Entering Table 8 with 0.01760 lbN/gal and 180 lbN/A, a

Table 7. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Gallons per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	240,000	480,000	720,000	960,000	1,200,000	1,440,000
100	0.00083	120,000	240,000	360,000	480,000	600,000	720,000
200	0.00167	60,000	120,000	180,000	240,000	300,000	360,000
300	0.00250	40,000	80,000	120,000	160,000	200,000	240,000
400	0.00333	30,000	60,000	90,000	120,000	150,000	180,000
500	0.00416	24,000	48,000	72,000	96,000	120,000	144,000
600	0.00500	20,000	40,000	60,000	80,000	100,000	120,000
700	0.00583	17,150	34,300	51,500	68,600	85,700	103,000
800	0.00667	15,000	30,000	45,000	60,000	75,000	90,000
900	0.00750	13,300	26,650	40,000	53,300	66,500	80,000
1000	0.00833	12,000	24,000	36,000	48,000	60,000	72,000
1100	0.00917	10,900	21,800	32,700	43,600	54,500	65,400
1200	0.01000	10,000	20,000	30,000	40,000	50,000	60,000
1300	0.01083	9,230	18,460	27,690	36,920	45,150	55,380
1400	0.01168	8,560	17,120	25,680	34,240	42,800	41,360
1500	0.01250	8,000	16,000	24,000	32,000	40,000	48,000
1600	0.01333	7,500	15,000	22,500	30,000	37,500	45,000
1700	0.01417	7,060	14,120	21,180	28,240	35,300	42,360
1800	0.01500	6,660	13,320	19,980	26,640	33,300	39,960
1900	0.01583	6,330	12,660	18,990	25,320	31,650	37,980
2000	0.01667	6,000	12,000	18,000	24,000	30,000	36,000
2100	0.01750	5,710	11,420	17,130	22,840	28,550	34,260
2200	0.01833	5,450	10,900	16,350	21,800	27,250	32,700
2300	0.01917	5,220	10,440	15,660	20,880	26,100	31,320
2400	0.02000	5,000	10,000	15,000	20,000	25,000	30,000
2500	0.02083	4,800	9,600	14,400	19,200	24,000	28,800
2600	0.02165	4,615	9,230	13,845	18,720	23,075	27,690
2700	0.02250	4,450	8,900	13,350	17,800	22,250	26,700
2800	0.02333	4,280	8,560	12,840	17,120	21,400	25,680
2900	0.02415	4,140	8,280	12,420	16,560	20,700	24,840
3000	0.02500	4,000	8,000	12,000	16,000	20,000	24,000

value of 0.38 ac in./A is obtained by interpolation. The total amount of effluent expressed in acre inches to be removed from the lagoon is 18.37 ac in. (1.53 ac ft x 12 in./ft). Dividing the amount of effluent to be spread by the application rate gives the acreage required for spreading. The result is 48.4 A (18.37 ac in. ÷ 0.38 ac in./A) which is approximately the same as obtained previously.

Two things are obvious from this example. Firstly, it would be sheer nonsense to use a tank spreader to spread the effluent. A 1400 gal spreader would require 357 trips (500,000 gal ÷ 1400 gal/trip).

Secondly, the amount of acreage necessary

Table 8. Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

N Concentration of Slurry or Effluent		Acre Inches per Acre Required to Give the Following Pounds of N per Acre					
MgN/l	LbN/gal	100	200	300	400	500	600
50	0.00041	8.82	17.64	26.48	35.28	44.10	52.96
100	0.00083	4.41	8.82	13.24	17.64	22.05	26.48
200	0.00167	2.20	4.40	6.60	8.80	11.00	13.20
300	0.00250	1.47	2.94	4.41	5.88	7.35	8.82
400	0.00333	1.10	2.20	3.30	4.40	5.50	6.60
500	0.00416	0.88	1.76	2.64	3.52	4.40	5.28
600	0.00500	0.74	1.48	2.22	2.96	3.70	4.44
700	0.00583	0.63	1.26	1.89	2.52	3.15	3.78
800	0.00667	0.55	1.10	1.65	2.20	2.74	3.30
900	0.00750	0.49	0.98	1.47	1.96	2.45	2.94
1000	0.00833	0.44	0.88	1.32	1.76	2.20	2.64
1100	0.00917	0.40	0.80	1.20	1.60	2.00	2.40
1200	0.01000	0.37	0.74	1.11	1.48	1.85	2.22
1300	0.01083	0.34	0.68	1.02	1.36	1.70	2.04
1400	0.01168	0.31	0.62	0.93	1.24	1.55	1.86
1500	0.01250	0.29	0.58	0.87	1.16	1.45	1.74
1600	0.01333	0.28	0.56	0.84	1.12	1.38	1.68
1700	0.01417	0.26	0.52	0.78	1.04	1.30	1.56
1800	0.01500	0.25	0.50	0.75	1.00	1.25	1.50
1900	0.01583	0.23	0.46	0.69	0.92	1.16	1.38
2000	0.01667	0.22	0.44	0.66	0.88	1.10	1.32
2100	0.01750	0.21	0.42	0.63	0.84	1.05	1.26
2200	0.01833	0.20	0.40	0.60	0.80	1.00	1.20
2300	0.01917	0.19	0.38	0.57	0.76	0.95	1.14
2400	0.02000	0.18	0.36	0.54	0.72	0.92	1.11
2500	0.02083	0.18	0.35	0.53	0.71	0.88	1.06
2600	0.02165	0.17	0.34	0.51	0.68	0.85	1.02
2700	0.02250	0.16	0.33	0.49	0.65	0.82	0.98
2800	0.02333	0.16	0.31	0.47	0.63	0.79	0.94
2900	0.02415	0.15	0.30	0.46	0.61	0.76	0.91
3000	0.02500	0.15	0.30	0.44	0.59	0.73	0.88

at one time is considerably lessened if smaller amounts are taken out more frequently. For instance, if the lagoon effluent is spread 4 times per year, only 12.2 A would be required for each spreading.

6. Is it possible to reduce the land area required for spreading the effluent?

The installation of a second lagoon in series with the existing lagoon will reduce the N concentration of the effluent from the existing lagoon by approximately 50%. Thus the N concentration of the effluent to be spread would be about 1053 mgN/1. Entering Table 7 with 1053 mgN/1 and 180 lbN/A, a value of 20,486 gal/A is obtained by interpolation. The acreage required would be 24.4 A (500,000 gal ÷ 20,486 gal/A).

If Table 8 were used, a value of 0.76 ac in./A is obtained by interpolation. The required acreage would be 24.2 A (18.37 ac in. ÷ 0.76 ac in./A).

Question 6 points out a problem that can exist when low concentrations are to be spread on fields that require high fertility rates. Assume that an effluent containing 100 mgN/1 is to be spread to satisfy a soil test recommendation of 400 lbN/A. From Table 8, 17.64 ac in./A would be required. This extra amount of water over and above normal rainfall would probably keep the soil too wet, especially in a wet season. This would result in poor soil aeration and in many instances in the growth of slime molds. As a result crop growth would be reduced or destroyed.

Soil Management

For most efficient utilization of nutrients, swine manure should be mixed with the soil either by plowing or disking. If it is left on the surface, some N will be lost by volatilization and perhaps some by surface runoff. Mixing with the soil will essentially eliminate this loss. It will also be very effective in eliminating odors.

The manure must be decomposed before most of the nutrients contained in it become available. Plants cannot use N, P, K and other chemcial elements contained in the organic manure; they must be released in the inorganic form.

Plowing or disking the manure into the soil will speed its decomposition and will enhance essentially all of the physical, chemical, and biological properties of the soil. However, when applying to pastures, grain, and certain other crops, it is not possible to mix it with the soil. If applied to vegetated areas as a slurry irrigation it is more apt to come into contact with, or perhaps enter, the soil than if applied as dry material.

Some other points to keep in mind include the following:

- Liquid manure should be applied in a manner that will not contaminate surface water. It should not be applied nearer than 50 feet to a stream or other surface water.
- Regardless of the method of application it must be prevented from going directly into waterways or into seepage areas leading directly to a waterway.
- The wind direction and velocity and the proximity of neighbors should always be kept in mind when applying manure to the land.
- When irrigation is used, it is desirable to follow the application of the effluent with an application of water. This will flush out the irrigation system and will wash the manure off the vegetation and cause more of it to penetrate the soil. However, care should be taken not to add too much water which might result in surface runoff and in poor soil aeration.

ODOR CONTROL

Although odor control is very difficult, any system of control must incorporate good management and good housekeeping techniques. The local situation which usually determines the feasible costs of control normally depends upon nearness of neighbors. Buffer zones should certainly be utilized when possible. The source of odor causing problems, wind direction or air drainage and availability of land all need to be considered.

Plenty of sunlight and good drainage around houses or any measures that promote dryness will tend to reduce odors. Control of dust and good air ventilation in a house reduce odors and promote dryness. Frequent removal of manure from a house and the prevention of sticky, pasty and heavy manure build-ups will prevent putrid odors. Although the addition of water to manure helps to remove the manure from the house, it dissolves some odorous gases and actually promotes the production of odorous compounds by improving the environment for anaerobic bacteria. Then with agitation or land spreading, the release of these stored odorous compounds can cause air pollution which is often unacceptable to neighbors and community. Twenty or more different compounds have been isolated in the odor from animal manure. A few such as hydrogen sulfide, ammonia, mercaptans and amines have been identified but they remain to be quantified.

Odors during and immediately following the spreading of liquid manure on the land constitute

a major problem. Injecting the manure into the soil, depositing in a furrow and plowing under or spreading on the land and disking it in can reduce the problem. Manure should not be moved on hot, damp, still days.

Uneven loading rates and changing weather conditions along with insufficient water capacities increase the undesirable odors associated with anaerobic lagoons. Warm weather is required for optimum operation of an anaerobic lagoon and minimum odor production is achieved only after stabilization of any accumulated manure load has occurred. Aerators can help in reducing lagoon odors but the criteria for necessary aeration have not been established.

PEST CONTROL

Flies. Good housekeeping and sanitation practices will help to eliminate fly breeding areas. Decaying vegetable matter, waste feed and manure are common materials that promote fly breeding. Therefore, cleanliness and dryness will reduce fly numbers. Removal of waste at frequent intervals will break a fly's cycle. Manure in a pit or lagoon covered with water will not support fly production.

Residual sprays applied to fly resting places are effective. Spraying should be repeated at 2 to 3 week intervals or as needed. Space sprays such as dichlorvos (Vapona), naled (Dibrom) or Pyrethrins effect a rapid kill. Poison baits can be used alone or in combination with sprays in and around houses. The most effective control results from dry baits and residual sprays used all year round as needed but in combination with good sanitation and manure management.

STORE ALL INSECTICIDES UNDER LOCK AND KEY. For up-to-date legal recommendations on chemicals to use, contact your county extension agent.

Rats. A rat will eat and waste approximately 25 pounds of feed per year and could contaminate much more. If only signs of rats were observed, there might be from one to 100 on the premises. If rats are observed at night, there might be 100 or more; and if observed in the daylight, there possibly would be upwards of 500 rats. They transmit many diseases and can carry several kinds of lice, fleas, ticks and mites. Then too, many fires of undetermined origin are caused by rats.

Eliminate rat harborage, such as tall weeds or grass, piles of trash, lumber, fence posts and brush. Follow with good day-to-day housekeeping. Make buildings and feed bins rat proof. Close cracks, breaks and spaces around pipes, vents and other openings with concrete, hardware cloth or sheet metal. Construct buildings to include rat barriers.

Ready-to-use or concentrated anticoagulant baits give good control with proper use. Some anticoagulant baits give good control with proper use. Some anticoagulants are being mixed with an antibacterial agent to prevent a natural build-up of vitamin K.

Lagoon Mosquitoes

Heavy populations of mosquitoes sometimes develop in animal waste lagoons. These mosquitoes need the protective vegetation along the shoreline for egg laying and survival of their young.

To help eliminate mosquito problems, remove the marginal vegetation including any flooded plants. Rake dead vegetation and debris away from the edge of the lagoon. Vegetation can be physically removed or killed with an approved herbicide. For emergency control, apply sprays of Flit MLO at 5 gallons per acre or Number 2 fuel oil at 10 gallons per acre.

ECONOMICS

If a producer is to make a rational choice among the various waste management systems, he must compare costs of these systems and estimate the value of the waste in a cropping program. Because each situation is different, no "best" system can be suggested—each producer must make his own comparisons.

Each producer must start with his present situation. A producer who is constructing new housing can simply compare the total annual costs of various waste management systems and weigh these costs against the environmental desirability and manure value for each system, realizing the limits upon the capital which he can invest.

Typically, however, a producer with functional existing houses finds that he may have to change his waste management system because of legislation, labor scarcity, or limited land on which to apply the manure. In this case, the producer will want to look at the net income effect of switching from his present system to another. The calculations involve adding the various additional annual costs associated with the switch.

Two types of costs are involved in any waste management system. They are ownership or fixed costs and variable or operating costs. Both fixed and variable costs should be considered in selecting the waste management system for a specific swine operation. Annual ownership costs are depreciation, interest on investment, insurance and taxes. Variable costs are for such items as fuel, labor,

repairs and any other out-of-pocket costs.

Annual depreciation is determined by dividing the original cost of the waste disposal system by the expected years of life for that system. Interest is computed at one-half the rate of interest paid. This is for intermediate (up to seven years) or long-term credit. If a person is paying 8 percent interest on an investment that is repaid over several years, on the average he will pay approximately 4 percent per year on the original investment. Insurance should be shown at its actual cost. Taxes will vary among counties depending on the tax rate and value used for tax evaluation.

In choosing a waste management system, the swine producer should first select the ones that will handle his situation. If only one system is believed suitable, then the only thing to determine is can he afford to continue producing swine with the added cost incurred in the waste management system.

Should two or more of the systems be suitable the producer should then itemize both the annual fixed costs involved in each system and the annual variable or operating costs. The system with the least annual total cost should be selected assuming that either system being considered will adequately handle the amount of waste produced.

Table 9 lists the estimated initial investment and annual costs for each alternative waste management system. It is based on a swine operation with a capacity of 500 hogs. The depreciation is 10 years for equipment and 20 years for structures. The interest is the initial cost times 4 percent, the insurance, initial cost times 0.5 percent; and

Table 9. Estimated Cost of Swine Waste Management Systems Based on a Swine Operation with a Capacity of 500 Hogs

	Estimated Cost (Spring 1973)		Your Cost	
	Initial	Annual	Initial	Annual
System I				
Storage tank (75,000 gal)	$10,000	$ 980.00		
Spreader (1,000 gal)	2,100	310.80		
Tractor, 55 hp diesel	6,200	917.60		
Labor		1,000.00		
Repairs		229.00		
Fuel and electricity				
System II				
Lagoon (150 cu ft/hog)	1,400	140.00		
Irrigation	6,000	888.00		
Labor		650.00		
Repairs		300.00		
Fuel and electricity				
System III				
Lagoon (150 cu ft/hog)	1,400	140.00		
Irrigation	6,000	888.00		
Labor		250.00		
Repairs		300.00		
Fuel and electricity				
System IV				
Spreader	2,100	310.80		
Labor		750.00		
Repairs		105.00		
Fuel and electricity				

taxes, initial cost times 0.3 percent. Only those components that comprise a system under each alternative should be used when making comparisons.

APPENDIX I

Lagoon Design For 500 Hogs

The tentative guidelines approved by the North Carolina Board of Water and Air Resources set the minimum volume per hog at 150 cu ft. For 500 hogs 75,000 cu ft of storage must be provided in the lagoon. If the depth is 10 ft, the *average* area (area at one-half the depth) is 7,500 sq ft (75,000 cu ft ÷ 10 ft). To facilitate movement of waste into the lagoon as well as physically construct the structure, an average width of 50 ft is selected. The average length will then be 150 ft (12,500 sq ft ÷ 50 ft). Therefore, a lagoon with 3:1 side and end slopes will have the dimensions as shown in Figure 1.

For other depths and widths, the procedure for sizing would be the same as outlined in this example.

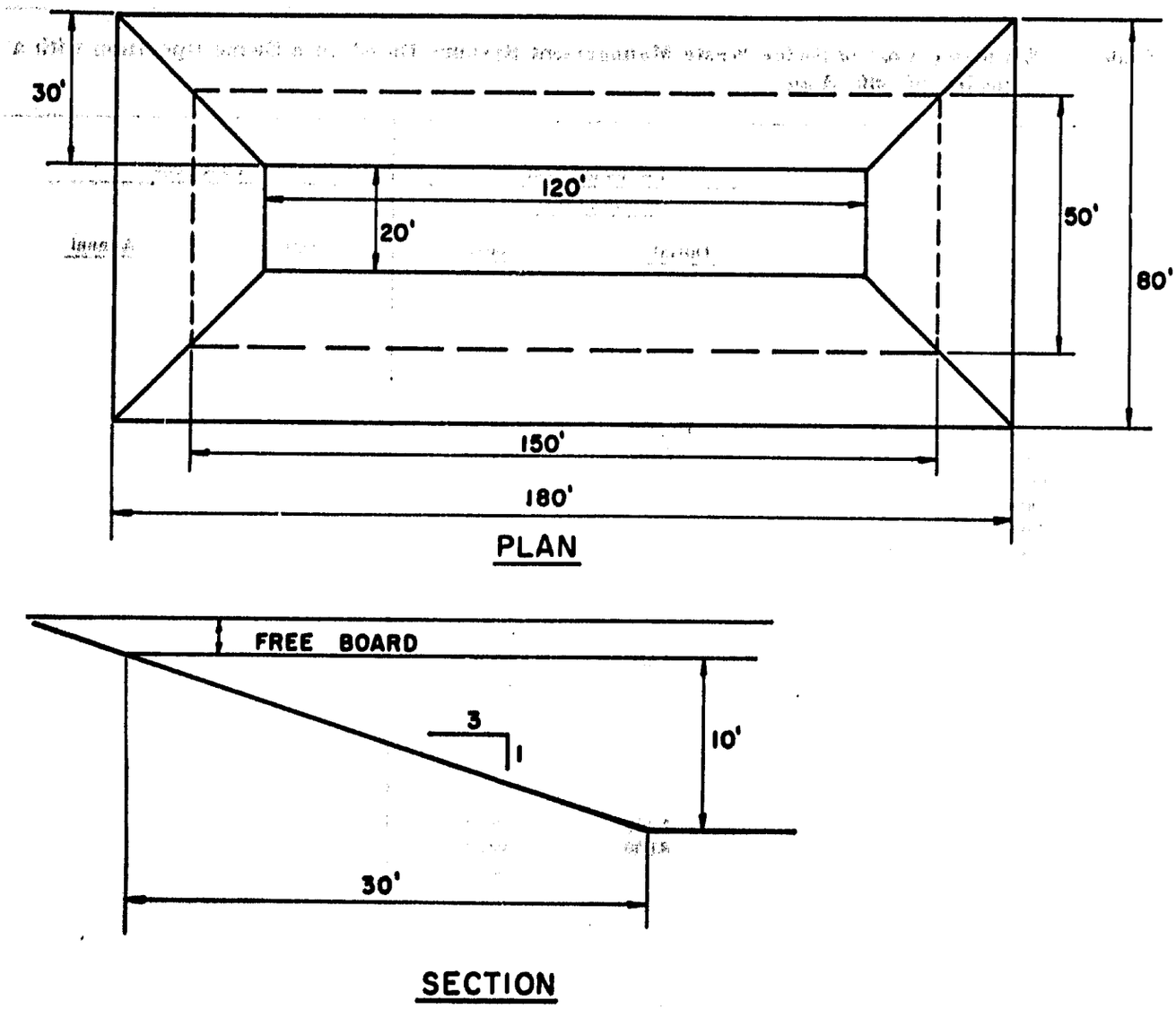


Figure 1. Plan and Section Views of a Lagoon.

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KEY FACTORS IN SELECTING WATER SOURCES

1. QUANTITY
2. QUALITY
3. COST

SOURCES OF WATER

PRECIPITATION
- DIRECT CATCHMENT
- ICE AND SNOW
- CLOUD SEEDING

SURFACE RUNOFF
- LAKES
- STREAMS

GROUND WATER
- SPRINGS
- WELLS
- INFILTRATION GALLERIES

SALINE WATERS
- OCEANS
- BRACKISH GROUND WATER

WASTEWATER REUSE
- SUCCESSIVE USE
- DIRECT REUSE

EVAPORATION CONTROL

1 Vertical Frame

2 Focus Slide

3 "Start" with this slide -----

4 STREAM SAMPLING -

LOCATION, TIMING AND TYPES OF SAMPLES

by

5 James C. Lamb III*

6

Slide No.	Script
7	In this discussion, we will review briefly the following aspects of water sampling: 1. Definition of survey objectives 2. Location of sampling points 3. Timing of sample collection 4. Types of samples to be collected, and 5. Field and other observations often required
	DEFINITION OF SURVEY OBJECTIVES
8	The first step in any stream or lake study should be to define carefully just why the study is being made, specific goals which you wish to attain, and time constraints within which you must work..... Why?
9	Well, in 1968 a report expressed very well the purpose of setting objectives: "The clearer the idea one has of what it is one is trying to accomplish, the greater the chances of accomplishing it."
10	There are many types of stream and lake investigations, including hydrologic studies of flows and flow variations, such as floods or droughts. Others may be concerned with evaluating the resource for various uses, such as recreation, fish or shellfish production, navigation, or municipal and industrial water supply. The type of stream study in which we are most interested here, and to which the rest of this discussion will be directed, is based on determining physical, chemical and biological quality of the water.

*Professor of Sanitary Engineering, Department of Environmental Sciences and Engineering, School of Public Health, The University of North Carolina at Chapel Hill. ESE Publication No. 384. Script of a taped lecture prepared for use with slides before a workshop on "Water Sampling and Analysis" for community college and technical institute faculty, January 17, 1975.

Slide No.	Script
11	Although water quality surveys may have many different objectives, it is reasonable to divide them into two very broad categories: (1) those concerned principally with monitoring of water quality to establish base-line records, or to evaluate its suitability for various specific uses, or to provide regulatory checks on its quality; and (2) those directed towards evaluating cause and effect in questions relating to assimilative capacities of streams and prediction of downstream quality with altered wastewater discharges.
12	Specific survey objectives should be prepared in writing, as onerous as that may seem. This could be the most important step in the study because those who invest wisely in productive planning here may enhance efficiency and economy later and insure that their efforts during the survey are entirely consistent with its goals.
13	LOCATION OF SAMPLING POINTS Many factors must be considered in selecting sampling stations along streams.
14	Obviously, the selection criteria depend heavily upon goals of the study because subsequent analyses of samples collected must give data necessary to meet those goals.
15	Some of the more obvious factors which must be considered include locations of tributaries entering the stream and outfalls through which wastewaters are discharged from municipalities and industries.
16	The opportunity for mixing of flows from those tributaries and outfalls throughout the stream flow is important, as well as time of travel of the flow, both of which are vital in determining concentrations of various pollutants in samples collected from the stream.
17	Facilities for measurement of stream flow, especially locations of U. S. Geological Survey gaging stations, are important because accurate estimates of flow are necessary to determine time of travel and to evaluate concentrations and quantities of constituents in the water.
18	Last, but by no means least, careful consideration must be given to the question of access for sample collection. Much stream sampling activity is conducted from bridges, which are especially convenient. Unfortunately, investigators sometimes forget that bridge locations are picked because of traffic flow patterns and are not always appropriate for stream sampling purposes.

Slide No.	Script
19	Having established locations along the stream at which sampling should be done, the next step is to identify exact sampling points at each station. Among the many factors to be considered are shape of the stream cross-section, velocity and depth of flow and the extent to which vertical and lateral mixing insure uniform water quality throughout the cross-section.
20	The basic problem is to select one or more points at each station from which samples can be collected with assurance that they are representative of the total stream.
21	Because variations in quality at different points in the cross-section of a stream at a station potentially could be major, it is essential to verify carefully validity of the point selected.
22	The most reliable approach is based on cross-sectioning the stream and collecting samples at several depths and locations across its width. At each point, velocity can be measured and samples analyzed for quality parameters selected to be appropriate to goals of the study.
23	These data then can be weighted by flow to produce composite figures representative of the stream as a whole. Subsequently, it may be possible to select one, or a few, points in the cross-section which would be reasonably representative of the flow.
24	Other systems employed by investigators have included dividing the stream into a few sections of equal area, with samples collected from the midpoint of each.
25	Another simpler alternative has been based on collecting samples from the three quarter points, often at only one depth at each.
26	Sometimes it is adequate to collect only a single sample, approximately at the center of flow of the stream cross-section.
27	In some instances, result of the various sampling schemes may indicate clearly that it would be excessively complex or expensive to collect samples giving data representative of the stream cross section. This suggests that the entire station might be abandoned in favor of some other location.
28	Obviously, many variables are important in selecting sampling stations along streams and identifying specific sampling points at those stations. Time restrictions prevent us from going further into detail on them here. Several references in the bibliography supplied will provide you with much more information.

Slide No.	Script
29	For now, here are a few specific practical suggestions to help identify some points and approaches which have proven practical in past investigations.
30	In general, consider sampling immediately above points at which tributaries and outfalls enter the stream. Usually, it will be necessary to sample and determine the flow of each major tributary or wastewater, unless it represents a very small proportion of the total. It is seldom desirable to sample immediately below tributaries or outfalls because of inadequate opportunity for mixing adequate to permit meaningful samples.
31	Critical points, such as zones of minimum dissolved oxygen and locations at which water from the stream is used, are logical areas for sampling, especially where the primary interest is in monitoring stream quality.
32	Because of uneven velocity distributions, one usually should avoid sampling at bends and should seek stations with reasonably uniform cross sections.
33	Because streams usually mix relatively rapidly in the vertical direction, it often is acceptable to sample at only one depth -- commonly the mid-depth.
34	Sometimes good samples can be collected conveniently from water intakes. It is essential that all lines be flushed thoroughly and that sample validity be checked by comparing analyses with others collected simultaneously in the stream.
35	Bridges do represent convenient sampling locations and should be considered carefully. To sample where bridges are not available, we must resort to boats, floats, or perhaps pumping water from the stream to shore. Samples should not be collected near shore because they usually differ substantially from those in midstream.
36	It is always worthwhile to check sampling points used by regulatory agencies, municipalities, industries and other groups because they may give valuable clues to good locations and allow building on data collected by those organizations.
37	It is almost always desirable, in checking the effects of wastewater discharges, to include upstream "control" stations in the sampling program to show "before" and "after" conditions.
38	Finally, all sampling locations should be identified carefully on maps and recorded along with data collected at that point.

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39	TIMING OF SAMPLE COLLECTION Our next topic for discussion concerns establishing the duration and frequency for collecting samples at each location.
40	Some factors which we must consider in setting the sampling schedule are listed here and include analysis of our survey goals, variations in water quality, precision of laboratory analyses, personnel available for the study, equipment limitations, costs of various alternatives and budget constraints, and any special questions relating to timing.
41	The survey goals may require only data to define the so-called "average" quality of stream water or may relate specifically to quality variations, including maximum and minimum values and patterns of variation of some of the parameters.
42	We must recognize that "averages" of quality parameters often may be meaningless, or even misleading. For example, data collected over a wide range of temperatures -- say, under summer and winter conditions frequently have absolutely no meaning when averaged. Also, it is often risky to average pH values, which actually are merely a shorthand method for reporting hydrogen ion concentration. "Average" dissolved oxygen concentrations can be misleading.
43	For example, 5 mg/l of D.O. is adequate for supporting most types of fish life, and all types of fish may be expected to die at 0 mg/l.
44	However, in a stream in which dissolved oxygen varies from, say, 0-10 mg/l, an "average" of 5 would be meaningless. After all, "you can only kill a fish once."
45	Accordingly, we usually are more concerned with changes in water quality parameters including maximum and minimum values and patterns of change.
46	Water quality variations in streams depend on many factors, some of the more obvious ones being variations in stream flow and wastewater discharges from municipalities and industries. Usually, variability will be maximum near points of addition of the discharges and decrease as flow progresses downstream. This can be attributed to longitudinal mixing and removal of some pollutional materials through settling or chemical or biochemical reactions.
47	Significant quality changes may result from daily variations in municipal and industrial discharges. It is common to observe a dissolved oxygen rise from early morning minimum to afternoon maximum because of oxygen production through photosynthesis by algae, using solar energy. A sampling program which ignores that diurnal variati could be in serious error because it may miss entirely the pe iod

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	of minimum dissolved oxygen, about sunrise. Also, it may lead to erroneous conclusions about relative quality at different points along a stream if that conclusion is based on data collected at different times of day.
48	Finally, there are many other causes for variations in water quality including, obviously, seasonal temperature and flow changes. Intermittent discharges of storm runoff from urban or rural areas have the dual effect of adding pollutional materials to the stream and modifying its flow.
49	Our decisions about frequency and duration of sampling may be influenced significantly by precision of the analytical procedures to be employed for quality determinations. For example, those familiar with the BOD test recognize it as a procedure with highly variable results, as compared with many others such as dissolved oxygen or pH.
50	Also, there may be wide variations among different laboratory analysts using the same procedures.
51	Although it is impossible to generalize on the number of samples needed to give data adequate for our goals, single grab samples seldom if ever can have much meaning in defining water quality at any given point. Many individuals who conduct stream studies think in terms of collecting at least 15-25 samples over a period time at each location. Often many more may be necessary.
52	Personnel, equipment and budget needs depend heavily on the number of samples collected and analyzed. This raises a cost-benefit question in which we must consider carefully the additional cost of handling more samples on balance with benefits to be derived from the extra data.
53	We must recognize that working within the constraint of a fixed budget, we really are trying to balance alternatives relating to sampling frequency at each location, the number of locations to be sampled, and duration of the study.
54	Long-term detailed monitoring programs may be conducted for indefinite periods by regulatory agencies, industries, or others having special interest in quality variations of a stream section.
55	On the other hand, some programs are conducted merely to spot-check quality at key locations and to determine which areas should be studied more critically from time to time.

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56	In some instances it's not necessary to sample throughout the year, but only during certain critical periods. For example, dissolved oxygen usually will reach minimum levels during late summer and early fall, when temperatures are high and flows minimum. This suggests, perhaps, intensified sampling during that period and much less during winter when D.O. usually is no problem. In other instances, we may be concerned with seasonal water uses, such as swimming or shellfish harvesting, and may sample only during that season.
57	For evaluating self-purification characteristics of streams and the impact of wastewater discharges, the most valuable information usually is obtained through intensive, short-term studies, perhaps with round-the-clock sampling for 1-3 days. Sometimes we find regulatory agencies conducting sampling programs only on the basis of spot-checks because of immense areas which must be covered with inadequate staff. This is a reasonable way to determine which sections of which streams require more detailed attention by their limited personnel. However, data collected at widely spaced times at the sampling points do not permit accurate assessment of assimilative capacity of the stream, which can be determined best through intensive studies, usually over rather short periods. Attempts by some regulatory agencies to do that provide an excellent example of using data collected in one program, which was valid for its purpose, to try to satisfy needs of another program whose goals would require entirely different sampling techniques.
	TYPES OF SAMPLES
58	This slide lists the types of samples most commonly employed in stream and wastewater investigations, including grab samples, composite samples collected on a predetermined time schedule, composites collected in a fashion to produce a sample weighted to flow, periodic and automatic measurements of parameters in the field, and continuous monitoring systems.
59	A grab sample is a single portion of flow, often collected manually, whose most important characteristic is that it must be representative of the flow in question.
60	Accordingly, it is exceedingly important that it be taken from a location at which mixing is adequate to insure uniform distribution of constituents throughout the flow because stratification of materials lighter or heavier than water at the top or bottom of the flow may persist for surprisingly long distances in sewers and streams.
61	Grab samples often are a necessary part of sampling programs, even when other types of samples may be collected also, because some quality parameters are not subject to preservation. Those include temperature, concentrations of certain volatile materials, as well as other transient quality characteristics.

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62	Frequently, grab samples must be collected in special containers to avoid addition of oxygen, contamination by bacteria, or loss of volatile materials.
63	A composite sample collected on a predetermined time schedule produces a single sample, usually made up of equal size portions collected at several different times. This gives an averaging effect, equivalent to that which would be obtained by averaging results of grab samples collected on the same schedule.
64	It's a good technique where the water flow is constant and where characteristics of the sample will not change significantly during the compositing period. This is the basis on which many commercial automatic samplers operate.
65	The next level of sophistication also produces a composite sample, but with portions added of proper size or collection frequency to proportion them to flow.
66	Obviously, this type of approach requires use of a flow meter to trigger the sampling device and produces an averaging which includes the effect of flow variations. It's a good technique to use where flow is variable and one which we adopt often for automatic sampling of wastewater discharges.
67	Periodic and automatic field measurements may be made by establishing a predetermined schedule for reading and recording, or automatically printing, the response of a continuous monitoring system.
68	An alternative involves an automatic sample collection and analysis system, operating on a predetermined time schedule or in response to commands.
69	Data from these types of systems may be voluminous, making computer handling desirable. There is need for regular summary and interpretation of the data through statistical and graphical techniques, perhaps also by computer.
70	Continuous monitoring systems are capable of providing an unbroken record of the parameter in question suitable for direct readout by an observer or automatic recording.
71	For example, monitors now are available for continuous recording of dissolved oxygen, temperature, conductivity, flow and other characteristics, Practical and reliable continuous monitors are not available for many of the characteristics of interest to us, such as BOD.
72	Continuous recording is especially valuable for actuating alarm systems when parameters exceed certain specified limits and can provide a continuous permanent record of variations. However, they may be a rather inconvenient method for handling data unless arrangements are made to extract readings periodically for storage and statistical treatment, all of which may be done through a computerized system.

Slide No.	Script
73	It would be incorrect to portray any one type of sample which we have discussed as "better" than the others. Each has its own place and utility, when considered in context of program goals, type of sample required, feasibility for preservation, and budgetary requirements for personnel and equipment. Careful consideration should be given to all and we must select that sample type or types most appropriate for our specific needs in the study.
74	FIELD AND OTHER OBSERVATIONS In planning a sampling program, there are many observations which must be made in the field or, occasionally, could be more conveniently compiled from records elsewhere. These include such obvious and changeable water quality parameters as temperature, dissolved oxygen, volatile, chemically reactive or biodegradable materials.
75	In addition provisions should be made in most instances to note certain environmental conditions which may be important in interpreting data subsequently. These include air temperature, wind conditions, rainfall or other precipitation, cloud cover and, in some instances, measurements of solar radiation.
76	Stream flows may be determined by using current meters in the field, but this is inconvenient and time consuming. Other approaches often employed include calibrated staff gages placed at sampling points, measurements taken directly from stream gages of the U.S. Geological Survey, or reference to stream flow records of that agency. Often, the USGS can supply reasonable estimates of average and minimum stream flows for locations where gaging stations are not available. These questions should be explored with USGS personnel before beginning the sampling program.
77	Wastewater flows can be determined by installing any of several different types of meters, if access can be obtained for that purpose. Sometimes municipalities or industries already meter their discharges and could make the data available for legitimate stream survey purposes. Also, daily flows are available from the State and Federal regulatory agencies, in many instances.
	SUMMARY
78	We have discussed (a) the importance of defining, carefully, specific objectives of the stream survey, (b) several factors which should be considered in establishing the locations of sampling points, (c) frequency, duration and timing of sample collection, (d) the different types of samples commonly used and utility of each and (e) some of the other observations which may be made in the field or obtained from the records of others.
79	Additional details of these questions are covered in the bibliography supplied, and other aspects of stream sampling and analyses are discussed by other speakers in this workshop.

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Department of Environmental Sciences and Engineering
SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF NORTH CAROLINA

SUMMARY OF PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS, 1961

(Reference: Report of the Advisory Committee on Revision of the Public Health Service 1946 Drinking Water Standards, May 3, 1961)

The requirements recommended are as follows:

I. SOURCE AND PROTECTION

1. The water shall be
   a) Obtained from the most desirable source which is feasible; or
   b) Effort should be made to prevent or control pollution of the source; or
   c) If the source is not adequately protected by natural means, the supply shall be adequately protected by treatment.

2. Frequent sanitary surveys shall be made of the water supply system to locate and identify health hazards which might exist in the system

II. BACTERIOLOGICAL QUALITY

Minimum number of samples examined per month -

2 for population of 2,000 and under
10 for population of 10,000
25 for population of 25,000
100 for population of 100,000
300 for population of 1,000,000.

The standard sample for the bacteriological test shall be

a) For the bacteriological fermentation tube test
   5 standard portions of either 10 ml or 100 ml
b) For the membrane filter technique not less than 50 ml.

<u>Fermentation Tube Test</u>

A. When 10 ml standard portions are examined.

1. Not more than 10 per cent in any month shall show the presence of the coliform group.

2. The presence of the coliform group in three or more 10 ml portions shall not be allowable if this occurs:

   a) In two consecutive samples
   b) In more than one sample per month when less than 20 are examined per month; or
   c) In more than 5 per cent of the samples when 20 or more are examined per month.

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B. When 100 ml standard portions are examined

1. Not more than 60 per cent in any month shall show the presence of the coliform group.

2. The presence of the coliform group in all five of the 100 ml portions shall not be allowable if this occurs:

   a) In two consecutive samples;
   b) In more than one sample per month when less than five are examined per month; or
   c) In more than 20 per cent of the samples when five or more are examined per month.

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Membrane Filter Technique

A. Coliform density of all standard samples

1. Arithmetic mean density shall not exceed one per 100 ml

2. Coliform colonies per standard sample shall not exceed 3/50 ml, 4/100 ml, 7/200 ml, or 13/500 ml in:

   a) Two consecutive samples;
   b) More than one standard sample when less than 20 are examined per month; or
   c) More than 5 per cent of the standard samples when 20 or more are examined per month.

III. PHYSICAL CHARACTERISTICS

Sampling: Under normal circumstances samples should be collected one or more times per week and examined for turbidity, color, threshold odor and taste.

1. Drinking water should contain no impurity which would cause offense to the sense of sight, taste, or smell. The following limits should not be exceeded:

Turbidity	-5 units
Color	-15 units
Threshold Odor Number	-3

IV. CHEMICAL CHARACTERISTICS

Sampling: Under normal circumstances, analyses for substances listed below need be made only semi-annually. If there is some presumption of unfitness because of the presence of undesirable elements, periodic determinations for the suspected toxicant should be made more frequently.

- The following chemical substances should not be present in a water supply in excess of the listed concentrations where other more suitable supplies are or can be made available.

Substance	Concentration mg/l
Alkyl Benzene Sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250.0
Copper (Cu)	1.0
Carbon Chloroform Extract (CCE)	0.2
Cyanide (CN)	0.01
Fluoride (F)	(see paragraph 3)
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3)*	45.0
Phenols	0.001
Sulfate (SO_4)	250.0
Total Dissolved Solids	500.0
Zinc (Zn)	5.0

*In areas in which the nitrate content of water is shown to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

2. The presence of the following substances in excess of the concentrations listed shall constitute grounds for rejection of the supply.

Substance	Concentration mg/l
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	(see paragraph 3)
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

3. Fluoride. When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit in Table I. Presence of fluoride in average concentrations greater than two times the optimum values in Table I shall constitute grounds for rejection of the supply. Where fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits in Table I.

Table I

Annual Average of Maximum Daily Air Temperatures *	RECOMMENDED CONTROL LIMITS Fluoride Concentrations in mg/l		
	Lower	Optimum	Upper
50.0 - 53.7 °F	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

* Based on temperature data obtained for a minimum of five years.

V. RADIOACTIVITY

Sampling: The frequency of sampling and analysis for radioactivity shall be determined after consideration of the likelihood of significant amounts being present. Where concentrations of Ra^{226} or Sr^{90} may vary considerably, quarterly samples composited over a period of three months are recommended. Samples for determination of gross activity should be taken and analyzed more frequently.

Limits: Any unnecessary exposure to ionizing radiation should be avoided. The concentrations of radioactivity specified below for drinking water are intended to limit intake of these substances by this route so that total radiation exposure of population groups does not exceed appropriate Radiation Protection Guides recommended by the Federal Radiation Council. Concentrations which exceed, on the average, the values presented below for a period of one year shall constitute grounds for rejection of the supply. Where the total intake of Ra^{226} and Sr^{90} from all sources has been determined, these limits may be adjusted so that the total intake of Ra^{226} and Sr^{90} will not exceed 7.3 uuc per day and 73 uuc per day respectively.

Radionuclides	Concentration uuc/liter
Radium^{226}	3
Strontium^{90}	10
Gross Beta activity (Strontium^{90} and alpha emitters absent)	1000

When mixtures of Ra^{226} and Sr^{90} and other radionuclides are present, the above limiting values shall be modified to assure that the combined intake is not likely to result in radiation exposure in excess of the recommended Radiation Protection Guides.

Comments of the Advisory Committee

The effects on large population groups of chronic exposure to low levels of radioactivity are not yet well defined. The limits presented herein are an effort to derive conservative values from the best information now available and may be adjusted upward or downward as new and better data become available.

The Committee has taken cognizance of the growing problem of potentially harmful chemicals in sources of drinking water. Limits for several new chemicals have been added, including a gross limit for the concentration of some types of synthetic chemicals. It was not feasible, however, to include limits for all the many chemicals that have varying degrees of toxic potential. Consideration was given to the more common chlorinated hydrocarbon and organophosphate insecticides, but the information available was not sufficient to establish specific limits for these chemicals. Moreover, the concentrations of these chemicals, where tested, have been below those which would constitute a known health hazard. The Committee believes that pollution of water supplies with such contaminants can become significant and urges that the problem be kept under closer surveillance.

Notes:

For the first time -

1. An appendix is attached which provides a rationale for determining the various limits.
2. In establishing toxic limits, intake from food and air is considered.
3. The standards apply to water at the free flowing outlet of the ultimate consumer.
4. Approval of a water supply depends upon availability of qualified personnel at the water works and the physical capacity of the works to meet peak demands of quantity without development of low pressures or other health hazards.

Source: 'The Industrial Environment--its Evaluation & Control', U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, Public Health Service, Centre for Disease Control, National Institute for Occupational Safety and Health, 1973.

CHAPTER 45

CONTROL OF INDUSTRIAL SOLID WASTE

P. H. McGauhey

SCOPE OF INDUSTRIAL WASTE GENERATING ACTIVITIES

The Problem of Definition

In reducing to comprehensible terms the vast spectrum of residues of resource utilization which comprise solid waste, it is necessary to resort to some scheme of classification.

At the broadest level of definition, relating wastes to the general sector of human activity in which they originate has been the most common approach. Thus municipal, agricultural, and industrial wastes commonly appear in both the literature and the language of solid waste management as categories which by implication, at least, are essentially of the same order. That they are not in fact of the same order is of little significance when the primary concern is for municipal wastes. However, when industrial waste is the problem, some distinctions between the three classes must be clearly understood.

1. *Municipal Wastes.* The domestic and commercial activities which generate municipal wastes are characteristic of cultural and social patterns which are national in scope. Thus, with some variations in regional and climatological factors which result in ashes in one community and year-round grass trimmings in another, the term "municipal wastes" has an identifiable meaning without great refinement of definition.
2. *Agricultural Wastes.* In the case of agricultural wastes there is currently some confusion of definition. Some individuals still consider the term to include everything from crop residues left in the fields to animal manures and the residues produced in processing food and fiber grown on the land. However, much of agriculture is organized and managed in the same manner as are factories. Land is prepared, and many crops are harvested, with sophisticated machinery. Thousands of animals are concentrated in milk, egg, and meat production enterprises. The distinction between a processing plant utilizing farm products as its raw material and one processing crude petroleum, for example, is quite artificial. Therefore, except for plant residues left in the fields and animal wastes deposited in the pastures, it seems appropriate to include much of what is now classed as agricultural waste in the industrial waste category. In fact there is already a trend to consider animal manures as a source of industrial pollution.[1]
3. *Industrial Wastes.* Although, as previously noted, there is a certain logic in classifying solid wastes as municipal, agricultural, and industrial, the logic breaks down when control of industrial wastes is the problem of concern. Consequently, in terms of control there is no way to define "industrial wastes" in the context of the simple classification cited. It is everything that is not included in "municipal wastes" and a large percentage of what is included in "agricultural wastes." Therefore, it can best be isolated only in relation to certain types of human activity.

Nature of Human Activity Involved in Industry

The range of human activities which might be described by the word "industry" is so broad and varied that essentially the only thing all industries have in common is that they generate residues they do not want. Although in the aggregate these unwanted residues comprise industrial solid waste, no one approach can resolve the waste control problem it presents, for the simple reason that there is no single identifiable problem. There are, however, types of activity which generate broad types of industrial solid waste problems, each amenable to some typical approach although not to a universal solution. For the purpose of this discussion these activities are divided into three classes: 1) extractive industries; 2) basic industries, and 3) conversion and fabricating industries.

Obviously these three classes are not mutually exclusive. Processing, for example, may be a feature of any type of industry, but each class has identifiable characteristic waste generating features which differentiate it from the other two.

INDUSTRY AS A GENERATOR OF SOLID WASTES

Extractive Industries

The normal concept of an extractive industry is, as the name implies, one in which raw materials are taken from the earth and marketed in essentially their original state with little or no value added by manufacture or processing. Consequently it is to be expected that the solid wastes generated by such industries are but components or products of the earth. Four extractive industries, namely mining, quarrying, logging, and farming are of particular significance as generators of solid wastes. A fifth, the petroleum industry, is a major contribution to industrial solid waste problems, but not in the extraction process itself.

1. *Mining.* In terms of the quantity of solid wastes generated, mining probably exceeds all other industries, estimates ranging as high as 1.6 billion tons per year.[2,3] Shaft and tunnel mining of coal and metal ores necessitates bringing to the surface large quantities of earth materials associated with the particular mineral sought, or overlaying it. Convenience, economics, and sheer weight and volume of materials dictate that these tailings be discarded near the mine head. Thus the major waste problem is fundamentally the local creation of an extremely large pile of inert material which is usually unsightly, destructive of the land resource it occupies, and may contribute to water pollution by leaching over a long period of time. Sometimes this waste pile is a menace to human life as well, as a result of instability due to fine particles, which may run as high as 40 percent.[2] A notable example is the 1966 tragedy in Aberfen, Wales, where 150 persons (mostly school children) were killed by a slide of an 800-foot-high pile of coal mine waste.

   Mine tailings are proving to be stockpiles of valuable resources, albeit by inadvertence rather than design.[3,4] A major example is the early discarding of tungsten and vanadium ores in iron mining operations. When later a use was found for these metals, more wealth was extracted from the waste pile than was originally generated from iron. However, this secondary extraction did little to diminish the size of the original heap of wastes.

   Concentration of solid wastes often occurs at locations which are relatively close to the mine where crushing, flotation, and other processing of ores is essential to the extraction process. Such secondary waste concentrations are generally smaller than those at the mine head but they are by no means insignificant in volume. For example, about 1.3 tons of wastes are generated for each ton of pelletized iron ore processed.[5] However, they still represent materials taken from the earth's crust and simply relocated and concentrated on the land surface.

2. *Quarrying.* Quarrying is often classified separately from underground mining. Open pit, or strip mining and the quarrying of glass sand, stone, and sand and gravel are typical of this type of extractive industry. In comparison with other types of mining, sand and stone quarrying displaces and concentrates smaller amounts of unwanted materials (approximately 0.5 to 5.0 percent).[6] Otherwise the solid waste problem is the same; i.e., inert earth materials piled on the surface. Although quarrying wastes may be deplored by citizens on the basis of effects on nearby property values, or of aesthetics or other emotional response, quarrying is more an environmental problem of noise, dust, traffic, and aesthetics than one of solid waste generation.

3. *Logging.* As a generator of solid wastes the harvesting of timber differs from mining and quarrying in that its residues are organic. Hence, in a matter of years rather than of geologic time they are returned to the soil by the biochemical processes of nature. It is estimated that traditional logging procedures leave in the woods some 30 to 40 percent of the original weight of the tree, or about one ton of debris per 1,000 board feet of logs harvested.[7] As a solid waste problem this material is scattered over a wide area, is unsightly, constitutes a fire hazard to the forest, may be a reservoir of tree-destroying diseases and insects, and represents a wastage of natural resources.

4. *Farming.* The solid waste generating aspects of farming include both plant and animal wastes, the estimated per capita production averaging 43 to 60 lb./day.[8,9] Plant residues of significance include unharvested or unharvestable crops, vines, straw and stubble, and orchard prunings. Here a variety of solid waste control problems accrue largely as a result of air pollution and other environmental considerations. Unfortunately, burning of certain seed grass stubble is necessary to control plant diseases. Straw and stubble plowed into soil increase the cost of nitrogen fertilizer to offset the carbon surplus. Unharvested products such as melons and tomatoes produce unpleasant odors and may attract insects and rodents. Tree prunings are both a physical problem and a reservoir of crop and tree-destroying pests if burning is not allowed. Burning of sugar cane remains an economic and technological necessity in eliminating leaves prior to processing.

   Disposal of manure and dead fowl constitutes an extremely difficult problem to the poultry and egg production industry. Although the wastes are organic and capable of incorporation into soil by natural processes, they are concentrated in location, 10,000 to 100,000 birds being housed in a single location. Moreover, they are aesthetically objectionable, uneconomical to collect, and unwanted by agriculturists. The same situation exists in dairy and animal fattening installations, the latter of which involve as many as 20,000 animals in a single operation and may soon involve 100,000.[1] Concentration of decomposable wastes, pollution of water, fly production, aesthetics, and economic and technological problems of collection and disposal are among the solid waste problems generated by animal husbandry as an extractive aspect of the farming industry.

In evaluating extractive industries as generators of wastes, the four examples cited have several things in common. They concentrate wastes at specific locations on the surface of the earth; the wastes are normal products of the earth and its living things; and they do little to multiply the basic value of the product. They differ, however, in nature, some being inert materials whereas others are biodegradable organic matter. Consequently, no single approach to solid waste con-

trol can overcome the problems man associates with the wastes of extractive industry.

Basic Industries

For the purpose of this analysis, basic industries are considered those which take raw materials from extractive industry and produce from them the refined materials which other industries convert into consumer goods. Basic industries differ from extractive in several ways, the most significant being in the value added by manufacture.

Products of the basic sector of industry are such things as metal ingots, sheets, tubes, wire, and structural shapes; industrial chemicals; coke; paper and paperboard; plastics materials; glass; natural and synthetic fabrics; and lumber and plywood. From the farming industry there is a tendency for fiber to go into basic industry, and food to conversion industries or directly into commercial channels. Exceptions might be the hulling of rice and the production of raw sugar from sugar cane, although these two might better be classed as conversion industries.

The solid wastes generated by basic industries may be said to differ from those generated by extractive industries in three major aspects: They are more diverse in composition; they differ markedly from the normal mineral and plant residues found in nature; and the industry itself generates a fraction of its own wastes. The solid waste generated by any type of industry in its business offices is, of course, considered a part of the normal commercial component of municipal wastes.

Eight basic industries are perhaps the major generators of solid wastes in their class: metals, chemicals, paper, plastics, glass, textiles, wood product, and power.

1. *Metals.* Blast furnace slag and ashes from the smelting of iron ore probably rank second only to mining wastes in volume of waste produced by industry. Slag produced in steel production is estimated to be more than 1,000 tons per day per furnace, or about 21 percent of the steel ingot production[10,11]. Similarly, the smelting of copper and the production of aluminum result in significant amounts (more than 5 million tons each in 1965)[10,12] of waste materials essentially of an inert nature, although subject to leaching if carelessly discarded in the environment. Like extractive industry wastes, basic metal wastes are concentrated at the points of generation. Here, however, the similarity begins to lessen. Mining wastes, for example, tend to occur in areas remote from any community which does not depend almost entirely upon mining for its livelihood. In contrast, smelting is more likely to be done in a community which through the years has diversified until it harbors many diverse urban interests. Thus both the physical freedom to create a large pile of slag at the smelter site and the willingness of people to accept it, become serious aspects of the problem of control of solid wastes from the metals industry.

   At the second level of the basic metals industry, where ingots are formed into shapes, smaller amounts of mill scale and spalls characteristic of the metal being processed appear as solid wastes. At this level of industry new types of solid waste appear: trimmings from the product itself; residues from the on-site use of other refined products associated with the process (e.g., lime sludges from the neutralization of spent pickling liquor); and miscellaneous wastes from the handling and shipping of the item produced.

2. *Chemicals.* For variety of wastes the chemical industry exceeds all other basic industries and generates some of the most economically and technologically difficult problems of solid waste management. The nature of these problems in any particular chemical plant, of course, depends upon the processes and the products involved. Producers of less exotic materials such as portland cement, carbon black, and lime have tended to locate in areas remote from urban communities. Their principal solid wastes have been air-transported particulates, deposited over a large downwind area, plus ashes and mineral residues accumulating at the plant site. In contrast, such industries as petro-chemicals have generally located in urban centers or have been overrun by urban expansion. The same may be said of producers of sulfuric acid, fertilizers, and many other basic chemicals.

   The range of waste materials generated by the more complex chemical industries is too extensive to catalog in detail in this summary. However, it includes off-specification material, tars, process sludges, and a vast variety of chemical residues. Although roughly one-third of industrial wastes are generated by the chemical processing industries,[13] the wastes are significant because of their particular chemical properties and their environmental effects.

   Generally, solid wastes from the more sophisticated chemical processes are generated in a liquid stream which, in many cases, has been discharged to the ocean or to surface streams, or injected into deep underground strata. Nevertheless, some are generated directly in the solid state. These include chemical residues, precipitated sludges, and the miscellaneous refuse associated with the import of necessary processing materials and shipment of the finished products. In the environmental climate of the 1970's an increasing fraction of air-borne particulates and water-borne process brines and sludges will have to be collected as solids and controlled by solid waste management techniques.

3. *Paper.* Although much public attention has been directed to paper as a waste material, most of the problems associated with its original production have been in the context of water pollution rather than solid waste control. As a generator of solid wastes the production of paper and paperboard is similar to other basic industries in that residues of materials used in the process and residues of the product itself must be dealt with. In the first category

are such things as tree bark, wood fiber, paper pulp, and inert filler, which are not difficult to remove from transporting water; and process chemicals and wood extractives which can be isolated as solids only with difficulty, at considerable expense. As in the case of basic chemicals, both components of this first category of residues are destined to be controlled as solids if they are allowed to become wastes.

The second category of wastes — residues of the product — consists primarily of trimmings of paper or paperboard, plus wastage occasioned by malfunction of the processing equipment. Much of this material may be reprocessed; some may be incinerated or deposited in landfills as are similar residues from the paper fabricating industry and from commercial and domestic sources.

The total volume of solid waste produced by the basic paper industry, although not insignificant, is not as much of a management problem as is the separation of dissolved solids from liquids in the waste stream which has historically been a water pollutant.

4. *Plastics.* In the case of plastics, the residues associated with production of the basic material are essentially a problem of the chemical industry. Much of this material then goes directly to the conversion and fabricating industries, but some is converted by basic industry into sheets and other forms used by fabricators. Wastes from this segment of the industry are largely trimmings from the product itself. No estimate is available of the amount of such solid waste, but it is undoubtedly only a small fraction of the overall plastics disposal problem of a community.
5. *Glass.* Solid wastes generated by basic producers of glass include slag from the purifying of glass sand, plus miscellaneous containers and residues from products used in coloring and laminating glass, cullet (glass fragments) from breakage during manufacture and trimming of sheets, off-grade, resin coated fibrous glass, and residues from on-site crating of glass for shipment to conversion and fabricating industries. Except in situations where cullet of various colors becomes mixed, the major fraction of solid waste from the basic glass industry is reused and hence does not appear as a waste requiring control measures.
6. *Textiles.* Basic textile industries vary in the nature and spectrum of solid wastes generated, depending upon the type of material being processed. Trash from the ginning of cotton may be generated at the extractive industry level or as an intermediate step between extractive and basic industries. It is a fraction of the original cotton plant and is generally concentrated as a waste in comparatively small fractions of the total at a number of dispersed locations in cotton farming communities. Wastes specifically characteristic of the cotton textile mill are more commonly such things as strapping and burlap used in baling, plus comber wastes and fibers damaged during storage or shipment which are generally reutilized in the industry.[14]

   Linen textile manufacturers likewise must dispose of plant residues and materials used in shipment of the raw flax. Fiber, twine, dirt, and wool fat characterize the wastes from preparing wool for textile processing. In addition to waste fibers, synthetics generate special wastes in the form of containers used in shipping chemicals from the basic chemical producers.

   Residues from spinning, weaving, and trimming operations occur with all types of fabrics. Dye containers and residues from on-site preparation of cloth for shipment are a fraction of the overall solid waste generated by the basic textiles industry.
7. *Wood Products.* Tree bark, sawdust, shavings, splintered wood, and trimmings constitute the major solid wastes of the lumber producing industry. In weight they amount to some 10 percent of that of the original tree in the forest, or about 1.26 tons per 1,000 board feet.[15] Conversion of wood to plywood sheets contributes plywood trimmings, knots, and glue containers to the overall solid waste of the wood products industry at its basic level. Wood ashes are typical wastes of this industry as a result of on-site burning of wastes for power production or to dispose of sawdust and other wood wastes.

   Typically, sawmills are located in smaller communities and are notable for their untidy appearance. Broken cable, discarded machinery, and miscellaneous debris often characterize the environment of a wood processing plant, albeit out of scale with the amount of such wastes generated.

   Air pollution and aesthetic considerations may be expected to intensify the solid waste control problems of the basic wood products industry as particulates now discharged to the atmosphere by burning become converted to solid wastes in response to restrictive legislation.
8. *Power.* Fly ash, bottom ash, and boiler slag accompany the production of power by burning of coal. Production of these three wastes by the U.S. power industry in 1969 was 21, 7.6, and 2.9 million tons, respectively.[16] Often such power plants are located in metropolitan areas, hence the objection to air-borne fly ash, dust, and ash heaps confronts the power producing industry with solid waste problems. Where high ash coals are utilized, the volume of ashes and clinkers may approach that of the original coal consumed, although, of course, its dry weight is generally appreciably less than 20 percent of that of the coal from which it was derived.

As generators of solid waste, basic industries such as those herein cited have several things in common. With few exceptions, they draw upon more than one extractive industry for raw materials; a fraction of the raw materials they refine appears as a solid waste; they utilize refined products of

other basic industries and of conversion industries, importing in the process things such as shipping containers which become wastes for which they must assume responsibility; a fraction of their own product must be handled as a waste; and a considerable value is added by manufacture, or processing by the basic industry. In comparison with a purely extractive industry, a basic industry produces more categories of solid waste, some of which it can recycle directly in its own processes. However, in comparing one basic industry with another, the things they have in common are not reflected in any similarity of waste generated. Hence no common approach to solid waste control characterizes the problem of basic industries.

Conversion and Fabricating Industries

It is beyond the scope of this chapter to attempt any listing of the myriad enterprises which convert the products of basic industry into the goods which characterize our economy and our standard of living. Value added by manufacture is a maximum in the conversion and fabricating industries. As generators of solid waste, such industries also have many things in common. Particularly significant is the extent to which the output of one type of industry comprises a combination of raw materials and solid waste for another. For example, one modest sized industry engaged in converting plate glass to windows and mirrors in the Los Angeles area estimates its cost of disposing of crating materials received from its suppliers at one thousand dollars per month.

A second common characteristic of the conversion and fabricating industries is that residues of the basic materials they utilize generally constitute the greatest fraction of the waste they generate. Moreover, unlike a basic industry which may directly recycle the trimmings and rejects of its own product, the conversion or fabricating industry must rely on some secondary enterprise to take such of its residues as are reclaimable. Thus broken glass, metal trimmings, imperfect castings, and similar salvable residues can seldom be utilized directly by the conversion industry which generates them.

To illustrate the type of solid waste problems associated with the conversion and fabricating industries, such broad categories of industry as packaging, automotive, electronics, paper products, hardware, soft goods, food processing, and construction may be cited as typical, though by no means all inclusive.

1. *Packaging.* For the purpose of this summary, production of packaging materials is classed as basic industry, hence only the conversion of packaging materials to containers is considered. However, the scope of this sector of the industry is itself extremely broad and varied as regards the nature and resource value of the waste it produces. Aluminum, steel, glass, plastics, cardboard, corrugated paperboard, plastic-paper laminates, and paper with or without any of a broad range of coatings are among the materials used by the container industry. Whether or not an appreciable number of these items appear in any industrial waste stream depends, of course, upon the range of activities engaged in by a single company or plant. Recoverability of residues often depends upon the cleanness and uniformity of the waste material. For example, conversion of glass to containers generates an appreciable amount of cullet; however, whether this is recoverable or useless, generally depends upon the extent to which colored and clear glass is mixed in the waste. Nevertheless it may be said that, at the industrial level, wastes from the packaging industry are primarily fractions of the material converted, although the range of possible materials is unlimited.

   A secondary waste of any individual packaging plant is packages passed along to it by its suppliers, together with residues on its own on-site shipping preparations.

2. *Automotive.* There are two major waste-generating sectors of the automotive industry. One makes and ships specialty components; the other assembles the components into a finished vehicle. Conversion and fabricating industries in the first of these categories produce such things as tires, generators, carburetors, radios, speedometers, wheels, bumpers, hub caps, lamps, bearings, and other of the dozens of systems or devices that go to make up an automobile. In each of these the solid waste generated is a function of the special activity of the individual industry, and comprises residues of the materials used and the packaging received from suppliers.

   Painting and upholstering of automobile bodies adds both container and material residues to the solid waste stream of the manufacturer. However, by far the greatest component of the automobile assembly plant waste is the discarded packaging and shipping materials associated with the delivery of components from other industrial suppliers. In fact, there is probably no other sector of industry which compares with automobile assembly in the amount of solid wastes it inherits from its relationship with other industrial activities.

3. *Electronics.* Like the automotive industry, the electronics industry includes both a components and an assembly sector. Plastics, glass, wire and sheet metal scrap and residues of a variety of other basic products appear as solid waste of the many industries associated with production of electronic components. However, in comparison with the waste from most other conversion and fabricating industries, the actual amount is relatively small.

   Packaging materials, particularly cardboard, corrugated paperboard, polystyrene foams, and padding materials utilized in shipping electronic components is the major waste generating problem of the assembly activity of the electronics industry. Shipping of the assembled equipment is generally in specially designed containers, the manufacturing wastes of which are ascribable to the packaging industry.

4. *Paper Products.* Conversion of paper into products used in commerce and by the public largely results in solid waste in the form of paper trimmings. Facial and toilet tissue, paper towels and napkins, and similar products yield a high quality waste which may or may not be salvable through a secondary enterprise, depending upon whether white and colored paper residues are mixed together in the conversion process. Conversion of kraft paper into bags, for example, yields a readily salvable waste. Publishing of books and magazines, which might be classed as a fabricating industry in the context of solid waste generation, is a major source of filled paper residues which are commonly disposed of as solid wastes.
5. *Hardware.* The term "hardware" rather than "hard goods" is used herein because the latter embraces many classes of basic as well as conversion and fabricating industries. "Hardware" is confined further herein to the metals industry which produces the machines and tools (with the exception of the automobile), and the utensils and gadgets used by all classes of industry and by the public. Solid waste from such hardware industry includes residues from boring and machining of metals; trimming and sizing of plates, tubes, and structural shapes; and miscellaneous residues from casting and forging processes. It also includes plating, etching, and similar liquid borne wastes which, like similar wastes from the basic chemical industry, must eventually be managed in the solid form.
6. *Soft Goods.* Conversion of such materials as textiles, leather, and plastics into articles of commerce constitutes the soft goods industry in the context of conversion and fabrication. As is characteristic of all industries in this classification, residues of the material processed represent the major item of solid waste generated, with incoming and outgoing goods yielding secondary wastes associated with shipping.
7. *Food Processing.* As a waste generating industry, food processing presents problems somewhat different from other conversion industries. Like extractive and basic industries concerned with material of plant and animal origin, food processing produces wastes which are subject to the normal recycling processes of nature. However, they are generated seasonally and in large amounts at locations which may be either urban or intermediate between farm and city. With the exception of a few residues such as rice hulls, food wastes are putrescible, attractive to insects, and occur in a semi-liquid or liquid state. Preparation of fruits and vegetables for canning yields a slurry of such things as leaves, soil, skins, peelings, pits, seeds, and cores, along with spoiled, outsized, and damaged fruit. In California alone this type of cannery waste totaled 750,000 tons in 1967.[1] Washing and cooking operations yield a companion stream of water-borne dissolved and suspended solids. Because of water pollution problems, these solids increasingly are being removed from water for disposal by solid waste management techniques.

   Processing of fish and animals for marketing or canning likewise generates putrescible liquid and semi-liquid wastes. The solids content of these waste streams, along with bones and other inedible fractions, are destined to be handled as solid wastes as water quality objectives become more restrictive.

   Because the food processing industry is linked directly to extractive industry without an intermediate basic refining, containers coming to the plant are reused in the fields and orchards. Furthermore, shipment of the finished product makes use of containers already prepared by the packaging industry. Consequently, wastes from the food processing industry are predominantly fractions of the material processed.
8. *Construction.* Among the most significant generators of solid waste is the construction industry. In its purely fabricating activities its waste products are typical residues of the materials it employs — lumber, plasterboard, wire, paper, cement bags, sheet metal scrap, etc. However, unlike other industries in the conversion and fabricating category, most construction wastes result from peripheral activities essential to its production phase. Demolition of buildings, breaking up of pavement, and preparation of site produce very large volumes of such materials as earth; rock; broken concrete, tile, brick, lumber, and plaster; tree stumps, poles, and piling; and miscellaneous rubble.

The eight foregoing examples by no means cover the full range of activities which might be classed as conversion and fabricating industries. They illustrate, however, that the wastes generated by this class of industry are primarily residues of the materials they process or convert into consumer goods, and that the measures necessary to move products from one sector of industry to another impose a secondary solid waste burden on the receiver. More important, it is significant that at this most complex level of industrial solid waste generating activity the value added by manufacture is greatest. This suggests that the economic capability of conversion and fabricating industries should generally be greater than that of a basic or an extractive industry as such. Moreover, conversion and fabricating industries tend to be activities of a diverse urban community. Therefore, social pressure for solid waste control can be expected to be exerted most heavily upon such industries, especially since their products, along with the associated packaging, constitute the major solid waste which the citizen himself ultimately casts off.

MANAGEMENT OF SOLID WASTES

Earlier in this chapter it was found convenient to arrange industry into three categories, each having specific waste generating characteristics. These categories were presented in ascending order of magnitude of value added by manufacture,

responsibility for creating wastes, and degree to which their activities are conducted in urban communities. To evaluate each category, and type of industry within that category, as a generator of wastes it was necessary to treat extractive, basic, and conversion and fabricating industries as discrete entities. In the real world of industry, however, these three may be only sectors of a single large industry which owns and operates every aspect from raw material source to the finished consumer product. Thus the conclusion that no common waste management technique is appliable to all types of industry in a single category, although valid, is complicated by the fact that industry may be stratified vertically along ownership lines as well as horizontally along functional lines. To get at the general problem of solid wastes management in such a complex situation, it is convenient to consider waste control approaches in relation to the source of solid wastes rather than the composition of the waste itself.

Disposal as a Condition of Production

The simplest situation in solid waste control applies especially to an extractive industry in which the feasibility of operating at all is contingent upon satisfactory control of its solid wastes. In such a circumstance a mining, quarrying, or logging operation might be undertaken by industry only when waste control is not an economically overwhelming consideration. Feasibility may, of course, be based on geographic or topographic conditions, property holdings, access, or regulation by public law or public policy. It does not necessarily imply environmental perfection, although there is a tendency (1971) for aesthetics to be given increasing weight where public interest or public opinion is a factor. Uneconomical conditions, whether natural or man-imposed in a wastes management context, generally have discouraged an extractive industry operating entirely on its own resources. However, in an industry which covers the whole range from extraction to conversion, extraction of raw material may well be operated at a loss in order to produce profits at the higher industrial level where value added by manufacture is sufficient to offset losses. Moreover, control of solid wastes by an industry of this sort may be subject to considerable upgrading in technique and cost without causing the system to fail economically. Nevertheless, in such activities as mining there is no choice but to dispose of wastes upon the land, albeit under conditions acceptable to society.

In the case of farming as an extractive industry, constraints imposed by solid waste management have seldom been insurmountable unless urban environmental conditions are required of the farmer. Generally, he is not part of an industrial complex which can take a loss continually at the extractive level. Thus if society asks too much in the name of solid waste control or other environmental context, the agriculturist, unless subsidized, ceases operations and converts his land to urban development.

Incidental Residues Produced By An Industry

As noted in a preceding section, processing, converting or fabricating activities within several types of industry result in slag, ashes, clinkers, and similar solid residues, as well as air-borne particulates or liquid carried process sludges, generated at the site of operation. For air and water-borne solids, control measures may include electrostatic precipitators, bag filters, wet scrubbers, sedimentation, chemical precipitation, or other conventional waste treatment processes. Disposal of bulky worthless solids involves simple deposition on the land in some location and under some conditions, acceptable to the public. More valuable incidental wastes may, however, be reclaimable or convertible to useful resource materials if the level of cost is acceptable. For example, about 14 percent of power plant solid wastes were utilized outside the power industry in 1969.[36] Other measures which may assist in controlling the residues produced incidental to industrial output may include such expedients as abandoning on-site generation of power, or making changes in process. Abandonment of an entire plant, especially one with obsolescent processes, is a measure sometimes taken by industry confronted with solid wastes which are a by-product of its fundamental processes.

Product Residues Generated By A Basic Industry

When refinement rather than conversion of raw materials is the goal of production, product wastes occasioned by spillage, breakage, or malfunction of process may be managed by direct recycling within the plant. The same is true of metal trimmings, cullet and paper trimmings in industries producing metal, glass, or paper as basic products.

Residues From Materials Conversion Or Fabricating

Cullet, metal trimmings, packaging materials, and other residues resulting from the conversion of basic industrial products into consumer goods cannot be directly reused by the waste producer. To him they represent a solid waste, some of which might be salvaged or reused economically; some of which he shall have to pay someone to remove for disposal. Metal scrap, clear glass, and uncoated corrugated paperboard are typical of the material which might be returned to more basic industries for reprocessing. Similar trimmings from plastics, fiberboard, laminated plastic-paper, lumber, cloth and a host of other materials are generally useless and are relegated to the landfill or incinerator.

Waste From Interindustry Transfer

Packaging and shipping of basic materials or finished products, a necessary part of industrial activity, require that most industries accept various amounts of materials, which immediately become a waste, in order to acquire the materials necessary to their enterprise. Thus each industry helps to create a solid waste management problem for those with which it does business. In general, the waste-to-product ratio goes up from basic to conversion industry, reaching its maximum value at the conversion industry-to-consumer level. Most of the waste generated by interindustry transfer of materials and components is waste, although there

are instances where intra- or inter-industry practices work to hold down waste production. Where producer and fabricator are favorably located with respect to each other, such things as cable spools and protective packaging for television tubes are commonly reused repeatedly for their original purpose.

Special Problem Materials

Waste materials which present especially difficult problems of management at present (1972) include both natural and synthetic products. Organic wastes, particularly food processing wastes, are a nuisance because they are putrescible, whereas plastics are a nuisance because they are not. Process sludges of a wide variety of activity, ranging from industrial waste treatment to saline water reclamation, present an unsolved problem both because of their high liquid content and because they are so newly recognized as solid waste problems that no economic technology for converting them to drier solids has been developed.

CONTROL OF INDUSTRIAL SOLID WASTES

In the preceding section attention is directed to the internal management of solid waste generated at various levels in the industrial scale. However, to determine what methods of control are needed in solving the overall problem of industrial solid wastes, it is first important to understand the relationship of industrial practice to the generation of society's total solid waste problem.

To a significant degree it is true that the entire industrial effort of the nation is dedicated to the production of solid wastes. The product of extractive industry is the raw material of basic industry; and the product of basic industry feeds the conversion and fabricating industry. Each sector of the system discards what it cannot pass along to the next in line. Finally, the entire product of the conversion and fabricating industry becomes the solid waste of all sectors of society — industry, commerce, and citizens. The rate at which the overall system functions governs the economy of the nation and depends upon the acceptance of goods by the consumer at the top of the scale. This encourages industry to mistake the act of physical acceptance of goods by the citizens for actual consumption of these goods. The next logical step is to create through advertising a dissatisfaction on the part of the consumer so that he discards his purchases on the basis of obsolescence rather than loss of utility. Thus it is clear that quite aside from any question of whether industry is giving the public what it demands, or the public is accepting what industry persuades it to demand, the overall waste generation of the commercial and municipal sectors of society is a function of what flows from industry into these sectors.

Carried to its logical conclusion, this system would eventually convert all nonrenewable resources into discarded wastes unless reuse and recycling are a matter of industrial practice and public policy. Therefore it seems logical to conclude that public agencies, industry, and education of the public each play a role in industrial solid waste control.

Role of Public Agencies in Industrial Solid Waste Control

In the absence of any public agency concerned with overall environmental quality, solid waste control would be a problem of individual enterprises in specific locations rather than one confronting the entire sector of human activity loosely described as "industrial." Thus, for example, a mining operation with land area for spoils would have no disposal problems, whereas waste disposal might be the most compelling problem of a less fortunately situated operator. Without public constraints, wastes generated incidental to production, and residues of materials conversion as well, might be hauled to some public or private dump and so pose no problem other than that of cost to the generating industry. The same may be said of particulates discharged to the atmosphere, or of process brines and sludges discharged to the water resource.

Industry would, of course, share in any ultimate disaster that wastes might bring upon mankind, but in the interval industry's wastes like those of everyone else would react only to degrade the general environment. In such a situation, responsibility for deciding what sort of a world society wants accrues to the public; and implementing public goals is the function of public agencies. Therefore, some agency of the public must decide what constitutes an environmental problem, at what level the problem is to be tolerated, and what measures should be taken to alleviate it.

In the context of problems associated with industrial solid wastes public agencies play a role in four distinct areas: public health, environmental quality, resource conservation, and economics.

1. *Protecting Public Health.* The concept that industrial solid waste poses a threat to public health apart from that of municipal refuse is of quite recent origin. It developed from a realization that air pollution is a menace to human health and that industrial pollution of water has health implications beyond that of historical water-borne disease. Constraints imposed on industry in the interests of health of workers and citizens in general are, therefore, currently reflected in the concept that air and water pollutants should be separated from their transporting media and dealt with directly as solid wastes. As with municipal refuse, however, industry is expected to handle its putrescible organic residues in such a manner as to keep down insect and rodent vectors of disease.

   Thus, the role of the public health agency in industrial solid waste control is essentially regulatory.

2. *Attaining Environmental Objectives.* Environmental objectives which call for clean air, pure water, freedom from nuisance and affront to the aesthetic sensibilities of man, and a healthy ecological balance in nature are perhaps the major concern of public agencies in relation to industrial (and other) solid wastes. At the local level attainment of such objectives may be the responsibility of the health department, but at the federal level and in many

states protection of the environment is a role assigned to some agency with broader regulatory powers than the department of health. It is the role of this agency to determine where and under what conditions wastes may be deposited on land, burned, or otherwise disposed of by those who generate them. In carrying out this role the agency, in the long run, continuously must strike a balance between the environmental perfection desired by an emotional public and the industrial freedom considered necessary to an ever-expanding and changing civilization to arrive at a point at which environmental objectives are attainable at an acceptable reduction in our level of civilization.

3. *Implementing Resource Conservation Policies.* Resource conservation is a matter of public concern which has been assigned to numerous agencies with various powers and specific interests for more than half a century. In relation to solid waste, conservation has been interpreted[17,18] in terms of both land resources and the value of resource materials in the solid waste. Thus, a public agency, alone or in concert with other public agencies, might decree in one case that a spoils dump or a slag heap in a certain location would be destructive of a land resource either by physical occupancy of land or by environmental degradation. In another case the conclusion might be that a properly constructed landfill in a particular location would create a new land resource.

   Concern for the resource value of residues such as glass, metal, and paper wastes from the conversion and fabricating industries might lead a public agency to any of several alternate decisions. For example, the decision might be that enhancement of land resources is important enough to justify sacrificing resource residues as landfill material. In contrast, there might be reason to decide that resource residues should be stockpiled in a fill for reclamation at some future date; or that they should immediately be recycled in the interest of resource conservation regardless of cost.

   Both the multiplicity of public agencies having interest in land use and in resource conservation, and the scope of possible policy decisions, gives the public agencies a broad and flexible role in determining the conditions industry must meet in managing its solid wastes.

4. *Overcoming Economic Constraints.* In the matter of economic constraints, public agencies may play either of two important roles. They may force industry into actions regarding solid waste control previously thought to be too costly by regulatory actions directed to resource conservation, environmental quality, or any other objective. At the other extreme, they may establish economic incentives for action by industry.

   It is not likely that regulation of what conversion and fabricating industries must do with their solid wastes will be a deciding factor. Instead, a requirement that resource materials be recycled will strike at the consumer-waste hinge of the system and so feed back through the entire industrial equilibrium. That is, it will change the kind of materials required by the conversion industry and, consequently, what basic industry produces and what amounts of specific raw materials are extracted.

   In the matter of economic incentives, tax breaks or tax penalties,[19] demonstration grants for exploring new processes, direct subsidy of recycling, and equalization of freight rates for new and scrap metal* are examples of actions which might be taken by public agencies under appropriate public policy. The result might be both a change in the nature of solid waste generated by industry, and in the ultimate fate of such wastes.

Role of Industry in Industrial Solid Waste Control

Because industry accounts for a very large fraction of the total solid wastes of society and the processes by which many wastes are generated are proprietary to industry, it is logical to expect that industry should play a significant role in the control of its wastes and, consequently, of the total waste load upon the land.

The Matter of Options. If all discarded material is considered as waste, the mining and basic metals industries appear as the major source of industrial waste. To deal with such things as mine tailings and blast furnace slag, however, man has few options. Thus at the lower end of the scale the role of industry in solid waste generation is relatively fixed. Similarly, the small value added by processing at the extractive level limits feasible disposal methods, unless higher levels of industry or government subsidize waste control.

Further up the scale, however, such rigidity no longer pertains. The material to be used for any given purpose, as well as the resulting waste-to-product ratio, is a function of the inventiveness and ingenuity of man. Competition for markets encourages the producer of consumer goods to use that ingenuity in finding better processes and cheaper materials and production methods. Constraints imposed by public policies concerning resources, environment, and waste management may likewise react to this same end. Therefore, at the higher end of the scale the role of industry in the overall waste problem is not fixed by circumstance.

Reducing the Amount of Waste. Better processes and cheaper materials do not lead necessarily to a lesser amount of wastes generated. In fact, it is possible that quite the opposite might result. Therefore, industry's role in controlling the amount of solid waste society generates is one of looking to its own design and materials selection activities with consideration for the final disposition of its product in the environment.

The concept that purchase is synonymous with consumption of goods leads logically to a limitation of the objectives of design to such traditional factors as ease of manufacture, saving in cost of fab-

*In Minnesota the 1970 freight rate for scrap was $4.25/ton as contrasted with $1.84 for raw material.[20]

rication, appeal to the buyer, novelty, and obsolescence. Responsibility for solid waste control and for resource conservation, however, now requires that degradability of synthetic materials, ease of dismantling for segregating component materials, minimum number of types of material, and other materials recovery considerations or disposal objectives be among the specifications designers should seek to meet.

Role of Public Education

It is particularly important that people understand the inter-relationships within industry and the dependence of our level of civilization upon industrial activity.

An informed public plays an especially significant role in the control of industrial solid wastes, both because public opinion is respected by industrialists and because public attitudes are the basis of policy legislation which creates the institutions which carry out public policy. Public education is both important and urgent at such times in history as the 1970's when prophets of doom abound, and citizens are bombarded daily with propaganda and with naive and simplistic answers to complex environmental problems.

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International Program on the Environmental Aspects of Industrial Development

PLANNING FOR WATER MANAGEMENT PROJECTS

by Daniel A. Okun

Inasmuch as industrial development carries with it an obligation to provide water supply and wastewater collection and disposal facilities for the industry, and often for the associated community, the planning for such projects is worth exploring in some detail. The technology involved is extensive, but it is not our purpose here to discuss all the technology as the appropriate professional personnel can be expected to have the resources for exploiting the appropriate technology. However, there is a substantial difference between using existing technology as it is applied in industrialized countries as compared with such technology as it can be applied most economically and efficiently in developing countries. Not only does this difference apply to the planning, design, construction and operation of water supply and wastewater disposal facilities, but many of the principles described for such projects may be applied to the industrial developments themselves.

Mechanization and automation are beginning to appear in every phase of human activity. Not only are they ubiquitous in all manner of physical operations, they are now important in data management and analysis. Where do mechanization and automation fit in water and wastewater treatment plant design, and by analogy, in industrial design?

Three criteria should form the basis for decisions on the extent of mechanization and automation to be incorporated in designed systems; desired quality, required overall plant reliability, and system economy. The decision to incorporate a particular system of mechanization or automation depends on

the environment within which the system must function. Factors to be considered include the relative costs of labor of all types, cost of equipment, complexity and essentiality of the system or its elements. and the service resources of the owner or the supplies of components.

Lessons learned from mistakes are often those which are learned most thoroughly, albeit painfully. About nine years ago, in a provincial capital of a Latin American country, a typical rapid sand filtration plant, with modern instrumentation and control, was built. Each filter was equipped with electrically-operated valves, a modern rate control system and control tables with all normal appurtenances. In addition, the plant included a supervisory control center from which all plant functions could be monitored and controlled. All instruments and mechanisms were of high quality and rugged construction.

A few years after the completion of the plant, not one instrument was functioning! Most of the recorders and controllers had been removed from their mountings. When the flow indicators and recorders on the filter rate controllers failed, the controllers were simply wired down so that the control valve would stay in the wide open position at all times. It was not even possible to measure the raw water inflow or the rate of treated water delivery to the city as the venturi meter recorders were out of order. In this case, the misapplication of instrumentation and control was extreme. This control system was installed in a location where skilled maintenance was not available and where spare parts were extremely difficult to obtain. In addition, the function and purposes of the system were not understood by the plant operators.

The end result was a water treatment plant relatively high in first cost which produced a water of lower average quality than could have been produced with a control system more suited to the local situation.

On the other hand, in industrialized countries, there are numerous situations where the increased use of instruments and automated controls improves the operation of plants.

Reliability

One of the principal concerns of managers is to provide a service with highest possible degree of reliability. Designers and plant operators are continually searching for the most reliable methods of plant control. Reliability, in this case, implies that a particular function will be performed or some process characteristic or quality will be controlled with little likelihood of failure. Reliability may outweigh economy.

Control of residual chlorine in wastewater treatment plant effluents provides an example of a situation where full automation may be more reliable than manual methods and in addition can result in both economy and higher quality effluent. Chlorine demand varies and control of chlorine dosage by a residual recorder-controller would maintain a more uniform residual level in the effluent. Manual methods, if a certain residual is to be maintained, require either an overdose of chlorine or continual attention.

Control systems for such physical variables as pressure, tar flow and temperature have been in use for years. System components for the control of these physical variables have been developed to a point of high reliability. Their application enhances the reliability and economy of the entire plant operation.

The reliability of some of the newer instrumented and automated control systems is more uncertain. Perhaps a comparison with the reliability of manual methods is in order; in other words, man against machine. Realistic answers to the following questions may aid in achieving objectivity:

1. What is the probability of instrument or control system failure versus the probability of human error?

2. What is the probable magnitude of instrument or control system error versus human error?

3. What is the result of instrument or control system failure versus human error in terms of (1) plant effluent quality, (2) overall reliability of service and (3) cost?

Economy

As cost of labor increases while the relative cost of instruments and equipment decreases, the replacement of personnel through mechanization and automation becomes more attractive. The present cost of manning one around-the-clock seven-day position in the U. S. is between $30,000 and $40,000 per year. The elimination of such an annual cost would justify an investment in mechanization and automation of between $250,000 and $300,000, assuming the equipment is amortized over ten years with interest at 6%. In developing countries, where wage rates are much lower and interest rates high, much less can afford to be invested in labor-saving automation and control.

Systems of automation are, moreover, completely dependent on proper maintenance attention if they are to provide the service for which they were designed. It is very wasteful of the designer to install automation unless he is assured that adequate funds will be available for their maintenance. It is discouraging to visit plants and see that many of the instruments are inoperative.

The proper maintenance of instrumentation and control systems requires highly trained personnel. Personnel of this quality is not always available and must frequently be trained on the job. The cost of training the necessary personnel and the relatively high wages that they command must be taken into consideration in any economic analysis.

Other Considerations

An important ancillary benefit deriving from automation is the opportunity to attract highly qualified engineers and scientists to the field of public water supply and pollution control. These skilled personnel, freed from routine tasks, can use their energies for research and investigations leading to improved procedures. Mechanization can help eliminate many of the unpleasant tasks, now requiring manual labor, thereby encouraging the employment and retention of fewer but more highly skilled operators.

Modern systems of automation used in connection with appropriate data processing equipment can produce timely and valuable reports for management. In many of our facilities such reports are, at present, not available because of the tedious and time-consuming work required in their preparation. When such reports are prepared in the traditional manner, the information they contain is frequently outdated before the report is finished. The preparation of such reports by modern methods will leave more time for analysis and judgment, promoting a higher quality of operation and service.

Computers are rapidly becoming more reliable and relatively less costly. Specialized process control computers of both the digital and analog type are being developed. Some of these computers can be effectively used, at present, in the control of our water and wastewater systems. Currently, the most

successful applications of computer control in these fields involve the simple measurement and control of such variables as flow, level, pressure, and temperature. With processes involving chemical or physical changes, which are more difficult to measure, progress is being made in the development of reliable automatic instruments.

Appropriate incorporation of mechanization and automation holds great potential in meeting the continually growing demands for expanded and higher quality water and wastewater service.

The Planning of Projects

When a major industrial development is contemplated, in the planning for the supporting services and for minimizing the detrimental impact of the facility on the environment during both the construction and operation phases, it is important that qualified professionals be employed to prepare the necessary feasibility studies. Whether the needs are for water supply, for water or air pollution control, for the disposal of solid wastes, for the control of the environment within the plant, or for the other utilities and services, a report outlining the technical, political and financial feasibilit of alternative solutions must be prepared.

In dealing with the water phase of the environment, two approaches have been used. One is to call for a single contractor to be responsible for all phases of the project including the planning, design, provision of equipment and the construction. Such approaches have been given the name "turnkey". Turnkey approaches may be suitable where the client is fully familiar with what is needed, has the technical staff to prepare a set of

tight specifications, and has the knowledge and depth of personnel necessary to review the provision of the facilities so as to be certain that what is being proffered is, in fact, appropriate and technically and economically the best that can be afforded for the available funds. However, this approach is seldom suitable for public water supply or water pollution control. Turnkey contractors, particularly where they are associated with manufacturers, have a stake in a certain type of equipment, and will offer designs that will maximize the use of proprietary devices so as to maximize their profit. Also, such approaches tend to increase the use of sophisticated equipment, while minimizing the use of labor. Turnkey contractors often pay little attention to the problems of operating the facility after the project is accepted.

The second approach is to employ consulting engineering organizations that have no tie with contractors or manufacturers, and whose only stake in the project is providing the best professional service to the client. Such an engineering organization would prepare a report offering several alternatives from which the client might choose. After the report has been accepted and the processes and approaches decided upon, detailed plans and specifications are prepared by the engineer and submitted for bids by independent contractors. These contractors may be local or may be a combinatio of local and foreign contractors. The engineer might select from a large numbe of purveyors of equipment that combination that appears to be the most suitable for the project. The consulting engineer may then serve to review proposals and help select the best. When construction is initiated, he may serve to supervise the construction on behalf of his client. When construction is complete, he may also assist his client with "start-up".

That the latter approach is to be preferred is evidenced by the fact that the World Health Organization on behalf of the United Nations Development Program and the World Bank as well as the regional development banks all require that consulting engineering organizations be used in the preparation of reports and plans and specifications.

In the selection of consulting engineers, full recognition should be given to the qualifications of the engineering organization in the field of specailty involved, namely, water supply and water pollution control, as well as his experience in working in the region of the world for which the project is proposed. While many engineering organizations are competent in a wide range of engineering designs, the provision of water supply and the design of sewerage and water pollution control facilities constitutes a specialty that is often not within the purview of the conventional civil engineering organization. Most civil engineering requires only an understanding of construction materials, structures, hydraulics, foundations and the like. The provision of water supply and the control of water pollution require, in addition, a sound understanding of the chemistry and biology of water and how these can be managed to provide the water quality desired. Such special competence is generally designated as sanitary engineering, public health engineering, or environmental engineering. In the United States, engineers with this special competence in the environmental field are certified, becoming diplomates in the American Academy of Environmental Engineers. If engineers are to be selected from the United States, firms that are staffed by large numbers of diplomates are to be preferred. In other countries, the experience that the firm has in designing a wide range of water supply and water pollution control facilities is important in their selection.

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PARTMENT OF ENVIRONMENTAL SCIENCES AND ENGINEERING

SOURCES OF WATER

In general order of water quality:

Rain water - very pure

Gibraltar; Bermuda; Jerusalem

Subterranean Water - biologically pure, troublesome chemically

Natural springs - Rome; San Antonia, Texas

Confined (artesian) ground water - Brussels; Houston, Texa

Free Ground Water (subject to pollution) - Peoria, Illinois; Utrecht, Netherlands.

Limestone Aquifers (likely to be polluted) - Tallahassee, Florida; Liege

Infiltration galleries (variable quality) - Parkersburg, W. Va.; Cerro Bolivar, Venezuela.

Infiltration Basins (variable quality) - Ruhr

Artificial recharge - Netherlands

Brackish ground waters - desalinization - Coalinga, Calif.

Surface Waters

Teutonic (mountain) lakes, excellent physical quality, may be contaminated Geneva, Switzerland; Manchester, England.

Erosion (glacial) lakes likely to be polluted - Chicago, Lake Michigan

Mountain rivers, impounded, good quality, limited quantity - New York City; Boston; Asheville, North Carolina.

Lowland rivers run-of-river supplies, ample quantity, poor quality- St. Louis; Cincinnati; London; Cairo; New Orleans, La.

Estuaries, diurnal withdrawals, poor quality - Rotterdam

Waste waters - industrial supplies.

The oceans, desalinization required - Brownsville, Texas; Aruba; La Guaira, Venezuela.

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WATER AND INDUSTRIAL DEVELOPMENT

by Daniel A. Okun

Few elements of the environment are as closely linked with industrial development as water which, in sufficient quantity and of suitable quality, is a prerequisite for industrial development. Not only must sufficient water of appropriate quality be available for industrial processing to make an industrial development viable, but water of potable quality must also be available for the population that services the industrial development.

Furthermore, the industrial development may have considerable impact on the water resources of the nation. In using water, the industry may foul it or heat it or otherwise make it unsuitable for domestic purposes, recreation or even other industrial purposes. Industry may actually consume water by evaporating it, thus denying the water to others. An industry that is entirely appropriate for one location, where water resources are ample and where its waste can be readily assimilated, may not at all be appropriate in another location within the same country, where scarce resources must be husbanded for the sustenance of communities. In this way industry may have a detrimental effect on tourism, which itself has a potential for economic development. Hence, water is of first importance amongst all environmental considerations in industrial planning, and is a significant element in developing a land use plan.

An automated slide show with tape narration, presented by Dr. James C. Lamb, illustrates the role of water in our society.

Sources of Water

An understanding of water resources includes an understanding of the following sciences: meteorology, water in the atmosphere; oceanography, water in the oceans; potamology, water in the rivers; limnology, water in the lakes; and geohydrology, water underground.

Water has unusual properties that influence its role: it has its maximum density as 4°C; it has high viscosity which permits it to transport sediment; and it is an excellent solvent and its chemical quality is affected by the materials that contact it in the air and on and in the earth. Water is not only abstracted for use, but in place it is a medium for the support of aquatic life, an aesthetic resource, and a locale for important recreational activities.

The following are the specific sources of water in general order of water quality:

Rain water.

Subterranean water: natural springs, artesian ground water, free ground water, limestone aquifers, infiltration galleries, infiltration basins, artificial recharge areas, and brackish ground waters.

Surface waters: mountain lakes, erosion or glacial lakes, mountain rivers, lower reaches of rivers, estuaries, and the oceans.

Wastewaters, by reuse.

Water Supply Quality

Industrial water quality requirements vary from water of almost any quality that can be used for cooling to water of exceedingly high quality that is necessary for boiler feed or for food processing. Any one large industrial development may, in fact, have several water systems that

range from raw water, that may be drawn from a river or the sea without treatment for once-through cooling, to a settled water for one process or a filtered water for another, to a disinfected water for potable supplies, to finally a demineralized water for boiler feed. An important principle, enunciated by the United Nations Economic and Social Council in 1958 states that "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade."

In addition to the water quality requirements for industry, if an industrial development is to be sustained, it must be in a locale where its workers can be assured of a public supply of potable quality. Whereas in the industrialized countries of the world, and in a few (unfortunately too few) capitals of developing countries, a satisfactory water supply is available, most of the developing world is without such supplies. For example, of the 480 million urban population in developing countries in 1970, it is estimated that 175 million do not have piped water supply service, and for many of those who do have piped service, the reliability and the quality are generally questionable. Of the 1250 million rural population in developing countries, some 1100 million have no access to piped water supply service. An even smaller proportion of the population is served by sewerage or other adequate wastewater disposal system. Hence to develop industry, an important requirement is the quality of water management available.

Failure to provide water of suitable quality in the developing countries has resulted in an exceedingly high rate of enteric disease which, in addition to its debilitating effect on the population, interferes with the industrial and economic development of a nation. Parasitic

diseases, the dysenteries, cholera and schistosomiasis all take an exceedingly heavy toll of the population of developing countries. An estimated half billion people are victims and five million infants die of enteric diseases each year and an estimated one hospital bed in four is occupied by a patient ill with enteric disease. Death rates from enteric disease in some of the non-industrialized countries are more than 100-fold greater than death rates in industrialized countries, the major factor being the quality of water management.

Proper water management constitutes a necessary investment in "social overhead capital," capital required for the orderly and productive activities associated with a healthy economy.

While the most important water quality problem in the developing countries originates from the improper disposal of human wastes, the introduction of industry initiates a whole new set of problems. Wastes from industry, unless rigidly controlled and monitored, inevitably contribute chemicals to the waters into which they discharge which may often be used as sources of drinking waters for communities in the vicinity. Often the wastes from these industrial plants, after appropriate treatment, may be innocuous. Food-processing industries that discharge the residuals of readily biodegradable organic materials are in this category. On the other hand, the revolution in synthetic chemicals has resulted in their extensive use in industry, both in connection with their own manufacture as well as in the processing of other materials.

It has been estimated that some 500 new chemicals are developed annually in the United States. It is clear that identifying them, let alone controlling them, is a task that we in this country have not yet begun to address seriously. Some of these chemicals have been identified

as being carcinogenic, mutagenic and/or teratogenic. Their significance when ingested from a water supply over a long period of time is generally not known, but there is reason to suspect that they have a serious potential for introducing chronic health damage. Thus, one of the major responsibilities in the location of certain types of industry is an assessment of their possible impact on water quality for drinking as well as for aquatic life and recreation.

Some chemicals have a potential for being magnified in the biological chain. That is, they are absorbed by small species which are the food for larger species and finally they accumulate in fish or in plants that are used by humans as a source of food.

Water Supply Requirements

Industrial water supply requirements vary widely depending upon the industry. Per unit of capital investment, electronics manufacturing will have among the smallest water requirements and accordingly the smallest wastewater disposal problems, while a pulp and paper mill will have among the largest. The latter, together with other large water-using plants, may just not be appropriate for many locations. On the other hand, in-plant attention to the possibilities for recycling may sharply reduce the amount of fresh water required as well as the amount of wastewater discharged.

One of the best instruments available to government for the control of industrial wastewaters is the institution of effluent charges for discharge either into municipal sewerage or into surface waters. Such charges have the effect of encouraging reduction of waste production in plant operations as well as the introduction of recycling of both waste products and wastewater. For example, the wastewater of one process,

with or without some modest treatment, might become the water supply for another. Effluent charges, as well as inadequate supplies of fresh water, encourage practices that have in effect reduced water requirements in major water-using industries by 95 per cent.

Water supply must also be made available for fire protection for the industry and for the other developments established in association with major industry, such as residential commercial and public areas. Whereas the requirements for potable purposes for sustenance of life amount to some two liters per capita per day, the actual requirements for drinking, food preparation, bathing and cleanliness, depending upon the water-using facilities available in the home, may range from a low of 100 liters per capita per day to as much as 500 liters per capita per day. The larger figure generally provides water for the household for use in the watering of lawns and gardens particularly in arid areas.

If an industry is to be located in a virgin area, studies are required to indicate what the supporting population per employee is likely to be and requirements would be based upon providing the total community needs for this total population. Should no provision be made for the supporting population, slums are immediately created and the integrity of the industrial development is seriously threatened. Even if provision is made for housing for employees and their families, some provision also must be made for the service installations to serve the needs of this population. This may include a responsibility for the industry or government to provide services beyond the boundaries of the employees' housing and industrial areas, or supporting a community organization that would perform the same services.

Water Supply and Wastewater Disposal Systems

These systems vary in complexity depending upon the sources of water available, their quality, and the opportunity for the discharge of wastewaters without detriment to the environment. Often, the furnishing of these facilities involves the largest single investment after housing requirements for the community. Costs for complete water service may range from $200 to $600 per capita including the following facilities:

Development of the water source, either by the impoundment of streams by the construction of dams and reservoirs, which represents the highest cost, or the development of wells, or direct pumping from large rivers or lakes which represents the least cost.

The construction of transmission mains from the source to the treatment facility.

The construction of the treatment facility, which may provide only disinfection if the source is of high quality, or which may involve screening, sedimentation, flocculation and coagulation with chemicals, filtration and disinfection.

Storage of water in service reservoirs which should be elevated t provide water for fire protection and water service during power outages and other emergencies.

Distribution systems, often designed to be large enough to provide water for fire protection.

Service lines from the distribution system into the home which would include meters and the plumbing system in the home.

House plumbing for carrying away wastewaters from the house.

Lateral or common sewers to receive household wastes

Main sewers or interceptors to receive the discharges from many laterals.

Wastewater treatment, the degree depending upon the requirement of the receiving stream. Primary treatment, namely, sedimentation of the solids, would generally be a minimum, with secondary or biological treatment often being necessary. In some cases, an even higher degree of treatment may be required, particularly where reuse of the wastewater is intended.

An outfall into the receiving stream or discharge to point of use.

Reference: Pescod and Okun, Water Supply and Wastewater Disposal in Developing Countries, Asian Institute of Technology, Bangkok, 1971.