PN AAA 349

628.5
O'Ild

VOLUME FIVE

Environmental Case Studies

The last in the series of five volumes
on the Environmental Aspects of Development

Prepared by:

International Program on the Environmental
Aspects of Industrial Development (IPEAID)
Department of Environmental Sciences and Engineering
School of Public Health
University of North Carolina
Chapel Hill, North Carolina 27514 USA

1979

VOLUME FIVE

PAGE

-- ENVIRONMENTAL CASE STUDIES --

Carmichael, Jack B. Environmental Considerations in the Planning and Evaluation of Development Projects. Excerpts: "Case Study: Ecological Survey of the Menta River in the Country of Farmington" ..... V- 1

"Hydroelectric Project for the Country of Odi" ..... V- 11

"Case Study: Iron Ore Project in the Country of Edel" ..... V- 21

"Case Study: Nickel Ore Mining and Refinery Project in the Country of Teleroy" ..... V- 29

Mancy, Khalil A. "Water Quality Studies on the River Nile and Lake Nasser" ..... V- 36

Barre, Remi. Energy and the Environment ..... V- 52

Lamb, James C. III. "Guidelines for the Control of Industrial Wastes: #3--Cane Sugar Industry Wastes" ... V- 97

"#5--Pulp and Paper Manufacturing Wastes" V-114

"#6--Metal Finishing Wastes" V-135

World Bank. Manual on General Environmental Protection for the Industrial Sector V-153

Kriz, George J. et al. "Beef Cattle Waste Management Alternatives" V-283

Kriz, George J. et al. "Dairy Waste Management Alternatives" V-327

Kriz, George J. et al. "Poultry Waste Management Alternatives" V-371

Lamb, James C. III. "Guidelines for the Control of Industrial Wastes" V-408

Case Studies: Excerpts from

Environmental Considerations in the Planning and Evaluation of Development Projects[a]

by

Jack B. Carmichael

Case Study: Ecological Survey of the Menta River in the Country of Farmington

I. Introduction

The major motivation for this survey is that a proposal is pending to locate the first pulp and paper mill in Farmington in the vicinity of Temer Falls on the Menta River.

Pulp and paper mills produce substantial volumes of chemical-laden effluents which can poison the water for biota or human users and degrade its quality for other industrial or agricultural users. A French newspaper recently called the paper mills "the veritable cancers of the Swedish environment."

The ecological survey reported here originated from the consciousness of the government of Farmington that the overall economic benefits of such an industrial plant might be reduced if there is a negative pollutional impact on the environment in the Menta River Basin. Thus it was deemed desirable to assess the present ecological balance of the river environment and the impact which pollutants could exert on it.

The following terms of reference were established for the survey:

i. A chemical, physical, and biological analysis of Menta River water and water life will be carried out from Temer Falls to the mouth of the Menta 157 km. away. A similar analysis will be carried out at Lake Constan in the vicinity of where it receives the Menta discharge.

---

[a]A monograph published by the Organization of American States, Washington, DC, 1974.

ii. There will be a survey of all vegetation on the river shores.

iii. To the extent possible, a census will be carried out of those wildlife which are dependent on the river for water.

iv. The present pattern of human consumption of Menta River water will be determined, along with estimates of present and future requirements for such uses.

v. Other projected water needs presently contemplated in the development of the watershed will be considered.

II. Methodology

A. The Aerial Survey.

A limited aerial survey was carried out over the entire course of the Menta River from Temer Falls to Lake Constan.

B. Ground Surveys.

Ground surveys were concentrated on selected parts of the river. Sixteen study areas (stations) were surveyed along the course of the Menta. Two stations were upstream from the proposed site of the pulp and paper plant (the vicinity of Temer Falls). Thirteen stations were downstream from the falls, and one was located in Lake Constan. Since hydrobiological techniques and measurements require several hours work, an average of two stations were studied per day by a two man scientific team. Six stations were chosen near major bridges or ferries. The rest were in the rural hinterlands with difficult access by land rover.

Vegetation profiles were taken at each station in both parallel and perpendicular directions to the bank. Plant species were identified. Land use practices were noted and the density of livestock and humans was estimated. Birds and other animals were observed but there was no trapping of small riverbank mammals.

The following water quality measurements were carried out at the field stations:

1. Temperature (measured by a bulb type thermometer or thermister probe).

2. Dissolved oxygen content (measured by probe as percent saturation).

3. Specific conductivity (measured with a portable conductivity bridge). For practical purposes, this is equivalent to total dissolved solids. See Appendix B, p. A-8.

4. pH, or hydrogen ion concentration (measured by a colorimeter).

5. Total alkalinity was measured by titration. For background, see Appendix B, Explanations of Common Water Quality Parameters.

The following biological samplings were carried out:

1. Invertebrate bottom fauna, usually collected from stones situated in rapids.

2. Fish were caught using a 20 mm mesh gill net and were preserved in 4% formalin.

Hydrological analyses included streamflow and velocity data. Existing data records were utilized.

III. The Menta River Environment

A. The Basin.

The Menta River drains an area of 13,000 km^2 which includes plateau areas and rolling hills. The river flows through the northern part of Constan Swamp to enter Lake Constan about three miles south of Constan City.

The Menta has a drainage area of 9000 km^2 below the proposed pulp and paper mill site in the vicinity of Temer Falls. Three important tributaries enter the Menta between the falls and the mouth. The average flow of the Menta is 3 billion m^3/year.

B. Nature of the River Channel.

Where the river leaves the foothills of its source the channel has a gradient of approximately 1% (10 m per km.) This decreases to about 0.6% in the vicinity of Temer Falls. Below the falls, the gradient decreases to about 0.3% 70 km. from the mouth. By the time the river has reached the swamp prior to entering the lake the gradient has decreased to 0.06%. The flow gradient of the channel changes frequently in short reaches throughout the course of the river.

Generally the flow is fast and highly turbulent with a high capacity for reaerating organic wastes. Even between major rapids the river has a high velocity. Standing waves are common and the aeration is great. The river becomes sluggish only in the lower alluvial section near the mouth.

At Temer Falls, when the river is at mean annual flow of 1500 cfs, the average velocity is 3 feet/sec. When the discharge of the river declines to 200 cfs, the average velocity is only 1 foot/sec. Flows of 200 cfs or less occur on 12 days in an average year.

C. Geology.

At Temer Falls the river begins a southwesterly course for many miles over granite outcroppings. Below the first major tributary, the Menta flows through banks of siltstone, pebbles, and sand.

The Menta flows in a mature valley with many rapids. There are unmistakable signs of rejuvenation due to earth movements in the escarpment which runs along the valley. In most parts of the surveyed areas the river flows swiftly over rocky beds which are being cut deeper.

D. Soils.

Just below Temer Falls the Menta flows through an area of well drained red loamy soil. Further downstream there is a section of black to grey clays which is gradually replaced by brown clay loams. Both show signs of impeded drainage. Near the mouth of the river there are sandy soils.

E. Rainfall.

The average annual rainfall amounts to about 1000 mm at the river mouth and 1500 mm at Temer Falls. The rainfall is seasonal. Roads and lands are dried out and dusty during the four months of the dry weather.

F. Population.

The Menta River below Temer Falls flows through a countryside inhabited by 100-200 persons/km^2 on both sides of the river. Thus 32,000-64,000 people populate the lands within 1000 m from the river.

G. Most of the course of the river is flanked with traditional subsistence agriculture, mostly maize. There is a 20 km stretch of mostly rangeland. The tributaries in the mountains flow through forests.

IV. Results of the Field Studies

A. The Aerial Survey.

The Menta River has a very low flow at the end of the dry season. The Temer Falls appeared like small trickles in an empty stream bed. The river was observed to be between 30-40 m wide during most of its 160 km to the lake. There are 75 major curves as the river winds its course. Ten rapids were evident and many islands.

More than a dozen large fish weirs were built across the river, some 100 km. above the mouth. This is evidence for large scale fishing and fish migration up the river.

The Menta flows through a man-altered environment. No riverine forest exists at all. Human settlements, fields, and pasture lands often extend right to the river bank itself.

Most of the population in the river area is located on higher elevated areas several hundred meters away from the river. This pattern is presumable due to floods and mosquitos.

At the mouth of the river many fishing nets, boats, and traps were observed. The yellowish color of the Menta is recognizable and distinct for at least 500 meters into the lake.

B. The Ground Survey at the Stations.

To illustrate the kinds of data gathered, results from selected stations are reported.

Station 3

The location is 500 m below the Temer Falls bridge, 157 km above the river mouth. Altitude at this point is 1,450 m.

The area around Temer Falls is densely populated. Building and road construction is going on and there is a mining of sand from the river bank near the bridge. There is very little undergrowth and generally thinned out vegetation. This is due to heavy grazing pressure and the daily movements of cattle.

Cultivation is frequently carried out up to the edge of the river bank. In most cases a strip no wider than 10-50 meters is left uncultivated. Some natural vegetation is found along these strips, but is heavily grazed by livestock. Soil along the river at this point is silt and sand with few alluvial deposits. There is a rather high rate of soil erosion.

Eighteen different species of bottom fauna were identified. Micronecta (21 samples), chironomidial (18 samples), and ecdyonuridae (10 samples) were the most abundent. The wide variety of species indicates an undisturbed natural environment and an absence of pollutants.

Water analyses were carried out from the bank. Data are shown in Table 1 following the discussions of the stations. The waters were completely oxygenated, had a nearly neutral pH of 7.3, and showed a very low concentration of dissolved salts. No evidence of pollutants was observed.

One hour of fishing with a 20 mm mesh net of 33 m length and 1.5 m depth yielded a total of 5 fish of 3 different species ranging in size from 7.9 to 12.9 cm.

On the left bank of the river there were many large boulders and pools of water which were separated from the river. Persons from the nearby village were draining water from the pools in

order to catch fish. Another group of women worked to separate a side bay from the main river by constructing a mud dam. Other women used pots and bowls to drain the water from this artificially created pool. At the end, two dozen people jumped into the empty pool to hunt for fish. What a joy when five 20 cm. catfish and 4 10 cm. tilapias were caught!

Section 8

The location of the station is at Kaplan Bridge, 60 km. downstream from the proposed pulp and paper mill. The neighborhood of the bridge is overgrazed, burnt, and poor in tree cover. Just below the bridge there is a succession of sugar cane fields which border the bank.

Three years from now a large sugar factory will be completed. This factory will require large amounts of river water for its operation.

The fishing net was set for one hour. Four catfish ranging from 10.2 to 16.1 cm. and 4 tilapias ranging from 8.3 to 12.9 cm. were caught.

To the human eye the Menta is unchanged from its appearance at Station 3 - no larger, no dirtier, no cleaner. Water analyses (see Table 1) showed the waters were 95% saturated in oxygen, contained few dissolved salts, and had a nearly neutral pH of 7.4. The yellowish color of the Menta is apparently due strictly to the sediment loading.

Twelve species of bottom fauna were observed from the samplings. Ecdyonuridae (12 samples) and macronema sp. B. (10 samples) were the most abundent. This diversity of species again confirms the lack of pollutants in the river.

Station 9

This station is located at the juncture of the Elio River with the Mensa, 70 km. downstream from the paper mill site and 10 km. downstream from the proposed future site of the sugar factory.

Here the most natual and scenic area of the surveyed area of the Mensa was found. The river flows through a narrow valley with steep hills rising on the left bank. The stream flow is swift through rapids of granite boulders.

Few people were observed. A family was seen washing themselves in the river. The man explained that they lived some two km away but came often to bathe. He said that they liked the good water of the Menta very much.

Two large wooden fish weirs were the only permanent signs of human activity. A zone of 150 meters width is untouched along

both banks. Obviously there is no high grazing pressure. More indigenous vegetation is found here than at any other study area along the Menta, including some beautiful orchids. Furthermore, the only colony of the white-necked pratincole known to exist in Farmington is found here on the rocks in the river.

A dozen common plant species identified included wild apple trees, wild date palm, and a wild reed widely utilized for handicraft work.

Because of the well preserved natural envirionment, this area is important from a scientific and an educational point of view.

Water analyses again revealed a supersaturation of oxygen. The pH of 7.6 is very slightly more alkaline than upstream. The increase is probably due to natural causes-changes in soil characteristics, for example. Data are shown in Table 1.

Eleven species of bottom fauna were collected. Most abundent were Ecdyonuridae (12) and Macronema sp. B. (10).

Station 15

This station was located in the mouth of the Menta River, 157 km. from Temer Falls and the proposed paper mill and 97 km. downstream from the future sugar factory. The elevation at this point is 1,130 m.

The Menta here is a 40 meter wide stream with a maximum depth of 4 meters. It is yellowish in color, similar to the color of the upper reaches of the river. The mouth of the river is almost devoid of any kind of water plants. For that reason, it flows with quite a strong current into Lake Constan.

Some two km. from the mouth of the river the lake abounds in aquatic vegetation, especially papyrus. Wild reed, antelope grass, water lettuce and nettles are other common plant species found here.

The mouth of the Menta is full of fish. Many fish were caught within 5 minutes after placement of the net. Mullet, catfish, and tilapias abound. Several kingfishers were observed fishing at the mouth of the Menta.

Water quality data were obtained from midstream. The river was found to be 90% saturated with oxygen and a pH of 7.7. These and the other water quality data indicated a very slight lessening of water quality in the mouth of the Menta compared to the upstream reaches. Water quality here would be classified as very good based on these limited analyses.

Table 1 - Water Quality Analyses at the Stations

	Station 3	Station 8	Station 9	Station 15
Day	3/25	3/27	3/30	4/2
Time	13:00	17:30	11:45	14:30
Temp., °C	22.8	24.2	25.2	27.2
% Oxygen Saturation	106	95	103	90
pH	7.3	7.4	7.6	7.7
Specific conductance, micro-mhos/cm.	135	137	140	150
Alkalinity meq/l.	1.5	1.5	1.55	1.6

These data reveal an unpolluted stream which is easily able to assimilate the present small waste loading that is received from the human population and animal population. The slight increase in specific conductance probably indicates an increase in ions due to materials in the increased sediment loading as one moves downstream.

IV. Water Pollutional Aspects of the Mill

According to the information received by World Wide Paper Mills Ltd., the output of their proposed sulfate pulp mill will be 125 tons of Kraft pulp per day. At full capacity the factory will have a water demand of 20 cfs. This is 10% of the low flow which occurs on 12 days of an average year. Much of the industrial water will be recycled for use within the plant.

The major portion of the pollution from paper making originates in the pulping process. When the wood is received, the bark is removed and the wood is reduced to chips by grinding. Chips are then converted to pulp after a chemical preparation, called cooking. In the kraft process, the wood chips are cooked in either batch or continuous digesters with a mixture of caustic soda and sodium sulfide.

The wastewater produced from this process contains suspended solids, dissolved solids, color, odor, specific chemical residues, and, in general, a high loading of wastes which will consume the oxygen of the waterway. (See Appendix A-2, An Explanation of Common Water Quality Parameters).

The requirement of oxygen for degradation of the wastes is called the biochemical oxygen demand. It is a good single measure of the pollutional loading of these wastes. An organic waste loading to a stream is gradually assimilated through oxidation by the bacteria present. Oxygen must be provided so that the bacteria can grow and oxidize the waste materials. A waste loading on the stream thus depletes the oxygen present in the stream. High concentrations of dissolved oxygen are therefore a good indication of a healthy river, whereas low concentrations are an indication of a polluted river. Dissolved oxygen is essential to stream life. Total consumption of the dissolved oxygen by wastes results in a dead river.

On the average, the kraft pulping operation is known to produce about 40 lbs. of BOD in the effluent per ton of pulp produced. Thus the total BOD generated by the World Wide Paper Mills plant will be about 5000 lbs. of BOD/day.

A water pollution expert has recently completed estimates of effects of given BOD loadings at Temer Falls on the levels of dissolved oxygen at Station 8, Kaplan Bridge. This is the site of the proposed future sugar plant. Results of the calculations appear in Table 2.

Table 2. Effects of Pollutional Loadings at Temer Falls on Dissolved Oxygen Levels at Kaplan Bridge (calculated through measurements of the reaeration capacity of the river).

	Calculated Dissolved Oxygen, % saturation	
# of lbs. of B.O.D./day	mean annual flow 1500 cfs.	low flow for 12 days of ave. year 200 cfs.
500	96%	90%
1000	90%	80%
5000	70%	50%
10,000	40%	10%

A pollutional loading of 500 lbs/day can be assimilated by the stream with no effects upon the present uses.

A pollutional loading of 1000 lbs/day would render the river unfit for drinking at least as far as Kaplan Bridge. The river would be unsuitable for use by the sugar plant during the 12 or so days of low flow in a given year.

A pollutional loading of 5000 lbs/day would render the river unfit for drinking and unsuitable for use by the sugar plant without pretreatment. Some damate to the biota of the stream would occur during the periods of low flow.

A pollutional loading of 10,000 lbs/day would cause the effects listed above but would still permit the survival of many species of fish except during periods of low flow. Severe damage to the biota would occur and few if any fish would survive. Fish populations could be expected to remain depressed for substantial periods of time following periods of low flow in the river. Effects of this level of pollutional loading would remain substantial all the way to the mouth of the river. Some effects on the ecology of Lake Constan would be expected.

As mentioned, the pollutional loading of the untreated wastes from the pulp mill will be 4000 lbs/day. World Wide would like to consider doubling the capacity of the plant in ten years, which would increase the effluent loading to 8,000 lbs/day.

Various means are available to treat these wastes. More efficient treatment methods are more costly.

Primary treatment involves allowing the wastes to settle in earthen basins prior to discharge. This treatment removes about 50% of the BOD loading at a cost of about 50¢/ton of kraft pulp produced.

Secondary treatment involves oxidation in storage lagoons for extended periods of time. This treatment removes about 75% of the BOD and costs about $1/ton of kraft pulp produced.

Secondary treatment by mechanical treatment plant involves oxidation of the wastes by mechanical agitation in a reactor. This treatment removes about 90% of the BOD and costs about $2/ton of kraft pulp produced.

Tertiary treatment involves secondary treatment by mechanical plant followed by lime addition and filtration through activated charcoal. This treatment removes about 95% of the BOD and costs about $4/ton of kraft pulp produced.

The company expects to realize a profit of $20/ton of pulp produced, and has indicated that a profit reduction of 5% is all it wishes to sacrifice due to pollution abatement costs.

Case Study: Hydroelectric project for the Country of Odi

Project Description

The Odi hydroelectric project will develop power from El Rio Caballo. A rockfill dam 85 m high by 800 m crest length will be constructed. The project will also consist of a spillway, intakes and pressure tunnels, surface powerhouse with two 70 MW turbogenerator units, and a switchyard connecting to a double circuit 115 Kv line to Odiville, capital of Odi.

The dam will form a reservoir with the following dimensions at its maximum operating level: Surface area of 150 km^2; length of 40 km. upstream from the dam site; storage of 1.5 billion m^3 within the operating limits of 15 m vertical drawdown plus 0.75 billion m^3 reserve storage.

The entire watershed of El Rio Caballo and its tributaries suffers a severe six month dry season. Reservoir levels will therefore fluctuate greatly and a 15 meter drawdown is anticipated during the dry season.

Justification for the Project

During the past ten years, energy consumption in Odi has increased annually by 10%. The forecasted annual growth rate for electricity demand is also 10% through 1985. There is a present sufficient installed generator capacity in Odi to meet the demand only until 1975.

The completion of this hydroelectric project in El Rio Caballo plus two other planned power generation projects in other parts of Odi will enable the country to meet its projected power needs through the late 1980's.

The project will provide employment of unskilled labor for up to 1500 people per year during the construction period of the project.

Environmental Impact Assessment

Human Ecology

The major impact of this project will be on peoples who must be relocated. For background reading on this subject, see the paper "The problem of population resettlement in reservoir projects in Africa. Cultural and human ecological factors and the need for adequate resettlement planning." Ten thousand people live in the area to be flooded and will be forced to abandon their homes. An adequate resettlement plan has not been developed. Such a plan will be necessary and must include the components of relocation, employment, and community development.

Watershed Management and Sedimentation

The problem of expected sediment buildup in the reservoir is the environmental impact expected to be next largest in magnitude. Quantitative studies of erosion and siltation in this portion of El Rio Caballo watershed are absent, but a high siltation rate into the new reservoir is expected. An existing dam in the same region in Odi is receiving sediment at a rate which will fill the reservoir in 20 years. A watershed management/reforestation plan is necessary to monitor and reduce erosion and siltation and improve the resources of the project area.

Vegetation

There are neither rare plants nor especially valuable tracts of vegetation in the area to be flooded.

An expected large impact will be growth of aquatic vegetation in the reservoir and an adequate program of control will be required.

Animals

No rare animals exist in the area. Various mammals may be trapped by the project flooding. A contingency plan is needed for their rescue and transport to new habitats.

There is a plan to develop a substantial commercial and sport fishery in the new reservoir. The reservoir is expected to become a popular habitat for waterfowl.

Archaeology

The Government of Odi has reported no known archaeological sites within the affected area. However the area is poorly known archaeologically. Through a cultural exchange program, the government of Odi plans to bring in visiting archaeologists to help inventory the area and develop contingency plans to protect any valuable artifacts which are unearthed.

Public Health

The waters which will drain into the new reservoir presently carry a heavy loading of raw sewage. Reducing the quantity of raw sewage entering the reservoir will reduce the incidence of fecal-oral transmitted diseases, such as hepatitis.

The project is expected to lead to an increase in malaria. This should be checked through a program of vector habitat destruction, chemotherapy, and isolation of victims.

Waterweeds should be controlled to reduce disease vector habitats.

Detailed Environmental Analysis

A. Human Ecology

The benefits of a development project are usually assessed at the national level. However, benefits should extend to a maximum number of individual citizens as well. People are a country's most valuable resource.

Necessary considerations for the Resettlement Plan for the Odi Hydroelectric Project are the following:

1. A complete census of people displaced by the project should include an inventory of work skills.

2. Relocation.

a. Suitable areas must be obtained and plots assigned as soon as possible. All the families of this area need a backyard in which to raise chickens and harvest fruit trees. An objective should be to allow time for the clearing and planting of the backyard so that food trees are bearing by the time the move occurs.

b. There are compelling reasons for a formal resettlement program organized by the government of Odi. There may not be enough plots available privately for sale or lease to accommodate all the displaced people. Furthermore, the value of these plots would rise in value due to scarcity, putting them above the amounts paid to the displaced citizens for indemnification. The region is already overpopulated, and natural resources are scarce. Many plots will not yield enough timber to construct buildings.

c. A formal relocation program is therefore essential. Every family unit should receive a plot of sufficient size to support the family.

d. Expert planning assistance is needed from a sociological community development specialist and an agricultural extension expert. Some input from an economist, a watershed management expert, and an ecologist may also be necessary.

3. Employment.

Immediate employment opportunities should be offered the displaced persons either on the dam construction project or the recommended environmental protection program of erosion control and reforestation.

4. Unplanned land use.

In an overpopulated region, people may be expected to concentrate near a development project. Impoverished squatters will

begin to arrive and settle in the area to be flooded in the hope of receiving some indemnification. This is already occurring at the Odi site, where squatters have established a settlement just outside the boundaries of the construction camp.

a. The government of Odi should impose a moratorium on, or require permission to be sought for, all property transactions in the area.

b. A plan should be developed to integrate unplanned arrivals into the work programs of reservoir site preparation and reforestation.

B. Watershed Management and Sedimentation Control

1. Stream protection for the tributaries.

A program is recommended for revegetation of banks and construction of rock barriers, revetments, and other necessary measures to reduce erosion and siltation in the tributaries.

2. Reduction of sheet erosion on slopes.

Slopes which drain into the watershed or directly into the reservoir often show substantial erosion. Stone walls constructed in fields within the project area frequently show one meter or more accumulation of soil on the uphill side after a year or two.

3. Drainage areas susceptible to gully erosion should receive special attention. Gullied road cuts should be stabilized by means of vines or grasses.

4. The government of Odi should acquire a 100 meter strip of land surrounding the reservoir. This land should be managed for watershed protection.

5. Reforestation is an effective means of watershed protection. Trees capable of tolerating severe dry seasons should be planted and maintained. A rational sustainable harvesting plan should be established.

6. The government of Odi should establish a regionally administered extension program to reduce burning, overgrazing, shifting agriculture, and other bad practices in the watershed.

C. Construction Activities

1. Borrow areas for aggregate, rock fill, sand, and other construction materials are nearby. Transport roads will not signifiantly contribute to environmental degradation of the area. Use of the borrow locations will not destroy any special environmental features. Customary industrial protection measures for noise and dust pollution control must be complied with. Otherwise no problems are envisioned.

2. Engineering environmental protection plans.

a. There should be a plan for restoration in the borrow area and minimizing erosion.

b. The topsoil is a scarce and valuable resource in the project area. All topsoil scraped off during construction should be stored for replacement or reuse.

c. When practicable, quarries or sand pits should be exploited as fish ponds or recreational areas.

3. Clearing most of the area to be flooded is strongly recommended. Another reservoir built 20 years ago in Odi was not cleared of trees beforehand. These trees are still present, show little signs of decay, are a hazard to navigation, interfere with fishing, and increase susceptibility to buildup of waterweeds.

D. Project Operation

1. Drawdown schedules should be developed in conjunction with fisheries experts. Many fish depend on shallows at the waters edge for food, shelter, or reproduction. Drawdown at an unpropitious time could kill all reproductive stages of certain fish species.

2. The reservoir will regulate flows downstream and reduce the frequency of flooding in the lower Caballo Valley. Flow augmentation will vary from 70 cu. m./sec. to 140 cu. m./sec. during the dry season. These well regulated flows should be exploited for irrigation of fertile valley land.

E. Vegetation

1. Terrestrial.

There is no undisturbed natural vegetation in the project area. In an earlier era, the area was forested. Much of the area to be flooded is planted in sugarcane, maize, and sorgum. There is some rotational pasture land.

Near the proposed reservoir site there are some small and isolated patches of vegetation which contain a higher density of trees and more species of trees than the project area. These patches can provide seeds for the reforestation program and should be carefully conserved and protected.

2. Aquatic

A heavy growth of waterweeds should be expected and a control program should be planned from the earliest stages. The water hyacinth (Eichhornia crassipes) is the most waterweed found in this area and will be the greatest threat. Cattle cannot control this plant even though they feed upon it, because they generally eat only the tops.

The waterweed second in abundance in the project area is water lettuce (pistia stratiotes). Floating fern (salvinia auriculata) has been observed in heavy abundance at other reservoirs in Odi and may be expected in this new reservoir. Hornwort (ceratophyllum demersum) is an inconspicuous plant because it floats beneath the surface of the water. However, the dense, rootless spheres of the hornwort can accelerate the deoxygenation of a water body. These waterweeds have occurred in dense growth in two other reservoirs in similar geographical regions of Odi. A heavy growth in this project should also be anticipated.

The several adverse effects of heavy growths of waterweed are listed below:

a. Floating aquatic plants increase the surface area from which water is lost from a reservoir. If such plants cover wide areas, evapotranspiration can cause a serious loss of water, especially in the seasonally dry climate of the project area.

b. Dense mats of waterweeds mechanically interfere with fishing and navigation and occasionally also interfere with the turbine intakes.

c. Waterweed mats contribute to a decline in water quality through reducing the amounts of light and oxygen that can enter the water and by consuming already present dissolved oxygen.

d. A serious health problem is also attendant with mats of waterweed. Surfaces of the mats provide ideal habitats for malarial mosquitos, for example. Roots of the water hyacinth are a habitat for the snails which carry schistosomiasis. This disease has already been reported in Odi, and snails in the same subfamily as the disease carriers have been found in water hyacinth roots in two other reservoirs of Odi.

Therefore a plan should be developed to control waterweeds over an indefinite duration. The government of Odi suggested control through herbicides in its original project proposal. This should not be accepted. Means of mechanical control and removal, habitat manipulation by drawdown, and biological control by fish and insects should be evaluated and incorporated first.

F. Animals

1. Terrestrial.

Population pressures and the destruction of all large forest areas have caused the migration of the extinction of large mammals in this project area of Odi. Presently some racoon, weasel, paca, agouti, coati, and grison are thought to occur within the project area.

Although the project will not endanger any particular mammal, the fauna of the region is generally depleted. Substantial efforts should be made to preserve existing fauna. No hunting or trading in hide or flesh of wild animals should be permitted. Also, all animals trapped by rising waters should be rescued and sent to predestined habitats.

There are relatively few species and numbers of birds presently in the project area due to the absence of wet forest. The existing species are not rare, but should be protected, in part because of benefits in controlling insect pests.

2. Aquatic.

There are many lakes throughout Odi and the country abounds in water fowl. Several species of duck and agret are especially abundent. The new reservoir is likely to develop into a fine stopover for migratory birds.

Migratory fish are already prevented from passing up El Rio Caballo by the presence of another dam. The new project will not change this situation.

A great benefit could accrue to peoples of the region by developing the reservoir into a warm water fishery. Fish is a staple in the local diet, and current fishing yields from El Rio Caballo are decreasing. The government of Odi has envisioned creation of a fishery with an annual production of 500,000 kg of fish and employment of 400 men. These estimates seem over optimistic, but potential exists for a good fishery.

A large and newly created reservoir will often have an initial burst of fish productivity followed by a decline. The process of maintaining a viable and productive fishery over a long time period is a biologically and technically complicated procedure. A surprisingly large fish breeding program is required along with lengthy pilot investigations.

Fish which are presently common to Odi and which could be expected to thrive in the new reservoir include the Tilapias, catfish (Galeichthys guatemalensis), the mullet (mugil), and the chimbola, or top minnow (molliensia sphenops). The top minnow is very abundant and well distributed throughout Odi. Apart from being a reasonable food source, this species can serve a valuable role in mosquito control.

Specific recommendations regarding the establishment of a commercial fishery

1. A fish culture station should be immediately established at the reservior site by the Ministry of Agriculture of Odi.

2. The personnel of the fish culture station should advise on the clearing operation in order to optimize future fishing.

3. The fishery station personnel should be involved in a program of restoration of the lake margin, including reforestation.

4. The station should establish a limnological research program to include studies of algae and invertebrates, especially shrimp.

5. The fish program should emphasize game fish. Work with top feeders for insect control, vegetarians for waterweed control, bottom feeders, and snail feeders should all be encouraged. The many lakes in Odi can provide the breeding stock for this project.

G. Public Health

Diseases expected to increase due to the project if no precautions are taken include hepatitis, malaria, schistosomiasis, and Chagas' disease.

1. Hepatitis.

A recent outbreak of infectious viral hepatitis is causing concern in the National Health Service of Odi. About 10,000 cases are reported annually in the country. Fecal contamination of drinking water is usually responsible for this disease. There is reason for concern over possible future epidemics in the project area because the waste waters from the city of Las Montanas (pop. 400,000) drain directly into the projected reservoir. According to the National Health Service of Odi, these wastewaters are raw and untreated.

2. Malaria.

Malaria is presently endemic to the project area. Although the country reports 50,000 annual cases, there are few deaths. The larva of the Amopheles mosquito vector is aquatic. The creation of the proposed reservoir will increase the breeding habitat of this mosquito. Special preventative measures may be called for.

3. Schistosomiasis.

Presently there are only a few cases of schistosomiasis in Odi. The disease was unreported before 1970.

The disease vector is an aquatic snail through the parasitic blood fluke is passed on to humans. The snails flourish in the roots of the water hyacinth. Since there are snails of the same subfamily flourishing in other waters of Odi, there is legitimate concern that the Schistosomiasis vector would flourish if introduced.

4. Chagas' disease.

Chagas' disease is a potential and not an actual problem in the project area. About 300 cases are annually reported in Odi. The vector is the bloodsucking triatomine bug. The use of mud, adobe, and thatch must be restricted in the project area in order not to afford habitat to the bug.

Public health recommendations

1. The National Malaria Control Service of Odi should assign a small permanent detachment to the new reservoir project. This detachment can collaborate with other groups to reduce and destroy breeding sites and encourage programs to stock larval-eating fish. The unit should stock free chemotherapeutics and be prepared to offer free treatment to a sizable number of cases.

2. A full Public Health Clinic might be justified for the project area, of which the Malaria Unit would be a part. Clinical staff would be on the alert for symptoms of all four of the major diseases and would provide free care to anyone.

H. Archaeology

According to the Ministry of Cultural Affairs of Odi, there are no known archaeological, historic, or otherwise noteworthy sites in the project area. However, the area is poorly known archaeologically. Through a cultural exchange program, the government of Odi plans to bring in visiting archaeologists to help inventory the area and develop contingency plans in case valuable artifacts are unearthed.

A valuable ruins of an anchient community at Aguas Calientes lies just outside the area to be flooded. The government of Odi has developed a plan to protect and inventory this area.

I. Scenic and Aesthetic Qualities of the Reservoir

The new reservoir will have a prolonged 15 meter drawdown during the dry season. This will expose unattractive and probably pungent mudbanks. The drawdown will make access to the water difficult. However, the seasonally exposed banks will be beneficial in establishing a waterfowl santuary.

Water quality in the reservoir is expected to improve with the better watershed management practices, but the reservoir will be at least initially turbid in some parts.

There are other rivers in this area of Odi with attractions similar to that which will be flooded. No noteworthy waterfalls, gorges, unusual geological formations, or caves are likely to be affected by the project.

The presence of a clean lake amid the rugged mountains of the area will enhance the attrativeness of the region.

J. Tourist Potential

There are many large and medium sized natural lakes in the country of Odi. The additon of another large lake will not add greatly to the attraction of tourists. The proposed fishery development will ensure much sport fishing opportunity.

The government of Odi should carefully designate sites for picnics, camping, bathing, and (non-power) boating. These activities should be managed so as to be compatible with water quality control, watershed management, power generation, and gocd health conditions.

Case Study: Iron Ore Project in the Country of Edel

Project Summary

The project involves the exploitation of large quantities of high grade iron ore in the interior of the country at a site called La Teirra de Fierro. The ore will then be transported by rail to a terminal to be located at the ocean port of Baja Linda. There it will be transferred onto large half-million ton combination oil/ore boats for transportation to the world markets.

Environmental Impact Summary

The area which stands to suffer the greatest environmental impact unless proper precautions are taken is the Bay of Baja Linda. Baja Linda is a largely unspoiled bay of great esthetic beauty. The small town of the same name is located on the bay. The attraction of the bay causes the population of Baja Linda to swell from 3000 permanent residents to 15,000 during the summer months. The Bay of Baja Linda also supports important shellfish and finfish commercial fishery.

Studies of the currents and tides show that the bay does not readily flush itself of impurities. Accumulation of oil and other discharged pollutants is likely to occur. If the oil/ore boats clean their holds with detergents, the discharged mixture of oil/detergent/water could prove toxic to large areas of shellfish and begin a process of ecological deterioration of the bay.

Other environmental impacts considered at Baja Linda were the proposed 2 km. rail trestle which would cross the bay to an island-based marine ore loading terminal, and the total impact of the project on tourism development.

Environmental impacts associated with the mining site and rail transport of the ore are considered to be less severe. These are discussed in detail in the text.

Alternatives to Mitigate Environmental Impacts at Baja Linda

The following agreements to mitigate environmental impacts at Baja Linda were achieved through negotiations with the borrower (the Govt. of Edel):

1. A safe procedure was established for handling the slops (the oil/detergent/water mixture) from the ships' holds.

2. An improved navigation system for the oil/ore boats was designed to prevent accidents.

3. A contingency plan with standby equipment was established to better preserve the esthetic qualities of the bay.

4. A plan was established for dust control from the ore.

5. Plans for solid wastes handling and sewage treatment at the ore terminal were developed.

Detailed Project Description

The Government of Edel requested a loan from the World Bank to finance a project for mine and export 10 million tons of iron ore per year from a large deposit in the interior of the country at a site called La Tierra de Fierro. Once extracted, the ore would be shipped by rail about 200 kms. to the seaport of Baja Linda. A new marine terminal would be constructed on an island in the bay to receive the ore and transfer it to ocean-going vessels. The terminal design would enable it to handle vessels up to a half-million tons.

Transfer of the ore from the mine to the terminal will be provided by the state-owned railway system, Los Ferrocarriles de Edel.

The iron reserves in La Tierra de Fierro are high grade and substantial. The deposit to be mined contains 500 million tons of ore with an average iron content of 70%. Other deposits nearby contain another 500 million tons of ore. The deposit has very little overburden and is well suited to the planned open pit operation.

Economic justification for the project is substantial. World iron ore prices are firm, after an earlier depressed period during the 1960's. World iron ore demand is expected to require an increase in annual production of 40 million tons each year throughout the 1970's.

The Government of Edel has already obtained long term sales contracts for 90% of the initial iron ore output of the project. An expected return to the Government of 20% has been calculated at a sales of 10 million tons per annum. Even under the adverse conditions of increased operating costs and price erosion the economic return should not decrease below 12%.

The average net foreign exchange benefits to the Govt. of Edel are expected to range between US $50 millions and $75 millions annually.

A. The Mining Plan

The orebody at La Tierra de Fierro is massive and outcropping. Thus it is well suited to open-pit mining and has a quite favorable stripping ratio. Conventional hillside open-pit mining methods will be used. Ore and waste will be drilled, blasted, and loaded by shovels into trucks for haulage to the processing plant or waste dumping sites. The mining will occur over 3

shifts operating 6 days per week. About 12 million tons of crude ore will be extracted to produce 10 million tons of salable ore.

B. Ore Preparation

The ore preparation plant will consist of primary crushing, screening, secondary crushing, final screening and washing, and hydraulic classification facilities. The plant will be designed to process 15 million tons of crude ore per year with provisions for future expansion.

About 80-85% of the ore mined will emerge from processing as salable ore. The remainder, consisting of very fine material, will be stored in hopes of developing a future market.

C. Overland Import

The ore will be transported the 200 km. to the port of Baja Linda via a commercial railway system which presently exists and is operated by the government railways, Los Ferrocarriles de Edel.

D. Ore Transfer

Transfer of the ore will occur at an ocean terminal to be constructed on a small island about 1 km. off the coast in Baja Linda. The site was selected from various alternatives after weighing the various technical and economic factors, including feasibility of transport.

The terminal will receive and unload unit trains of iron ore, provide stockpiling facilities, and load oceangoing vessels of up to a half million tons. Linkage with the mainland will be through a railroad trestle 2000 meters long.

The ore transfer operation has been designed to be easily expandable to double the present annual capacity.

Environmental Impact Analysis

A. The Mine Site

1. Dust created by mining operations at La Tierra de Fierro is not expected to cause major problems. Blasting will cause considerable dust and flying rock for brief periods. The blasting will occur so infrequently, however, that the impact is expected to be negligible. Drills will be equipped with dust collectors and will be essentially dust free. Dust will be caused by traffic on haul roads. This will be minimized by sprinkling. The main access roads around office areas will be paved.

Dust from transfer operations will also be minimized. The mined ore will be transferred by truck from the mine to the

crushing plant. The plant will be equipped with dust collectors connected to hoods at the feeder and crusher. If necessary, water sprays will be used on the feeder discharge and ore conveyer. Water sprays will be used to control dust on the open piles of ore stored after crushing.

2. Tailings from the processing operation require proper disposal. These tailings will consist of a slurry of fine hematite sand and slimes. The slurry will be thickened by passing through a cyclone and the reclaimed water will be reutilized in the process. The final slurry will be stored in a pond formed by damming up a valley behind the plant. The plan is to recycle pond water to the processing plant. To accomplish this, a synthetic polyelectrolyte flocculant will be utilized to clarify the pond waters. Overflows will then be passed through a filtering dam prior to reuse.

3. Processed ore will be stored in an area with a system of underdrains. Drainage water will flow to the process water reservoir. Piles in storage for long periods in the dry season will be sprinkled periodically. Bucket wheel excavators will dig into the pile and mix the underlying damp material with any dry surface material. The bucket wheel excavators will discharge to conveyros, bins, shuttle conveyors, and to a continuously moving train.

4. Erosion in the mining and processing areas will be minimized by fitting lined ditches into the top and base of cuts. Cuts will be designed to minimize the area exposed to surface water. Sediment carried by the runoff and drain streams will be deposited by siltation in the process water reservoir.

5. Reforestation will also be employed to control erosion at the mining site and to minimize the visual impact of the mining operation.

6. The nearby city of El Fierro Grande is located on the opposite side of the mountain from the mining operation. Thus the inhabitants will not directly view the mining operation.

7. Sanitary wastes from the various facilities will receive treatment in an aerated sewage treatment plant designed for 1000 people.

8. The water supply system will be constructed for the project. A reservoir will accumulate natural runoff behind a dam to be constructed below the plant.

B. <u>Ore Transport Overland</u>

1. Noise will be a major problem. The roar of 3000 hp locomotives, signal whistles, screaming of loaded ore cars on curves, and the rumble of empty cars returning will frequently exceed the 80 db. level commonly set as tolerable.

When the ore processing plant operates at capacity, twelve trains daily of 100 cars each will be required. Los Ferrocarriles de Edel have proposed welded track and muffled locomotives to lessen the noise. Even so, the passage of trains at night would disturb the sleep of persons in villages along the right of way.

2. A hazard to pedestrians will be introduced if trains are restricted to daylight hours to eliminate disturbance to sleep. The tracks run along the coast for the last 100 km. before Baja Linda and many people cross these tracks to visit coastal beaches.

3. Some new railroad construction will be required. Unless controlled, erosion associated with construction could be a major problem.

4. Ore dust can fly from the open cars unless kept moist. Sprinkler systems should be installed enroute.

C. Ore Terminal Site-Baja Linda

A sketch of the site appears on the following page.

1. Presently the Baja Linda area is undeveloped. Ecological investigators described it as the most beautiful they had seen.

2. The most serious existing environmental problem is erosion. This is especially true on the low hillsides of deep lateral soil which have been cleared for pasture. Road cuts and natural washouts from these areas are highly visible.

3. Slash and burn agriculture is practiced but is not intensive. Few environmental problems are presented.

4. The natural vegetation is lush. There exists a variety of species and the growth is dense.

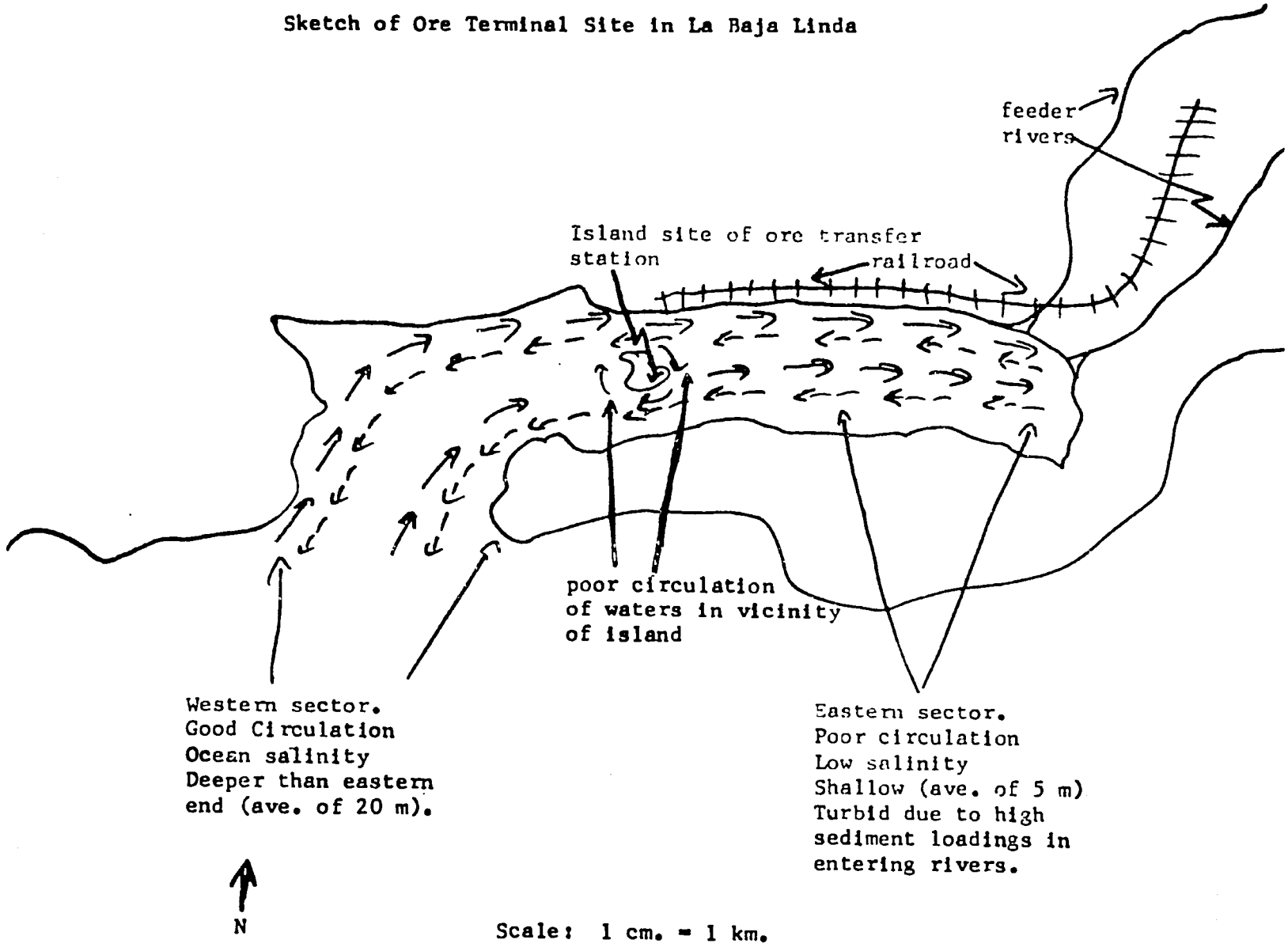
5. There are many lovely sandy beaches with clean white and tan sands.

6. Population density is low and the homes blend pleasantly with the natural environment.

7. The tide flows in the bay have been measured. The circulation pattern is poor around the island which is to serve as the terminal for the ore boats. Any waterborne wastes or pollutants emanating from the ore terminal would tend to circle around the island and would not be well dispersed.

8. Presently there is an extensive fishery in La Baja Linda. The principal species caught is shrimp. A dozen species of fish are taken, including corvina and catfish. Virtually all

Sketch of Ore Terminal Site in La Baja Linda



Scale: 1 cm. = 1 km.

of the species taken are known to be highly dependent, as juveniles, on the estuarine environment of the bay. Probably they migrate to the deeper western end or to the ocean to spawn. Habitat alteration in the shallow eastern end by pollution or filling will reduce the productivity of the bay for fish and shrimp.

About 200 metric tons of shrimp are harvested annually from the eastern end of La Baja Linda. The worth of this catch is about $US 250,000. This figure, plus the value of the fish caught commercially, plus the value of the estuary as a nursery area indicate that this bay is of real value to the commercial fishing industry of the country of Edel.

9. An extensive biological sampling program was carried out throughout the bay to establish the major biotic communities of the project area and their floral and faunal components. For example, 53 species of mollusks were identified.

This sampling has established ecological conditions before the construction and operation of the ore terminal so that benchmarks exist. Changes due to proejct-caused pollution can be quantitatively related to these earlier conditions.

10. The tourism potential of Baja Linda is great. The attractiveness of the area is such that the town of Baja Linda increases from 3000 permanent residents to a summer population of 15,000.

Environmental recommendations regarding the ore terminal facility

1. The site for the ore terminal has been recommended to be based at the southern portion of the island so that it will not be visible from shore. A further recommendation is that no alteration be made on the northeast side of the island by forest cutting or blasting.

2. The face of the excavation on the south side of the island should be provided with broad terraces. These will prevent erosion and encourage natural regrowth of vegetation. The aesthetic advantage will be to help soften the visual impact of the ore terminal transfer site.

3. No signs advertising the project should be permitted except those required by law.

4. The 2 km. railroad trestle will be an eyesore. The trestle and terminal facilities should be painted appropriate soft colors to blend with the sea (trestle) and the island background (terminal).

One possible advantage of the trestle will be to serve as a catwalk for fishermen. This may add to the recreational potential of the area.

5. A plan should be developed to provide solutions to the anticipated water supply and sewage disposal problems that will accompany the increased population in the Baja Linda area due to the project construction. It is specifically recommended that the Government of Edel begin planning now to install a new water treatment plant and a secondary level sewage treatment plant.

6. The Government of Edel should assign an environmental inspector to the project. Such an inspector would have authority to order measures to prevent environmental degradation and, if necessary, to order work halted until remedial measures are taken.

7. The greatest potential for project environmental impact is from oil spills.

a. The possibility for oil discharges within Baja Linda will exist even if prohibited by law. The harbor of Baja de Oro, for example, is located in the adjoining country of Spar. This harbor receives heavy industrial traffic and is now grossly polluted by oil discharges which occur in flagrant violation of existing law.

b. The oil/ore boats have a procedure of washing the oil from bulkheads with water and detergent when switching cargos from oil to ore. At least 10 tons of "slurry" or "slop" is produced from each of the several holds of the vessel. Total discharges of more than 100 tons can be expected.

c. Possibilities for construction of shore facilities to reclaim the oil should be investigated. Alternatively, a law requiring discharge of slop far out at sea should be rigidly enforced.

d. The detergents used in hold cleaning are extremely toxic to marine organisms ad special precautions should be taken to prevent detergent from entering the waters of Baja Linda.

e. A large oil spill in Baja Linda could have disastrous effects upon the ecology of the bay and on the commercial fishery. The problem would be compounded because pollution from the ore terminal would tend to circle the island and not be well dispersed. Effects from a spill would thus linger over a long period of time.

8. Planning should include a modern shoreside facility for solid wastes disposal. Furthermore, close policing will be required to prevent the too common practice of shipside disposal of solid wastes.

9. If a future market is developed for the fine spoil from the mining operation, this should be pelletized at the mine site. Extreme dust problems would be otherwise associated with shipping and processing these fines.

Case Study: Nickel Ore Mining and Refinery Project in the Country of Teleroy

Project Summary

The State-owned mining corporation of Teleroy, Corporacion de Explotacion de las Minas, has proposed a project to mine and refine one million tons per year of ore containing an average of 1.5% nickel. The ore will be mined from a mountainside on the northeastern side of El Lago Capitan in southern Teleroy. The site is about a mile to the north of the processing site and 4000 feet up into the mountains. The mined ore will be trucked down the hill to the processing site.

The refinery will be built on the lakeshore adjacent to the mine. A port will be constructed to receive supplies and export the refined nickel. A 60 MW oil-fired power plant will be constructed to provide both steam and power for the plant. Another major construction associated with the project will be a residential area of 200 homes for plant supervisors.

The ore processing will proceed by crushing the ore followed by rotary drying to 25% moisture. Roasting at 1700°F with sulfur and in the presence of air selectively reduces the iron and produces NiS. The reduced ore is smelted in an electric furnace at 2700°F. The floating slag is skimmed, cooled with water, and disposed. The settled matte contains about 25% nickel. It is transferred in 30 ton batches to a top blown rotary converter with blown air and a sand flux. Another slag is produced. This time the slag sinks and the converter matte is separated by skimming. This converter matte contains about 75% nickel. It is water cooled, granulated, dried, and packaged for shipment. The processing of a ton of ore yields about 50 pounds of final product.

Environmental Impact Summary

Environmental impacts can occur at the mining site, the refinery, a sand mining operation on the shores of El Lago Capitan, the port, and the new village.

El Lago Capitan is an unpolluted lake of about 500 km^2 with an average depth of 15 m. The greatest potential for project environmental impact is deterioration of this lake from a variety of sources. These include wastewater discharge from the refinery, siltation from the sand mining operation and the mine site, accidental spillage at the port, and effluent discharge from the new village.

The refining operation is pyrometallurgical and does not produce liquid process wastes. However a total fo 30,000 gallons per minute of cooling water will be discharged with a 20°F temperature differential over ambient. Also 9,000 gallons per minute of various processing waters will be produced. Some water quality impacts can be expected from the thermal discharge and the (relatively small amounts of) pollutants in the process waters.

The sand mining operation will produce 200 tons of sand per day and is calculated to produce 50 tons per day of silt. This is expected to have a substantial local impact to the southeastern area of El Lago Capitan. Another source of siltation in the lake could occur from erosion at the mine site but is expected to be minimal.

Large amounts of oil will be transported to the port. Sizeable leaks or spills would have a substantial and lasting impact upon El Lago Capitan.

A package secondary treatment plant will be installed to serve the new village. The effluent will be discharged into a stream which drains into the lake.

The impact upon the air environment will be due to the 30 tons of sulfur as SO_2 which will be discharged from the power plant and the converter at the ore processing plant. Filtration and electrostatic precipitation will remove essentially all the particulate matter from exhaust gases of the power plant and the processing operations.

Good methods of controlling erosion and restoration of the mining area will insure that little environmental damage will occur there.

Procedures to Mitigate Environmental Impacts

The following agreements were reached with the government of Teleroy to mitigate various impacts of the nickel ore mining and refining project.

1. An emergency system of boom containment and absorbers will be in place at dockside to restrict and collect any oil spills which might occur.

2. A lagoon will be constructed for the sand washing operation to prevent siltation of the southeastern end of the lake.

3. Process waters discharged from the ore processing and refinery operation will pass through a settling tank prior to discharge to the lake. Suspended solids will settle and oil will float on the surface and can be removed by skimming. Little cooling will occur due to the short residence time.

4. Two air sampling stations will be located to the east and west of the plant to insure that ground levels of SO_2 are not excessive. (If these show that excessive concentrations of SO_2 are present, additional treatment facilities should be conisdered for this plant and should definitely be required for any plant expansions).

5. A water sampling station will be placed at the discharge of the cooling and process waters. Analysis should in-

clude temperature, suspended solids, oils, and metals such as Fe, Ni, and Zn.

Disagreements over Impact Mitigation Procedures

There is a disagreement over the need to mitigate the thermal effects of the cooling water discharge. The discharge will undoubtedly cause a substantial localized temperature rise. However the Corporacion de Explotacion de las Minas has disputed the claim that the discharge will cause a temperature rise sufficient to disrupt the ecology of a substantial area of the lake. The recommendation that heat be dissipated through a diffuser pipeline with perforated openings has not been accepted on the grounds that it is not necessary. The matter remains to be resolved.

Detailed Environmental Analysis

A. The Mine Site

The ore is a silicate of iron and magnesium containing an average of 1.5% nickel. This ore will be surface mined to depths of 10 to 30 meters. The average depth will be 20 meters and will consist of about equal layers of ore and overburden. This overburden will be spoiled, and the spoil from one bench will be replaced into a previously mined out bench. The benching of the mine area will start at the bottom and mined out sections will be replaced from above. This is a substantial environmental protection action designed to preserve the mine area in as close to its original state as possible.

The other major environmental measure at the mine site will be that topsoil will be separated and redistributed on top of the spoil following the mining operation. The plan is to plant a commercial crop on the regenerated land after the mine has been abandoned.

Some loss of topsoil, especially silt, will occur during periods of heavy rainfall. This will increase the sediment loading in the clear mountain stream that runs down the mountain. Sediment may, on occasion, reach the lake. Periodic increases in turbidity in the lake would present an unsightly condition and interfere with fishing operations. If a heavy rainfall occurs at a time when topsoil has been freshly excavated and is unprotected, a substantial short term increase in turbidity in the lake can be expected.

The overburden is fully weathered rock and no further leaching of soluble minerals or metals is likely to occur.

B. Ore Transport

Since the distance between mine site and refinery is so short, no environmental effects associated with transport are considered noteworthy.

C. The Ore Processing and Refinery Operation

1. Impacts upon the Land.

Land use is not intensive in the vicinity of the proposed ore processing and refinery operations. Use is about equally divided between pasture for cattle and farming (corn and rice). These activities are not judged to be likely affected by the new operation.

One potential problem could develop from the slag buildup from ore processing. The present plan is to store the slag at the plant site pending possible future utilization for recovery of other metals. Few soluble minerals will be present to be leached. If unplanned, the slag heaps could be quite unsightly.

2. Impacts upon El Lago Capitan

a. Present condition of the lake.

El Lago Capitan is an unpolluted, relatively clear lake that is ideally suited for recreation, fishing, and even use as a water supply. The major use of the lake at present is fishing by individual commercial fishermen. Representative water analyses (based on 5 to 25 samples) are shown in the table below.

Constituent	Representative Concentration ppm unless otherwise indicated
Silica (as SiO_2)	15
Total hardness (as $CaCO_3$)	96
Suspended solids	6
Dissolved solids	126
Chemical oxygen demand	5
Iron	0.22
pH	8.3 (pH units)
Californ bacteria/100 ml.	20 (number of colonies)
Ave. temperature (winter)	75 °F
Ave. temperature (summer)	90 °F

The only potential difficulty for use of the water in the ore processing and power plants is the silica content. Water for

high pressure boilers and turbines of the power production unit may require pretreatment.

The lake should be considered a major recreational resource as development of the area proceeds. The lake should be preserved in a good condition for such purposes.

b. Port operations

A port will be constructed next to the ore processing plant to receive the raw materials sulfur, sand, and oil. Oil is the only material which poses an environmental hazard. Oil barges will unload at the dock into an oil pipeline through which the oil will be pumped to storage tanks at the plant site. This Bunker C type oil will be used to fuel the 60 MW power plant which will provide steam and power for the ore processing plant.

Potential environmental problems could be Bunkder C oil leakage from a barge, an oil transfer pipeline, or from the onshore fuel storage tank. In the absence of controls, an oil spill would float on the surface and jeopardize fish, waterfowl, recreation, and the aesthetics of the lake.

The Bunker C oil will barged in under contract to a supplier. He may not be as reliable or as concerned with the local environment as La Corporacion de Explotacion de las Minas de Teleroy. The Corporacion has therefore agreed to insist on guarantees for oil spill clean up from the supplier. Furthermore, oil spill containment booms and absorbents will be stocked at the port in the event this equipment is needed to control a spill.

c. The ore processing and refining operation

Water from El Lago Capitan will be brought into the plant for two major purposes: (1) 30,000 gpm for the power plant condensor and auxiliaries cooling, and, (2) 9000 gpm for process and drinking water.

The 30,000 gpm of cooling water will be drawn in at an average winter temperature of 75 °F and an average summer temperature of 90 °F. Maximum temperature in the water body is about 95 °F. During use, these waters will be heated about an average of 20 °F, and will be discharged without treatment. Maximum temperature of the discharge will thus be about 115 °F. These waters will pass into a canal which will discharge into the lake. The matter of including a perforated diffuser pipe to disperse the heated water into the lake is under discussion.

Of the 9000 gpm of process water, all except 300 gpm will be used as withdrawn from the lake. The remainder will be processed through a water treatment plant for drinking water (200 gpm) and boiler feedwater (100 gpm). Major uses of the process water will be for wet ore crushing, cooling slag, cooling matte,

and pelletizing the final product. Corporacion de Explotacion de las Minas has asserted that the mixcellaneous process waters will be unpolluted, since they are essentially used in various cooling operations. Water is not used as a reaction medium since the ore processing is purometallurgical.

However, the presence of emulsified oils resulting from leakage of lubricating oils into cooling waters appears to be unavoidable in an operation of this magnitude. In total, the discharge of process waters from the plant will be contaminated with soluble boiler salts, oils, heat, and suspended mineral solids.

La Corporacion de Explotacion de las Minas has agreed to install a settling basin through which the process waters will pass prior to discharge to the lake. This will allow settling of suspended solids and oils will float on the surface and can be removed by skimming. This precaution is important because emulsified oils are unsightly and will coat, clog, and cling to objects found in the lake. Emulsified oils are a hazard to waterfowl and fish. Suspended mineral solids such as iron, sand, and various oxides cause turbidity and settle in coves and other areas of little water movement. A soft and shifting lake bottom is created, unsuitable for the roe of most fish.

The Corporaciion plans to construct a small sewage treatment plant for domestic sewage from the plant. Details of this plant are not presently available. Good treatment of sewage effluents is important, because bacteriological contamination of the lake by direct discharge of sewage or poorly treated sewage effluent might endanger the users who are dependent upon the lake as a source of drinking water. Excessive sewage discharges into a lake lead to many other problems as well.

d. The new village

The new village will house about 800 people in 200 homes. Water will be supplied from an intake pipe from the lake about 10 km. from the plant site. A package secondary sewage treatment plant will be installed in the village. The treated effluent will be discharged into a small stream which travels 5 km. prior to discharge into the lake. Discharge will occur about 2 km. from the intake pipe for potable water for the village. No pollutional problems are anticipated due to the ample dilution of the secondary effluent.

3. Air Quality Impacts

There is no available data on air quality in Teleroy. Apparently no air sampling and analysis has been carried out. Visual observations and conversations with inhabitants indicates that the present air quality is good. The only notable existing source of air pollution is smoke from the slash and burn practice of agriculture. However the smoke from this operation is reported to frequently hang in the air for a day or more at a time, especially during the summer.

The plant and the new village are surrounded by mountains, and inversions are apparently a common occurrence during the summer months. No hazards exist at present because of the low level of man's activities in the region. A potential problem is posed by the ore processing plant and the power plant. Potential contaminants from both the ore processing plant and the power plant are flyash and sulfur dioxide.

Extensive air pollution control facilities are planned to eliminate fly ash and other particulates from exhaust gases. A series of multicyclone filters and electrostatic precipitators will eliminate particulates from gases in the ore processing and power plant operations.

No plans are incorporated for removal of SO_2. Twenty two tons of sulfur (as SO_2) per day will be emitted by the power plant, and another eight tons will originate in the converter operation of the processing plant. Two stacks of 400 feet will be constructed in order to disperse the exit gases. Those gases are expected to contain about 0.05% SO_2.

Sulfur dioxide is hazardous to human health when breathed. It is odorous and corrosive to plant life as well as many metals. Two air pollution monitoring stations will be established at ground level one mile east and west to the processing plant to insure that ground levels of SO_2 are not excessive. (Editorial comment: If ground level concentrations exceed 0.1 ppm for 24 hours or 0.5 ppm for ½ hour during the months of heavy atmospheric inversion, then some requirement ought to be considered for the installation of SO_2 - control technology, such as a wet scrubber).

D. Environmental Control Costs

The total cost of the planned air pollution control facilities is $US 2.5 millions. Another $US 2.5 millions will be required for construction of the tall stacks.

Total water pollutional control costs are estimated at $US 1.5 million not including the cost of construction of a cooling water diffuser pipeline. The cost becomes $US 1.9 millions with the cost of the diffuser pipeline included.

The total of $US 6.5-6.9 millions represents about 4% of the total estimated cost of the project.

ACADEMY OF SCIENTIFIC RESEARCH & TECHNOLOGY
&
THE UNIVERSITY OF MICHIGAN

WATER QUALITY STUDIES ON THE RIVER NILE AND LAKE NASSER[a]

By

Khalil H. Mancy[b]

INTRODUCTION

The Egyptian Academy of Scientific Research and Technology, in collaboration with The University of Michgan, is conducting a five-year research program on the environmental impacts of the Aswan High Dam. The project was initiated with the financial and technical support of the U.S. Environmental Protection Agency (EPA) and The Ford Foundation.

This project addresses itself to issues of vital importance to Egypt and the scientific community at large. These issues have been receiving a considerable amount of attention in the literature and in the news media. For example, the AID Manual of Environmental Assessment Guidelines[1] states that,

> Dramatic examples of change can be seen where man has altered the course of nature. It is vividly evident in his well-intentioned but poorly thought out tampering with river and lake ecosystems. The Aswan High Dam was primarily built to generate electric power. It produced power, but it also reduced the fish population in the Mediterranean, increased the number of disease-bearing snails, and markedly lowered the fertility of the Nile valley.

---

[a]A summary statement of goals and objectives, prepared for presentation to the Agency for International Development, U.S. State Department, October 10, 1976.

[b]Principal Investigator and Professor of Environmental Chemistry, School of Public Health, The University of Michigan, Ann Arbor, Michigan 48109

[1]Agency for International Development, Environmental Assessment Guidelines Manual, page 4, September 1974.

The Aswan High Dam was primarily designed for water storage and river flow control for the purpose of increased agricultural production. The fulfillment of this goal is of vital importance to Egypt since the River Nile constitutes over 90% of the country's fresh water resources and where the present population of 36 million people inhabit approximately four percent of the land and the rest is barren desert.

The construction of the Aswan High Dam resulted in the formation of Lake Nasser reservoir, and the storage of approximately 150 billion cubic meters of water, at an elevation of 175 meters above sea level, as of June 1976. Furthermore, river flow has been maintained at levels compatible with irrigation requirements, as shown in Figures 1 and 2. This resulted in the reclamation of new land for agriculture and enabled the farmer to raise new crops and to cultivate his land all year around.

In addition to water storage and river flow control, the Aswan High Dam has a maximum hydroelectric power output of 8 billion kilowatt-hours per year. In 1974, the total amount of electric power consumed in Egypt was 8.5 billion kilowatt-hours. Of this amount, 4.46 billion kilowatt-hours were provided by the Aswan High Dam, i.e., about 53% of the total national annual power requirements. In 1976, Egypt completed an impressive rural electrification program, which utilizes the hydroelectric power of the Aswan High Dam.

It is important to note that the total installed capacity of the hydroelectric power station in Aswan is 2.1 million kilowatts. This is considered to be small in comparison to other major dams in the world, as shown in Figure 3.

RESEARCH GOALS

Benefits from the Aswan High Dam project cannot be fully realized in the absence of appropriate strategies to deal with the environmental impacts of the dam and their human implications. Ecological alterations resulting from the construction of the Aswan High Dam and Lake Nasser reservoir have significant effects on the multipurpose use of the river as well as public health, social, and economic implications. It is the goal of this project to assess current and future environmental impacts of the Aswan High Dam and to utilize this information for the development of water resources management schemes. Specifically, this project aims to assess the effect of water impoundment in Lake Nasser and the impact of river flow regulation on water quality and multipurpose river use in Egypt. This includes public health, agricultural, and socio-economic implications. The overall aim is to provide policy and decision makers in Egypt with factual information on present conditions, predictions of future trends, and strategy alternatives for river resource management.

Figure 1: River Flow Control Afforded By The Aswan High Dam

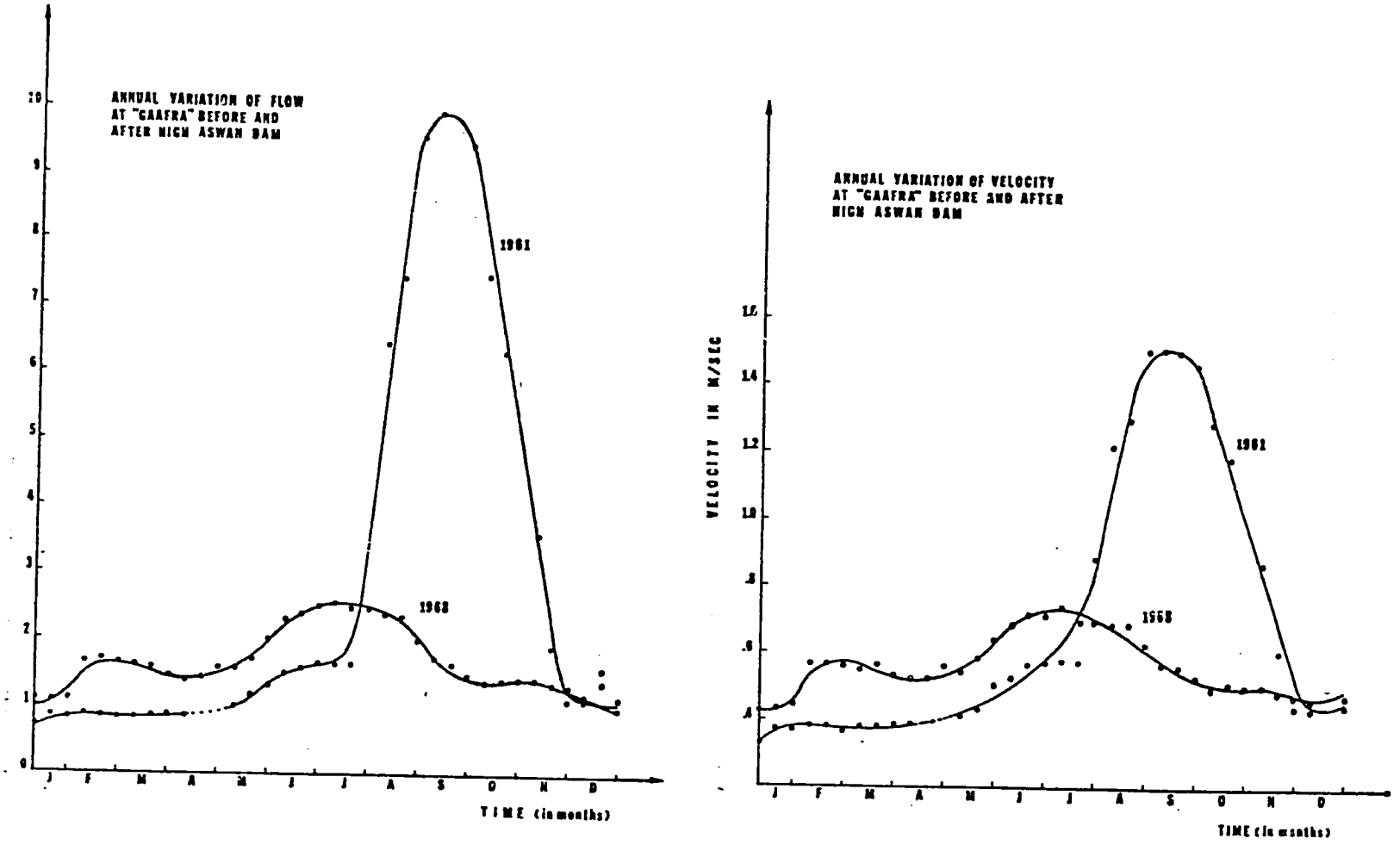


Figure 2: Hydrological Balance of Lake Nasser

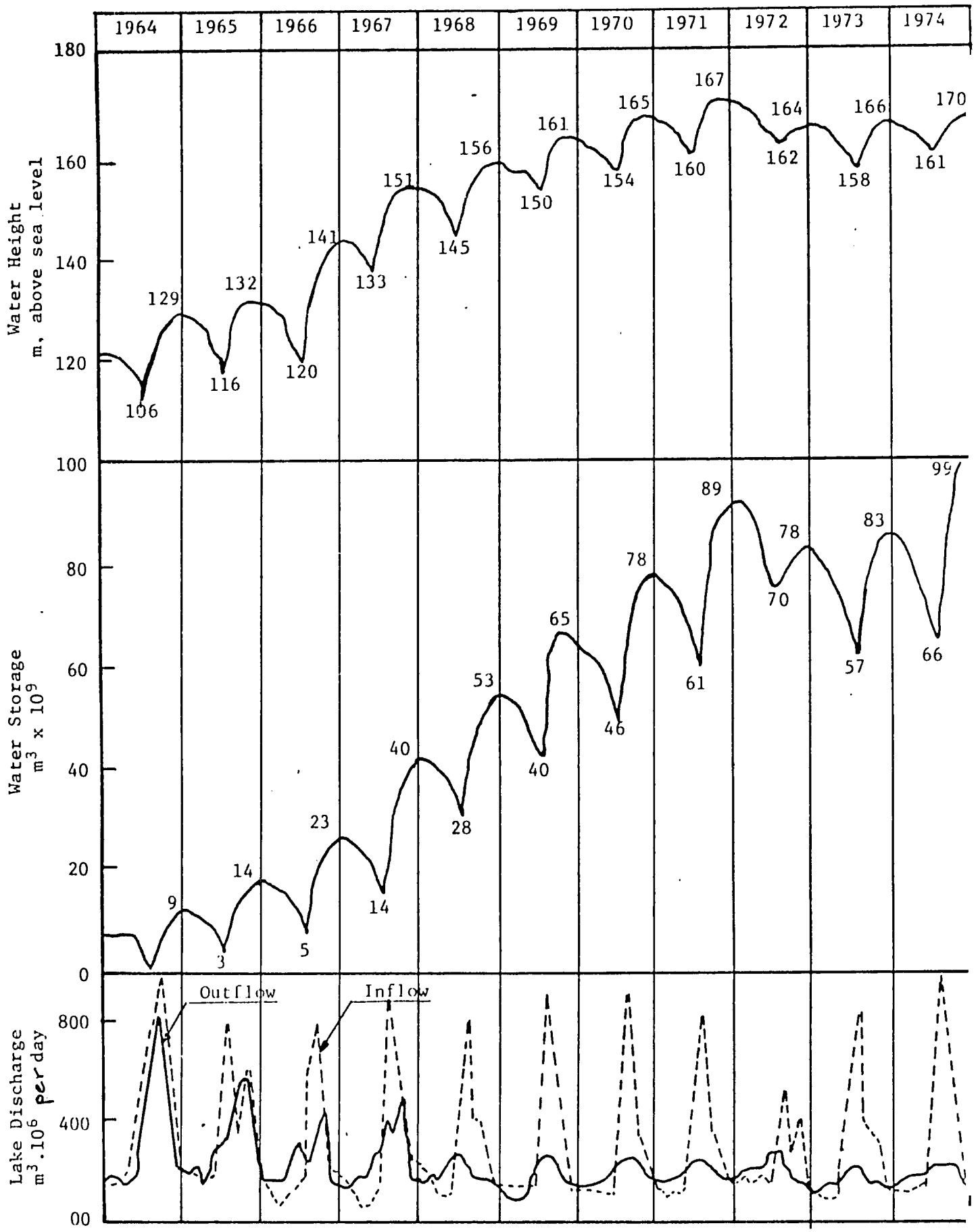
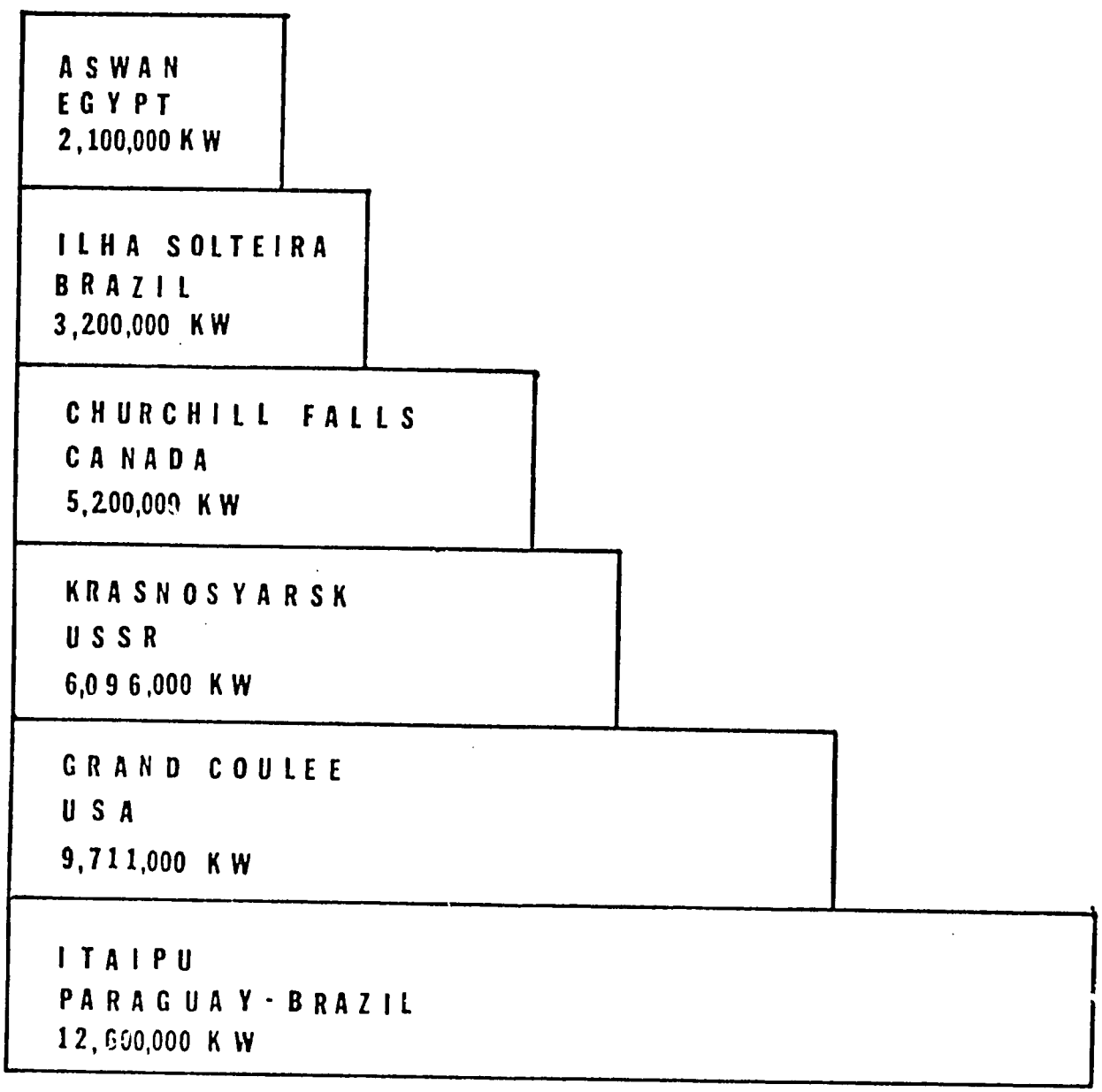


Figure 3:

CAPACITY OF HYDROELECTRIC POWER OF MAJOR DAMS IN THE WORLD



Current research activities are designed to provide scenarios, based on current conditions and predicted future changes in the Nile water quality, and their impact on water use. Lake ecosystems studies aim to assess current conditions and predicted future changes and their impact on lake resources. This information will be used to develop strategies for industrial and agricultural development in the lake region and the rest of the Nile valley in Egypt. It is important to note that this project will not only generate the above needed information, but it will also guarantee the involvement of policy and decision makers in Egypt. This is done by incorporating key ministries in the project plan of operation (e.g., Ministry of Irrigation and Agriculture and Aswan Regional Planning) and assuring their participation in all relevant activities.

In order to achieve the above stated goals we aim to:

a) strengthen and integrate research resources in Egypt into multidisciplinary water resources problem-solving teams, and

b) utilize these teams in developing information and comprehensive methodologies that will aid resource planners and decision makers in perceiving, recognizing, defining, and solving River Nile resource problems.

OVERVIEW OF PROJECT ACTIVITIES

This study was founded on two basic assumptions:

1) The Aswan High Dam has been both beneficial and disruptive to social, economic, and environmental health conditions in Egypt.

2) Planning and control of the beneficial and disruptive effects of the Aswan High Dam are both rational and essential.

This project constitutes a unique case study, the first of its kind, which encompasses both a man-made lake and its river basin. A schematic categorization of variables is shown in Figures 4, 5, and 6.

A schematic diagram of project components is shown in Figure 7. The arrows in this figure indicate the direction of flow of information.

In view of the comprehensive nature of this study and the sheer magnitude of work to be accomplished, it was planned to rely on the collaboration of various government agencies and research institutes in Egypt.

Figure 4: CONCEPTUAL ASSESSMENT MODEL

A. NEW TECHNOLOGY

ASWAN HIGH DAM

1. RESERVOIR MAN MADE LAKE + 2. RIVER FLOW REGULATION + 3. HYDROELECTRIC POWER

B. PRODUCT ORIENTED DEVELOPMENT

1. WATER STORAGE
   - a. Increase Agricultural Production
   - b. Land Reclamation
   - c. Flood Control
   - d. River Navigation
2. LAKE RESOURCES
   - a. Lake Shore Development
   - b. Fishery
   - c. Recreation
   - d. Navigation
3. ELECTRIFICATION PROGRAMS
4. INDUSTRIAL DEVELOPMENT

C. ECOLOGICAL AND ENVIRONMENTAL IMPACTS

1. CHANGES IN RIVER WATER QUALITY
   - a. Dissolved Organics
   - b. Suspended Matter
   - c. Plankton
2. CHANGES IN RIVER ECOSYSTEM
   - a. Benthos
   - b. Plankton
   - c. Hydrophytes
   - d. Fishes
3. BANK ERROSION RIVER
4. COASTAL ERROSION - SEA
5. WATER TABLE - DELTA
6. MICROCLIMATE - ASWAN

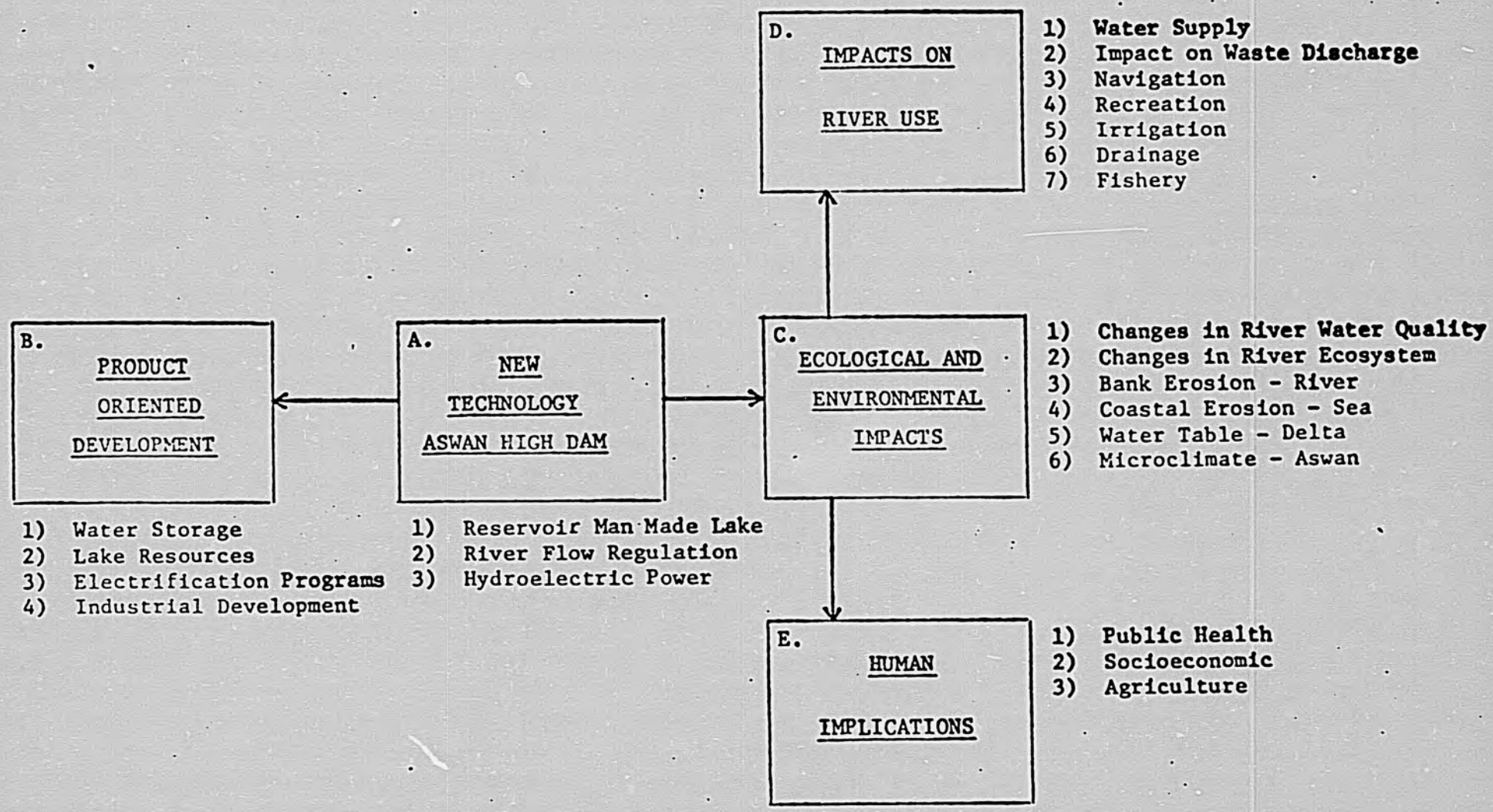
D. IMPACTS ON RIVER USE

1. WATER SUPPLY
2. IMPACT ON WASTE DISCHARGE
3. NAVIGATION
4. RECREATION
5. IRRIGATION
6. DRAINAGE
7. FISHERY

E. HUMAN IMPLICATIONS

1. PUBLIC HEALTH
   - a. Water born Diseases
   - b. Environmental Health
2. SOCIOECONOMIC
   - a. Human Displacement
   - b. Human Settlement
   - c. Human Migration
   - d. Changes in Agricultural Practices
   - e. Industrial Developments
3. AGRICULTURE
   - a. Production: Types & Quantities
   - b. Lack of silt & use of chemical fertilizers
   - c. Land Reclamation
   - d. Drainage, Water Logging and Salinization

Figure 5: CONCEPTUAL ASSESSMENT MODEL



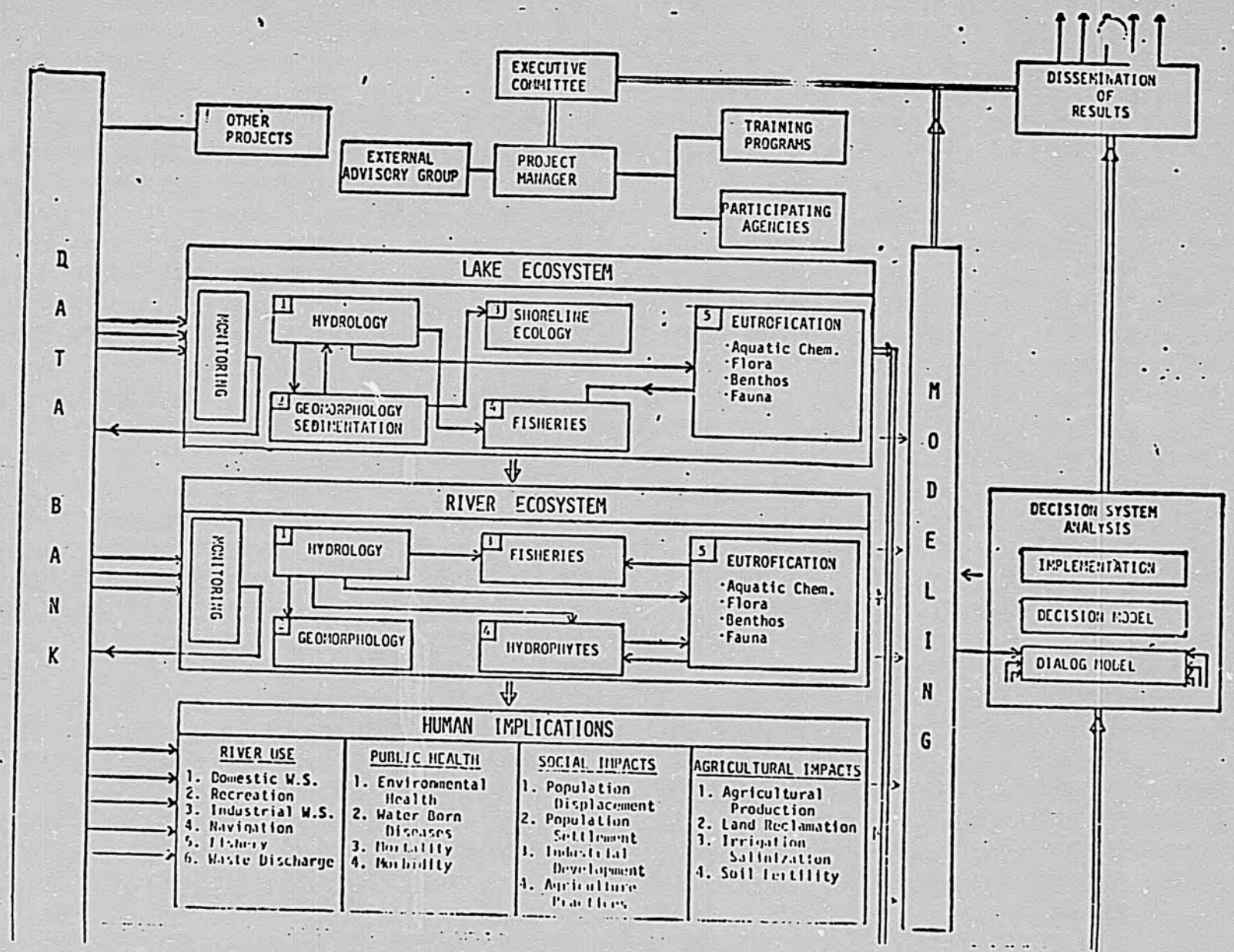
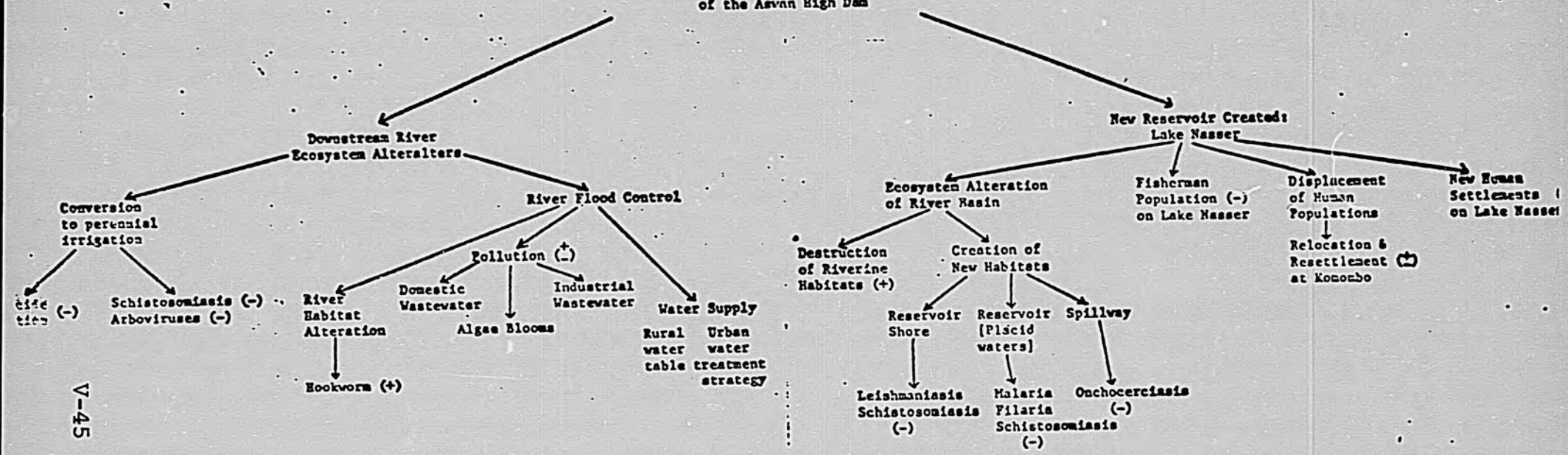

DATA BANK
OTHER PROJECTS
EXECUTIVE COMMITTEE
EXTERNAL ADVISORY GROUP
PROJECT MANAGER
TRAINING PROGRAMS
PARTICIPATING AGENCIES
DISSEMINATION OF RESULTS
LAKE ECOSYSTEM
MONITORING
1 HYDROLOGY
2 GEOMORPHOLOGY SEDIMENTATION
3 SHORELINE ECOLOGY
4 FISHERIES
5 EUTROFICATION
·Aquatic Chem.
·Flora
·Benthos
·Fauna
RIVER ECOSYSTEM
MONITORING
1 HYDROLOGY
2 GEOMORPHOLOGY
3 FISHERIES
4 HYDROPHYTES
5 EUTROFICATION
·Aquatic Chem.
·Flora
·Benthos
·Fauna
HUMAN IMPLICATIONS
RIVER USE
1. Domestic W.S.
2. Recreation
3. Industrial W.S.
4. Navigation
5. Fishery
6. Waste Discharge
PUBLIC HEALTH
1. Environmental Health
2. Water Born Diseases
3. Mortality
4. Morbidity
SOCIAL IMPACTS
1. Population Displacement
2. Population Settlement
3. Industrial Development
4. Agriculture Practices
AGRICULTURAL IMPACTS
1. Agricultural Production
2. Land Reclamation
3. Irrigation Salinization
4. Soil fertility
MODELING
DECISION SYSTEM ANALYSIS
IMPLEMENTATION
DECISION MODEL
DIALOG MODEL

Figure 7
Potential Human Health Implications of the Aswan High Dam



Key

+ Health implication
Decrease in either vector or of suitable habitat for transmission

- Health implication
Increase in vector population
New habitat favorable for transmission

± Combined health implication

Viral
arboviruses
viral hepatitis

Bacterial
leptospirosis

Protozoan
malaria
leishmaniasis
trypanosomiasis
intestinal protozoans

Helminth
schistosomiasis
filariasis
hookworm
onchocerciasis

This study is based on the following six main research functions:

1) Nile Information Center and Data Bank

2) Training

3) Lake Studies

4) River Studies

5) Human Implications

   a) Public Health Implications

   b) Agricultural Implications

   c) Socioeconomic Implications

6) Policy and Decision Analysis

A brief statement on the nature of work for the above research functions is given below.

1) Nile Information Center

This entails the development of a central sorce of information and referral services on the River Nile in Egypt. A unique data bank, utilizing Cairo University computer center is being developed. This will be capable of storage and retrieval of various types of information on the River Nile and Lake Nasser, e.g., hydrology, water quality, multipurpose river use, and relevant public health and socioeconomic information.

2) Training

An inherent part of this project is to train Egyptian scientists and engineers. This is done by means of a series of short training courses conducted by U.S. and Egyptian specialists. Examples of the training courses are as follows:

a) Water Quality and Treatment Technology (June, 1975)

b) Water Quality Surveillance and Monitoring (December, 1975)

c) Water Resources Management (December, 1977)

d) Mathematical Modeling of Aquatic Ecosystems (December, 1976)

Programmed instruction and videotaped sessions in color are being used for individualized, on-site training.

3) Lake Studies

Studies on Lake Nasser include the following subprojects:

a) Lake Geomorphology

Lake Nasser will experience significant geomorphological changes as a result of the hugh amount of silt being deposited in the southern portion of the lake. The objectives of this subproject are to (1) develop morphological maps of the current lake bed and lake shoreline area, (2) predict the effects of sedimentation and erosion on future lake and shoreline morphology, and (3) produce a sequence of maps of present and future lake and shoreline morphology.

b) Lake Hydrology

This includes the establishment of a water budget model for Lake Nasser. This model will take into account the various water inputs and outputs from the lake, e.g., evaporation and seepage. This model will be used for lake level forecasting and to predict optimum storage conditions.

c) Limnology of Lake Nasser

This is based on the assessment of pertinent physical, chemical, and biological interactions in Lake Nasser required for appropriate lake resources development. The main points of interest here are: (1) water circulation and stratification; (2) aquatic chemistry, including lake sediments; (3) distribution, identification, and en umeration of plankton, periphyton, macrophytes, benthos, and fish; and (4) ecosystem modeling, e.g., primary productivity and secondary productivity, food web, and fish population models. These models will be used to predict lake eutrophication, propagation of aquatic plants and fishery.

d) Lakeshore Ecology

This study aims to assess shoreline ecological transformations and their impact on lakeshore development. This entails the assessment of: (1) the effect of the lake, with its fluctuating levels and ground water, on coastal zone habitat and geological formations; (2) input of minerals, organic matter, and nutrients to the lake (especially in the Khores) from the coastal zone and

flood plain; and (3) impact of coastal zone development schemes (industrial, agricultural, urbanization, etc.).

4) River Studies

These studies are designed to assess current and future changes in the river ecosystem and their impact on river multipurpose use. A series of river segments, at different geographical locations and representing different degrees of human exploitation, are under investigation. These investigations include the assessment of segment geomorphology, hydrology, aquatic chemistry and sediments, and aquatic flora and fauna, e.g., aquatic plants, fishery, and benthos organisms. Furthermore, pollution studies are being conducted on each segment, e.g., the effect of industrial and municipal waste discharge and agricultural drainage. Special emphasis is on outstanding problems, e.g., (a) turbidity, (b) river vegetation, (c) pesticides and herbicide residues, and (d) oil and oil degradation products. This includes the assessment of abatement technologies and the offering of recommendations on alternative modes of action.

Mathematical models will be developed for each segment which will be used for prediction of future trends and development of multipurpose decision system analysis.

5) Human Implication Studies

This includes studies on public health, socioeconomic, and agricultural implications which can be directly or indirectly related to the Aswan High Dam.

a) Public Health Implications

These studies are concerned with both environmental health and community health implications, e.g., water supply and water related diseases. Although this project is not concerned with the epidemiology of such diseases as schistosomiasis and malaria, we intend to investigate pertinent ecological changes which may influence the propagation of the disease intermediate vectors, e.g., snail ecology.

b) Socioeconomic Implications

The scope of these studies covers the following implications:

(1) Population displacement and settlement, and the flooding of archaeological sites resulting from land inundation and the creation of Lake Nasser

(2) The impact of industrial expansion in certain regions in Egypt, e.g., Aswan, and the disappearance of certain industries, e.g., sardine fishery in the Mediterranean coast.

(3) Changes in agricultural practices, e.g., from basin irrigation to perennial irrigation.

c) Agricultural Implications

The main points of concern in these studies are:

(1) Land reclamation

(2) Increase of agricultural production

(3) Elevation of water table, salinization, and drainage problems and how to increase the irrigation efficiency

6) Policy-Decision Analysis

An important function of this subproject is to guarantee the effective involvement of user agencies and decision and policy makers.

A Policy Decision Committee was established and met for the first time on July 19, 1976. The objectives of this committee have been specified as follows:

(1) Develop systems and methodologies for the collaborative assessment of the impacts of the Aswan High Dam.

(2) Assist in the formation of adequate data bases for comprehensive, in-depth assessment.

(3) Formulate a list of priorities of impacts and control variables that can be manipulated.

(4) Suggest a timetable for the forecasting of impacts and the implementation of control strategies.

OVERVIEW OF PROJECT ACHIEVEMENTS

Activities during the first year (1975) were primarily concerned with project initiation. This included the (a) formalization of work plans with the collaborating institutions, (b) purchases of equipment, and (c) training of project personnel. Funds from EPA and The Ford Foundation were made available in March and August, respectively. The major bulk of equipment was delivered in January, 1976.

In spite of a number of difficulties, and because of the enthusiasm and eagerness of project personnel, a considerable amount of effort was made in 1975. In terms of achievements, this included the establishment of the data bank, conducting monthly and quarterly river surveys, and performing preliminary investigations on public health implications. In addition, limited activities on lake investigations, social aspects, and agricultural implications have been reported.

In 1976, project activities became more intensified on all fronts, and a large amount of new information was gathered in a systematic way. In addition, a special effort was made to gather historical information. It is important to note that the assistance and advice provided by project consultants, including Walter M. Sanders, III, Gilbert White, Kingsley Haynes, and M. Kassas, have been most effective in gaining a reasonable momentum. In certain areas of research we deliberately reduced the rate of generation of information, e.g., quarterly surveys instead of monthly river surveys in the Cairo Section. In contrast, in another research area efforts were made to organize and accelerate the gathering of information, e.g., lake ecosystem studies.

Based on the limited amount of information gathered so far, it is possible to formulate a number of early findings based upon a comparison between conditions before and after the construction of the High Aswan Dam.

1) Suspended matter in the Nile water, especially in the early fall, is primarily made of fine particulates, which are difficult to remove by conventional water treatment practices. This is a direct result of the creation of Lake Nasser reservoir. During the flood periods, the heavy fractions of suspended matter are believed to settle in the lake. The absence of these heavy fractions of suspended matter from the river water makes it more difficult to treat.

2) Water quality data indicate higher organic content in the Nile water which increased from south to north. This is manifested by an increase in the free nitrogen values (NH_3:NO_2^-:NO_3^-), especially nitrates. This can be attributed to direct waste discharge and agricultural drainage. The impact of this waste discharge is more pronounced since the control of the river flow afforded by the construction of the Aswan High Dam.

3) The creation of Lake Nasser reservoir and the control of river flow resulted in a different distribution of algae and diatoms in the Nile water. Certain microscopic algae are difficult to remove by conventional water treatment practices and are believed to be the cause of taste and odor problems in the drinking water supplies.

4) The bacteriological water quality of the Nile water is also different from pre-dam conditions. This is manifested by a disappearance of the high bacterial counts which used to occur during the flood period prior to the construction of the Aswan High Dam.

5) A more visible, and a dramatic impact of the Aswan High Dam, is the proliferation of aquatic plants in the river and irrigation canals. The situation is rather serious, particularly in the northern delta regions. The river channel north of Mansoura is practically blocked by submerged and floating aquatic weeds.

   The type and distribution of these hydrophytes have been studied by this project (Zahran, Imam, El Sharkawy). The Ministry of Irrigation used to apply herbicides (2,4,D) as a control measure. During 1975, more than a million Egyptian pounds were spent for the clearing of the canals.

   During Dr. Zahran's recent visit to the USA, he reviewed several techniques for weed control, including new equipment for mechanical removal.

6) The riverine fish industry has suffered significantly as a result of the Aswan High Dam. This was the result of the disappearnace of certain species and a net decrease in the total commercial catch. This problem is more prominent in the delta region than in southern Egypt. In the Damietta branch, north of Mansoura, about 95% of the Nile fish disappeared completely.

In addition to the above listed observations, certain early findings have been reported by project workers concerned with the public health, social, and agricultural implications.

At this stage of project development, a decision should be made on how to collaborate with the Sudan. This should include (a) the acquisition of information on upstream river conditions and (b) the consideration of the implications of land reclamation projects in the Sud region and their impacts on the lake and river multipurpose use in Egypt. Information on river conditions in Sudan is essential for the assessment of the effects of water impoundment in Lake Nasser reservoir. Furthermore, it is expected that the Johgli Canal Project and land reclamation schemes in southern Sudan will alter the Nile water quality and its habitat. This will have a direct effect on Lake Nasser and the river ecosystems in Egypt.

Furthermore, it is important to explore with the Egyptian Government the long-term plans for this study. At the present time, this project constitutes the only river and lake surveillance and monitoring program, and the only comprehensive river basin program, in Egypt. An important question is, what are the plans after the completion of this project in 1980?

ENERGY AND THE ENVIRONMENT

by

Remi Barre

TABLE OF CONTENTS

List of Tables V-54

Introduction V-55

First Part: The Energy - A Perspective View V-56

Second Part: The Environmental Impact of Energy Systems ...V-59

1. Hydroelectric Power V-59

2. Fossil Fuels V-60

3. Nuclear Power Plants V-65

Third Part: The Control of Energy Systems' Environmental Impact V-68

1. Energy Conservation V-69

2. Direct Reduction of the Environmental Impact V-71

3. New Energy Systems V-77

Conclusion V-81

Footnotes V-83

Appendix A: Environmental Impacts of Coal and Oil Electricity Systems Associated with a 1,000 Megawatt Powerplant V-86

Appendix B: Efficiency of Coal, Oil, Nuclear Electricity Generating Systems V-90

Appendix C: Annual Environmental Impact and Additional Costs for Coal, Oil and Nuclear Power Plants V-93

LIST OF TABLES

Table 1: The Shift to Energy Intensive Passenger Transport V-57

Table 2: Energy from Hydro-Potential Environmental Damage .V-60

Table 3: Estimate of Petroleum Oils Entering Oceans V-61

Table 4: Emission Characteristics for a Fossil Fuel Plant .V-61

Table 5: Economic Effect of Energy Related Air Emissions ..V-62

Table 6: Energy from Coal, Oil and Gas. Potential Environmental Damage V-63

Table 7: Environmental Impact of a 1,000 Megawatt Electric Energy System V-64

Table 8: Probability of Accidents in Nuclear Plants V-66

Table 9: Health Effects of a Nuclear Power Plant V-67

Table 10: Energy from Nuclear Fuels - Potential Environmental Damage V-67

Table 11: Environmental Impact of a Nuclear Electricity System V-68

Table 12: Increase in Cost of Living Due to Energy Taxes by Income Class V-69

Table 13: Community Cost Analysis, Annual Energy Consumption V-71

Table 14a, b, c: Component Efficiency of Coal, Oil and Nuclear Electricity Systems V-72

Table 15: Some Selected Policy Options in Energy Environment Conservation V-74

Table 16: Advantages and Disadvantages of Particulate Control Devices V-76

Table 17: Costs of Controls and Changes in Environmental Impact of Electric Energy Systems V-77

Table 18 (a, b, c, d, e): Increased Electric Power Costs Reflecting Environmental Control Expenditures (Generation, Transmission, Distribution, Right of way and Total) V-78

"The optimist proclaims that we live in the best of all possible worlds; and the pessimist fears this is true."

INTRODUCTION

Energy is the new "in-thing" at present; it is fashionable to talk about the problems of energy development, especially since the discovery of the "energy crisis." If we bring into the picture the fact that obviously very serious environmental damages have stemmed from the energy industry, and that energy has become a symbol of our entire system of industrial development and economic growth, we link together the three key-words of the '70's: energy - environment - development.

The purpose of this paper is not to explore in any depth those linkages, but, focusing on the environmental consequences of energy systems, to provide a framework for analysis and decision-making in an area where rational evaluation and planning is often obscured behind amounts of unrelated and partial pieces of information, and shaky conceptual basis.

In a first part, we will put the energy systems concept in perspective, and relate it to development and collective choices. Then, in a second part, we will assess the various environmental impacts of energy systems. Finally, in a third part, we will discuss the possibilities and means of controlling and reducing those impacts by structural and non-structural methods, with special attention to the relationship between the costs of the possible measures to be taken, and their objective results.

Clearly, for all environmental problems linked to industrialization, the issues and goals are extremely different between developing and developed nations; the standards to be applied, the relevant techniques and policies, the priorities, costs and benefits: almost nothing can be held universally true. Nevertheless, it is not because information and results concerning the relationships between energy and the environment are to be interpreted and translated into policies in a different way, nor that it means the information and results are not needed; on the contrary, if they have to be re-discussed, re-analyzed, re-framed into policies relevant to developing nations - and they indeed do -then the information and results have to be all the more accurate and carefully studied.

The goal of this paper is to help make a step in that direction.

NOTA: We call the energy system, the system which consists of all the components necessary to bring a basic energy resource from its natural state to a place and in a form in which it is used: extraction, processing, sometimes conversion into another form (electricity), transportation between operations, delivery or transmission to the final users, and use.

FIRST PART: THE ENERGY - A PERSPECTIVE VIEW

Energy is the ability to do work. It is the potential for useful work, in storage batteries, in muscles, in coal or flowing water. Man's use of energy was for long limited to that provided by his muscles. Later he learned to use fire for cooking and protection against the cold. Later still he captured the energy of the wind with sailboats and windmills. Today, we are exploiting a broad array of energy resources based mainly on fossil fuels, and tomorrow on nuclear fission and maybe later on solar and nuclear fusion energy - virtually unlimited energy sources.

But where does this energy come from? The earth's energy balance is composed for more than 99% of solar radiation reaching its surface - part of it being immediately reflected (about 35%), part of it heating the atmosphere (about 43%), used for evaporation, atmospheric and sea movements (about 20%), the remaining 1% being used by plants to convert CO_2 and H_2O into carbohydrates by the process of photosynthesis[1], simultaneously releasing oxygen in the atmosphere. When plants decay, the process is reversed. Over geologic periods of time, since half a billion years ago, a fraction of these organisms have been buried before complete oxidation; they underwent chemical changes and were transformed into natural gas, coal, oil, lignite. The stored energy is released by oxydation, emitting CO_2 and H_2O and heat.

The radioactive materials have been formed when the whole solar system still was a big diffuse star, subject to intense nuclear activity. In nuclear plants it is the energy stored at that time which is released.

The shift from agrarian to an industrial economy resulted in vast increases in energy consumption, both for powering the industry and for mechanizing and fertilizing agriculture to increase productivity. In addition, an energy-intensive transportation system ties together any highly specialized, and therefore interdependent economy (see Table 1)[2] (note: 1 BTU = 0.26 calories). Total world energy consumption has increased 5 times in the last 50 years, and the rate of increase has been increasing: +2.2% per year between 1925 and 1950, +4.9% between 1950 and 1960, +5.5% since then.[3] The very characteristics of "modern living" and the technological age, namely, urbanized area development, high productivity, industrial production, high specialization, are extremely energy-intensive processes. Actually, half the coal burned by man has been burned in the last thirty-one years, and half the petrol consumed has been burned in the last thirteen years.

The relative share of Europe and North America tends to decline, but there are still huge disparities in the per capital energy consumption per year: three times more in North America than in Europe and the USSR, ten times more than in Latin America, thirty times more than in Africa and Asia (excluding Japan); North America, with 8% of the global population consumes 37% of

the world's energy, whereas the poorest half of the world population consumes only 10% of the total energy produced.

TABLE 1

The Shift to Energy-Intensive Passenger Transport

	Percent of total passenger-miles			Average Btu's per passenger-mile	Load factor
	1950	1960	1970		
Urban					
Walking	.....	NA	NA	300 (human energy)	1
Bicycle	.....	NA	NA	180 (human energy)	1
Bus	.....	5.9	2.7	2,100 (diesel fuel and gasoline)	[1] .36
Automobile [2]	.....	89.2	94.5	8,100 (gasoline)	[1] .28
Intercity					
Bus	4.5	2.5	2.1	1,600 (diesel fuel and gasoline)	[1] .45
Railroad	6.5	2.8	.9	2,900 (diesel fuel)	.35
Automobile	86.8	90.1	86.6	3,400 (gasoline)	[1] .48
Airplane	2.0	4.3	10.1	8,400 (gasoline and jet fuel)	.50

[1] Based on 50-passenger average capacity for buses and 5-passenger capacity for automobiles.
[2] Includes taxicabs.

Sources: Transportation Association of America. 1972. *Transportation Facts & Trends, Ninth Edition.* Washington, D.C.: T.A.A., p. 16; U.S. Department of Transportation. July 1972. *1972 National Transportation Report.* Washington, D.C.: D.O.T., p. 189; personal communication with Richard Strombotne, U.S. Department of Transportation; Rice, Richard A. 1971. "Historical Perspective in Transport System Development," in *Advanced Urban Transportation Systems.* Pittsburgh, Pa.: Transportation Research Institute, Carnegie-Mellon University, p. 89; and Hirst, Eric, and Robert Herendeen. January 1973. "Total Energy Demand for Automobiles." A paper presented before the Society of Automotive Engineers, Inc., New York, N.Y., International Automotive Engineering Conference, Detroit, Mich. p. 3.

There is a definite positive correlation between energy consumption and GNP per capita, and between the rate of increase of these two variables. Nevertheless, the industrial structure plays a significant role and countries like Canada, Norway, Czechoslovakia, East Germany, Poland and Venezuela show a higher use of energy per unit of GNP than the USA. Clearly it would be hazardous to draw a simple causal relationship between GNP and energy use, but there is a definite linkage.

Between 1950 and 1960, there has been a drastic shift in energy sources; coal declining from 56 to 34%, oil and natural gas increasing from 38 to 60%, hydroelectricity staying at 6%, but nuclear energy's share is expected to boom from about zero to 21% of the world's energy production in 25 years from now. Let us now focus on a few issues related to energy:

1. Energy and food production[4]: there is a particularly clear interdependency between agricultural productivity and energy use: fertilizers, farm machinery and irrigation are highly energy-intensive products, as well as the food transportation and processing industry. For many countries though, and indeed for all countries in the longer run, the US type of this very energy-intensive agricultrue doesn't make any sense, when 10 calories of energy are needed to produce 1 calorie of food output. The crit-

ical variable in food production is precisely this energy subsidy to food output ratio, provided the protein diet is adequate.

2. Energy and international relations. There is no need to elaborate the fact that the world balance of power is drastically affected by the dependence of many countries on imported oil, generally from the Middle East. The whole monetary system is threatened by the importance of the transfers this dependence generates and the interdependency between political and military alliances, industrial and technological power and fossil fuel supply is every day more clear. The oil embargo of November 1973, which helped bring oil to a more realistic price, has been the first sign of the deep meaning of the basic interdependency between the world's nations, which has shown the power of any nation upon the whole system, and therefore the responsibility of all nations in the world's affairs.

The economic and social systems are increasingly dependent on energy, and Buckminster Fuller has estimated that if we took away the whole industrial network of energy consuming machinery in the world, half of humanity would die of starvation within 6 months.

3. Energy and collective responsibility. Energy is certainly the field for which the exhaustion of resources has been the most discussed, which contributed to the consciousness of the fundamental finiteness and limits of the earth's resources. This brought a major technological challenge in the form of the need of alternative energy system developments. It brought too, wide discussions and criticism of highly energy-intensive societal models, first of all because of the dubious feasibility of their world-wide application (24,000 power plants of 5000 mega-watts each would be necessary to supply electricity to the world, if everyone had to have the same electricity consumption rate as the USA). Finally, it brought the notion of the environmental impact of the scale far beyond the individual, both in terms of space (world-wide pollution) and time (exhaustion of resources or necessity of storage of nuclear wastes for thousands of years).

All of these elements are important in that while they stress the very sharp and inadmissible world inequalities in energy consumption (50% of the world consumes 10% of the energy), they stress not less strongly the interdependence between nations: the responsibility for energy development for further increase in material welfare and a more equitable repartition - its far-reaching good and bad potential consequences - is really collective.

We will focus now on the environment, energy systems linkages, which we consider as one of the basic elements to assess in order to define an energy policy which would be rational both at local level in terms of the development objectives of a country, and at a global level in terms of long term feasibility and viability; as the Council on Environmental Quality put it:

"the conflicts between the consumption we all want and the environmental ill effects we all wish to avoid is sharper for energy than perhaps any other aspect of natural resources use."[5]

Precisely, energy is a natural resource (fossil fuels), an industry of major importance (energy systems) and a major waste product (heat).

SECOND PART: THE ENVIRONMENTAL IMPACT OF ENERGY SYSTEMS

We will make a review of the adverse or potentially adverse effects due to the various energy systems, and not about the various benefits of power production.

These adverse effects concern human health, the natural environment (plants, forests, crops, fish, the atmosphere...) and man-made structures - thus impacting upon the social, economical and ecological systems, from very local to global scale, through air, water and earth. Some of these effects are monetary, others non-monetary but measurable, others non-measurable; some are direct, others indirect effects, reversible or irreversible, short term or long term. In other words, energy systems, being a very substantial element of man's industrial activity has complex, widespread and significant impacts at the level of society as a whole.

1. Hydroelectric power generation systems.

The most obvious impact there is the presence of an artificial lake which can have various effects on the local climate and more generally the whole natural-physical systems and the hydrology of the area. In fact, their interactions are so complex and so little understood that ecologists cannot predict those effects with any certainty, and several unpredictable situations can develop. Very often a dam has a role of flood regulation, but this can adversely affect the soil quality by preventing the salt deposits due to evaporation of irrigation water, to be annually washed out. This happened for example in the Kaipur area of Pakistan[6]. Sometimes too, a reservoir has an impact on the amount and flow of downstream waters which can have its nutrient composition changed, which can affect the fishlife. This has happened with the Aswan dam in Egypt where soil salination and sardine disapparation in the Mediterranean have become major problems. The presence of an artificial lake has a social impact by displacing populations, disrupting communication channels and taking land of agricultural value. We have to take into account too the increased health hazard due to the presence of a large body of water, as has been the case for the Kariba dam in Zambia.

Finally, if we consider the total energy system of hydroelectric production, we have the following table (Table 2.)[7]

TABLE 2

Energy from Hydro–Potential Environmental Damage

	Air	Water	Land	Other
Exploration and Extraction				
Upgrading				
Transportation			Transmission lines	
Utilization	Micro-climate Evaporation	Changes in water quantity (level, discharge, velocity, groundwater and losses) and quality (sediments, nutrients, turbidity, salinity and temperature)	Flooding Submerged Land Loss of Animal Habitat Landslides Earthquakes Drawdown Zone	Food Chain Repercussions Disease Vectors Submerged Vegetation Benthos Aufwuchs Zooplankton Phytoplankton

2. Fossil fuel energy systems (coal, natural gas, petroleum)

By very far they represent the largest share of energy production (more than 93% for the whole world in 1968). Coal's share is decreasing and will continue to do so, from about 34% in 1968 to about 12% in 2000, but this still means, in absolute terms a 50% increase. Oil, which reserves are far less important than coal or natural gas will increase its share from 43% in 1968 to 48% in 2000, which means a production at that time 4 times the actual one, and which will begin to decrease in relative terms at the turn of the century. Natural gas, an abundant and clean source will slowly increase its share, with a production multiplied by 5 in 2000.[8]

2.1 Exploration, extraction and upgrading steps

Coal extraction is a notoriously dangerous occupation, where accidents still regularly occur, and with a long term negative impact on health. It is also a well known source of water pollution. In the US for example, 13,000 miles of streams and 145,000 acres of lakes and reservoirs have been affected by acid mine drainage and siltation from coal extraction.[9] Surface mining degrades land to a point of precluding any posterior use. Mining wastes are another problem, and represent in the US almsot 40% of the total solid waste generation.[10]

Oil pollution occurs during accidents at the exploration and extraction phases or during normal and accidental operations during the transportation phase. 2.2 million metric-tons of oil go annually in the seas, 90% of which is during normal operations. (See Table 3)[11] This figure is projected to be 4.5 million annually in 25 years, and even more if off shore drilling goes on increasing so sharply (+175% in 4 years), thus multiplying the risks of major accidents. The main consequences of that are the poisoning of marine life, and of the food chain process, changes in the radioactive properties of sea-water (less evaporation), and degradation of the coastal areas.

TABLE 3

Estimate of Petroleum Oils Entering Oceans, 1969

	Metric tons/Year
Normal Operations	
Tankers	500,000
Other Ships	500,000
Offshore Oil Production	100,000
Accidental Spills	
Ships	100,000
Other	100,000
Refinery and Petrochemical	
Plant Operations	300,000
Industrial and Auto Wastes	
in Rivers	500,000
in Sewage Outfalls	100,000
Partial Total	2,200,000
Natural Seepage	100,000
Naturally Occurring Hydrocarbons	
In the Sea	large
Airborne Petroleum Hydrocarbons	large
Airborne Terpenes	large

Oil refineries produce oil spills, air pollution by burning some residual gases, water and earth pollution due to the chemical catalysts used in the refining process and which enter the environment with largely unknown consequences.

2.2 Utilization step

Fossil fuel combustion is the most important source of air pollution generation in the world. The fuel's energy can be used directly (heating, transportation) or indirectly through the production of electricity by power plants. The share of electric energy is increasing rapidly, especially in the developed countries, and the world wide percentage of energy used in the form of electricity is expected to go from 22.4% now to 39% in 2000.[12]

In the US, fossil fuel combustion accounts for 98% of the SO_2 generation, 80% of the CO, 60% of the hydrocarbon, and 40% of particulates.[13] The emissions characteristic for a fossil fuel plant are: Table 4).[14]

TABLE 4

Pollutant	Emmission in pound per KWH
Particulates	.0306
SO_2	.0294
Nitrogen oxydes	.0073
CO	.00014
Hydrocarbon	.000078

Furthermore, fossil fuel combustion also contributes to environmental pollutants which can be highly toxic. In the US, in 1968, 180,000 tons of lead have been emitted in the air by automobiles,[15] oil combustion also releases significant amounts of vanadium[16] and mercury.

Let us examine the economic effects of air pollution, which as we have seen, is due roughly for 2/3 to energy systems burning fossil fuels. These air pollutants are generally found in low concentrations, and their effects have long been unknown, because they develop over long periods of time. Now, several epidemiological studies have clearly shown the impact of air pollution on human health, nature and materials. In the US, it is now recognized that 50% of the bronchitis cases, 25% of other respiratory diseases and 25% of lung cancer, as well as 10% of all other cancers and cardiovascular diseases are due to air pollution.[17] It is considered, too, that about 4.5% of all health costs can be attributed to air pollution. An amount of economic loss of the same order of magnitude can be attributed to the effects on materials: paint, ainc, cement, metals, building stones, rubber, glass, paper, are damaged. There is also a damage of vegetation and crops. Even though much more needs to be known, we know the economic cost of air pollution is very high. An estimate has been done for the US (Table 5).[18]

TABLE 5

	HEALTH		PROPERTY - MATERIAL VEGETATION	
Year	Stationary sources	Transportation	Stationary sources	Transportation
1968	8.2	2.8	8.4	0.5
1985	16.7	3.9	19.0	1.2

(in billions $)

Table 5: Economic effects of energy related air emissions.

Another aspect of air pollution is the global impact. Many scientists suspect CO_2 and energy production contributed to the temperature increase of the earth up to 1940 (CO_2 tends to absorb the infrared waves reflected by the surface of the earth, and thus "traps" more solar energy) and that this trend was overtaken by the cooling effect of the increased particulate matter emitted into the atmosphere, which directly reflects more and more incoming solar radiation. But the question cannot be resolved yet with much confidence. Nevertheless, it is clear that the CO_2 of the whole atmosphere, from 1860 to now has increased from 290ppm to 320ppm on the average, and could reach 600ppm in 50 years. Another global effect is the acidification by SO_2 of the water contained in the atmosphere, thus giving place to the so called

"acid rains", which can have very detrimental effects on some soils and bodies of water. This is particularly the case of Scandinavia which receives rain of a PH sometimes around 4, due to the SO_2 production in England and the Rhur Valley.

TABLE 6

	Energy from Coal–Potential Environmental Damage			
	Air	Water	Land	Solid Waste
Exploration and Extraction	Fuel combustion products Waste pile fire	Acid mine drainage Leaching of waste piles Erosion and silting of watercourses	Strip mining effects Land subsidence	Underground mining waste
Upgrading	Particulates from fine coal drying Waste bank fires	Plant effluents Leaching of waste piles		Coal cleaning waste Sulphur
Transportation				
Utilization	*Power Plant* Carbon dioxide Sulphur oxides Nitrogen oxides Particulates *Coke oven* Particulates Hydrogen Sulphide Carbon Monoxide Hydrocarbons	Thermal discharges	Aesthetic pollution of landscape	Fly ash and slag Failure of slag heaps

	Energy from Oil–Potential Environmental Damage			
	Air	Water	Land	Solid Waste
Exploration and Extraction	Fuel combustion products	Drilling accidents Brine disposal		
Upgrading	Sulphur oxides Nitrogen oxides Carbon monoxides Hydrocarbons	Thermal discharge Sulphuric acid Spent caustic		Spent phosphoric acid catalyst Spent clay
Transportation	Power sources	Oil Spills	Pipeline accidents Effect on permafrost	
Utilization	Emissions from internal combustion engines Sulphur oxides Nitrogen oxides Particulates	Thermal discharge Used oil disposal		

	Energy from Gas–Potential Environmental Damage			
	Air	Water	Land	Solid Waste
Exploration and Extraction				
Upgrading				
Transportation	Nitrogen oxides at compressor stations		Pipeline problems	
Utilization	Thermal discharge Nitrogen oxides			

Another major effect of energy production is the heat generation: the laws of thermodynamics tells us the process of transformation of heat into useful energy - mechanical or electrical - is necessarily a very inefficient one, and fossil fuel plants reject 45 to 50% of the heat in water, and 15% in the air, using effectively only 35 to 40% of the initial heat. A power plant on the average releases 10,494 BTU/KWH in the environment.[19] The effects of thermal discharge are far from being fully understood, and can have beneficial effects too. But in general, thermal discharges in streams and lakes alter drastically the natural balance of the aquatic life and can damage lakes, bays, estuaries and rivers, especially in hot climates. Temeprature elevation does increase the activity and toxicity of some waterborne pollutants such as nitrates and phosphates, by speeding up the chemical reaction processes, increases the BOD levels by favorizing biological activity.

TABLE 7

Environmental Impacts of 1,000-Megawatt Electric Energy Systems Operating at a 0.75 Load Factor With Low Levels of Environmental Controls or With Generally Prevailing Controls[1]

System		Air emissions			Water discharges				Solid waste			Land use		Occupational health		Potential for large-scale disaster
		Tons ($\times 10^3$)	Curies ($\times 10^3$)	Severity	Tons ($\times 10^3$)	Curies ($\times 10^3$)	Btu's ($\times 10^{13}$)	Severity	Tons ($\times 10^3$)	Curies ($\times 10^3$)	Severity	Acres ($\times 10^3$)	Severity	Deaths	Workdays lost ($\times 10^3$)	
Coal	Deep-mined	383	.....	5	7.33	.....	3.05	5	602	.....	3	29.4	3	4.00	8.77	Sudden subsidence in urban areas, mine accidents
	Surface-mined	383	.....	5	40.5	.....	3.05	5	3,267	.....	5	34.3	5	2.64	3.09	Landslides
Oil	Onshore	158.4	.....	3	5.99	.....	3.05	3	NA	.....	1	20.7	2	.35	3.61	Massive spill on land from blowout or pipeline rupture
	Offshore	158.4	.....	3	6.07	.....	3.05	4	NA	.....	1	17.8	1	.35	3.61	Massive spill on water from blowout or pipeline rupture
	Imports	70.6	.....	2	2.52	.....	3.05	4	NA	.....	1	17.4	1	.06	.69	Massive oil spill from tanker accident
Natural gas		24.1	.....	1	.81	.....	3.05	2	.....	.....	0	20.8	2	.20	1.09	Pipeline explosion
Nuclear		.....	489	1	21.3	2.68	5.29	3	2,620	1.4	4	19.1	2	.15	.27	Core meltdown, radiological health accidents

NA = Not available.

Severity rating key: 5 = serious, 4 = significant, 3 = moderate, 2 = small, 1 = negligible, 0 = none.

[1] See the Appendix for details.

Finally, let us mention the aesthetically damaging and land intensive aspects of overhead electric transmission lines. In the US for example, the total land occupied by the 300,000 miles of lines is almost as vast as the state of Massachusetts. There are also the oil and gas pipelines, covering more than 1 million miles in the US only, with risks of breakage, explosion, and seepage.

Table 6 shows a summary of the effects for all fossil fuels,[20] per step, and Table 7 shows, for electric power plants using coal, gas and oil, the impact per environmental medium (land, air, water).[21] A qualitative estimate of the severity of each impact is provided on a 0-5 scale, to facilitate the reading.

Appendix A[22] shows these impacts broken down per step or element of the energy system and per medium of transmission.

3. Nuclear power plants

Nuclear power is now on its way to replace fossil fuels little by little and its share of total energy supply will go from about nothing in 1970 to about 21% in 2000, or about 52% of the total electricity production, which means the presence of some 3,200 large nuclear power plants around the world.[23] There has been, and still is, an intense debate over the safety and environmental impact of nuclear power plants, with three important issues not yet definitively settled down:

- the possibility of an accident with catastrophic consequences, or sabotage and stealing of fissible material.

- the question of storage of highly dangerous material in substantial quantities for 6 to 10 centuries.

- the problem of maintaining very high competence and strict observation of standards of safety when thousands of nuclear plants will be operating.

The most probable kind of very grave accident would be a sudden loss of primary coolant water through the plugging of a cooling duct or pipe of a primary coolant system and resultant melt down of the fuel rods which would be followed then by a transfer of a substantial fraction of radioactive material into the environment causing the loss of several hundred lives and permanent contamination of an area of about 30 square miles. According to the Chairman of the Atomic Energy Commission, such an event has 10^{-6} chances to occur per reactor per year,[24] which means a probability similar to the one of an equal number of person being killed by a meteorite (see Table 8).[25]

But it is suspected the limit concentration for plutonium not being dangerous might have been underestimated by a hugh factor,[26] thus increasing the damage caused by an accident. Furthermore, the study substantiating the results about the probability of accidents,[27] a 2 year study which cost about $3 million, has been critically discussed by some scientists, including official agencies.[28] Concerning sabotage and irrational conduct, the question is: how many controls are enough? David Rose contends that "illegal use is the most worrisome and least resolved hazard."[29]

TABLE 8

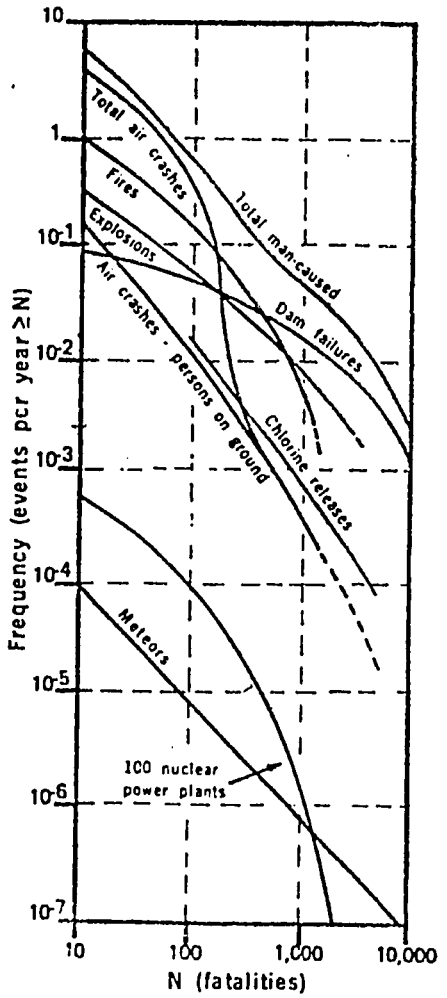


Chart adapted from AEC report compares the probability of accidents in nuclear plants with natural and other man-made disasters.

The nuclear waste disposal problem is another critical question. The wastes fall into two categories: the fission products, which are dangerous for about 7 centuries, and the actinides (mainly Plutonium) which must be stored about 10,000 centuries. This second category can be eliminated either by keeping it in the reactor itself, or by using it as a fuel in the next generation of nuclear plants, which will need it. But the fission products, anyway, must be transported (with risks of accidents) and stored for centuries. As a 1000 Mw plant generates about 30 tons of such waste annually, one sees the problem is considerable,[30] and during each operation, small quantities of radioactive material are released into the environment, with quite unknown long term consequences.

Finally, nuclear power plants, operating at lower temperatures than fossil fuel plants, discharge into the environment, as

waste heat, 70% of their total produced heat, or about 10,977 BTU per KWH,[31] which poses with even more acuity the problem of heating rivers and lakes.

But, provided that nuclear power plants do not generate almost any air or water pollutant, that the probability of accident is very small, the probability of sabotage uncomputable, as well as the probability of radioactive materials storage leaks, it has been computed that they are by very far less dangerous for the health than coal-burning power plants.[32]

Table 9 shows a summary of health effects of a nuclear power plant of 1000 Mw, in terms of injuries and fatalities for each step of the energy system.[33]

TABLE 9

Summary of health effects of civilian nuclear power, per 1000 Mw(e) plant-year

Activity	Fatalities			Injuries (days off)
	Accidents (not radiation-related	Radiation-related (cancers and genetic)	Total	
Uranium mining and milling	0.173	0.001	0.174	330.5
Fuel processing and reprocessing	0.048	0.040	0.088	5.6
Design and manufacture of reactors, instruments, and so on	0.040		0.040	24.4
Reactor operation and maintenance	0.037	0.107	0.144	158
Waste disposal		0.0003	0.0003	
Transport of nuclear fuel	0.036	0.010	0.046	
Totals	0.334	0.158	0.492	518

Table 10 gives a description of those effects.[34]

TABLE 10

Energy from Nuclear Fuels–Potential Environmental Damage

	Air	Water	Land	Solid Waste	Radiation
Exploration and Extraction		Waste banks leaching Uranium mine water	Strip mining effects	Underground mining wastes	Exposure to miners
Upgrading	Particulate emission	Waste banks leaching		Ore dressing waste	Exposure to plant workers
Transportation			Transmission lines		Possible accidents
Utilization	Radiation fallout	Thermal discharge		Waste disposal from fuel processing plants	Exposure during generation and disposal of wastes Possible accidents

And Table 11[35] shows the details of the impact, per step and per transmitting medium.

TABLE 11

Annual Environmental Impacts of a Light Water Reactor Nuclear Electricity System Associated With a 1,000-Megawatt Powerplant With a Load Factor of 0.75 and With Generally Prevailing Controls

Impact		Extraction [1]	Processing [2]	Transport	Conversion	Transmission	Total
Land	Acres	[3] 785	[4] 9.12	0	[5] 300	[6] 17,188	18,300
Water	Tons	[3] 20,400	[4] 42.9	0	[7] 813	0	21,256
	Curies	[3] 1.9	[4] 2,348	0	[8] 332	0	2,682
	Btu's	[3] nil	[4] 3×10^{12}	0	[8] 4.99×10^{12}	0	5.29×10^{12}
Air	Tons	[3] nil	[4] 6,192	[10] nil	0	0	6,192
	Curies	[3] 69.9	[4] 3.49×10^{3}	0	[11] 1.40×10^{4}	0	4.89×10^{4}
Solid or stored waste	Tons	[3] 2.62×10^{6}	[4] 58	0	[12] 0	0	2.62×10^{6}
	Curies	[3] 1,125	[13] 1.4×10^{8}	0	[14] 31,500	0	1.4×10^{8}
Occupational health	Deaths	[15] .09	[16] .048	[16] .002	[16] .013	NA	.153
	Injuries	[15] 3.45	[16] .563	[16] .045	[16] 1.31	NA	5.37
	Workdays lost	[15] 208	[16] 34.3	[16] 2.7	[16] 25.6	NA	270.6

NA=Not available.

[1] Includes mining and milling operations and is based on a 0.75 powerplant load factor. Does not include effects of electric power consumed.

[2] Processing includes UF_6 production, enrichment, fabrication, reprocessing, and waste management. Includes impacts of coal-fired electricity production for the enrichment process.

[3] Developed from U.S. Atomic Energy Commission. Directorate of Licensing, Fuels and Materials. November 1972. *Environmental Survey of the Nuclear Fuel Cycle*. Washington, D.C.: A.E.C., Tables A-1 and B-1. Ten percent solids is assumed.

[4] *Ibid.*, Tables C-1, D-1, E-1, F-1, pp. C-3, C-4, D-3, D-4, E-2, F-1, F-25, G-3, G-9, G-10, G-17, G-18.

[5] Executive Office of the President, Office of Science and Technology, Energy Policy Staff. 1968. *Considerations Affecting Steam Power Plant Site Selection*. Washington, D.C.: Government Printing Office, p. 11. Note that acreage is based primarily on nuclear reactor exclusion area rather than on facility size.

[6] See Table A-2, note 8.

[7] See Table A-2, note 11.

[8] Derived from data in Tennessee Valley Authority. May 1971. *Draft Environmental Statement for Watts Bar Nuclear Plant, Units 1 and 2*. Knoxville, Tenn.: T.V.A.; U.S. Atomic Energy Commission. 1971. *Final Safety Analysis Report, Donald C. Cook Nuclear Plant, Indiana and Michigan Electric Company*. Washington, D.C.: A.E.C., Volume 4, Section 11.1.3; U.S. Atomic Energy Commission. November 25, 1970. *Final Safety Analysis Report, Zion Nuclear Plant, Commonwealth Edison*. Washington, D.C.: A.E.C., Volume VI, Appendix 14A; U.S. Atomic Energy Commission. November 16, 1970. *Environmental Report for Quad Cities Units 1 and 2*. Washington, D.C.: A.E.C., AEC Dockets 50-254 and 50-265; Battelle-Columbus Laboratories. November 1971. *Environmental Impact Assessment: Supplemental Information to the Quad Cities Environmental Report*, and supplements, prepared for Commonwealth Edison Company. Columbus, Ohio: Battelle; U.S. Atomic Energy Commission. 1968. *Quad Cities Safety Analysis Report*. Washington, D.C.: A.E.C., Volume II, Section 9, Radioactive Waste System; and testimony of James M. Smith, General Electric Co., before the Illinois Pollution Control Board, May 24, 1971, PCB 71-20.

[9] See Table A-10, note 5.

[10] Based on 47,000 miles of trucking. *Environmental Survey of the Nuclear Fuel Cycle, op. cit.*, Table II-1, p. II-3; and U.S. Environmental Protection Agency, Office of Air Programs. February 1972. *Compilation of Air Pollutant Emission Factors*. Washington, D.C.: Government Printing Office, Table 3-2.

[11] *Environmental Survey of the Nuclear Fuel Cycle, op. cit.*, p. F-5, based on data in Oak Ridge National Laboratory. July 1971. *Siting of Fuel Reprocessing Plants and Waste Management Facilities* (ORNL-4451). Oak Ridge, Tenn.: O.R.N.L.

[12] Considered as part of waste management. See note 4.

[13] See note 11.

[14] The gross radioactivity of all surface burial of radioactive wastes for nuclear powerplants in 1970 was 101,565 curies, calculated assuming no escape of radioactive materials to the water or air environment. *Ibid.* Nuclear powerplants generated 21.8 billion kilowatt-hours in 1970. Federal Power Commission. 1972. *Annual Report—1971*. Washington, D.C. Government Prinitng Office, p. 11.

[15] U.S. Atomic Energy Commission. December 1972. *The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities*. Draft. Washington, D.C.: A.E.C., pp. 6-25, 6-26. Workdays lost per stage are based on the nonfatal accident rates and total workdays lost for the system.

[16] See note 15.

THIRD PART: CONTROL OF ENERGY SYSTEMS' ENVIRONMENTAL IMPACTS

To reduce the environmental impact of energy systems, there are three types of possible directions, complementary in space and time:

- to use less energy, or rather, to reduce the projected consumption levels rate of increase

- to reduce the environmental impact per BTU produced by input modification, technological improvements or various residual control devices; in short - amelioration of the existing systems.

- to introduce totally new technologies for producing energy.

We will successively discuss these three types of strategies.

1. Energy conservation

In a very short term, a crisis period for example, it is possible to decrease the energy consumption by some form of rationing of energy distribution. This cannot be considered as a general strategy for the long term, and we will discuss here the ways in which pricing, taxation and regulatory measures can bring an overall more efficient use of energy through technological improvements, changing patterns of the firms' and consumers' behavior, and evolution of the life style in the long run.

A simple idea which is often argued for is to price energy at its real, social cost; that is, including all external costs borne by society, due to environmental impact. To the actual cost we would add: the dollar cost of pollution related illnesses in terms of medical and loss of work costs, loss of commercial fishing resources due to thermal pollution, loss of recreational land and water, cost of relocating housing and industry due to air pollution.[36]

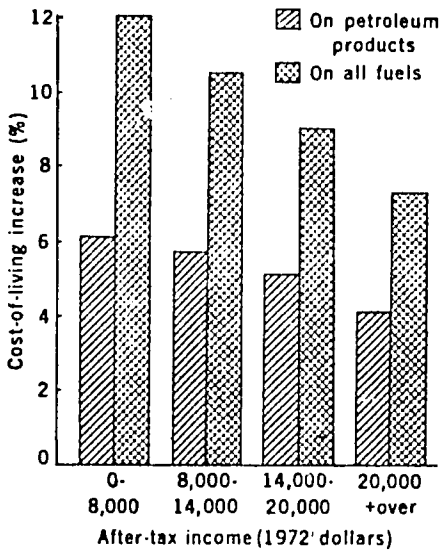


TABLE 12

Increases in cost of living due to energy taxes by income class.

But an "across the board" price increase would be very inefficient though, because the social cost of energy depends on its form, its time of demand and other factors, and one could imagine a taxation of petroleum products only, because, in the long run, they are the most scarce resources and most environmentally dangerous, or tax peak-hours use of energy. This new pricing policy should be designed carefully to be efficient, and to be equitable because as shown in Table 12,[37] a tax on energy is

very regressive. The interest of such policy is that, coupled with appropriate regulations, incentives, national research programs, it will bring the technological changes, evolution of consumers' behavior and life pattern which will increase the efficiency of use of energy.

Let us discuss more in detail some of those changes.

1.1 Energy conservation by increased thermal performance of structure.

Space heating can need 20 to 30% less energy with adequate insulation of buildings, new standards for air conditioning and ventilation. Furthermore, municipal waste could be burned in power plant boilers along with coal, further reducing fossil fuels requirements for space heating.

1.2 Thermal effectiveness of industrial processes.[38]

It has been computed that a very substantial fraction of the amount used in the industry can be saved by applying the already developed conservation techniques of industrial processes. Furthermore, heat transfer and combustion techniques, waste heat management devices, vacuum insulation principles have been applied to improve equipment design, and new methods for the systematic use of waste heat in plants can yield further energy savings. Actually, the major industrial sectors have all achieved a general decline in energy used per unit of output over the last decade in the US.

1.3 Effective use of energy in transportation.

As we have seen in Table 1, enormous differences exist in the energy effectiveness of different transportation modes, from 22 passengers-mile per gallon in a plane, to 200 in a train. Recently, the general shift to the individual automobile has decreased the efficiency of use of transportation and it is urgent to develop mass transit systems, which would probably in turn favor more dense construction patterns of cities and suburbs, which have been proved more energy efficient than low density housing. (See Table 13.)[39]

This long term type of evolution is an element of what can be called the adaptation of man's life pattern to the needs of energy conservation. Mass transit needs a lot more research and capital investment over the next years.

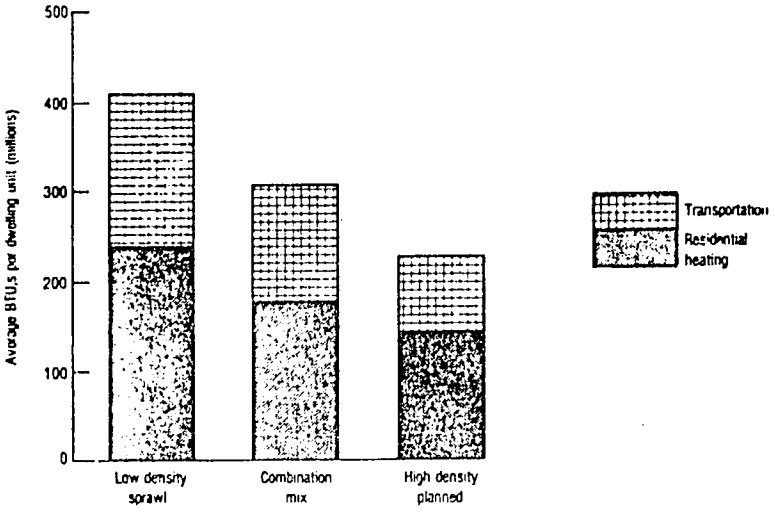
1.4 Efficient electric power generation.

Over the past 25 years, efficiency in electricity generation has increased by more than 30%, to reach 38 to 40% in modern power plants, and, for the next decade or two, the prospects for significant improvements in overall efficiency of steam electric power plants are not good, because the materials capable of hand-

ling higher temperature and pressure have not yet been developed. The most promising approaches lie in changes like advanced power cycles (coal gasification with a gas turbine, steam, turbine power plant), magneto hydrodynamics (direct conversion of heat into electricity) and breeder nuclear reactor.

TABLE 13

Community Cost Analysis
Annual Energy Consumption



Tables 14a, b, and c[40] show that total system efficiency for coal, oil and nuclear electricity generating plants is between 15 to 35% of the theoretical energy potential, and it has been argued electricity was an inefficient way of using energy.[41] In fact, direct fuel use would be done by small units which are very difficult to control in terms of pollution and energy efficiency. Furthermore, energy distribution being more efficient in the case of electricity, on total it is not clear that electric power generation and distribution is a wasteful form of energy use.[42]

On total, the rate of growth of energy demand can easily be reduced, provided that, on the whole, there will still be a growth, unless the very basis of our technological society changes. Table 15 shows the short-term possible actions for energy conservation,[43] and Appendix B shows the details of the efficiency of various energy systems producing electric energy.[44]

2. Direct reduction of the environmental impact.

2.1 Extraction, processing and transportation stages.

About coal mining, there are obvious improvements to be made for miners' safety and appropriate working conditions. In the case of strip mining, regulations can specify the state in which the stripped land must be left, which can be quite costly in capital and water resources. For oil extraction, further studies

need to be done to assess the exact leaks of oil dangers of underwater drilling. Concerning the transportation of oil, some international agreements should provide better possibilities of controlling oil tankers' operations in the high sea when they was their tanks. A legislation on the maximum authorized size of tankers could be thought of too, because no one knows what would happen if a tanker with 500,000 tons of crude oil sank near a coastal area. Ways of improving pipe-line transmission and electric distribution lines design and siting (including new technologies like cryogenic transmission lines, or underground lines) are under study.[45]

TABLE 14a

Component Efficiencies of Coal-Fired Electricity Systems

[In percent]

	Extraction		Processing	Transport	Conversion	Transmission	System [1]	
	Deep	Surface					Deep	Surface
Resource recovered [2]	[3] 57	[4] 80	[5] 92.1	[6] 99	[7] 38	[8] 91.2	18.0	25.3
Energy input [9]	[10] 8	[10] 8	[10] 1	[11] 9	0	0	----------	----------
Component net efficiency [12]	56.2	79.2	92.0	98.1	38	91.2	17.8	24.9

[1] System efficiency is the output energy of the last component divided by the total energy input to the system, including external energy.

[2] Percent of energy value of coal energy entering each component which remains after that component.

[3] Lowrie, Raymond L. 1968. *Recovery Percentage of Bituminous Coal Deposits in the United States. Part 1. Underground Mines.* Washington, D.C.: U.S. Department of the Interior, Bureau of Mines, p. 1.

[4] Averitt, Paul. 1970. *Stripping Coal Resources of the United States—January 1, 1970.* U.S. Department of the Interior, Geological Survey Bulletin 1322. Washington, D.C.: Government Printing Office, pp. 7-8.

[5] Total 1969 raw coal production and percentage of raw coal wet cleaned, dry (pneumatically) cleaned, and unprocessed are shown in Figure A-1. U.S. Department of the Interior, Bureau of Mines. 1971. *Minerals Yearbook—1969.* Washington, D.C.: Government Printing Office, pp. 309, 347, 348. Total raw coal production includes processing plant wastes. Processing removes approximately 12 percent of the British thermal unit value of the coal, based on Leonard, Joseph W., and David R. Mitchell, eds. 1968. *Coal Preparation.* New York: American Institute of Mining, Metallurgical and Petroleum Engineers, p. 5-32.

[6] Approximately 1 percent of the coal is blown away during transport unless it is wetted. Delson, Jerome K., and Richard J. Frankel. April 1972. "Residuals Management in the Coal-Energy Industry." Manuscript to be published by Resources for the Future, Inc. Washington, D.C.: R.F.F., p. IV-45.

A large new powerplant is assumed to have a heat rate of 9,000 British thermal units per kilowatt-hour, equivalent to a 38 percent conversion efficiency. The best plants have achieved around 8,530 to 8,900, whereas the national average is around 10,500. Federal Power Commission. 1972. *The 1970 National Power Survey.* Part I. Washington, D.C.: Government Printing Office, pp. I-5-6, I-5-7.

[7] Power sold divided by power produced, 1969. Federal Power Commission. 1972. *Annual Report—1971.* Washington, D.C.: Government Printing Office, pp. 11, 13.

[8] Expressed as percent of energy content of the coal (or electricity) entering each stage. Based on 11,639 British thermal units per pound of coal, the 1969 average for coal burned at powerplants. National Coal Association. 1972. *Steam-Electric Plant Factors, 1971 Edition.* Washington, D.C.: N.C.A., p. 107.

[9] Data supplied by InterTechnology Corporation, Warrenton, Va.

[10] Assumes all coal is shipped by rail for an average of 300 miles. Actual 1965 average distance is 297 miles. National Coal Association. 1970. *Bituminous Coal Facts—1970.* Washington, D.C.: N.C.A., p. 91. Two-hundred ton-miles of cargo movement requires approximately 1 gallon of fuel with an energy content of 136,000 British thermal units per gallon. Rice, Richard A. "System Energy as a Factor in Considering Future Transportation." A paper presented at the American Society of Mechanical Engineers Winter Annual Meeting, November 29-December 3, 1970.

[12] Component net efficiency=(% resource recovered)−(% energy input).

TABLE 14b

Component Efficiencies of Oil-Fired Electricity Systems

[In percent]

	Extraction		Processing [1]	Transport			Conversion	Transmission	System [2]		
	On-shore	Off-shore		On-shore	Off-shore	Import			On-shore	Off-shore	Import
Resource recovered [3]	[4] 30	[4] 40	[5] 97.8	[6] 99.9	[6] 99.9	[6] 99.9	[7] 38	[8] 91.2	10.2	13.5	34.6
Energy input [9]	[10] .15	[10] .2	[11] 10.0	[12] 1.8	[12] 1.8	[12] 2.1	0	0	----------	----------	----------
Component net efficiency [13]	29.9	39.8	37.8	98.1	98.1	97.8	35	91.2	9.8	12.9	33.9

[1] To determine the impacts of refineries attributable to residual oil production for electricity generation, a model is developed of a refinery complex consisting of topping and cracking stages and producing at the same percentage as the national average for oil products.

[2] See Table A-1, note 1.

[3] Percent of energy value of oil energy entering each component which remains after that component.

[4] Approximate percentages of known oil deposits which are considered recoverable. National Petroleum Council. 1972. *An Initial Appraisal by the Oil Supply Task Group, 1971-1985.* Washington, D.C.: N.P.C., p. 45. Note also that there is a resource loss of about 0.019 percent associated with incomplete separation of oil and brine and with spills, based on brine production of 2.7 barrels brine per barrel of crude oil. National Petroleum Council. 1972. *Environmental Conservation: The Oil and Gas Industries.* Volume Two. Washington, D.C.: N.P.C., p. 147. Also based on 0.005 percent oil content in the brine, the Federal regulation applying to offshore drilling. U.S. Department of the Interior, Bureau of Land Management. 1972. *Final Environmental Statement—Proposed 1972 Outer Continental Shelf Oil and Gas General Lease Sale, Offshore Eastern Louisiana.* Washington, D.C.: D.O.I., pp. 132-34.

[5] This refinery produces the following mix: residual fuel oil at 0.0600 barrel per barrel input and other products, 0.9705 barrel per barrel input. U.S. Department of the Interior, Bureau of Mines. December 1971. *Mineral Industry Surveys: Crude Petroleum, Petroleum Products, and Natural-Gas-Liquids: 1970 (Final Summary).* Pittsburgh: D.O.I., B.O.M., Table 14. All inputs and environmental impacts are then weighted by the British thermal unit values of the end products. In terms of British thermal unit values, residual fuel oil represents 6.65 percent of production. *Ibid.* British thermal unit values are taken from American Petroleum Institute. 1971. *Petroleum Facts and Figures—1971 Edition.* Washington, D.C.: A.P.I., p. 589. In terms of volume, therefore, 0.0665 barrels of crude input is attributed to production of 0.0600 barrels of residual fuel oil, a 90.2 percent recovery. In terms of British thermal unit value, however, this is a 97.8 percent recovery.

[6] For prerefinery transport (domestic), assume all oil is transported by pipeline. Approximately 0.001 percent of the oil transported is lost in spills. *Environmental Conservation: The Oil and Gas Industries.* Volume Two, *op. cit.*, p. 209. For postrefinery transport (domestic and imported), it is assumed that all domestic oil is shipped by barge, all imports by tanker. Barges lose approximately 0.028 percent of their oil in discharges, leaks, and spills; tankers lose 0.11 percent. Porricelli, Joseph D., Keith-Virgil F., and Richard L. Storch. "Tankers and the Ecology." *Transactions.* Vol. 79, 1971, pp. 170, 172, 175. It should be noted that oil as a source of energy for transport is considered an energy input rather than a resource loss.

[7] See Table A-1, note 7.

[8] See Table A-1, note 8.

[9] Expressed as percent of energy content of the oil (or electricity) entering each stage. Based on 5.80 million British thermal units per 42-gallon barrel of crude oil; 6.287 million British thermal units per barrel of residual fuel oil. *Petroleum Facts and Figures—1971 Edition, op. cit.*, p. 589.

[10] Data supplied by InterTechnology Corporation, Warrenton, Va. Pumping energy is 0.5 percent of energy output.

[11] *Mineral Industry Surveys: Crude Petroleum, Petroleum Products, and Natural-Gas-Liquids: 1970 (Final Summary), op. cit.*, Table 19.

[12] For prerefinery transport—0.23 percent (domestic only), *ibid.*; and energy input required for pipeline transport is approximately 450 British thermal units per ton-mile. Hirst, Eric. 1972. *Energy Consumption for Transportation in the U.S.* Oak Ridge, Tenn.: Oak Ridge National Laboratory, p. 5. An average length of movement of 200 miles is assumed. For postrefinery transport—1.58 percent (domestic); fuel oil consumption ton-miles, for a one-way trip. Rice, Richard A. "System Energy and Future Transportation." *Technology Review.* January 1972, p. 32. Fuel oil consumption for transport—1.86 percent (import) by a 50,000-ton tanker is taken at 1 gallon per 850 ton-miles. This is an average of two estimates: one (920) from *ibid.*, obtained by doubling the fuel consumption rate of a 100,000-ton tanker, the other (770) from *Compilation of Air Pollutant Emission Factors, op. cit.*, p. 3-11, by using the highest fuel consumption rate in the range given and assuming a 50,000-ton tanker. One-way trips of 1,000 miles for domestic oil and 2,000 miles for imported oil are assumed; fuel consumption is then doubled to account for the return trip. Conversion factors are 6.56 barrels per ton for crude (average between foreign and domestic); 6.04 barrels per ton for residual fuel oil. *Petroleum Facts and Figures—1971 Edition, op. cit.*, p. 588.

[13] Component net efficiency=(% resource recovered)−(% energy input).

TABLE 14c

Component Efficiencies of a Light Water Reactor Nuclear Electricity System

[In percent]

	Extraction	Processing	Transport	Conversion	Transmission	System [1]
Resource recovered	[2] 95.0	[3] 62.2	[4] 100.0	[5] 31.0	[6] 91.2	16.7
Energy input	[7] .4	[3] 5.2	0	0	0	----------
Component net efficiency	94.6	57.0	100.0	31.0	91.2	16.3

[1] See Table A-1, note 1.

[2] Extraction includes mining and milling. Mining recovery is assumed to be 100 percent. Milling recovers 95 percent of the resource. U.S. Senate, Committee on Interior and Insular Affairs. 1972. *Conservation of Energy.* Serial No. 92-18. Washington, D.C.: Government Printing Office, p. 25.

[3] Processing includes conversion, enrichment, fabrication, and reprocessing. Resource loss in conversion is based on Kerr-McGee data as conveyed to the Council by Seymour Smiley, U.S. Atomic Energy Commission. Enrichment, fabrication, and reprocessing losses and energy inputs are determined from *Conservation of Energy, op. cit.*, p. S-6. Energy inputs are from *ibid.*, pp. C-3, D-3, E-2, F-2.

[4] Based on 47,000 miles of trucking. *Ibid.*, Table H-1, p. H-3. At 5 miles per gallon, the consumption is 9,400 gallons, or 224 barrels, capable of producing less than 160 thousand kilowatt-hours.

[5] A 31 percent powerplant efficiency is assumed. Federal Power Commission. 1971. *The 1970 National Power Survey.* Part I. Washington, D.C.: Government Printing Office, p. I-1-25.

[6] See Table A-1, note 8.

[7] Energy input is from U.S. Atomic Energy Commission, Directorate of Licensing, Fuels and Materials. 1972. *Environmental Survey of the Nuclear Fuel Cycle.* Washington, D.C.: A.E.C., pp. A-3, B-3.

TABLE 15

Some Selected Policy Options in Energy-Environment Conservation

Policy Options	Impact			Public	Implementation
	Environmental	Economic	Social- Political	Acceptability	Possibility
More emphasis on mass transit –Improve and expand service –Reduce fares or no fares –Improve arterial mass transit –Better feeder services, i.e., dial-a-bus –Exclusive bus lanes –Provide fringe parking –Controlled entry to downtown cores –Make parking expensive in downtown cores –Pedestrians only oriented clusters –Develop better and more convenient forms of mass transit	High	Medium to High	High	Medium	Medium
Improve intercity passenger and freight services –Improve and expand service and network –Provide fringe parking –Ban subsidy on short flights by long flights –Encourage containerization and piggy-backing –Develop new and better passenger and freight handling systems	Medium to High	Medium to High	Low to High	Medium to High	Medium
Improve transportation efficiency –Improve automobile efficiency, i.e., better engines and drive trains, low loss tires, improved engine tuning –Improve urban design –Selective registration taxes on size, power, ancillary equipment, attachments –Develop energy efficiency standards for transportation –Encourage research to develop non-petroleum engines, advanced propulsion systems, advanced traffic control systems, etc.	High	High	Medium	Medium	Medium
Improve insulation of buildings to reduce heat loss in winter and heat gain in summer –Make improved and increased insulation mandatory under CMHC regulations –Make arrangements for better caulking and double glazing windows –Reduce excessive window areas –Provide tax incentives for adding insulation	High	Medium	Medium	Medium	Medium
Increase energy prices to reduce demand and achieve better efficiency –Initiate inverse rate structure –Ensure 'normal' investment return –Borrow money for capital investment at the market rate –Include environmental and social costs in the price of energy –Impose taxes and regulations	High	Low	Medium	Low	Medium
Shift heavy load to off-peak hours –Restructure rates –Ban or restrict heavy use of energy during peak hours	Medium	Low	Medium	Low	Low
Provide centralized and efficient heating and air conditioning system to serve a number of buildings	High	Low	Medium	High	Medium
Limit energy which can be consumed by each household and commercial building annually	Medium	Low	Low	Low	Low
Establish minimum efficiencies for air-conditioners, furnaces and other appliances	Medium	Medium	Medium	High	High
Establish more rational lighting standards for homes and offices	Medium	Medium	Medium	High	High
Increase recycling and reuse of materials and products	High	Medium	Medium	Very High	High
Provide economic incentive to upgrade inefficient processes and equipment	Medium	Medium	Low	Medium	Medium
Impose fuel and/or energy tax to generate revenue for research to develop environmentally clean sources of energy, and to improve efficiencies in generation and utilization of energy	Very High	Medium	High	Low (tax increase) Very High (R&D)	Medium
Develop public information and education program to promote efficient utilization of energy	High	Low	High	Very High	High

2.2 Utilization stage

At this stage, where the most important environmental impact occurs, there are basically two ways to proceed: clear up the input fuel or treat and remove the wastes at the output.

2.2.1 Treatment of input fuel

Petroleum has a very wide range of sulfur content and a very simple way to reduce SO_2 emissions is to use low sulfur oil. But fuel oil with less than 0.3% sulfur costs 35% more than with 2% sulfur, and 20% more than with 1% sulfur. For coal, the problem is the same, and low sulfur coal is in increasingly short supply, with increasing costs. An important new perspective could be the gasification of coal which would provide a full desulfurization in the process and, provided that technology of electricity generating systems is adapted (combined cycle gas turbine), would allow too, higher thermal efficiency. But is still too early to assess the real competitivity of such systems.[46] The other pollutants cannot economically be handled so far by input treatment.

2.2.2 Treatment of emissions. (Mainly for electricity generating plants)

Particulate emissions can be controlled by cyclones (devices which force the gas stream in a circular motion, trapping particulates by gravity force), filtration methods, electrostatic precipitators which can remove up to 99% of the total amount but which are quite energy consuming (5% of the capacity of the power plant), and scrubbers, the most thoroughly studied system, which can control SO_2 as well (injection of lime into the boiler, which absorbs SO_2, and the reacted material is removed in a wet scrubber or removed by reacting to form calcium sulfates in a scrubbing tower). Several variants of the scrubber process have been studied,[47] but on the whole, as the National Academy of Engineering said, "commercially proven technology for control of sulfur oxides from combustion processes does not exist."[48] No system is really superior to the others, for particulate removal (see Table 16)[49] nor for gaseous pollutants control.

The average increase in electricity costs to consumers is expected to be about 3 to 6%, due to SO_2 and particulate removal. For nitrogen oxides control, very little is known and scrubbing methods do remove them along with sulfur oxides.

For dissipating waste heat, the best known process is simply to withdraw water from a lake, stream or river, pass it through the condenser and return it heated to the source. One can too, dissipate the heat in the air using wet cooling towers which evaporate water into the atmosphere, or dry cooling towers which reject warm air. Both systems are expensive, are hugh unaesthetic structures and in both cases the meterological effects of cooling the air are unknown. Another solution is to develop beneficial uses for this waste heat.

2.2.3 Land use considerations. (for power plants)

An important parameter in the minimization of environmental impact is the one of location. At macro level, it is the question of the distance of the plant to the load center and to its

fuel inputs, and the trade-offs in costs and environmental impact which are implied. At micro level, it is the choice of a site within the chosen area, according to meteorological, topographical, geological and existing land use elements.[50]

TABLE 16

ADVANTAGES AND DISADVANTAGES
OF PARTICULATE CONTROL DEVICES

Device	Advantages	Disadvantages
Cyclones	- Low Initial Cost - Simplicity of Construction and Operation - Applicability Over Broad Range of Temperatures	- Power Requirements May Increase Over Time - Relatively Low Maximum Efficiency - Inability to Remove Small Particles
Filters	- High Efficiency at All Loads (bags)	- High Maintenance Cost - Require Highly Controlled Operating Conditions - Large Space Requirement
Electrostatic Precipitators	- Low Operating Cost and Power Requirements - High Efficiency - Can Operate at High Temp.	- Require Highly Controlled Operating Conditions - High Initial and Maintenance Costs - Large Space Requirement
Scrubbers	- May be Used as Cooling Devices - By-product Recovery Possible - Removal of Both Gaseous Pollutants and Particulates Possible - High Efficiency - Applicability for Wide Range of Operating Parameter	- High Initial Cost - High Operating Cost and Power Requirements - Subject to Operating Problems - Large Volume of Sludge is Produced

2.2.4 Possible results and costs (for power plants)

Various cost evaluations have been made which of course would have to be adapted to other countries, give at least an order of magnitude of the costs which are implied. Table 17[51]

shows that for coal and oil plants cost increases would be of 30 to 35%, 70 to 80% for air pollution removal, and a 5% cost increase for nuclear and natural gas plants (because natural gas is already a clear fuel and nuclear plants major problems cannot be addressed with end-of-the-pipe devices.

TABLE 17

Cost of Controls and Changes in Environmental Impacts of 1,000-Megawatt Electric Energy Systems Operating at a 0.75 Load Factor With a High Level of Environmental Controls [1]

[In percent]

System		Air		Water [2]		Land		Solid waste [3]	Total cost increase [8]
		Tonnage change	Cost increase	Tonnage change	Cost increase	Acreage change [4]	Cost increase	Tonnage change	
Coal	Deep-mined	−81.3	23	−96.2	4	+1	0	+159	28
	Surface-mined	−81.3	23	−92.4	4	−37	4	+29	31
Oil [5]	Onshore	−73.0	11	−38.8	5	0	0	0	36
	Offshore	−73.0	31	−38.8	5	0	0	0	36
	Imports	−39.4	28	−77.2	5	0	0	0	34
Natural gas		0	0	0	5	0	0	0	5
Nuclear		[7] −29.8	1	0	4	0	0	0	5

[1] See the Appendix for details.
[2] Costs of cooling tower construction and operation are considered with water controls.
[3] Solid waste costs are included in air and water pollution controls.
[4] Land impacts are reduced by reclamation but are increased for solid waste disposal.
[5] The total percentage cost increase may differ from the sum of the media percentage cost increases because of rounding.
[6] In the case of oil-fired systems, price increases for desulfurized oil are the primary cost effect.
[7] Radioactive emissions from the nuclear system are reduced by controls at the powerplant.

The details of the calculus and pollution control devices are given in Appendix C,[52] which breaks down the figures. Table 18[53] gives the costs per step for the energy system: generation (table 18a), transmission (18b), distribution (18c), right of way (18d), and for anti-pollution device or element (18e).

3. New energy systems

There are many techniques under development for exploiting new energy resources, improving the efficiency of use of those already developed, and for reducing the environmental impact. Those which seem to offer the greatest promises for the short term include tapping geothermal energy and oil shale, gasifying coal and developing several advanced nuclear power systems. Long term promising technologies are nuclear fusion and solar energy, which hold promise of significantly freeing us from reliance on earth's limited fossil and nuclear fuel resources and whose environmental impact may be substantially less than alternative technologies.

Geothermal steam or superheated water is produced when the earth's heat energy is transferred to surface waters. When the pressure and temperature are adequate, the steam may be used in

TABLE 18a

. Increased Generating Costs Due to Environmental Control Expenditures

Steam electric generation	Cost per kw	
	Fossil[a]	Nuclear[b]
	(-------*dollars*-------)	
1. Tall stack	4.00	2.00
2. SO_2 removal, minus credit	8.00	–
3. Advanced electrostatic precipitator	2.00	–
4. Wet cooling tower, induced draft	4.00	6.00
5. Wet cooling tower, natural draft	5.50	8.25
6. Dry cooling tower, minus credit	18.00	27.00
7. Noise suppression	0.50	–
8. Monitoring devices	0.50	0.50
9. Improved architectural design and landscaping	3.00	4.00
10. Intake and discharge structures, improved design	3.00	4.00
11. General improved design standards	2.00	8.00
	(------*mills/kwh*------)	
12. Higher-cost fuel[c]	0.510 0.864 1.125	–
13. Operating cost of monitoring devices	0.012	0.020
14. Increased research	0.050	0.050

NOTE: These costs apply to both new and old plants.

[a] 1,300 mw unit size.
[b] 1,100 mw unit size.
[c]

TABLE 18b

. Summary of Increased Electric Power Transmission Costs, Reflecting Environmental Control Expenditures

	End of decade		
	1970-1980	1980-1990	1990-2000
1. Investment cost, new, no allowance for environmental costs (*$/kw*)	68.00	53.30	45.50
2. Investment cost, weighted new and old, no allowance for environmental costs (*$/kw*)	74.00	65.20	57.80
3. Environmental cost to modify old equipment (*$/kw*)	10.00	10.00	10.00
4. Environmental cost component of new equipment (*$/kw*)	7.80	8.00	8.53
5. Sum of lines 2, 3, and 4	91.80	83.20	76.33
6. Incremental cost (line 5 minus $80) (*$/kw*)	11.80	3.20	-3.67
7. Annual incremental capital charge (line 6 at 15%) (*$/kw*)	1.77	0.48	-0.55
8. Total incremental cost (*mills/kwh*)	0.331	0.090	-0.103

NOTES: These calculations apply to a system having a 1970 peak of 10,000 mw and a net utility plant (original cost minus depreciation reserve) of $325/kw of maximum demand, and consisting of the following costs: generation, $140; transmission, $80; distribution, $85; miscellaneous, $20.

These judgments and calculations of the author are based in part on the following assumptions and considerations, each of which relates to the corresponding line in the table.

(1) New investment cost shown in line 1 declines by approximately 33 percent every 20 years due to technological improvement (including higher voltages).

(2) Demand doubles in the first decade, increases 75 percent in the second decade, and increases 60 percent in the third decade.

(3) Modification of old plant, shown in line 3, is based on the following estimated costs:

$1.33/kw/year in first decade
$0.55/kw/year in second decade
$0.46/kw/year in third decade

(4) Environmental cost of new equipment, shown in line 4, assumes the following increments to new equipment costs:

20 percent in first decade
35 percent in second decade
50 percent in third decade

(6) Calculated as the difference from new investment cost in 1970.

(8) Based on 5,350 hours per year. Note that the figures in this line reflect the combined effect of changes in power costs arising from environmental factors, on the one hand, offset to a limited extent by assumed technological improvements—hence reduced real costs—in transmission, on the other.

Best Available Document

TABLE 18c

Summary of Increased Electric Power Distribution Costs, Reflecting Environmental Control Expenditures

	End of decade		
	1970–1980	1980–1990	1990–2000
1. Investment cost, new, no allowance for environmental costs (*$/kw*)	79.05	73.52	68.37
2. Investment cost, weighted new and old, no allowance for environmental costs (*$/kw*)	82.03	78.50	74.50
3. Environmental cost to modify old equipment (*$/kw*)	10.00	10.00	10.00
4. Environmental cost component of new equipment (*$/kw*)	13.84	14.20	14.10
5. Sum of lines 2, 3, and 4	105.87	102.70	98.60
6. Incremental cost (line 5 minus $85) (*$/kw*)	20.87	17.70	13.60
7. Annual incremental capital charge (line 6 at 15%) (*$/kw*)	3.13	2.65	2.04
8. Total incremental cost (*mills/kwh*)	0.585	0.495	0.381

NOTES: System characteristics are described in note to table 4a.

These judgments and calculations of the author are based in part on the following assumptions and considerations, each of which relates to the corresponding line in the table.

(1) New investment cost shown in line 1 declines by 7 percent every 10 years due to technological improvements (including higher distribution voltages).

(2) Demand doubles in the first decade, increases 75 percent in the second decade, and increases 60 percent in the third decade.

(3) Modification of old plant, shown in line 3, is based on the following estimated costs:

$1.33/kw/year in first decade
$0.55/kw/year in second decade
$0.46/kw/year in third decade

(4) Environmental cost of new equipment, shown in line 4, assumes following increments to new equipment costs:

35 percent in first decade
45 percent in second decade
55 percent in third decade

(6) Calculated as the difference from new investment cost in 1970.

(8) Based on 5,350 hours per year. Note that the figures in this line reflect the combined effect of changes in power costs arising from environmental factors, on the one hand, offset to a limited extent by assumed technological improvements—hence reduced real costs—in distribution, on the other.

TABLE 18d

Summary of Increased Costs of Rights-of-Way and Public Information due to Environmental Control Expenditures

	End of decade		
	1970–1980	1980–1990	1990–2000
Incremental costs (*mills/kwh*) for:			
1. Rights-of-way	0.017	0.017	0.017
2. Public information	0.020	0.020	0.020
Total	0.037	0.037	0.037

NOTES: The distinguishing characteristics of rights-of-way and public information components of electricity costs should be noted: a rights-of-way cost can be amortized over a period of years, while a public information charge cannot be amortized and has to be charged off in the year it is made.

Data on system characteristics, capital charge, and load factor appear in Table 4a.

These judgments and calculations of the author are based in part on the following assumptions and considerations, each of which relates to the corresponding line in the table.

(1) The calculation for the first decadal interval is based on a total system rights-of-way cost of $9 million per year, which reduces to an average of $0.60/kw/year or 0.017 mills/kwh. The estimates for the succeeding two decades were computed so as to equalize costs with the first decade.

(2) Based on a system public information cost during the first decade of $1.5 million per year, which reduces to $0.10/kw/year or 0.020 mills/kwh. Succeeding decades estimated as in line 1.

TABLE 18e

. Summary of Total Increases in the Cost of Electric Power, Reflecting Environmental Control Expenditures

(*mills/kwh*)

	End of decade		
	1970-1980	1980-1990	1990-2000
1. Generation:			
Fossil fueled	0.791	1.249	1.547
Nuclear fueled	0.218	0.419	0.461
2. Transmission	0.331	0.090	-0.103
3. Distribution	0.585	0.495	0.381
4. Miscellaneous (rights-of-way and public information)	0.037	0.037	0.037
Subtotal	1.962	2.290	2.323
5. Factor of ignorance (25 percent)	0.491	0.573	0.581
Total of above	2.453	2.863	2.904
Total (rounded)	2.50	2.90	3.00

turbines for conversion of electricity. Exploitable sites have been developed in Japan, Italy, Iceland, New Zealand, and other places, but generally this energy resource is not economic. Few surveys of geothermical resources have been made so that it is impossible to assess the real potential of this new source. But it is probable that the environmental impact would be significant, since noxious gases are discharged with the water, which too is very loaded in salts: the temperature not being very high, the system would not be very efficient, and a large amount of waste heat would be discharged. Exploitation of thermal energy of the terrestrial magna is a longer term possibility which feasibility is still unpredictable.

Oil shale containing more than 25 gallons of petroleum per ton of shale do exist in many parts of the world in huge amounts, and the technological framework considered applicable to commercial oil shale applications using surface mining techniques, is accurately developed. The problem is that very large surfaces of land would be disrupted, and large amounts of solid residual generated, with significant discharges of hydrogen sulfide.[54] Large amounts of water would be needed for shale oil upgrading.

In the nuclear area, there are too, potential developments, and in particular the Liquid Metal Fast Breeder Reactor (LMFBR) which is given top priority in research, and may become available for commercial application in the late 1980's. The specific feature of these reactors is that they produce more nuclear fuel than they consume, and are able to use 60% of the total energy of Uranium as opposed to 2% for the actual reactors, thus drastically diminishing the fuel needs. They will produce less waste heat, less radioactivity in the air, no (or almost no) Uranium mining and enrichment, but they will oblige the shipment, handling and management of fission products of much greater radioac-

tivity, produced in ever increasing quantities, remaining highly dangerous practically forever (plutonium). Despite the potential problems, the LMFBR holds promise as a relatively clean source of energy with a fuel supply that would last for centuries.

A longer term possibility is the controlled thermo nuclear fusion: under extreme condition the nuclei of deuterium can fuse to make a heavier element releasing enormous quantitites of energy which can then be converted in an almost infinite source of energy, since deuterium can be extracted at low cost from the sea. But the temperature needed for fusion is more than 100 million degrees, and the fusion has to be contained somehow in a magnetic field which would be used to convert the energy into electricity directly too. The technological and economic problems are great, a demonstration fusion power system might be built before the end of the century. The translation in an economical system would require many more billions of dollars and years of effort.

It has been quite long since it is known how to power an engine by solar energy or heat water. But it remains to show that the solar heat collecting devices are economic, and the geographical location is always a crucial factor. Solar cell converting solar energy directly into electricity need to be ameliorated to have better efficiency and be built at relatively low cost. Owing to the highly unfavorable economics of the solar cell produced electricity, it is quite unlikely that solar energy will become anything else than a support energy for individual or very local purposes for many years.

CONCLUSION

The attainment of a sensible trade-off between energy growth and the environment is seriously hampered at present at the energy stage of analysis and decision making by ignorance. By lack of knowledge of the effects of various discharges in land, air and water, by the relative unavailability of economic methodologies to determine the value society puts on incremental improvements or worsening of environmental parameters due to different levels of pollution or to determine how regulations to curb pollution would affect prices, employment or location of different industries. We might take decisions which may create irreversible environmental damages or sacrifice acceptable development due to unreasonable or unnecessary environmental regulations.

But the problem is not only one for technicians, scientists, economists or administrators. It is ultimately a question of finding out what the people want and if what they want is feasible within technological, economic, and administrative limits. And the ultimate answer can only be found in the political arena.

Finally, we can recall the UN Stockholm Conference on the human environment (1972) which declared that "it is essential to

consider multiple choices in the planning and management of any energy economy" and adopted the following recommendation: "each nation should set up a national energy board to corodinate energy developments and utilization policies, staffed with highly qualified personnel, icnluding some in the discipline relating to the adverse environmental effects of energy" that would already be, if implemented, a serious reason for hoping once again the genius of man will make him find his way to much higher degrees of human development.

FOOTNOTES

[1]See Gordon J. McDonald, "Energy and the Environment," in Sam Schurr, ed., Energy, Growth and the Environment, Johns Hopkins University press, 1973, p. 102.

[2]Source: Council on Environmental Quality, Washington, D.C., Energy and the Environment, Electric Power, August 1973, p. 4.

[3]For this discussion on energy consumption, see: Joel Darmstadter, "Energy Consumption," in Sam Schurr, ed., op. cit., p. 176.

[4]See J.S. Steinhart, "Energy use in the US Food System," in Science, 19 April 1974, pp. 307-316 and

E. Hirst, "Food Related Energy Requirements," in Science, 12 April 1974, pp. 134-138.

[5]Council on Environmental Quality, Environmental Quality, First Annual Report, 1970, p. 159.

[6]Naylor, T., International Journal of Agrarian Affairs, Oct. 1963.

[7]Source: Asit K. Biswas, Energy and the Environment, Planning and Finance Service, Report no. 1, Canada, 1973, p. 13.

[8]From Joel Darmstadter, op. cit., p. 206.

[9]U.S. Department of the Interior, Surface Mining and our Environment, Washington, D.C., 1967, p. 117.

[10]Council on Environmental Quality, Environmental Quality, First Report, 1967, p. 107.

[11]Source: Asit K. Biswas, op. cit., p. 14.

[12]Joel Darmstadter, op. cit., p. 206.

[13]Ford Foundation Report, Time to Choose, 1974, Ballinger Publishing Co., p. 1[illegible]).

[14]Source: OECD, Energy and the Environment, Paris, 1974, p. 45.

[15]Council on Environmental Quality, op. cit., p. 11.

[16]U.S. Health, Education and Welfare Department, Preliminary Air Pollution Survey of Vanadium, Raleigh, N.C., 1969, p. 29.

[17]Lave and Seskin, "Air Pollution and Human Health," Science, 1970, pp. 723-753.

[18]Source: Gordon J. McDonald. "Energy and the Environment" in Sam Schurr, ed., op. cit., p. 108.

[19]Federal Power Commission, Steam Electric Plant Construction Costs and Annual Production Expenses, 23rd Annual Supplement, 1970, p. xxxi.

[20]Source: Asit K. Biswas, op. cit., p. 18.

[21]Source: Council on Environmental Quality, Energy and the Environment, Electric Power, p. 14.

[22]Ibid, pp. 42, 43, 48, 49.

[23]Joel Darmstadter, op. cit., p. 216.

[24]David J. Rose, "Nuclear Electric Power," Science, 19 April, 1974, p. 355.

[25]"Nuclear Safety; Calculating the Odds of Disaster," Science, 6 Sept. 1974, p. 838.

[26]See A. R. Tamplin and T. B. Cochrane, Radiation Standards for Hot Particles, Natural Resources Defense Council, Washington, D.C., 1974, and D. J. Rose, op. cit.

[27]National Technical Information Service, An Assessment of Accident Risks in US Commerical Nuclear Power Plants, Washington, D.C., Atomic Energy Commission, August 1974.

[28]"EPA Cites Errors in AEC's Reactor Risk Study," Science, 13 Dec. 1974, p. 1008.

[29]David Rose, op. cit., p. 355.

[30]D.J. Rose and A.S. Kubo, Science, Vol. 182, p. 1205 (1973).

[31]OECD, op. cit., p. 46.

[32]C.B. Lave and L.C. Freeburg, Nuclear Safety, Vol. 14, p. 409 (1973) and C. Starr et.al., Nuclear News, Vol. 15, p. 37, (1972).

[33]Source: D.J. Rose, op. cit., p. 354.

[34]Source: Asit K. Biswas, op. cit., p. 10.

[35]Source: CEQ, Energy and the Environment, Electric Power, p. 57.

[36]See Neil Fabricant and Robert M. Hallmann, Towards a Rational Power Policy, Georges Brazillier, New York, 1971, p. 186.

[37]Source: Anna P. Carter, "Application of Input-Output Analysis to Energy Problems," Science, 19 April 1974, p. 329.

[38]See Charles A. Berg, "Energy Conservation through Effective Utilization," Science, 13 July 1973, p. 132, and G. A. Lincoln, "Energy Conservation," Science, 13 April, 1973, p. 157.

[39]Source: Council on Environmental Quality, Fifth Annual Report, 1974, p. 17.

[40]CEQ, Energy and Environment, op. cit., p. 40, 46, 55.

[41]N. Fabricant, op. cit., p. 77.

[42]G.A. Lincoln, op. cit., p. 160.

[43]Source: Asit K. Biswas, op. cit., p. 37.

[44]Source: Council on Environmental Quality, Energy and the Environment, pp. 41, 47, 56.

[45]Charles J. Cichetti, Alaskan Oil, Resources for the Future, Johns Hopkins University Press, 1972.

[46]A.M. Squires, "Clean Fuels from Coal Gasification," Science, 19 April, 1974, p. 340.

[47]J.T. Dunham, "High Sulfur Coal for Generating Electricity," Science, 19 April, 1974, p. 346.

[48]National Academy of Engineering, National Research Council, Abatement of Sulfur Oxides Emissions from Stationary Combustion Sources, NTIS, Springfield, Va., 1970.

[49]Source: Ralph Stone & Co., Inc., Decision Maker's Guidebook for Industrial Pollution Control, Feb. 1975, p. IV-6.

[50]Ralph Stone and Co., Inc., op. cit.

[51]Source: Council on Environmental Quality, op. cit., p. 19.

[52]Source: ibid, pp. 44-45, 50-51, 58.

[53]Source: Philip Sporn, "On Energy Growth and the Environment," in Sam Schurr, ed., op. cit., pp. 82-87.

[54]U.S. Department of the Interior, Draft Environmental Statement for the Proposed Oil Shale Leasing Program, Washington, D.C.

Annual Environmental Impacts of Uncontrolled Coal-Fired Electricity Systems Associated With a 1,000-Megawatt Powerplant With a Load Factor of 0.75

Impact		Extraction		Processing	Transport [1]	Conversion	Transmission	Total	
		Deep	Surface					Deep	Surface
Land [2]	Acres	[3] 9,120	[4] 14,010	[5] 161	[6] 2,213	[7] 696	[8] 17,188	29,378	34,268
Water	Tons	[9] 2,661	[9] 35,820	[10] 3,853	0	[11] 813	0	7,327	40,486
	Btu's	0	0	0	0	[12] 3.05×10^{12}	0	3.05×10^{12}	3.05×10^{12}
Air	Tons	[13] NA	[13] NA	[14] 4,714	[15] 26,270	[16] 352,217	0	383,201	383,201
Solid waste	Tons	[17] 97,141	[17] 2,762,000	[18] 454,092	0	[19] 50,800	0	602,033	3,266,892
Occupational health	Deaths	[20] 1.67	[20] 0.308	[21] 0.0238	[22] 2.30	[23] 0.012	NA	4.00	2.64
	Injuries	[20] 85	[20] 13.9	[21] 2.56	[22] 23.4	[23] 1.38	NA	112.3	41.2
	Workdays lost	[20] [24] 12,688	[20] 499	[21] 99.5	[22] 2,340	[23] 152.9	NA	15,280	3,091

NA = Not available.

[1] Impacts of coal transport are based on coal transport exclusively by rail for an average distance of 300 miles. See Table A-1, note 11. Annual coal transport for a 1,000-MWe powerplant is 0.10 percent of the total 1970 national ton-mileage. Transportation Association of America. July 1972. *Transportation Facts and Trends, Ninth Edition*. Washington, D.C.: T.A.A., p. 8.

[2] All land impacts are expressed as a time average of the amount of land in use over 30 years. Fixed land use is therefore taken as its full amount; average variable use is 15 times the annual incremental damage.

[3] Annual incremental land impact is 608 acres, including 607 acres affected by subsidence and less than 1 acre for storage of solid wastes. The subsidence rate is 0.1 acre per 500 tons produced. Delson, Jerome K. and Richard J. Frankel. April 1972. "Residuals Management in the Coal-Energy Industry." Manuscript to be published by Resources for the Future, Inc. Washington, D.C.: R.F.F., p. II-2a. The land disturbed by storage of underground mining wastes is based on a land use rate of 84,400 tons of waste per acre of waste bank. McNay, Lewis N. 1971. *Coal Refuse Fires: An Environmental Hazard*. U.S. Department of the Interior, Bureau of Mines. Washington, D.C.: Government Printing Office, pp. 1, 8. This figure corresponds to waste banks averaging 35 feet high, assuming a density of 1.5 tons per cubic yard for the refuse. See note 17 for a discussion of tonnage produced.

[4] Annual incremental land impact is 934 acres. Derived from 308 acres per million tons mined. U.S. Bureau of Mines data for 1969. U.S. Senate Committee on Interior and Insular Affairs. December 1971. *The Issues Related to Surface Mining*. Serial No. 92-10. Washington, D.C.: Government Printing Office, p. 2.

[5] Fixed land use is 80 acres and annual incremental land use is 5.4 acres. For fixed land use, it is assumed that one processing plant is required for every million tons of raw coal processed. Based on data in U.S. Department of the Interior, Bureau of Mines. 1971. *Minerals Yearbook—1969*. Washington, D.C.: Government Printing Office, p. 347. Each processing plant is assumed to occupy 40 acres. See notes 3 and 18 for a discussion of the acreage affected by solid wastes.

[6] Total railroad track in 1969 was 365,000 miles. U.S. Bureau of the Census. 1971. *Statistical Abstract of the United States: 1971*. Washington, D.C.: Government Printing Office, p. 545. A right-of-way of 50 feet is assumed. Total land utilized is then multiplied by .0010. See note 1.

[7] Typical plant size for 3,000-MWe plants with fly ash controls is 1,050 acres, including 350 for ash storage and 40 for coal storage. Executive Office of the President, Office of Science and Technology, Energy Policy Staff. 1968. *Considerations Affecting Steam Power Plant Site Selection*. Washington, D.C.: Government Printing Office, pp. 11, 14. Land requirements for an uncontrolled 1,000-MWe powerplant are similar except that coal and ash storage acreages are reduced by factors of 3 and 15, respectively. See note 19 for the level of ash control.

[8] Based on estimated land right-of-way of 4 million acres. U.S. Department of the Interior and U.S. Department of Agriculture. 1970. *Environmental Criteria for Electric Transmission Systems*. Washington, D.C.: Government Printing Office, p. III. This acreage is multiplied by .00130, the share of total 1970 U.S. electricity production represented by a 1,000-MWe plant. Federal Power Commission. 1972. *Annual Report—1971*. Washington, D.C.: Government Printing Office, p. 11.

[9] Comparison of aggregated figures here is deceptive, because they consist mostly of acid for deep mining and siltation for surface mining. Disaggregated figures, in tons, are:

	Deep	*Surface*
Sulfuric acid	2,129	166
Dissolved iron	532	42
Silt	0	35,612

These figures are based on an increment of 20,000 tons of sulfuric acid and 5,000 tons of dissolved iron from 1-year's U.S. coal production with runoff continuing for 15 years. Delson and Frankel, *op. cit.*, p. II-8. This drainage was then allocated to deep mines (95.4 percent) and surface mines (4.6 percent), according to data on active mines in Appalachian Regional Commission. 1969. *Acid Mine Drainage in Appalachia*. Washington, D.C.: A.R.C., p. 30. The drainage was further allocated to the 1,000-MWe powerplant by its share of the annual U.S. production, namely 0.74 percent of annual deep-mined production or 1.20 percent of surface-mined production. U.S. totals from *Minerals Yearbook—1969, op. cit.*, p. 309. Siltation was estimated at 3.0 tons per acre per year for 15 years. U.S. Department of the Interior, Geological Survey. 1970. *Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin, Kentucky, 1955–66*. Professional Paper 427-C, Washington, D.C.: Government Printing Office, p. C2. Calculation based on 308 acres per million tons of surface-mined coal. See note 4.

[10] The discharge of blackwater solids from current plants is used as the basis for the "uncontrolled" plant because settling ponds are common practice; discharges would be about 250 times greater were there no control measures. Calculated from an estimate of 1968 nationwide discharges of 100,000 tons. Delson and Frankel, *op. cit.*, p. II-9. The fraction of coal mined in 1968 that is used in a 1,000-MWe plant is based on Figure A-1 and *Minerals Yearbook—1969, op. cit.*, p. 309. Siltation from processing waste banks is taken to be 42 tons per acre per year for 15 years, based on data in *Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin, Kentucky, 1955–66, op. cit.*, p. C2. There is some acid drainage, but it is believed to be much smaller. See note 5 for acreage data.

[11] Although reliable data are not available, the following preliminary estimates were derived from Aynsley, Eric, and Meryl R. Jackson. May 1971. "Industrial Waste Studies: Steam Generating Plants."

Unpublished draft prepared for the U.S. Environmental Protection Agency, Water Quality Office, Research Triangle Park, N.C., p. 67. Note that suspended solids from ash are assumed to be controlled to over 99 percent, and dissolved solids from ash ponds are not included. Water discharges, in tons, are:

Suspended solids: Ash	14
Suspended solids: Other	411
Nondegradable organics	55
BOD	2
Acid	68
Alkali	9
Chlorine	22
Phosphates	25
Boron	205
Chromates	2
Total	813

[12] Based upon a powerplant efficiency of 38 percent, 62 percent of the British thermal units input is rejected heat. Of this, one-sixth is rejected with the stack gases. Delson and Frankel, *op. cit.*, p. II-13.

[13] Burning underground or surface coal seams have undetermined air emissions. Air pollution data from fuels needed to power mining equipment are not available (new mining equipment often runs on electricity rather than fossil fuels).

[14] Air emissions consist of coal dust from dry processing and from thermal drying of some wet processed coal. Emissions from current plants are used as the basis for an "uncontrolled" plant because cyclone dust collectors are common practice and pay for themselves in coal reclaimed. Delson and Frankel, *op. cit.*, p. IV-40. Calculated from estimate of 1968 emissions of 1 million tons, almost entirely from thermal drying, *Ibid.*, p. II-9, times fraction of coal used in that year by a 1,000-MWe powerplant.

A significant quantity of air pollution occurs from the uncontrolled burning of coal waste banks. These are estimated below but are not included in the total because it is assumed that new processing plants would not have this problem. Nationwide emissions in 1968 are estimated in U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration. 1970. *Nationwide Inventory of Air Pollutant Emissions 1968.* Washington, D.C.: Government Printing Office. These emissions are multiplied by the fraction of 1968 coal production represented by a 1,000-MWe plant. *Minerals Yearbook—1969, op. cit.*, p. 300. Air pollution from burning waste banks related to a 1,000-MWe electrical plant, in tons, are:

Carbon monoxide	6,510
Particulates	2,180
Sulfur oxides	3,270
Hydrocarbons	1,090
Nitrogen oxides	1,090
Total	14,170

[15] Air emissions (570 tons) based on railroad consumption of diese fuel at the rate of 1 gallon per 200 ton-miles assuming 136,000 British thermal units per gallon. Rice, R. A. "System Energy as a Factor in Considering Future Transportation." A paper presented at the American Society of Mechanical Engineers winter annual meeting, November 29-December 3, 1970. Also assuming a 300-mile average movement of coal by rail and all coal for the 1,000-MWe powerplant sent by rail. Uncontrolled emissions are based on data from U.S. Environmental Protection Agency, Office of Air Programs. 1972. *Compilation of Air Pollutant Emission Factors.* Washington, D.C.: Government Printing Office, p. 3-7. Specific emissions, in tons, include:

Carbon monoxide	135
Particulates	48
Sulfur oxides	125
Hydrocarbons	96
Nitrogen oxides	145
Aldehydes	8
Organic acids	13
Total	570

In addition, 25,700 tons of coal is blown away during transport. See Table A-1, note 6.

[16] Emission factors are from *Compilation of Air Pollutant Emission Factors, op. cit.*, p. 1-3. They apply to a "general" pulverized-feed furnace of over 100 million British thermal units per hour without control equipment. Ash content is estimated at 10 percent. Smith, W. S., and C. W. Gruber. 1966. *Atmospheric Emissions from Coal Combustion—An Inventory Guide.* Cincinnati: U.S. Department of Health, Education, and Welfare, Public Health Service, p. 12. Sulfur content is taken as 2.58 percent, the average for 1969, from Princiotta, Frank T. "Control of Sulfur Oxide Pollution from Power Plants." Paper prepared for the American Public Power Association, Engineering and Operations Workshop, March 14, 1972. Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Control Systems Division. Air emissions from the powerplant, in tons, are:

Particulates	203,200
Sulfur oxides	124,500
Carbon monoxide	1,270
Hydrocarbons	381
Nitrogen oxides	22,860
Aldehydes	6
Total	352,217

An insignificant amount (equivalent to approximately 2.2 curies) of radioactivity is emitted annually from a 1,000-MWe coal-fired plant. This figure was derived from Martin, James E., Harvard, Ernest D., and Donald T. Oakley. 1969. "Comparison of Radioactivity from Fossil Fuel and Nuclear Powerplants." Washington, D.C.: U.S. Department of Health, Education, and Welfare.

[17] About 90 percent of the overburden from surface mining is redeposited on the site. This portion is excluded from the total. Nationwide estimates for solid wastes from 1966 coal production are 12.8 million tons for deep mining and 210 million tons of overburden wastes from surface mining. U.S. Department of the Interior. 1970. "Environmental Effects of Underground Mining and Mineral Processing." Unpublished report. Washington, D.C.: D.O.I., pp. 124, 126. Production figures for 1966 are from *Minerals Yearbook—1969, op. cit.*, pp. 300, 371.

[18] Of the extracted coal, 65.9 percent is processed, and 23 percent of that, or 459,257 tons, is waste. *Ibid.*, p. 347. Of this, 451 tons is blackwater solids and 4,714 is airborne, leaving 454,092 tons as solid waste. See notes 10 and 11.

[19] In note 16 it was estimated that 10 percent of the coal burned, 254,000 tons, is ash, 203,200 tons of which is emitted to the air as fly ash. The remainder is solid waste.

[20] The following 1970 death and injury rates were provided to the Council by Mary McNair, U.S. Department of the Interior, Bureau of Mines, Office of Technical Support, based upon Moyer, Forrest T., ed. 1971. *Injury Experience and Worktime in the Mineral Industries, 1969-1970.* Washington, D.C.: U.S. Department of the Interior, Bureau of Mines. For deep mines, there were 0.65 fatalities and 28.07 nonfatal injuries per million tons mined and 55 workdays lost per injury. For surface mines, there were 0.12 fatalities, 5.40 nonfatal injuries, and 36 workdays lost per injury.

[21] The death rate for processing operations is 0.0147 per million tons and the injury rate is 1.58 per million tons. Each injury averages 28.9 workdays lost. *Ibid.*, p. 29. Coal production statistics from *Minerals Yearbook—1969, op. cit.*, p. 300.

[22] National railroad death and injury statistics are from U.S. Bureau of the Census. 1971. *Statistical Abstract of the United States: 1971.* Washington, D.C.: Government Printing Office, p. 519. It is assumed that the average injury leads to a loss of 100 workdays. It should be noted that most railroad deaths occur at grade crossings. An additional major component of deaths is trespassers. Personal communication with the National Safety Council. Also see Table A-1, note 11.

[23] Olmstead, Leonard M. "17th Annual Steam Station Cost Survey." *Electrical World.* November 1, 1971, p. 46, based on 0.113 men per MWe. Injury data are from National Safety Council. 1971. *Accident Facts—1971 Edition.* Chicago: N.S.C., p. 35. One-half the combined deaths and permanent injuries are assumed to be fatal injuries. Permanent total disabilities are considered to represent 6,000 workdays lost, and other disabilities are estimated as 100 days lost.

[24] Pneumoconiosis workdays lost are attributed solely to complicated pneumoconiosis cases as determined by roentgenographic findings in 1964 field examinations. These cases are assumed to cost 6,000 workdays each. Based upon the average number of years each miner had worked, prevalence data are converted into estimated incidence rates. Lainhart, W. S., Doyle, H. N., Enterline, P. E., Henschel, A., and M. A. Kendrick. 1969. *Pneumoconiosis in Appalachian Bituminous Coal Miners.* Section IV, "Prevalence of Respiratory Symptoms in Two Appalachian Communities." Cincinnati: U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Occupational Safety and Health. In *Hearings before the Subcommittee on Labor of the Committee on Labor and Public Welfare, United States Senate, Ninety-Second Congress, First and Second Sessions, on S. 2675, S. 2289, H.R. 9212.* 1972. Washington, D.C.: Government Printing Office, pp. 482, 486. Incidence rates are 3.47 simple cases per 1,000 man-years; 1.60 complicated cases per 1,000 man-years; and 2.14 suspect cases per 1,000 man-years. Productivity per workday data are from *Minerals Yearbook—1969, op. cit.*, p. 332. These data are based on coal shipments, reflecting cleaning losses, and are modified according to Table A-1. Two-hundred workdays per man-year are assumed, and 834 man-years are needed to supply coal for a 1,000-MWe powerplant. The number of workdays lost as a result of complicated pneumoconiosis is estimated at 8,010.

Annual Environmental Impacts of Uncontrolled Oil-Fired Electricity Systems Associated With a 1,000-Megawatt Powerplant With a Load Factor of 0.75

Impact		Extraction		Processing	Transport			Conversion	Transmission	Total		
		Onshore	Offshore		Onshore	Offshore	Import			Onshore	Offshore	Import
Land	Acres	[1] 1,572	[2] 164	[3] 76	[4] 1,656	[4] 168	[4] 10	[6] 250	[7] 17,188	20,742	17,846	17,448
Water	Tons	[8] 111	[9] 102	[10] 4,631	[11] 435	[11] 527	[11] 1,711	[12] 813	0	5,990	6,073	2,524
Air	Btu's	0	0	0	0	0	0	[13] 3.05×10^{13}	0	3.05×10^{13}	3.05×10^{13}	3.05×10^{13}
Solid waste	Tons	0	0	[14] 87,524	[15] 1,507	[15] 1,507	[15] 1,326	[16] 69,321	0	158,352	158,352	70,647
	Tons	0	0	0	0	0	0	0	0	0	0	0
Occupational health	Deaths	[17] 0.21	[17] 0.21	[18] 0.08	[19] 0.05	[19] 0.05	[19] 0.05	[20] 0.010	NA	0.35	0.35	0.06
	Injuries	[17] 21	[17] 21	[18] 5.6	[19] 4.5	[19] 4.5	[19] 4.5	[20] 1.15	NA	32.3	32.3	5.7
	Workdays lost	[17] 2,135	[17] 2,135	[18] 785	[19] 562	[19] 562	[19] 562	[20] 127.2	NA	3,609	3,609	689

NA = Not available.

[1] One thousand seventy-two onshore wells are required to supply a 1,000-MWe plant, based on average well production for the United States. U.S. Department of the Interior, Bureau of Mines. December 1971. *Mineral Industry Surveys: Crude Petroleum, Petroleum Products, and Natural-Gas-Liquids: 1970 (Final Summary)*. Pittsburgh: D.O.I., B.O.M., Table 3. Land area required for drilling rig and attendant equipment and supplies is estimated at 1 acre per well. InterTechnology Corporation, Warrenton, Va.

[2] One hundred sixty-four offshore wells are required to supply a 1,000-MWe plant, based on average well production of Gulf Coast offshore wells. U.S. Deprtment of the Interior, Bureau of Land Management. 1972. *Final Environmental Statement—Proposed 1972 Outer Continental Shelf Oil and Gas General Lease Sale, Offshore Eastern Louisiana*. Washington, D.C.: D.O.I., pp. 63, 132. Sea surface area required for equipment, considered a land impact, is estimated as in note 1.

[3] Land required for production facilities, administration, maintenance, storage, and surrounding "green belt," for a refinery of 51.75 million barrels per year capacity, is estimated at approximately 400 acres. Arthur D. Little, Inc., Cambridge, Mass.

[4] Land impact for pipeline transport is based on 1969 figures for total U.S. crude oil trunkline mileage (73,630) times the fraction of the total number of wells in the U.S. needed for a 1,000-MWe plant. American Petroleum Institute. 1971. *Petroleum Facts and Figures—1971 Edition*. Washington, D.C.: A.P.I., p. 215; and notes 1 and 2. A 62.5-foot right-of-way is assumed, averaged from data in Petroleum Extension Service and Pipeline Contractors Association. 1966. *A Primer of Pipe Line Construction*. Austin: Texas Education Agency.

[5] Terminal storage facilities of approximately 30 days' supply are necessary due to irregularities inherent in tanker shipments. For a terminal handling 2,190 million barrels per year, an estimated 2,000 acres is required. Arthur D. Little, Inc., Cambridge, Mass.

[6] Because of buffer zones, the land required for a 1,000-MWe plant is given as 150 to 350 acres in Executive Office of the President, Office of Science and Technology, Energy Policy Staff. 1968. *Considerations Affecting Steam Power Plant Site Selection*. Washington, D.C.: Government Printing Office, p. 11.

[7] See Table A-2, note 8.

[8] Quantity of oil emitted to waters from onshore oil production is the oil released by the incomplete separation of brine and oil at the wellhead. Based on production of 2.7 barrels of brine per barrel of crude oil and 16 percent of the brine disposed of in water bodies. National Petroleum Council. 1972. *Environmental Conservation: The Oil and Gas Industries*. Volume Two. Washington, D.C.: N.P.C., p. 147. Also based on 0.005 percent oil content in the brine, which is the Federal regulation applying to offshore drilling. *Final Environmental Statement—Proposed 1972 OCS Lease Sale, op. cit.* Conversion to tons from *Petroleum Facts and Figures—1971 Edition, op. cit.*, p. 588. Outer Continental Shelf data, calculated from water and accident data in *Final Environmental Statement—Proposed 1972 OCS Lease Sale, op. cit.*, pp. 133, 134, are used to estimate accidental spills.

[9] One other water impact that does occur but is not included on the summary table is pollution of waters by salts and suspended solids by the release of the brine to marine environments. Brine discharge to water bodies based on the above, 4.5 million barrels.

[10] Calculated from "achievable" effluent emission factors for topping and cracking plants divided by "achievable" reduction factors. U.S. Environmental Protection Agency. 1972. "The Industrial Waste Studies Program: Summary Report in the Petroleum Refinery Industry," S.I.C. 2911. Research Triangle Park, N.C., pp. 5, 6. Refinery water emissions, in tons, are:

Ammonia (as N)	52
BOD_5	390
Chromates	3
COD	1,036
Oil	167
Phenols	87
Sulfides	52
Suspended solids	455
Dissolved solids	2,342

[11] Water pollution results from oil discharges. See Table A-4, note 6. Conversion to tons from *Petroleum Facts and Figures—1971 Edition, op. cit.*, p. 588. For prerefinery transport, oil loss is from barges for domestic oil (435 tons) and from tankers for imported oil (1,711 tons).

[12] See Table A-2, note 11.

[13] See Table A-2, note 12.

[14] See Table A-4, note 5, for hypothetical refinery. Given the output indicated in Figure A-2, we calculate input (assumed to be entirely crude oil) and total production. We calculate heat input from residual fuel oil and from natural and petroleum gas from *Mineral Industry Surveys: Crude Petroleum, Petroleum Products, and Natural-Gas-Liquids: 1970 (Final Summary), op. cit.*, Table 19. We calculate the refining capacity, storage capacity, and storage throughput from U.S. Environmental Protection Agency. 1972. *The Economics of Clean Air*. Washington, D.C.: E.P.A., p. 4-108:

Input (crude oil)	156.5 million barrels per year.
Output:	
Total	161.3 million barrels per year.
Residual fuel oil	9.39 million barrels per year.
Refinery capacity	189.7 million barrels per year.
Fuel oil burned	1.68 million barrels per year.
Gas burned	80.9 billion cubic feet per year.
Storage capacity	8.20 million barrels.
Storage throughput	71.8 million barrels per year.

The fraction attributable to residual fuel oil production is 6.65 percent.

Additional assumptions are that the fluid catalytic cracking process is used (representative of new refineries); that one-third of the crude undergoes vacuum distillation; that storage is 93 percent as finished products, 7 percent as crude; that hydrocarbon evaporation for crude and residual products is statistically similar; and that no floating roof storage is used. *The Economics of Clean Air, op. cit.*, pp. 4-105, 4-110.

From these data, and from emission factors in U.S. Environmental Protection Agency. 1972. *Compilation of Air Pollutant Emission Factors.* Washington, D.C.: Government Printing Office, pp. 1-7, 9-3, 9-4, we calculate air emissions. Refinery air emissions, in tons, are:

Source	Particulates	SO_x	HC	CO
Process heat:				
Residual oil	47	558	8	0
Gas	54	0	81	0
Catalytic cracking	318	2,732	1,145	71,290
Blowdown	0	0	1,894	0
Vacuum distillation	0	0	226	0
Storage	0	0	7,224	0
Total	419	3,290	11,027	71,290

Source	NO_x	Aldehydes	Ammonia (as N)	Total
Process heat:				
Residual oil	161	2	0	778
Gas	619	2	0	762
Catalytic cracking	328	99	281	75,193
Blowdown	0	0	0	1,894
Vacuum distillation	0	0	0	226
Storage	0	0	0	7,224
Total	1,108	109	281	87,524

[14] See Table A-4, note 12, for assumptions and fuel consumption. For prerefinery transport (domestic), pumps are assumed to be diesel engines with emission factors similar to those for heavy-duty trucks and buses. *Compilation of Air Pollutant Emission Factors, op. cit.*, p. 3-7. For postrefinery transport, barges (domestic oil) have diesel motors, whereas tankers (imports) are steamships. Emission factors in tons per gallon of fuel consumed are derived from "underway" columns in Tables 3-6 and 3-7, *ibid.*, p. 3-11. Air emissions for oil transport, in tons, are:

	Domestic			Import
	Prerefinery	Postrefinery	Total	Postrefinery
Particulates	7	327	334	34
SO_x	14	246	260	885
CO	116	197	313	.17
HC	19	146	165	17
NO_x	191	231	422	386
Aldehydes	2	11	13	4
Total	349	1,158	1,507	1,326

[15] Air emissions, assuming 1.5 percent sulfur in the fuel, are calculated from *Compilation of Air Pollutant Emission Factors, op. cit.*, p. 1-7. Powerplant air emissions, in tons, are:

Particulates	1,578
SO_x	46,438
CO	8
HC	395
NO_x	20,705
Aldehydes	197

[17] Based on an injury rate for oil extraction developed from data in Watts, Gwendolyn M. 1972. *Disabling Work-Injury Experience of the Oil (All Activities) and the National Gas Industry (Excluding Distribution Activities) in the United States, 1970.* Washington, D.C.: U.S. Department of the Interior, Bureau of Mines; and on number of man-hours worked in oil extraction, which was developed from U.S. Bureau of the Census. 1971. *Statistical Abstract of the United States: 1971.* Washington, D.C.: Government Printing Office, pp. 219, 496. Rates of fatal injuries (1 death per 100 nonfatal injuries) and workdays lost due to nonfatal injuries (101 days lost per injury) are from U.S. Department of Labor, Bureau of Labor Statistics. 1971. *Injury Rates by Industry—1969.* Washington, D.C.: D.O.L., p. 18.

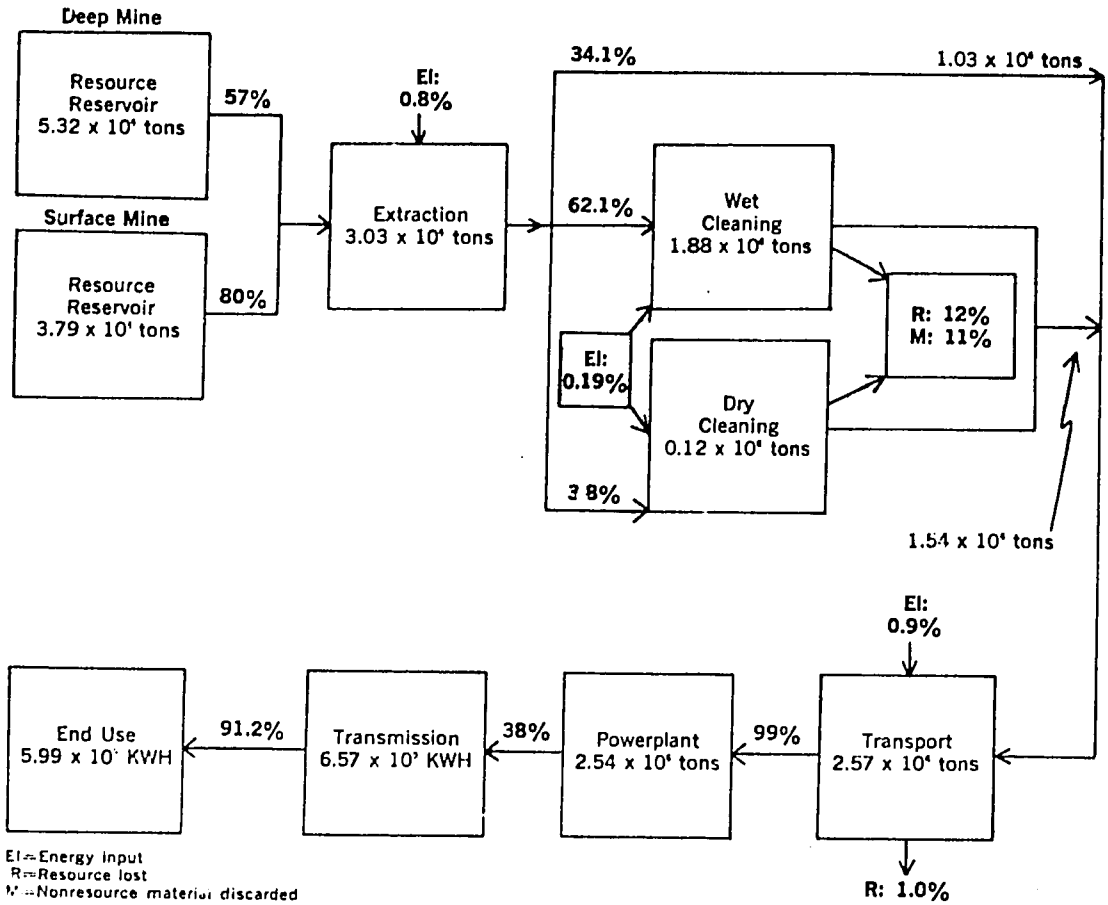
[18] Based on total man-hours worked, derived from U.S. Bureau of the Census. 1970. *Statistical Abstract of the United States: 1970.* Washington, D.C.: Government Printing Office, pp. 222, 656; and on injury rate statistics in *Injury Rates by Industry—1969, op. cit.*, p. 10.

[19] Based on 1969 occupational health data in Fish, George. 1970. *Disabling Work-Injury Experience of the Oil Industry (All Activities) and the Natural Gas Industry (Excluding Distribution Activities) in the United States, 1969.* Washington, D.C.: U.S. Department of the Interior, Bureau of Mines, p. 8; on the total work hours of marine transport in the oil industry, derived from National Petroleum Council. 1969. *People in the United States Oil and Gas Industries.* Washington, D.C.: N.P.C., p. 5; and on the share of all oil needed to fuel a 1,000-MWe powerplant for 1 year, derived from data in Figure A-2 and in U.S. Department of the Interior, Office of Oil and Gas. 1970. *1968 Petroleum Supply and Demand in the Free World.* Washington, D.C.: D.O.I. On first estimate, imports and domestic production are not separated.

[20] See Table A-2, note 23, using 0.009 men per MWe.

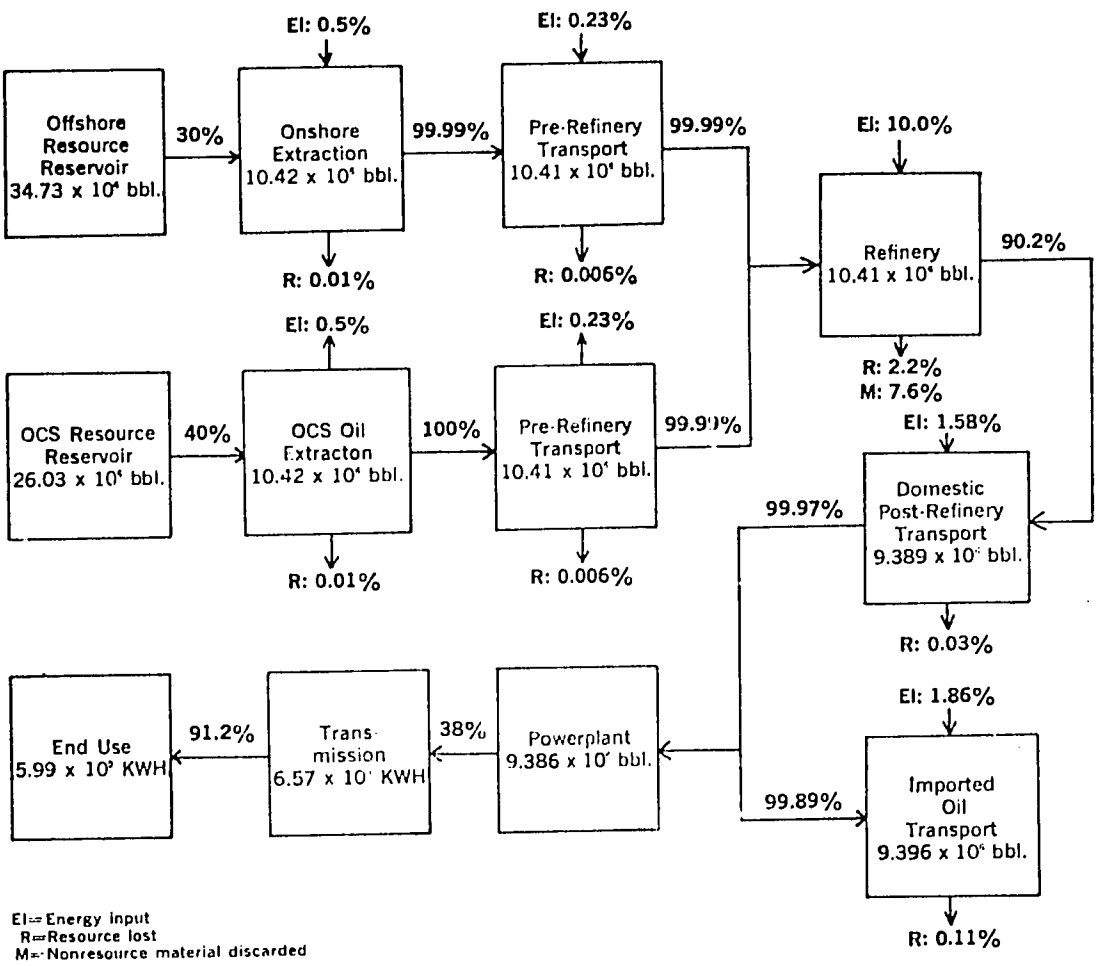
APPENDIX B

Coal-Fired Electricity System for a 1,000-Megawatt Powerplant Operating Annually at a 0.75 Load Factor

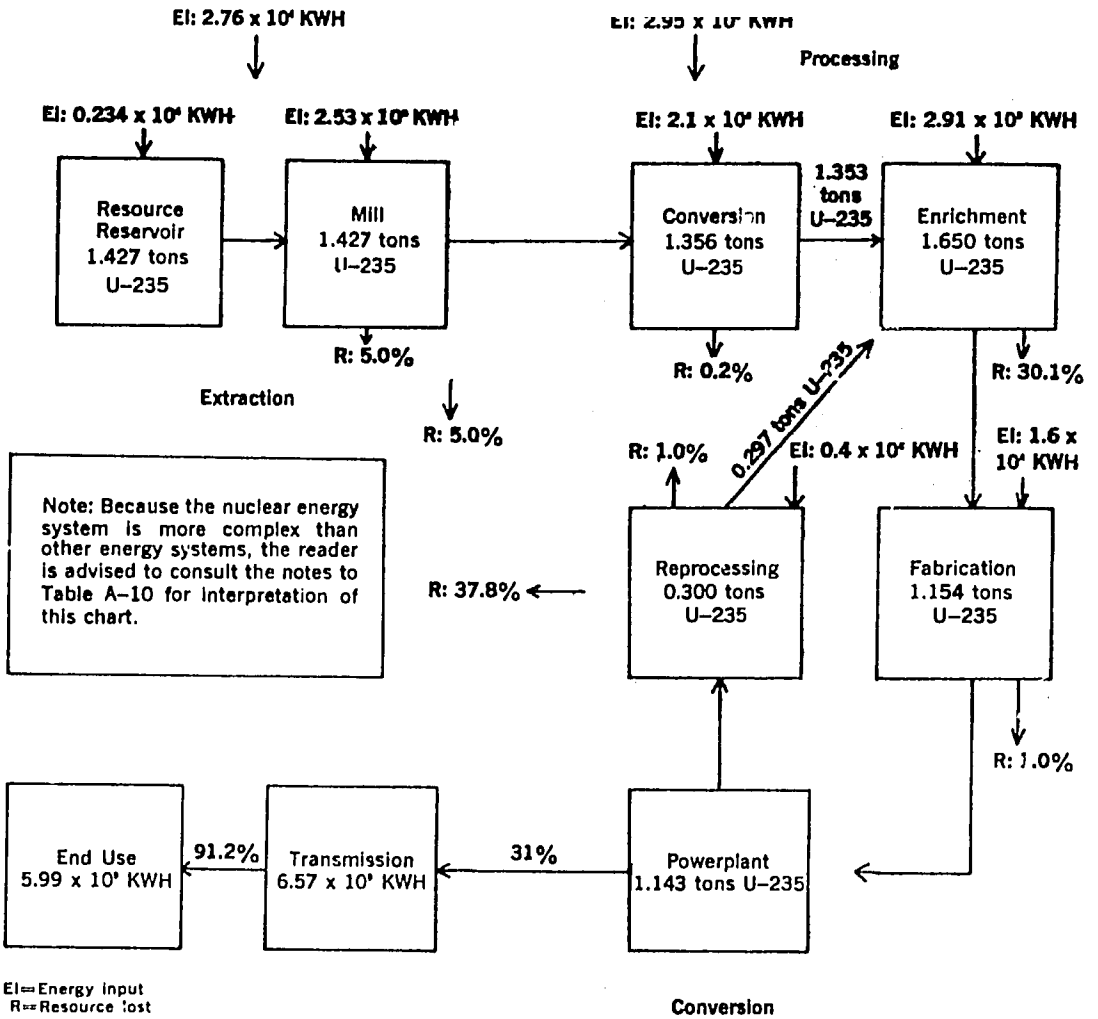


APPENDIX B

Residual Fuel Oil-Fired Electricity System for a 1,000-Megawatt Powerplant Operating Annually at a 0.75 Load Factor



Nuclear-Powered Electricity System for a 1,000-Megawatt Powerplant Operating Annually at a 0.75 Load Factor



Annual Environmental Impacts of Controlled Coal-Fired Electricity Systems Associated With a 1,000-Megawatt Powerplant With a Load Factor of 0.75 [1]

[Costs in thousands of dollars or mills per kilowatt-hour]

Impact		Extraction		Processing	Transport	Conversion	Transmission	Total	
		Deep	Surface					Deep	Surface
Land	Acres	[2] 9,120	[3] 934	[4] 85	2,213	[5] 941	17,188	29,637	21,461
	Percent change	0	−94.3	−47.2	0	+35.2	0	+0.88	−37.4
	Costs								
	Annual total	0	1,868	10.8	0	0	0	10.8	1,878.8
	Mills per kilowatt-hour	0	.28	.002	0	0	0	.002	.282
Water	Tons	[6] 0	[7] 2,802	[7] 227	0	[8] 55	0	282	3,084
	Percent change	−100	−92.2	−94.1	0	−93.2	0	−96.2	−92.4
	Costs								
	Annual total	460	0	5.99	0	NA	0	465.99	5.99
	Mills per kilowatt-hour	.07	0	.001	0	NA	0	.071	.001
	Btu's	0	0	0	0	[9] 0	0	0	0
	Percent change	0	0	0	0	−100	0	−100	−100
	Costs								
	Investment	0	0	0	0	10,000	0	10,000	10,000
	Annual total	0	0	0	0	2,153.5	0	2,153.5	2,153.5
	Mills per kilowatt-hour	0	0	0	0	.328	0	.33	.33
Air	Tons	NA	0	[10] 59	26,270	[11] 45,175	0	71,501	71,501
	Percent change	NA	0	−98.7	0	−87.2	0	−81.3	−81.3
	Costs								
	Investment	NA	0	NA	0	40,000	0	40,000	40,000
	Annual total	NA	0	14	0	11,826	0	11,840	11,840
	Mills per kilowatt-hour	NA	0	.002	0	1.80	0	1.80	1.80
Solid waste [12]	Tons	[13] 101,316	[13] 2,762,328	[14] 462,373	0	[14] 994,000	0	1,558,000	4,219,000
	Percent change	+4.3	+0.01	+1.8	0	+1,957	0	+159	+29.1

NA = Not available.

[1] Costs of coal-fired powerplants are estimated at $180 per kilowatt, based on unpublished, updated data for Federal Power Commission. 1968 and 1969. *Hydroelectric Power Evaluation* and its *Supplement No. 1*. Washington, D.C.: Government Printing Office. The 14.8 percent annualization rate was developed using *Hydroelectric Power Evaluation, Supplement No. 1*, p. 3; and Board of Governors of the Federal Reserve System. "Bond and Stock Yields." *Federal Reserve Bulletin*. April 1973. Vol. 59, No. 4, p. A 34. Fuel is estimated at $0.35 per million British thermal units based on data in Federal Power Commission, Bureau of Power. February 1973. *Monthly Report of Cost and Quality of Fuels for Steam-Electric Plant*. Washington, D.C.: F.P.C., p. 2. Operation and maintenance costs are estimated at 0.39 mills per kilowatt-hour, based on data in "17th Steam Station Cost Survey." *Electrical World*. November 1, 1971, p. 46. Coal storage is set at 3 months, with the cost of capital taken as 10 percent. Electricity costs based on minimal controls, in mills per kilowatt-hour, are:

Powerplant	4.05
Coal	3.14
Coal storage	.08
Operation and maintenance	.39
Total	7.66

Incremental electricity costs with controls, in mills per kilowatt-hour are:

	Deep	*Surface*
Total costs of controls	2.13	2.41
Total costs with controls	9.79	10.07
Percent increase with controls	27.8	31.5

APPENDIX C

Annual Environmental Impacts of Controlled Oil-Fired Electricity Systems Associated With a 1,000-Megawatt Powerplant With a Load Factor of 0.75 [1]

[Costs in thousands of dollars or mills per kilowatt-hour]

Impact		Extraction		Processing	Transport			Conversion	Transmission	Total		
		Onshore	Offshore		Onshore	Offshore	Import			Onshore	Offshore	Import
Land	Acres	1,572	164	[2] 76	1,656	168	10	[3] 260	17,188	20,752	17,856	17,458
	Percent change	0	0	nil	0	0	0	+4	0	0	0	0
Water	Tons	111	102	[4] 3,063	435	527	[5] 520	[6] 55	0	3,664	3,747	575
	Percent change	0	0	−44	0	0	−69.6	−93.2	0	−38.8	−38.3	−77.2
	Costs											
	Investment	0	0	[7] 1,100	0	0	0	NA	0	1,100	1,100	0
	Annual operation and maintenance	0	0	110	0	0	0	NA	0	110	110	0
	Mills per kilowatt-hour	0	0	.026	0	0	0	NA	0	0.026	0.026	0
	Btu's	0	0	0	0	0	0	[8] 0	0	0	0	0
	Percent change	0	0	0	0	0	0	−100	0	−100	−100	−100
	Costs.											
	Investment	0	0	0	0	0	0	10,000	0	10,000	10,000	10,000
	Annual total	0	0	0	0	0	0	2,498	0	2,498	2,498	2,498
	Mills per kilowatt-hour	0	0	0	0	0	0	[9] .377	0	.377	.377	.377
Air	Tons	0	0	[9] 3,210	1,507	1,507	1,326	[10] 38,362	0	43,079	43,079	39,688
	Percent change	0	0	−96.3	0	0	0	−44.7	0	−72.8	−72.8	−43.8
	Costs											
	Investment	0	0	[11] 1,415	0	0	0	0	0	1,415	1,415	0
	Annual operation and maintenance	0	0	229	0	0	0	14,242	0	15,471	15,471	14,242
	Mills per kilowatt-hour	0	0	.067	0	0	0	2,168	0	2,355	2,355	2,168
Solid waste	Tons	0	0	[12] 213	0	0	0	0	0	213	213	0
	Percent change	0	0	+	0	0	0	0	0	+	+	0

NA = Not available.

[1] Costs of oil-fired powerplants are estimated at $150 per kilowatt based on unpublished, updated data for Federal Power Commission. 1968 and 1969. *Hydroelectric Power Evaluation* and its *Supplement No. 1*. Washington, D.C.: Government Printing Office. See Table A-3, note 1 for 14.8 percent annualization rate. Fuel is estimated at $0.45 per million British thermal units based on data in Federal Power Commission, Bureau of Power, February 1973. *Monthly Report of Cost and Quality of Fuels for Steam-Electric Plant*. Washington, D.C.: F.P.C., p. 3. Operation and maintenance costs are estimated at 0.21 mills per kilowatt-hour, based on data in "17th Steam Station Cost Survey." *Electrical World*. November 1, 1971, p. 46. Fuel storage is set at 1 month, with the cost of capital taken as 10 percent. Electricity costs based on minimal controls, in mills per kilowatt-hour, are:

Powerplant	3.38
Fuel	4.04
Fuel storage	.04
Operation and maintenance	.21
Total	7.67

The incremental electricity costs with controls, in mills per kilowatt-hour, are:

	Onshore	*Offshore*	*Imports*
Water discharges	.03	.03	0
Heat discharges	.38	.38	.38
Air emissions	2.36	2.36	2.17
Fuel storage	.02	.02	.02
Total costs of controls	2.79	2.79	2.57
Total costs with controls	10.46	10.46	10.24
Percent increase with controls	36.4	36.4	33.5

[2] Virtually no land is needed for added solid wastes disposal.

[3] See Table A-3, note 5 for the acreage needed for cooling towers.

[4] See Table A-5, note 10.

[5] The load-on-top system is about 80 percent effective in reducing oil discharges from tankers. Porricelli, Joseph D., Keith, Virgil F., and Richard L. Storch. "Tankers and the Ecology." *Transactions*. Vol. 79, 1971, pp. 2, 4, 7. The LOT system pays for itself.

[6] See Table A-3, note 8.

[7] Costs of control were estimated by InterTechnology Corporation, Warrenton, Va.

[8] See Table A-3, note 9. Costs are computed using $0.68 per million British thermal units for residual fuel.

[9] Carbon monoxide boilers eliminate CO and 95 percent of the HC from the catalytic cracking stage. U.S. Environmental Protection Agency. 1972. *The Economics of Clean Air*. Washington, D.C.: E.P.A., pp. 4-106, 107. Sulfur recovery plants and tail gas cleaning can reduce SO_x from the cracking stage by 99.5 percent. *Ibid.*, p. 4-106. Electrostatic precipitators can reduce particulates from the catalytic cracking stage by 67 percent. *Ibid.*, p. 4-107. Floating roofs on storage tanks can reduce emissions by 89 percent. *Ibid.*, p. 4-105. Blowdown emissions can be reduced by 98.3 percent with controls. U.S. Environmental Protection Agency, Office of Air Programs. February 1972. *Compilation of Air Pollutant Emission Factors*. Washington, D.C.: Government Printing Office, p. 9-3. Emissions from vacuum jets can be eliminated by controls. *Ibid.*, p. 9-4. The purchase of 0.6 percent sulfur fuel oil is assumed, thus reducing SO_x from fuel oil combustion by 80 percent.

[10] Based on the use of 0.6 percent sulfur residual fuel costing $0.68 per million British thermal units. Based on data in *Monthly Report of Cost and Quality of Fuels for Steam-Electric Plant*, *op. cit.*, p. 3.

[11] Costs based on data in *The Economics of Clean Air*, *op. cit.*, p. 4-110.

[12] Electrostatic precipitators can reduce particulate emissions from catalytic cracking by 67 percent. *The Economics of Clean Air*, *op. cit.* p. 4-107. See Table A-5, note 11.

Best Available Document

Annual Environmental Impacts of a Controlled Light Water Reactor Nuclear Electricity System Associated with a 1,000-Megawatt Powerplant With a Load Factor of 0.75 [1]

[Costs in thousands of dollars or mills per kilowatt-hour]

Impact		Extraction	Processing	Transport	Conversion	Transmission	Total
Land	Acres	785	9.12	0	[2] 314	17,188	18,314
	Percent change	0	0	0	+4.7	0	.1
Water	Tons	20,400	42.9	0	[3] 55	0	20,498
	Percent change	0	0	0	−93.2	0	−3.6
	Curies	1.9	2,348	0	332	0	2,682
	Percent change	0	0	0	0	0	0
	Btu's	[3] 0	[3] 0	0	[4] 0	0	0
	Percent change	−100	−100	0	−100	0	−100
	Cost						
	Investment	0	0	0	14,000	0	14,000
	Annual total	0	0	0	2,600	0	2,600
	Mills per kilowatt-hour	0	0	0	.39	0	.39
Air	Tons	nil	6,192	nil	0	0	6,192
	Percent change	0	0	0	0	0	0
	Curies	69.9	3.49×10^{4}	0	[5] 1.40×10^{3}	0	3.50×10^{4}
	Percent change	0	0	0	−99	0	−29.3
	Costs						
	Investment	0	0	0	4,000	0	4,000
	Annual total	0	0	0	614	0	614
	Mills per kilowatt-hour	0	0	0	.093	0	.093
Solid or stored waste	Tons	2.62×10^{6}	58	0	0	0	2.62×10^{6}
	Percent change	0	0	0	0	0	0
	Curies	1,125	1.4×10^{4}	0	31,500	0	1.4×10^{4}
	Percent change	0	0	0	0	0	0

[1] Note that the Atomic Energy Commission is developing cost and effectiveness data on reducing systemwide radioactive emissions. Using data from Federal Power Commission. 1969. *Hydroelectric Power Evaluation Supplement No. 1.* Washington, D.C.: Government Printing Office, pp. 10–12, inflated by 15 percent to cover cost rises since 1969, the construction cost of nuclear powerplants is estimated at $300 per kilowatt. Updated from *ibid.* The annualization rate is based on Table A-3, note 1, with 0.55 mills per kilowatt-hour added for insurance. *Ibid.*, p. 3. Modifications, based on *Hydroelectric Power Evaluation* and its *Supplement No. 1, op. cit.*, are made to change the load factor to 0.75. In this way, operation and maintenance costs are determined to be $2,565,000 per year, or 0.44 mills per kilowatt-hour, and fuel costs are 1.79 mills per kilowatt-hour. Cooling towers are based on a 14.8 percent annualization rate. On this basis, the nuclear system with limited controls produces power at a cost of 9.24 mills per kilowatt-hour prior to transmission. The controlled systems produce power at 9.72 mills per kilowatt-hour, an increase of 5.19 percent.

[2] See Table A-3, note 5. Because nuclear units have over 60 percent greater thermal discharge than fossil-fired powerplants, 14 acres is added for cooling towers, with the costs included in water control.

[3] See Table A-3, note 8.

[4] See Table A-3, note 9, for an analysis of cooling tower costs. The Council estimates the capital cost at $14 per kilowatt, based on over 60 percent greater thermal discharge of nuclear units but some economies of scale. Detailed annual cooling tower costs are:

Annual cost of investment	2,072,000
Operation and maintenance	328,500
Additional fuel	159,000
Total annual cost increase	2,559,500
Cost increase (mills per kilowatt-hour)	0.39

[5] Reducing powerplant radiation emissions by 99 percent is estimated to cost $4 million.

[2] Less than 1 acre is required for disposal of solid wastes from water pollution control.

[3] Complete reclamation is assumed after 1 year of mining. The Council estimates the cost at $2,000 per acre. U.S. Council on Environmental Quality, 1972. *Environmental Quality—1972*. Washington, D.C.: Government Printing Office, p. 275. Also see note 2.

[4] Fixed land use is the same as for the uncontrolled plant (80 acres) because land required for additional pollution control equipment is assumed to be negligible. For variable land use, it is assumed that the 5.4 acres of waste banks from solid wastes (see Table A-2, note 18) remains 1 year before reclamation, at a reclamation cost of $2,000 per acre.

[5] Annual incremental land use for disposal of solid waste generated by air pollution control is 15 acres and averages 15 years' duration. Based on 201,200 tons of dry ash averaging 33 cubic feet per ton and 742,000 tons of limestone sludge averaging 22 cubic feet per ton. Table A-2, note 16, with 99 percent control; and Federal Interagency Committee for Evaluation of State Implementation Plans, Sulfur Oxide Control Technology Panel. November 16, 1972. "Preliminary Draft of Final Report on Projected Utilization of Stack Gas Cleaning Systems by Steam Electric Plants." Washington, D.C., p. 58. Thirty-five-foot high waste banks are assumed. Costs are included in air pollution control costs. Cooling towers are estimated to occupy 10 acres. This cost is included under water impacts control.

[6] Acid drainage is assumed to be treated completely by adding lime and allowing it to settle in tanks or ponds. Cost, including capital, operating, and maintenance, is estimated at $0.185 per ton of coal deep mined. Delson, Jerome K., and Richard J. Frankel. April 1972. "Residuals Management in the Coal-Energy Industry." Manuscript to be published by Resources for the Future, Inc. Washington, D.C.: R.F.F., p. IV-25a. Siltation from surface mining is assumed to end with reclamation 1 year after mining. Cost for both acid and siltation control on surface-mined land is included in the land reclamation cost.

[7] Blackwater emissions can be completely prevented by sedimentation plus water recirculation, at a cost of approximately $0.003 per input ton. *Ibid.*, pp. II-3a, IV-37a. Waste banks are assumed reclaimed after 1 year at $2,000 per acre, as for surface-mined land, leading to cessation of siltation after 1 year.

[8] Aynsley, Eric, and Meryl R. Jackson. May 1971. "Industrial Waste Studies: Steam Generating Plants." Unpublished draft prepared for the U.S. Environmental Protection Agency, Water Quality Office. Research Triangle Park, N.C., p. 69, indicates that all effluents except nondegradable organics can be virtually eliminated. Cost data are being developed by the U.S. Environmental Protection Agency.

[9] Natural draft cooling towers have been estimated to cost from $6 to $9 per kilowatt. Federal Power Commission, "Problems in Disposal of Waste Heat from Steam-Electric Plants." A staff study supporting the 1970 National Power Survey, p. 15. Our study uses $10 per kilowatt however, based upon unpublished supplemental data for *Hydroelectric Power Evaluation* and its *Supplement No. 1, op. cit.*

Operating costs are estimated at 0.05 mills per kilowatt-hour, with an additional 150 British thermal units per kilowatt-hour thermal loss cost resulting from the required energy input. National Economic Research Associates, Inc. 1972. *Possible Impact of Costs of Selected Pollution Control Equipment on the Electric Utility Industry and Certain Power Intensive Consumer Industries*. New York: N.E.R.A., p. III-3. Total costs assume the annualized capital cost rate at 14.8 percent. See note 1. The average cost of coal is estimated at $0.35 per million British thermal units, based on *Monthly Report of Cost and Quality of Fuels for Steam-Electric Plant, op. cit.*, p. 2.

[10] A system employing a wet scrubber and air recirculation, in addition to a cyclone, is used to control air emissions from thermal drying. Costs of the system are $0.037 per input ton of coal, and emissions are reduced to 0.1 ton of dust per 500 tons input coal. Delson and Frankel, *op. cit.*, pp. II-3a, IV-40a. Twenty percent of the mechanically cleaned coal is thermally dried. U.S. Department of the Interior, Bureau of Mines. 1971. *Minerals Yearbook—1969*. Washington, D.C.: Government Printing Office, p. 351.

[11] Assumes wet limestone scrubber system for both SO_2 and particulate control. Removal efficiencies are taken at 85 percent for SO_2 and 99 percent for particulates. Princiotta, Frank T. "Control of Sulfur Oxide Pollution from Power Plants." A paper prepared for the American Public Power Association Engineering and Operations Workshop, March 14, 1972. Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Control Systems Division, Table 8. Capital cost is estimated at $40 per kilowatt including settling pond, and annualized cost for a new 1,000-MWe unit burning 2.6 percent sulfur coal at 38 percent efficiency and a 0.75 load factor is estimated at 1.8 mills per kilowatt-hour. Developed from Burchard, John K., et al. 1972. "Some General Economic Considerations of Flue Gas Scrubbing for Utilities." Research Triangle Park, N.C.: U.S. Environmental Protection Agency, pp. 21, 22. Costs of solid waste disposal are included.

[12] Cost of disposal of the extra solid waste generated by air or water pollution controls is included in the air and water cost estimates.

[13] Additional solid wastes result from control of acid drainage. The addition of lime should precipitate 1.61 tons of calcium sulfate per ton of sulfuric acid and 1.46 tons of iron hydroxide per ton of iron, based on the atomic weights of the reagents. See Table A-2, note 9. Thus the additional solid waste generated is 4,205 tons for deep mining and 328 for surface mining. Note that gob and offsite overburden are still considered solid wastes, even though the reclamation process disposes of them satisfactorily.

[14] Additional solid wastes result from air and water pollution controls. See notes 7 and 10.

[15] See note 5 for additional solid wastes.

GUIDELINES FOR THE CONTROL OF INDUSTRIAL WASTES

3. CANE-SUGAR INDUSTRY WASTES

by

James C. Lamb III[a]

CONTENTS

	Page
Preface	V- 98
1. Introduction	V- 99
2. Manufacturing process	V- 99
3. Quantity and characteristics of wastes	V-100
3.1 Cane wash-water	V-102
3.2 Floor washings and boiler blowdown	V-103
3.3 Soda and acid wastes	V-103
3.4 Condenser wastes	V-103
3.5 Other sources of wastes	V-104
4. Reclamation and recycling	V-104
5. Treatment and disposal of wastes	V-107
6. Survey and appraisal	V-108
References	V-111
Select bibliography	V-112

[a]Professor of Sanitary Engineering, University of North Carolina, Chapel Hill, North Carolina, United States of America

Preface

The satisfactory disposal of industrial effluents is a major problem causing growing concern to public health authorities. Direct discharge of wastes into water courses may deplete dissolved oxygen, destroy aquatic life, and make the stream unfit for community water supply and other beneficial uses. On the other hand, the discharge of some industrial effluents into municipal sewers may have damaging effects on sewers or overload the sewage treatment works. Public health authorities are also aware of possible long-term physiological effects of some new organic chemicals which are found in industrial effluents, many of which are not removed by conventional treatment processes. Highly persistent detergents, pesticides and other toxic wastes have become serious problems in developed countries and will in time present a similar threat to developing countries.

In the developing countries the situation is particularly serious in view of the scarcity of qualified professional personnel (sanitary engineers, chemists and biologists), analytical laboratories, and finances for planning and operating industrial-wastes control programmes. It is important to consider the problem not only as it is at present, but also in the light of expected population increase, and of urban and industrial growth. Early government action is required for determining the extent of the problem and forplanning and implementing efficient measures for the control of industrial wastes discharges.

This is one of a series of documents prepared by the World Health Organization covering the most prevalent industries in developing countries. The objective of these guidelines is to assist the responsible staff of health agencies and of other regulatory authorities to carry out surveys, interpret laboratory findings, advise industries on inplant remedial measures and disposal of wastes, and make recommendations concerning acceptance of wastes into municipal sewers. The first document in this series described the problem in general terms, and advised on how to carry out surveys and institute programmes of industrial wastes control.[1] The guidelines dealing with wastes from specific industries cover a description of the manufacturing process, with flowchart, the quantity and characteristics of wastes including health hazards, reclamation and recycling practices, methods of treating and disposing of wastes, suggestions for surveying and appraising existing facilities, and selected references to the literature.

It is planned to revise and update the documents from time to time by including information on new processes and procedures with special reference to experience in developing countries. Information and suggestions in this connection will be welcomed by the Organization.

---

[1] Document WHO/WD/70.6.

1. Introduction

Most of the world supply of sugar is obtained from two types of raw material sources - sugar cane and sugar beets. The cane is a giant grass which grows 10-20 feet (3.5-7.0 m) high and 1-3 in (2.5-7.5 cm) in diameter, averaging about 15 percent fibre and 85 per cent water and soluble solids, including sugar (sucrose) equivalent to 10-12 per cent of the cane weight.

Sugar cane is cultivated throughout the world in 56 countries located within a belt between 30° North and South latitudes. Some of the important sugar-producing regions are in Brazil, China, Colombia, Cuba, Dominican Republic, Hawaii, India, Mexico, Nicaragua, Peru, the Philippines, Puerto Rico, the United States of America and the Virgin Islands, (Jenser, 1965; Keller & Huckabay, 1960). World production of cane-sugar in 1962 was estimated (Guzman, 1962) at 30 million tons annually, manufactured in about 6000 factories varying in size over a range of 1-20 000 tons of cane processed per day. Obviously, such facilities also will vary widely in processing techniques and efficiencies.

Although the exact periods for harvesting differ among the regions, this seasonal operation generally lasts three to six months. Milling of the cane to produce raw sugar must be accomplished during the harvesting season, as promptly as possible to avoid serious loss in quality and quantity of sugar. Subsequent refining of raw sugar to produce various market products may be accomplished on a year-around basis, though storage of raw sugar for processing later and, perhaps, elsewhere.

2. Manufacturing process

A simplified flow sheet for production of raw sugar from cane is shown in Fig. 1, but one must recognize that the processes vary considerably depending upon location, size and age of mill, and local resources, labour and customs. Washing of the cane before grinding may not be necessary where it is harvested manually with reasonable care to exclude dirt and impurities. Recent trends in many areas have been twoards mechanical harvesting, because of increasing labour costs. Data from Louisiana and Hawaii indicate increases in extraneous material from less than five percent with manual harvesting to five to 50 per cent after adoption of mechanical harvesting (keller, 1959). Also, mechanical handling results in more damage to the cane and consequently an increased loss of sugar to the wash-water used to clean the cane at the mill before cutting and griding.

Water which has been used for condensing vapours from evaporators usually is re-used for cane washing, where practiced, thereby conserving water and taking advantage of heat available in the flow. Effluent from this operation represents a major waste-water flow from the plant and will be referred to as "cane wash-water".

Sugar juice is extracted from the cane by cutting it into short lengths and crushing between roller mills in series. Some juice from this process is returned to inlet of the grinding operation to improve effectiveness of water use, a process referred to as maceration.

Fibrous residue from grinding and screening of particles from the sugar juice is called "bagasse" and normally amounts to about 30 per cent by weight of the cane processed. This usually is burned in the boiler plant for generation of steam and provides enough fuel for operation of the factory. An alternate use for bagasse is as a raw material for production of fibreboard or paper.

The screened juice is treated with lime to a pH above 8.0, to prevent inversion of the sucrose, and enters heaters where the temperature is raised to about 215°F (102°C). Thence it flows into tanks called "clarifiers", where some insoluble compounds settle as a sludge and others rise to form a scum. Both underflow and overflow pass to vacuum filters, from which juice is returned to the process, and filter cake is disposed of on land.

Clarified juice from the center of the unit is withdrawn for concentration in multiple-effect evaporators, producing a syrup containing 60-70 per cent solids. Water content is further reduced and crystallization accomplished in single-effect vacuum pans, causing formation of a dense mixture of crystals and syrup called "massecuite". This is centrifuged for separation of the crystals as "raw sugar". The remaining "molasses" is returned to the vacuum pans for further crystallization and ultimately the spent molasses is removed from the process for use in alcoholic fermentation, hog-feeding, or for other purposes.

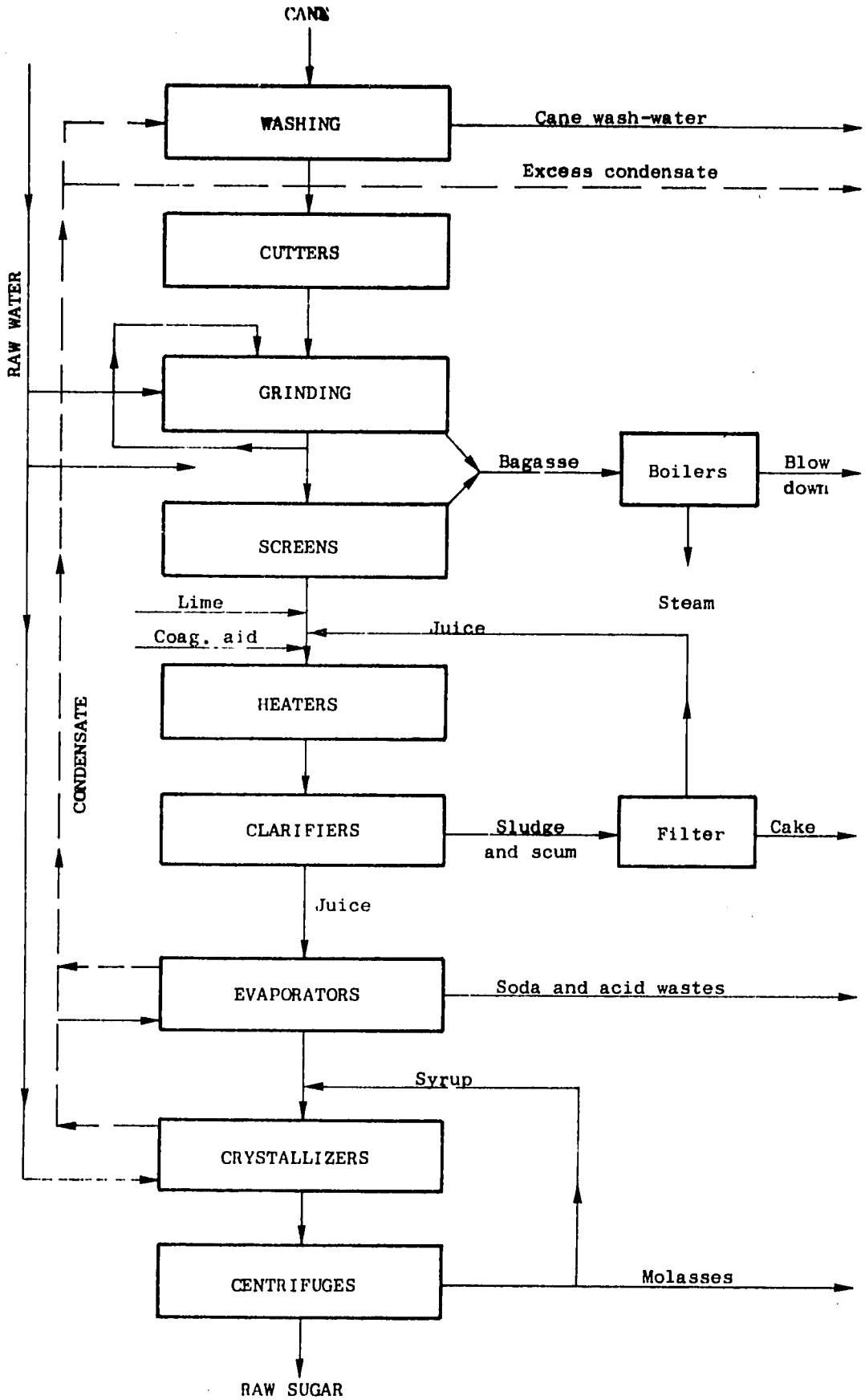
Most raw water entering the plant is used for condensing vapours in the barometric condensers. Some also may be used in the boiler plant, although that often operates on condensate instead. Condenser waters subsequently are used for washing incoming cane and excess flow is discharged as waste water.

Major sources of water pollutants from the process include: (1) cane wash-water, (2) floor washings and boiler blowdown, (3) soda and acid wastes, and (4) excess condenser waters.

3. Quantity and characteristics of wastes

Waste-water flows and characteristics vary widely depending upon local conditions and methods of plant operation. Generally, where sources of fresh water are abundant water consumption is high, but in water-short areas factories practice extensive re-use, reducing water-supply requirements and volumes of waste-water discharges. An extreme example of successful operation with very limited water resources has been reported for a factory in the West Indies faced with a total supply of only about one

FIG. 1. CANE-SUGAR PROCESS



Adapted from Biaggi, 1968; Guzman, 1962; Jensen, 1965; Keller, 1959; Keller & Huckabay, 1960; Stone, 1951.

million gallons available at the beginning of each season (Keller, 1959). About 60 per cent by weight of cane entering the process may be recovered by condensation of water evaporated from the juices. Conservation of this water makes it possible to operate the plant for extended periods with condensers maintained on a closed circuit through using a cooling tower or pond.

A survey of 103 cane-sugar factories in North India (Bhaskaran et al. 1963) indicated an average production of 290 UK gal (1320 l) of waste water per ton of cane, with a five-day BOD of 570 mg/l (1.4 lb BOD/ton of cane). A subsequent publication (Bhaskaran & Chakrabarty, 1966) reports that waste waters from manufacture of cane sugar in India vary widely because of differences in processes used in the mills, but are reported to have BOD values ranging from 300-2000 mg/l. Table 1 shows characteristics reported in that paper for specific cane-sugar wastes which were studied in pilot plant investigations.

Table 2 shows quantities of wastes reported for raw cane-sugar production in Puerto Rico. Table 3 summarizes sugar balances reported for 17 mills in Puerto Rico, and pollutional characteristics of cooling and condenser waters from those mills are presented in Table 4. Average effluent BOD was 97 mg/l in a flow of 10.8 mgd. This yields a "population equivalent" for a 4200 ton/day plant of 52 000, an average BOD loading of 2.2 lb (1 kg) per ton of cane and flow of 2500 gal (9500 l) per ton of cane. These data were interpreted by the author (Biaggi, 1968) as "clear evidence" that too much sugar was being lost through entrainment into cooling and condenser waters.

Table 5 summarizes waste-water characteristics from raw sugar production in Louisiana, United States of America, based on a mill handling 2400 tons of cane per day without re-use of condenser water. BOD load of plant effluent was calculated to be 5.3 lb (2.4 kg) of BOD per ton of cane processed, 64 per cent of which was in the cane wash-water, leaving 1.9 lb (.86 kg) BOD per ton of cane in other flows, principally condenser waters.

3.1 Cane wash-water

As indicated earlier, this step is a major source of pollutants, but may not be necessary in intallations processing cane harvested manually with care to exclude dirt and extraneous matter. Where mechanical harvesting is employed, cane washing is necessary and very large volumes of water are used. Rates of flow for such plants in Louisiana have been reported at 500-5000, averaging 1000 gal/min (63 l/s).

As shown in Table 5, the cane wash-water contains high concentrations of suspended solids (typically over 2000 mg/l). Much of the suspended material is colloidal or finely divided and may be stabilized by organic compounds acting as protective colloids. This makes the liquid very difficult to clarify through conventional coagulation with ordinary chemicals.

Because of damage which the cane suffers during mechanical harvesting, the cane wash-water may contain substantial concentrations of sugar, leading to BOD values of 300-1000 mg/l. From the point of view of total BOD contribution, this flow constitutes a most serious source, as reflected in data of Table 5 showing 64 per cent of the plant total to be in the cane wash-water.

3.2 Floor washings and boiler blowdown

Occasional spills, leaks in piping and general carelessness in operation require frequent floor washings. Boilers for production of steam may be operated on raw water or condenser waters. BLowdown may contain substantial concentrations of various chemicals used to treat the boiler water and organics used for treatment or introduced with the condenser water.

Flow rates of combined wastes from floor washing and boiler blowdown may vary radically in strength from time to time and plant to plant, depending on the nature of facilities and care exerted in their operation. Floor washings may contribute major loadings when the plant is cleaned thoroughly and equipment emptied for weekend shutdowns. Data in Table 5 indicate that, nevertheless these wastes represent a relatively small portion of total BOD discharged from the manufacturing operation.

3.3 Soda and acid wastes

At intervals ranging from weekly to as long as three weeks it is necessary to clean heating surfaces throughout the plant to remove accumulations of scale. This is accomplished usually by rinsing the equipment with water, boiling for several hours with caustic soda, rinsing again, boiling with inhibited dilute hydrochloric acid and giving final rinses to remove acid residues.

Cleaning solutions and rinse waters contribute additional pollutional materials in rather small flow but may have very objectionable characteristics, principally because of inorganic constituents rather than BOD. Wastes from this operation usually are accumulated in an impoundment and released at low rates of flow over extended periods of time.

3.4 Condenser waters

As indicated in Tables 4 and 5, condenser waters represent a major source of pollution from the manufacturing process, second only to cane wash-water. Where cane is not washed, condenser waters represent the bulk of organic pollution from the process. The BOD load can be attributed principally to carryover of sugar into the condensate of evaporators through excessive foaming, or improper control of the evaporators and entrainment of liquid in the vapours.

Characteristics of condenser waters may vary from virtually pure water at temperatures of 35-50°C to solutions containing sufficient organics to produce BOD as high as 300-600 mg/l. Because of the variable nature of condensate and its dependence upon operating care, this represents a strategic location for applying in-plant controls to reduce pollutional loads, as will be discussed subsequently.

3.5 Other sources of waste

Generally, highly concentrated wastes from the plant are not allowed to enter the liquid waste-water system but occasionally this may occur. One such waste is bagasse, usually used as a fuel in the boiler plant or recovered as raw material for manufacture of paper products.

Filter cake amounts to three to four per cent of the weight of cane processed and has a high BOD (8000-25 000 mg/l), total solids (40 000-100 000 mg/l) and 0.21 per cent sucrose (Biaggi, 1968). For convenience in some older plants, the cake has been slurried and discharged to streams or lagoons. This is not considered desirable practice from the point of view of water pollution control and it is highly preferable that it be discarded to the land as a fertilizer.

Spent molasses from the process has an exceedingly high BOD (400 000-900 000 mg/l) and should not be discharged to receiving streams (Biaggi, 1968; Stone, 1951). Normally, it is recovered and may be used for conversion into alcohol or fed directly to cattle.

4. Reclamation and recycling

Pollutional materials from sugar-cane processing plants may be summarized as (a) extraneous substances adhering to cane upon arrival at the mill, (b) cane residues separated from the sugar, (c) chemicals used in cleaning equipment, and (d) sugar lost during proecessing. It should be evident that lost sugar is undesirable for two reasons - the waste of valuable food material, and creation of water pollution problems.

Sugar balances for Puerto Rican factories in Table 3 indicate total sugar losses averaging 2.468 per cent by weight of cane processed (22.5 per cent of sugar entering the mill) and variations in those losses of 1.66-3.08 per cent of cane weight. When viewed from the aspect of water pollution, this indicates a ratio of sugar loss between the worst and best mills of about 2:1. An even greater range in pollutional discharges from various mills is indicated by the lb/BOD/ton of cane reported in Table 4. All of the data suggest possibilities for reduction of water pollution problems from canesugar mills through application of in-plant controls.

As indicated earlier, some of the highly concentrated wastes from manufacturing operation include bagasse, filter cake, and spent molasses. Proper controls should be included to ensure that these materials do not escape with waste-water flow under any circumstances.

Improved housekeeping, operating techniques and plant maintenance can have a significant effect on discharges of pollutional materials in floor washings and other cleanup waste waters. Because they are highly variable in character these flows usually are impounded and released after storage for sufficient time to attain stabilization. Reduction of spills to minimize necessity for washing and institution of reasonable controls on volumes of wash-waters used for that purpose can reduce volume of the flow substantially, making it easier and more economical to impound the waste water for extensive periods. Where cane washing is employed, floor washings frequently are combined with cane wash-waters for treatment and disposal.

For economic reasons and the reduction of water pollution, recovery of alkali from cleaning heat-exchange equipment frequently is practiced. This can be accomplished by adding new alkali to the spent solution and settling for removal of suspended material. Careful design and operation to ensure thorough draining of equipment is desirable because it minimizes quantities of alkali discharged in rinse-waters. These waste waters usually are retained in separate basins for discharge over a fiarly long period of time to minimize pollutional impact.

As indicated earlier, the cane wash-water represents a major source of pollution from this type of factory and quantities of pollutants discharged depend upon cane-harvesting methods employed. Any steps which reasonably could be taken to leave dirt and trash in the fields instead of delivering them to the mill with the cane would have a favourable impact on characteristics of cane wash-water discahrges. Also, pollutional characteristics of this flow may be improved substantially by taking steps to minimize damage to the cane which can cause increased loss of sugar during washing. In those instances where economics still permit manual cane harvesting, it frequently is unnecessary to wash the cane, as already indicated earlier. Thus, avoiding mechanical harvesting and continuing careful manual harvesting where economically feasible, could offer one approach for minimizing pollution from cane sugar mills. In regions where manual harvesting now is practiced, the possibility for changing to mechanical methods should be viewed with caution, and where both techniques are employed it might be reasonable for mills to scale payments for cane depending upon cleanliness. After all, cleaner cane can offer reduced pollution control problems, thereby yielding lower operating costs.

Volumes of waste waters from cane washing may be reduced substantially through adoption of counter-current washing techniques, which may include settling of water re-used in the pro-

cess (Keller, 1959). However, this may not have significant effect on organic loads which depend upon impurities and sugar removed from cane during washing, not on volume of flow. Nevertheless, reduction in volume can have a beneficial effect where impoundment or other treatment of the waste waters may require construction of detention basins.

Sugar losses in condenser cooling waters represent a major source of pollution and are amenable to control through careful design and operation, as reflected by the observation (Keller, 1959) that BOD values reported for condenser waters in Louisiana plants range from 2-600 mg/l. In two instances (Keller & Huckabay, 1960) installation of efficient entrainment separators reduced BOD in condenser waters from several thousand to 20-30 mg/l, resulting in product savings of about $2500 per day. In Puerto Rico, Guzman (1962) reported BOD discharges of 14 lb per ton (6.36 kg) of cane processed in one factory, reflecting excessive loss of sugar through entrainment. Replacement of old separators by modern ones reduced BOD of cooling and condenser waters to 2.8 lb. per ton (1.27 kg) of cane. Further investigation indicated that multiple-effect evaporators and vacuum pans were being operated at excessively high levels of syrup, causing sugar loss through entrainment. Marks placed on sides of the units to indicate maximum syrup levels reduced effluent BOD to 30 mg/l, totalling only 0.86 lb per ton (0.39 kg) of cane processed.

Guzman (1962) also indicates that recirculation of cooling and condenser waters reduced volumes of these flows and produced higher concentrations of organic pollutants than in once-through systems. He indicates that the total organic load generally is reduced somewhat where this practice is followed.

Sugar losses in condenser waters should be evaluated frequently by analysing condensates for sugar (Jensen, 1965; Keller, 1959). Also, separators should be examined weekly to ensure good mechanical condition and open lines. With good control and maintenance of equipment, disposal of condenser waters should not create problems. Where problems arise, much or all of the solution may lie in reducing sources of contamination within the plant, instead of resorting to treatment of excess condensate.

It is worthwhile to emphasize the importance of distinguishing carefully between flow reductions and changes in organic loadings attending reclamation and recycling operations. Accurate evaluations require consideration of both aspects of the question because very different unit water flows may be used for the same purpose under different circumstances. As indicated earlier, quantities of water used often reflect availability more than process needs. Thus, it is virtually impossible to evaluate pollutional loads, or the impact of reclamation and recycling, through considering BOD concentrations only.

Stone (1951) indicates that intelligently-designed and operated cane-sugar mills ideally should not have water pollution

problems because wastes from production of sugar can and should be employed for fuel, fertilizer, byproducts, or irrigation water and that "sugar cane waste pollution is the result of poor plant engineering and/or bad mill operation".

5. Treatment and disposal of wastes

About one-half of the total solids in case wash-water (Table 5) may be removed by plain sedimentation. However, the large amounts of organic materials in the flow, some of which may serve as protective colloids, create difficulties with coagulation and chemical oxidation (Keller, 1959; Keller & Huckabay, 1960).

Although several studies have been conducted to evaluate treatment systems for waste waters from cane sugar processing, most of those actually in operation employ some type of lagooning (Jensen, 1965). Studies in Louisiana have indicated that a multi-basin system appears promising and suggest division of available space into three basins. The first should have a detention of two to three days and incorporate aeration to decrease the BOD to, perhaps, 100 mg/l. Effluent from that unit passes successively through two more lagoons for further reduction before discharge at a concentration of 50-60 mg/l BOD (Keller, 1959). Pre-settling is considered important to prevent accumulations of settleable solids on bottoms of the basins, which could retard stabilization substantially by reducing basin volumes and increasing organic loading.

Puerto Rican engineers have observed (Guzman, 1962) that high concentrations of carbohydrates make it difficult to treat concentrated wastes because their degradation may produce sufficient volatile acids to overcome the buffer capacity of the waste water and reduce pH enough to inhibit growth of micro-organisms. This problem can be reduced by enhancing buffer capacity through addition of enough lime or other inexpensive alkali to neutralize the acids produced.

Bottle digester experiments were conducted to evaluate feasibility of anaerobic decomposition (Guzman, 1962). In eight days at a temperature of 29°C, BOD was reduced by 78 per cent at an average loading of 0.020 lb BOD/day ft^3 (0.32 kg/m^3). It was concluded that the many difficulties encountered with conventional treatment made it desirable to consider other approaches, such as anaerobic decomposition in lagoons - a simple process requiring no equipment, but utilizing more land. Several basins were constructed adjacent to a sugar factory and a waste-water survey performed to minimize flow rates in order to reduce land requirements. Production of volatile acids initially reduced pH to 4.3 in the first lagoon, but after two or three days detention decomposition proceeded at a rapid rate in the second basin. Eventually, stabilization rates decrease when BOD reaches 100 mg/l or less. The author concurs with results reported in Louisiana (Keller, 1959) to the effect that stabilization proceeds faster if space available for lagooning is divided into several basins.

In India, Bhaskaran et al (1963) report that waste waters from sugar-cane factories can be treated by oxidation ponds to an effluent BOD of 20-95 mg/1. Subsequently, studies are described (Bhaskaran & Chakrabarty, 1966) leading to a conclusion that trickling filters are not effective for treating the waste because of nitrogen deficiency. Pilot plant studies conducted over extensive periods showed the waste water to be amenable to treatment by anaerobic digestion, followed by aerobic oxidation ponds. This type of approach produced over-all efficiencies approximating 90 per cent BOD removal. Anaerobic digestion can produce BOD reductions of 60-70 per cent in seven days in open, unheated basins, or in two days in a closed digestor maintained at 37°C.

6. Survey and Appraisal

Evaluation of pollution problems in a sugar factory should include careful attention to in-plant controls for minimizing waste discharges through good housekeeping, efficient process operation, and equipment maintenance. Frequent or even continuous sampling is preferred over intermittent (Keller, 1959) because faulty equipment or entrainment may occur erratically and grab samples may not indicate true extent of losses.

Samples of condenser or other waters may be checked for traces of sugar by using an alcoholic solution of alpha-naphthol, but sometimes this analytical technique is not reliable because of other organic substances in the water. Frequently, the permanganate oxygen consumed test has been used for this purpose, but is not specific for sugar.

A more quantitative method is based on use of ammonium-phosphomolybdate for sugar analysis. This technique produces a blue colour in the presence of sugar, the colour intensity being related directly to concentration of sugar. Colour standards for this analytical technique must be prepared frequently to ensure accurate results.

TABLE 1. CHARACTERISTICS OF CANE-SUGAR WASTES, AS REPORTED IN INDIAN STUDIES

Characteristic	Range of values
pH	4.6 - 7.1
Total solids (mg/l)	868-3500
Suspended solids (mg/l)	220-800
Volatile solids (mg/l)	400-2196
5-day, 20°C BOD (mg/l)	303-1966
COD (dichromate method) (mg/l)	607-4380
Total nitrogen, mg/l	10-40

From Bhaskaran & Chakrabarty (1966) p. 1161.

TABLE 2. QUANTITIES OF CANE-SUGAR WASTES REPORTED FOR PUERTO RICO

Waste	lb (kg)/ton of cane	Gal (l)/ton of sugar
Bagasse fibre	240 (109)	
Filter cake	60 (27)	
Condenser waters		30 000 (113 550)
Concentrated wastes[a]		Unknown

[a] Floor washings, soda and acid wastes, tank washings, spills. Adapted from Biaggi (1968) p. 1427.

TABLE 3. SUMMARY OF SUGAR BALANCES FOR 17 PUERTO RICO FACTORIES (EXPRESSED AS PER CENT. OF CANE WEIGHT)

Source	Minimum	Average	Maximum
Total sucrose	9.274	10.948 (100)	12.797
Sucrose recovered	7.199	8.479 (77.45)	10.040
Losses in:			
Bagasse	0.719	1.01 (9.23)	1.336
Molasses	0.817	1.122 (10.25)	1.337
Filter cake	0.095	0.212 (1.94)	0.483
Miscellaneous	0.077	0.123 (1.13)	0.525
Total losses	1.663	2.468 (22.55)	3.081

Figures in parentheses represent averages expressed as per cent. of total sucrose.

Adapted from Biaggi (1968) p. 1429.

TABLE 4. POLLUTIONAL CHARACTERISTICS OF CONDENSER WATERS IN PUERTO RICO

Cane processed tons/day	Flow mgd	Solids, mg/l		5-day, 20°C BOD		
		Total	Suspended	mg/l	lbs/day	lbs/ton of cane
4 000	17.0	180	56	70	9 900	2.47
1 500	2.0	190	13	72	1 200	0.80
4 000	15.8	250	0	130	17 100	1.28
2 400	7.2	260	43	69	4 100	1.73
5 400	5.7	310	96	32	1 500	0.28
7 000	31.7	-	-	90	23 800	3.41
1 800	12.9	200	20	79	8 500	4.72
3 600	Recirculated	690	84	-	-	-
5 000	12.9	525	45	59	6 400	1.27
3 400	12.0	190	20	90	9 000	2.65
6 000	Recirculated	360	20	-	-	-
3 000	10.0	280	43	185	15 400	5.14
1 800	7.2	995	20	147	8 800	4.91
4 200	12.5	-	-	90	9 400	2.23
700	4.3	700	100	183	6 600	9.38
3 750	8.0	-	-	75	5 000	1.33
1 450	4.4	770	230	-	-	-
4 214	10.8	421	56	97	9 050	
4 000	10.0	335	43	84.5	8 750	

Note: Average BOD of water entering mills for cooling purposes was 8.06 mg/l (range = 0.9 to >25).

Adapted from Biaggi (1968) p. 1430.

TABLE 5. VOLUME AND CHARACTER OF WASTES FROM CANE-SUGAR PRODUCTION IN LOUISIANA (BASED ON 2400 TONS/DAY CANE)

Waste water	Flow gal/min	l/s	5-day BOD mg/l	BOD load lb/day	kg/d	Solids, mg/l		
						Total	Suspended	Settle
Cane wash-water	1 000 (500-5000)	63 (31.5-315)	680 (300-1000)	8 157	3 703.28	2 900	2 104	1 7
Floor washings and boiler blowdown	100	6.3	378	453	205.66	-	-	
Soda and acid wastes	10	0.63	-	-	-	-	-	
Condenser waters**	5 000	315	69 (2-600)	4 138	1 878.65	-	-	
Totals (rounded) BOD/ton of cane	6 100	384		12 750 5.31	5 788			

Principal pollutants are NaOH, NaCl, HCl.

Assumes once-through operation. Temperature = 110-130°F (43.3 - 54.5°C).

Adapted from Keller (1959) p. 8.

REFERENCES

Bhaskaran, T. R. et al. (1961) Treatment and disposal of sugar factory effluents, New Delhi Indian Council of Medical Research (Special report series No. 39) Sug. Ind. Abstr., 1963, 25, 57

Bhaskaran, T. R. & Chakrabarty, R. M. (1966) Pilot plant for treatment of cane-sugar waste, J. Wat. Pollut. Control Fed., 38, 1160-1169

Biaggi, N. (1968) The sugar industry in Puerto Rico and its relation to the industrial waste problem, J. Wat. Pollut. Control Fed., 40, 1423-1433

Guzman, R. M. (1962) Control of cane sugar wastes in Puerto Rico, J. Wat. Pollut. Control Fed., 34, 1213-1218

Jensen, L. T. (1965) Sugar. In: Gurnham, C. F. ed. Industrial wastewater control, New York, Academic Press, pp. 133-145

Keller, A. G. (1959) An industrial waste guide to the cane sugar industry, Washington, D.C., Govt. Printing Office (U.S. Public Health Service Publication No. 691)

Keller, A. G. & Huckabay, H. K. (1960) Pollution abatement in the sugar industry of Louisiana, J. Wat. Pollut. Control Fed., 32, 755-760

Stone, R. (1951) Sugar cane process wastes, Sewage Ind. Wastes, 23, 1025-1028

SELECT BIBLIOGRAPHY

Anon (1952) Cane sugar bagasse offers new source for newsprint, Chem. Engrg News, 30, 2708

Biglane, K. E. (1958) Some current waste treatment practices in Louisiana industry. In: Proceedings of the 13th Industrial Waste Conference, Purdue University, Lafayette, Indiana, pp. 12-20

Chakrabarty, R. N. (1964) Cane sugar wastes and their disposal, Environ. Hlth (Nagpur), 6, 265-273

Chakrabarty, R. N. et al. (1963) Treatment of cane sugar wastes in stabilization ponds. In: Proceedings of Symposium on Waste Treatment by Oxidation Ponds, Nagpur, October 1963, Nagpur, Central Public Health Engineering Research Institute

Duvall, A. R. (1967) Hawaii's hydroseparator systems transform cane-cleaner effluent, Sug. Azuc., 62, No. 10, 31-33, Wat. Pollut. Abstr., 1968, 41, Abstr. No. 2354

Edeline, F. & Leclerc, E. (1957) Study on some installations for the sedimentation of waste waters from sugar refineries, Trib. CEBEDEAU, 36, 135, Wat. Pollut. Abstr., 1959, 32, Abstr. No. 519

Gibbons, M. M. (1960) The treatment of cane sugar mill wastes, Revista del Colegio de Ingenieros de Puerto Rico, 10, 123

Godchaux, W. (1954) Sugar refinery waste problems. In: Proceedings 3rd Annual Water Symposium on Water Pollution, Louisiana State University Engineering Experiment Station, Bulletin No. 43

Isacks, A. J. (1946) Nature and disposal of cane sugar factory wastes in Louisiana. In: Water Conference. Stream Control Commission, Baton Rouge, Louisiana, pp. 37-39

Keller, A. G. (1953) Water usage and conservation in the Louisiana sugar industry. In: Proceedings 2nd Annual Symposium on Water Conservation and Industrial Development, Louisiana State University, Engineering Experiment Station, Bulletin No. 38

Lafleur, R. A. (1961) The sugar factory pollution abatement in Louisiana - The case history of a drainage basin. In: Proceedings of the 16th Industrial Waste Conference, Purdue University, Lafayette, Indiana, pp. 212-216

Wheeler, J. E. (1955) Water pollution and the sugar industry. In: Proceedings 4th Annual Water Symposium, Louisiana State University Engineering Experiment Station, Bulletin No. 51

Wheeler, J. E. & Keller, A. G. (1956) Pollution abatement in the Louisiana sugar industry. In: Proceedings 5th Annual Water Symposium, Louisiana State University Engineering Experiment Station, Bulletin No. 55, pp. 31-45

Wheeler, J. E. & Keller, A. G. (1956) Water pollution and the sugar industry. Sug. J. (April) pp. 29-23

Yarbrough, M. V. (1946) Water quality and quantity requirements for cane sugar manufacture in Louisiana. In: Water Conference, Stream Control Commission, Baton Rouge, Louisiana, pp. 29-36

GUIDELINES FOR THE CONTROL OF INDUSTRIAL WASTES

5. PULP AND PAPER MANUFACTURING WASTES

by

James C. Lamb[a]

CONTENTS

	Page
PREFACE	V-115
1. INTRODUCTION	V-116
2. MANUFACTURING PROCESSES	V-116
2.1 Generalized flow sheet	V-116
2.2 Wood preparation	V-117
2.3 Pulping processes	V-117
2.4 Bleaching	V-118
2.5 Paper manufacture	V-118
3. QUANTITY AND CHARACTERISTICS OF WASTE WATERS	V-119
4. RECLAMATION AND RECYCLING	V-120
5. TREATMENT AND DISPOSAL OF WASTE WATERS	V-121
6. SURVEY AND APPRAISAL	V-123
REFERENCES	V-131
SELECT BIBLIOGRAPHY	V-131

[a]Professor of Sanitary Engineering, University of North Carolina, Chapel Hill, NC., United States of America.

Preface

The satisfactory disposal of industrial effluents is a major problem causing growing concern to public health authorities. Direct discharge of wastes into water courses may deplete dissolved oxygen, destroy aquatic life, and make the stream unfit for community water supply and other beneficial uses. On the other hand, the discharge of some industrial effluents into municipal sewers may have damaging effects on sewers or overload the sewage treatment works. Public health authorities are also aware of possible long-term physiological effects of some new organic chemicals which are found in industrial effluents, many of which are not removed by conventional treatment processes. Highly persistent detergents, pesticides and other toxic wastes have become serious problems in developed countries and will in time present a similar threat to developing countries.

In the developing countries the situation is particularly serious in view of the scarcity of qualified professional personnel (sanitary engineers, chemists and biologists), analytical laboratories, and finances for planning and operating industrial-wastes control programmes. It is important to consider the problem not only as it is at present, but also in the light of expected population increase, and of urban and industrial growth. Early government action is required for determining the extent of the problem and forplanning and implementing efficient measures for the control of industrial wastes discharges.

This is one of a series of documents prepared by the World Health Organization covering the most prevalent industries in developing countries. The objective of these guidelines is to assist the responsible staff of health agencies and of other regulatory authorities to carry out surveys, interpret laboratory findings, advise industries on inplant remedial measures and disposal of wastes, and make recommendations concerning acceptance of wastes into municipal sewers. The first document in this series described the problem in general terms, and advised on how to carry out surveys and institute programmes of industrial wastes control.[1] The guidelines dealing with wastes from specific industries cover a description of the manufacturing process, with flowchart, the quantity and characteristics of wastes including health hazards, reclamation and recycling practices, methods of treating and disposing of wastes, suggestions for surveying and appraising existing facilities, and selected references to the literature.

It is planned to revise and update the documents from time to time by including information on new processes and procedures with special reference to experience in developing countries. Information and suggestions in this connection will be welcomed by the Organization.

---

[1]Document WHO/WD/70.6.

1. INTRODUCTION

Pulp and paper manufacturing is one of the largest industries in the world and has exhibited rapid and steady growth. Increased need for the wide variety of materials produced by this industry and continued development of many new products and uses for them promise extensive further growth over many years into the future.

Products supplied by the pulp and paper industry have been classified into four major categories: fine papers, coarse papers, tissues, and specialties (Gehm, 1965). The fine papers include writing materials, papers used in many types of quality publications, and white papers in general. Coarse papers comprise newsprint, wrapping papers, boards used to manufacture containers and many types of building products. Tissues consist of special wrapping papers, utility tissues and glassine. The specialty products encompass a wide variety of materials, including: electrical insulation, cigarette papers, photographic stock, cards and papers used for printing money.

Manufacture of the wide variety of items produced by this industry involves an extensive array of processes, each of which has been developed to permit economical manufacture of one or more products meeting certain specific performance and appearance criteria. As expected, the application of many types of manufacturing processes to a variety of raw materials to poduce substantially different end products leads to great diversity in characteristics and effects of waste-water discharges from those operations. In general, however, water usages are high in pulp and paper industries because water is a basic raw material used for many purposes including transportation of raw and intermediate materials, preparation of chemical solvents and additives, and removal of undesirable constituents and by-products.

Accordingly, water pollution problems in the pulp and paper industry are varied and frequently reach major proportions. Pollution problems and methods for their solution long have been the subject of extensive investigations by many segments of the pulp and paper industry and other interested organizations.

2. MANUFACTURING PROCESSES

2.1 Generalized flow sheet

Pulp and paper manufacturing operations conveniently can be divided into steps related to the (1) production of pulp from wood or other raw materials, (2) further treatment of the pulp, and (3) manufacture of the paper product. Raw materials most commonly used for pulping include wood, flax, cotton, rag, straw, hemp, esparto, jute, bagasse, and waste paper.

Some mills may execute only part of the operations involved in manufacturing a finished product. For example, some specialize in conversion of various types of raw materials to pulp, which subsequently may be shipped elsewhere for production of the final paper in other mills. Many manufacturing processes could be used for each step of the operation depending upon the nature of the raw materials and specifications for the product. Because of the number of variables involved and limited scope of this paper, it is not feasible to review all or even most combinations here. Fig. 1 presents a generalized flow sheet for a typical integrated mill in which all of the basic operations are executed, as practiced at many locations today. The major steps outlined for preparation of paper, beginning with wood as the raw material, consist of: (1) wood preparation, (2) the pulping process, (3) bleaching of the pulp and (4) manufacture of the paper product.

2.2 Wood preparation

Wood preparation includes steps involved in the transportation and preparation of wood for pulping. This often is based on moving wood by water carriage in flumes, washing and debarking. Water used in these operations may accumulate extensive concentrations of bark particles, wood slivers and silt, as well as solids dissolved in the water by leaching sap and other materials from the wood.

Usually most of the bark is separated as a solid waste and may be disposed of through dumping, incineration, composting or recovery for manufacture of by-products.

If the wood is to be pulped through chemical action, it is chipped to produce uniformly-sized particles small enough to facilitate chemical digestion. This step may be unnecessary in the groundwood pulp process where the wood is mechanically ground.

2.3 Pulping processes

The several types of pulp most commonly produced include groundwood (mechanical pulp), chemi-groundwood, kraft (sulfate), sulfite, neutral sulfite and semi-chemical pulp.

In mechanical pulping, pieces of the log are pressed against revolving grindstones in the presence of water. This type of operation is used to manufacture newsprint, low-grade sanitary tissue and paperboard. In the chemi-groundwood process, the log is cooked before grinding, producing a pulp which drains more rapidly and has greater strength than groundwood pulp.

Kraft pulping uses an alkaline sulfate solution to dissolve lignin and other constituents of the wood which bind the cellulose fibres together. This action releases the fibres for use in

manufacture of the paper product. The technique offers the advantage of producing a higher quality pulp which often is used for making brown wrapping paper and similar materials.

The acid sulfite process is based on digestion of wood chips in an aqueous solution of calcium bisulfite and sulfur dioxide. In new mills, more stringent pollution control regulations have led to selection of magnesium, ammonium, or sodium bisulfite instead of calcium bisulfite because of the possibility for producing a waste liquor more amenable to chemical recovery.

The semi-chemical process uses relatively mild chemical treatment to soften the chips, which subsequently are separated mechanically. This approach produces a higher yield of pulp.

After cooking, contents of the digestor are released into a blow tank for separation of vapours and spent liquor from the stock. The crude pulp from this operation is screened and washed to separate coarse from fine fibres and to remove dirt, residual chemicals, and foreign matter. The purified pulp then is thickened, often by use of vacuum filters, before bleaching.

2.4 Bleaching

Bleaching is necessary where it is desired to brighten the pulp, the specific type of bleaching operation depending on character of the pulp and desired end-product. Chemicals most often employed for bleaching are oxidizing agents, including chlorine, chlorine dioxide, hypochlorites, peroxides, and hydrosulfites. Often the bleaching operation may involve several stages with water used for washing and leaching of extractable materials after each step.

2.5 Paper manufacture

In stock preparation, the pulp is prepared for forming into a sheet of paper, often with addition of chemicals to produce a product of desired characteristics and finish. Operations in this phase may include beating and refining, mixing, addition of fillers, sizing, wet-strength resins and colouring materials.

The pulp is converted into a sheet on the paper machine by formation of a wet web, removal of water by pressing, and removal of additional water by heat. Frequently, this is accomplished by flowing the slurry of fibres in water on to a moving 4-denier wire screen to form the wet sheet, excess water being removed by passage through the wire. The wire and sheet then pass through a series of press rolls for removal of additional water and the sheet travels through steel smoothing rolls. Finally, the sheet is carried through a series of dry rollers heated by steam.

Finishing and converting operations prepare the paper for shipment and may include improvement of the surface finish, rewinding, cutting into sheets, or other similar operations. Most

of these are basically dry in character and little liquid waste originates here, except for clean-up and occasional spills.

3. QUANTITY AND CHARACTERISTICS OF WASTE WATERS

Pulping blowdown liquor represents a major source of pollutional materials from pulp and paper mills. These waste waters generally are high in BOD nad in colour caused by lignin derivatives, and other decomposition products of wood, formed and released during the cooking process. The flows generally are relatively small in volume but highly concentrated in chemical constituents, providing a high proportion of all pollutants in the plant effluent. Accordingly, major impact on character of the overall plant effluent can be realized through recovery or separate disposal of the blowdown liquors. Wastes from bleaching operations also contain very high concentrations of BOD and dissolved constituents. Waste waters from the paper machine generally are more dilute and contain fibres and fillers. Using savealls, most of this water can be recycled within the machine and excess flow used to dilute stock or to satisfy other needs in the mill.

Table 1 summarizes the current range of effluent flows which may be expected in the United States of America from manufacture of various types of pulp and paper products (Gehm, 1965). The quantitites of waste water discharged differ radically among the several manufacturing processes and also may vary widely from plant to plant of the same type. These variations often are a function of age of the plants, newer ones usually using less water per ton of product because of growing pressures for water conservation and pollution control.

Table 2 summarizes suspended solids and BOD loadings for various types of pulp and paper manufacturing plants (Gehm, 1965). The same author points out that BOD in effluents from pulping operations, without considering recovery, vary inversely with pulp yield of the process. Accordingly, mechanical pulping plants which yield pulp representing a high proportion of wood used have relatively low discharge BOD per ton of pulp. Chemical pulping processes produce substantially lower yield but higher quality pulp and may discharge two to three times as much BOD per ton of product.

Table 3 presents a more detailed listing of waste water discharges and pollutional loadings from various types of pulp and paper operations, as reported in an extensive waste water profile for pulp and paper industry in the United States of America (Anon., 1967). Table 4 has been calculated from average values for integrated pulp and paper mills in Table 3 to illustrate the magnitude of waste water flows and pollutants in this flows as revealed by that survey. Total flows, loadings, and population equivalents were calculated for a 300-ton per day mill and show the major potential impacts of such facilities. It

should be noted that the impact actually could be much larger by a mill practicing less than normal care in water conservation and inplant pollution control efforts.

4. RECLAMATION AND RECYCLING

Waste reduction practices in the pulp and paper industry are of major importance in influencing quantities and characteristics of waste water discharged. Techniques which have bene employed successfully include water re-use, chemical recovery, fibre and solids recovery and many types of manufacturing process improvements. Table 5 shows the extent to which various process modifications could reduce waste water discharges from processes often found in "older" types of mills. In each instance, the potential estimated reduction in waste water is given relative to conditions which could be expected under "before" conditions as indicated in each section of the Table (Anon., 1967). The potential impact of water re-use or other inplant modifications is shown to be drastic in many instances and the importance of this approach to pollution control in the pulp and paper industry should be evident.

It is estimated that about 80-90% reduction in waste loads and 70% reduction in waste water flow from wood preparation processes could be attained through water re-use. Adoption of the "long log" preparation method could reduce waste loadings as much as 95% and flows up to 85%.

Re-use of water in pulping processes can reduce waste water loads significantly and recovery of cooking liquors can result in reductions of 60-90%. Waste reductions of 20-60% from the pulp screening process may be obtained currently by partial water re-use, but complete elimination of this flow could be attained in the future with additional inplant recycle.

Recirculation in multi-stage bleaching operation reduces waste water loads by 30-80%. Fibre recovery and white water re-use in paper machine operations can reduce waste loads by 20-60% and flows by 60-80%.

By-product recovery from certain spent liquors in the pulp and paper industry has been successful for turpentine and tall oil. Some small mills manufacture other by-products including lignin sulfonates, acetic acid, formic acid, yeast and alcohols (Anon., 1967; Gehm, 1965). About 10 mills in the United States of America produce by-products, accounting for 10-15% of the liquor produced, but the market for these materials is limited and several of the products can be produced more economically from other materials. Two papers provide excellent information on this subject (Anon., 1963; Wiley & Holderby, 1960). Other by-products which have been investigated or actually produced for market from pulp and paper wastes including roofing felts, heating insulation, and cheap paper manufactured from bark. Spent

sulfite liquor has been utilized in production of emulsions for insecticides, scaling inhibitors, tanning agents, fertilizers, flotation agents, well-drilling lubricants, additives for storage batteries, reinforcing agents for rubber, and road binders.

In spite of major activity in this area, the production and sale of by-products from pulp and paper waste water flows does not appear to be attractive and the general trend is towards installation of recovery systems and substitution of pulping processes offering better possibilities for chemical recovery.

5. TREATMENT AND DISPOSAL OF WASTE WATERS

The treatment systems most commonly applied to pulp and paper waste waters are similar in principle to those used for many other types of wastes including municipal sewage, care being exerted to develop and use design parameters appropriate to the specific waste water in question. Table 6 summarizes levels of performance which may be expected in pulp and paper waste water treatment systems incorporating various types of elements. Primary treatment consists of sedimentation or flotation for removal of suspended matter and may attain 50-95% removal of suspended solids and 10-50% removal of BOD. Secondary treatment is based on biological processes to remove biodegradable materials and, depending upon type and design, can attain 30-95% BOD removal.

Suspended solids in pulp and paper mill wastes include fibres, clays, other filling and coating materials and debris. Usually, most of these materials are removed from machine waters by some type of saveall and returned to the system for re-use. Where further treatment is necessary, the most common approach is sedimentation in mechanically cleaned clarifiers similar to those used for many other types of industrial and municipal waste waters. Some mills use multiple earthen basins, arranged to permit intermittent excavation of solids, but sometimes odour problems have resulted. Where higher removals of suspended solids are required, coagulants such as alum, activated silica, and polyelectrolytes may be used to improve performance to 90% removal or higher. Clarifiers commonly are designed for overflow rates of 600-1000 US gal/ft^2 of surface area per day (25 000-40 000 l/m^2/day).

Activated sludge systems can attain very high BOD removals when properly designed and operated. Where land is moderate in cost many pulp and paper mills have adopted aerated lagoons, which are similar in principle to activated sludge but have no return sludge or final settling facilities, with much longer aeration periods - usually 3-10 days. Where land is cheap, stabilization basins offer additional advantages because the long detention periods minimize process upsets, and operating costs are minimal because the system requires little attention. Design of oxidation pond for pulp and paper wastes is similar to municipal sewage treatment practice, with units 3-5 ft (0.90-1.50 m)

deep loaded at about 50 pounds of BOD per acre per day (23 kg/ha/day).

Although trickling filters have been applied to a few pulp and paper mill waste waters, presence of fibres occasionally has caused plugging of stone media (Anon., 1967; Gehm, 1965; Waldmeyer, 1957). Systems with plastic media have been used successfully in several installations as roughing filters for partial removal of BOD, sometimes before further treatment or discharge into municipal systems. This approach also offers the advantage of waste cooling before further treatment, which occasionally is desirable.

Properly designed irrigation systems can be used successfully for treatment and disposal of these waste waters. Application rates vary from 10,000, to 100,000 gal per acre per day (93 500-935,000 l/ha/day) and loadings should be less than 200 lb of BOD per acre (225 kg/ha) per day. Land requirements for this approach are high (40-50 acres per m.g.d. of effluent) (4.3-5.3 ha per 1000 m^3/day) offering serious economic disadvantages in many areas. Also the potential for groundwater contamination must be recognized, especially when highly coloured pulping liquors are applied to the soil. The potential for disposing of waste waters by this technique usually is maximum during drought periods, when stream assimilative acpacities are minimum and demand for irrigation water is maximum. On the other hand, this approach may offer disadvantages in hilly terrain or in freezing climates.

Sludges withdrawn from the primary clarifier and biological treatment system usually must be thickened before disposal. Techniques which have been employed include gravity thickening of mixed primary and secondary sludges, air flotation, centrifugation and vacuum filtration. Ultimate sludge disposal has been accomplished by land filling and lagooning with other waste materials such as bark, grit, ashes and other debris. Where high land costs and regulations have justified more expensive approaches, incineration has been employed. Techniques which have been considered for separate disposal of strong wastes include recovery of chemicals and deep well disposal.

Other treatment systems which have been investigated extensively for possible future application to pulp and paper waste waters include filtration for removal of BOD and COD, chlorination or ozonation for removal of bacteria, activated carbon absorption, mass lime treatment for colour removal, and separation of inorganics by electrodialysis, reverse osmosis and ion exchange. These approaches have not yet been employed to a significant extent in practice, except for experimental purposes.

6. SURVEY AND APPRAISAL

The importance of inplant operations and controls in solving pulp and paper waste water problems has been indicated earlier. Serious consideration should be given to recovery of chemicals and separate collection, treatment and disposal of concentrated cooking liquors. In many instances, this approach may include modifying of the cooking process to use chemicals more amenable to subsequent recovery.

Survey of waste water pollution problems in pulp and paper mills should include careful evaluation of water use and re-use patterns in the installation. Major reductions in waste water discharges and pollution loads often can be attained through economical inplant modifications. Now it is common practice to provide savealls for recovery of fibres and other raw materials within the manufacturing process and opportunities for reduction in waste water discharges by this technique should be given careful consideration.

Great care should be exercised in sampling waste water streams to ensure accurate flow metering and collection of samples truly representative of the discharges. Blowdown from cooking processes usually are intermittent and without careful evaluation could lead to grossly erroneous conclusions about overall characteristics of the mill effluent. Discharges from paper machines are less variable but offer difficulties with respect to continuous sampling because of suspended solids content.

Analytical measurements should be conducted in accordance with proven procedures. Suspended solids and BOD determinations usually do not offer special difficulties. Determination of dissolved oxygen in mill effluents and in streams receiving such discharges may suffer from interferences by waste water constituents. One approach which has been proposed to circumvent this type of problem is the use of membrane-covered oxygen electrodes.

Usually, use of the dichromate COD test to predict BOD values in raw and treated waste waters has proven rather unsatisfactory. However, some mills have found reasonable correlation between certain non-standard COD tests and BOD. In particular, some employ a version of a permanganate COD test in preference to the dichromate method.

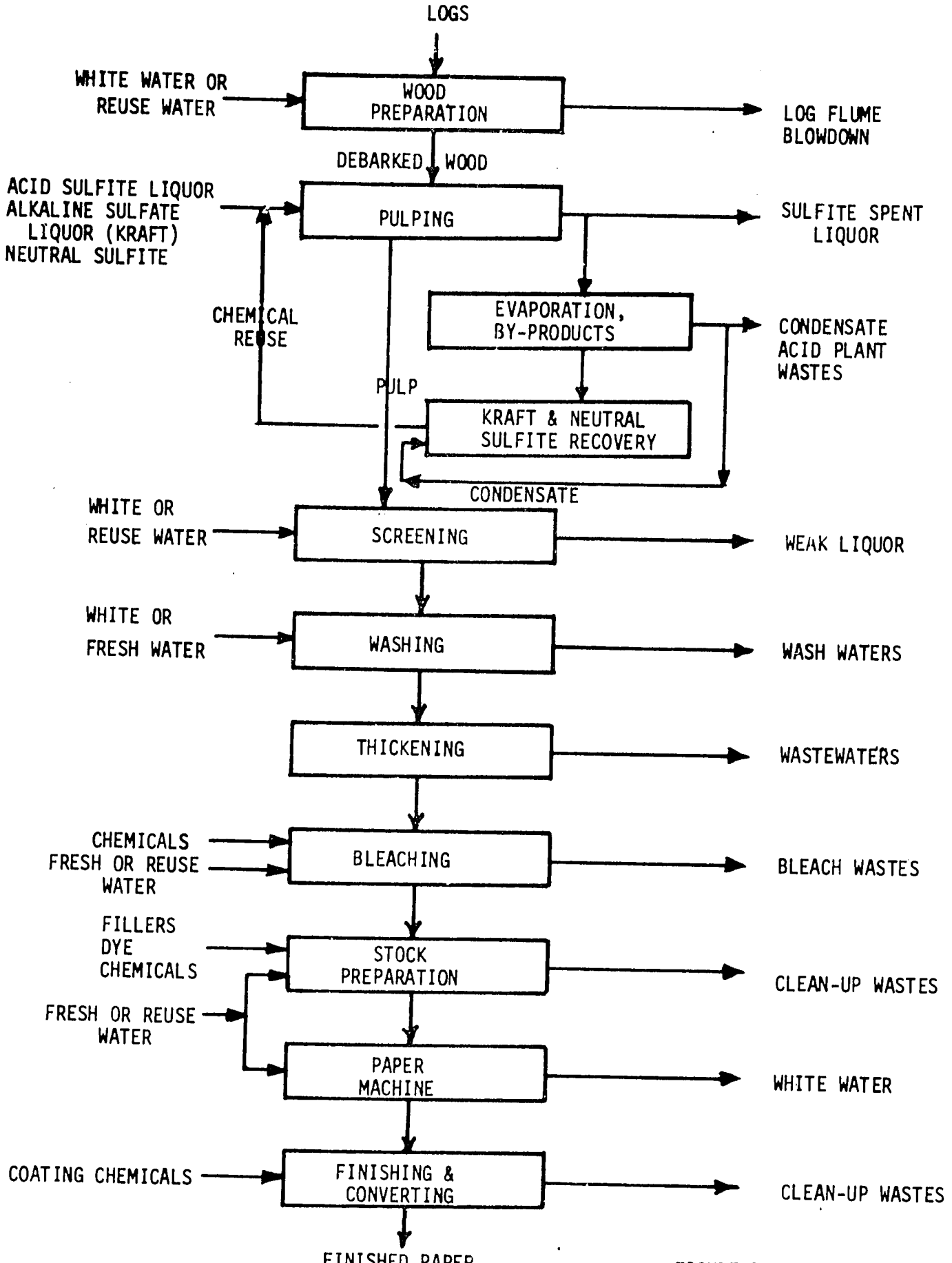


FIGURE 1
GENERALIZED FLOW SHEET FOR AN INTEGRATED PULP AND PAPER OPERATION (After: Anon., 1967)

TABLE 1. EFFLUENT FLOWS FROM MANUFACTURE OF PULP AND PAPER PRODUCTS

(Gehm, 1965) p. 359

Process	US gal per ton*
Pulp manufacture	
Kraft and soda pulps	15 000 - 35 000
Sulfite pulp	40 000 - 60 000
Semi-chemical pulp	30 000 - 40 000
Groundwood pulp	4 000 - 10 000
Deinked pulp	20 000 - 35 000
Pulp bleaching	
Kraft and soda pulp	15 000 - 60 000
Sulfite pulp	30 000 - 50 000
Neutral sulfite pulp	40 000 - 60 000
Paper manufacture	
White papers	20 000 - 40 000
Tissues	8 000 - 35 000
Kraft papers	2 000 - 10 000
Paperboard	2 000 - 15 000
Specialty papers	20 000 - 100 000

* 1 US gal per ton = 4.17 litres per metric ton.

TABLE 2. EFFLUENT LOADS FROM PULP AND PAPER MILLS

(Gehm, 1965) p. 363

Effluent	lb per ton of product*	
	Suspended solids	5-day BOD
Kraft and soda pulp	20 - 30	25 - 50
Groundwood pulp	40 - 80	15 - 25
Sulfite pulp (no liquor recovery)	20 - 40	400 - 600
Neutral sulfite semi-chemical pulp	100 - 180	250 - 450
Textile fibre pulps	300 - 500	200 - 300
Straw pulp	400 - 500	400 - 500
Bleaching	6 - 35	12 - 200
Deinked pulp	500 - 800	100 - 130
Fine papers		
Tissue	50 - 100	15 - 30
Bond, mimeo, and printing	50 - 100	20 - 10
Glassine	10 - 15	15 - 25
Coarse papers		
Boxboard	50 - 70	20 - 40
Corrugating board	50 - 70	25 - 60
Kraft wrapping	15 - 25	5 - 15
Newsprint	20 - 60	10 - 20
Specialty papers		
Fibre	200 - 300	140 - 170
Asbestos	300 - 400	20 - 40
Roofing felt	50 - 100	40 - 60
Insulating board	50 - 100	150 - 250

* 1 lb per ton = 0.50 kg per metric ton.

TABLE 3

WASTEWATER LOADINGS AND FLOWS FROM TYPICAL PULP AND PAPER OPERATIONS

(From: Anon., 1967)

Processes	Wasteload, in lbs/ton of Product *							Wastewater Quantities in gallons/ton **	
	Suspended Solids		Total Solids		BOD		pH		
	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Mean[2]	Range[1]	Range[1]	Mean[2]
A. Wood Preparation	1.9-40	9	4-50	13	2-10	3	6.5-8.0	1,000-10,000	3,400
B. Pulping									
Groundwood		--		--		--			--
Sulfate (Kraft)									
Blow Tower	(3.7)	4	(21.0)	21	(1.3)	1	(12)	(1,000)	1,000
Dirty Condensate	0-0.5	0.1	6-11	7	6.5-9.0	8	9.5-10	950-1,900	1,200
Evaporator Ejector	0.06-0.2	0.1	1-3	2	1.6-4.5	3	9-10	290-640	300
Causticizing Waste	2.2-5.7	5	46-240	101	8.0-10.5	9	9-11.0	600-9,600	2,500
Green Dreg	(1.0)	1	(22)	22	(1.0)	1	(12)	(200)	200
Floor Drain	0.5-10	6	11.0-11.5	11	0.3-1.7	1	11.6-12	340-580	400
Sub-total		17		164		23	9.5-12.0		5,600
Sulfite									
Blow Tower	0.42-1.9	1	36-348	247	29-194	116	2.2-2.9	1,840-1,950	1,900
Condensate	0.05-0.2	0.1	18-87	47	48-71	66	2.3-3.1	750-1,700	1,100
Uncollected Liquor	0.3-43	21	50-515	105	50-61	53	2.2-2.6	2,000-10,000	7,500
Acid Plant Wastes	(5)	5	(10)	10		--	(1.2)	(300)	300
Boiler Blowdown	(2)	2	(22)	22	(0.05)	0.05		(100)	100
Sub-total		29		411		235	1.2-2.9		10,900
Semichemical									
Blow Tower	(2)	2	(8)	8	(1)	1		(1,000)	1,000
Condensate	(0.1)	0.1	(2)	2	(3)	3		(2,000)	2,000
Recovery system	(9)	9	(150)	150	(8)	8		(2,000)	2,000
Uncollected Liquor	(11)	11	(40)	40	(18)	18		(2,000)	2,000
Sub-total	(22)	22		200		30	2.5-4.0		7,000
Deinking									
All sources[3]				--	11-25	--		9,700-36,000	--
C. Pulp Screening									
Groundwood		--		--		--			--
Sulfate (Kraft)	5-8.0	4	60-63	62	10-18	14	9-10	900-9,600	3,600
Sulfite	1.7014	8		27	22-10.7	8	5.4-5.7	1,700-14,300	6,000
Semichemicals		--		--		--			--
Deinking		--		--		--			--
D. Pulp Washing & Thickening									
Groundwood (No Washing)	9-14	11	51-107	75	22-46	33	5.0-6.25	4,800-10,000	7,500
Sulfate (Kraft)	10-30	15	94-180	142	10-35	25	8.9-9.4	3,000-11,000	7,000
Sulfite	6.5-9.0	8	68-1037	131	7.4-34.0	18	2.4-3.9	1,800-15,000	7,500
Semichemical	0.9-6.0	3	42-141	93	10-42	24	7.0-7.9	2,400-7,800	5,400
Deinking		--		--		--			--
E. Bleaching									
Groundwood		--		--		--			4,000
Sulfate (Kraft)	14-124	60	216-294	240	8-88	30		12,000-32,000	19,000
Sulfite	4-44	15	131-415	220	17-44	25	2.9-6.8	9,000-30,000	15,000
Semichemical	--	--	--	--	--	--	--	--	--
Deinking	--	6	--	125	--	12	--	--	5,500
F. Paper Making[4]									
General	10-166	46	31-591	119	3-80	16	4.3-6.9	5,700-40,000	13,000
Products Related:									
Newsprint	20-60	40	--	--	10-20	15	--	37,000	--
Uncoated Groundwood	--	--	--	--	--	--	--	--	--
Coated Printing Paper	--	--	--	--	--	--	--	--	--
Uncoated Book Paper	--	30	--	116	--	16	--	8,000-28,000	14,000
Fine Paper	47-100	73	--	153	15-40	20	--	9,000-40,000	18,000
Coarse Paper	10-30	20	--	--	10-25	15		2,000-29,000	10,000
Special Industrial Paper	200-400	300	--	--	140-170	155	--	20,000-100,000	--
Sanitary & Tissue Paper	50-100	50	--	200	15-30	22	--	8,000-37,000	14,000
G. Total Mill Effluent (Integrated Pulp & Paper Mills)									
Bleached Sulfate & Paper	50-200	170	200-1300	810	30-220	120	--	39,000-54,000	45,000
Bleached Sulfite & Paper	40-100	100	600-1700	1140	235-430	330	--	40,000-70,000	55,000

1 Single pieces of data are entered under the "Range" column with parenthesis.
2 The mean values shown are not truly statistical average; they are considered to be probable average values based on the available data.
3 Deinking process includes pulping, screening, washing, and thickening.
4 Wastewaters from papermaking include those from stock preparation, paper machine, and finishing and converting operations.

* 1 lb per ton = 0.50 kg per metric ton
** 1 US gal per ton = 4.17 litre per metric ton

TABLE 4. ILLUSTRATIVE FLOWS AND LOADINGS FROM HYPOTHETICAL 300 TON/DAY INTEGRATED PULP AND PAPER MILLS, BASED ON DATA "G" TABLE 3

Characteristic	Bleached sulfate and paper	Bleached sulfite and paper
Flows:		
Average, m.g.d.	14	17
Range, m.g.d.	12 - 16	12 - 21
BOD:		
Average, lb/day	36 000	99 000
Range, lb/day	9 000 - 66 000	70 000 - 129 000
Average, mg/l	320	720
Suspended solids:		
Average, lb/day	51 000	30 000
Range, lb/day	15 000 - 60 000	12 000 - 30 000
Average, mg/l	435	210
Population equivalent*	216 000	594 000

* Based on 1/6 lb (0.075 kg) BOD_5 per day per capita

TABLE 5

POTENTIAL WASTE REDUCTION EFFICIENCIES OF VARIOUS PROCESS MODIFICATIONS

(From Amen., 1967)

Processes and Alternative Subprocesses	Waste Reduction Efficiency (per cent.) Suspended Solids	Dissolved Solids	Total Solids	BOD_5	Waste Water Volume
A. Wood Preparation (No Water Reuse)	0	--	--	0	0
With Water Reuse	77	--	--	93	72
Long Log Preparation	95	--	--	99	86
B. Pulping					
Mechanical Pulping					
Groundwood	0	0	0	0	0
Refining Mechanical Pulp	46	89	85	37	71
Sulfate (Kraft) Pulping (Batch, no Reuse)	0	0	0	0	0
Batch Process With Water Reuse	37	-4	-1	56	72
Continuous Process	89	42	47	60	77
Sulfite Pulping (Ca Base, no Reuse)	0	0	0	0	0
Calcium Base with Water Reuse	24	84	83	35	29
Soluble Bases with Liquor Recovery	71	84	87	80	57
Semichemical Pulping (NSSC Batch Process)	0	0	0	0	0
NSSC Kraft Batch Process with Water Reuse	53	-28	-29	30	32
Deinking (Cooking and Washing Without Reuse)	—	—	—	—	0
Cooking and Washing with Water Reuse	—	—	—	—	66
C. Pulp Screening					
Sulfate (Kraft) Pulp (Screening Without Reuse)	0	0	0	0	0
Screening with Partial Water Reuse	55	18	23	22	62
Screening and Cleaning With Water Reuse	(100)	(100)	(100)	(100)	(100)
Sulfite (Screening Without Reuse)	0	0	0	0	0
Screening with Partial Water Reuse	43	9	23	38	34
Screening and Cleaning With Water Reuse	(100)	(100)	(100)	(100)	(100)
D. Pulp Washing and Thickening					
Mechanical Pulp (Thickening and Cleaning With Decker)	0	0	0	0	0
Thickening with Vacuum Filtration	21	52	30	30	25
Thickening and Cleaning With V. F.	57	77	75	79	81
Sulfate (Kraft) Pulp (Diffuser Washing With Decker Thickening)	0	0	0	0	0
Vacuum Filter Washing and Thickening	17	21	20	40	72
Multistage V.F. Washing and Thickening	17	78	72	81	80
Sulfite Pulp (Diffuser Washing With Decker Thickening)	0	0	0	0	0
Vacuum Filter Washing and Thickening	72	50	52	52	62
Multistage V.F. Washing and Thickening	79	75	75	71	90
E. Bleaching					
Sulfate (Kraft) Pulp (Bleaching Without Reuse)	—	—	0	—	0
Bleaching With Low Degree of Water Reuse	—	—	40	—	58
Bleaching With High Degree of Water Reuse	—	—	69	—	74
Sulfite Pulp (Bleaching Without Reuse)	0	0	0	0	0
Bleaching With Low Degree of Water Reuse	50	32	34	37	67
Bleaching With High Degree of Water Reuse	80	80	80	72	84
F. Paper Making (Without White Water Recovery)	0	0	0	0	0
With White Water Recovery	34	27	25	20	60
With Improved White Water Recovery	50	60	56	50	77

TABLE 6. WASTE REMOVAL EFFICIENCIES OF VARIOUS PROCESSES APPLIED TO TYPICAL PULP AND PAPER WASTE WATERS

(From: Anon., 1967)

Removal method	Per cent. of gross waste load removed			
	Suspended solids	BOD_5	COD[1]	Colour[2,1]
Primary treatment				
Sedimentation basin	50 - 90	10 - 40	10 - 30	-
Gravity clarifier[3]	60 - 90	10 - 40	10 - 30	0 - 10
Dissolved air flotation	70 - 95	20 - 50	10 - 40	-
Secondary treatment				
Oxidation pond	0 - 90	30 - 50	-	0 - 10
Trickling filter	-	30 - 70	20 - 50	0 - 15
Aerated lagoon	-	40 - 85	30 - 60	0 - 10
Activated sludge	-	75 - 95	30 - 70	10 - 30
Irrigation	-	60 - 95	-	-
Sedimentation basin[4]	60 - 95	-	-	-
Secondary clarifier[4]	70 - 98	-	-	-

[1] Estimated.

[2] "True" colour (dissolved).

[3] With or without chemical addition and/or flocculation.

[4] As used to remove biological solids in secondary treatment.

REFERENCES

Anon. (1963) Chemicals from the other half of the tree, Chemical Engineering News (USA), 41 No. 6, 83-89

Anon. (1967) Paper mills - industry wastewater profile. The cost of clean water, Vol. III, Washington, D.C., United States Federal Water Pollution Control Administration (Publication I.W.P.-3)

Gehm, H.W. (1965) Pulp and paper. In: Gurnham, C. F., ed. Industrial wastewater control, New York, Academic Press, pp. 357-373

Waldmeyer, T. (1957) The treatment of papermill wastes. In: The treatment of trade-waste waters and the prevention of river pollution, London, Contractors' Record Ltd., pp. 215-226

Wiley, A. J. & Holderby, J.M. (1960) Pulp and Paper Magazine of Canada, 61, pp. T212-T217

SELECT BIBLIOGRAPHY

Altieri, A. M. & Wendell, T. W. (1967) De-inking of wastepaper (Tappi Monograph Series, No. 31), Technical Association of the Pulp and Paper Industry (USA)

Amberg, H. R. (1965) By-product recovery and methods of handling spent sulfite liquor, J. Wat. Pollut. Control Fed., 37, 228

Amberg, H. R., Pritchard, J. H. & Wise, P.W. (1964) Supplemental aeration of oxidation lagoons with surface aerators, Tappi, 47, 27A

Anon. (1966) Scottish paper mill avoids polluting local waters, Wat. Waste Treat, J., 11, 132-134 and 136

Banford, R. A. (1964) Centrifugal dewatering of paper mill waste, Tappi, 47, [illegible] A

Berger, H.F. (1966) Evaluating water reclamation against rising costs of water and effluent treatment, Tappi, 49, 79A

Blosser, R. O. (1958) BOD removal from de-inking wastes. In: Proceedings of the 13th Industrial Waste Conference, Purdue University, Lafayette, Ind., pp. 630-639

Blosser, R. O. & Caron, A.L. (1965) Recent progress in land disposal of mill effluents. Tappi, 48, 43A

Blosser, R. O. (1966) Practice in handling barker effluents in mills in the Unitedd States, New York, National Council for Stream Improvement, (Tech. Bull. No. 194)

Bolger, J. C., Tate, D. C. & Hopfenberg, H. B. (1967) a new process for improved recovery of tall oil from sulfate liquor, Tappi, 50, 231-237

Brown, R. W. & Spalding, C. W. (1966) Deep-well disposal of spent hardwood pulping liquors, J. Wat. Pollut. Control Fed., 38, 1916-1924

Burns, O. B., Jr. & Mancini, J. R. (1967) Disposal system for mixed primary and secondary sludges, Tappi, 50, 99A

Central Public Health Engineering Research Institute (1972) Pulp and paper mill wastes, Techn. Dig. (Nagput), No. 25

Coogan, F. J. & Stovall, J. R. (1965) Incineration of sludges from kraft pulp mill effluents, Tappi, 48, 49A

Copeland, C. G. (1964) Water re-use and black liquor oxidation by the Container-Copeland Process. In: Proceedings of the 19th Industrial Waste Conference, Purdue University, Lafayette, Ind. (Engineering Extension Series No. 117) pp. 391-401

DeHass, G. G. & Amos, L. C. (1967) Reocvery systems for mixed kraft and sulfite liquors, Tappi, 50, 75A-78A

Dhaneshwar, R. S. et al. (1970) Characteristics of wastes from pulp and paper mills in the Hoogly estuary, Environ. Hlth (Nagpur), 12, 9-23

Economic Commission for Europe (1967) Economic aspects of treatment and disposal of certain industrial effluents. New York, United Nations (Wat.Pollut./Econ./6). Vol. II. Case studies of techniques and costs of treatment and disposal of effluents from t the pulp, paper and board industries in ECE Countries

Erdman, A., jr (1967) Application of fluidized bed processing to spent sulfite liquor combination, Tappi, 50, 110A-112A

Follet, R. & Gehm, H. W. (1966) Manual of practice for sludge handling in the pulp and paper industry, New York, National Council for Stream Improvement (Tech. Bull. No. 190)

Foster, J. H. (1963) Fundamentals of primary treatment, Tappi, 46, 155A

Gehm, H. W. (1963) The application of stabilization ponds in the purification of pulp and paper mill wastes, J. Wat. Pollut. Control Fed., 35, 1174-1180

Gehm, H. W & Gellman, I. (1965) Practice, research, and development in biological oxidation of pulp and papermill effluents, J. Wat. Pollut. Control Fed., 37, 1392-1398

Gellman, I. (1965) Aerated stabilization basin treatment of mill effluents, Tappi, 48, 106A

Hall, H. R. (1963) Paper coating additives (Tappi Monograph Series, No. 25), Technical Association of the Pulp and Paper Industry (USA)

Haynes, D. C. (1966) Water reuse - a survey of pulp and paper industry, Tappi, 49, 51A-52A

Holderby, J. M. & Moggio, W. A. (1960) Utilization of spent sulfite liquor, J. Wat. Pollut. Control Fed., 32, 171-181

Jansson, L. B. (1967) Turpentine recovery systems for continuous digesters, Tappi, 50, 114A-116A

Knapp, C. A., Coughlan, F. P. & Baffa, J. J. (1964) Sedimentation practices for paper industry wastes, J. Sanit. Engng Div., Proc. Amer. Soc. Civ. Engrs, 90, No. SA6, pp. 41-49

Makkonen, O. A. P. (1956) Wastes from paper and pulp mills; a problem of the Northern European countries, with special reference to Finland, Bull. Wld. Health Org., 14, 1079-1088

Martin, W. C. (1962) Paper mill and de-inking effluent treatment. In: Proceedings of the 17th Industrial Waste Conference, Purdue University, Lafayette, Ind., p. 211

Meinck, F., Stooff, H & Kohlschutter, H. (1968) Industrie-Abwasser. 4., verb. and erw. Aufl. von Nr 6 der "Schriftenreihe des Vereins fur Wasser-, Boden- und Lufthygiene, Berlin-Dahlem". Stuttgart, Geo. Fischer., pp. 517-550 "Abwasser der Zellstoff- and Papier-industrie"

National Council for Stream Improvement (1961) Recent developments in the application of the activated sludge process for the treatment of pulp and paper mill wastes, New York (Tech. Bull. No. 138)

National Council for Stream Improvement (1963) Bibliography of biological oxidation as applied to pulp and papermill effluents, New York (Tech. Bull. No. 161)

Nemerow, N. L. (1963) Theories and practices of industrial waste treatment, Reading, Mass., Addison-Wesley

Nemerow, N. L. (1971) Liquid waste of industry theories, practices and treatment, Reading, Mass., Addison-Wesley

Quirk, T. P., Olson R. C. & Richardson, G. H. (1963) Bio-oxidation of concentrated board machine effluents. In: Proceedings of the 18th Industrial Waste Conference, Purdue University, Lafayette, Ind. (Engineering Extension Series No. 115) pp. 655-673

Rayet, R. (1965) L'epuration des eaux usees des papeteries et le traitement des boues, Trib. Cebedeau, 18, 386-391

Ross, E. N. (1964) Reuse and reduction of paper mill wastes, Tappi, 47, 180A

Screenivasan, A. & Raj., R. S. (1967) Effects of certain wastes on the water quality and fisheries of rivers Cauvery and Bhavani, Environ. Hlth (Nagpur), 9, 13-21

Spalding, C. W., Halko, D. L. & Carpenter, H. S., jr (1965) Deep well disposal of spent pulping liquors, Tappi, 48, 68A

Van Horn, W. M. (1964) Multiple water use for the pulp and paper industry, Tappi, 47, 50A

Warner, H. L. & Miller, B. C. (1963) Water pollution control by in-plant measures, Tappi, 46, 260-266

Weiss, C. M. et al. (1971) A review of the 1970 literature on wastewater and water pollution control, J. Wat. Pollut. Control Fed., 43, No. 6, pp. 956-983 "Paper and allied products"

Westinhouse, R. (1963) Irrigation disposal of wastes, Tappi, 46, 160A

Whisler, R. C. (1964) A tight white water system, its operation and problems, Tappi, 47, 181A

White, M. T. (1965) Surface aeration as a secondary treatment system, Tappi, 48, 128A

GUIDELINES FOR THE CONTROL OF INDUSTRIAL WASTES

6. METAL FINISHING WASTES

by

James C. Lamb III[a]

CONTENTS

	Page
Preface	V-136
1. Introduction	V-137
2. Quantity and characteristics of waste waters	V-137
3. Pollutional impact of waste waters	V-138
4. In-plant controls	V-141
5. Methods of treatment and disposal	V-142
5.1 Treatment for metals removal	V-142
5.2 Treatment of cyanide waste waters	V-143
6. Surveys and evaluations	V-145
References	V-150

[a]Professor of Sanitary Engineering, University of North Carolina, Chapel Hill, North Carolina, United States of America

Preface

The satisfactory disposal of industrial effluents is a major problem causing growing concern to public health authorities. Direct discharge of wastes into water courses may deplete dissolved oxygen, destroy aquatic life, and make the stream unfit for community water supply and other beneficial uses. On the other hand, the discharge of some industrial effluents into municipal sewers may have damaging effects on sewers or overload the sewage treatment works. Public health authorities are also aware of possible long-term physiological effects of some new organic chemicals which are found in industrial effluents, many of which are not removed by conventional treatment processes. Highly persistent detergents, pesticides and other toxic wastes have become serious problems in developed countries and will in time present a similar threat to developing countries.

In the developing countries the situation is particularly serious in view of the scarcity of qualified professional personnel (sanitary engineers, chemists and biologists), analytical laboratories, and finances for planning and operating industrial-wastes control programmes. It is important to consider the problem not only as it is at present, but also in the light of expected population increase, and of urban and industrial growth. Early government action is required for determining the extent of the problem and for planning and implementing efficient measures for the control of industrial wastes discharges.

This is one of a series of documents prepared by the World Health Organization covering the most prevalent industries in developing countries. The objective of these guidelines is to assist the responsible staff of health agencies and of other regulatory authorities to carry out surveys, interpret laboratory findings, advise industries on inplant remedial measures and disposal of wastes, and make recommendations concerning acceptance of wastes into municipal sewers. The first document in this series described the problem in general terms, and advised on how to carry out surveys and institute programmes of industrial wastes control.[1] The guidelines dealing with wastes from specific industries cover a description of the manufacturing process, with flowchart, the quantity and characteristics of wastes including health hazards, reclamation and recycling practices, methods of treating and disposing of wastes, suggestions for surveying and appraising existing facilities, and selected references to the literature.

It is planned to revise and update the documents from time to time by including information on new processes and procedures with special reference to experience in developing countries. Information and suggestions in this connection will be welcomed by the Organization.

---

[1] Document WHO/WD/70.6.

1. INTRODUCTION

Many uses of metal products require finishing to enhance appearance and protect against corrosion. The total number of metal finishing facilities in the world is unknown, but one author (Foulke, 1965) has estimated that there are 15 000-02 000 in the United States of America, alone. These range in size from thousands of small shops to very large facilities which may be associated with manufacturing concerns requiring the finished metal components or end-products.

Activities in the metal finishing industry have been divided into three categories: (a) cleaning and conversion coatings, (b) organic coatings, and (c) plating and anodizing (Foulke, 1965). A universal requirement in this industry is an adequate supply of water of appropriate quality, the most important use of which is rinsing after cleaning, plating, or other operations. The water may accumulate substantial quantities of metals or other chemicals from cleaning and plating baths and many of the constituents could have serious environmental impact, if discharged without proper controls.

None of the waste waters discharged from metal finishing operations present problems which cannot be solved through recognized in-plant control techniques or existing treatment processes, because ample technology has been developed for this purpose over the past several years. Nevertheless, it should be recognized that a special problem exists in this industry because a high proportion of metal finishing shops are small. This situation often renders impractical capital costs in small installations or lack of practical methods for their day-to-day operation (Battelle Memorial Institute, 1968). Accordingly, many small plants discharge waste waters with little or no treatment directly into receiving waters or, more frequently, into municipal sewerage systems. Often small flows may be diluted sufficiently by other waste waters or the receiving stream to eliminate serious problems. On the other hand, large metal finishing installations, or smaller facilities in areas where many are located, may require extensive waste water controls.

2. QUANTITY AND CHARACTERISTICS OF WASTE WATERS

Most of the flow from a metal finishing plant consists of rinse waters from plating, cleaning, or other surface finishing operations. Rinses are used between processing steps to reduce contamination of solutions and to remove residual chemicals from the metal upon completion of the finishing operation. It has been estimated that 1-25 US gallons (about 4-100 litres) of rinse water is used daily for each gallon of plating solution (Foulke, 1963). However, the flows vary widely from plant to plant, because of different processes and practices, covering a range extending from as low as 25% of the plating solution to as much as 50 times that volume.

In addition to wide flow variations, there may be radical differences in chemical losses because of the range of practices employed in metal finishing plants. Waste waters may have pH as low as 1.0 and up to almost 14 and may contain may types of toxic metals, depending upon processes employed, including: chromium, copper, zinc, cadmium, nickel, iron, bariu, precious metals, and others. Also they may contain high concentrations of cyanides, cyanates, oils, ketones, solvents, sludges, phosphates, carbonates, silicates, and other potential pollutants. One author illustrates the wide ranges of waste water character by giving "typical" rinse water analysis from general plating operations as, perhaps, 2-76 mg/l hexavalent chromium, 0.5-32 mg/l copper, 0.1-2 mg/l nickel, and 12-68 mg/l zinc. Tables 1-4 contain data selected from articles by two authors (Foulke, 1963; Lowe, 1970) giving "typical" concentrations in effluents from metal finishing plants.

The highly variable flows and concentrations of constituents in waste waters from metal finishing shops suggest strongly the impossibility of accurate generalizations about quantities and characteristics of waste waters from these type of operations. Thus, in the metal plating industry it is especially important to survey each facility carefully before attempting to arrive at final judgment concerning magnitude of problems caused by the facility and methods best suited for thier solution.

Most attention in control of metal plating wastes is directed towards rinse waters because of their large volumes. However, it must not be overlooked that serious pollution sometimes results from periodic or accidental dumping of concentrated plating or cleaning solutions. Spills or leaks of concentrated baths, waste waters from clean-up operations, sludges, filter cakes, and ion exchange regenerants may cause serious difficulties if handled in haphazard fashion. Normally these wastes should not be discharged directly into the disposal system but should be hauled away or treated batch-wise, using procedures adapted from techniques used for treating rinse waters.

Concern for control of most metal finishing waste waters is based on the presence of acids, alkalies, heavy metals and cyanides. Generally, BOD-causing constituents are present only in relatively small quantities and are not of major interest.

3. POLLUTIONAL IMPACT OF WASTE WATERS

Waste waters from metal finishing operations may have serious direct effects on the environment through action of corrosive or toxic constituents which can interfere directly with aquatic life, or other beneficial uses of watercourses. Although discharges from these facilities seldom, if ever, create oxygen-demand problems directly, many constituents of metal finishing waste waters may interfere seriously with performance of biological systems used to treat municipal and industrial waste waters.

Thus, their discharge into municipal systems could lead indirectly to oxygen-demand problems downstream even without significant addition of BOD-causing materials.

Discharge of acid waste waters in quantity sufficient to depress pH significantly may have serious corrosive effects on concrete, steel and cast iron pipes and other structures in municipal sewerage systems, treatment plants, and downstream facilities.

Plating wastes containing cyanides may create serious health hazards to sewer workers under certain conditions. Experiments have demonstrated that in sewage containing 50 mg/l cyanide, the presence of acid conditions could lead to release of lethal concentrations of the gas into the sewerage system. Investigators have suggested that cyanide concentrations in sewers should be maintained below 10-20 mg/l (Battelle Memorial Institute, 1968).

Release of volatile solvents from these waste waters into sewerage systems may create serious health hazards to workers because of excessive concentration of toxic constituents in the atmosphere. Sometimes solvents may lead to serious explosion hazards within sewerage systems or at treatment plants receiving the waste-water flows.

Adverse effects on biological processes used for treating municipal sewage may be serious. In particular, heavy metals and cyanides can interfere with biological processes, including activated sludge, trickling filters, oxidation ponds, and sludge digestion. Aerobic organisms may become acclimatized to low concentrations of cyanides and can even decompose them under certain circumstances, but slug discharges of cyanides have been observed to cause serious disruptions of aerobic and anaerobic (sludge digestion) processes. Considering the health implications of cyanides and to avoid possibility of interference with treatment processes, many municipalities limit cyanide concentrations to low lvels, usually approximating 1-2 mg/l (Battelle Memorial Institute, 1968).

Metallic waste-water constituents can exert toxic effects on bacteria and other organisms in biological treatment processes. Many heavy metals may precipitate and accumulate in the plant to levels several times those in incoming waste water, leading to very high concentrations in aerobic systems and in sludges discharged to anaerobic digesters. Accordingly, in reviewing observations on heavy metals in biological treatment processes, it is necessary to distinguish carefully between allowable concentrations in incomin; sewage and those which actually may be attained in the treatment process.

Partly because of this situation, evaluation of concentrations at which various heavy metals become objectionable in biological treatment plants has been the subject of extensive controversy. Until only a few years ago, it generally was con-

sidered that toxic thresholds in sewage for chromium, copper, cadmium, zinc, nickel and several other metals ranged from less than 1 mg/l to, perhaps, 5 mg/l. More recent work indicates that toxic thresholds of most metals in aerobic processes are substantially higher and today many individuals suggest that allowable concentration in waste waters undergoing biological treatment may be increased safely to, perhaps, 5-10 times the levels previously considered to be acceptable. Specific data summarizing toxic effects of metals on various treatment processes may be found in many references (Baily et al. 1970; Battelle Memorial Institute, 1968; Jackson & Brown, 1970; McKee & Wolfe, 1963; US Department of Health, Education, and Welfare, 1965).

Adverse effects of cyanides and metals in receiving streams usually are manifested through toxicity to fish and many other types of aquatic life. Lethal concentrations of many constituents of metal finishing waste waters to fish are summarized in numerous publications (Battelle Memorial Institute, 1968; Jackson & Brown, 1970; McKee & Wolf, 1963; US National Technical Advisory Committee on Water Quality Criteria, 1968). Table 5 summarizes concentrations which have been reported to be fatal to fish, but it must be noted that values reported by different investigators vary widely both above and below those in Table 5 (Pickering & Henderson, 1966). Allowable concentrations in a receiving stream in which it is desired to protect fish life obviously must be below the lethal concentration. Standards published by various agencies usually permit metals in streams not exceeding 1/10 to 1/100 of the LD_{50} - that concentration which kills half of the test fish during the bioassay test.

An effect of toxicants on fish life which has been ignored all too often is impact which the material may have on fish-food organisms. These adverse effects may be related simply to destruction of fish food, thereby having an obvious harmful effect on productivity. An alternate type of impact may be found in accumulation of metals in organisms comprising the food chain, ultimately leading to destruction of fish through toxicity of its food supply, as contrasted with direct toxic effects from constituents dissolved in the water.

Waste waters from metal plating operations also may be important because of adverse effects on other beneficial uses of the watercourse. For example, many incidents have been reported where plating waste waters caused death of livestock using the receiving stream for watering. Also, some constituents of waste waters may exert serious adverse effects on agricultural utility of the water because of toxicity to the crop being grown or accumulation of objectionable materials in harvested produce. Also, biological accumulation may cause objectionable concentrations of metallic constituents in fish taken from streams receiving metal finishing wastes, making them unsafe for human consumption.

An exceedingly important potential impact of metal finishing waste waters may be found in instances where the receiving stream is used subsequently as a public water supply. The important health effects of cyanides and numerous metals on persons consuming water has been well documented. This is illustrated by existence of recommended or required limitations on concentrations of those constituents in potable water standards of the World Health Organization (1970, 1971), the US Department of Health, Education, and Welfare (1962), and of many other countries. Some of the requirements are summarized in Table 6.

4. IN-PLANT CONTROLS

In the metal finishing idustry, as in few others, costs for treating and disposing of waste waters may be influenced radically by relatively simple in-plant controls applied to the processing operations. These measures are directed towards reducing the volume of flow and losses of objectionable constituents and, if pursued with sufficient diligence, ultimately could result in virtual elimination of major waste-water flows and pollution problems.

Much of the pollutional load from metal finishing plants results from drag-out of plating solutions from processing baths into rinse tanks and any approach which reduces drag-out will reduce discharges of potential pollutants. Some steps commonly incorporated into processing operations to reduce drag-out include provision of facilities for increasing time in which the treated objects can drain before passing into the next bath or rinse, installation of dripboards or tanks, air jetting, tumbling, or vibrating the pieces to facilitate removal of liquid. All of these help reduce losses of processing chemicals, which represent the bulk of pollutants discharged from plating facilities.

Recovery of chemicals sometimes may be practiced successfully, but this requires very sharp reductions in water usage to alow concentration of rinses to volumes small enough to permit their return to the plating bath. Several techniques reported to give major reductions in rinse water requirements include: installation of multiple rinse tanks through which the work passes in series, adoption of counter-current rinsing techniques to reduce water consumption even further, increased care in control of water flows through rinse tanks, use of sprays for rinsing, adoption of improved techniques for supporting work parts, and good maintenance of racks and tanks to reduce opportunities for drag-out, drips and leaks (Battelle Memorial Institute, 1968; Chalmers, 1970; Foulke, 1963).

Another step which has been reported as helpful in reducing waste-water discharges and facilitating treatment of waste waters is to provide tanks for impounding possible spills. Occasionally, segregation of waste waters may be accomplished into a

non-toxic flow which can be discharged without treatment and other flows requiring treatment. Also, sometimes it is desirable to segregate wastes requiring different types of treatment into separate collection systems, each leading to treatment units most appropriate for that flow.

Many waste-disposal problems in even the smallest shop could be reduced radically through adopting many of the measures which have been outlined (Battelle Memorial Institute, 1968). However, space requirements and costs of installing equipment to accomplish all of these steps may preclude their use in many small metal finishing shops and their operation may be too complex and expensive to be justifiable based on potential savings.

5. METHODS OF TREATMENT AND DISPOSAL

Metal finishing waste waters may contain several materials with potential for causing pollution problems, but space limitations here do not allow detailed discussion of the many types of constituents and appropriate treatment processes. Accordingly, waste-water treatment will be reviewed briefly only for two of the most common categories of potential pollutants - (1) processes useful for removal of metallic constituents, and (2) those often used for destruction of cyanides.

5.1 Treatment for metals removal

Most of the metallic constituents in metal plating waste waters may be removed by precipitation at pH 8-10 with lime, followed by settling. An exception is hexavalent chromium, which occurs in waste waters from chromium plating as chromic acid or chromates. Chromium rinse waters and concentrated baths have to be kept separate for treatment because hexavalent chromium does not precipitate readily, it first is reduced to chromic acid (trivalent chromium), which precipiates at pH 8-9. Reducing agents commonly used for this operation include sulfur dioxide, sodium bisulfite, metabisulfite, and ferrous sulfate. In large plating facilities, the approach most often followed involves reduction of chromium with sulfur dioxide at a pH of 2.0-3.0;

$$SO_2 + H_2O \longrightarrow H_2SO_3$$

$$2CrO_3 + 3H_2SO_3 \longrightarrow Cr_2(SO_4)_3 + 3H_2O.$$

This reaction usually requires about 1 lb (0.45 kg) of sulfur dioxide for each pound of chromic acid (CrO_3). Sulfur dioxide may be purchased or waste flue gas in boiler plants may be used by installing scrubbers to absorb the sulfur dioxide into the chromium waste water. If reduction of the chromium is not complete, sodium bisulfite or some other reducing agent may be added to complete the reactions. Sodium bisulfite or sodium metabisulfite could be used to accomplish all of the reduction with similar effects.

Ferrous sulfate may be used but usually is practical only if a plentiful supply of waste ferrous sulfate is available nearby. Even so, use of this material frequently is questionable because of very large volumes of sludge generated when the iron precipitates, in addition to sludge produced by precipitation of chromium after the pH is raised with lime.

After reduction has been completed, the acidic solution is neutralized to a pH of 8-0 through addition of lime, sodium hydroxide, or alkaline waste waters such as treated cyanide wastes. Hydroxides of most heavy metals precipitate and may be removed by settling and dewatering for separate disposal. Effluent from this type of process usually will contain relatively low concentrations of metals, but sometimes may require additional treatment, such as filtration, for removing the last traces of precipitate before discharge.

Several other methods have been proposed for removing chromium from waste waters (Battelle Memorial Institute, 1968, 1971). One of these is based on precipitation of hexavalent chromium with barium salts but this requires addition of a highly toxic chemical which must be controlled rigorously. Further, sludges produced in the process may cause serious disposal problems because of potential toxicity. Dialysis and reverse osmosis have been proposed for purifying chromium and cyanide rinse waters. Also, electrolytic reduction of hexavalent chromium, using scrap metal, has been suggested.

Ion exchange has been used to recover chromium from diluted metal plating rinse waters, concentrated rinses from countercurrent operations, and to regenerate plating baths. This may involve use of cation exchangers to remove iron and trivalent chromium from contaminated baths, cation exchangers to recover chromic acid from rinse water and removal of chromium using both cation and anion exchangers to remove trivalent and hexavalent forms. Sometimes evaporation may be used to concentrate solu tions in such recovery schemes.

5.2 Treatment of cyanide waste waters

Of the many approaches proposed for treating cyanide-containing waste waters, that most commonly used today involves destruction of the cyanide by alkaline chlorination to produce nitrogen gas and carbonate:

$$2\ NaCN + 5\ Cl_2 + 12\ NaOH \longrightarrow N_2 + 2\ Na_2CO_3 + 10\ NaCl + 6\ H_2O.$$

The reactions actually occur in two steps, with the cyanide first oxidized to cyanate which is much less toxic. That reaction is substantially complete within a few minutes and theoretically requires 2.7 lb (1.23 kg) of chlorine and 3.1 lb (1.41 kg) of sodium hyrodxide for each pound of cyanide (CN) destroyed. The

second reaction completes destruction of the cyanide and may require 1-24 hours, with theoretical chemical requirements of 6.8 lb (3.09 kg) of chlorine and 7.3 lb (3.31 kg) of sodium hydroxide for each pound of cyanide. In practice, about 8 lb (3.63 kg) of chlorine usually is required per pound of cyanide.

Although either step may be carried out on batch or continuous-flow systems, the most common approach involves use of multiple tanks for batch treatment. This offers the advantage of permitting testin of plant effluent to ensure satisfactory treatment before discharge, without necessary for relying on the sophisticated automatic control equipment required for safe operation in a continuous-flow installation. Because the process is carried out under alkaline conditions, most heavy metals accompanying the cyanide precipitate, producing sludge which may require separate dewatering and disposal.

It is important to note that caution must be applied in operating this process because it is necessary to handle chlorine, a relatively dangerous chemical, to treat cyanide, another dangerous chemical. It is of critical importance that proper alkalinity be maintained in the solution to prevent formation and evolution of highly poisonous cyanogen chloride (Battelle Memorial Institute, 1968).

The same type of reaction, exactly, may be accomplished using hypochlorites instead of chlorine. This approach is relatively simple because it may be based on adding hypochlorite directly to the rinse water, often without requirements for additional alkalis. With any of the chemicals, however, good agitation is necessary to insure proper mixing and complete reaction. Use of hypochlorite is suggested, especially, for treatment of waste waters from small metal finishing facilities.

Ozone also may be used to oxidize cyanide to cyanate. Economic studies indicate that this approach is more expensive than chlorination, but future changes in cost of equipment and power for producing ozone could alter that situation. In a few facilities, cyanide has been removed from waste water by acidifying and stripping the volatile cyanide gas. This must be done only with greatest caution because hydrogen cyanide is extremely toxic. The approach requires dilution with large volumes of air and discharge through a high stack, or absorption in caustic solution.

Another approach which has been suggested for treating cyanide waste waters is based on conversion of cyanide to ferrocyanide by adding ferrous sulfate or pickling liquor. Where waste ferrous sulfate is available, this technique could be relatively inexpensive, but produces large quantities of sludge and strongly coloured effluent. There is some evidence that ferrocyanides may decompose under the influence of sunlight in receiving streams to release cyanide to the water. This method has not been accepted in the United States of America, but is used in Europe.

Other oxidizing agents which have been suggested for destruction of cyanides include potassium permanganate and hydrogen peroxide. Also cyanides may be complexed through adding nickel salts to form very stable nickle-cyanide compounds. It has been found that cyanides may be destroyed biologically in trickling filter and activated sludge plants, provided the organisms are properly acclimatized and cyanide concentrations do not reach toxic thresholds. Reverse osmosis and dialysis are being considered today for purifying cyanide rinse waters. Laboratory and pilot work have indicated that ion exchange can be used to treat cyanie rinse waters but that the process may be subject ot "poisoning" of the resin through irreversible absorption of complex metal cyanides. Also, passage through cation exchange units, producing an acid effluent, could lead to production of hydrogen cyanide within the equipment.

6. SURVEYS AND EVALUATIONS

It has been pointed out earlier that the flows, constituents, and concentrations of metal finishing waste waters may vary radically depending upon many factors related to the type of establishment, its operating efficiency, and size. Accordingly, each facility must be studied independently if potential problems which could be caused by that installation are to be evaluated accurately.

Evaluation of waste-water discharges from a metal finishing plant will require careful flow metering, interpretation of production schedules to select proper times to measure flows and sample, and development of carefully designed programmes to ensure collection of samples which are representative of effluent actually discharged from the installation. Usually, grab samples will mean little unless many are collected in a carefully designed programme which permits the investigator to combine the results mathematically to arrive at average and extreme values for waste-water discharges and concentrations.

Analytical measurements most likely to be appropriate for analyzing the samples include appropriate metals (exact types depending upon processing undertaken at the facility), pH and cyanide determinations. Metals analyses, in particular, can be very tedious using conventional wet methods. If available, a highly desirable approach is based on using atomic absorption, which expedites such analyses greatly and usually enhances their accuracy. If this type of equipment is not available in water pollution control laboratories, it would be worthwhile to investigate to determine whether it might be available in local medical, food, chemical or industrial laboratories or to consider shipping the samples elsewhere for analyses.

Composite samples of the waste water are likely to be of little value unless collected in a fashion to ensure that they are weighted to flow, because great variations in flow from metal

finishing installations often may distort results obtained from such samples. Where baths are dumped periodically, care should be taken to analyze them separately and to consider them individually in evaluating potential pollutional effects of the discharge.

TABLE 1. TYPICAL RINSE WATER COMPOSITION (FOULKE, 1963), p. 149

Constituent	Average mg/l	Range, mg/l
Cyanide (CN)	25	10-500
Chromate (CrO_3)	50	10-500
Nickel (Ni)	20	10-200

TABLE 2. TYPICAL EFFLUENT FROM AUTOMATIC PLANT FOR COPPER, NICKEL, AND CHROMIUM PLATING OF ZINC-BASE DIECASTINGS (LOWE, 1970), p. 279

Constituent	Concentration-mg/l
Active alkalinity as Na_2O	10-20
Hydrofluoric acid (HF)	5-10
Sulfuric acid (H_2SO_4)	60-70
Total cyanide as CN	30-40
Copper as Cu	20-30
Nickel as Ni	45-55
Zinc as Zn	3-8
Chromate as Cr	5-10

TABLE 3. TYPICAL EFFLUENT FROM AN AUTOMATIC BARREL ZINC AND CADMIUM PLATING AND PASSIVATING PLANT (LOWE, 1970), p. 280

Constituent	Concentration-mg/l
Active alkalinity as Na_2O	70-95
Hydrochloric acid (HCl)	160-200
Nitric acid (HNO_3)	0-10
Chromate as Cr	5-10
Zinc as Zn	20-30
Cadmium as Cd	10-15

TABLE 4. TYPICAL EFFLUENT FROM A MIXED MANUALLY-OPERATED BARREL AND RACK PLATING PLANT (LOWE, 1970), p. 280

Constituent	Concentration-mg/l
Active alkalinity as Na_2O	80-100
Hydrochloric acid (HCl)	140-190
Sulfuric acid (H_2SO_4	420-470
Nitric acid (HNO_3)	140-190
Phosphoric acid (H_3PO_4)	200-270
Chromate as Cr	15-25
Cyanide as CN	40-50
Copper as Cu	3-8
Nickel as Ni	15-25
Zinc as Zn	5-10
Cadmium as Cd	7-12
Tin as SN	1-2
Silver as Ag	0.03-0.07
Gold as Au	Trace or nil

TABLE 5. EFFECTS OF PLATING WASTES COMPONENTS ON FISH LIFE (BATTELLE MEMORIAL INSTITUTE, 1968; PICKERING & HENDERSON, 1966)

Component	Levels of concentration fatal to some fish, mg/l
Hexavalent chromium	5
Trivalent chromium	about 5
Cyanide	0.05
Ferrocyanide	1.45
Copper	0.02
Zinc	0.3
Cadmium	0.6
Nickel	5

TABLE 6. SOME CHEMICAL CONSTITUENTS IN DRINKING-WATER STANDARDS OF THE WORLD HEALTH ORGANIZATION (1970, 1971) AND THE U.S. PUBLIC HEALTH SERVICE (1962)

Chemical constitutent	Concentrations in milligrams per litre						
	WHO International (1971)			WHO EUROPEAN (1970)		U.S.P.H.S. (1962)	
	Highest desirable level	Maximum permissible level	Upper limit of concentration	Approx. level above which trouble may arise	Upper limit of concentration	Recommended limit	Maximum allowable
Arsenic (as As)			0.05		0.05	0.01	0.05
Barium							1.0
Cadmium			0.01		0.01		0.01
Chloride (as Cl)	200	600		200		250	
Chromium (hexavalent)					0.05		0.05
Copper (as Cu)	0.05	1.5		3.0*		1.0	
Cyanide (as CN)			0.05		0.05	0.01	0.2
Iron (total as Fe)	0.1	1.0		0.1		0.3	
Lead (as Pb)			0.1		0.1		0.05
Mercury (total as Hg)			0.001				
Selenium (as Se)			0.01		0.01		0.01
Silver							0.05
Sulfate (as SO4)	200	400		250		250	
Total Solids	500	1500				500	
Zinc (as Zn)	5.0	15		5.0		5.0	

*After 16 hours' contact with new pipes; but water at pumping station should have less than 0.05 mg/l of copper.

REFERENCES

Bailey, D. A., Dorrell, J. J. & Robinson, K. S. (1970) The influence of trivalent chromium on the biological treatment of domestic sewage, Wat. Pollut. Control, 69, 100-110

Barnes, G. E. (1966) Disposal and recovery of electroplating wastes, Plating, September, pp. 1115-1121

Battelle Memorial Institute (1968) A state-of-the-art review of metal finishing waste treatment, Washington, D.C. (US Department of the Interior, Federal Water Quality Administration, Report No. 12010 EIE 11/68)
Note: A 28-page "Bibliography of foreign literature on cyanide and hexavalent chromium wastewater treatment and analysis" is appended to the report.

Battelle Memorial Institute (1971) An investigation of techniques for removal of chromium from electroplating wastes, Washington, D.C. (US Environmental Protection Agency, Water Quality Office, Water Pollution Control Research Series, Report No. 12010 EIE 03/71)

Chalmers, R. K. (1970) Pretreatment of toxic wastes, Wat. Pollut. Control, 69, 281-291

Foulke, D. G. (1693) The economic use of water in the electroplating industry. In: International Union of Pure and Applied Chemistry, Re-use of water in industry, London Butterworths, pp. 147-163

Foulke, D. G. (1965) Metal finishing products. In: Gurnham, C. F., ed. Industrial wastewater control, New York, Academic Press, pp. 339-356

Jackson, S. & Brown, V. M. (1970) Effect of toxic wastes on treatment processes and watercourses, Wat. Pollut. Control, 69, 292-303

Lowe, W. (1970) The origin and characteristics of toxic wastes, with particular reference to the metal industries, Wat. Pollut. Control, 69, 270-280

McKee, J. E. & Wolf, H. W., eds. (1963) Water quality criteria, 2nd ed., Sacramento, Resources Agency of California, State Water Quality Control Board (Publication No. 3-A)

Pickering, Q. H. & Henderson, C. (1966) The acute toxicity of some heavy metals to different species of warm water fishes; Air Wat. Pollut. Int. J., 10, 453-463; Trans. Am. Fish. Soc., 91, 175-184

US Department of Health, Education, and Welfare (1962) Public Health Service Drinking Water Standards, 1962, Washington, D.C. (US Public Health Service Publication No. 956)

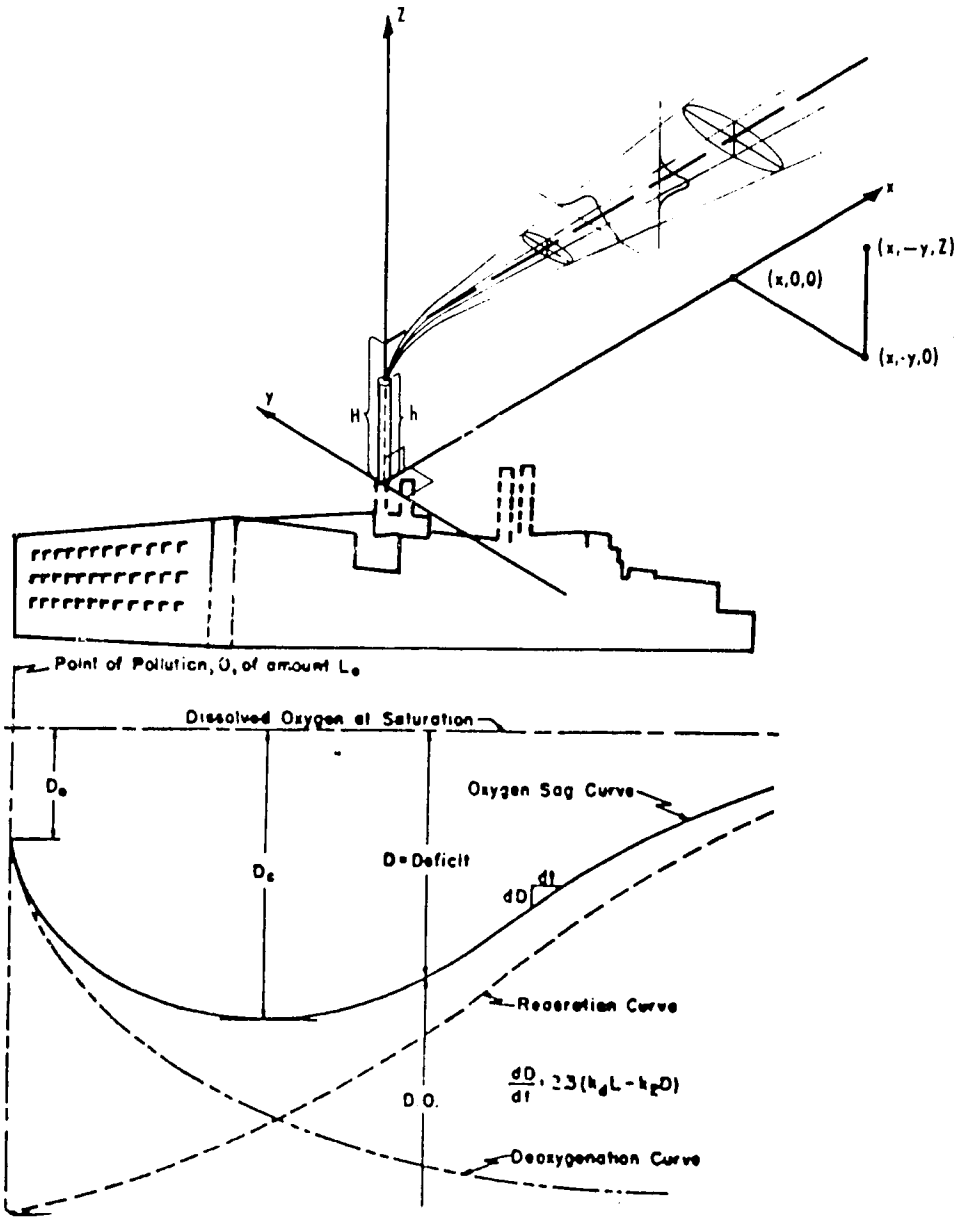
US Department of Health, Education, and Welfare (1965) Interaction of heavy metals and biological sewage treatment processes, Cincinnati, Ohio (US Public Health Service Publication No. 999-WP-22)

US National Technical Advisory Committee on Water Quality Criteria (1968) Water quality criteria; report . . . to the Secretary of the Interior, Washington, D.C., Federal Water Pollution Control Administration

World Health Organization (1970) European standards for drinking-water, 2nd ed., Geneva

World Health Organization (1971) International standards for drinking-water, 3rd ed., Geneva

Manual
on
General Environmental Protection
for the
Industrial Sector



THE WORLD BANK
Washington, D.C.

1977

V-152

This Manual was prepared under the direction of the World Bank's Office of Environmental & Health Affairs by Professor Leonard Nemerow, Syracuse University, New York, for and with the cooperation of the staff of the World Bank.

This Manual on industrial pollution control for the general protection of the environment is designed primarily for use by staff of the World Bank. Its use by other institutions, agencies, and individuals, particularly in the developing countries, is welcomed and encouraged.

Comments and suggestions to improve the Manual are invited. These should be addressed to:

Office of Environmental and Health Affairs
The World Bank
1818 H Street, N.W.
Washington, DC 20433, USA

Telephone: (202) 477-6151
Cable: INTBAFRAD

MANUAL A -- GENERAL ENVIRONMENTAL PROTECTION

Table of Contents

Page

I. INDUSTRIAL ENVIRONMENTAL POLLUTION -- CAUSES AND RESULTS V-161

A. Air V-161

1. Definition of Air Pollution V-161
2. Origin of Industrial Air Contaminants V-161
3. Some More Common Air Contaminants V-161
4. Effects of Air Contaminants on the Environment V-162

B. Water V-162

1. Definition of Water Pollution V-162
2. Origin of Industrial Water Contaminants V-163
3. Some More Common Water Contaminants V-163
4. Effects of Industrial Wastewater Contaminants on the Environment V-163

C. Land V-164

1. Definition of Land Pollution V-164
2. Origin of Industrial Land Contaminants V-164
3. Some More Common Land Contaminants V-165
4. Effects of Industrial Solid Wastes on the Environment V-165

II. ENVIRONMENTAL CONTROL PRACTICES BY GOVERNMENTS V-166

1. Problems of Environmental Control of Air, Water and Land Contaminants V-166
2. Local Government Control V-167
3. State or Provincial Government Control V-167
4. Regional Government Control V-168
5. National Government Control V-168
6. International Pollution Control Considerations ... V-169

III. ENVIRONMENTAL CONTROL MEASUREMENTS V-170

A. Air V-170

1. Source Testing/Monitoring of Air Contaminants V-170
2. Atmospheric Monitoring V-172
3. Analysis of Air Contaminants V-175
4. The Computation of Mass Quantities of Air Contaminants V-176

B. Water V-177

1. Monitoring of Industrial Wastewater Contaminants V-177
2. Analysis of Industrial Wastewater Contaminants V-181
3. Computation of Mass Quantities of Wastewater Contaminants V-184

C. Land V-185

1. Monitoring of Land Contaminants V-185
2. Analysis of Land Contaminants V-185
3. Computation of Mass Quantities of Solid Wastes V-186

IV. ENVIRONMENTAL CONTROL -- TECHNICAL (ENGINEERING) V-187

A. Air V-187

1. Use of Standards V-187

a. Effluent Standards V-187
b. Ambient Air Standards V-189
c. Significance of Standards V-189

2. Dispersion Techniques V-191

a. Meteorological Principles V-191
b. Stack Heights V-193

3. Computation of Treatment Required V-196
4. Treatment Techniques V-197
General V-197

a. Gas Removal Techniques V-197

(1) Gaseous Adsorption Removal Techniques V-198
(2) Gaseous Absorption Removal Techniques V-198
(3) Gaseous Chemical (Catalytic) Conversion Techniques V-199

b. Particulate Removal System V-200

(1) Filters V-200
(2) Sedimentation Units V-201
(3) Centrifugal Separators V-201
(4) Electrostatic Precipitators V-202
(5) Wet Scrubbers V-202

c. General Achieved and Acceptable Removal Efficiencies V-203

d. Redesign of Production System V-203

(1) Change of Raw Material (Oil for Coal, Low S Fuels for High S Fuels, etc.) V-203
(2) Change Process or Operation (Increase Temperature of Combustion, etc.) V-205
(3) Reuse Normal Wastes (Recirculate Stack Gases, etc.) V-205

e. Heightening of Stack V-206

B. Wastewater V-206

1. Stream Protection Measures V-206

a. Stream Standards V-208
b. Effluent Standards V-208
c. Significance of Standard as it Relates to Government V-208

2. Dispersion Techniques V-210
3. Computation of Treatment Required V-210
4. Combined Municipal and Industrial Wastewater Treatment V-212
5. Treatment Techniques V-214

a. Preliminary Techniques V-214

(1) Wastewater Volume Reduction V-214
(2) Waste Strength Reduction V-215
(3) Neutralization V-215
(4) Equalization and Proportioning V-217

b. Suspended Solids Removal Systems V-219

(1) Sedimentation V-219
(2) Flotation V-219
(3) Screening V-220

c. Colloidal Solids Removal V-220

(1) Coagulation with Chemicals V-220
(2) Adsorption V-221

d. Inorganic Dissolved Solids Removal V-222

(1) Evaporation V-222
(2) Dialysis V-222
(3) Ion Exchange V-222
(4) General Appraisal V-223
(5) Other Methods V-223

e. Organic Dissolved Solids Removal V-224
Introduction V-224

(1) Lagooning V-224
(2) Activated Sludge V-225
(3) Other Modifications of Activated Sludge V-226
(4) Trickling Filtration V-226
(5) Biodisc Treatment V-227
(6) Spray Irrigation V-228
(7) Other Systems V-228

(a) Wet Combustion Technique V-228
(b) Anaerobic Digestion V-229
(c) Deep Well Injection V-229
(d) Foam-Phase Separation V-229

f. Treatment and Disposal of Sludge Solids V-229
Introduction V-229
Sludge Treatment (Concentration and Preparation V-230

(1) Digestion V-230
(2) Vacuum Filtration V-230
(3) Drying Beds V-231
(4) Centrifugation V-231

Ultimate Sludge Disposal V-232

(5) Lagooning V-232
(6) Sludge Barging or Pumping V-233
(7) Drying and Incineration V-233
(8) Atomized Suspension V-234
(9) Wet Combustion V-234
(10) Miscellaneous Sludge Treatment Methods V-235

g. Bacterior or Micro-organism Removal V-235

(1) Chlorination V-235
(2) Ozonation V-236
(3) Ultraviolet Radiation V-236

C. Land V-236

1. Use of Standards V-236

a. Inplace Conditions V-236
b. Leachate Control V-237
c. Gas Control V-238
d. Significance of Standards (Local, National and International) V-238

2. Collection and Delivery Concerns V-239
3. Treatment Techniques V-239

a. Sanitary Landfill V-239
b. Grinding (Shredding) V-242
c. Incineration -- Central and Individual . V-242

V. ENVIRONMENTAL CONTROL -- ECONOMIC ASPECTS V-245

A. Air V-245

1. Costs of Air Pollution Abatement V-245
2. Benefits of Pollution Abatement V-248
3. Method of Payment for Abatement V-249

B. Water V-249

1. Costs of Water Pollution Abatement V-249
2. Benefits of Pollution Abatement V-250
3. Method of Payment for Abatement V-252

C. Land V-252

1. Costs of Solid Waste Collection and Disposal V-252
2. Benefits of Pollution Abatement V-253
3. Method of Payment for Abatement V-253

VI. ENVIRONMENTAL CONTROL -- POLITICAL ASPECTS V-254

A. Air, Water and Land Zoning for Environmental Protection V-254
B. Location of Industrial Plants for Environmental Protection V-254
C. General Problems Involved in Enforcement for Environmental Protection V-255
D. Relation of Local to National to World Politics for Environmental Protection V-256

VII. ENVIRONMENTAL CONTROL -- SOCIOLOGICAL ASPECTS V-256

Introduction to Philosophy of Survival by Environmental Protection V-256

A. Planning Land Utilization to Protect the Environment V-257
B. Planning Industrial Type and Location as it Relates to Local Environment V-257

1. Advantages V-258
2. Disadvantages V-259

VII. ENVIRONMENTAL CONTROL -- RANGES OF ACCEPTABLE ENVIRONMENTAL QUALITY LEVELS .....

A. Air .....

1. Normal Levels of Uncontaminated Air .....
2. Health Hazard to Humans .....
3. Reasonable Industrial Effluent Levels of Air Contaminants V-261

B. Water V-261

1. Quality of Uncontaminated Water V-261
2. Health Levels of Contamination in Receiving Waters V-262
3. Reasonable Industrial Effluent Levels of Water Contaminants V-266

C. Land V-267

1. Quality of Uncontaminated Land V-267
2. Health Hazards of Contamination On and From Land Sites V-268
3. Reasonable Industrial Effluent Levels of Solid Wastes V-269

IX. REFERENCES V-270

A. Selected Texts in Air, Water and Land Environmental Protection V-270
B. Selected Reference Papers and Documents for Environmental Protection V-271
C. Selection of Technically-qualified Expert Assistance for Environmental Protection V-271
D. Selected Agencies Which Possess Special Knowledge and Competence in Environmental Protection V-271

Conversion Factors V-274

MANUAL OF ENVIRONMENTAL PROTECTION
INDUSTRIAL POLLUTION CONTROL

MANUAL A
GENERAL ENVIRONMENTAL PROTECTION

I. INDUSTRIAL ENVIRONMENTAL POLLUTION -- CAUSES AND RESULTS

A. Air

1. Definition of Air Pollution

The addition to the air by any natural or man-made processes of any contaminant(s) in such quantities as to render the air unsuitable for its classified and established best usage. More specifically, air pollution is the presence in the outdoor atmosphere of one or more contaminants in quantiites, characteristics, and duration which are or may be injurious to human, plant or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property.

2. Origin of Industrial Air Contaminants

a. The mining or manufacturing of products for sale.

b. The production of power, steam, or water, involving the combustion of either fossil fuel or use of radioactive materials.

c. The burning of industrial refuse.

d. The construction or demolition of buildings.

e. The movement of materials to or on an industrial property.

f. The treatment of liquid wastes so as to release gaseous products.

3. Some More Common Air Contaminants

a. Ammonia -- NH_3
b. Sulfur oxides -- SO_x

c. Nitrogen oxides -- NO_x
d. Hydrogen sulfides -- H_2S
e. Mercaptans
f. Methyl amines
g. Carbon monoxide
h. Particulate matter of carbon origin
i. Particulate matter of dust origin
j. Radioactive gases
k. Methane
l. Chlorine
m. Various organic solvents

4. Effects of Air Contaminants on the Environment

a. General effects such as odor -- closely associated and related to taste. The result of odors is to retard any useful development in the area and to aggravate any existing use of the land area. Unpleasant odors can also be aesthetically intolerable.

b. General effects such as turbidity -- caused by clouds of stream, dust and smoke, interfering with sight, air traffic, sunlight penetration, and aesthetics.

c. General effects of particulate matter -- caused by burning, manufacturing or moving materials and buildings which result in layers of dust, dirt, grime and unburned particles on all surfaces. Excessive cleaning costs as well as nuisances will result.

d. Hazardous effects of toxic gases -- such as chlorine, SO_2, H_2S, CO, radioactive gases which can cause or lead to serious illness, usually of the respiratory system but also potentially to the blood and circulatory and nervous systems.

e. General effects of gases -- discolor fabrics, corrode metals, interfere with proper operation of electrical equipment.

B. Water

1. Definition of Water Pollution

The addition to the water by any natural or man-made processes of any contaminant(s) in the form of heat radiation, or matter, in such quantities as to render the water unsuitable for its classified and established best usage.

2. Origin of Industrial Water Contaminants

a. The mining or manufacturing of products for sale either as an intermediate or final product.

b. The production of power, steam or water involving either the combustion of fossil fuel or use of radioactive materials.

c. The production of potable water from surface or groundwater supplies.

d. The maintenance, cleaning, or general housekeeping of fixed surfaces of machines, buildings, etc., used in manufacturing products or maintaining equipment.

e. The transportation of persons and products by water, such as by boats and ships.

f. The leaching of contaminants from industrial refuse.

g. The condensing and/or absorption of gaseous wastes by water.

3. Some More Common Water Contaminants

a. Alkalinity and acidity
b. Colored matter
c. Heated liquids
d. Toxic chemicals
e. Detergents
f. Floating matter
g. Non-biodegradable organic matter
h. Organic matter
i. Suspended solids
j. Mineral salts
k. Algal nutrients
l. Foaming agents
m. Bacteria and viruses

4. Effects of Industrial Wastewater Contaminants on the Environment

a. Produce a general effect such as causing water to appear aesthetically undesirable or to smell; water which appears polluted is never fully used, resulting in a degradation of the general area. Unsightliness gives the appearance of pollution regardless of whether the water is actually polluted, and therefore is harmful to the environment.

b. Kill fish and other aquatic life.

c. Increase corrosion of all types of surfaces with which the water comes into contact.

d. Lower land use and monetary values of the land surrounding the water.

e. Encourage the growth of undesirable biological life, often in excessive quantities.

f. Cause disease in persons who may drink the water or who may eat life forms grown in the water.

g. Interfere with the recreational value of water for swimming, boating, etc.

h. Render the water unsuitable for irrigation purposes.

i. Make the water unsuitable for industrial use.

C. Land

1. Definition of Land Pollution

The addition of contaminant(s) to or the alteration of existing land in such quantities and/or in such a manner as to render the land unusable for its best[1] zoned use or cause it to become a nuisance or hazard to the nearby population in its present use.

2. Origin of Industrial Land Contaminants

a. The disposal of industrial solid wastes by improper landfill operations.

b. The burning of industrial solid wastes on land sites.

c. The mining of minerals.

d. The demolition of existing land-based structures yielding residual debris.

e. The storing either temporarily or permanently of materials which may create nuisances, either visual or sensual, (such as old autos or wastewater sludges).

---

[1]Determined by the municipal Government.

f. The damming or draining of lands to obtain more or to remove excess water.

3. Some More Common Land Contaminants

a. Packing material, such as paper, cartons, boxes, plastics, etc.

b. Residual tires, cans, and ash materials after burning.

c. Rubble from demolition such as lumber, bricks, stone, concrete blocks, etc.

d. Exposed errodable soil after mining.

e. Unusable stripped soil and rock from mining operations.

f. Slag heaps from smelting operations.

g. Tailings from mined ore concentration operations.

h. Organic sludges from canneries (pulp, pits, culls, vines, etc.).

i. Partially concentrated organic sludges from paper and pulp mills, textile, or water-producing companies.

j. Stored unusable materials such as junk cars, parts, and oil drums.

k. Waste oils, both as sludges and as contaminated oils from garages or oil reprocessing plants.

l. Cuttings into soil by quarrying operations for stone, gravel, or sand.

m. Waste caused by damming of flowing streams.

4. Effects of Industrial Solid Wastes on the Environment

a. Produce a general aesthetic effect of unsightliness such as is caused by changing the land from a forested area to one of denuded soil, or by storing on any type of previously used land such undesirable materials as junk metal, rubble and tires. Unsightliness also results from residual tires, cans and ash left on a barren area following the burining of industrial waste products.

b. Produce a general aesthetic effect of bad odors such as are caused by decomposing organic matter from stored sludges or oil.

c. Increase runoff and flooding which result from stripping land of its vegetation and cover material.

d. Kill valuable and/or rare vegetation and wildlife by dumping of tailings, oil, rubble, etc.

e. Kill grasses and cause siltation of soil by inundating the land with runoff water.

f. Kill rare birds, animals, and wildlife by draining swamplike lands for water supply.

g. Cause fires or explosions by storing in an improper manner building materials, oil, etc.

h. Breed disease (rats, mosquitoes, flies) by storing decomposing organic matter and liquid sludges.

i. Contaminate groundwaters and surface waters during rains by storing metals, organic matter and toxic sludges on the land by leaching and runoff.

Soil and mineral erosion which follows certain poor mining practices can lead to both water and air pollution and a loss of valuable soil materials. For example, saltation of water and dust infestation of air are typical environmental consequences of mining operations.

II. ENVIRONMENTAL CONTROL PRACTICES BY GOVERNMENTS

1. Problems of Environmental Control of Air, Water and Land Contaminants

a. Pollution knows no man-made, governmentally constituted boundaries but transgresses across city, state, and county borders without any man-made interferences or without regard for its origin. No method has yet been devised within the given conventional structure of governmental boundaries to control this type of environmental violation. It is of great importance for each technician and administrator alike to have a good understanding of the various governmental bodies, interests, viewpoints, and potential for the solution to given environmental problems.

b. There is a definite need for some form of governmental control of the environment for two major reasons:

(1) The environment belongs to no man or industry but to all mankind and biological life, and

(2) mankind has proven unable to control pollution simply on a voluntary or individual basis but has shown dependence upon larger groups represented by some form of government for both guidance and enforcement.

c. The conventional forms of government can be classified into five (5) groups as follows: local, state, regional, national, and international. All of these conventional forms are based upon some on-ground type of well-defined boundary(ies). They are based also on groups of people who are obligated to perform in accordance with laws and regulations established within those well-defined boundaries. For example, they are served by separate governmental representatives; they pay separate taxation for separate governmental services; and they are obliged to respond to separate and often quite different laws for operation. As the geographical scope of these governments broaden from local to worldwide the customs, laws, taxes, and indeed peoples themselves exhibit greater differences. And, lastly, the thinking and ideas of people also differ from government to government. Therefore, what one government feels is gross pollution another government might consider a normal environmental condition.

Some insight into the general nature and thinking of each type of government is necessary in order to understand the problems facing environmental control. Better understanding will lead to earlier and easier-to-enact governmental regulations.

2. Local Government Control

This form of government represents the one closest to a given environmental problem. It is usually long-time, well-respected inhabitants who must operate its services to the people with a relatively small budget. Because of the low capital budget and great number of services it usually provides (police, fire, roads, health, etc.), it generally cannot afford high-caliber type of people to administer an environmental control system. Its members may be subjected to abnormal or unusual political and economic pressures in making environmental decisions -- primarily because they live, work, and socialize simultaneously in the same area producing the contamination. Thus, this government represents the one most directly affected and with the most at stake and, at the same time, the one with the least competence and ability to control environmental problems.

3. State or Provincial Government Control

This form of government represents a collection of local governments usually possessing the same or similar social,

political, and economic interests, stemming from a historic origin. It comprises a larger sector of people and therefore possesses a greater economic base from which to work. At the same time, it may be less influenced by or concerned with any one specific environmental problem existing within its boundaries. However, it is not completely free from political and economic pressures, especially when in completion with other states. In addition, it may find itself "trapped" between the interests of its constituent local governments and those of its outside federal or national government. Also, no one local government, while admittedly possessing a pressing envirionmental problem, may be strong enough in the state government picture to influence it to act in its behalf. Thus this government, while generally possessing the competent professional personnel to administer an environmental program, is often torn between influence or prejudices to local problems and the influence or fear of domination by a larger national government.

4. Regional Government Control

This form of government generally represents a collection of state governments which possess some common environmental resource interest, such as an interstate river or common air corridor. While the goals, specific objectives, and needs of these state governments which comprise the regional governmental body may be different, their interest in the subject of environment is real and shared. However, getting this body to make decisions or enact laws may be lengthy, cumbersome, and frustrating. Each constituent must obtain approval of decisions from its own state government which, in itself, may be difficult and time consuming. The pooled resources of the constituent state governments is greater than any one state government. Therefore, the regional government is capable of undertaking projects of greater magnitude from economic as well as technical points of view.

The magnitudes of the environmental problem may be very different from one regional governmental member to another. Thus, unless each member is genuinely interested in environmental protection and possesses great empathy for the problems of others it may be difficult to get agreement by the governmental members. Therefore, the regional government is technically and economically more able to act in interstate environmental problems, but is often hampered by self-interests and inability to arrive at an early decision.

5. National Government Control

This form of government represents a cross-section of broad viewpoints on environmental protection. This type of governmental body is concerned primarily with providing information to smaller operating agencies and to establishing and maintaining general standards of environmental quality de-

sirable to all forms of biological life existing within a nation. Each member, while being well-educated and environmentally concerned, may have little interest and less incentive to seek immediate solutions to isolated, distant, and seemingly insignificant environmental problems. The "cold" objective viewpoint, however, often does away with local pressures and prejudices. The national government has more access to both higher levels of technical competence and greater amounts of financial assistance. It usually must seek national governmental approval for utilizing these services and monies; the decision of which can be influenced abnormally by politics which may have little or nothing to do with the particular environmental problem. There is also the danger that a national governmental body may use its greater weight and power to gain environmental decisions simply as a means for obtaining more power and authority over local matters. The rationale for the latter actions may be politically motivated and bear no resemblance, once again, to the environmental question under consideration.

A national government is able to bring an objective view to an environmental problem but can be either genuinely disinterested or politically motivated in its action. However, it is most able to supply the manpower, money, and legislative power necessary to implement an environmental plan within a country.

6. International Pollution Control Considerations

A joint agreement or organization established by two or more national governments represents the most comprehensive form of conventional environmental government structure. Matters relating to location of boundaries of sea, air and land in regard to contaminants, origin of contaminants, and joint means of control of such contaminants are of major importance to international organizations. Usually a small number (often only one) of persons are selected from each country to serve in such an organization. Members must be both politically astute and technically highly qualified (or obtain the consulting or advising services of ones so able). The resulting body concerns itself with environmental problems common to the countries involved. Agreements reached by such organizations must be ratified by each national government. Because of international politics, only environmental matters of the most general nature are considered by these bodies. In addition, solutions to environmental problems are described in very general terms, leaving specific procedures and quality levels up to individual national members. This form of organization is relatively new but appears to be gaining in favor and importance. Much greater resources can be made available for environmental problems of much greater magnitude jointly affecting one or more countries. Selfish national political and economic interests make for very slow, cautious, and usually rather

weak decisions. Implementation of laws and regulations of these bodies are fraught with national dangers of open conflict.

III. ENVIRONMENTAL CONTROL MEASUREMENTS

A. Air

There are two very general applications in monitoring air contaminants. They are emission source testing and atmospheric monitoring. In both cases the location of monitoring devices, the type of equipment, the duration of sampling, and pollutant discrimination are of paramount importance in quantitatively appraising air quality. Furthermore, these considerations require an intimate knowledge of the emission source(s) background pollution, meteorology and topography of an affected area under study.

1. Source Testing/Monitoring of Air Contaminants

Source testing requires a relatively elaborate set of measurements to establish a starting of final contaminant conditon. Because industrial processes involve frequent cyclic changes, the timing of source testing or monitoring must be planned accordingly. Process operations should be carefully reviewed so that individual polluting substances and classes of pollutants can be identified. Fluctuations of peak loadings must be determined and thus prediction of process peculiarities, such as equipment-caused effluent and temperature variations, are possible. All the variables of source testing must be accounted for so that the final pollutant analysis will be representative of the entire source process.

The first step in source sampling is the determination of the gas flow rate through a stack or the exhaust port where pollutant monitoring will take place. The approximate range of air velocity must be known before isokinetic sampling procedures can be instituted. To accomplish this, a wide variety of instruments are used. Most commonly the standard pitot tube is used. Other instruments used for measuring flow rates are the rotating vane anemometer, swinging vane anemometer, double pitot tube heated thermometer anemometer, and the thermal anemometer. However, all of these instruments have limited application, depending on the type of source to be monitored.

Most sampling devices consist of a vacuum source, a metering device for measuring air volumes, an inlet tube, a collection device (usually a filter or cyclone followed by impingers), an overflow trap, a manometer

and thermometer. All of these essential components must be constructed of materials which are chemically resistant or abrasion-resistant to the composite air volume being sampled. The types of collection devices vary, depending on the collection efficiency needed and the type of contaminant being sampled. The following is a list of collection methods commonly used in aerosol (particulate) sampling:

Particulate Contaminant Samplers

Principle	Collection Device
Filtration	Fiber filters Salicylic acid, naphthalene packed containers Granular filters Controlled pore filters High-volume samplers
Impingement	Wet impingers Cascade impactors Dry impingers Single-jet impactors
Sedimentation	Sedimentation in stagnant air Thermal precipitators
Centrifugal Force	Cyclones
Precipitation	Electrostatic precipitators Thermal precipitators

The most common method of emission source sampling is by taking grab samples, using a sampling train as mentioned earlier. Continuous sampling is usually done only on select processes where the potential emissions are very substantial, such as large power plants. More recently, automatic optical smoke density meters have been developed to collect and quantitatively analyze particulates in a combined procedure. In short, an instrument, such as the bolometer, measures the extinction of a light beam across a fixed distance within the stack of vent itself. This method has essentially replaced, in some US states, the use of opacity estimates by Ringleman Charts; however, its use is still recommended for developing countries. Gas sampling requires separation of the gas or gases being sampled from other gases present in the air stream. The temperature and pressure conditions under which the sample is collected must be accurately noted. The following is a list of collection methods commonly used in gas source sampling:

Gaseous Contaminant Samplers

Principle	Collection Device	Gas
Absorption (Chemical)	Midget Impinger (Water)	Ammonia
	Impinger (Water)	Sulfur dioxide
	Fritted Glass Scrubber (Sulfanilic acid, etc.)	Hydrogen sulfide
Adsorption (Physical)	Carbon Column	Nitrogen Carbon dioxide Hydrogen sulfide Sulfur dioxide
Condensation or Successive Cold Traps Freeze-out		Gross sample of all the polluting gas constituents

In summation, gases emitted from stacks are collected by suitable absorbents, or in a freeze-out trap, or by bubbling them through a suitable absorbing fluid. The gases commonly analyzed include, among others, carbon dioxide, sulfur oxides, nitrogen oxides, organic vapors, and halogen compounds. In recent years the use of optical systems has permitted in situ or remote analysis by infrared absorption for particular gases, which makes the analysis of gas compositions from emitting sources practical because gas sampling procedures are eliminated thus allowing the determination of gas concentrations under optimum conditions.

The preceding comments indicate the numerous appraoches to quantitatively collecting source samples of air contaminants. A review of the various combinations of devices and techniques and their inherent limitations in current literature is required. In this way the project director can certify the application of the optimum sampling method for a general range of problems such as optimum reliability, minimum cost, minimization of required personnel skills, ease of access and duration of sampling for each specific sampling environment.

2. Atmospheric Monitoring

This requires the establishment of an optimum air monitoring network which supplies aerometric data necessary to support air pollution prevention, control and abatement activities while consuming the minimum amount of financial and manpower resources. The first step in establishing an air monitoring network is to identify

the use of the aerometric data, collection devices available, the limitations of the sampling procedures and equipment, what pollutants must be monitored, location of pollutant monitors, and the duration of monitoring. This section will discuss the general rules for monitoring network design because the very nature of the air pollution problem varies widely from area to area, depending upon the peculiarities of meteorology, topography, source characteristics, and legal and administrative situations.

The location of atmospheric monitors is determined from the needs of the data or the specific contaminants under scrutiny. In every case, the approximate location of a monitoring site is decided on the basis of meteorological considerations, a rough source inventory, location accessibility, availability of space and needs for electric power and security. Choices should be made on site priorities for:

a. source-oriented monitoring for enforcement purposes;
b. zone of highest pollutant concentration;
c. background studies where industrial development is imminent;
d. areas of high population density; and
e. background studies where further development is not imminent.

The decision as to what pollutants must be monitored depends on the list of data needs as defined by the source inventory. In most cases, it is necessary to set priorities because of resource limitations, and the following order of priorities should be considered for pollutants which:

a. represent a definite hazard;
b. are expected to become hazardous to the public health and welfare at some time in the near future; and
c. have legal standards.

A monitoring network is normally continuous. However, the monitoring duration is usually governed by the use of the data, financial resources and statistical validation.

The types of instruments which should be employed for air monitoring are simply variations of the devices described in the previous section on source sampling. The choice of instruments for the following pollutants are:

Pollutant	Sampling Device
Total suspended particulates	High volume sampler
Heavy metals	Dust fall jars
Carbon dioxide	Non-dispersive infrared analyzer
Hydrocarbons	Flame ionization monitors
Sulfur oxides	Chemical absorption methods or flame ionization monitor
Nitrogen oxides	Chemical absorption method

Instruments which employ these techniques are specified in US published standards. Wet chemical methods should be avoided wherever and whenever possible for pollutants for which standards have not been established. Instruments which are commercially available should be purchased on the basis of reliability rather than cost.

The following is an example of a typical atmospheric monitoring program:

Typical Atmospheric Monitoring Program

I. Monthly Samples (All Stations)

1. Dustfall: trace substances

2. Composited daily high volume sampler filters: trace substances and total suspended particles

3. Sulfation plates

II. Twenty-four Hour Samples (All Stations)

1. High volume sampler: suspended sulfates and nitrates

2. Cyclone sampler: respirable particulates and trace substances

3. Integrated gas bubbler: sulfur dioxide

III. Continuous Samples

1. Automatic data acquisition with magnetic tape storage:

SO_2 (coulometric method)
NO^2 and NO_2 (coulometric method)
Hydrocarbons (flame ionization)
Ozone (chemiluminescent method)

IV. Meteorological Samples

1. Hygrothermograph (temperature and relative humidity)

2. Wind speed and direction

3. Analysis of Air Contaminants

In general, the methods of analysis for sootfall and dustfall, suspended particulate matter, gaseous pollutants and organic pollutants fall within some or all of the following categories:

a. Chemical methods -- A sample pollutant collected by chemical absorption is analyzed by appropriate titrimetry.

b. Physical methods:

Spectrophotometer -- A sample of pollutant is collected by chemical absorption and an appropriate reaction is allowed to occur which produces a solution color change. This solution is then measured colorimetrically or spectrophotometrically and compared to standards of the same solution.

Thermal Conductivity -- The concentration of gases can be determined by measuring the thermal conductivity of the sample gas as compared to that of a known reference gas.

Chromatographic Analysis -- Essentially all of the polluting gases may be collected in a chromatographic column. The difference in the mobility or the diffusion rate of the component gases in the mixture is a function of the molecular structure of the gas. Selection of a suitable detector from thermal conductivity, flame ionization, and electron capture methods depends on the composition of the gases to be analyzed.

Mass Spectrometer -- The instrumental technique is the bombardment of atoms or molecules to be analyzed with electrons, ions, or ultraviolet light, causing ionization. The instrument then measures the quantitative dissociation by spectra analysis.

c. Biological methods:

Bacterial cultivations of organic contaminants and monitoring respiration rates as a correlation of the quantity of organic pollutant.

d. Gravimetric methods -- Weighing or counting particulates.

There are many variations to these basic methods of analyzing for air contaminants, depending on the specific atom or compound of interest. Consequently, the investigator should thoroughly review the recent literature for specific test methods for specific contaminants. Consideration of specific methods will be given in the specific industry manuals where appropriate contaminants are expected.

4. The Computation of Mass Quantities of Air Contaminants

In order to achieve international standardization and comparability, the results of air pollution measurements should be expressed in CGS units. Using this system, the concentration of pollutants are reported in terms of mass per unit volume at a standard temperature and pressure. The standard pressure of 760 mmHg and the temperature of 0° centigrade should be employed. Normally, the concentration of air contaminants is expressed in terms of micrograms per cubic meter (g/m^3).

Computation of the results of atmospheric sampling and analysis is considerably simplified if they are expressed in the units recommended in the following:

Item	Recommended Units	Alternatives or Derived Units
Concentration of particle contaminants (liquid or solid) of known composition	Milligrams per cubic meter	Micrograms per cubic meter
Concentration of suspended or airborne particulate matter	Milligrams per cubic meter	Micrograms per cubic meter
Concentration of gases or vapors	Milligrams per cubic meter	Micrograms per cubic meter
Gas Volumes	Cubic meters at standard conditions	

Volume Emission Rates	Cubic meters per second	
Mass Emission Rates	Cubic meters per second	
Velocity	Meters per second	
Air Sampling Rates	Cubic meters per second or cubic centimeters per minute	Liters per minute
Temperature	Degrees Celsius (°C)	
Pressure	Millibars (mb) or millimeters or mercury	
Visibility	Kilometers	
Light Transmission	Percentage transmittance (%T)	
Light Reflection	Percentage reflectance (%R)	
Particle Size	Microns	
Wavelength of Light	Millimicrons	Angstroms (A)

B. Water

1. Monitoring of Industrial Wastewater Contaminants

a. The location of a monitoring station should be selected such that the flow conditions encourage a homogenous mixture. The velocity of flow at the sampling point should, at all times, be sufficient to prevent the deposition of solids, therefore assuring the collection of a well mixed representative sample. Homogenous flow conditions normally exist after channeling all flow at a weir, Parshall flume or hydraulic pump. A free-falling discharge from a pipe is also an excellent sampling location. A sampling point of approximately one-third the wastewater depth from the bottom and as near to the center of flow as possible is recommended for monitoring flows in sewers and channels.

b. Types of Equipment for the monitoring of industrial wastewater contaminants vary from manual to

automatic type devices. The selection of the appropriate sampling equipment is dependent upon the type of sample desired. Samples are of two basic types: "grab" or composit.

A "grab," also known as a "catch," sample consists of a portion of wastewater taken at one time in a random fashion. "Grab" samples generally are collected manually and reflect the conditions and characteristics existing at the time when the sample was collected.

Composite or integrated samples consist of portions of wastewater taken at regular intervals of time and combined to produce one final volume of sample. Composite samples tend to level off peaks and indicate average conditions over the sampling period. A common sampling time interval is every hour during the operations period. Shorter time intervals may be required if plant operations are extremely variable. Samples may be composited on the basis of time or flow. Composite samples compiled on the basis of time are composed of constant sample volumes collected at even time intervals, regardless of the rate of flow. Samples composited on the basis of flow will contain proportional sample volumes collected with respect to the flow rate at even time intervals. High flows would demand a higher proportion of sample, and vice versa. Composite samples are either collected manually or automatic sampling equipment is commercially available to collect samples on the basis of flow or time.

The scope of this manual does not permit a complete description of the many automatic sampling devices for industrial wastewater monitoring. More detailed information may be found in H.F. Lund, Industrial Pollution Control Handbook.

c. Flow Measurement plays an integral part in the monitoring of wastewater contaminants. The selection of one of the various methods for measuring flow will depend upon the facilities available, the degree of precision required, and the conditions under which the waste is discharged. Some of the more common methods of determining rates of flow are the following:

Container and Stopwatch -- The time required to obtain a known volume of wastewater in a container is measured and thus calculations of volume per unit of time can be made. This method applies well to sewers or outfalls

where free fall occurs and where flows are small.

Weirs -- A weir acts like a dam or obstruction, with the water flowing over the dam or through a notch cut in the dam. The notch is normally rectangular or V-shaped. The crest on the weir is defined as the level to which the water must rise before it can go over the weir and is either the top of the dam or the bottom of the notch cut into the dam. The head on the weir is the height of the water surface in the pool upstream from the weir above the crest. Knowing the type of weir (rectangular or V-notched) and the head upstream from the weir, calculations of rate of flow in cubic feet per second are a relatively easy task with the appropriate formula. The triangular or V-notch weir gives greater heads for a given discharge than does the rectangular notch of the same width of water surface. This greater sensitivity of the V-notch is useful in measuring relatively small rates of discharge. For discharges above 900 gallons per minute ($3.35m^3$/min) rectangular weirs should be used. Both rectangular and V-notch weirs are most commonly constructed of steel.

Parshall Flumes -- A Parshall flume can be built when there is the need for continuous measurement of open channel wastewater flows at or near the ground surface. The Parshall flume is a permanent structure made of metal, concrete or wood and is not recommended for small plants. the Parshall flume consists of a converging section, a throat and a diverging section. The floor of the converging section is level but the floor of the throat is included downward frm the horizontal and the floor of the diverging section is inclined upward at a definite slope from the horizontal. Because the throat width is constant, the discharge can be obtained from a single upstream measurement of depth under free flowing conditions. Flow under submerged conditions requires several measurements of head at various locations for the determination of flow rate. Maintenance of the unit is minimal due to its inherent ability to clean itself and and the hydraulic head loss is also minimal. Texts and handbooks for further discussion of Parshall flumes along with weirs may be found in

Chapter IX -- Water -- Metcalf and Eddy, Wastewater Engineering, and H. F. Lund, Industrial Pollution Control Handbook.

Venturi Meters -- This type of flow measuring device is installed in closed conduits or pipelines under pressure. It consists of a throat carefully machined to a specific diameter, a converging section which tapers from the pipeline to the throat and a diverging secton from the throat to the pipeline. Taps are provided for the measuring of the pressure head. The only measurements necessary to compute the rate of flow from the formulae is the difference in the pressure head between two tap points. Considerable loss of head is experienced through the Venturi meter. For additional information on the theory and operation of Venturi meters see K. H. Mancy, Instrumental Analysis for Water Pollution Control.

Orifice Meters -- These are often used also to measure flows in closed pipes. They contain sudden reduction in diameter of the pipe causing a change in pressure which is equated to the flow. These meters result in significant head loss in the system and therefore their use is limited.

Velocity Meters -- Also known as current meters, are usually used to measure stream flows but may be employed for the determination of the velocity of flow in large sewers or open channels. They consist of a rotating vane and cup arrangement with a sounding component by which velocity is measured according to the revolutions of the submerged cups. Combining the velocity measurement with a calculation of cross sectional area results in the rate of flow or discharge per unit of time.

Magnetic Flow Meters -- These consist of a non-magnetic tube of the same diameter of the pipe in which the water or wastewater is flowing and across which a magnetic field is established. Water or wastewater flowing through the magnetic field produces a voltage proportional to the velocity and is converted by electrical and mechanical means to indicate rate of flow.

d. The duration of sampling will be governed by the objectives of the monitoring program and the operating schedule of the industry. Samples should be collected over the entire day's operating schedule and continuous monitoring may be desired. An industrial waste survey should be conducted for at least five consecutive days and a two-week period is often recommended. Seasonal variations in production levels should be considered.

The quantity of sample to be collected varies with the extent of laboratory analysis to be performed. A sample volume between two and three liters is normally sufficient for a fairly complete analysis. The total number of samples will depend upon the objectives of the monitoring program. The use of a few locations and enough samples to define the results in terms of statistical significance is usually much more reliable than using many stations with only a few samples from each.

e. The importance of wastewater monitoring in industries should be stressed. Wastewater flows are measured to determine the quantity of wastewater being discharged. The combination of flow rate data with analytical data obtained from laboratory analysis results in the calculation of pounds of contaminants being discharged into the receiving stream. The next logical step after the amount of contaminants is known is to determine what effect these contaminants have on the receiving body of water and then finally establish some acceptable level of contaminant discharge (see Chapter VIII -- Water -- of this Manual). Analytical techniques for the qualitative determinations of wastewater will be discussed in the next section and computations of mass quantities of contaminants will follow the analytical techniques section.

Monitoring of wastewater also allows for locating major sources of wastes and permits the computation of budgets for varying operations.

2. Analysis of Industrial Wastewater Contaminants

One of the basic objectives of the monitoring of industrial wastewater is to determine the loading or quantity of contaminants discharged into the receiving body of water. Two essential components for computing contaminant loadings are the rate of flow and the concentration of contaminants in the wastewater. Some of the more common techniques for determining rate of flow in wastewater have been discussed in Section 1. Tech-

niques and methods for the qualitative analysis of wastewater contaminants are of four basic categories: (a) chemical; (b) physical; (c) biological; and (d) biochemical.

a. Analysis by chemical techniques are either by titration, precipitation or chemical reaction.

   -- Titration involves the measurement of a volume (volumetric analysis) of a known concentration (standard solution) that is required to interact exactly with the desired chemical component or another substance chemically equivalent to it. Titration proceeds to a definitive end point, normally to either a color change or some electrical meter response. For example, acidity and alkalinity are determined by titration with a standard basic or acidic solution respectively.

   -- Precipitation techniques are applied by converting the desired chemical component to an insoluble product. Probably the best example of a precipitation determination is the chloride ion (Cl^-) determination with silver nitrate as the standard titrant, converting the chloride ion to an insoluble white precipitate which is then weighed for quantitative analysis.

   -- Chemical reaction techniques vary in complexities ranging from the addition of simply one chemical reagent to the combination of many compounds to produce the desired chemical component. For example, the dissolved oxygen determination calls for the addition of three reagents followed by a titration with standardized sodium thiosulfate. The addition of the reagents converts the oxygen to an equal amount of iodine and then becomes appropriately titrated.

b. Two types of physical methods of analytical analysis of wastewater are filtration and adsorption.

   -- Filtration of precipitates and solids is accomplished by passing the wastewater through a standard size filter mat (asbestos or glass films are commonly used). The suspended solids determination is an example of this filtration principle by passing a known volume of sample through a special crucible with a filter mat placed inside the crucible. The filter retains suspended particles and

allows for the passage of liquid. The retained particles are weighted and thus a calculation of weight per unit volume (milligrams per liter) can be made.

-- Adsorption techniques using activated carbon for the detection of low but significant quantities of organic compounds are frequently used in wastewater analysis. The determination of phenols by the carbon chloroform extract (CCE) technique calls for the passing of a column of water through a carbon adsorption unit; the carbon is then removed, dried, and the contaminants are extracted by washing the unit with chloroform and collecting the washings for weighing or further instrumental analysis. Another adsorption technique which is a relatively new method of analysis is atomic adsorption spectrophotometry. A sample solution is atomized into a flame, producing atomic vapors of the element in question, which are measured by passing a monochromatic light of the same wave length through the vapor in the flame. Atomic adsorption spectrophotometers are relatively expensive instruments but are excellent for the determinations of true quantities of elements such as copper, iron, magnesium, nickel and zinc in wastewaters and waters.

c. Biological methods for wastewater analysis include culturing techniques for bacteria and also microscopic analysis. The standard plate count (SPC) determination provides an estimate of the total number of bacteria in a wastewater or water sample that will grow under specified conditions. The culturing techniques essentially involve providing a food supply and the correct conditions for growth through the use of an agar culture medium and then counting the bacteria formed. Microscopic examinations provide information concerning growths of minute plants and animals in the wastewater.

d. Probably the most important biochemical method of analysis is the biochemical oxygen demand (BOD) of determination. This test is used for determining the oxygen requirements for the decomposition of organic matter in trial wastewaters under specified conditions of time (normally five days) and temperature (normally 20°C). The BOD analysis is a biochemical method because the analysis involves the oxygen consumed by aerobic bacteria and by the chemical oxidation of reduced compounds such as

H_2S, NO_2, and Fe++ that can be oxidized by molecular O_2.

Finally, it should be noted that the analysis run on any specific wastewater sample will depend upon the nature of the industrial operation. Determinations that may be conducted are:

pH	Phenols
Alkalinity and Acidity	Cyanide
Total Hardness	Copper
Chloride	Zinc
Sulfate	Iron
Phosphate	Manganese
Suspended Solids	Chromium
Volatile Solids	Nickel
Total Solids	Lead
Settleable Solids	Biochemical Oxygen Demand (BOD)
Total Nitrogen	Chemical Oxygen Demand (COD)

For detailed procedures on these and other analyses concerning waters and wastewaters, see Standard Methods for the Examination of Water and Wastewater, 13th Edition, and K. H. Mancy, Instrumental Analysis for Water Pollution Control

3. Computation of Mass Quantities of Wastewater Contaminants

One of the objectives of monitoring wastewater flows is to measure the load of contaminants discharged per day or per unit of production. To determine the load of contaminants, rates of flow and concentrations of contaminants must be known. Methods for determining both of these parameters have been previously discussed.

Concentrations of contaminants are expressed as parts per million, which means kilograms of contaminants in a million kilograms of water. Milligrams per liter are equivalent to parts per million. Rates of flow are expressed as cubic meters of water per day.

Computations of waste loadings are made relatively simple by mutliplying the concentration of contaminant times the rate of flow with the appropriate conversion factor (i.e., 8.34 when rate of flow = MGO and concentration = ppm). Some of the more common units for expressing loadings are kilograms of contaminants per day or kilograms of contaminant per unit(s) of production.

C. Land

1. Monitoring of Land Contaminants

Records should be maintained and the environmental impact of the land disposal sites should be monitored. The following records should be kept by the owners or operators of the land area:

a. major operational problems, complaints or difficulties;

b. quantitative and qualitative evaluation of the environmental impact of the land disposal site with regard to the affectiveness of gas and leachate control, including results of leachate sampling and analyses, gas sampling and analyses, ground and surface water quality sampling and analyses upstream and downstream of the site;

c. vector (a carrier that is capable of transmitting a pathogen from one organism to another) control efforts;

d. dust and litter control efforts;

e. quantitative measurements of the solid wastes handled; and

f. description of solid waste materials received, identified by source of material.

Upon completion of the site, a detailed description, including a plan, should be recorded with the area's land recording authority. The description should include general types and location of wastes, depth of fill, and other information of interest to potential landowners.

2. Analysis of Land Contaminants

Chemical, physical, and biological methods are used to analyze the air and water effluents from solid waste disposal land areas. These have been described already in Parts A and B of this chapter. In addition, some consideration should be given to an analysis of hazardous materials in landfill areas. Hazardous wastes can usually be classified into four general categories:

a. radioactive -- laboratory wastes, power generation wastes, etc.;

b. toxic chemicals -- metals, pesticides, pharmaceuticals, etc.;

c. biological -- antibiotics, pathogens, enzymes, etc.; and

d. miscellaneous -- flammables, explosives, irritants, corrosives, etc.

and most should not be allowed to be landfilled in the normal manner with other industrial solid waste. Because it is often difficult to classify all of the above solid wastes as definitely hazardous in a landfill operation, some type of waste rating system can be used. The system may include evaluation of the solid wastes effect on:

(1) human toxicity;
(2) groundwater toxicity;
(3) disease transmission potential;
(4) biodegradability; and
(5) mobility.

3. Computation of Mass Quantities of Solid Wastes

a. Solid waste quantities are measured in terms of both volume (m^3) and weight (kg or ktons). The volume is significant from a transportation standpoint and also from a land-occupation consideration when compacted. Volume is measured by recording the number of a fixed volume hauler while weights of solid wastes are computed by scale readings of the hauler loaded weights minus their empty weights.

b. Leachates are measured by collecting all drainings from the land area, passing them through single or multiple weirs to compute the flow and to select samples for analyses and multiplying by the contaminant concentrations to obtain total weight (kg or kt) of contaminants in a fixed time period. The computations are similar to those made on industrial liquid wastewaters.

c. Land area air contaminant mass quantities are made exactly like those determined in land areas surrounding any industrial plant emitting stack gases.

IV. ENVIRONMENTAL CONTROL -- TECHNICAL (ENGINEERING)

Air

1. Use of Standards

Standards used can either be related to industrial production or to the quality of the air in the atmosphere surrounding the industry. In the former case they are referred to as effluent standards or standards of performance, whereas in the latter case they are called ambient air quality standards. The former are more useful for design and control whereas the latter are preferable for environmental quality measurement and protection. Both are useful and important to the project engineers and administrators of environmental protection systems.

a. Effluent Standards

One method of pollution abatement is to establish a contaminant level for each industrial manufacturing operation. The level of allowable contaminant should be based on the use of a reasonable degree of environmental control equipment, good process control, and manufacturing in a modern designed plant. The omission or absence of any one of the three above bases will place undue hardship on the other two -- often resulting in exceeding the allowable standard of emission. The allowable standard of emission is related to a unit of feed or production from a given industry or in many cases is based upon the volume of gas generated.

An example of standards of emission[1] from five industries as established by the Environmental Protection Agency in the United States is given in the following table (Table 1).

The engineer designer or administrator reviewing environmental control procedures and standards must recognize that this type of standard will not necessarily protect the air from becoming polluted. Nor will it give any direct indication of the level of contamination existing at any time in the air. It simply provides a working tool for satisfactory design and operation with the optimum methods available today for these plants.

---

[1]Federal Register, December 23, 1971

Table 1

Standards of Performance for New Sources[a/]

Type Industry	Emission Quantity	
1. Power facilities for producing steam from fossil fuel (for plants of 250 million BTU/HR heat input or greater)		
A. Particulates	(.18 gram/10^6 cal)	0.1 lb/10^6 BTU (Max. 2 hr. avg.)
B. SO_2		
Oil fired	(1.44 gram/10^6 cal)	0.8 lb/10^6 BTU
Coal fired	(2.16 gram/10^6 cal)	1.2 lb/10^6 BTU (Max. 2 hr. avg.)
C. Nitrogen Oxides		
Gas fired	(.36 gram/10^6 cal)	0.2 lb/10^6 BTU
Oil fired	(.54 gram/10^6 cal)	0.3 lb/10^6 BTU
Coal fired	(1.26 gram/10^6 cal)	0.7 lb/10^6 BTU (Max. 2 hr. avg. as NO_2)
D. Visible Emissions	Not to exceed 20% opacity, except that for 2 min. in any 1 hr. emissions may be as great as 40% opacity.	
2. Incinerators		
A. Particulates	(.185 gram/m^3	0.08 grains/SCF
3. Nitric Acid Plants		
A. Nitrogen Oxides	(1.5 gram/kg)	3.0 lb/ton acid
B. Visible Emissions		<10% opacity
4. Sulfuric Acid Plants		
A. SO_2	(2 gram/kg)	4 lb/ton acid
B. Acid Mist		0.15 lb/ton acid
C. Visible Emissions	(.075 gram/kg)	<10% opacity
5. Portland Cement Plants		
A. Particulates		
1. Kilns	(.15 gram/kg)	0.30 lb/ton feed
2. Clinker Coolers	(.05 gram/kg)	0.10 lb/ton feed
B. Visible Emissions		
1. Kilns		10% opacity
2. Others		<10% opacity

a/ Federal Register, December 23, 1971

b. Ambient Air Standards

The other method of air pollution abatement is that of limiting the final air concentration surrounding an industry or existing in a community. The limit for each type of contaminant should be based upon the latest information available concerning physical and other health effects of the contaminant as well as the practicability of attaining the level desired. It provides little clue for the designer for remedial action in the industrial plant except when exact mixing ratios of gas volumes of industry and diluting atmosphere are known. The level of contaminant measured in the atmosphere at any one time is directly related to the method used for collecting sample and analysis. In Table 2 the six Federal Primary Standards now in effect in the United States are given, along with the methods of sampling and analysis. You will note that the allowable level of concentration of each contaminant varies with time of exposure (even though other times are not given here for most of them). The shorter exposure periods permit higher concentrations of contaminant. The health effects of each level of the most important contaminants are discussed in Chapter VIII, Section A.2. (p. 91)

c. Significance of Standards

The use of effluent standards, while quite helpful for enforcement purposes and for plant and equipment operational checks, often provide environmental quality inequities. For example, two similar steam power plants, both discharging the maximum 0.8 pounds of SO_2 per million BTU of heat energy (1.44 gram/10^6 cal), would produce drastically different effects on the environment if one was located in Los Angeles, California, and the other in New York City. Although both are large metropolitan areas, the former is located in a bowl surrounded by mountains and is subjected to numerous and almost continuous daily inversions. This limits the vertical mixing and thus the amount of dilution air available. The high pressure atmosphere which is usually present near Los Angeles also helps to bring in and down warm airs which keep a "lid" on the contaminating city gas vapors. New York City gases, while just as contaminating, generally rise unimpeded and are diluted with ample fresh air. While these power plants and needed equally in both cities, it is obvious that local standards would be desirable to supplement national ones in order to protect the

Table 2

Ambient Air Quality Standards

	Pollutant	Averaging Time	Concentration	Method of Collection of Analysis
1.	Photochemical Oxidants	1 hour	160 $\mu g/m^3$	Chemiluminescent method
2.	CO	1 hour	40 mg/m^3	Non-dispersive infrared spectroscopy
3.	NO_2	Annual avg.	100 $\mu g/m^3$	Colorimetric method using NaOH
4.	SO_2	Annual avg.	80 $\mu g/m^3$	Pararosaniline method
		24 hour avg.	365 $\mu g/m^3$	" " "
5.	Suspended particulate matter	Annual geometric mean	75 $\mu g/m^3$	High volume sampling
		24 hour avg.	260 $\mu g/m^3$	" " "
6.	Hydrocarbons (corrected for CH_4)	3 hour avg. (6-9 AM)	160 $\mu g/m^3$	Flame ionization detection using gas chromatography

air quality in particular locations. In effect, this is done in some cases. For example, both Los Angeles and New York City have their own air quality control standards which suggest limits of industrial operation at certain predetermined levels of contaminant concentration.

In cases where air crosses national governmental border lines, it may be necessary to enact different effluent standards in one or the other country in order to comply with ambient air quality level requirements of the other country. This can only be determined by consulting the standards of the other country, studying the meteorological conditions which prevail on the border, and either mathematically computing or physically measuring (empirically) the resulting border-crossing contaminant levels in the air at various given effluent standard levels.

2. Dispersion Techniques

a. Meteorological Principles

There exists several rather elementary principles with which the user of this Manual should be familiar.

In order for air to be put in motion a force is required --thus producing a wind effect. The wind developed is a result of an equilibrium condition between the pressure, rotation of the earth on its axis (Coriolis), and friction forces. The pressure is created by high or low pressure regions existing in the atmosphere. In high pressure areas, the air moves clockwise and in low pressure areas it moves counterclockwise, both in northern latitudes only, the reverse being true in southern latitudes. Also in the northern hemisphere, the rotation of the earth causes a turning of this air flow to the right rather than along lines of equal pressure (isobars). Resultant wind speeds are greater as the distance from the earth's surface increases as a consequence of freedom from the earth's friction effect.

The motion of air will exhibit some degree of turbulence -- although sometimes very slight -- depending upon both the character of the ground surface and the time of the day. The ground surface causes mechanical turbulence and the heating of the earth at different times of the day causes thermal turbulence. Turbulence produces eddies in the atmosphere and eddies are very important in

the dilution of air contaminants. Turbulence will diffuse air contaminats rising from the earth in both horizontal and vertical directions. Large eddies often result in large plume motion but little plume dispersion while the opposite may be true for small eddies. An eddy about the same size as the plume will cause its maximum dispersion and thus reduce air contaminant concentration to a minimum.

Wind roses (plots of predominant wind directions and speeds) indicate to the reader from which direction the predominant winds are blowing during a given period of time and hence to which direction air contaminants will be carried initially after emission.

Wind created at the ground surface causing mechanical turbulence can be generated largely by either (1) a mountain-valley or (2) a sea-land situation. In both cases, wind here is caused by unequal heating of the surfaces and as a result a temperature differential exists between the air over each surface, causing the cooler air to flow toward the rising warmer air. Daytime wind directions here are usually opposite to night time ones because of changes in temperature and differential cooling rates. The direction of the wind will affect people and matter located downwind from sources of air contamination.

Separated flows -- caused by physical structures impeding the movement of a plume of air contaminants -- often result in a cavity on the downwind side of the structure. The cavity is an area of little air movement and often contains an increased concentration of contaminants.

The temperature change which occurs with altitude plays a great part in the movement of ground air contaminants. As a "normal" occurrence both pressure and temperature decrease with height above ground level. The normal increase in temperature with height (lapse rate) is -3.5°F/1000 ft or -.65°C/100 meters. For isoentropic case (atmosphere with a constant heat value as a function of height):

$$dT/dz = -5.4°F/1000 \text{ ft or}$$
$$dT/dz = -1°C/100 \text{ meters}$$

As the contaminated air rises and encounters lower pressures, it expands and as it expands it does work on the surroundings and the central air of

the contaminants temperature reduces slightly. However, the work process occurs fast and it can be presumed to occur without any heat transfer or adiabatically. A comparison of the adiabatic lapse rates of both the contaminated rising and existing air temperature will determine the future vertical position and hence contaminant concentration at any level. If the two adiabatic lapse rates are exactly the same then the contaminated air would be at the same temperature, pressure, and density of the surroundings and exhibit no buoyant force (tendency to rise)or gravitational force (tendency to return downward). If the contaminated air arrives at an upper elevation at a temperature lower than its surroundings but at the same pressure, it will be heavier than its surroundings (P = oRT) and it will sink to a lower level (stable condition). If, on the other hand, it arrives at a higher temperature, it will continue to rise to a higher level (unstable condition). A stable condition will result in an inversion which, in effect, limits the dilution of contaminants with more air. The height to which mixing of air contaminants with relatively cleaner atmosphere is effective is very significant and is often referred to as mixing height.

b. Stack Heights

A trace of the smoke or other gaseous contaminants emanating from an industrial plant point source is known as a plume. The dimensions (vertical and horizontal) of the plume dictate the relative position and concentration of contaminants at any time and are directly related to the vertical temperature gradient. Therefore, plume conditions for any stack depend on where the stack is situated relative to the local topography and to its position on a world basis. In general, stacks in warm, dry climates may result in some inversion conditions in the early morning hours whereas in a damp, cloudy climate inversions are less frequent. The width of the plume will vary with the time of observation, that is, for short periods it will have a narrow bend diffusion, whereas the band widens over longer periods. However, the maximum concentration still exists at the centerline of the plume. The general problem of the air pollution analyst is to compute the concentration of a given contaminant at some point downwind from the discharge. In specific calculations the following Gaussian dispersion equation is useful:

$$\chi(x,y,z,H) = \frac{Q}{2\pi\sigma y\sigma z\ \bar{u}} \exp\left[-\frac{1}{2}(y/\sigma y)^2\right]$$

$$\left[\exp\left\{-\frac{1}{2}\left(\frac{z-H}{\sigma x}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z+H}{\sigma z}\right)^2\right\}\right]$$

where x, y and z are specific distances from the emission in the direction of the mean wind, horizontal plane perpendicular to the X axis, and vertical distance respectively

Q is grams per second of contaminant
$\bar{u}$ is average wind speed in meters/second
X is pollutant concentration at point (x,y,z) in grams/cubic meter
H is the effective stack height in meters
oyoz are standard deviations of plume concentration distribution in horizontal and vertical directions

If one wishes to find the concentration at gorund level, then z = o and the equation simplifies to:

$$\chi(x,y,0) = \frac{Q}{\pi\sigma y\sigma z\ \bar{u}} \exp\left[-\frac{1}{2}(y/\sigma y)^2\right]$$

$$\exp\left[-\frac{1}{2}(H/\sigma z)^2\right]$$

Where the calculation is to be calculated along the centerline of the plume, then y = 0 and the equation further simplifies to:

$$\chi = (x,0,0) = \frac{Q}{\pi\sigma y\sigma z\ \bar{u}} \exp\left[-\frac{1}{2}(H/\sigma z)^2\right]$$

The users of this Manual should be aware of some limitations of the use of the equation: (1) the diffusion coefficients are probably only accurate to values of ±50%; (2) the Coriolis effect has been omitted from the calcuations; (3) any deposition or absorption of contaminants by physical structures or the ground have been neglected; (4) shifts in wind direction and velocity during the plume dispersion time used; (5) use of diffusion coefficients derived from short-term studies for longer term computations leads to some error.

In the equation used to compute the contaminant concentration at any point downwind, the value of H used is extremely important since the height of stack, H_s, is generally increased by the plume rise, H, to give H, the effective stack height,

which is the actual value used in the equation. The computation of the added height of plume rise, H, is of considerable importance and often quite controversial.

The diffusion coefficients (oy,oz) are functions of the atmospheric stability and downwind distance from the source. These values are valid for concentrations averaged over a few minutes and apply to open level country. The atmospheric stability is dependent on surface wind speed and incoming solar radiation and is designated by the letters A - F with A being the most unstable and F the most stable. The horizontal coefficient, oy, varies from 35 to 200 meters at 1 km downwind distance, whereas the vertical varies from 15 to 400 meters for the same distance. Tables and graphs are available in air pollution meteorology textbooks to assist in these calculations.

One common equation for estimating plume rise is Holland's equation (see M. Katz, Measurements of Air Pollutants). It often slightly underestimates the effective stack height and therefore provides a safety factor.

Holland's equation is:

$$\Delta H = \frac{V_s d}{\bar{u}}\left(1.5 + 2.65 \times 10^{-3} p \frac{T_s - T_a}{T_s} d\right)$$

where:
- H is the rise of the plume above the stack in meters
- V_s is the gas exit velocity in meters/second
- d is the inside stack diameter in meters
- $\bar{u}$ is the wind speed in meters/second
- p is the atmospheric pressure in millibars
- T_s is the stack temperature in °K
- T_a is the atmospheric temperature in °K

Holland suggests a value of 1.15 times the H from the equation be used for unstable conditions and a value of .85 for stable conditions with the calculated H for neutral conditions (D stability).

The contaminant concentration equation given can also be used by design engineers to solve for H_s and H is computed separately.

3. Computation of Treatment Required

Treatment required by any industry must be based upon a comparison of what is currently being emitted from the plant and what is an allowable emission, based upon Table 1 (p. 27) for a specific type of plant. If no emission standard for the industry has been adopted or recommended the designer must compare once again the plant's emission with the allowable air standard shown in Table 2 (p. 28) for each contaminant. He must compute the downwind ground level concentrations of contaminants, using the equation and methods suggested in Part 2 of this section for every possible wind speed, stability class and downwind distance. This may require a computer program; however, it is the only means for determining potentially harmful concentrations under specific atmospheric conditions. If the resulting contamination at ground level exceeds the allowable limits, some form of plant process correction, stack height increase, or treatment must be used to control the excess contaminant.

For example, if a copper mining plant emits sufficient SO_2 from its roasting operation such that X, the SO_2 level, downwind at ground level concentration is 490 ug/m^3 on a daily average under given atmospheric conditions, remedial action must be taken so as to reduce this concentration to below the allowable 365 ug/m3. Background and projected increases in SO_2 must also be considered. The designer should note that although Table 1 (p. 27 gives no emission standards for copper mining and smelting plants -- hence making the use of Table 2 (p. 28) necessary -- these standards may be available from the government office administering the environmental protection program.

The percent removal of contaminants depends upon the relationship between the present and allowable emission. In the above case, the percent removal must be

$\frac{490 - 365}{490}$ = about 25.5%. If a process change is made

to accomplish the 25% removal, an exact percentage usually cannot be predicted beforehand. It can only be estimated and then verified empirically, following the process modification. If the stack is increased in height as a solution, the exact increase, H, can be computed as shown in Part 2 (pp. 29-33) of this section to yield all X values downwind of $\leq$ 365 ug/m^3. If treatment systems such as scrubbers or oxidizers are selected to solve the excess contaminant problem, the designer must compare the equipment's rated efficiency at the maximum plant output with that required. He should select equipment which will yield a stated

greater efficiency of removal than that required in order to protect the industry and the environment from unpredictable occurrences.

4. Treatment Techniques

General

It is normally desirable, from a cost standpoint, to remove contaminants by changing a process or by heightening the stack where emission is occurring. In most cases, however, the extent to which the former can be accomplished is limited because prior commitment of plant capacity, equipment, and labor. In new plants some improvements in operation can usually be made to minimize or eliminate completely the final treatment of emissions. These are more fully described in Part d. (p. 39) of this section. Heightening of the stack is a question of reviewing the structures and economics involved. More description of the use of this method is given in Part e. (p. 41) of this section. When final treatment is needed to meet air standards, gas and/or particulate removal devices are selected. The basic principles upon which the design and operation of these devices are based are presented below. However, the reader is referred to the forthcoming industrial manuals, specific to each industry, for details pertaining to their use for each particular waste air stream.

a. Gas Removal Techniques

Gases can be purified to remove contaminants by either adsorption, absorption, or some type of chemical process, usually catalytic conversion. When gaseous contaminants are removed by enmeshing on some surface the phenomenon is referred to as adsorption. This is a physical process depending primarily upon the amount and type of surface exposed to the gaseous vapor contaminant. Since odors are generally removed in this manner, the reader may be familiar with activated carbon filters used in gas masks. When gaseous contaminants are removed by solution in a liquid, or by soaking up in a solid material, the process used is referred to as chemical absorption. The gaseous contaminants are dissolved in an excess of ever present liquid. The efficiency of removal depends primarily upon the relative quantities of liquid absorbent and gaseous contaminant and the means of contact between the two media. The third process is one which chemically changes the contaminant, usually in the presence of a catalyst, to an innocuous material which is harmless to the environment. Such a system is generally referred

to as a chemical conversion or catalytic conversion. Typical gaseous contaminants which could be removed by the above three processes include SO_2, NO_2, and NH_3 as well as CO or CO_2 when necessary. Probably, the removal of SO_2 is most important and more common in the 1970s. However, this may change and the same general type of processes may be used to remove the other named contaminants.

(1) Gaseous Adsorption Removal Techniques

The gas to be purified comes into contact with the adsorbent where selective combination of solid and solute occurs on the pore surfaces. The best known adsorbents include activated carbon, silica or alumina gel, fuller's earth and other clays. Usually the adsorbent is regenerated. This can be done by changing the equilibrium conditions and could involve a change in temperature, in carrier fluid, or both. Particulate matter such as dust or soot will also be removed from the bas by the adsorbent but it will plug the pores on the adsorbent surface and be a physical barrier against adsorption. For this reason, the gas should be free of solid particles. A typical reaction is:

$$\text{Activated Carbon} + NH_3 \longrightarrow \text{Carbon } NH_3$$

One must realize that, if this technique is highly successful for removing impurities with small concentrations in the fluid, it becomes less economical in the percentage range. It also leaves the operator with the disposal of the same impurity in the carrier fluid after regeneration.

(2) Gaseous Absorption Removal Techniques

Gases such as SO_2 commonly are soluble in alkaline solutions such as Na_2CO_3, Na_2SO_3, or NaOH. The absorbed SO_2 can then be removed in a more concentrated stream. For example, one system uses the Wellman-Power gas process as follows:

$$SO_2 + Na_2SO_3 \xrightarrow{H_2O} 2\ NaHSO_3$$

For removal of CO_2 one can use the reactions:

$$K_2CO_3 + H_2O + CO_2 \longrightarrow 2KHCO_3$$

$$CO_2 + KOH \longrightarrow KHCO_3$$

that remove the CO_2 from the gas.

The regeneration will proceed as follows:

$$2KHCO_3 \xrightarrow{heat} K_2CO_3 + H_2CO_3$$

$$H_2CO_3 \xrightarrow{heat} H_2O + CO_2$$

The sodium acid sulfite is quite soluble and serves to concentrate the SO_2 from a dilute stream (generally only 0.3% maximum in power plant stack gases). If desired, the SO_2 can be liberated at a later time from the $NaHSO_3$ by heating it. This results in a concentrated SO_2 stream of about 10% suitable to manufacture sulfuric acid. In this way, no SO_2 wastes contaminate the atmosphere. Other scrubbing solutions can be utilized, depending upon the gaseous contaminant being removed and the subsequent disposition of the concentrated and fully exhausted absorbent. The rate of gaseous flow, the quantity of absorbent, ad thecontact surface exposed to the gas per unit of time are all important considerations in the design and selection of equipment of this absorbent type. These processes will give a concentrated flow of gas after regeneration. In the preceding examples, SO_2 can be the raw material for sulfuric acid production, and CO_2 one of the raw materials for urea manufacturing.

(3) <u>Gaseous Chemical Conversion Techniques</u>

The conversion can be a straight chemical reaction as in the case of removal of SO_2 from a flue gas by lime or magnesia. This process is used extensively in the USA for cleaning the power station stack gases. The problem of solid waste disposal remains, however, and is difficult to solve. Sometimes, the reaction will only proceed at commercial rates if a catalyst is present. This is the case in automobile catalytic converters where the reaction of NO_x with hydrocarbons on a platinum base catalyst produces nitrogen, CO_2 and H_2O. The same technique could be applied to a stream of SO_2

to produce sulfuric acid. Even more so than for adsorbents, the gas in contact with the catalyst must be clean physically (no particulates) and chemically (no chemical poisons) to prevent poisoning of the catalyst.

b. Particulate Removal System

It can be expected that there will be particulates in emissions from vehicles and regional refuse "dump" areas as well as from any industry, for example, cement, mining, and steel mill industrial operations. Particulate matter in the air is generally accepted to be larger than .0002u but smaller than 500u in diameter. Depending upon their size, concentration, and distribution in the air, they result in mists, smokes, dusts, etc. Because of the great range of sizes in particulates and their specific characteristics, there are many potential types of removal systems. All depend upon the differential size, density, and electrostatic changes of particles and their accompanying air molecules. There are five major removal systems with which the reader of this Manual should be familiar: (1) filters; (2) sedimentation; (3) centrifugal separation; (4) electrostatic precipitation; and (5) wet scrubbers.

(1) Filters

These are fine-meshed media purposely designed to "trap" or "screen" the particles as they move with the air stream. A typical type of filter is one known as a baghouse and consists of a number of filter bags very similar to those used in the household vacuum cleaner. Since these filters must be operated continuously, it is necessary to shake loose and remove the mass of particulates which have been filtered out. This is accomplished by either vibration of the filters or by scraping the filter surface periodically and automatically by a moving surface or by reversal of airflow. If the solids are not removed regularly, excessive head loss will develop with subsequent reduction in quantities of air emissions which can be treated by the system. The baghouse is an efficient air pollution control device and can be used for very small particles.

(2) Sedimentation Units

For emissions which possess a large percentage of particles greater than 50-75u, simple gravimetric units can be used for their removal. Sometimes, simple settling is also desirable when preceding other types of treatment such as chemical conversion. This affords protection against malfunctioning or overloading of subsequent units designed primarily to remove much smaller particles. The efficiency of gravitational units decreases quite measurably as the size of the particle diminishes. The diameter of the largest size particle which can be removed completely by this method is directly proportional to the viscosity of the air, the mass velocity of the emission, and the height of the settling chamber, and is inversely proportional to the length of the settling chamber, acceleration of gravity, and the particle density. Settling chambers are only recommended when a better grade of collection, such as a cyclone, is not economically feasible or when only very large particles are generated.

(3) Centrifugal Separators

By designing a chamber so that peripheral velocities of air and its particles are increased, one can effect a differential separation leading to subsequent removal of the separated fractions. Heavier particles tend to be thrown to one side of such a device while lighter particles and free air molecules move very rapidly in the center stream and pass in and out of such units without being separated. Units of this type are commonly called cyclone separators. In order to effect maximum particle separation in a cyclone unit, the tangential velocity must be accelerated which in turn calls for relatively small diameter units. The use of small diameters leads to magnified pressure drops, the major objection for the use of cyclones, for the high pressure drops require excessive pumping and power costs and/or a multitude of units to handle a given quatity of emission. The smallest practical diameter of cyclone appears to be about 24 cm. To obtain efficiencies of greater than 80%, the particle size should not be much less than 5-20u in diameter. In general, reducing the

diameter of a cyclone by half will result in about a tenfold increase in head loss; maximum typical head loss values are about 1.5 cm of mercury.

(4) Electrostatic Precipitators

When a current is made to flow by a negatively charged center wire and a positively charged wall collector, the gas near the wire is ionized and the particles in turn become charged. Once the particles are charged they are drawn by the electric field surrounding them towards the wall or collector from where they are removed by hitting the collector or inclining the collector downward if the material is to be removed in the form of a liquid. The DC voltage applied to ionize the particles is somewhere between 20 kV and 110 kV. For high efficiencies of removal one must utilize low flow rates of gas, high particulate matter velocity, and large collector surface areas. These units are quite useful where particles to be removed are relatively small -- in the categories of mists -- and where pressure drops are a major concern. The pressure drop is generally in the area of about 15% of that of a cyclone separator. However, decrease in efficiency and excessive power costs can develop if solids are not properly removed from the collector.

(5) Wet Scrubbers

When it is desired to remove particles in the 1-5u size range, either as a pretreatment for subsequent treatment systems or as the sole treatment, with high efficiencies, of small particles in gas streams, liquid scrubbing of the gas is recommended. Although there are a multitude of varieties of design for scrubbers, essentially they all consist of a liquid spray (usually water) in contact with the gaseous emission so as to entrap the particles in the liquid. The simplest forms of a scrubber uses a downward flow of water spray or drops contacting an upward flow of the gas emission. Many types of surface contacts, such as balls, rings, plates, etc., are used to enhance the contact and subsequent removal of particulates. Sometimes, head loss systems such as venturis are used to increase the turbulence and hence contact

of the gaseous and liquid phases. However, the velocity increase results in increased power costs which must be balanced against the increase in particulate removal expected.

c. General Achieved and Acceptable Removal Efficiencies

Many factors must be taken into consideration when selecting equipment for removal of particulates and chemical gases. Economics or some measure of cost per unit of contaminant removal is generally the most important criterion used in arriving at the ultimate decision. However, some parameters which influence that criterion include: particulate or gaseous size distribution; required efficiency; allowable pressure drop at various emission flows; concentration of particles or gas; capital and operating cost of treatment systems; chemical properties of gases in emission; final contaminant disposition, and the ability to maintain the equipment operation with reliability. The material in Table 3 was obtained from various sources to give some direction to the reader on equipment selection; however, each specific case should be investigated on its own.

d. Redesign of Production System

Serious consideration should be given by project personnel to making industrial production more environmentally sound before installing costly contaminant removal systems. This can be accomplished by changing raw materials or processes of manufacturing or by reusing materials formerly wasted to the stack emission.

(1) Change of Raw Material (Oil for Coal, Low S Fuels for High S Fuels, etc.)

The substitution of oil or natural gas for coal as a fuel for boilers for industrial steam production or for power production will serve to lessen, if not eliminate entirely, the need for sulfur dioxide removal systems on the waste gas stream. The change is dictated by air quality criteria and local environmental meteorological conditions. However, one should balance the normal increase in fuel cost against the lower cost of air stream waste treatment required. Sometimes it might be necessary only to change from a high contaminant type of fuel to the same fuel with a lower contaminant level. This

Table 3

Removal Efficiencies

Treatment System	Efficiency by weight	Pressure loss in inches H_2O	Temperature limits	Power HP/1000 cfm of gas	Costs per ft^3 gas	Used Primarily for
Settling chamber	Good above 50u	0.2-0.5 (.5-1.27 cm)	700-1000°F limited only by construction materials (371-537°C)	.04-0.12 (.017-.5 $\frac{kw}{1000m^3/min}$)	.01-.05 (35.7-178.5 $\frac{¢}{m^3}$)	Fly ash, metalurgical dust.
High efficiency cyclones	About 80% on particles of 10u	3-5 (7.62-12.7 cm)	700-1000°F limited only by materials of construction (371-537°C)	.73-1.2 (.324-5 $\frac{kw}{1000m^3/min}$)	.07-.15 (250-536 $\frac{¢}{m^3}$)	Product recovery woodwork-material conveying.
Gas cyclone Impingement scrubber	90% on particles of 10u	1-5 (2.54-12.7 cm)	700°F (371°C)	.24-1.2 (.106-.5 $\frac{kw}{1000m^3/min}$)	.06-.10 (214-357 $\frac{¢}{m^3}$)	Boiler fly ash, cement clinker coolers, air cleaners for engines and turbines.
Electrostatic precipitator	80% of 15u	No loss	700°F (371°C)	Power consumption varies	.05-.15 (178.5-536 $\frac{¢}{m^3}$)	All dry dust of 10u and above

would eliminate the extra capital cost of the changeover from one type of fuel storage, feeding and combustion system. Once again, it may be necessary to pay premium prices for the higher raw quality of fuels which must be compared to the resultant abatement costs. In light of recent scarcities of oil and gas this system should be carefully scrutinized before installation.

(2) Change Process or Operation (Increase Temperature of Combustion etc.)

If the possibility exists to alter manufacturing of a product in order to ameliorate environmental effects, this should be attempted prior to or in place of final treatment. For example, an increase in temperature of combustion of power plants or incinerators will ensure more complete combustion of organic matter. In this way particulate (unburned) organics can usually be eliminated from smokestack emissions. Nitrogen oxides emitted from the open burning of refuse can be reduced by abut 80% by burning the same refuse in a properly designed and operated incinerator. Also, the utilization of larger chemical operations rather than small-batch-type operations will result in greater efficiencies and must less release of by-products in the waste gases per ton of acid produced.

(3) Reuse Normal Wastes (Recirculate Stack Gases, etc.)

Instead of discharging stack gases directly to the atmosphere one should examine the possibility of reusing the gases for a useful purpose which also may make the gases less contaminating to the environment. An example of this can be found in the cement industry where shale or limestone is calcined at very high temperatures to release the CO_2, impurities, and all forms of bound water. The gas emissions contain SO_2 from the fuel combustion as well as some unburned limestone particles (dust). When this gaseous emission is reused to aid in the initial drying of the mineral rock, the amount of SO_2 and dust can be reduced in the waste gas per ton of cement produced. This is one way in which heat generated can be conserved and at the same time air pollutants reduced. Reuse may be limited in some cases by the product requirements.

Most cements, for example, have an upper limit of sulfates. The process engineer, once again, should investigate the potential for reuse from an economic as well as a technical basis.

e. Heightening of Stack

As described in Part 2b (pp. 31-33) of this section, the contaminant concentration at a given ground point downwind from an emission can be reduced considerably by heightening the discharge above the ground. This can be accomplished by constructing a higher smokestack. The higher stack costs more money and may also interfere with air vehicle traffic and render the environment aesthetically undesirable. Again, the project director should balance the tangible and aesthetic costs of higher stacks against the benefits of lower air contamination resulting from the stack height increase. If lower contamination is mandated by law, then it becomes a question of deciding between a higher stack or utilizing one or more of the other methods previously described for abating air contamination. Economics would play a significant role.

B. Wastewater

1. Stream Protection Measures

In general, the quality of receiving waters can be preserved by either or both of two methods: (a) stream standards or (b) effluent standards. Although the ultimate goal is to raise the quality of the river or lake to the optimum for its best usage, it is sometimes easier to accomplish this by requiring each polluter to discharge only a given quantity of contaminant or a given concentration with a stipulated total volume of wastewater. Many state agencies ascertain the best usage of a stream and assign certain quality standards to that water use. Any polluter found adding contaminants in such quantities as to contravene these stream standards is cited as a violater and must then abate the pollution. A more recent trend followed by some agencies is to establish the receiving water quality desired and attempt to maintain this quality by controlling each waste discharge to the minimum contaminant units per unit of production or per capita. The latter is generally determined on an industry-wide basis from an analysis of effective treatment potential on an economically feasible basis. An example of the stream standards system (a) is shown in Table 4, as used in New York State, while an illustration of the

Table 4

New York State Classes and Standards for Fresh Surface Waters

Class and best use[1]	Water Standards[2]				
	Minimum dissolved oxygen ml/liter	Coliform bacteria median no/100 ml	pH	Toxic wastes, deleterious substances, colored wastes, heated liquids odor-producing substances[3]	Floating solids, settleable solids, oil, and sludge deposits
AA - Source of unfiltered public water supply and any other usage	5.0 (trout) 4.0 (nontrout)	Not to exceed 50	6.5-8.5	None in sufficient amounts or at such temperatures as to be injurious to fish life or make the waters unsafe or unsuitable.	None attributable to sewage industrial wastes or other wastes
A - Source of filtered public water supply and any other usage.	5.0 (trout) 4.0 (nontrout)	Not to exceed 5000	6.5-8.5		None which are readily visible and attributable to sewage, industrial wastes or other wastes.
B - Bathing and any other usages except as a source of public water supply.	5.0 (trout) 4.0 (nontrout)	Not to exceed 2400	6.5-8.5		
C - Fishing and any other usages except public water supply and bathing	5.0 (trout) 4.0 (nontrout)	Not applicable	6.5-8.5	None in sufficient amounts or at such temperatures as to be injurious to fish life or impair the waters for any other best usage.	
D - Natural drainage, agriculture, and industrial water supply.	3.0	Not applicable	6.0-9.5	None in sufficient amounts or at such temperatures as to prevent fish survival or impair the waters for agricultural purposes or any other best usage.	

[1]Class B and C waters and marine waters shall be substantially free of pollutants that: unduly affect the composition of bottom fauna; unduly affect the physical or chemical nature of the bottom; interfere with the propagation of fish. Class D and SD (marine) will be assigned only where a higher water use class cannot be attained after all appropriate waste-treatment methods are utilized. Any water falling below the standards of quality for a given class shall be considered unsatisfactory for the uses indicated for that class. Waters falling below the standards of quality for Class D, or SD (marine) shall be Class E or SE (marine), respectively, and considered to be in a nuisance condition.

[2]These Standards do not apply to conditions brought about by natural causes. Waste effluents discharging into public water supply and recreation waters must be effectively disinfected. All sewage-treatment plant effluents shall receive disinfection before discharge to a watercourse and/or coastal and marine waters. The degree of treatment and disinfection shall be as required by the state pollution control agency. The minimum average daily flow for seven consecutive days that can be expected to occur once in ten years shall be the minimum flow to which the standards apply.

[3]Phenolic compounds cannot exceed 0.005 mg/liter; no odor-producing substances that cause the threshold-odor number to exceed 8 are permitted; radioactivity limits are to be approved by the appropriate state agency, with consideration of possible adverse effects in downstream waters from discharge of radioactive wastes, and limits in a particular watershed are to be resolved when necessary after consultation between states involved.

effluent standards system (b) as used by Pennsylvania is shown in Table 5.

a. Stream Standards

The main advantage of the stream standard system is the prevention of excessive pollution regardless of the type of industry or other factors, such as the location of industries and municipalities. It also allows the public to establish goals for present ad future water quality. Loading is limited to what the stream can assimilate, and this may impose a hardship on an industrial plant located at a critical position on the stream. On the other hand, pollution abatement should be as carefully considered in decisions concerning the location of the plant (see Chapters VI and VII) as those on labor transportation, market and other conditions.

b. Effluent Standards

The effluent standard system is easier to control. No detailed stream analyses are needed to determine the exact amount of waste treatment required. On the other hand, unless the effluent standards are upgraded this system does not provide any effective protection for an overloaded stream. Standards for effluents are based more on economics and predictability of treatment than on absolute protection of the stream; the best usage of the stream is not the primary consideration. Rather, the usage of the stream will depend on its condition after industrial effluent standards have been satisfied. Upgrading and conservation of natural resources are somewhat neglected in favor of industrial economics.

It is recommended that an appropriate combination of effluent and stream standards be used; effluent standards to aid in measurement and assit industry in operation, and stream standards to protect receiving waters for their best usage. The latter standards should dictate the level of effluent standards for industry.

c. Significance of Standard as it Relates to Government

The more local the governmental domain, the more the government prefers standards in order to protect the quality of its own nearby watercourses. National or international governments are interested largely in uniformity and ease of adminis-

Table 5

Pennsylvania Raw-Waste Standards for Pulp and Paper Mills

Type of product or process	Population equivalent, per ton of product, based on 5-day BOD		Pounds of suspended solids per ton of product	
	3-day average*	8-hr average	3-day average	8-hr average
Group A				
Tissue paper	75	80	40	50
Glassine paper	25	30	15	20
Parchment paper	40	45	20	30
Miscellaneous papers	25	30	5	10
Flax papers - Condenser	375	415	300	350
Group B (specialty group)				
Fiber paper	800	850	200	235
Asbestos paper	125	185	290	350
Felt paper	210	230	60	65
Insulating paper	2250	2500	325	350
Specialty papers	1000	1200	135	160
Group C (coarse paper)	90	120	35	50
Group D (integrated mills)				
Wood preparation	80	100	40	50
Pulp (sulfite)	3000	3500	35	40
Pulp (alkaline)	300	350	20	35
Pulp (groundwood	115	130	80	85
Pulp (de-inked unfilled stock)	500	650	375	500
Pulp (de-inked filled stock)	400	500	600	800
Pulp (rag cooking)	1400	1550	475	500
Bleaching (long-fiber stock, multi-single-stage bleaching and short-fiber stock, single-stage bleaching)	60	70	3	6
Bleaching (short-fiber stock, multi-stage bleaching)	165	185	30	35
Paper-making	100	125	75	85

*All averages are for periods of consecutive operation and may be divided by 907 to obtain values per kilogram of product.

tration of systems to effect the same protection and hence tend to prefer some type of effluent standard. Once again, since both types of government agencies must be satisfied in matters of pollution control, industry should plan on meeting both standards during production of any product.

2. Dispersion Techniques

a. Outfalls -- These should be designed so as to distribute the final wastewater after treatment (if any) to the receiving water in a manner to mix the entire effluent with the entire receiving stream in as short a time as possible. This usually calls for either (1) a pipe discharging at its end into the center (both horizontally and vertically) of the small section of main stream fow, or (2) a pipe laid across the entire width of the stream discharging through jets or spaced holes so that the flow is uniformly distributed. Tracers (dyes, salts, radioactive matter, etc.) injected into the entrance to the outfall pipe with subsequent analysis of the receiving stream for the tracer can be used to assess the efficiency of dispersion of waste with stream flow.

b. Diffusion -- If the plant wastewater effluent can be mixed instantly and completely with the entire receiving water in a narrow confine of the river or in a separate race flowing nearer to the plant, better diffusion can usually be obtained. Other methods of accomplishing the same effect are installing mechanical mixing in the stream or adding rocks and rubble to the stream so as to cause turbulent flow. Better diffusion in a shorter distance will enhance more complete assimilation of the plant waste within the stream with a minimum affect on the watercourse. The main reason for the minimization of pollution is because of the lowered concentration of any contaminant resulting from efficient mixing and diffusion.

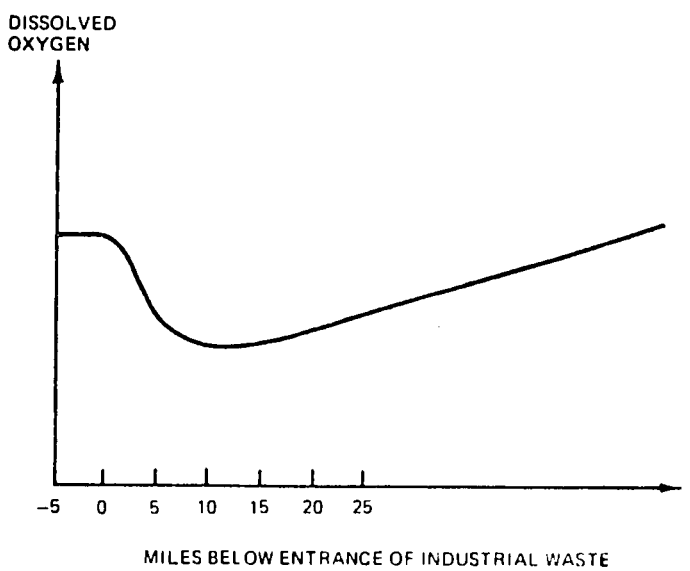
3. Computation of Treatment Required

If a regulatory agency decides to allow an industry to use a portion of the assimilating capacity of the receiving water, the agency must resort to some method of predicting an acceptable organic loading. The agency makes a decision usually based upon presentation of a certain minimum concentration of dissolved oxygen in the stream. Many factors determine the consumption of dissolved oxygen in streams. Some of these include: (a) nature of the organic matter -- whether easily decomposable for normal stream biota; (b) amount of

receiving water -- as a diluting effect as well as an oxygen provider; (c) physical nature of the stream -- swift or sluggish, pools or riffles; (d) biological nature of the stream -- whether containing adapted flow, slime growths, benthal deposits, algae growth; (c) chemical nature of the stream -- whether containing toxic chemicals, nutrients for promoting biological growth; and (f) environmental character of the stream -- temperature and pH of the water. It is not possible to discuss all of these parameters in this treatise and the reader is therefore referred to N. L. Nemerow, Liquid Wastes of Industry (Chapter 3) for a more complete coverage of the subject.

In general, industry should determine the ultimate (20-day) biochemical oxygen demand, BOD_{20}(g/L), of its waste and the quantity (cubic meters or gallons) discharged per day. For the reaction of the receiving water, the engineer must compute the stream deoxygenation rate, k_1, and its re-aeration rate, k_2, as well as the travel time of the industrial waste downstream from its entrance. From an evaluation of the stream assets and liabilities, one can predict with some degree of approximation the resulting dissolved oxygen sag curve below for the industry as shown in the following Figure 1:

FIGURE 1



The Streeter-Phelps sag curve formula is generally used

$$D_t = \frac{k_1}{k_2-k_1} L_a \left(10^{-k_1 t} - 10^{-k_2 t}\right) + D_a^{-k_2 5}$$

where D_t = dissolved oxygen deficit at waste travel time, t, downstream and L_a = BOD_u in the receiving water after the industrial waste has mixed with the stream water.

Several simplifications of the above formula have been proposed as well as several methods for arriving at the true values of the stream reaction rates, k_1 and k_2. Variations in values of the reaction rates can result in vastly different oxygen sag curves with correspondingly different degrees of waste treatment required. Considerable cost differences develop from these situations. Industry often decides to overtreat its wastes (at greater costs) to protect itself against the unpredictable nature of the stream as well as conservative decisions of the regulatory agencies.

The project director should reduce the value of L_a in the above equation until the D_2 obtained is low enough (less than 3 ppm is suggested) at critical flow (both stream and waste). The percent reduction of the industrial plant waste BOD is obtained by calculating the following:

$$\frac{L_a \text{ (allowable to yield } D_t \leqq 3 \text{ ppm)}}{L_a \text{ (original untreated plant waste)}} \times 100$$

4. <u>Combined Municipal and Industrial Wastewater Treatment</u>

It is often advantageous to an industrial manufacturing plant to deliver its entire wastewater -- under control -- to a municipal sewer and sewage system. The many advantages of joint treatment of municipal and industrial wastes are as follows:

a. Responsibility is placed with one owner, while at the same time the cooperative spirit between industry and municipality is increased, particularly if division of costs is mutually satisfactory.

b. Only one chief operator is required, whose sole obligation is the management of the treatment plant; i.e., he is not encumbered by the miscellaneous duties often given to the industrial employee in charge of waste disposal, and the chances of mismanagement and neglect, which may result if industrial production men operate waste treatment plants, are eliminated.

c. Since the operator of such a large treatment plant usually receives higher pay than separate domestic plant operators, better trained people are available.

d. Even if identical equipment is required, construction costs are less for a single plant than for two or more.

e. The land required for plant construction and for disposal of waste products may be obtained more easily by the municipality.

f. Operating costs are lower, since more waste is treated at a lower rate per unit of volume.

g. Possible cost advantages resulting from lower municipal financing costs, federal grants, and municipal operation can be passed on to the users and may permit higher degrees of treatment at lower removal levels.

h. Some wastes may add valuable nutrients for biological activity to counteract other industrial wastes that are nutrient deficient. Thus, bacteria in the sewage are added to organic industrial wastes as seeding material. These microorganisms are vital to biological treatment when the necessary BOD reduction exceeds approximately 70%. Similarly, acids from one industry may help neutralize alkaline wastes from another industry.

i. The treatment of all wastewater generated in the community in a municipal plant or plants enables the municipality to assure a uniform level of treatment to all users of the river and even to increase the degree of treatment given to all wastewater to a maximum level obtainable with technological advances.

j. Acceptance of the joint treatment project and relinquishment of individual allocations would give the municipality full control of the river's resources and permit it to use the capacity of the river to the best advantage for the public at large. The municipality has greater assurance of stream protection, since it has the opportunity for closer monitoring of effluent quality.

Among the many problems arising from combined treatment, the most important is the character of the industrial wastewater reaching the disposal plant. Equalization and regulation of discharge of industrial wastes are sometimes necessary to prevent rapid change in the environmental conditions of the bacteria and other organisms which act as purifying agents, to ensure ample chemical dosage in coagulating basins, and to ensure adequate chlorination to kill harmful bacteria before the effluent is discharged to a stream.

In recent years, two factors in particular have focused attention on the subject of combined treatment for sewage and industrial wastes. These are the increased

interest in stream pollution abatement and the phenomenal growth of industry in the post-war years, with the subsequent increase in demand for water.

Since most sewage plants use some form of biological treatment, it is essential for satisfactory operation that extremes in industrial waste characteristics be avoided and the waste mixture be:

a. as homogeneous in composition and uniform in flow rate as possible and free from sudden dumpings (shock loads) of the more deleterious industrial wastes;

b. not highly loaded with suspended matter;

c. free of excessive acidity or alkalinity and not high in content of chemicals which precipitate on neutralization or oxidation;

d. practically free of antiseptic materials and toxic trace metals;

e. low in potential sources of high BOD, such as carbohydrates, sugar, starch, and cellulose; and

f. low in oil and grease content.

If the industrial waste characteristics are such that the waste can be treated safely and effectively in the municipal sewage plant, there still remain two major considerations: a municipal ordinance which protects the treatment plant from any individual or industrial violation and sewer rental charges which enable the municipality to defray the increased costs of construction and operation resulting from acceptance of the industrial wastes.

5. Treatment Techniques

a. Preliminary Techniques

(1) Wastewater Volume Reduction

Although reduction of waste volume per se may not result in any less total pounds of contaminants in wastewater, it will contain the pollution in a smaller volume. Usually this means less capital expense for waste treatment. Sometimes when reducing the volume of wastes, the total quantity of contaminants will also be reduced. This is accomplished by incorporating more waste matter in the final manufacturing product rather than

allowing it to be wasted to streams. Another procedure for accomplishing the same result is to "dry-collect" as much waste material as possible from manufacturing machines and operating floors rather than "hosing" down the same matter into drains. However, this results in an increase of the solid waste disposal problem. Likewise, burning of reclaimed wastes may create an air pollution situation. One must consider all environmental impacts of manufacturing and process change decisions such as those involved with a reduction of wastewater volume. Most beneficial changes to effect this reduction can be achieved by a careful study and evaluation of manufacturing processes by an industrial waste engineer.

(2) Waste Strength Reduction

This usually makes a wastewater effluent stream less pollution-oriented in nature. It can be accomplished by: (1) changing mechanics or operation of the process; (2) eliminating a step in (or an entire) process; and/or (3) substituting a lesser contaminating material or chemical for the original raw material or process chemical. Segregating small volumes of "strong" wastes will give an industry a large volume of relatively weak waste and a very small volume of strong waste. Both may be treated in different manners and sometimes more economically and effectively than when combined as one waste. Unless either costs or total pollution are reduced by waste strength reduction, this step as an aid in waste treatment should be omitted. Figure 2 depicts the results of waste strength reduction on both waste treatment cost and the amount of contaminant remaining.

(3) Neutralization

Adjustment of the reaction pH is required for many reasons in numerous instances. Some of these are listed below:

(a) to protect sewer lines and plant structures from corrosion;

(b) to prevent requiring of excessive chemicals for coagulation as a treatment method;

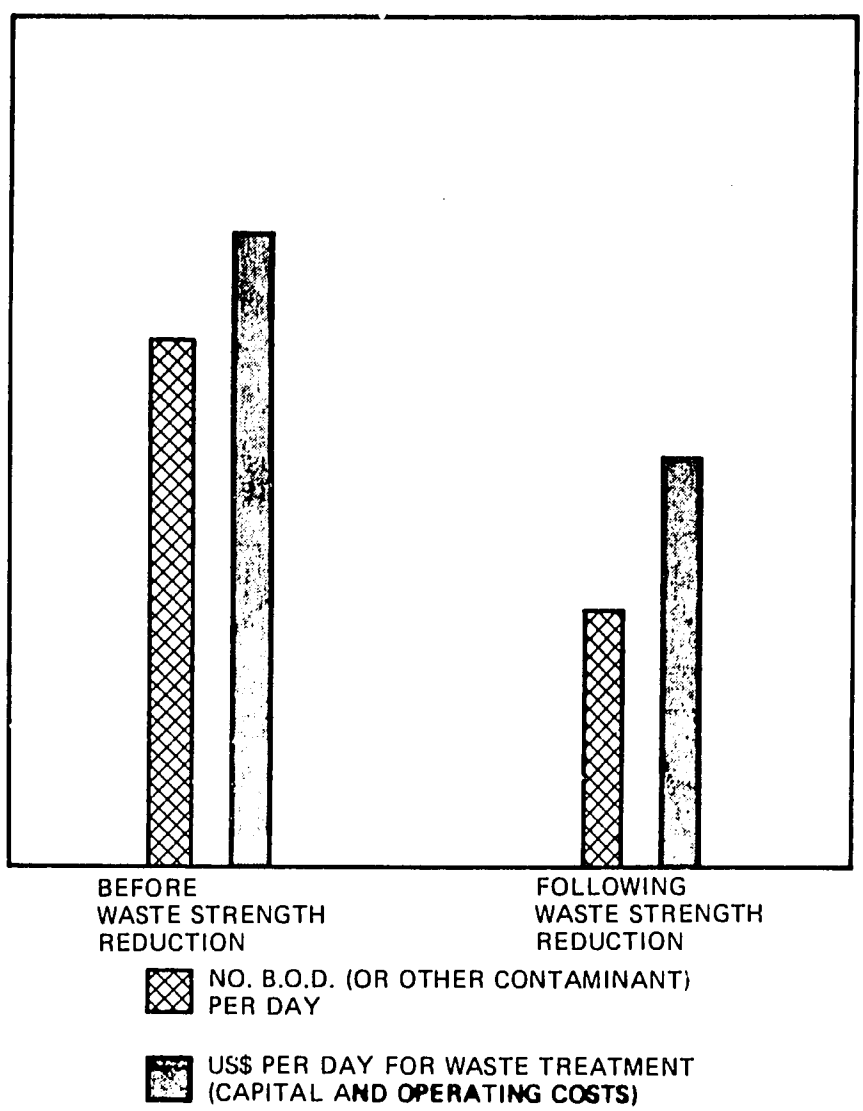
(c) to protect optimum bacterial activity in biological treatment of wastes;

(d) to prevent odors which may emit at low or high pH values; and

(e) to protect receiving waters from detrimental effects of wastes with either less than 6.0 or greater than 9.5 pH values.

pH adjustment to correct values can be obtained by (1) adding acid (usually sulfuric) or base (usually sodium hydroxide or lime); (2) mixing acid wastes with alkaline wastes in proper proportion; (3) acidifying with flue gas; (4) acidifying with submerged combustion (burning of fuel under water); or (5) passing acid wastes through limestone beds.

FIGURE 2



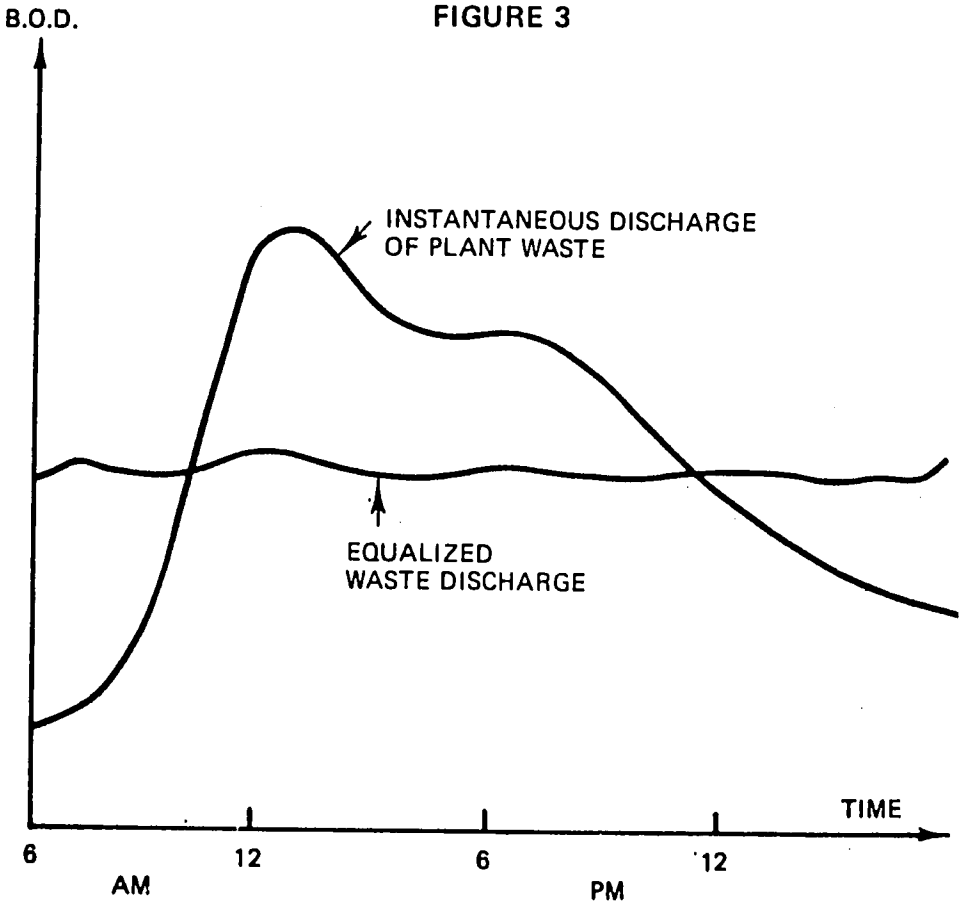
World Bank–16344

(4) Equalization and Proportioning

Often when industrial wastes are introduced into a domestic sewage treatment system in a uniform volume and strength in accordance with sewage flows, more effective combined treatment results.

Equalization involves the holding or retention of industrial wastes for period of time sufficient to produce at the discharge end of the basin a waste more uniform in quality. This treatment is illustrated in terms of BOD in the following graph (Figure 3). The optimum retention time depends upon the nature and repetition of various industrial manufacturing processes. For example, a process resulting only once every 24 hours may require a 24-hour holding period (Figure 3).

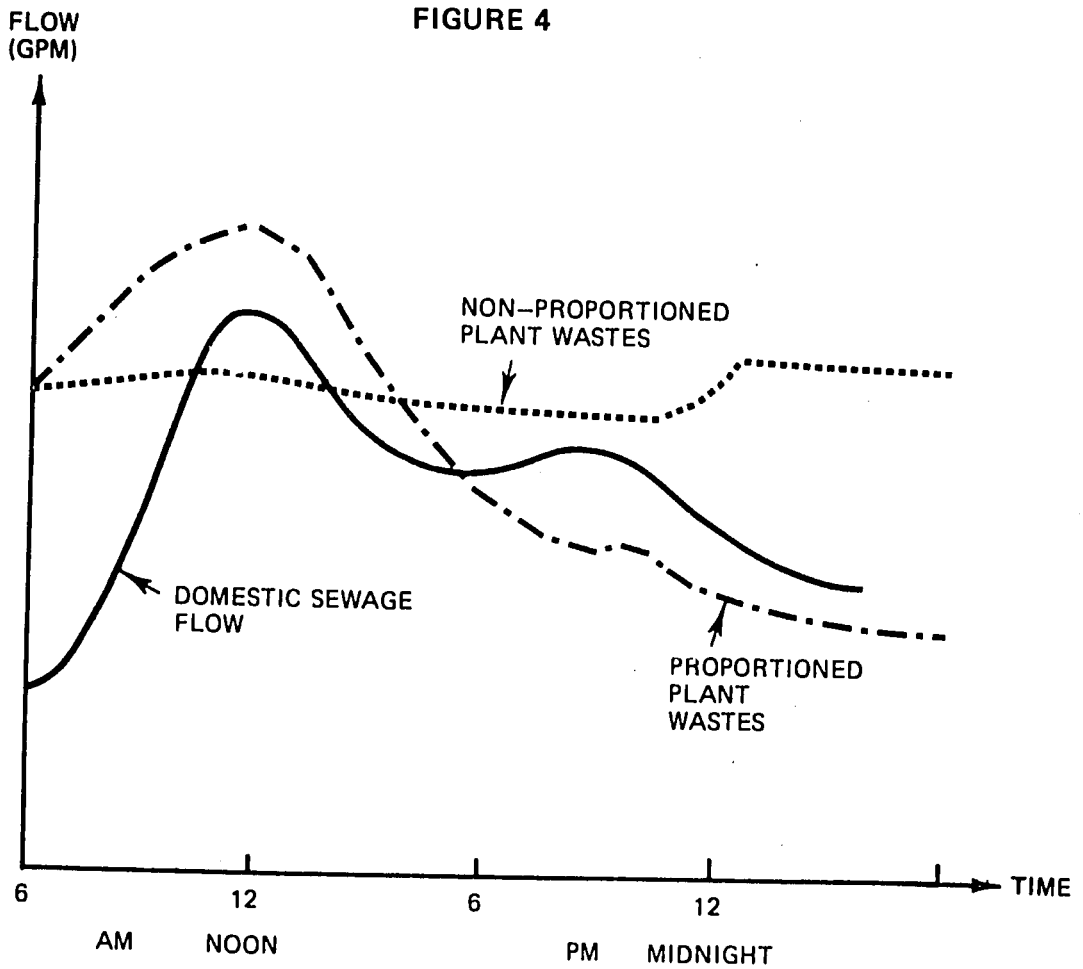
FIGURE 3



World Bank-16345

The plant waste may also be discharged in proportion to the sewage flow at the treatment plant or to the river flow into which the waste flows. Proportioning wastes assures that neither treatment plants nor receiving streams are overloaded with "slug" loads of industrial wastes. Proportioning can be accomplished by pumping or discharging industrial plant wastes at previously contemplated or at instantly signaled rates. The system requires flow measurement, signal transmission, and value responses at plant waste pumping devices. An example of the effects of one type of proper proportioning is shown in Figure 4.

FIGURE 4



World Bank–16346

Proportioning of plant wastes can also be practiced to prevent overloading of a contaminant in the system at any one time. This

often means revising our previous concept and reducing industrial plant waste flows when municipal flows and contaminants are high.

b. Suspended Solids Removal Systems

(1) Sedimentation

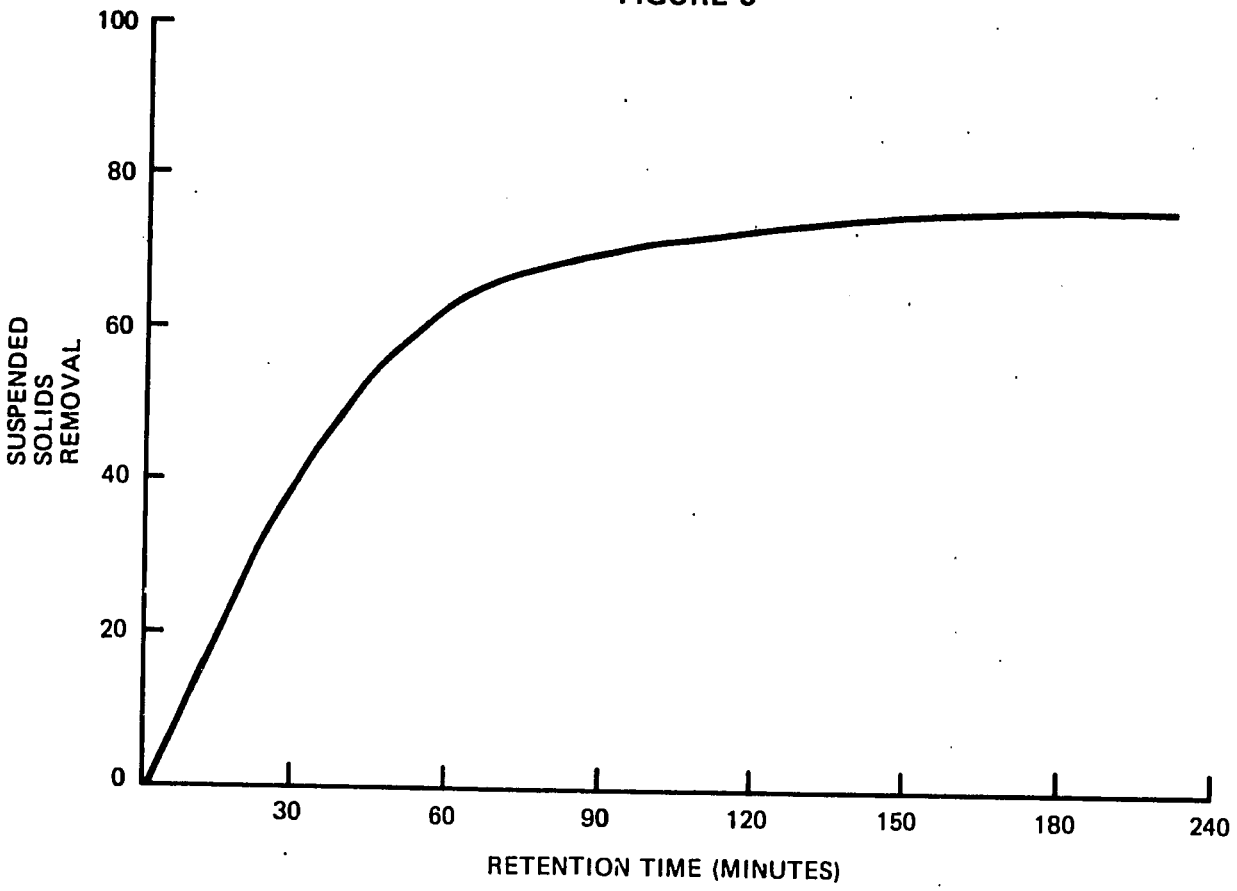
Many industrial wastes such as cannery, pulp and paper, and tannery contain suspended matter. In general, these solids are usually removed by either differential sedimentation, flotation, or screening. Since suspended matter in wastes is generally more dense than water, they can be separated by providing ample retention time to settle.

(2) Flotation

In many instances these types of solids may contain sufficient surface area relative to their density so that they may stratify, be buoyed up, and subsequently floated to the surface and skimmed off. Air dissolved in wastewater under pressure and then released at atmospheric pressures is generally used to accomplish effective flotation of suspended solids. Industrial wastes of the kind which contain suspended solids normally contain from 1% to 20% of these solids by volume. Either sedimentation or flotation produces a sludge with from 2% to 12% solids on a dry weight basis.

Suspended solids removal by settling or flotation generally reduces the solids by approximately 70% to 90%. In settling removal methods an optimum retention time of one to three hours is required while only 20 to 30 minutes are necessary in flotation solids removal. A typical removal curve is shown in Figure 5.

FIGURE 5



World Bank–16347

(3) Screening

Screening of industrial wastes is generally practiced on wastes containing larger suspended solids of variable sizes. Either rotary, self-cleaning, gravity-type or circular, overhead-fed, vibrating type units. The screen sizes vary from coarse (10-20 mesh) to fine (120-320 mesh). Little or no BOD is removed by screening but generally 60% to 95% of the larger suspended solids can be removed.

c. Colloidal Solids Removal

(1) Coagulation with Chemicals

These solids may vary in size from 1 mu to 200 mu and border in characteristics between the suspended and dissolved solids. They are small enough to exhibit stability by virtue of the slight residual electrical charge (generally negative), but large enough to

interfere with the passage of light and therefore cause turbidity. They will not settle physically unless destabilized, coagulated and flocculated into larger masses with sufficiently greater densities than water. Generally, it follows that this is precisely the treatment that is used to remove them from industrial wastewater. Coagulants employed are normally those electrolytes possessing strong positive charges when dissolved in waters; for example, salts of FE^{+++} or Al^{+++}. The coagulants appear to react simultaneously with the negative hydroxyl ions and the negative colloidal impurities in the wastewaters. Both are reduced substantially by the reaction. An example of such a reaction is shown below:

$$\text{coagulant} + \text{water} + \text{colloid} \longrightarrow \text{precipitate}$$

i.e.,

$$Al_2(SO_4)_3 + 6H + 6OH + \text{stable negative colloidal impurity} \rightarrow \underbrace{\left[2\,Al(OH)_3 \cdot \text{destablized colloidal impurity}\right]}_{\text{PRECIPITATE}}$$

In many instances colloidal solids may represent from 1/3 to 1/2 of the total oxygen demand of industrial wastewater. On the other hand, little benefit will be gained by attempting to employ chemical coagulation to remove solids which are not truly colloidal -- for larger ones could be removed by settling and smaller ones will not be affected by this method of treatment.

(2) <u>Adsorption</u>

A large number of compounds which are not amendable to other types o treatment may be removed from wastes by adsorption. For example, pesticides, herbicides, and insecticides may be removed by adsorption on powdered activated carbon. Clays are also used for some long-chain but relatively small colloids. Removal is effected by either passing the waste through packed columns of adsorbent or by mixing the waste with the adsorbent and agitating to cause adsorption. The mixture is then generally filtered and the adsorbent with the impurities stop on the filter and the purified waste liquid is the filtrate.

d. Inorganic Dissolved Solids Removal

The removal of certain salts from wastes is beginning to become increasingly more important as concentrations of these minerals build up in receiving waters. These salts often originate from boiler ash and blowdowns and backwashes from water treatment plant softeners which are quite common in all large industrial plants. Among the methods employed for removing them are: (1) Evaporation; (2) Dialysis; (3) Ion Exchange; (4) General Appraisal; and (5) Other Methods.

(1) Evaporation

This is a process of bringing wastewater to its boiling point and vaporizing pure water. The vapor can either be used for power production or condensed and used for heating, or simply wasted to the surrounding atmosphere. The mineral solids concentrate in the residue, which may be sufficiently concentrated for the solids either to be reusable in the production cycle or to be disposed of easily. Major factors in the selection of the evaporation method are: (a) economics; (b) initial dissolved solids; (c) foreign matter; and (d) pollution situation in the receiving stream. Scale formation as the wastewater concentrates is generally a major problem.

(2) Dialysis

This is the separation of solutes by means of their unequal diffusion through membranes. It is most useful when recovering pure solutions for reuse in manufacturing processes. The restrictive characteristics of porous membranes are due to both a mechanical sieve action and a physiochemical interaction between solute, solvent, and membrane. Cellulose nitrate, parchment, and cellophane are the principal membranes in use today.

(3) Ion Exchange

This is basically a process of exchanging certain undesirable cations and anions of the wastewater for sodium, hydrogen, or other ions in a resinous material. As a means of waste treatment it is only a new application of a traditional method of water softening. It offers great potential for material and water conservation. Organic matter and pH

have a pronounced effect on the operation and efficiency of resin beds; the leaching of organic matter from certain resins may have a detrimental effect. Wastewater is passed through these resinous beds where ion exchange occurs until the exchange material is used up. The resin is then regenerated with chemicals. Chemicals used for regenerating resin beds may also require special treatment before disposal.

(4) General Appraisal

Ion exchange is most useful when water or chemicals of the highest quality are required, but it involves complex chemical reactions and therefore requires careful operation and supervision at all times. Ion exchange processes sometimes utilize chemicals for regeneration which are hazardous to personnel and equipment. Evaporators are uneconomical in certain instances, e.g., when the flow is light. Dialysis is normally economical and can compete in efficiency with both evaporation and ion exchange when the recovery of a pure compound is considered essential and when there is considerable difference between the solids to be removed and those to pass through the membrane. The decision whether to use evaporation or demineralization can be made intelligently only after a thorough evaluation of the heat balance of the plant and expected operating conditions. These factors, as well as operating costs, must be considered in relation to the capital investment needed for either system.

(5) Other Methods

Less tried but nevertheless sometimes used methods to remove minerals include: (a) growing algae with its subsequent removal; (b) reverse osmosis using pressure to overcome osmotic pressure and force water through a semi-permeable membrane; and (c) freezing, thus effecting a separation of pure water as ice crystals and salts as slush.

e. Organic Dissolved Solids Removal

Introduction

Manufacturing of textiles, paper, canned goods, leather, as well as preparing many food products such as milk, cheese, and meat results in the wastage of certain amounts of dissolved organic matter. This matter is readily available to micro-organisms ever present in streams as a source of food, resulting in a diminution of dissolved oxygen in the watercourses. Because these solids are amenable to bacterial degradation, waste treatment methods are largely patterned after biological treatment. In effect biological treatment is that which is occurring in streams but only differs in that it is accelerated by creation of optimum environmental conditions for bacterial growth. Some types of biological treatment used on industrial wastes containing a relatively high percentage of dissolved organic solids include activated sludge and its many modifications, trickling filtration and its variations, as well as oxidation pond treatment.

(1) Lagooning

Lagooning in oxidation ponds is a common means of both removing and oxidizing organic matter and wastewater as well. Stabilization or oxidation of wastewater in ponds results from several natural self-purification phenomena. The first phase is sedimentation; some suspended and colloidal matter is precipitated by the action of soluble salts; decomposition occurs by microorganisms of both the settled solids and soluble organic matter converting it to mineral matter, and the mineral matter and carbon dioxide are utilized by algae and other larger plant life to assimilate the inert matter and to produce oxygen and organic growth which, in turn, serves the bacterial population. All the micro-organisms (bacteria, protozoans, and algae) live in equilibrium and harmony with each other in properly designed and operated lagoons. Two versions of ponds: one deep (8 ft to 20 ft), one shallow (4 ft) are used. The first permits anaerobic decomposition in the bottom and aerobic completion of the oxidation in the surface. Under some conditions it is desirable to follow the deep pond with a very shallow one (2 ft or less) to enhance algal growth and oxygen production. In the

second, it was attempted to keep the entire pond depth aerobic; thus these are not used when there is settleable solids. Oxidation pond treatment is recommended when land is available at a low cost, where population density is low, and where the receiving water can assimilate a variable amount of residual organic matter.

Oxidation pond treatment is less effective, requires much land area and retention time, can yield odors unless properly designed or aerated, but is much less expensive to build and to operate. Some ponds develop an algal growth especially in shallow basins which assist in providing oxygen to the bacteria as well as in removing inorganic nutrients. Some 50% to 75% BOD reduction can usually be easily obtained with these wastes and one to three days retention.

(2) Activated Sludge

Activated sludge treatment consists of aerating biological flocculent growths within the industrial wastes. Surface for biological oxidation takes place on the flocculent growths (floc). With sufficient retention time for biological reaction, ample supply of oxygen, and a readily degradable organic matter to serve as bacterial food, activated sludge treatment would be effective. In trickling filtration, the surface for biological oxidation consists of solid media such as rocks, plastic, or glass. The surface must provide maximum area for biological growth, be resistant itself to deterioration, be relatively light in weight, and allow for sufficient pore or void space for heavy volumetric loadings of industrial waste. Oxygen for biological oxidation in trickling filters comes from the void area in the media. As the gelatinous coating builds up on the media some sloughs off and is removed by final clarification. Some seed material after filtration is usually returned to the filter inlet to keep the media biologically active. Both activated sludge and trickling filtration are capable of removing from 80% to 90% of the BOD.

Normal design loadings for activated sludge units are in the range of 35 pounds of BOD per 1000 ft^3 (565 $kg/1000m^3$) of aeration

basin and about 1000 ft^3 ($61.8m^3kg$) of air is provided per pound of BOD removed. Air is provided either from compressors or by mechanical means as a result of high-speed rotation of submerged rotors. Retention times vary from 6 to 24 hours. Various degrees of efficiency can be obtained by controlling the contact period and/or the concentration of active floc. The desired concentration of active floc is maintained by recirculating a specific volume of secondary settled sludge, normally about 20% of the raw wastewater flow.

(3) Other Modifications of Activated Sludge

There are many biological aeration systems somewhat similar but also significantly different from the conventional activated sludge treatment process. They are each designed specifically either for certain types of waste or for certain quality of effluent, or both. Some of the major ones include: (a) modified aeration (tapered aeration) which supplies air at points where the organic oxygen demand is greatest and lessens the supply at points where the demand is lessened; (b) dispersed growth aeration recirculates seconday effluent rather than sludge and utilizes longer aeration retention times. It is especially useful for organic wastes in which the solids are highly dissolved instead of colloidal; (c) contact stabilization uses a shorter period of aeration with recirculated sludge and a longer, separate sludge reaeration period; (d) total or extended aeration provides a long -- usually 24 to 36 hours -- aeration period so as to "use up" the organic cell growths which form during oxidation. This system is useful for smaller industrial plants where final sludge solids handling would be burdensome; and (e) brush aeration which accomplishes the aeration by a rotating cylinder partially submerged and fixed across the width of an elipitcal channel. Settling and sludge recirculation (if used) occur in subsequent segments of the elipitcal channel system.

(4) Trickling Filtration

This treatment process is one which utilizes fixed surface areas for biological growth and oxidation over which the organic wastes are

fed. The fixed biological units are usually some form of erosion-resistant rock material such as granite or traprock. However, other equally resistant surface material such as glass or plastic can be used, provided it has the structural stability required in deep beds of six feet, the surface area needed for growth, and pore capacity to filter wastewater rapidly and hold ample oxygen. The surfaces readily and rapidly become coated with a gelatinous slime growth after repeated and continuous dosing with the wastewater. These growths absorb and oxidize dissolved and colloidal organic matter from the wastes applied to them. A flocculent humus-like residue or sludge accumulates on the surface and when it gets too heavy it will slough off and resettle in the secondary settling basin. Trickling filters when loaded at about 35 pounds of BOD per 1000 ft^3 (565 $kg/1000m^3$) of filter bed will also remove 85% of the BOD load applied when followed by secondary sedimentation and when utilizing either some recirculation in beds of depths of 4 ft (1.22 meters) or no recirculation in beds of the depth of 6 ft to 7 ft (1.83 - 2.13 meters). Variation in removal efficiencies of this process may be obtained by increasing the recirculation rate and/or adding a series of filters and varying the flow sequence arrangement.

(5) Biodisc Treatment System

This is a rotating biological disc system consisting of a number of large-diameter, light-weight plastic discs, which are mounted on a horizontal shaft and placed in a semi-circular-shaped tank. The system has all the advantages of an activated sludge unit but with much less power required and the advantages of a trickling filter unit but with more efficient utilization of the surface area. The use of closely spaced parallel discs achieves a high concentration of active biological surface area. This high concentration of active organisms and the ability to achieve the required aeration rate by adjusting the rotational speed of the discs enables this process to give effecitve treatment to highly concentrated wastes. Loadings in the range of 5 to 15 pounds of BOD per day per 1000 ft^2 (50 $kg/1000m^2$) of surface area will result usually in more than 75% BOD removal.

(6) Spray Irrigation

Spray irrigation is an adaptation of the familiar method of watering agricultural crops by portable sprinkling-irrigation systems; wastes are pumped through portable pipes to self-activated sprinkler heads. Light-weight aluminum or galvanized piping equipped with quick-assembly pipe joints can be easily moved to areas to be irrigated and quickly assembled. Wastes are applied as a rain to the surface of the soil, with the objective of applying the maximum amount that can be absorbed without surface runoff or damage to the cover crops. A spray irrigation system is composed of the following units: (1) the land on which to spray; (2) a vegetative cover crop to aid absorption and prevent erosion; (3) a mechanically operated screening unit; (4) a surge tank or pit; (5) auxiliary stationary screens; (6) a pump which develops the required sprinkler-nozzle pressure; (7) a main line; (8) lateral lines; and (9) self-activated revolving sprinklers operating under 35 to 100 psi (2.38-6.8 atm) nozzle pressure. With good cover crops of dense, low-growing grasses and fairly level areas, waste to a depth of 3 to 4 inches (7.62-10.16 cm) can be applied at a rate of 0.4 to 0.6 inch per hour (1.02-1.52 cm per hour). The potential for the dual purpose system of disposing of wastewater and growing crops for food makes spray irrigation a desirable system for both developing and developed countries.

(7) Other Systems

The removal of organic dissolved solids can also be accomplished by more sophisticated and specially designed treatment systems. Some of them include:

(a) Wet Combustion Technique which burns wastewater at elevated pressures (1200 psi -- 81.6 atm) is an excellent process for rapid oxidation of organic matter when steam is essential and inexpensive enough to justify the cost of the equipment. Wet combustion can maintain itself only when the waste has at least 5% solids of which at least 70% are organic. The potential exists for recovery of expensive inorganics such as ash.

(b) Anaerobic Digestion is a bacteriological process for oxidizing organic matter in closed vessels in the absence of air. Generally anaerobic processes are less effective than aerobic processes, mainly because of the small amount of energy that results when anaerobic bacteria oxidize organic matter. Anaerobic processes are therefore slow and require low daily loadings and/or long retention periods. However, since little or no power need be added, operating costs are very low. Where liquid waste volumes are small and contain no toxic matter and there are high percentages or readily oxidizable dissolved organic matter, this process has definite advantages over aerobic systems.

(c) Deep Well Injection disposal of wastes containing dissolved organic matter by injecting them into deep wells has been successful in areas of low or nonexistent streamflow, especially when wastes are malodorous or toxic and contain little or no suspended matter. To be effective, the wastes must be placed in a geological formation which prevents the migration of the wastes to the surface or to groundwater supplies. Other factors to be considered in addition to geology are depth and diameter of wells, injection pressures, and the volume and chracteristics of the wastes.

(d) Foam-Phase Separation can be used on concentrated organic wastes which possess a high degree of foamability. A sparger produces small gas bubbles (usually air) on a tank bottom and when these bubbles rise through the liquid they absorb surface-active solutes and suspended matter. When the bubbles reach the surface, a foam forms, which is forced out of the foamer, collapsed, and discharged as a concentrated waste.

f. Treatment and Disposal of Sludge Solids

Introduction

Of prime importance in the treatment of all liquid wastes is the removal of solids, both suspended and dissolved. Once these solids are removed from

the liquids, however, their disposal becomes a major problem. When the solids-disposal system is poor, the solids tend to build up on the flow-through treatment units, and overall removal efficiencies then begin to decrease. Therefore, proper sludge handling enhances the overall treatment of all wastes. Sludges are usually anaerobically digested, concentrated and lagooned or returned into the land, or dried on specially designed drying beds. Other sludge treatment systems such as centrifuging, barging, incineration, etc., are used in specific circumstances.

Sludge Treatment (Concentration and Preparation)

(1) Digestion

Digestion is commonly used for sludge solids which are relatively high in organic matter. It is a convenient method to use when the volumes of sludge would otherwise be expensive to handle from a labor standpoint and where initial capital expense is not a major deterrent. Digestion is a slow microbiological process carried out in a sealed reaction vessel for 20 to 60 days. Products of digestion include combustible gases such as methane, organic acids remaining in the supernatant liquor, and digested solids of about the same solids content as the raw solids (5% to 10%) but much lower organic matter (35% to 65%). After digestion, the sludge is dried and/or burned, or returned to the land for soil conditioner. pH (7-7.4), organic solids loading (0.1 to 0.3 pounds per ft^3 (1.60-4.8 kg/m^3) per day), and mixing of tank contents (mechanical, sludge recirculation, or gas recirculation), and tank contents temperature (90 degrees F -- 32.2 degrees C) are carefully controlled in order to ensure efficient digestion.

(2) Vacuum Filtration

Vacuum Filtration is a means of dewatering sludge solids in order to reduce the solids volume and to facilitate its handling. In a typical unit, a porous cylinder overlying a series of cells revolves slowly about its axis with its lower portion passing through a trough containing the sludge to be dried. A vacuum applied from inside the cylinder picks up a layer of sludge as the filter surface passes through the trough. When the cylinder

has completed 3/4s of a revolution, a slight air pressure is produced on the appropriate cells, which aids the knife edge to dislodge the sludge in a thin layer. Sometimes, chemicals are added to the sludge to enhance the filtration rate which should be from two to ten pounds of dry solids per square foot per hour. When space is limited and good mechanically trained personnel and shop equipment are available, vacuum filtration is recommended for sludge concentration (to about 70% water).

(3) Drying Beds

These remove moisture from sludge, thereby decreasing its volume and changing its physiochemical characteristics so that sludge containing about 25% solids can be moved with a shovel or garden fork and transported in watertight containers. Sludge filter beds are usually made up of 21 to 24 inches (53.34-60.96 cm) of coarse sand, and about 12 inches (30.48 cm) of coarse gravel beneath the sand. below the gravel, the earth floor of the bed is pitched to a slight grade into open-joint tile underdrains 6 or 8 inches (15.24 or 20.32 cm) in diameter. Disposing of the underdrain liquid sometimes is a problem; this should never be discharged without an analysis of its constituents and usually some form of treatment. Drying time is dependent on dosing depth, eight inches (20.32 cm) being generally accepted as most desirable for rapid drying, as well as on climate. This form of sludge solids treatment is recommended for regions of plentiful land and sunshine, scant rainfall, low relative humidity, and more than average wind velocity since water is separated from the solids by both evaporation and draining.

(4) Centrifugation

This is a method of concentrating sludge to enhance final disposal. Installations now using 20 hp (14.9 kw) built-in drive motors can handle 3000 to 4000 gallons per hour of waste sludge containing 0.5% to 0.75% solids on a dry basis. Speeds of bowl revolution reach 6100 rpm. The resulting sludge can be concentrated to about 5% solids. The centrifugal force throws the denser solid material to the wall of the bowl, where it is dis-

charged through nozzles located in the periphery. The effluent from which the solids are separated travels towards the center of the bowl. This form of sludge concentration is recommended when electrical power is available at a reasonable price and both space and labor for other sludge concentration systems are lacking.

Ultimate Sludge Disposal

(5) Lagooning

Lagooning (storage) in natural or artificial earth basins is practiced when suitable land is available and the cost of other ultimate means of disposal is prohibitive. Factors to be considered when using this method include:

(a) nature and topography of the disposal area;

(b) proximity of the site to population area;

(c) meteorological conditions, especially whether prevailing winds blow toward or away from populated areas;

(d) soil conditions;

(e) chemical composition of sludge (toxicity and odor-producing constituents);

(f) proximity to surface or groundwater supplies;

(g) effect of waste materials on the porosity of the soil;

(h) means of draining off the supernatant liquid to provide more space in the lagoon;

(i) fencing and other safety measures when the lagoons are deeper than five feet; and

(j) nuisances, such as weed growth, odors, and insect breeding. Lagoons vary in depth depending upon local conditions.

(6) Sludge Barging or Pumping

Barging and pumping are means of final disposal of sludge and are applicable mainly to coastal industries and are especially useful where there is little or no land space for sludge storage. There are no recommended standard design techniques or procedures for such systems. The system selection for solving each industrial sludge problem of this type is based upon specific and special considerations of any one plant. The project manager should be aware of the real conclusion that no resource to which the sludge is being transferred is unlimited in capacity. Oceans have become contaminated with sludge products and recreation and fishing uses of these waters have been violated in certain cases. Ocean dumping by barging or pumping should be considered only as a temporary method of ultimate disposal and one which must be selected after evaluation of the capital expense involved in purchasing ships or pumps and long pipelines.

(7) Drying and Incineration

A large volume of sludge can be reduced to a small volume of ash which is free from organic matter and therefore easily disposable, by a combination of heat drying and incineration.

Usually sludges are "flashed" dried by passing the sludge through a stream of hot gases, which ensures practically instantaneous removal of moisture. When hot gases created by the drying and oxidation of the sludge itself are used directly for drying, there are no conversion losses. After the flash drying, the gas containing sludge particles usually passes to cyclone separators, where the dried sludge is separated from the moisture carrying cooler gases. This sludge can be used for returning to the land for agricultural purposes or reused by an industry as a starting raw material -- depending upon its dried solids content. Unused dried sludge is incinerated by blowing it through a duct to a burner in the combustion chamber of a furnace. The sludge blower simultaneously supplies air for combustion. Combusted gases are recirculated and returned to the furnace to eliminate their odors. Ash

is removed from the furnace bottom either manually or by sluicing with water. Furnaces should provide for the release of about 12,000 BTU per cubic foot (108×10^6 cal/m^3) of furnace volume per hour.

When small volumes of irregularly produced industrial sludges are discharged, they can be burned in "pit-type" incinerators consisting of a rectangular pit lined with firebrick. Air is supplied and distributed so as to retain particulates. It is less efficient than the larger flash drier-incinerators and should be used only after considering the plant location relative to the prevailing wind and nearby development.

(8) Atomized Suspension

With certain high solids concentration type of industrial sludges, it is possible to spray the slurry in the top of a tower, the walls of which are maintained at an elevated temperature (by hot gases). No external gases mix with the drying sludge solids which are recovered by cyclone separation for reuse or further treatment at the bottom of the drier. The hot gases released (usually only water vapor) are taken off the top of the cyclone separator and cooled by passing through a condenser or are recirculated directly to the drier for heating the walls.

(9) Wet Combustion

In this process oxidation of sludge solids with at least 5% to 10% solids content of which most (60% to 90%) are organic is brought about by continuously pumping the sludge and air at elevated temperatures and pressures into a reactor vessel. Combustion occurs as the oxygen in the compressed air combines with the organic matter in the sludge to form CO_2 and N_2 and steam while the ash remains in the residual water. The characteristics of the final products of ash, condensate and gases depend upon the operating temperatures and pressures as well as the sludge character and flow-through rate. Typical pressures of 500 to 600 psig (34 to 40.8 atm) and temperatures of 400-500 degrees F (204-260 degrees C) are used. The process is recommended where other means of ultimate disposal of large sludge volumes are either

unavailable or unacceptable and where initial capital costs are not a major concern.

(10) Miscellaneous Sludge Treatment Methods

Other systems which are sometimes used for further sludge concentration include:

(a) flotation and thickening;
(b) chemical coagulation;
(c) mechanical concentration by rotating paddle contactors; and
(d) composting.

All of these provide a sludge after treatment which is of lesser volume and of more use for some ultimate purpose (usually for land disposal). All are recommended for consideration where transportation costs to the land areas are relatively high but where land utilization as a means of ultimate disposal is called for and where a certain moisture content may be desirable. The references in Section IX can be consulted for specific process design and details of operation.

g. Bacteria of Micro-organism Removal

Some industrial wastewaters such as tannery, slaughterhouse, and cannery effluents may contain undesirable micro-organisms which either interfere with their reuse or with their introduction into the envirionment. Removal of Micro-organisms is recommended when the wastewater is being discharged into a receiving stream used for drinking water or swimming or being reused within a plant and coming into contact with an edible or deteriorative product. In these cases they can be disinfected generally by the use of chlorination, ozonation, ultraviolet radiation or other means.

(1) Chlorination

This involves contacting the wastewater thoroughly with liquid chlorine for sufficient time (usually 15 to 30 minutes) to provide a residual chlorine content of about 0.5 parts per million. The contact time and quantity of chlorine required will both vary with the nature of the wastewater and especially the organic matter content. For this reason chlorination is used as a final process after organic matter has been removed from the wastewater.

(2) Ozonation

Air is passed over a hot wire system and the liberated ozone (O_3) is conveyed into the wastewater in sufficient amounts for ample time so as to render the wastewater sufficiently free from bacterial contamination for discharge or reuse. Free ozone is difficult to measure or maintain in the effluent and is often more costly to produce but has been shown to be quite effective.

(3) Ultraviolet Radiation

This method can be used in certain cases where the suspended and colloidal solids content of the wastewater is relatively low and where a drinking water supply is not involved. Wastewater is simply passed slowly in a relatively shallow layer under a bank of ultraviolet lights during which time microorganisms are killed.

C. Land

1. Use of Standards

a. Inplace Conditions

The land and the surrounding environment is protected by municipal (local) regulations generally put forth in the form of ordinances. Each ordinance will vary in its details depending upon the local conditions as well as the larger (county, state or national) minimum requirements. The subjects ordinarily covered by a final disposal provision of solid waste removal ordinance will include the following:

(1) definitions:

(2) responsibility for reuse disposal;

(3) management of disposal facilities (designation of authorized sites and facilities, who may use sites, responsibility of site users, salvage);

(4) control of types of refuse (separation of refuse, hazardous refuse, dead animals);

(5) control of private sites;

(6) on-site disposal;

(7) air pollution controls;

(8) financing;

(9) penalties for violations; severability; and

(10) accounting of refuse disposal of toxic wastes.

Any industry utilizing municipal disposal facilities should consult these ordinances carefully before agreeing to use them. If private facilities are selected for disposal by industry, local ordinances should be examined for all provisions related to their acceptable use. A practice of requiring a permit or license for all private (industrial) use of land for solid waste disposal is quite common and ensures that the plant complies with all local ordinance requirements.

The disposal land alone is not the only concern for the pocket manager, but also the surrounding air and groundwater. While the air quality is generally controlled by either air standards in general effect in the disposal area or in the ordinance specifically related to air quality, groundwater quality is less defined.

b. Leachate Control

In solid waste landfill disposal sites which become supersaturated because of artificial wetting, inadequate drainage of surface run-off from the site, or inundation by high ground water, the chance of leachate groundwater pollution exists. Most landfills will eventually produce leachate, the first appearance of which depends on site conditions, including surface grading, vegetation and soil parameters such as soil type, thickness, density, permeability, field capacity and initial moisture content. The leachate produced by solid wastes in a sanitary landfill may be highly polluted, especially in the relatively early life of the fill. The composition of the leachate depends greatly upon the industrial solid waste itself. In general, it tends to be acidic and contain great quantities of dissolved minerals and suspended matter. Leachate which impairs groundwater can be prevented if the landfill is so located and constructed that no portion of it intercepts groundwater. A minimum distance of two feet is recommended between the maximum groundwater level

and solid waste depth. A natural or artificial layer of 1 ft to 3 ft (.304-.912 meters) of clay or a sheet of synthetic liner will help ensure separation of the water and solid waste. The intercepted water should be drained away from the site by gravity or pumped intermittently by a well-point system. Surface water streams should be diverted away from the landfill disposal sites by either regrading or collection and redirection of streams expected at least once in 50 years.

c. Gas Control

When industrial refuse such as cannery residues contains considerable quantities of organic matter, decomposition gases result in the landfill. These gases are mainly CO_2 and CH_4 but may also contain some NH_3 and H_2S, depending upon the composition of the industrial refuse. Some gases are explosive (CH_4) and others are odorous and poisonous (NH_3 and H_2S). In general, no extensive damage to persons in the immediate landfill area occurs when the gases can disperse slowly, continuously, and completely into the atmosphere. Gases can be vented to the atmosphere, when the soil and/or refuse type are impermeable, by the construction of gravel vents or gravel filled trenches. A moist clay barrier can also be used to contain all the gas in a certain section of the landfill which is then vented through a pipe collection system to the atmosphere.

d. Significance of Standards (Local, National and International)

Solid waste disposal standards or resulting land use standards are extremely variable from one locality to the next, depending mostly upon the availability of sufficient land, density of the population, and concern of the citizens for protection of the quality of the environment. Although national codes and requirements normally dominate performance standards in local operations, the latter are greatly influenced by municipal laws. Municipal laws often are confusing, unenforceable, and conflicting. The reasons for the complexity of local ordinances are based on the dichotomy that all solid wastes must be returned to the land but no one wants their land or land near them to be used for this purpose.

2. Collection and Delivery Concerns

Industrial refuse can be collected and delivered for final disposal by one of three methods:

a. Collected by the plant itself and disposed of on the plant property;

b. Collected by a private contractor and disposed of outside the plant property; or

c. Collected by a local government and disposed of in a municiaplly owned or leased land area.

In the United States about 30% of all industrial refuse is handled by (a); about 57% by (b), and only 13% by (c). The form of the solid refuse from any plant may be a liquid, semi-liquid, as well as packaging, films, sheets, granules, shavings, turnings, powders, and defectively manufactured products of all shapes and sizes. The collection system selected by an industrial plant will have little ultimate effect on the environment. The least expensive and most efficient collection system should be used. It should provide for continuous, complete, and clean removal of solid waste from the industrial plant site.

3. Treatment Techniques

a. Sanitary Landfill

This method is defined as an engineered method of disposing of solid wastes on land by spreading them in thin layers, compacting them to the smallest practical volume, and covering them with soil each working day in a manner that protects the environment. The selection of a site and the operation and design should be based on a systematic, integrated study and an evaluation of all physical conditions, economics, and social/political constraints.

If the industrial refuse is largely organic in nature, it will degrade biologically in the fill and yield solid, liquid, and gaseous products. The liquid and gases must be handled as described in Parts 1b and 1c (pp. 69-70) of this section. The solid residue remains quite inert and porous. Each type of organic waste degrades to a different extent and at a different rate. For example, canning plant residues decompose quite readily and completely while plastics, rubber, and glass decompose very slowly, if at all. Initial decomposition is aerobic and will yield products such as CO_2, water, and NO_3 while subsequent biological breakdown products will be anaerobic, such as CH_4,

organic acids, NH_3, and sulfides, as well as some CO_2 and water. By a knowledge of the composition of the industrial refuse and the porosity of the soil, the project engineer can predict the type and amount of degradation products, including the final refuse volume remaining. This is especially helpful in ascertaining the life of a given fill area and in predicting the extent of gas and leachate problems to be encountered. Most of the information currently available relates to municipal refuse, but since this normally contains a considerable percentage of industrial waste, some of the data can be extrapolated. For example, Merz and Stone[1/] found that 40 ft^3 of gas were produced per cubic yard of solid waste over a 907-day period. Theoretically, complete decomposition of a 75% organic matter residue will yield up to 6.6 ft^3 (2.01 m^3) of gas for each pound (.45 kg) of refuse. It is good practice to prevent excessive landfill water infiltration by:

(1) diverting incoming drainage;
(2) draining and grading the daily soil cover to enhance runoff; and
(3) adding clay to cover soil to decrease permeability.

Soil cover (daily) serves many purposes. For example:

(1) controls flies;
(3) controls rodents;
(3) prevents scavenging bird feeding;
(4) prevents moisture;
(5) prevents or enhances gas emerging through the cover;
(6) prevents erosion and provides good appearance; and
(7) grows vegetation

Six inches of compacted sandy loam is recommended for daily addition and two feet of final soil is recommended to grow vegetation after fill is ended. The soil cover used will depend upon the final desired use of the filled land. Peat and highly organic soils are not recommended for soil cover because of compaction difficulties.

1/ Merz, R. C. and Stone, R., "Special Studies of a Sanitary Landfill," Washington, D.C., US Department of Health, Education, and Welfare, 1970. (Distributed by National Technical Information Service, Springfield, Virginia, as PB-196, 240 p.)

Refuse can usually be compacted in the fill to 1000 pounds per cubic yard (592.7 kg/m^3). If the designer knows the volume of refuse collected daily and its weight, he can compute the volume of fill required daily. He can then predict the life of the fill area, if he establishes the final height and area of the fill.

Site improvements are usually necessary to allow for freer flow of truck traffic in and out of the area, construction of buildings, fencing, and utilities necessary to carry out efficient landfill operation.

The two basic landfilling methods are trench and area types. In general, the trench method -- where waste is spread and compacted in an excavated trench -- 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 used on most topographies and is often used if large quantities of solid waste must be disposed of. In the area method, the waste is spread and compacted on the natural surface of the ground and cover material is spread and compacted over it. It is recommended on all types of land but especially in natural land depressions. Usually all fills are done in almost square cell units so that a cell can be completed daily and covered immediately with a minimum of fill. Therefore, the cell should be as deep as practical so as to minimize the surface area involved (and thus use less cover). Trenches can be as deep as soil and groundwater conditions safely allow, and should be at least twice as wide as any compacting equipment will work in it. Final slopes of the fill should be graded to at least 3 to 1 to induce drainage away from the fill and to prevent erosion of the cover.

The disposal of industrial solid or liquid wastes in landfills should be contingent upon whether they will be hazardous to the environment. If they are deemed hazardous -- such as radioactive or explosive wastes -- they should not be accepted unless special provisions are made for environmental protection. These provisions will be discussed in the appropriate separate manuals.

Because every landfill settles to some extent, the surface should be periodically inspected and soil added and regraded when necessary.

b. Grinding (Shredding)

In situations where the type of plant refuse is variable in size, shape, and consistency, grinding can be used to make the solid waste more uniform. This is especially desirable where using incineration or landfilling as major final treatment methods. Firing a uniform product into an incinerator is desirable from an operating efficiency standpoint. Landfilling a ground solid waste enhances compaction (both in transfer trucks and in the landfill), decomposition, and rat and odor control. It minimizes the amount of cover soil required. Grinding requires increased power despite the fact that little additional labor cost is needed. However, in many instances the increased power costs have been more than compensated for by lower and more efficient subsequent treatment costs.

c. Incineration -- Central and Individual

Incinerators are power plant-like structures designed to burn solid wastes under controlled, nuisance-free conditions, and at relatively high temperatures (1500°F-1900°F) for the purpose of reducing the combustible components to an inert residue which can then be readily disposed of by landfilling or, after further treatment, as a roadway or construction material.

Since incinerators for solid wastes are generally purchased as a "package" from an equipment manufacturer, the project engineer can contribute relatively little to the design of the unit. The engineer can make certain, however, that the incinerator is designed for high temperature combustion to prevent odors, for complete combustion of all solid waste to minimize residue for ultimate disposal, and for reuse of the combustion products for energy production to minimize treatment costs.

In addition, it is extremely important for project personnel to know when to select incineration as a prime method of refuse treatment. The following include some of the major factors favoring a decision for selection of incineration: (1) lack of abundant land for disposal; (2) availability of an ideal central station site to minimize transportation costs and optimize environmental (aesthetic) appearances; (3) production of a very small volume residue of organic-matter-free ash; (4) availability of a site relatively unaffected by local weather conditions. This treatment can

handle a variable daily load with great efficiency and can provide many by-product potentials, including waste heat, salvageable metals and ash. It is equally important to be aware of situations which may dictate against incineration. For example, (1) a suitable central site in a densely built-up area at a reasonable cost is often difficult to find; (2) management and operational skills required are of a relatively high order; and (3) a large capital investment with relatively high operating costs may be required. Incineration must be recognized not as an ultimate disposal system in that a disposable ash still remains.

The major components of a basic incineration system and their function are summarized briefly in Table 6 as follows:

Table 6

Major Components of a Basic Incineration System

Component	Function
1. - Truck scale	Weighing, indicating, and recording of solids
2 - Tipping floor	Maneuvering, positioning and dumping of collection trucks and trailers
3. - Storage pit	Providing about 24 hours feed storage
4 - Cranes	Charging the furnace via grapples
5 - Residual (ash) removal	Quenching bath and conveyor belt for continuous removal of flyash and undergrate siftings
7 - Gas cleaning system	Cooling and scrubbing (or precipitating) the particulate matter from the stack gas
8 - Exhaust stack	Providing proper positive air draft flow (enhanced by induced draft fans) of combustion gases
9 - Building	Providing space for administration, washroom storage, and all services excluding tipping and air pollution control
10- Exterior treatment	Providing parking and transportation services in an aesthetically pleasing a setting as possible.

In addition, fragmentizers, pathological incinerators, electrostatic precipitators for stack gases complete particulate matter removal, and various means of residual handling are often utilized when and if economic and environmental conditions justify the expenditure.

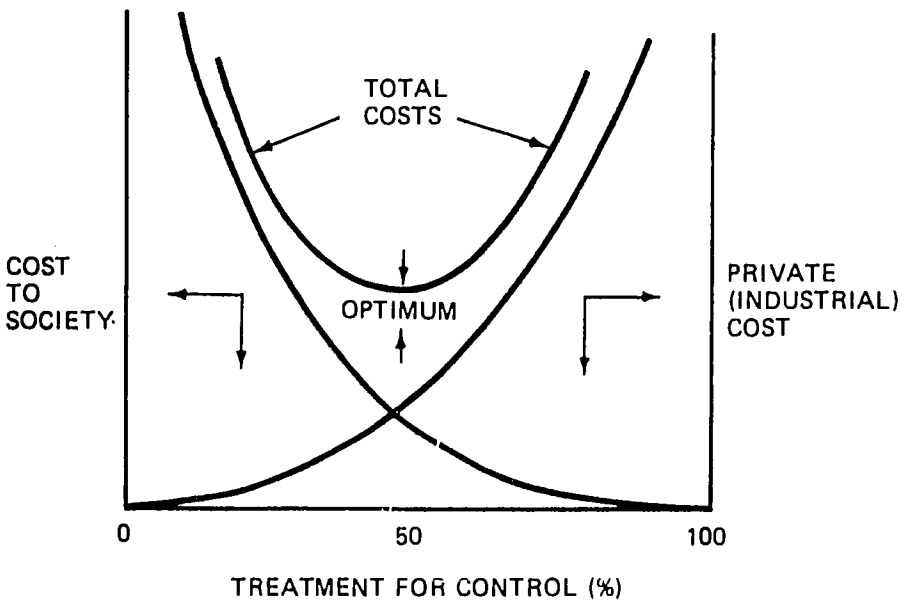
Incinerators, whether local or central, should be located so as to be readily accessible to existing main highways, to utilities such as water, electricity and telephone, should not pose any sanitary or health problems in general or to neighborhood communities in particular. Specifically, it may be desirable to locate central incinerators (1) near to a power station for zoning and traffic enhancement and for utilization of the excess heat obtained from burning refuse; (2) near to an ocean, bay or large river to be used as cooling waters for spent steam and condensation; (3) near to the refuse-generating industries to minimize transportation costs; (4) on favorable subsurface foundation conditions; and (5) near to inexpensive lands to allow for the disposal of residues from the incinerator.

V. ENVIRONMENTAL CONTROL -- ECONOMIC ASPECTS

A. Air

1. Costs of Air Pollution Abatement

It will be attempted to identify some of the costs of pollution to society in this section. However, as control measures are used costs to society decrease and private (industrial) costs increase. There is an optimum which minimizes the summation of the two costs as shown below:



World Bank–16348

The following table of data (Table 7) collected from various sources provides some general costs to the private (industrial) sector for emission control. In some cases, increased efficiency of production is obtained by emission control (indicated by negative cost values).

Table 7

Costs for Emission Control

Contaminant	Type Control	% Control	Cost of Control
NO_x	Combustion modification (flue gas recirculation)	33	$12-20/ton (907 kgs) fuel
	(low excess air plus 2-stage combustion)	60 - 90	-$14 to +$12/ton (907 kgs) fuel
	(2-stage combustion)	35 - 50	$0-29/ton (907 kgs) fuel
	(Low excess air)	25 - 33	-$5 to -$30/ton (907 kgs) fuel
SO_2	Linestone scrubber		$15/kW of power construction cost for retrofitted plant - $3-6/ton (907 kgs) c coal operation cost
			1968 Costs Installed
Particulate Matter	Gravity collector		*$28,000/100,000 cfm (47,190 l/sec) of gas flow
	Mechanical collector (cyclone centrifugal)		$23,000/100,000 cfm (47,190 l/sec) of gas flow
	Wet scrubber		$55,000/100,000 cfm (47,190 l/sec) of gas flow
	High voltage electrostatic precipitator		$120,000/100,000 cfm (47,190 l/sec) of gas flow
	Low voltage electrostatic precipitator		$200,000/100,000 cfm (47,190 l/sec) of gas flow
	Fabric filter (=500°F) (260°C)		$155,000/100,000 cfm (47,190 l/sed) of gas flow
	(=250°F) (121°C)		$82,000/100,000 cfm (47,190 l/sec) of gas flow

*Unit costs will be larger for smaller treatment units.

2. Benefits of Pollution Abatement

The identifiable sufferers of air pollution are:

a. agricultural plants;

b. materials corroding and deteriorating:

   (1) metals, rubber and paint;
   (2) art treasures; and
   (3) clothes;

c. Human beings:

   (1) aesthetic;
   (2) visibility interference; and
   (3) health

Many of the costs of pollution to society are measurable, but others are intangible and all costs are subjective to some degree or at least are open to dispute from a quantitative standpoint. Project directors are advised to be as specific as possible when quantifying the effects of pollutants.

The chemical components So_2 and NO_2 bleach leaves and suppress growth of some plants, including some fruits and vegetables. The chemical component SO_2 is largely responsible for corrosion of metals, building materials, and fabrics when it is covnerted into the acid form (H_2SO_4). Particulate matter, especially dust and unburned carbon or ash, can cause clothes, fabric and household dirtying that requires a great deal of both measurable and immeasurable cleaning costs. The wearing and cracking of rubber, the fading and coloring of fabrics, the blackening of painted buildings, the staining of some, as well as the deterioration of rails, wires, electrical contacts, etc., are just a few of the examples of difficult to assess depreciation of materials by air contaminants. Even more difficult to measure and assess are the disintegrations to leather and paper and valuable pieces of art by the gases and gritty particulates. Damages to the Roman Coliseum or the Parthenon in Athens are examples of long-term, intangible costs resulting from air pollution. In the United States figures of about $60 to $85 per person per year have been quoted as arising from the measurable (excluding health) effects of air contaminants.

The health effects to humans of air pollution exist and largely affect the respiratory system and mostly of these weakened persons already suffering from respiratory or cardiovascular disease. Disasters, generally

caused by a combination of air inversions and high industrial and auto outputs, accentuate the health effects.

Normally inhaled gaseous pollutants can be absorbed along the pharynx of bronchioles and inhaled particulates can be deposited in the mucus layer surrounding the bronchial cilia. This implies that a person is healthy and has normal, healthy bronchioles and cilia and mucus layer. In many persons these may already be damaged by smoking or other irritants and these people are much mroe sensitive to even low levels of air contaminants.

The two major respiratory diseases of the lung claimed to be a direct result of air pollution are:

a. lung cancer, and
b. bronchitis.

Lead and CO are two other specific air contaminants which are dangerous to human life and health.

Accidents and additional operation costs for airplanes, trucks and autos are caused by reduced visibility as a result of dust or smog caused by industrial air emissions. These costs can be identified in some cases by case studies and must be estimated in others.

3. Method of Payment for Abatement

Air emission control must be included as a part of the cost of production by an industrial plant. The extra cost -- normally from 1% to 10% of the capital expense of a plant -- can be passed on to the consumer in the price of the product or deducted from the gross profits of the plant when it is not possible to raise the product cost.

B. Water

1. Costs of Water Pollution Abatement

At each level of receiving water qualtiy there exists a given cost and also associated total benefits to society. Many of these benefits are measurable while others definitely exist but at present no method of their quantitative evaluation is available. As long as the measurable benefits equal or exceed the direct cost of industrial pollution control, waste treatment practices should be constructed.

The cost of industrial pollution control varies from one industry to the next and within the same industry

within plants. The major reasons for these variations within a given industry are:

a. extent of treatment used;

b. inclusion or exclusion of costs which are designed to aid production as well as pollution abatement;

c. difference in treatment units selected by engineers to accomplish similar objectives;

d. amount of design or construction which is actually done "in house" and not considered on a uniform basis as part of the cost; and

e. size of the treatment facility.

In general, a conventional secondary treatment facility for an organ-laden industrial waste can cost in the range of $50 to $150 per pound. (.454 kg) of BOD per day for capital expenses. Less conventional, more innovative treatment systems can cost less than $50 per pound (.454 kg) per day. For canneries, poultry processing, and tanneries, it is possible to design and construct treatment facilities yielding 85% BOD removal for the cost of about 1% of production or value added costs, which is equivalent to about 24 cents per 1000 gallons of wastewater treated.

2. Benefits of Pollution Abatement

There are three classifications of benefits in any industrial pollution abatement project:

a. Primary
b. Secondary
c. Intangible

Primary benefits accumulate to those who benefit as a result of products and services originating directly from the project. These benefits are largely savings to the industrial plant as a result of wastewater reuse as well as compliance with regulatory agencies, thus avoiding legal, expert and management costs.

Secondary (indirect) benefits tend to occur to those who do not use the output of the product and services directly. Many readily-understood benefits of waste treatment fit into this category, such as a community's recreational use of clean water downstream after waste treatment by an industrial firm. The people of the community in which the industry is located (or of a nearby community to a lesser extent) benefit indirectly from the industrial firm's treating its waste. This

situation can be referred to as a "technical external economy" for the community.

Intangible benefits are irreducible since no direct dollar value can be easily assigned to them, although it is readily apparent that they exist. For example, waste treatment might improve the morale of the community by virture of its possession of a clean river: a sort of mental well-being which, although real, defies quantification. These benefits are necessarily subjective and subject to variable quantitative emphasis, depending on the position in society of the reviewers. Other examples of intangible benefits which should be realized by project engineers include:

a. good public relations and an improved industrial image after installation of pollution abatement devices;

b. improved mental health of citizens in the area confident of having adequate waste treatment and clean waters;

c. improved conservation practices, which will eventually yield pay-offs in the form of more clean water for more people for more years;

d. renewal and preservation of scenic beauty and historical sites;

e. residential development potential for land areas nearby because of the presence of clean recreational waters;

f. elimination of relocation costs (of persons, groups, and establishments) because of impure waters;

g. removal of potential physical health hazards of using polluted water for recreation;

h. industrial capital investment assures permanence of the plant in the area thus lending confidence to other firms and citizens depending on the output produced by the industry;

i. technological progress, resulting from the conception, design, construction, and operation of industrial waste treatment facilities.

From a practical engineering standpoint, the benefits of waste treatment are directly related to the total value of the water and associated land downstream and should include a summation of

a. the lowered true cost of the water downstream;

b. The lessened damages for consumers utilizing contaminated water downstream; and

c. the increased opportunities of associated land and water use downstream.

3. Method of Payment for Abatement

Costs of wastewater treatment can either be paid for directly by an industrial plant, included in production costs and subsequently passed on to the consumer (purchaser of the industry's products) or be subsidized either wholly or partly by a local or national government in whose jurisdiction the plant is located. In the first case the product buyers and users only would pay for the costs of pollution abatement. In that case the risk capital or initial startup costs must be borne by the industrial plant which would anticipate reimbursement at a later date by product purchases. In the second case, all residents of the local community or country would assume their proportionate share of the costs at the onset of the abatement program. These same people may or may not be recipients or purchasers of the industrial product. In any event, they would be shouldering the burden of pollution abatement costs in order to allow the industry to operate in an environmentally safe manner and at a subsidized (artificial) lowered production cost.

C. Land

1. Costs of Solid Waste Collection and Disposal

Little collection cost information is available on solid wastes of industrial plants. This is because the collections systems are vaiable from one plant to another and are often considered for accounting purposes to be just a part of some other production cost. Municipal collection costs, however, are well known and represent about 80% of the total disposal costs when sanitary landfill is used. Current US collection costs for municipal refuse is about $9 to $12 per short ton of refuse. Industrial collection costs should represent a smaller percentage of the total cost since larger concentrations of solids are found within shorter distances from each other and at fewer sites. Also, when incineration of the solid wastes is utilized, collection represents a much smaller percentage of total costs although approximately the same quantitative cost. A major portion of collection costs can be attributed to personnel or labor. In industries where labor is abundant and inexpensive these costs can be

minimized, especially if these represent only the part-time duties of production personnel.

Disposal costs for landfill, whether municipal or industrial, should be similar if realistic land values are used. The capital costs should approximate $300 to $3000 per ton (907 kg) per day or $1.00 to $3.50 per ton (907 kg) disposed for basic to refined sanitary landfill operations. Incinerator capital costs range from $5 to $20,000 per ton (907 kg) per day or $2.50 to $10 per ton (907 kg) of refuse.

Disposal techniques of solid waste by other methods such as rendering, open burning, or plain dumping are not suggested for industries. Composting, however, can be used for organic solid wastes such as those from slaughterhouses and tanneries and fruit and vegetable processing plants.

These plants cost about $10 per ton (907 kg) per day for capital costs and $6 per ton (907 kg) of solid waste to operate, based upon municipal refuse experience in the United States (60% to 65% combustible).

2. Benefits of Pollution Abatement

When land is preserved or utilized beneficially in a state which emits no adverse effect on the total environment, the local inhabitants are recognized as obvious beneficiaries. Their daily lives, their homes, and even their work are enhanced by this type of pollution abatement. People living and working near a properly utilized solid waste disposal or land utilization area will not suffer from the unsightliness, odors, or subsurface leachate contaminant. These become direct beneficiaries. The land area resulting from proper utilization preservation usually belongs to local government, which also benefits from these activities. Since the adverse effects can travel many miles, other residents quite distant from the land in question might also benefit from proper abatement.

3. Method of Payment for Abatement

Unfortunately, the major means available to date for paying for these proper abatement services has been to charge the solid waste suppliers (land users) a direct charge based upon quantity of waste. It is not accepted practice to charge the other direct or indirect beneficiaries for land disposal and utilization. Therefore, there exists little incentive to spend any other money except the bare minimum necessary for solids handling. It is suggested that the other beneficiaries be identified and assessed a small charge to

gain additional revenue for reclaiming the land in its highest use. Perhaps solid waste disposal zones could be established, each zone paying a decreasing amount of revenue as the distance from the land area increases.

VI. ENVIRONMENTAL CONTROL -- POLITICAL ASPECTS

A. Air, Water and Land Zoning for Environmental Protection

Industrial plants producing air, water or solid wastes are generally located in remote land areas of the local community which are readily accessible to man and relatively inexpensive to purchase. Often, entire industrial zones are set aside for this purpose with the basic premise that industry, because of common interests, needs, and environmental problems, is best placed in isolated zones. These zones permit different and often lower environmental quality standards than those of residential areas of the same communities. Political interests often lead to preferred tax rates and land subsidization costs for industrial plants located in these zones. Project engineers should recognize these problems and expect somewhat higher environmental contamination in these zones. However, wherever and whenever contamination from these zones diffuses and flows out so as to affect other people with other land uses, such pollution should be abated.

B. Location of Industrial Plants for Environmental Protection

An industrial plant should be located in areas which tend to minimize its environmental effects. This is especially true of large plants and plants unsuitable for one reason or another for location in industrial zones. Proper location of an industrial plant will not eliminate necessarily the need for final treatment for environmental protection but it will lessen the degree of treatment needed. A plant producing a large quantity of highly contaminated wastewater should be located:

1. on a watercourse having a maximum dilutent waste-carrying capacity;

2. in an area where the wastewater can be reused preferably with a minimum of treatment for agricultural or industrial purposes. The resulting wastewater discharge to the watercourse, if any, should not interfere with any beneficial use of the watercourse;

3. Within a municipality which is able to accept the plant wastes in a properly designed and operated sewage treatment plant.

A plant producing a large volume of air contaminants should be located (from an environmental standpoint) at a high elevation, in an area not subject to air inversions, and where the prevailing winds are towards relatively unpopulated and/or unused land areas.

A plant producing large volumes of solid wastes should be located:

1. on a large enough plot of land so as to be able to landfill or otherwise dispose of its own wastes on its own land;

2. in an area near to a suitable disposal site; and

3. in an area which is convenient for public or private contractors to collect and haul the solid wastes for final disposal.

Solid wastes from the plant should never be allowed to accumulate at the plant site because they tend to:

1. decompose, yielding odors; and

2. disperse by wind action and become unsightly and more difficult to collect fully.

C. General Problems Involved in Enforcement for Environmental Protection

Often the cost of any type of pollution control is relatively small and can be absorbed in production costs or offset by governmental subsidization. However, the costs uually are reflected in the final product costs which may make an industry's product somewhat less competitive with that of similar industries in other countries. Political pressure will be brought upon the government to relax environmental control requirements to eliminate the gap in production costs in order to increase competitiveness. It is important for a project manager to recognize this and to plan for political intervention for this purpose. It is recommended that the project manager stand firm against this political pressure to make certain that the environment is not sacrificed unnecessarily and excessively in the name of competitiveness.

On the other hand, government may excert pressure on the industry to effect some unnecessary or excessive environmental controls. Efforts should be made to come to an agreement with government as to the precise environmental controls and effluent levels to be maintained by industry to protect the environmental quality from deteriorating beyond the level necessary to support its best usage. The objective here should be to provide ample measures but not excessive to protect environmental quality.

D. Relation of Local to National to World Politics for Environmental Protection

In Chapter II the viewpoints of the various levels of government relative to pollution control were described. It should be evident to the project manager that each level of government views pollution control from a different vantage point. Therefore, it must be expected that different types and directions of political pressure will be placed upon industry. For example, usually local government urgently desires and needs industrial production but, at the same time, is most adamant about living with its pollution. National governments may also wish for the industrial production at that site but to a lesser degree (because of the varieties of choices for industrial sites, all within its governmental jurisdiction) and may also be less concerned about local pollution since it is further removed from the problem. However, it may be forced to be more concerned and more demanding when it reflects the influence being brought to bear upon it by international (worldwide) agencies of government. Project engineers should ascertain the position of each government and make certain that the plant's abatement measures conform to the most limiting constraints placed upon it by any of the governmental agencies involved.

VII. ENVIRONMENTAL CONTROL -- SOCIOLOGICAL ASPECTS

Introduction to Philosophy of Survival by Environmental Protection

A town, a country, the world depend on a clean, desirable environment for their survival. All three communities must continue to grow in order to provide the products and income necessary to support more people, or even the same number of people in more modern ways. The decision faced by towns, countries, or the world is whether each will expend the money and effort to provide environmental control and protection along with the increased production. This question can easily be resolved -- at least in theory -- when alternatives are examined. If it is decided to prosper in growth at the expense of the environment, providing only token or no environmental controls, a temporary period of illusionary wealth will be experienced. Companies will make more money, workers will get more money and in turn will buy more goods and services, thus stimulating a short-term buoyant economy. But, as environmental contamination increases, these same people will suffer from both mental and physical diseases at the worst and move away from the pollution at the best. In either case property values will decline, slum areas will develop, industrial product demand will diminish rapidly, less money will be made by plants and workers will receive less compensation and in turn will purchase fewer products and services. The town, country, or the world then wouldbegin a spiral towards out-of-control pollution problems.

The alternative, that of protecting the environment with every increase in industrial production, would cost money. It would result in either an increase in product cost or a decrease in industrial profit, or both. If industrial profits decrease somewhat, it would be offset largely by increased sales in an expanding market. Thus gross and net industrial profits should increase in the long run.

A. Planning Land Utilization to Protect the Environment

Land are must be shared for life's major purposes: household residences, schools, commercial stores, religious services, parks and recreation, municipal and other governmental buildings, and industrial plants. The exact proportion which should be delegated to each of these uses is still debated among planners. The criteria for land area depend upon the philosophy, needs and special interests of the local citizenry and thus necessitate variation in requirements from one area to the next. But the important fact to be remembered by project managers is that a definite plan for shared land usages should be made prior to acceptance of any new industrial plant. Land area for industrial plants should include appropriate allocations for liquid and solid waste disposal as well as to allow for sufficient air space overlying the land area to assimilate the air contaminants from industrial plants. The basic principle which project managers should adhere to is that land area should be used in such a manner so as to cause no adverse environmental consequences on any other land area. Nor should that land area be so great that the allocation or use of other proper land areas is either elminated or totally reduced to a level less than desirable for the community.

B. Planning Industrial Type and Location as it Relates to Local Environment

There are two main considerations for project managers as related to industry in municipal areas: the type of production and its location within the community. Type of production should depend upon the type of labor market available, needs and desires of community and surrounding area, and the quantity, quality, and uses of environmental resources such as receiving streams. For example, a community with little or no receiving water should discourage plants producing pulp and paper, steel, or textile finishing even though labor and needs of the local people are favorable for these plants.

Even in the most developed countries it is recommended that all industries locate in specifically zoned areas in which all plants operate. These industrial zones or estates do not have to be far from the municipality but they should be located properly so that prevailing winds and waters lead wastes away from high concentrations of people and be con-

venient to raw materials for production and product distribution by good transportation systems. Plants operating in the industrial zones should be as compatible as possible. In fact, it would be extremely desirable for each plant to be able to utilize the wastes from another for its production and in this way minimize environmental quality control costs. There are both advantages and disadvantages to the location of all industrial plants in these estates. Some of these are listed below to acquaint the project manager with both sides. Should the disadvantages of industrial zones outweigh the advantages, industrial plants should be dispersed throughout the community rather than in zones in one area. In other words, industrial zoning, although more desirable if designed and operated properly, is not always better for every community.

1. Advantages

a. A concentrated development of factories enhances the control of environmental contamination. This presumes that there exists adequate, enforceable legal means for restraining factories from polluting the air, water or land. This presumes also that it is economically feasible for each factory to continue in production after providing efficient pollution control devices and systems. If these presumptions are confirmed, then it will be easier to supervise or administer all of the factories located in close proximity to each other.

b. Proper types of industries can be selected on a prearranged and preplanned scheme in order to minimize the overall effects of pollution. For example, a plant producing an acid waste can be located near a factory producing a basic waste -- resulting in a neutralized liquid wastewater requiring no costly adjustment.

c. Industries can be selected to complement each other as far as production is concerned. For example, the wastes of one plant can serve as the raw material for the next. In that way normal waste treatment costs can be minimized and raw material transportation costs can also be minimized. An example is that of a slaughterhouse producing blood and hides of animals as by-products for disposal or shipment to another factory. An adjacent tannery could utilize the hides in making leather while another adjacent fertilizer manufacturer or plywood producer could utilize the blood. Not only a saving in transportation cost but also in product preparation and preservation -- such as salting of hides -- would be possible. In turn, a glue manufacturing factory

could be located next to the tannery to receive and render the fleshings into both grease and animal glue. A soap manufacturer or the already mentioned fertilizer manufacturer would be likely customers for the grease.

Similar cases could be made for other complementary raw material-dependent industries, such as a sulfuric acid chemical manufacturer locating next to the steel mill producing a waste $FeSO_4$ pickling liquor.

d. By locating all factories in specially plannd and zoned industrial estates, potential environmental contaminations would be removed from residential and recreational areas of the community.

2. Disadvantages

a. If adequate, enforceable laws do not exist or if the economic pinch of pollution control is too great, one factory might pollute a nearby industrial neighbor and the entire estate may become an "environmental eyesore" to the community. More dispersions of wastes may have been preferable under those conditions.

b. While industrial wastes and by-product uses matched, it may be much more difficult to interest each complementary plant in locating in a specific estate because of other reasons, such as markets for products at the time.

c. Even if complementary industries can be obtained for given estates, the quantitites of wastes produced by some may not match the raw material needs of another plant. Or the wastes from some plants -- at their current optimum production level -- may not be enough to neutralize the wastes from others at their production level.

d. Raw materials for some factories in an estate may be less expensive from some other outside source rather than from an adjacent plant within the estate. For example, sulfur may be less expensive at the time from natural gas or petroleum refinery sour gas than from steel mill pickling liquors or pyrites slag from mine operations. In addition, these prices and marekts may change from month to month even after a rather firm, irrevocable decision has been made on specific industrial type and location for the estate.

VIII. ENVIRONMENTAL CONTROL -- RANGES OF ACCEPTABLE ENVIRONMENTAL QUALITY LEVELS

A. Air

	1. Normal Levels Uncontaminated Air	2. Health Hazard to Humans
CO	.03 ppm	50 ppm (90 min.)
		10 ppm (8 hrs.)
NO_2	4 ppb	.06 ppm (Mean 24 Hr.)
NO	2 ppb	
HC + CH_4	1 - 1.5 ppm	>500 ppm (aliphatic) (alicyclic)
Other HC	0.1 ppm each	>25 ppm (aromatic)
		>.06 ppm (HCHO)
		>.25 ppm (acrolein)
		>50 ppm (Acetaldehyde)
SO_2	<.002 ppm	>.04 ppm
O_3	.01 - .05 ppm	0.3 ppm
Particulates	10 - 60 $\mu g/m^3$	>80 - 100 g/m^3

References: Pollution Control Technology, Staff of Research and Education Association, 342 Madison Ave., New York, N.Y. 10017. 1973

3. Reasonable Industrial Effluent Levels of Air Contaminants

Certain industrial operations such as power plants, cement production, and incinerators which are known to be large contributors to air contamination, regardless of their location, should be required to control their gaseous and particulate emissions to some certain level. That level can be ascertained on a plant-by-plant, country-by-country basis, but minimum degrees of emissions should be attainable by all of these plants in any country. Their allowable emission can be expressed in either a quantity of contaminant per unit of production or on an exhaust gas basis.

B. Water

1. Quality of Uncontaminated Water

Nearly all natural waters are contaminated in some form or another. Natural waters when compared to a control such as pure or distilled water are substantially contaminated. Certain amounts of contaminants, for example, calcium, magnesium and iron, are absolutely essential to man as well as to aquatic life to function. Pure or distilled water does not contain any of these essential nutrients required by any form of life.

From the moment water vapor condenses to form rain, the contamination process begins. Water accumulates substances in solution and in suspension from the air as it falls towards the earth. Later changes in character as a result of chemical and biological processes, as well as human activities, occur as it moves over, into and through the land on its way to the sea.

A typical sanitary analysis of an uncontaminated river water may be: (For reference see Water (3), p. 100)

pH	6.8
Dissolved oxygen	9.0 ppm
Temperature	13°C
Color	5 ppm
Turbidity	5 ppm
BOD (5 day @ 20°C)	1.2 ppm
Hardness	225 ppm as $CaCO_3$
Total solids	500 ppm
Chloride	10 ppm as Cl

Caution should be exercised when categorizing natural waters as contaminated or uncontaminated. The characteristics of natural waters vary widely with location and other influencing factors such as climatic conditions, topography and geological formations.

Some "typical" chemical analyses, as presented in Table 8, provide the reader with some common chemical components on the basis of the type of natural water.

Table 8

"Typical" Water Analysis (After Rand [1])

Chemical Component	Expressed as	NATURAL WATER TYPES				
		Rain	Surface Soft	Ground Soft	Surface Hard	Ground Hard
Calcium	$CaCO_3$ equiv., mg/l	16	30	29	80	142
Magnesium	$CaCO_3$, mg/l	3	16	32	40	59
Sodium and Potassium	Na, mg/l	6	9	26	19	20
Bicarbonate	$CaCO_3$, mg/l	12	42	60	106	143
Chloride	Cl, mg/l	5	7	9	23	23
Sulfate	SO_4, mg/l	10	12	17	38	59
Nitrate	N, mg/l	0.1	1.5	—	0.4	0.06
Iron	Fe, mg/l	0.0	1.1	1.8	0.0	0.18
Silica	SiO_2, mg/l	0	30	41	18	12
Carbon Dioxide	$CaCO_3$, mg/l	4	4	59	4	14
pH	—	6.8	6.9	6.6	7.8	7.4

2. Health Levels of Contamination in Receiving Waters

The National Academy of Sciences and the National Academy of Engineering published "Water Quality Criteria - 1972" at the request of the Environmental Protection Agency, in March 1973. Table 9 summarizes the findings on maximum allowable concentrations of various

components in natural waters to be used for drinking water with the defined treatment process (coagulation, sedimentation, filtration and disinfection) to produce a safe, clear, potable, aesthetically pleasing water supply. In developing countries health levels of contaminated waters may be somewhat different than in the United States because of adaptation or special conditions, but the US data can serve as valuable guidelines for all peoples.

Table 9

Table of Criteria for Public Water Supplies
(National Academy of Sciences -- Water Quality Criteria -- 1972)

Constituent or characteristic	Permissible Criteria	See Page
Physical -		
Color (color units)	75*	63
Odor	Narrative+	74
Temperature*	Narrative+	89
Turbidity	Narrative+	90
Microbiological		
Coliform organisms	20,000/100 ml	58
Fecal Coliforms	2,000/100 ml	58
Inorganic chemicals	(mg/1)	
Alkalinity	Narrative+	
Ammonia	0.5 (as N)	55
Arsenic*	0.1	56
Barium*	1.0	59
Boron*	1.0	59
Cadmium*	0.01	60
Chloride*	250.0	61
Chromium*, Hexavalent	0.05	62
Copper*	1.0	64
Dissolved oxygen	Narrative+	65

Table 9 (continued)

Constituent or characteristic	Permissible Criteria	See Page
Inorganic Chemicals (cont.)		
Fluoride*	Narrative+	66
Hardness*	Narrative+	68
Iron (filterable)	0.3	69
Lead*	0.05	70
Manganese* (filterable)	0.05	71
Mercury	0.002	72
Nitrates*	10 (as N)	73
Nitrite*	1.0 (as N)	73
pH (range)	5.0 - 9.0	80
Phosphorus*	Narrative+	81
Selenium*	0.01	86
Silver*	Narrative+	87
Sulfate*	250.0	89
Total Dissolved Solids* (filterable residue)	Narrative+	90
Uranyl ion*	Narrative+	91
Zinc*	5.0	93
Organic Chemicals		
Carbon chloroform extract* (CCE)	0.30	75
Cyanide*	0.20	65
Methylene blue active substances*	0.5	67
Oil and grease*	Virtually absent+	74
Pesticides		
Aldrin*	0.001	77

Table 9 (continued)

Constituent or characteristic	Permissible Criteria	See Page
Organic Chemicals (cont.)		
Chlorodane	0.003	77
DDT*	0.05	77
Dieldrin*	0.001	77
Endrin*	0.0005	77
Heptachlor*	0.0001	77
Heptachlor expoxide*	0.0001	77
Lindane	0.005	77
Methoxychlor	1.0	77
Organic phosphates plus carbamates*	0.1	79
Toxaphene*	0.005	77
Herbicides		
2, 4-D plus 2, 4, 5-T, plus 2, 4, 5-TP*	0.02	79
Phenols	0.001	80
Radioactivity	(pc/l)	
Gross beta*	1,000	85
Radium - 226*	3	85
Strontium - 90*	10	85

*The defined treatment process has little effect on this constituent. (Defined treatment process - coagulation, sedimentation, filtration and disinfection)

+See narrative on page shown for a discussion of the recommended allowable levels.

3. Reasonable Industrial Effluent Levels of Water Contaminants

It is not the intent of this general manual to quantify acceptable levels of industrial effluents for each specific industrial product. For this information, the reader is referred to the specific industrial manual for the particular industry of interest. There are, however, some basic concepts applicable to all types of industries regarding the effect of wastes and pollution loads on receiving bodies of water.

Because of the nature of each type of industrial process, a different quantity and characteristic waste will be produced. The degree of contamination caused by each industry will be a function not only of the nature of the waste but also of the character and intended use of the receiving body of water. As defined early in this Manual, water pollution is simply the addition to water of contaminant(s) in such quantities as to render the water unsiutable for its classified and established best use.

Presently, there exist in the United States two types of water quality standards for the use of controlling water pollution. The first is referred to as "stream standard." It involves a standard amount of receiving stream dilution for a given unit volume of waste discharge. This stream standard is largely outmoded due to the fact that similar volumes of wastes contain vastly different amounts and types of pollutants. Another "stream standard" more prevalently applied utilizes limiting values for various specific substances when mixed with the receiving water. The current philosophy is that one set of water quality standards based on the most beneficial use of the receiving water should be established. The National Academy of Sciences, in establishing Water Quality Criteria 1972 at the request of the Environmental Protection Agency, has developed the following six best use classifications:

a. recreation and aesthetics;
b. public water supplies;
c. freshwater aquatic life and wildlife;
d. marine aquatic life and wildlife;
e. agricultural uses of water; and
f. industrial water supplies.

For detailed descriptions, classifications and criteria the reader is urged to consult the above reference.

The second type of water quality standard for controlling water pollution deals with the quality and quan-

tity of contaminant wastes being discharged from any source and is called an "effluent standard." Because of the varying nature of the many industrial processes, no single effluent standard is practicable. The Environmental Protection Agency is currently developing effluent guideline standards, the date of which will appear in the appropriate succeeding specific manual on each industry.

A law (PL-92-500) published on September 28, 1972, in the US Congressional Record deals specifically with effluent standards. This Act calls for effluent limitation for point sources (other than publicly-owned treatment works). These shall require the best practicable control technology currently available (as defined by the Administrator). Effluent standards do have inherent disadvantages. Firstly, full use of assimilative capacity of a stream is not necessarily used. Secondly, the system involves very detailed knowledge of each polluting industry. Finally, the system does not necessarily even protect the water resource.

It is, therefore, believed that effluent standards must be used in conjunction with stream standards to fully utilize and protect the water quality itself. It is suggested, then, that the project manager makes certain that:

a. the industrial plant utilizes the best practical treatment in producing a residual of contaminants for discharge into the receiving water, and

b. the receiving stream possesses suitable quality after the industrial waste addition to maintain its best use.

C. Land

1. Quality of Uncontaminated Land

There exists no actual quantitative values for uncontaminated land. There are only generalizations for land specifications for various uses. In this Manual the concern has been primarily with the use of land for the disposal of solid wastes from industry. Such land should have the following characteristics in an uncontaminated state:

a. relatively close to industrial plant and reached by wide roads which preferably only pass through industrial areas;

b. soil is of the sandy or silty loam type with only small (less than six inches in diameter) rocks;

c. ample depth to bedrock;

d. unfractured bedrock which would allow leachate to escape under the filled area;

e. ample depth to groundwater;

f. uncontaminated groundwater flowing under the filled land in a direction away from habitation and high water use such as drinking, recreation, or fishing;

g. no detectable odors from decomposing matter exist;

h. no leachate from the land exists regardless of the quality; and

i. no open burning and firebox burning only after a permit which validates compliance with air quality standards.

Although experts do not agree on the specific definition of an uncontaminated land suitable for use as a landfill site for solid wastes, some parameters of both the land and the industrial solid waste to be disposed of on it have been suggested for consideration. They include the following:

a. infiltration potential;
b. bottom leakage potential;
c. bottom soil filtration capacity;
d. adsorptive capacity within the soil;
e. organic content of the groundwater;
f. buffering capacity of groundwater;
g. travel distance (leachate to the sea);
h. groundwater velocity;
i. prevailing wind direction; and
j. population near site.

All of the above parameters should be evaluated by the project manager and either an objective or subjective measure of the land's status as related to use for solid waste should be made.

2. Health Hazards of Contamination On and From Land Sites

The health hazards which arise from solid wastes disposal on land sites are those originating from the air and water emanating from the sites. These hazards would be the same as those given in Parts A and B of this section.

3. Reasonable Industrial Effluent Levels of Solid Wastes

No system of guidelines has been developed to date which allows one to predict a reasonable quantity and quality of solid wastes arising from specific industries.

IX. REFERENCES

A. Selected Texts in Air, Water and Land Environmental Protection

Air

1 - AIR POLLUTION Perkins, H.C., McGraw Hill Co. 1974 New York City

2 - AIR POLLUTION Edited by Arthur C. Stern, Academic Press, 2 Volumes 1962 New York City

3 - Quantitative Analysis of Gaseous Pollutants, Ruch, W.E., Ann Arbor - Humphrey Science Publishers, Ann Arbor, Michigan U.S.A. 1970

4 - Determination of Air Quality. Proceedings of Symposium 1972, Plenum Press, New York City

5 - Measurements of Air Pollutants, M. Katz, World Health Organization 1969, Geneva, Switzerland

Water

1 - WASTEWATER ENGINEERING - Collections, Treatment and Disposal, Metcalf and Eddy, Inc., McGraw-Hill, New York, Y, 1972. p. 89

2 - Water Pollution Control, Lund, H.F., Editor, Programs and Systems by E. G. Paulson, INDUSTRIAL POLLUTION CONTROL HANDBOOK, McGraw-Hill, New York, N.Y., 1971. p. 6-1

3 - STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 13th Edition, 1971

4 - Instrumental Analysis for Water Pollution Control, Mancy, K.H., Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, 1971

5 - Liquid Wastes of Industry, N.L. Nemerow, Addison Wesley Co., 1971, Reading, Massachusetts

Land

1 - Municipal Refuse Disposal, American Public Works Assoc., 3rd Edition 1970. Public Service Administration, 1313 E. 60th Street, Chicago, Illinois 60637

2 - Sanitary Landfill. Lexington Books, National Center for Resource Recovery, Inc. 1974. Lexington, Massachusetts

3 - Sanitary Landfill - Design and Operation. Brunner, D.R. and Keller, D.J. U.S. Environmental Protection Agency, SW - 65 TS, Washington, D.C. 1972

4 - Solid Waste Management. Haggerty, D.J., Pavoni, J.L., Heer, J.E. Van Nostrand Reinhold Co. 1973. New York, N.Y.

B. Selected Reference Papers and Documents for Environmental Protection

Ohio River Valley Water Sanitation Commission: PLANNING AND MAKING INDUSTRIAL WASTE SURVEYS, Cincinnati, Ohio 1952.

Black, H.H.: Procedures for Sampling and Measuring Industrial Wastes, Sewage & Industrial Wastes, Vol. 24, p. 45, 1952

Methods for Chemical Analysis of Water and Wastes, Environmental Protection Agency, Cincinnati, Ohio 1971

American Society of Testing Materials (ASTM) Part 23, Water, Atmospheric Analysis. 1970

National Academy of Sciences and National Academy of Engineerig, Water Quality Criteria 1972. Prepared at the request of the EPA, Washington, D.C. 1972.

C. Selection of Technically-qualified Expert Assistance for Environmental Protection

It may not be sufficient for a project engineer or manager to read this manual only. On the other hand it is very important to read and understand the contents of the manual in order to be able to communicate better with an 'expert' in the environmental area of particular concern. An expert should be called upon to assist you in planning the proper environmental control system and in evaluating whether the owner and/or contractor is providing that or another comparable abatement system. A technically qualified expert can usually be obtained by requesting such a person from one of the assisting agencies listed in part D of this section. Often the assisting agency itself is able to provide advice or review of the proposed project as it relates to environmental control.

D. Selected Agencies Which Possess Special Knowledge and Competence in Environmental Protection

The following agencies can be contacted for assistance in matters relating to information concerning maintaining optimum environmental quality as a result of industrial production:

CIER - Center for International Environment Information
c/o UNA-USA
345 East 46th Street
New York, NY 10017, USA
Telephone: (212) 697-3232

EPA - Environmental Protection Agency
Waterside Mall Building
401 M Street, S.W.
Washington, DC 20460 USA
Telephone: (202) 755-2770

IAEA - International Atomic Energy Agency
Kaerntnerring 11
A-1010 Vienna 1, Austria
Telephone: Vienna 52-45-11
Cables: INATOM, Vienna

IAWPR - International Association for Water Pollution Research
c/o Institut fuer Hydrobiologie
Olbersweg 24
2 Hamburg-50, Federal Republic of Germany
Telephone: 04-11-39107

IBRD - International Bank for Reconstruction and Development
1818 H Street, N.W.
Washington, DC 20433, USA
Telephone: (202) 393-6360
Cables: INTBAFRAD, Washington

ICEL - International Council of Environmental Law
214 Adenauerallee
53 Bonn, Federal Republic of Germany

IIED - International Institute for Environment and Development
c/o Hunter
21 Smith Terrace
London, S.W. 34 DL, England
Telephone: 01-352-3289

ILO - International Labour Organisation
International Labour Office
154 rue de Lausanne
Geneva, Switzerland
Telephone: 32-62-00
Cables: INTERLAB, Geneva

IMCO - Inter-Governmental Maritime Consultative Organization
101-104 Piccadilly
London, W1V OAE, England
Telephone: 01-499-9040
Cables: INMARCOR, London

IOC - Intergovernmental Oceanographic Commission
7, Place de Fontenoy
75700 Paris, France
Telephone: 566-57-57

IUCN - International Union for the Conservation of Nature and Natural Resources
110 Morges, Switzerland
Telephone: (021) 71-44-01

OECD - Organization for Economic Co-operation and Development
2, rue Andre Pascal
75116 Paris, France
Telephone: 524-82-00

PAHO - Pan American Health Organization
525-23rd Street, N.W.
Washington, DC 20037, USA
Telephone: (202) 223-4700
Cables: OFSANPAN, Washington

UNEP - United Nations Environment Programme
P. O. Box 30552
Nairobi, Kenya
Telephone: 33930
Cables: UNITERRA, Nairobi
(Includes: Environment Programme Information Centre, Global Environmental Monitoring System (GEMS), International Centre for Industry and the Environment, International Referral System for Sources of Environmental Information (IRS)

UNIDO - United Nations Industrial Development Organization
Lerchenfelderstrasse 1
A-1070 Vienna, Austria
Telephone: 4350-0
Cables: UNIDO, Vienna

USAID - United States Agency for International Development
Office of Science and Technology
Department of State
Washington, DC 20523
Telephone: (202) 632-2418

WHO - World Health Organization
1211 Geneva 27, Switzerland
Telephone: 34-60-61
Cables: UNISANTE, Geneva

WMO - World Meteorological Organization
41, avenue Giuseppe-Motta
Geneva, Switzerland
Telephone: 34-64-00
Cables: METEOMOND, Geneva

CONVERSION FACTORS

LENGTH

	cm	METER	km	in.	ft	mile
1 centimeter =	1	10^{-2}	10^{-5}	0.3937	3.281×10^{-2}	$6.214 \times 1-^{-6}$
1 METER =	100	1	10^{-3}	39.37	3.281	6.214×10^{-4}
1 kilometer =	10^{5}	1000	1	3.937×10^{4}	3281	0.6214
1 inch =	2.540	2.540×10^{-2}	2.540×10^{-5}	1	8.333×10^{-2}	1.578×10^{-5}
1 foot =	30.48	0.3048	3.048×10^{-4}	12	1	1.894×10^{-4}
1 mile =	1.609×10^{5}	1609	1.609	6.336×10^{4}	5280	1

1 angstrom = 10^{-10} meter

1 x unit = 10^{-13} meter

1 nautical mile = 1852 meters = 1.151 miles = 6076 ft

1 light-year = 9.4600×10^{12} km

1 parsec = 3.084×10^{13}km

1 fathom = 6 ft

1 yard = 3 ft

1 rod = 16.5 ft

1 mil - 10^{-3} in.

AREA

	$METER^2$	cm^2	ft^2	$in.^2$	circ mil
1 SQUARE METER =	1	10^4	10.76	1550	1.974×10^9
1 square centimeter =	10^{-4}	1	1.076×10^{-3}	0.1550	1.974×10^5
1 square foot =	9.290×10^2	929.0	1	144	1.833×10^8
1 square inch =	6.452×10^{-4}	6.452	6.944×10^{-3}	1	1.273×10^6
1 circular mil =	5.067×10^{-10}	5.067×10^{-6}	5.454×10^{-9}	7.854×10^{-7}	1

1 square mile = 2.788×10^8 ft^2 = 640 acres

1 barn = 10^{-28} $meter^2$

1 acre = 43,600 ft^2

VOLUME

	$METER^3$	cm^3	li	ft^3	$in.^3$
1 CUBIC METER =	1	10^6	1000	35.31	6.102×10^4
1 cubic centimeter =	10^{-6}	1	1.000×10^{-3}	3.531×10^{-5}	6.102×10^{-2}
1 liter =	1.000×10^{-3}	1000	1	3.531×10^{-2}	61.02
1 cubic foot =	2.832×10^{-2}	2.832×10^4	18.32	1	1728
1 cubic inch =	1.639×10^{-5}	16.39	1.639×10^{-2}	5.787×10^{-4}	1

1 U.S. fluid gallon = 4 U.S. fluid quarts = 8 U.S. pints = 128 U.S. fluid ounces = 231 $in.^3$

1 British imperial gallon = 277.4 $in.^3$

1 liter = the volume of 1 kg of water at its maximum density = 1000.028 cm^3

MASS

Quantities in the shaded areas are not mass units but are often used as such. When we write, for example, 1 kg "=" 2.205 lb this means that a kilogram is a mass that weighs 2.205 pounds under standard conditions of gravity ($g = 9.80665$ meters/sec^2).

	gm	KG	slug	amu	oz	lb	ton
1 gram =	1	0.001	6.852×10^{-5}	6.024×10^{23}	3.527×10^{-2}	2.205×10^{-3}	1.102×10^{-6}
1 KILOGRAM =	1000	1	6.852×10^{-2}	6.024×10^{26}	35.27	2.205	1.102×10^{-3}
1 slug =	1.459×10^{4}	14.59	1	8.789×10^{27}	514.8	32.17	1.609×10^{-2}
1 amu =	1.660×10^{-24}	1.660×10^{-27}	1.137×10^{-28}	1	5.855×10^{-26}	3.660×10^{-27}	1.829×10^{-30}
1 ounce =	28.35	2.835×10^{-2}	1.943×10^{-3}	1.708×10^{25}	1	6.250×10^{-2}	3.125×10^{-5}
1 pound =	453.6	0.4536	3.108×10^{-2}	2.732×10^{26}	16	1	0.0005
1 ton =	9.072×10^{5}	907.2	62.16	5.465×10^{29}	3.2×10^{4}	2000	1

DENSITY

Quantities in the shaded areas are weight densities and, as such, are dimensionally different from mass densities. See note for mass table.

	slug/ft^3	KG/METER^3	gm/cm^3	lb/ft^3	lb/in.^{3}
1 slug per ft^3	1	515.4	0.5154	32.17	1.862 X 10^{-2}
1 KILOGRAM per METER^3	1.90 X 10^{-3}	1	0.001	6.243 X 10^{-2}	3.613 X 10^{-5}
1 gram per cm^3	1.940	1000	1	62.43	3.613 X 10^{-2}
1 pound per ft^3	3.108 X 10^{-2}	16.02	1.602 10^{-2}	1	5.787 X10^{-4}
1 pound per in^3	53.71	2.768 X 10^4	27.68	1728	1

TIME

	yr	day	hr	min	SEC
1 year=	1	365.2	8.766×10^{3}	5.259×10^{5}	3.156×10^{7}
1 day=	2.738×10^{-3}	1	24	1440	8.640×10^{4}
1 hour=	1.141×10^{-4}	4.167×10^{-2}	1	60	3600
1 minute=	1.901×10^{-6}	6.944×10^{-4}	1.667×10^{-2}	1	60
1 second=	3.169×10^{-8}	1.157×10^{-5}	2.778×10^{-4}	1.667×10^{-2}	1

SPEED

	ft/sec	km/hr	METER/ SEC	mile/hr	cm/ SEC	knot
1 foot per second=	1	1.097	0.3048	0.6818	30.48	0.5925
1 kilometer per hour=	0.9113	1	0.2778	0.6214	27.78	0.5400
1 meter per second=	3.281	3.6	1	2.237	100	1.944
1 mile per hour=	1.467	1.609	0.4470	1	44.70	0.8689
1 centimeter second=	3.281×10^{-2}	3.6×10^{-2}	0.01	2.237×10^{-2}	1	1.944×10^{2}
1 knot=	1.688	1.852	0.5144	1.151	51.44	1

FORCE

Quantities in the shaded areas are not force units but are often used as such, especially in chemistry. For instance, if we write 1 gram-force "=" 980.7 dyncs, we mean that a gram-mass experiences a force of 980.7 dynes under standard conditions of gravity (g = 9.80665 meters/sec^2).

	.dyne	NT	lb	pdl	gf	kgf
1 dyne =	1	10^{-5}	2.248×10^{-6}	7.233×10^{-5}	10.20×10^{-3}	1.020×10^{-6}
1 newton =	10^{5}	1	0.2248	7.233	102.0	0.1020
1 pound =	4.448×10^{5}	4.448	1	32.17	453.6	0.4536
1 poundal =	1.383×10^{4}	0.1383	3.108×10^{-2}	1	14.10	1.410×10^{-2}
1 gram-force =	980.7	9.807×10^{-3}	2.205×10^{-3}	7.093×10^{-2}	1	0.001
1 kilogram-force =	9.807×10^{5}	9.807	2.205	70.93	1000	1

1 kgf = 9.807 nt 1 lb = 32.17 pdl

PRESSURE

	atm	dyne/cm^2	inch of water	cm-Hg	NT METER^2	lb/in.^{2}	lb/ft^2
1 atmosphere =	1	1.013×10^{6}	406.8	76	1.013×10^{3}	14.70	2116
1 dyne per cm^2 =	9.869×10^{-7}	1	4.015×10^{-4}	7.501×10^{-5}	0.1	1.450×10^{-5}	2.089×10^{-3}
1 inch of water* at 4°C =	2.458×10^{-3}	2491	1	0.1868	249.1	3.613×10^{-2}	5.202
1 centimeter of mercury* at 0°C =	1.316×10^{-2}	1.333×10^{4}	5.353	1	1333	0.1934	27.85
1 NETWON per METER^2 =	9.869×10^{-6}	10	4.015×10^{-3}	7.501×10^{-4}	1	1.450×10^{-4}	2.089×10^{-2}
1 pound per in.^{2} =	6.805×10^{-2}	6.895×10^{4}	27.68	5.171	6.895×10^{3}	1	144
1 pound per ft^2 =	4.725×10^{-4}	478.8	0.1922	3.591×10^{-2}	47.88	6.944×10^{-3}	1

*Where the acceleration of gravity has the standard value 9.80665 meters/se

1 bar = 10^6 dyne/cm^2 1 millibar = 10^3 dyne/cm^2

POWER

	Btu/hr	ft-lb/ sec	hp	cal/sec	kw	WATT
1 British thermal unit per hour =	1	0.2161	$3.929_4 \times 10^{-4}$	$7.000_2 \times 10^{-2}$	$2.930_4 \times 10^{-4}$	0.2930
1 foot pound per second	4.628	1	$1.818_3 \times 10^{-3}$	0.3239	$1.356_3 \times 10^{-3}$	1.356
1 horsepower =	2545	550	1	178.2	0.7457	745.7
1 calorie per second =	14.29	3.087	$5.613_3 \times 10^{-3}$	1	$4.186_3 \times 10^{-3}$	4.186
1 kilowatt =	3413	737.6	1.341	238.9	1	1000
1 WATT =	3.413	0.7376	$1.341_3 \times 10^{-3}$	0.2389	0.001	1

BEEF CATTLE WASTE MANAGEMENT ALTERNATIVES[a]

by

George J. Kriz, *et al*.

---

[a]North Carolina State University at Raleigh and the U.S. Department of Agriculture, Cooperating State University Station, Raleigh, N.C., March 1974, Circular 571.

CONTENTS

INTRODUCTION

ALTERNATIVE WASTE MANAGEMENT SYSTEMS

- System I: Paved Lot with Spreading in Solid Form
- System II: Paved Lot with Storage and Spreading in Solid Form
- System III: Paved Lot with Storage and Spreading in Liquid Form
- System IV: Paved Lot with Lagoon and Irrigation
- System V: Sheltered Dirt Lot with Spreading in Solid Form
- System VI: Dirt Lot with Limited Shelter with Spreading in Solid Form
- System VII: Dirt Lots (Cattle Rotated)
- System VIII: Pasture (Cattle Rotated)
- Other Alternatives
  - Recycling
  - Drying
  - Composting
  - Slotted Floors

STORM RUNOFF CONTROL

UTILIZATION AND LAND REQUIREMENTS

- Amount and Composition of Beef Cattle Manures
- Effects of Beef Cattle Manure on Soils and Crops
- Factors Affecting Rates of Application
- How To Determine the Amount To Apply
- Examples
  - Solid Form
  - Slurry Form
  - Lagoon Effluent
- Soil Management

ODOR CONTROL

PEST CONTROL

- Flies
- Birds, Rats and Mice
- Mosquitoes

ECONOMICS

- Comparison of Systems

APPENDIX

- Lagoon Design for 200 Beef Cattle

Table 1. Daily Production of Solid Manure from Different Size Herds of 1000-lb Beef Cattle

Table 2. Gallons of Storage Required for 1000-lb Beef Cattle by Days of Storage and Herd Size

Table 3. Storage Tank Capacity per Foot of Length

Table 4. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Table 5. Average Amount and Composition of Manure Produced by a 1000-lb Beef Animal

Table 6. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Table 7. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

Total 8. Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

Total 9. System I Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 10. System II Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 11. System II Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 12. System IV Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 13. System V Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 14. System VI Estimated Initial Investment and Annual Costs of Disposal for 500 Head of 1000-lb Cattle

Total 15. Ownership Cost Factors: Depreciation, Interest, Repairs, Taxes and Insurance, Rounded to Nearest Percent

Total 16. Estimated Initial Investment, Annual Costs and Labor Requirements for Six Alternative Waste Management Systems for a 500 Head 1000-lb Beef Cattle Operation

FIGURES

Figure 1. Typical Cross-section of a Retention Pond

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.

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.

Figure 4. Plan and Section View of a Lagoon.

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

Beef Cattle Waste

Management Alternatives

Beef production has become more complex, more specialized, and more restricted by certain environmental limitations. This bulletin is designed to help beef producers meet these problems in the most practical and economical way. The recommendations given herein are based upon the latest research information obtained by the Agricultural Experiment Station at North Carolina State University and other similar institutions, and on field experience and observation. Producers who follow the recommendations should be in compliance with the latest federal and state regulations concerning animal waste disposal known at the time of this writing.

A beef production unit should be envisioned as a total system. To achieve the systems concept, planning must begin with the idea to build or renovate and must be followed through until cattle are placed in the facilities. Because of the proximity of many feeding operations to industrial or residential areas, appearance is an important factor to be considered. The type of buildings, their upkeep, and landscaping are all important.

To avoid or overcome some of the problems confronting beef producers, a prospective producer or one who plans to renovate should consider the following suggestions.

- Locate the operation in the center of a large tract of land if possible.
- If the operation is on a small farm be sure sufficient land area is available for waste disposal.
- Do not locate the operation in a heavily populated area.
- Do not locate the operation near drainage ditches, streams, rivers or estuaries.

This bulletin is divided into six parts: alternative waste management systems, storm runoff control, utilization and land requirements, odor control, pest control and economics. The first section describes the various components of each system in each alternative. The section on storm runoff control gives the requirements for preventing runoff from lots from reaching surface waters. The section on utilization and land requirements

presents guidelines and examples of how much waste can be applied per acre. The sections on odor and pest control provide suggestions and methods for reducing odor and pest problems. The section on economics gives cost data and contains a partial budget sheet so that comparisons between the alternative waste management systems can easily be made. Appendix I gives the design details for a lagoon.

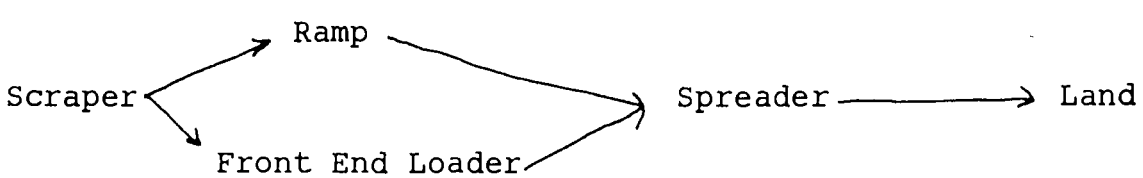
Alternative Waste Management Systems

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 reaching the surface waters of the state and violating 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 100 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

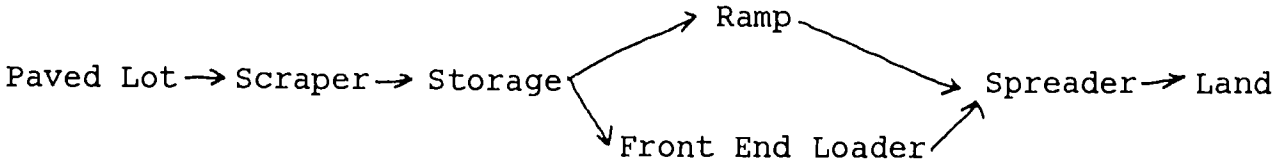
loads required to remove it daily. For 500-lb cattle, the quantity would be approximately one-half that shown in the table. When the waste handling is integrated into the planned production activities, associated problems are minimized with frequent handling. On the other hand, serious problems can arise and the chore becomes disillusioning when manure is allowed to accumulate. This problem is further aggravated as the numbers of animals increase.

Table 1. Daily Production of Solid Manure from Different Size Herds of 1000-lb Beef Cattle

No. of Cattle	Daily Production T	Daily Spreader Loads	
		108 bu spreader	180 bu spreader
10	0.3	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

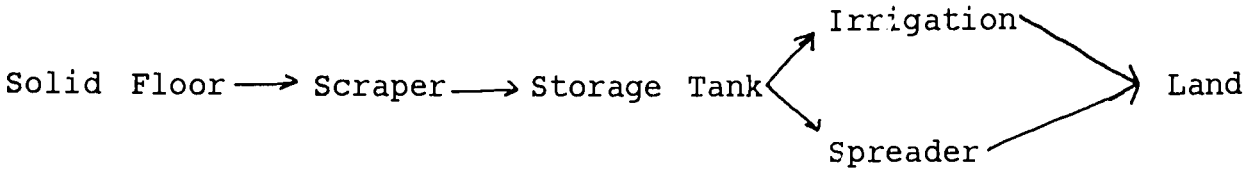
Field spreaders are available as tractor drawn or truck mounted units. Flail type tank spreaders will hold either liquids or solids and have either a side or rear discharge. A spreader with beaters should have a rear gate, preferably hydraulically operated, that can be opened and closed from the tractor 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.

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

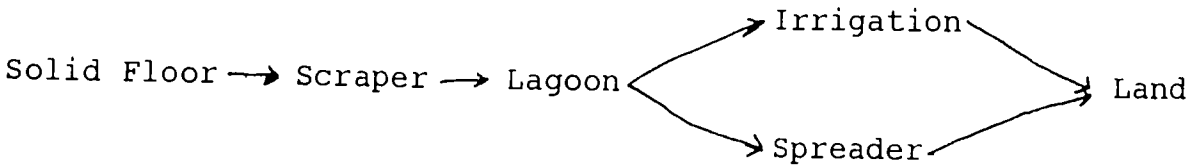
It is evident from Table 4 that the amount of water added to produce a pumpable slurry might be more than the original quantity of manure. For example, the addition of 11.25 gallons (gal) of water to 1 cu ft of fresh manure at 75% moisture raises the moisture content to 90% and changes the volume from 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.

When odor is a problem, the producer might elect to equip his spreader with a soil injector. This equipment placed 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 lagoons 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.

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	1,1125	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

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
w/ 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 used 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 especially 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 a vacuum pump might be used with small retention ponds, but its volume will limit its use.

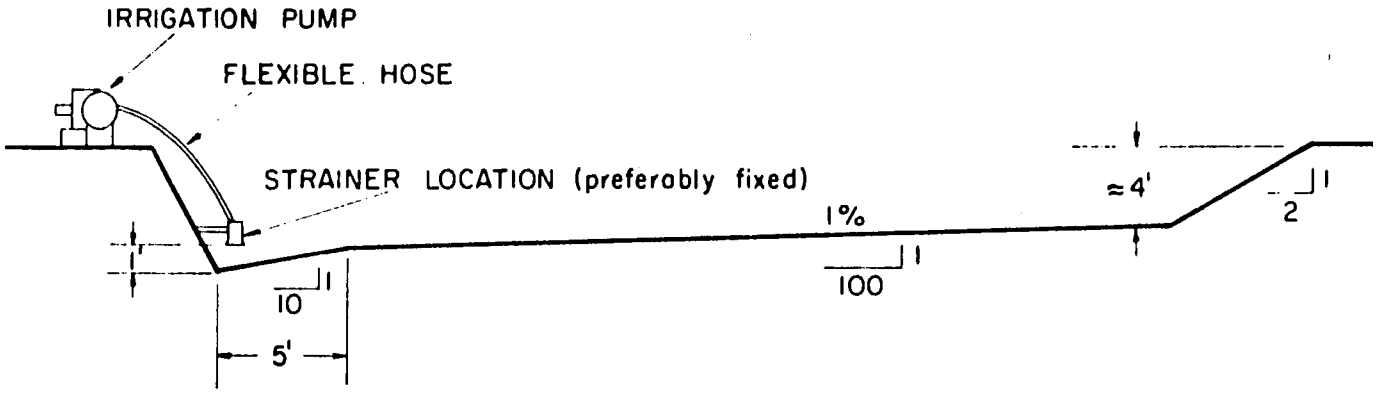


Figure 1. Typical Cross-section of a Retention Pond.

UTILIZATION AND LAND REQUIRMEENTS

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 area, the manure is often treated as an unwanted commodity to be disposed of by any means that are publicaly 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_xO). 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.

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 Fgures 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 fertili-

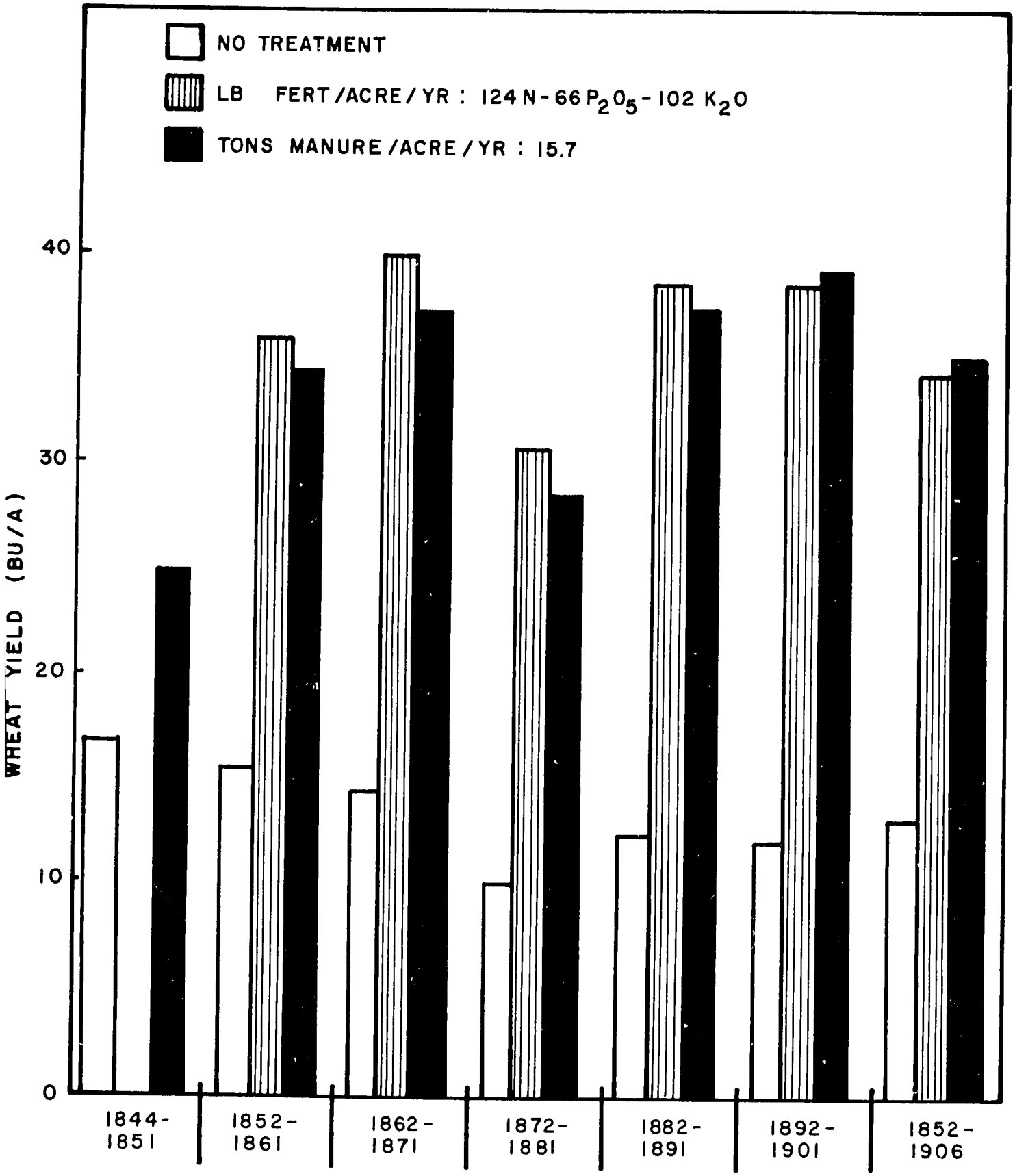


Figure 2. Effect of cattle manure on wheat yields on the oldest agricultural experiment station, at Rothamsted, England. The 10-year periods and the 53-year average (1852-1906) show that yields on the manured plots were about the same as those on the fertilized plots.

zers, 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.

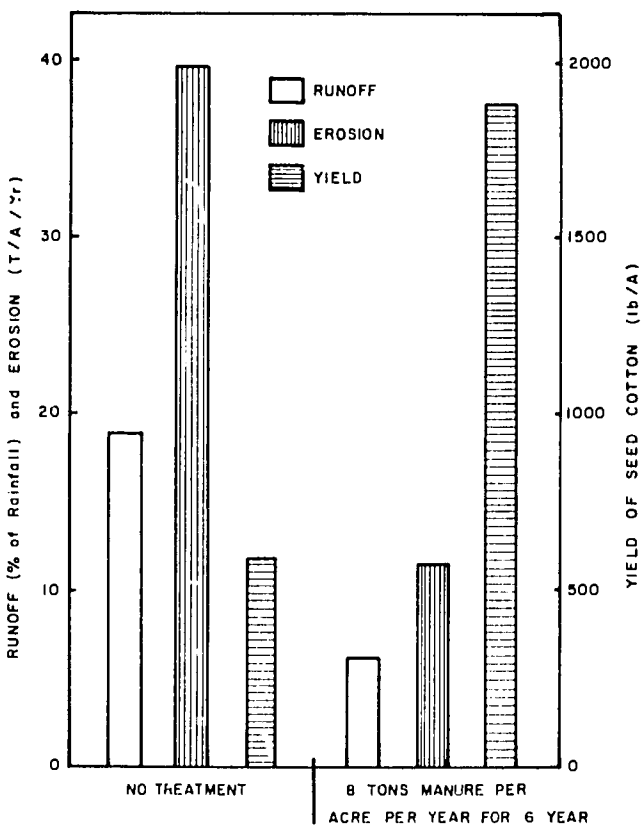


Figure 3. Effect of cattle manure on runoff, erosion and cotton yield at the Statesville Soil Erosion Experiment Station. (The yields are not comparable because the check plots were not fertilized. The good yield on the manured plot is important.)

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 alway 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 in-

soluble 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 amokunt 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 forages may cause tetany in animals. If the manure does not supply sufficient phosphorus, super-phosphate 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 of 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 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 in-

jury. 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 Divisionof 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 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 manure from 500 head of 1000-lb cattle:

- Rate of application.
- Total land area needed per year.

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, Whitestone, Wilkes
		High water table	Low	Medium to low	Lumbee, Raine, 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

- 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 is 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 x 356 days/yr) ÷ (200 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 ÷ 10T/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 x 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 x 69 ft x 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.

<u>Slurry Form</u>. 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 <u>Solid Form Example</u> 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) of 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 x 500 animals x 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 x 500 animals x 50 in./yr ÷ 12 in./ft).

NOTE! The local average amount of 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 x 15 in. ÷ 12 in./ft) is assumed to be added by the rain in excess of evaporation 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/l). 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 x 365 days/yr x 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 thanone 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 x 7.48 gal/cut 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 established 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 obtained by interpolating as follows:

$$\frac{180 \text{ lbN} - 100 \text{ lbN}}{200 \text{ lbN} - 100 \text{ lbN}}$$

15,000 gal/A - 7,500 gal/A

+ 7,500 gal/A = 13,500 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 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 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 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 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/l. Entering Table 7 with 800 mgN/l 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/l 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.

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	0.0041	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	30,0000	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 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 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 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 additng 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 (60-70 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 x 0.2 hrs)			2	2.5	5		
Total labor					$2,776		
Electricity for irrigation (680 kwh x 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 x 0.2 hr)			2	2.50	5		
Total labor					$2,388		
Electricity for irrigation (680 kwh x 2.5¢/kwh)					$ 17		
Total	$8,005				$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		
Irrigatin 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 x 0.2 hr)			320	2.50	800		
Total labor					$ 2,753		
Electricity for irrigation (680 kwh x 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[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		
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)							
Scrape			490	2.90	$1,421		
Clean shelter and spread[3]			490	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 x 50 hr)			200	2.50	500		
Total labor					$2,108		
Electricity							
(8100 kwh x 4¢/kwh)					$ 324		
Total	$16,745				$7,155		

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[1]	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[1]	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 yard)[5]	995	.12			120		
Irrigation system							
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 x 4 hr)			32	2.50	80		
Total labor					$1,173		
Electricity for irrigation (5680 kwh x 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 1/2 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 of 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 x 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	.13			192
Gate valves (2 - 4 in.)	120	.21			25
Labor (8 irrigations x 0.2 hr)			2	2.50	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 x 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 x 4 hr per irrigation)			16.0	1.85	30
Labor (4 irrigations x 7.2 hr per irrigation)			28.8	2.50	72
Electricity (8100 kwh x 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 x 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 x 1.0 hr/irrigation)			8.0	2.50	20
Electricity (5680 kwh x 4¢/kwh)					272
Total					$1,896

Permanent big gun 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. calss 160 w/fittings)	4,780	.13			615
Gate valves (11 - 2½ in.)	275	.21			58
Labor (8 irrigations x 2 hr/irrigation)			16	2.50	40
Electricity (2139 kwh x 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.

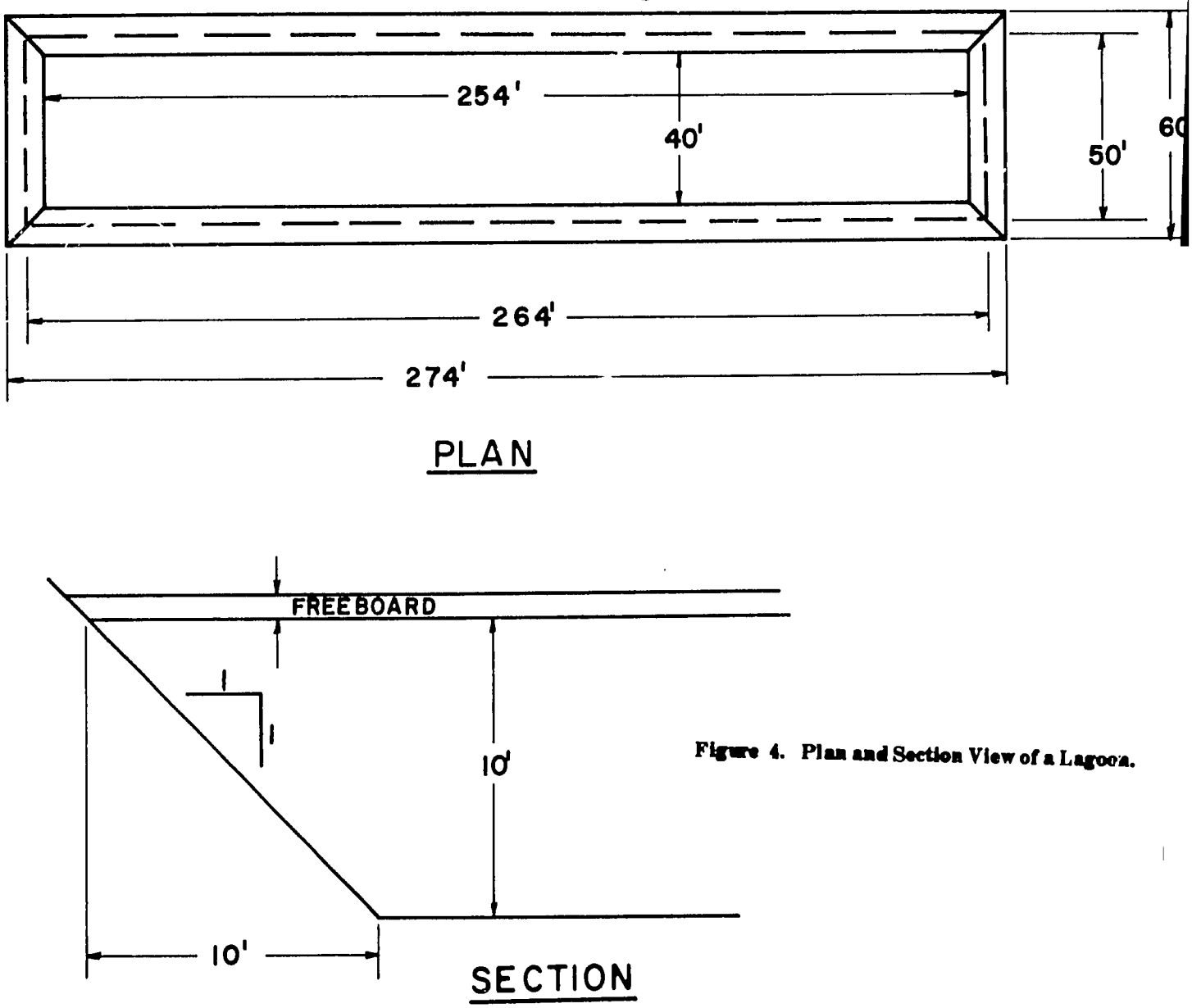


Figure 4. Plan and Section View of a Lagoon.

DAIRY WASTE MANAGEMENT ALTERNATIVES

by

George J. Kriz, *et al.*

CONTENTS

INTRODUCTION

ALTERNATIVE WASTE MANAGEMENT SYSTEMS

- System I: Direct Spreading in Solid Form
- System II: Storage and Spreading in Solid Form
- System III: Storage and Spreading in Liquid Form
- System IV: Lagoon and Irrigation
- System V: Flush, Storage and Irrigation
- System VI: Flush, Lagoon and Irrigation
- Other Alternatives
  - Drying
  - Refeeding
  - Composting

STORM RUNOFF CONTROL

PARLOR AND MILKHOUSE WASTE WATER

UTILIZATION AND LAND REQUIREMENTS

- Amount and Composition of Dairy Manures
- Effects of Dairy attle Manure on Soils and Crops
- Factors Affecting Rates of Applications
- How to Determine the Amount to Apply
- Examples
  - Solid Form
  - Slurry Form
  - Lagoon Effluent - Non-flush System
  - Lagoon Effluent - Flush System
- Soil Management

ODOR CONTROL

PEST CONTROL

ECONOMICS

- Comparison of Systems

APPENDIX

- Lagoon Design for 100 Cows

TABLES

Table 1 Daily Production of Solid Manure from Different Size Herds of 1400-lb Cows

Table 2 Gallons of Storage Required for 1400-lb Cows by Days of Storage and Herd Size

Table 3 Storage Tank Capacity per Foot of Length

Table 4 Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Table 5 Average Amount and Composition of Manue Produced by a 1400-lb Dairy Cow

Table 6 Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Table 7 Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

Table 8 Acre Inches per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

Table 9 System I - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow

Table 10 System II - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Table 11 System III - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Freestall System with a 30-day Storage Period

Table 12 System IV - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Table 13 System V - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Table 14 System VI - Estimated Initial Investment and Annual Costs of Disposal for a 100 Cow Free-stall System

Table 15 Estimated Initial Investment, Annual Costs, and Labor Requirements for Six Alternative Waste Management Systems for a 100 Cow Free-stall Dairy

FIGURES

Figure 1 Typical Cross-section of a Retention Pond

Figure 2 Effect of Cattle Manure on Wheat Yields on the Oldest Agricultural Experiment Station at Rothamsted, England

Figure 3 Effect of Cattle Manure on Runoff, Erosion and Cotton Yield at the Statesville Soil Erosion Experiment Station

Figure 4 Plan and Section View of a Lagoon

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

DAIRY WASTE MANAGEMENT ALTERNATIVES

Dairy production has become more complex, more specialized, and more restricted by certain environmental limitations. This bulletin is designed to help dairy producers meet these problems in the most practical and economical way. The recommendations given herein are based on the latest known research information obtained by the Agricultural Experiment Station at North Carolina State University and other similar institutions, and on field experience and observation. Producers who follow the recommendations should be in compliance with the latest federal and state regulations concerning animal waste disposal known at the time of this writing.

A dairy production unit should be envisioned as a total system. To achieve the systems concept planning must begin with the idea to build or renovate and must be followed through until cows are placed in the facilities. Because of the proximity of many modern dairies to industrial or residential areas, appearance is an important factor to be considered. The type of buildings, their upkeep, and landscaping are all important.

To avoid or overcome some of the problems confronting dairy producers, a prospective producer or one who plans to renovate should consider the following suggestions:

- Locate the operation in the center of a large tract of land if possible.
- If the operation is on a small farm be sure sufficient land area is available for waste disposal.
- Do not locate the operation in a heavily populated area.
- Do not locate the operation near drainage ditches, streams, rivers and estuaries.

This bulletin is divided into seven parts: alternative waste management systems, storm runoff control, parlor and milkhouse waste water, utilization and land requirements, odor control, pest control and economics. The first section describes the various components of each system in each alternative. The sections on storm runoff control and parlor and milkhouse waste water give the requirements for preventing the runoff from lots and the waste water from reaching surface waters. The section on utilization and land requirements presents guidelines and examples of how much waste can be applied per acre. The sections on

odor and pest control provide suggestions and methods for reducing odor and pest problems. The section on economics gives cost data and contains a partial budget sheet so that comparisons between the alternative waste management systems can easily be made. Appendix I gives the design details for a lagoon.

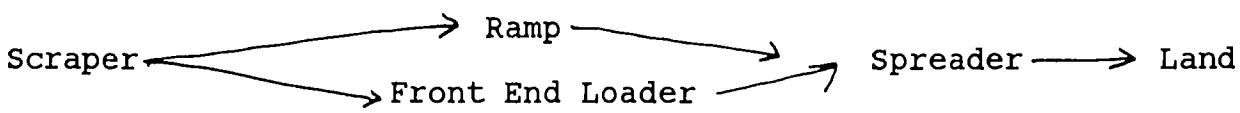
Approximately 90% of all dairy cattle in North Carolina are Holsteins with an approximate average weight of about 1400 pounds per cow. Therefore, all calculations in this bulletin are based on 1400-lb. cows.

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). 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.

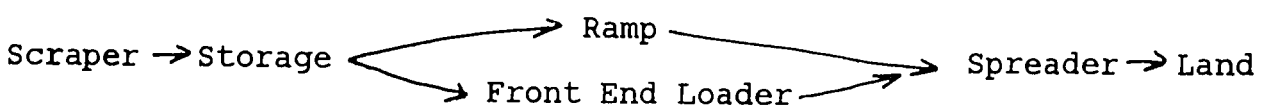
Field spreaders are available as tractor drawn or truck mounted units. Flail type tank spreaders will hold either

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.

Table 1. Daily Production of Solid Manure from Different Size Herds of 1400-lb Cows

Number of Cows	Daily Production T	108 bu Spreader	180 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

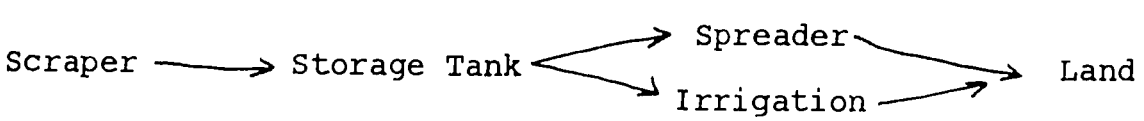
System II: Storage and Spreading in Solid Form



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 sanitatian 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 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 range of moisture content of the manure. An approximate range of moisture in manures without bedding is as follows:

75-82% moisutre-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 pumpagitator which serves the dual role of agitating and filling the spreader tank. Once distinct disadvantage with liquid manure storage is odor while agitating and field spreading. The liquid slurry should not be spread on a hot humit (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 imemdiately, 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

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	18,750	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. 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	99	1320	1650
24	1080	1440	1800

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.

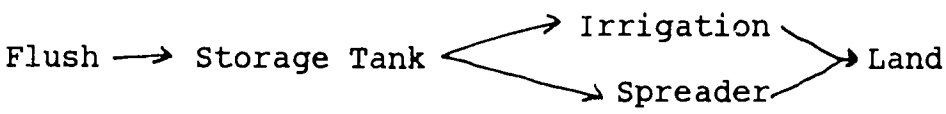
Lagoons are storage ponds in which the water level must be controlled. There has been very little experience with lagoons for dairy waste in North Carolina. Research with swine waste lagoons in North Carolina indicates explicitly that the effluent cannot be discharged into a watercourse. Research in 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.

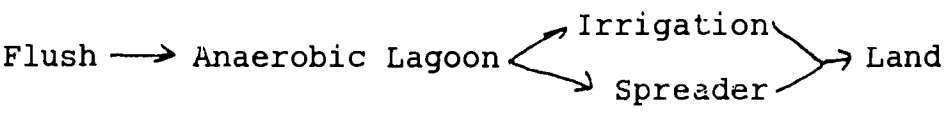
Evidence indicates that a lagoon serves as a nitrogen trap by accumulating nitrogen in the sludge build-up on the bottom. This build-up of solids indicates that the sludge must be removed at some future date. However, definite recommended cleaning intervals are not established at this time. Because the 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 adequate liquid waste retention facility to reatin 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 outisde by adjacent to the dairy 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.

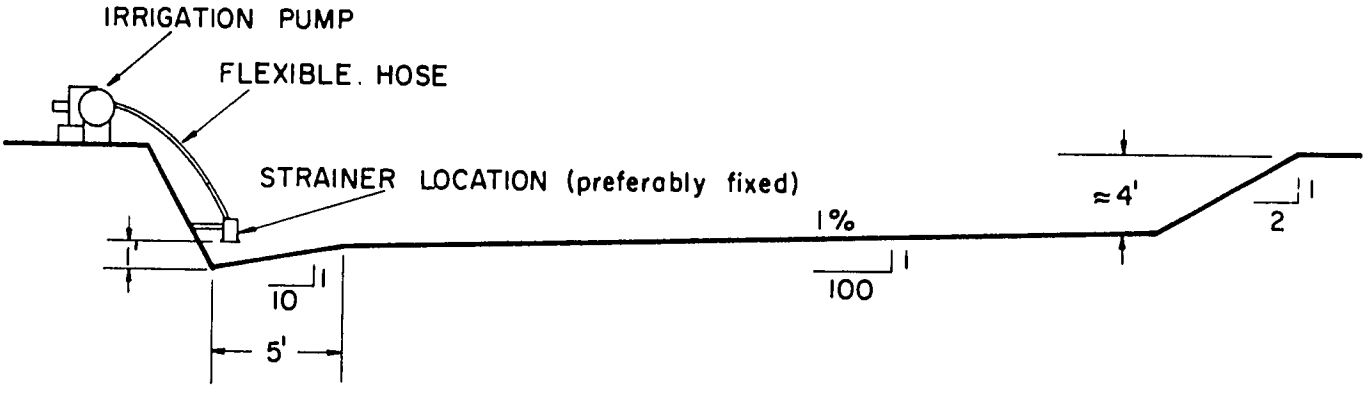


Figure 1. Typical Cross-section of a Retention Pond

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.

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

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 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 inall 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 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. 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.

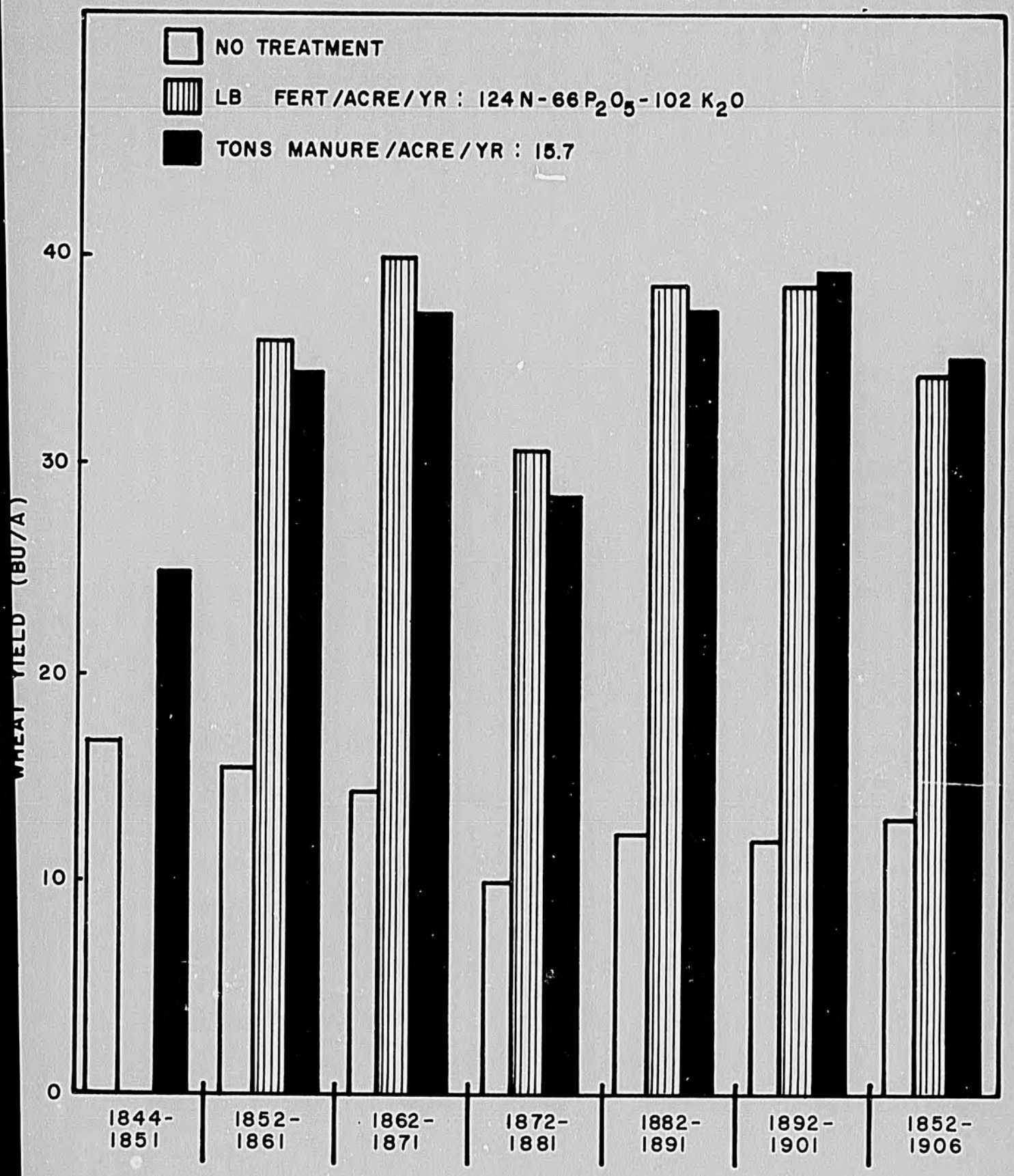


Figure 2. Effect of cattle manure on wheat yields on the oldest agricultural experiment station, at Rothamsted, England. The 10-year periods and the 53-year average (1852-1906) show that yields on the manured plots were about the same as those on the fertilized plots.

TABLE 5. AVERAGE AMOUNT AND COMPOSITION OF MANURE PRODUCED BY A 1400-LB DAIRY COW

Amount Lb/Day/Cow	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		
105	0.60	0.15	0.55	0.63	0.15	0.57	12	3	11

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 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 bilogical 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 yeild 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

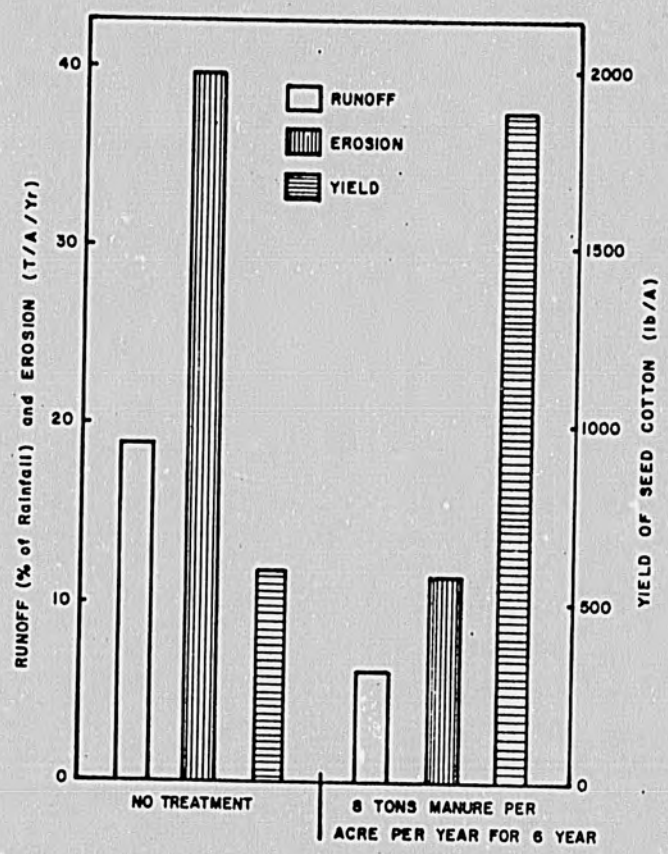


Figure 3. Effect of cattle manure on runoff, erosion and cotton yield at the Statesville Soil Erosion Experiment Station. (The yields are not comparable because the check plots were not fertilized. The good yield on the manured plot is important.)

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. 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.

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 and 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

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, Whitestone, 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

of sufficient manure to get the desired amount of nitrogen usually will aid 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 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 reate of manure decomposition and is much slower than that of nitrogen. Potassium in dairy cattle manure is an inorganic salt that is easily leached andis 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 leacing 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 he 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 commrcial laboratores 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 200-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 rentention 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 hendled in a slurry form. A 30-day cleanout interval is used. The same fertilizer recommendations is 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 reatin 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 prlor waste water and cleanup 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 gt + 62,500 cu ft + 14,045 cut 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 recommended, however, that the storm runoff water be diverted to the lagoon rather than constructing both a lagoon and a retention pond.

5. What is the nitrogen concentration of the lagoon liquor in the answer to Question 4?

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/l. 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 dairy 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/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

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	0.0041	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	30,0000	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

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.

$$\frac{180 \text{ lbN} - 100 \text{lbN}}{200 \text{ lbN} - \text{ lbN}} \quad [20{,}000 \text{ gal/A} - 10{,}000 \text{ gal/A}]$$

+ 10,000 gal/A = 18,000 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 (1,555,000 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 used.

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 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 sotm 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 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?

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

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/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 A 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 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 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 both 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 weight 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.

The sources of data for Tables 9-14 were:

1. Berge, O. I., Waste Disposal...Waht Does It Cost, Hoards Dairyman, April 10, 1971.

2. Jacobs, 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.

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					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					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, 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

STORAGE PERIOD

COSTS OF DISPOSAL FOR A 100 COW FREE-STALL SYSTEM WITH A 30-DAY

Item	Estimated Cost: Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Your Cost: 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					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: Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual	Your Cost: Initial	Annual
Scraper, rear mounted	$ 300	.18[1]			$ 54		
Tractor use, 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					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 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, 2 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

Comparison of Systems

Table 15 presents a summary of the estimated initial and annual costs of the six alternative systems.

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 system 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.

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 Ownership Cost[1]	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	1,391	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.

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.

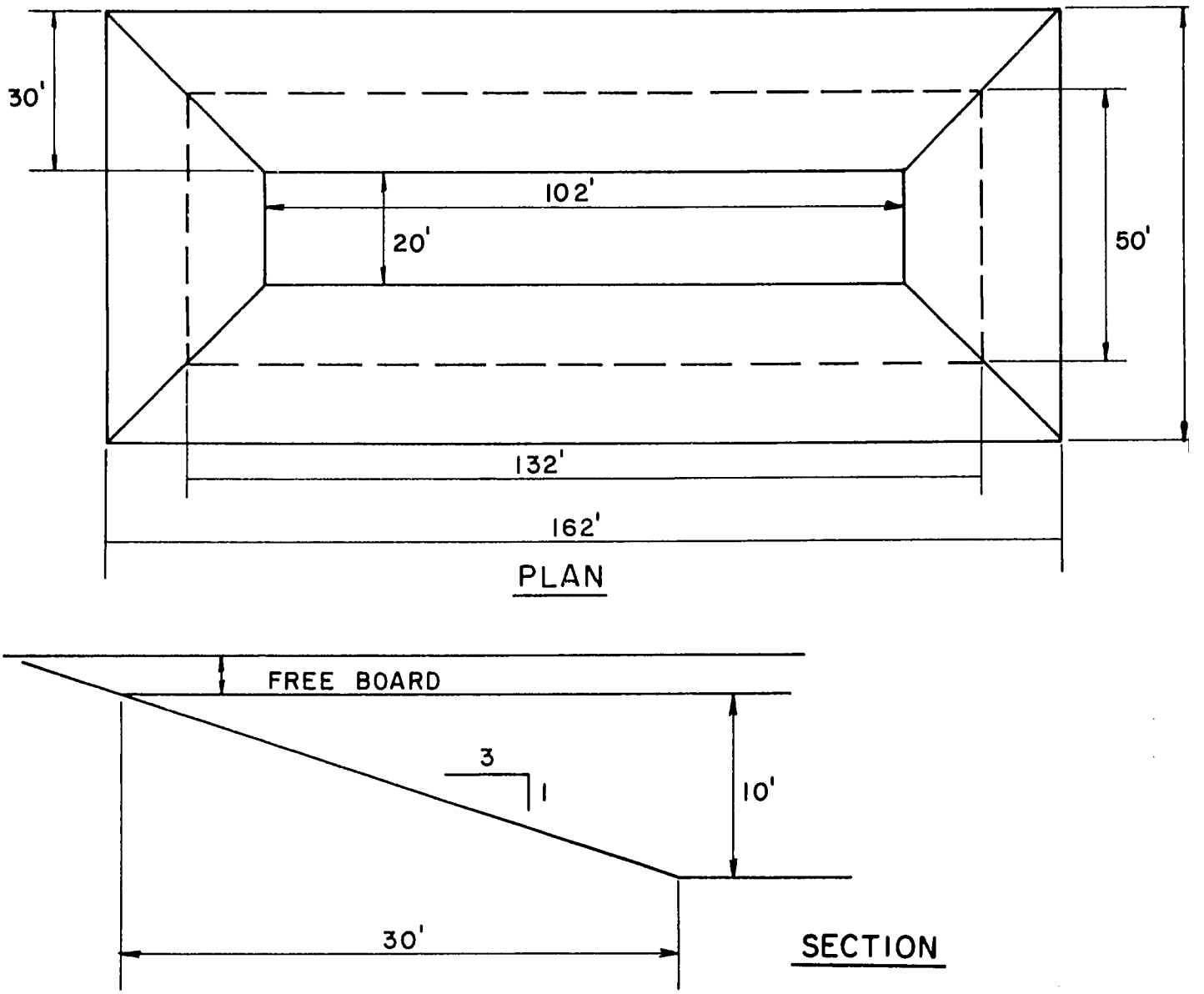


FIGURE 4. Plan and Section View of a Lagoon.

POULTRY WASTE

MANAGEMENT ALTERNATIVES

by

George J. Kriz, *et al.*

CONTENTS

INTRODUCTION

ALTERNATIVE WASTE MANAGEMENT SYSTEMS

- Waste Management System for Broilers and Turkeys
- Alternative Waste Management Systems for Caged Layers
  - System I: Direct Spreading in Solid Form
  - System II: Flush with Lagoon
  - System III: Storage and Spreading in Liquid Form
  - System IV: Flush with Aerated Lagoon
  - Other Alternatives
    - Drying
    - Deep Pit Houses
    - Composting
    - Refeeding

UTILIZATION AND LAND REQUIREMENTS

- Nutrient Composition of Poultry Manures
- Effects of Poultry Manure on Soils and Crops
- Factors Affecting Rates of Application
- How to Determine the Amount to Apply
- Examples
  - Solid Form
  - Slurry Form
  - Lagoon Effluent
- Soil Management

ODOR CONTROL

PEST CONTROL

ECONOMICS

APPENDIX I

- Lagoon Design for 25,000 Birds

TABLES

Table 1. Manure Production for Caged Layers

Table 2. Manure Production from Broilers

Table 3. Manure Production from Turkeys

Table 4. Amount of Water Required to Change One Cubic Foot of Manure from an Initial to a Desired Moisture Percentage

Table 5. Storage Tank Capacity per Foot of Length

Table 6. Nutrient Composition of Oven Dried Poultry Manure

Table 7. Effect of Moisture Content on the Average Nutrient Composition of Caged Layer Manure

Table 8. Relative Leaching Rates and Phosphate-fixing Capacity of Typical Soils

Table 9. Gallons per Acre of Liquid Manure or Lagoon Effluent Required to Supply Various Rates of Total Nitrogen per Acre

Table 10. Acre Inches of Liquid Manure or Lagoon Effluent Required per Acre to Supply Various Rates of Total Nitrogen per Acre

Table 11. Estimated Cost of Poultry Waste Management Systems Based on a Flock Size of 25,000 Caged Layers

FIGURES

Figure 1. Plan and Section View of a Lagoon

Prepared by

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

POULTRY WASTE MANAGEMENT ALTERNATIVES

Poultry production has become more complex, more specialized and more restricted by certain environmental limitations. This bulletin is designed to help poultry producers meet these problems in the most practical and economical way. The recommendations given herein are based on the latest known research results obtained by the Agricultural Experiment Station at North Carolina State University and other similar institutions, and on field experience and observation. Producers who follow the recommendations should be in compliance with federal and state regulations concerning animal waste disposal known at the time of this writing.

A poultry production unit should be envisioned as a total system. To achieve the systems concept, planning must begin with the idea to build or renovate and must be followed through until birds are placed in the facilities. In addition to planning for efficiency, appearance is important. Pride and pleasure cannot be denied the owner of an attractive building or group of buildings located on a landscaped site. Real estate value is also enhanced.

Prospective producers or producers who plan to renovate their facilities extensively should strongly consider the following suggestions:

- Locate in the center of a large tract of land if possible.
- If the operation is on a small farm be sure sufficient land area is available for waste disposal.
- Do not locate the operation in a heavily populated area.
- Do not locate the operation near drainage ditches, streams, rivers and estuaries.

This bulletin is divided into five parts: alternative waste management systems, utilization and land requirements, odor control, pest control and economics. The first section describes the various components of each alternative system. The section on utilization and land requirements presents guidelines and examples of how much waste can be applied per acre. The sections on odor and pest control provide suggestions and methods for reducing odor and pest problems. The section on economics gives estimated cost data and contains a partial budget sheet so that comparisons between the alternative waste management systems can

easily be made. Appendix 1 gives the design details for a lagoon.

Alternative Waste Management Systems

With an increase in size of layer, broiler and turkey production units and more concern for a clearer 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 Cu Ft	Monthly Manure Production Cu Ft	Yearly Manure Production Cu Ft	Yearly Manure Production 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 Cu Ft	Monthly Manure Production Cu Ft	Yearly Manure Production Cu Ft	Yearly Manure Production 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	421.5	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

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 houst 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.

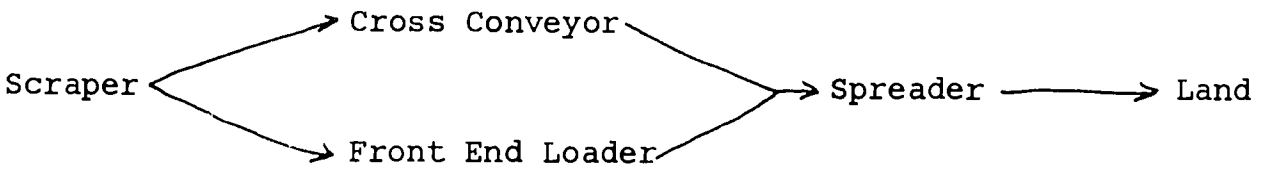
Be sure to select a spreader that will not leak the contents along the road but will spread the material in small pieces on the land surface so as to minimize fly breeding. If the material is very dry, exercise care on windy days to prevent dust and feathers from creating a nuisance.

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



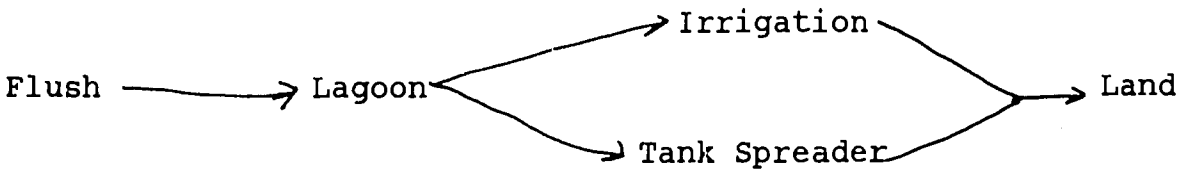
Mechanical pit scrapers are generally used in conjunction with a cross conveyor at one end of the poultry house. The two units operate simultaneously with the pit scraper depositing manure onto the cross conveyor which discharges the manure directly into a spreader for land disposal. This mechanized 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.

Surface 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.

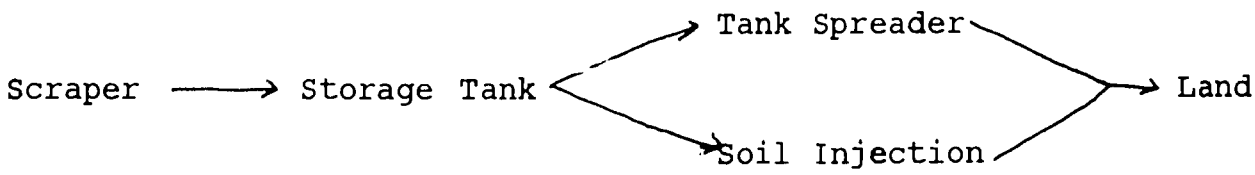
Irrigating lagoon effluent is probably the most practical way to control the water level in the lagoon because of the quantity. When using irrigation, care must be exercised to prevent surface runoff. The system should be designed for minimum pipe and sprinkler movement because this is a "nasty" job. 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 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% 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 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

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

exercised to select a field that is relatively free of large stones, stumps and roots when the injection method is used.

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.

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

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 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. 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 fertil-

izers, 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 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 man 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 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.

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 polutry 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

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 concerving 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 microorganisms 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 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

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, Whitestone, 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

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 29 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 approximateion 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 amountof 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/l). 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.

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	0.0041	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	30,0000	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

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 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 th land is 55.2 ac in. (4.70 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 th 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.

6. Is it possible to reduce the land area required for spreading the effluent?

This 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).

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

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 cna 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 fule, 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 adequately 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.

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	900.43		
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	900.43		
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 ssytem	6,000	888.00		
Labor		450.00		
Repairs				
Fuel and Electricity				

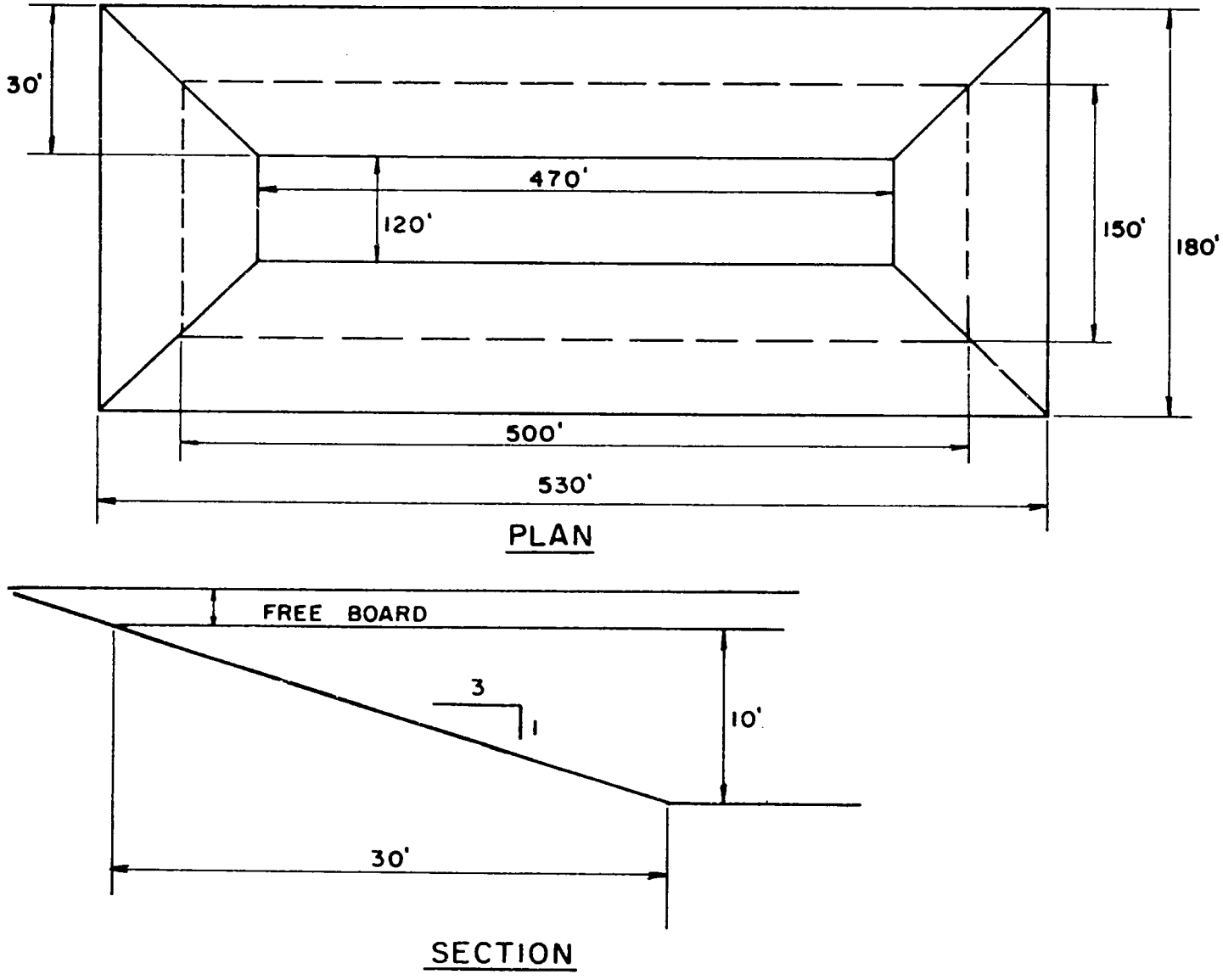


Figure 1. Plan and Section Views of a Lagoon.

GUIDELINES FOR THE CONTROL OF INDUSTRIAL WASTES

4. LIVESTOCK WASTES

by

James C. Lamb III
Professor of Sanitary Engineering
University of North Carolina
Chapel Hill, North Carolina
United States of America

CONTENTS

	Page
Preface	V-410
1. Introduction	V-411
2. Livestock production	V-412
3. Quantity and characteristics of waste waters	V-413
4. Reclamation and recycling	V-416
5. Treatment and disposal of waste waters	V-417
6. Survey and appraisal	V-419
References	V-427
Select bibliography	V-428

PREFACE

The satisfactory disposal of industrial effluents is a major problem causing growing concern to public health authorities. Direct discharge of wastes into watercourses may deplete dissolved oxygen, destroy aquatic life, and make the stream unfit for community water supply and other beneficial uses. On the other hand, the discharge of some industrial effluents into municipal sewers may have damaging effects on sewers or overload the sewage treatment works. Public health authorities are also aware of possible long-term physiological effects of some new organic chemicals which are found in industrial effluents, many of which are not removed by conventional treatment processes. Highly persistent detergents, pesticides and other toxic wastes have become serious problems in developed countries and will in time present a similar threat to developing countries.

In the developing countries the situation is particularly serious in view of the scarcity of qualified professional personnel (sanitary engineers, chemists and biologists), analytical laboratories, and finances for planning and operating industrial wastes control programmes. It is important to consider the problem not only as it is at present, but also in the light of expected population increase, and of urban and industrial growth. Early government action is required for determining the extent of the problem and for planning and implementing efficient measures for the control of industrial wastes discharges.

This is one of a series of documents prepared by theWorld Health Organization covering the most prevalent industries in developing countries. The objective of these guidelines is to assist the responsible staff of health agencies and of other regulatory authorities to carry out surveys, interpret laboratory findings, advise industries on inplant remedial measures and disposal of wastes, and make recommendations concerning acceptance of wastes into municipal sewers. The first document in this series described the problem in general terms, and advised on how to carry out surveys and institute programmes of industrial wastes control.[1] The guidelines dealing with wastes from specific industries cover a description of the manufacturing process, with flowchart, the quantity and characteristics of wastes including health hazards, reclamation and recycling practices, methods of treating and disposing of wastes, suggestions for surveying and appraising existing facilities, and selected references to the literature.

It is planned to revise and update the documents from time to time by including information on new processes and procedures with special reference to experience in developing countries. Information and suggestions in this connexion will be welcomed by the Organization.

---

[1]Document WHO/WD/70.6.

1. INTRODUCTION

Any discussion of water pollution problems arising from livestock production activities must proceed with caution to avoid the possibility of seriously misleading the reader. This can be attributed to the fact that there are radical variations in wastes characteristics among different types of livestock operations, and even greater differences in actual water pollution impacts and potential beneficial values of the wastes under different local circumstances.

It has been pointed out (Loehr, 1969) that animal wastes often have been recycled to the soil with minimum release to the aquatic environment. In its simplest form, livestock production can be based upon allowing animals to obtain their food supply from fields and discharging their wastes directly on to the land. With relatively low livestock population densities, little or no waste escapes the land to enter receiving streams and the water pollution potential is very low, or zero. At the other extreme, confinement of thousands of animals in a feedlot for final fattening before slaughter causes production of livestock wastes far in excess of amounts which can be absorbed by the small land area. Under these circumstances very serious stream pollution problems may be caused by discharge of the animal wastes, especially in heavy rainfalls.

In many areas of the world, accumulations of livestock manure are a valuable resource of humus and fertilizer and are carefully spread on land to increase crop production. In other areas, high labour costs make it unattractive to distribute manure on land because requirements can be satisfied more economically with chemical fertilizers.

These extremes illustrate that it is difficult, if not impossible, to make sweeping generalizations about livestock wastes. Also, they may help the reader understand the risk involved in attempting to assess the water pollution impact of animal wastes through examining total production of various types of farm animals and unit loadings expected from each to give a total pollution load from this industry. It has been pointed out (U.S. Federal Water Pollution Control Administration, 1970) that in many reports that approach has produced gross figures for animal waste production of startling magnitudes, which may serve no real purpose and actually mislead the reader. This could produce an adverse reaction by causing the reader to conclude that the data are too absurd to warrant serious consideration.

Another important point related to interpretation of data and development of solutions for animal waste disposal problems is that too seldom has it been recognized that these wastes differ from each other and from various types of municipal and industrial wastes for which treatment technology has been developed. Thus, some efforts to solve the problems have failed because wrong approaches were utilized, or wrong design parameters applied to what might have been the correct approach.

2. LIVESTOCK PRODUCTION

The types of livestock production activities, their organization, and magnitude vary radically among the many countries of the world, but some general types of production are common to many regions. The major categories might be considered profitably by viewing, briefly, components of livestock industry as presented by authors of a recent United States of America report (U.S. Federal Water Pollution Control Administration, 1970) and summarized in Table 1. The livestock industry in the United States of America is considered to consist principally of production of four major types of animals - cattle, poultry, swine and sheep, some of which should be sub-divided in evaluating water pollution potential.

The "beef cow" group is that segment of the cattle industry devoted principally to production of calves on range land. Because the success of this type of operation depends upon an adequate supply of grass, the animal population is retained at a density ensuring good utilization of the land, but low enough to avoid damage to the grass crop. The low animal density and tendency of grasslands to retain their wastes result in a very low water pollution potential by this type of operation.

Cattle for human consumption usually are fattened either by grass feeding or on feed concentrates, such as corn and other products with minerals and various components added to the animal's ration to produce a high rate of weight gain. Those fattened on grass under range conditions have very little water pollution potential, as noted above for beef cow production, because animal population densities are maintained low enough to preclude damage to the grass crop. This density level also usually precludes significant discharges of pollutants into streams.

Accordingly, many cattle make little or no contribution to stream pollution. Those which contribute usually do so because of high population densities in fattening operations, commonly carried out using concentrated foods with animals confined in feedlots. In the United States of America, these operations are numerous (208 596 in the year 1968) and caused serious water, land, and air pollution problems by the 23 million head of cattle handled in 1968. It is this category of United States of America beef cattle operation which attracts the greatest attention and which will require the greatest effort for solution. Parallel situations can be found in some regions of most other countries of the world.

The dairy cattle industry, of course, is concerned with the same general type of animal but has somewhat different water pollution potential and operating criteria. Dairy cattle have very different geographic distributions throughout the country and feeding programmes for these animals differ from those for fattening beef cows. Also, criteria relative to the products are very different fundamentally. Accordingly, there are many similarities, but also several differences, in character of waste

handling operations in the dairy industry.

Many cow milking operations employ water-flush systems, used for washing down animals before milking and to clean up after milking. Wastes derived from these operations usually include flows used to clean utensils, pipes, and other equipment, whether or not water-flushing systems are employed for carrying away wastes from stalls in which the cows are kept. In some installations, the animals are confined on sloping concrete floors arranged to ensure that wastes will be dropped where they can be readily flushed away. This flow can produce very severe pollution loads if discharged untreated from large dairy operations into watercourses.

Water-flushing systems also are readily adaptable to swine-raising facilities. Frequently, the barns may be equipped for direct drainage of floors into collecting gutters during flushing operations, making the general character of problems arising from swine barns very similar to those encountered in the dairy industry, except for differences in waste water quality characteristics.

Many sheep are raised on ranges. Accordingly, there may be relatively little water pollution problems arising from production of these animals. Little information has been collected concerning water pollution impact of sheep raising operations in the United States of America (U.S. Federal Water Pollution Control Administration, 1970).

Waste production and handling problems arising from chickens grown as broilers or layers (egg producers) are similar. Many poultry enterprises have water carriage systems to remove wastes from cages or pens in which the birds are raised. These were devised to minimize labour required to clean the pens and may create serious water pollution problems. In arid areas, a system based on taking advantage of natural drying conditions may be preferable to water carriage. Currently, several water management techniques are applied to wastes from poultry enterprises.

The production of ducks may present problems of very different complexion because, typically, the birds are raised near flowing water which aids in development of desirable feathers and carriage of wastes discharged directly into the stream. In addition to more or less uniform discharge of wastes by the ducks directly into the watercourse, slug discharges also are encountered during rainstorms. Although duck-raising enterprises do not represent a major national problem in the United States of America, there are very serious local problems arising from this type of operation.

3. QUANTITY AND CHARACTERISTICS OF WASTE WATERS

In those few operations using water flushing systems for management of animal wastes, it is feasible to establish a mean-

ingful estimate of expected flows. For example, flushing operations for carrying manure and debris from dairy barns may use as much as 50-60 US gallons (190-230 l) of water per day per cow, or as little as 20 gallons (75 l) per day per cow where special care is exerted to minimize usage. However, the origin of these wastes indicates that such instances are the exception rather than the rule. More frequently, the wastes do not enter the water cycle at all but are removed and disposed in dry or semi-solid form, using techniques appropriate to solid waste systems instead of waste waters.

Waste waters reaching streams may be due to rainfall and run-off from areas receiving discarded solid wastes or from feedlots directly. In this type of situation, the pollution potential of a livestock production operation is influenced heavily by its location relative to watercourses, the type of terrain on which the operation takes place, and local climate, especially rainfall. The amount of flow involved is of relatively less importance because the critical factors are suspended materials, organics, nutrients, and other pollutants carried into the stream, which are not directly due to rainfall.

Accordingly, it is clear that it is not feasible to relate pollutional potential of livestock wastes with flows as is frequently done for municipal sewage, in which substantially all of certain wastes from the tributary population are carried in the system. For this reason, and because of differences in wastes from various types of animals, livestock wastes usually are reported, summarized, and discussed in terms of unit loadings for each type of animal.

Differences in wastes among the various types of animal may be attributed to ranges in size, diet, and metabolism. Swine have single stomachs and tend to produce faeces and urine similar to those from humans. The types of diet consumed by swine and poultry are much more digestible than those of some other types of livestock, causing relatively small amounts of excreta. On the other hand, ruminants, such as cattle, have digestive systems capable of utilizin cellulose. Because some compounds accompanying cellulose consumed by the animals (such as lignin) are difficult to digest, these types of animals produce relatively large amounts of wastes having very different composition from those produced by the single stomach species. Thus, one must not assume that data collected for one type of livestock will apply to other species, or that studies relating to human wastes would apply to animal wastes as well (Loehr, 1969).

It has been demonstrated (Mills & Parker, 1967) that wastes from differenc classes of animals may have very different characteristics. The composition of animal manure depends upon digestibility, protein, and fibre content of the ffed, environment of the animal, and feed additives. Generally, those receiving concentrated foods for fattening or work may have a higher pollution potential than wastes from grass-fed animals. Twenty to 30 percent of the solid wastes consists of undigested food and

bacterial cells. Over 25 percent of the organic manure is humus, similar to that in soil (Loehr, 1969).

Variations in character of wastes with types of animals, their environment and type and quantity of feed indicate that waste discharges per unit of production should vary radically in different areas of the world, and even under different circumstances in the same country. Loehr (1969) states that it is difficult to correlate published data because investigators use different units and do not measure the same parameters in all studies. Tables 2-6 summarize data abstracted by him from publications of several investigators concerning physical and chemical characteristics of various types of animal wastes.

Many authors have used such data to calculate waste loadings from various types of animals in terms of human population equivalents. This approach is valid where it is desired to evaluate impact of livestock waste from a "point source", such as a dairy or swine barn with water-carriage system. Loehr (1969) has summarized "population equivalents", based on BOD, total solids, and nitrogen for chickens, swine, dairy cattle and beef cattle. He points out that use of these values to estimate overall stream pollution by livestock is questionable because most animal wastes are discarded on land directly by the animal or through spreading. Also, substantial variations exist in "population equivalents" of any specific type of animals under different conditions of feed, environment, etc.

Livestock wastes may create a wide variety of water pollution problems, depending upon circumstances attending their disposal. Examination of data especially in Tables 6 and 7 indicates that the wastes can carry very substantial contributions of organic substances capable of causing oxygen depletion in streams. Also, they may contain high concentrations of coliform bacteria, suspended solids, and nutrients. In some areas of the United States of America, for example, high coliform concentrations have made it necessary to prohibit taking shellfish from beds near duck farms (Davis et al., 1966). Also livestock operations have caused undesirable aesthetic effects and objectionable growths of algae and aquatic plants because of nutrient contributions.

Run-off from cattle feedlots has caused serious pollution of streams, by high concentrations of bacteria, BOD, suspended solids, and ammonia nitrogen, and has led to large fish kills. For example, Miner et al. (1966) reported concentrations in feedlot run-off of 1.0-140 mg/l ammonia, 1400-12 000 mg/l suspended solids and COD levels of 3000-16 000 mg/l. Other investigators have reported even higher concentrations (Loehr, 1967, 1969).

Many infectious diseases are common to man and other animals and it has been stated that over 100 diseases of animals may be transmitted to man (Decker & Steele, 1966). The same author re-

ports that the most significant pathogens include several types of salmonella; bacteria causing staphylococcal and streptococcal infections, tetanus, tuberculosis, brucellosis, leptospirosis; pathogenic fungi, and the rickettsia causing Q fever. Diseases which have been considered of great importance include anthrax, salmonellosis, which may be conveyed by water, tuberculosis, brucellosis, leptospirosis, and tularaemia. The parasitic disease trichinosis has been a problem in many areas of the world. In several countries its incidence has been reduced by eliminating the practice of feeding raw garbage to swine and by improved cooking of pork. The role of animal wastes in transmission of viral diseases is less well understood than for bacterial diseases, but their importance in reproduction of insects which are vectors of many viral diseases is well known (Gibson, 1966, 1967; Hibbs & Foltz, 1964).

A very bothersome aspect of bacterial pollution by animal wastes is related to high coliform concentration frequently present in such discharges. Coliform bacteria are used as an index of water quality. Thus, discharge of large numbers into watercourses from livestock wastes could create serious problems in evaluating downstream water quality because coliforms from these wastes do not carry the same implications for health as do coliforms originating in sanitary sewage. Because the quality of water, its suitability for a potable supply, and the degree and type of treatment required must be determined to a significant extent on concentration of these organisms, presence of large numbers of coliforms from livestock operations could lead to erroneous interpretation of water quality data (Geldrich et al., 1962).

Other problems associated with animal wastes include production of large numbers of flies and, sometimes, intensive odour problems. Waste waters from livestock operations also may be highly coloured, causing problems for downstream users (Loehr, 1969; Anderson, 1966).

4. RECLAMATION AND RECYCLING

When the population density of cattle can be maintained at a low level on grasslands, their wastes are returned to the soil directly in a most elementary form of reclamation and recycling. In other instances, it often is feasible to collect animal wastes in dry or semi-solid form and to distribute them on land manually or with the aid of mechanical spreaders. This involves a substantial amount of labour and is losing favour in many industrialized regions of the world where labour costs are high and chemical fertilizers of equivalent strength may be applied much more economically. On the other hand, in many countries it remains the most reasonable method for solving animal waste problems and, further, the wastes constitute a valuable resource for improving productivity of the land.

It should be noted here that where pollution control is being pushed vigorously, the addition cost of treating liquid livestock wastes before release should be considered in evaluating economic feasibility of land disposal, whether of dry or liquid wastes.

Since characteristics of animal wastes depend heavily upon the type and quantity of feed consumed, it might be desirable, from a waste abatement point of view, to reduce quantities of non-digestible materials in animal feeds, as well as excess feed which may be supplied for rapid gain of weight. This approach has not received major attention and, undoubtedly, would meet with resistance from many livestock producers who usually are concerned principally with obtaining maximum weight gain in the shortest possible period of time.

In summary, reclamation and recycling in this industry sometimes may be approached through keeping animal population densities low enough to ensure assimilation of wastes discharged directly on to the land. Obviously, this is not always feasible because frequently the animals must be concentrated into small areas to enhance economy of feeding operations or to hold animals for killing or milking. Under those circumstances, water pollution problems may be minimized by avoiding water carriage of wastes, if local economics permit. Removal of dry wastes for application to land, taking care to minimize removal by run-off into watercourses, often is desirable as a means of reducing water pollution problems.

Another method for recycling which has received considerable attention involves the reuse of some animal wastes as part of the feed for other animals of the same species, or different types of livestock. For example, chicken faeces, which are highly concentrated, have been proposed as part of the feed for chickens, dairy cattle, beef animals, and sheep. Investigations indicate that the milk or meat produced is not significantly different, as long as the material is properly dried and represents only part of the diet (Anthony, 1966; Fontenot et al., 1966; Loehr, 1969).

5. TREATMENT AND DISPOSAL OF WASTE WATERS

The first line of defense against water pollution problems arising from animal wastes lies in prevention by minimizing contact between the wastes and water. Another method for accomplishing this is to cover feedlots to reduce run-off. This has proven feasible in many operations involving dairies or production of hogs or chickens. As pressures for more rigorous stream pollution control increase, the number of facilities in which it will become feasible to resort to covering feedlots to reduce pollution problems, as contrasted with treatment and disposal of liquid wastes, should increase sharply.

Under circumstances where animal wastes must be handled in liquid form many treatment processes can be considered, but few

have been evaluated rigorously to determing appropriate loading criteria or performance. It must be emphasized that criteria applied for treatment of municipal waste waters will not necessarily be appropriate for livestock wastes.

Processes which have been investigated include anaerobic digestion of wastes containing high concentrations of solids and BOD. This technique often could be used successfully with several types of animal wastes, but the effluent usually would require further treatment before discharge into receiving waters. In some investigations, difficulties have been encountered which are not normally observed in anaerobic digestion of sewage sludge and caution must be exercised in applying the process to some types of livestock wastes.

Aerobic treatment of wastes can be applied, if adequate oxygen transfer into solution is provided. This usually requires detention periods of many days, because of high strength of the wastes. This approach also has been extended to further treatment of effluent from anaerobic treatment units (Scheltinga, 1966).

Oxidation ponds may be employed at loadings of 30-50 pounds of BOD per acre per day (Loehr, 1969). However, the very high BOD of livestock wastes indicate that extremely large areas would be required. Loehr (1969) gives an example of a unit for 1000 head of beef cattle which would require 20 acres of pond. Other approaches which have been investigated include aerated lagoons and Pasveer, or oxidation, ditches (Scheltinga, 1969).

Anaerobic lagoons are potentially promising for treating concentrated animal wastes because of high BOD and the fact that this type of unit can provide treatment and simultaneously help in controlling run-off from feedlot areas or serve as a holding basin prior to land disposal. Effluent quality from an anaerobic lagoon receiving livestock wastes usually is poor (300-1500 mg/l BOD and high in solids and nitrogen). Thus, additional treatment probably would be required in most instances before discharge to a receiving stream (Curtis, 1966; Loehr, 1969).

Spreading on land has been the usual method for disposing of solid wastes and also frequently is appropriate for liquid livestock wastes, with care to avoid run-off from the disposal area into receiving streams. This approach also allows recovery of nutrient content of the waste waters. Land disposal systems usually are based on using liquid holding units for equalization of waste flows and for storage during periods of adverse weather. It had been suggested that the lagoons or holding tanks provide at least two months capacity, although that design parameter obviously would be subject to local circumstances (Tietjen, 1966; Loehr, 1969).

Other approaches which have been suggested and investigated, but not used extensively, include incineration, drying, compost-

ing, vacuum filtration to reduce the volume of dilute poultry manure, dewatering of slurries from dairy operations on drying beds, use of lime and chlorine for treatment of hog wastes, and trickling filters (Loehr, 1969; Sobel & Ludington, 1966).

6. SURVEY AND APPRAISAL

Loehr (1969) has pointed out that some of the traditional analytical techniques, such as BOD, COD, and suspended solids, commonly used to evaluate pollution potential of waste waters are of less value with animal wastes. The latter are highly concentrated and require many dilutions before the standard waste water analytical techniques can be applied. Also, many livestock wastes may contain antibiotics and metals fed to optimize growth and minimize losses of animals. Those constituents can interfere with some of the analytical techniques. Another problem is that representative sampling of the wastes is very difficult because they are highly concentrated, often solid, and heterogeneous in nature.

Several problems concerned with evaluating the water pollution impact of these wastes have been discussed. Basic characteristics vary considerably from species to species of animal and also show extensive variability within each species, depending upon nature of feed, quantity of feed, environmental conditions, and other factors such as local climate which may lead to variations in run-off. Under some circumstances wastes from livestock operations can have exceedingly great pollution impact, while under other conditions there may be virtually no water pollution.

Even without detailed information to that effect, it is certain that water pollution impact by livestock wastes varies radically in different countries of the world, and among many regions of any given country. In the opinion of this writer, it would be even more risky than with most industrial wastes to attempt to generalize on the pollution impact of these wastes or on the types of treatment processes best suited for solving livestock wastes problems in different countries.

These circumstances indicate clearly the desirability of surveying and evaluating individual problems independently, as may be appropriate. To that end, data or other information in current literature will be valuable principally as aids in designing the programme and to identify types of investigations which should be conducted in each individual instance.

TABLE 1

MAJOR COMPONENTS OF LIVESTOCK INDUSTRY
(After: U.S. Federal Water Pollution Control Administration, 1970)

1. Cattle
    - A. Beef cows (calf production)
    - B. Cattle fattening
        - (1) Grass fattened
        - (2) Concentrate fattened (feedlots)
    - C. Dairy cattle
2. Poultry
    - A. Chickens
        - (1) Broilers
        - (2) Layers
    - B. Ducks
    - C. Turkeys
3. Swine
4. Sheep

TABLE 2

CHARACTERISTICS OF ANIMAL WASTES
(Taiganides & Hazen, 1966)

Item	Chickens	Hogs	Cattle
Animal size, in pounds	4-5	100	1000
Wet manure, in pounds per day	0.12-0.39	2.8-9.5	38.5-74.0
Total solids, percentage, wet basis	25-48	12-28	13-27
Total solids, in pounds per day	0.05-0.10	0.8-1.6	9.5-11.4
Volatile solids, percentage, dry basis	74-79	83-87	-
Nitrogen, in pounds per day	0.0012-0.0057	0.042-0.060	0.35-0.44
P_2O_5, in pounds per day	0.0010-0.0045	0.029-0.032	0.11-0.12
K_2O, in pounds per day	0.0005-0.0019	0.034-0.062	0.27-0.34

TABLE 3

CHARACTERISTICS OF LIVESTOCK WASTE*
(Hart, 1960)

Parameter	Dairy cattle	Beef cattle	Poultry	Swine	Sheep
Animal weight, in pounds (kg)	1400 (635)	950 (431)	5 (2.3)	200 (91)	100 (45)
Manure production, in cubic feet (dm^3) per day	1.3 (36.8)	1.0 (0.3)	0.0062 (0.175)	0.28 (7.93)	0.11 (3.11)
Manure density, in pounds per cubic feet (kg/dm^3)	62 (0.98)	60 (0.96)	60 (0.96)	62 (0.98)	65 (1.04)
Moisture, as a percentage	85	85	72	82	77
Nitrogen, as a per cent. of dry solids	3.5	3.1	5.4	3.3	5.4

*Fresh mixed manure and urine.

TABLE 4

NUTRIENTS IN ANIMAL WASTES
(Baines, 1964)

Parameter as % of slurry	Dairy cattle	Beef cattle	Hogs	Poultry
Nitrogen (as N)	0.13-0.42	0.24-0.60	0.3-0.9	0.41-1.7
Phosphorus (as P)	0.06-0.09	0.09-0.25	0.2-0.6	0.30-1.5
Potassium (as K)	0.13-0.30	0.14-0.28	0.2-0.4	0.13-1.25

Parameter as % of dry solids	Cattle	Hog	Sheep	Horse	Hen
N	0.3-1.3	0.2-0.9	0.9	0.66	1.8-5.9
P_2O_5	0.15-0.5	0.14-0.83	0.34	0.23	1.0-6.6
K_2O	0.13-0.92	0.18-0.52	1.0	0.68	0.8-3.3

TABLE 5

CHARACTERISTICS OF ANIMAL MANURES
(Benne et al., 1961)

Animal	Moisture, as a percent-age	Pounds per ton of manure								
		N	P	K	S	Ca	Fe	Mg	Volatile solids	Fat
Dairy cattle	79	11.2	2.0	10.0	1.0	5.6	0.08	2.2	322	7
Fattening cattle	80	14.0	4.0	9.0	1.7	2.4	0.08	2.0	395	7
Hog	75	10.0	2.8	7.6	2.7	11.4	0.56	1.6	399	9
Horse	60	13.8	2.0	12.0	1.4	15.7	0.27	2.8	386	6
Sheep	65	28.0	4.2	20.0	1.8	11.7	0.32	3.7	567	14

TABLE 6

POLLUTIONAL CHARACTERISTICS OF ANIMAL WASTES[a]
(Loehr, 1969)

		BOD		COD		Nitrogen		
Total solids,[b] pounds per day per animal	Volatile solids,[b] pounds per day	pounds per day	pounds per pounds of volatile solids	pounds per	pounds per pound of volatile solids	Total, pounds per day	Ammonia, pounds per day	P_2O_5, pounds per day
			CHICKENS (4-5 lb)					
	0.035			0.333	0.93			
0.063	0.044	0.015	0.34	0.050	1.14	0.0030	0.0006	0.0026
0.066	0.051	0.015	0.29	0.057	1.11	0.0036	0.0023	
		0.015-0.032						
0.057-0.084		0.006-0.010						
			SWINE (100 lb)					
0.80	0.62	0.20	0.32	0.75	1.20	0.032	0.024	0.025
0.97	0.80	0.43	0.54	0.96	1.20	0.064		
0.50	0.35			0.47				
			0.30		1.56			
		0.25						
		0.22				0.07		
0.71		0.56						
			DAIRY CATTLE (1000 lb)					
		1.53	0.13		1.57			
10.4	8.3	1.53	0.18	8.4	1.00	0.38		0.12
6.8	5.7	1.32	0.23	5.8	1.02	0.37	0.23	
7.5		0.44				0.49		
			BELF CATTLE (1000 lb)					
3.62	3.17	1.02	0.32	3.26	1.03	0.26	0.11	
9.00			0.28		1.15	0.26		
			DUCKS					
0.16		0.02-0.04				0.08		0.006-0.0

[a]Multiple entries in each category represent data reported by different investigators.

[b]Dry solids.

[c]As PO_4.

TABLE 7

AVERAGE ANIMAL WASTES CHARACTERISTICS
(loehr, 1969)

	Pounds per animal per day			Per capita equivalent,[a,b]		
Species	BOD_5	Total dry solids	Total nitrogen[c]	BOD_5	Total dry solids	Total nitrogen
Chickens	0.015	0.06	0.003	0.11	0.09	0.11
Swine	0.30	0.90	0.05	1.7	1.7	1.5
Dairy cattle	1.0	10	0.04	8	18	12
Beef cattle	1.0	10	0.30	6	18	9

[a]Based on average characteristics in municipal sewage: 0.17 pounds BOD_5 *per capita* per day, 0.55 lb total solids *per capita* per day, and 0.033 lb total nitrogen *per capita* per day.

[b]Number of people equivalent to one animal.

[c]Total Kjeldahl nitrogen.

REFERENCES

Anderson, J. R. (1966) Biological interrelationships between feces and flies. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Michi., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 20-23

Anthony, W. B. (1966) Utilization of animal wastes as feed for ruminants. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 109-112

Baines, S. (1964) Some aspects of the disposal and utilization of farm wastes, Inst. sewage Purif. J., pp. 578-588

Benne, E. J., Hogland, C. R., Longnecker, E. D. & Cook, R. L. (1961) Animal manures -what are they worth today? Michigan State Unviersity, Agricultural Experiment Station, Lansing, Mich. (Bulletin No. 231)

Curtis, D. R. (1966) Design criteria for anaerobic lagoons for swine manure disposal. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 75-80

Davis, R. V., Cooley, C. E. & Hadder, A. W. (1966) Treatment of duck wastes and their effects on water quality. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 98-105

Decker, W. M. & Steele, J. H. (1966) Health aspects and vector control associated with animal wastes. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 18-20

Fontenot, J. P., Bhattacharya, A. N., Drake, C. L. & McClure, W. H. (1966) Value of broiler litter as feed for ruminants. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 105-108

Geldrich, E. E., Bordner, R. H., Huff, C. B., Clark, H.F. & Kabler, P. W. (1962) Type distribution of coliform bacteria in the feces of warm blooded animals, J. Wat. Pollut. Control Fed., 34, 295-301

Gibson, E. A. (1966) Salmonellosis in cattle, Agriculture, 73, 213-216

Gibson, E. A. (1967) Disposal of farm effluent - animal health, Agriculture, 74, 183-192

Hart, S. A. (1960) The management of livestock manure, Trans. Amer. Soc. Agric. Engrs., 3, 78-80

Hibbs, C. M. & Foltz, V. D. (1964) Bovine salmonellosis associated with contaminated creek water and human infection, Veterinary Medicine/Small Animal Clinic (U.S.A.), 59, 1153-1155

Loehr, R. C. (1967) Effluent quality from anaerobic lagoons treating feedlot wastes, J. Wat. Pollut. Control Fed., 39, 384-391

Loehr, R. C. (1969) Animal wastes - a national problem, J. Sanit. Engng Div., Proc. Amer. Soc. Civ. Engrs, 95, No. SA2, pp. 189-221

Mills, K. C. & Parker, B. F. (1967) Some effects of composition of feed on the biochemical oxygen demand of the excreta produced from this feed (paper presented at winter meeting of American Society of Agricultural Engineers, Detroit, Mich.)

Miner, J. R., Lipper, R. I., Fina, L. R. & Funk, J. W. (1966) Cattle feedlot runoff - its nature and variation, J. Wat. Pollut. Control Fed., 38, 1582-1591

Sobel, A. T. & Ludington, D. C. (1966) Destruction of chicken manure by incineration. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 95-98

Taiganides, E. P. & Hazen, T. E. (1966) Properties of farm animal excreta, Trans. Amer. Soc. Agric. Engrs, 9, 374-376

Tietjen, C. (1966) Plant response to manure nutrients and processing of organic wastes. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366)

U. S. Federal Water Pollution Control Administration (1970) The economics of clean water. Vol. II, Animal wastes profile, Washington, D.C., Govt Printing Office

SELECT BIBLIOGRAPHY

Agnew, R. W. & Loehr, R. C. (1966) Cattle-manure techniques. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 81-84

Allred, E. R. (1966) Farm-waste management trends in Northern Europe. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 133-136

Cassell, E. A., Warner, A. F. & Jacbos, G. B. (1966) Dewatering chicken manures by vacuum filtration. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 85-91

Centre belge d'Etude et de Documentation des Eaux (1966) Livre de l'eau. Liege, CEBEDOC. Vol. 5 pp. 313-315: "Eaux usees provenant d'exploitations agricoles"

Cornell University Conference on Agricultural Waste Management (1969) Animal waste management. Proceedings . . . Syracuse, New York, January 1969

Culpin, C. (1964) Equipment for disposal of agricultural effluents, Chem. and Ind. (Feb. 29), pp. 350-353

Dornbush, J. N. & Anderson, J. R. (1964) Lagooning of livestock in South Dakota. In: Proceedings of the 19th Industrial Waste Conference, Purdue University, Lafayette, Ind. (Engineering Extension Series No. 117), pp. 317-325

Great Britain, Department of Scientific and Industrial Research (1964) Some further observations of waste waters from farms, Notes Wat. Pollut., No. 24

Forsyth, R. J. (1965) The collection of manure from housed livestock, J. Proc. Instn Agric. Engrs, 21, 124-134

Hart, S. A. & Turner, M. E. (1965) Lagoons for livestock manure, J. Wat. Pollut. Control Fed., 37, 1578-1596

Institute of Water Pollution Control (1970) Proceedings of Symposium on Farm Wastes, Newcastle-upon-Tyne, London

Jackson, S. W., Langlois, B. E. & Johnson, T. H. (1970) Growth of micro-organisms in fresh chicken manure under aerobic and anaerobic conditions, Poult. Sci., 49, 1749-1750

Karlgren, L. (1966) Der Einfluss von Jauche und Siloabwasser auf die Gewasser, Fod. Europ. Gewassersch., Inform.-Bl., No. 13, 33

Leuthier, H. (1963) Das Jauche- und Abwasserproblem in landwirtschaftlichen Grossbetrieb, Wasserwirtschaft-Wassertechnik, 13, 14-18

Liebman, H. (1963) Der Einfluss von Jauche auf Kleinklaranlagen in Landgemeinden, Munch. Beitr. z. Abw.-, Fischerei- u. Flussbiol., Bd. 10, 205-208

Little, F. J. (1966) Agriculture and the prevention of river pollution as experienced in the West of Scotland, Inst. Sewage Purif. J., pp. 452-454

Loehr, R. C. (1969) Animal wastes - a national problem, J. sanit. Engng Div., Proc. Am. Soc. civ. Engrs, 95, No. SA2, 189-221

Meinck, Stooff, H. & Kohlschutter, H. (1968) Industrie-Abwasser. 4., verb. und erw. Aufl. von Nr 6 der "Schriftenreihe des Vereins fur Wasser-, Boden- und Lufthygiene, Berlin-Dahlem". Stuttgart, Geo. Fischer. pp. 420-426 "Abwasser landwirtschaftlicher Betriebe"

Poelma, H. R. (1966) The biological breakdown of pig urine, Wageningen, Netherlands, Institute for Farm Buildings (Bulletin No. 18)

Reed, C. H. (1966) Disposal of poultry manure by plow-furrow-cover method. In: Proceedings of the National Symposium on Animal Waste Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 52-53

Rundle, W. T. A. (1965) Effluent disposal - still a major problem, J. Proc. Instn Agric. Engrs., 21, 134-139

Smith, S. M. & Miner, J. R. (1964) Stream pollution from feedlot runoff. In: Transactions 14th Annual Conference on Sanitary Engineering, University of Kansas, pp. 18-25

Symposium on Agricultural Wastewaters (1966) Proceedings . . . University of California, Davis, April 1966 (Water Resources Center Report No. 10)

Viehl, K. & Kollatsch, D. (1967) Die Ablaufe der landwirtschaftlichen Betriebe ein neues Abwasserproblem, Wasser u. Boden, 19, H. 9

Weiss, C. M. et al. (1971) A review of the 1970 literature on wastewater and water pollution control, J. Wat. Pollut. Control Fed., 43, No. 6, pp. 991-998 "Livestock wastes"

Wheatland, A. B. & Borne, B. J. (1963) Le traitement des effluents des fermes, Trib. CEBEDEAU, 16

Witzel, S. A., McCoy, E., Polkowski, L. B., Attoe, O. J. & Nichols, M. S. (1966) Physical, chemical and bacteriological properties of farm wastes (bovine animals). In: Proceedings of the National Symposium on Animal Wastes Management, St. Joseph, Mich., American Society of Agricultural Engineers (ASAE Publication No. SP-0366), pp. 10-14