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**US Army Corps
of Engineers**
Construction Engineering
Research Laboratory

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TECHNICAL REPORT N-85/C
September 1985

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Reference Guide for Industrial Wastewater Treatment

This report provides a general reference guide for identifying, designing, and reviewing industrial water pollution abatement projects. The guidance will be useful to environmental engineers in the Department of Defense who are responsible for industrial wastewater pollution abatement projects and to personnel responsible for operation and maintenance of domestic and/or industrial wastewater treatment plants.

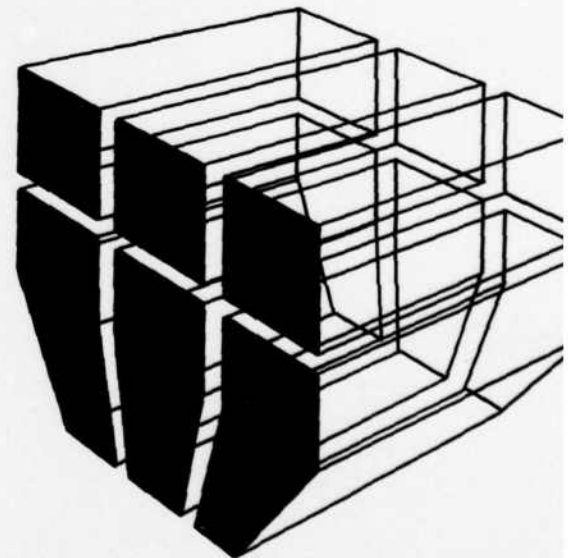
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The characteristics and sources of industrial wastewaters have been identified and methods for performing an industrial waste survey outlined.

Industrial wastewater control technologies have been summarized for preliminary treatment, primary treatment, biological treatment, stabilization, physical and chemical treatment, and sludge dewatering and disposal. Methods for solving industrial wastewater problems have been investigated, and various philosophies for pollution abatement outlined. Various disposal alternatives have been discussed and process selection guidelines provided. Methods for upgrading existing facilities have also been given.

This report also provides an overview of economic principles used to analyze a solution's costs. Example cost calculations have been provided for several alternatives in order to provide a basis for user applications of the economic principles.

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Industrial wastewater regulations have been summarized that provide the regulatory background for treating wastewaters generated by military industrial operations. Methods for handling and disposing of hazardous wastes have been identified. These include methods for identifying regulated and nonregulated hazardous wastes; hazard reduction techniques; contingency plans; and storage, treatment, and disposal techniques. Guidelines have been provided for generators, transporters, and owners and operators of storage, treatment, and disposal facilities.

The characteristics and sources of industrial wastewaters have been identified and methods for performing an industrial waste survey outlined. Survey methods discussed include objectives, organization, identification of sources, location of sampling and monitoring stations, measurement of wastewater flow, sampling, data evaluation, and safety factors.

Industrial wastewater control technologies have been summarized for preliminary treatment, primary treatment, biological treatment, stabilization, physical and chemical treatment, and sludge dewatering and disposal. Methods for solving industrial wastewater problems have been investigated, and various philosophies for pollution abatement outlined. Various disposal alternatives have been discussed and process selection guidelines provided. Methods for upgrading existing facilities have also been given.

One of the most important aspects of pollution control is an abatement method's cost-effectiveness. This report provides an overview of economic principles used to analyze a solution's costs. Example cost calculations have been provided for several alternatives in order to provide a basis for user applications of the economic principles.

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FOREWORD

This research was conducted for the Office of the Chief of Engineers (OCE) under FAD 2-3113 dated May 1983. The work was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (USA-CERL). Mr. Walt Medding, DAEN-ECE-G, was the OCE Technical Monitor.

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Chapter 1

Introduction

1-1. Background

a. The Army spends millions of dollars annually for operation and maintenance of its pollution treatment facilities. Thus, as increased limits are imposed on military spending, application of effective treatment technologies is becoming more important for efficient installation management.

b. One major source of pollutants is wastewater from industrial plants. Therefore, Army environmental engineers need to know how to identify and categorize industrial wastewaters and to understand the various available control technologies and their costs.

c. Managing industrial wastewater requires a broad understanding of water sources, industrial waste generation, and the environmental consequences of waste disposal. Nearly all industrial waste problems have an environmentally acceptable solution which can be carried out by a proven technology. The task of the environmental engineer is to identify the problem and apply the most appropriate technology.

d. Liquid wastes from industrial plants are disposed of into either water bodies or land. Some parts may be volatilized and discharged to the atmosphere, while part or all of the water may be recycled to the plant for reuse. Thus, an environmentally acceptable solution to an industrial waste problem should place equal emphasis on all three components of the environment: land, air, and water.

e. Although land disposal of wastewater has been studied recently, most industrial wastes are still discharged into the aquatic or marine environment.

f. There are many categories of water use: public water supply, industrial water supply, mining and mineral processing, irrigation and agricultural operations, fish and wildlife waters, and recreation. Each category requires a certain quality of water. Environmental legislation which regulates the quality of water for some uses has been passed (for example, drinking water parameters).

g. Wastewaters requiring disposal are typically discharged to surface waters. The wastewaters often contain contaminants that may adversely affect the environment of the receiving surface waters. Table 1-1 lists several typical undesirable industrial waste characteristics.

h. To control the detrimental effects of contaminants, Federal, State, and local governments have restricted wastewater discharge quality. These restrictions may define the required treatment system or specify effluent criteria, regardless of the treatment system. Sometimes the quality of and intended use of the receiving stream or body of water is considered. Each state has classified its major streams and bodies of water according to use.

i. Industrial plants on ocean coasts have historically discharged treated wastewater through an ocean outfall, a practice which has recently been discouraged by the U.S.

*Tables and figures may be found at the end of each relevant chapter.

Environmental Protection Agency. Although the ocean offers abundant dilution water, the fate of wastewater constituents and their effect on the marine environment should be studied carefully. Generally, most degradable organics can be discharged safely into the ocean with proper facilities. However, inadequate design of discharge facilities may result in oxygen depletion, color and turbidity, algae blooms, and public health problems. Nondegradable constituents and toxic materials should generally be eliminated. Once these materials reach the marine environment, their fate is unknown and uncontrollable. Toxic materials may be passed to man through marine food chains, or they may cause fish kills or have other sublethal effects on marine organisms.

j. Wastewater discharged to land should be considered on the basis of its individual constituents to ensure that no land is irreversibly removed from potential use. Land application of wastewater implies mixing and dispersion of the waste into the upper zone of the soil-plant system; the objective is assimilation of the constituents through microbial decomposition, absorption, adsorption, ion exchange, and plant uptake. A properly designed land application system should avoid groundwater or surface water contamination from return flows, air pollution, and other aesthetic nuisances from the application area. The assimilative capacities of each wastewater constituent must be carefully established to ensure that none are exceeded, since environmental damages are sometimes irreversible.

k. Industrial waste streams or their treatment byproducts may sometimes be classified as hazardous materials. In this case, the hazardous material component must be specifically addressed. Typical mitigation techniques include incineration, secure landfill disposal, encapsulation, and storage. Improper containment of these materials may result in significant negative impacts on both man and the environment.

l. Although only a small portion of the wastewater constituents is intentionally discharged to the air, unintentional discharges may be great enough to cause environmental concern. Atmospheric pollution can be caused by gaseous materials, particulates, or aerosols. The most frequent complaint is associated with malodorous gases near a treatment plant. Toxic gases and, less often, pathogen-carrying aerosols may also have significant public health effects. Some air pollutants are extremely harmful to plants or structures even though they are hardly detectable by human senses. Careful attention should be given to potential air pollution problems that may arise from any industrial waste treatment.

1-2. Purpose

The purpose of this report is to provide a general reference guide for Army engineers who must identify, design, or review industrial water pollution abatement projects and for personnel responsible for the operation and maintenance of domestic and/or industrial wastewater treatment plants. This report explains in detail the nature and origin of industrial wastewaters, regulatory requirements, and the final handling and disposal of the hazardous wastes. It describes the preparation of the industrial water survey needed to identify and categorize industrial wastewaters, and outlines control technologies, methodologies, and costs for solution development.

1-3. Explanation of terms and references

Abbreviations and special terms used in this report are explained in the glossary. Appendix A provides references and a bibliography.

1-4. Approach

Regulations applying to industrial wastewater treatment were summarized (Chapter 2), and methods for handling and disposing of hazardous wastes identified (Chapter 3). The sources of industrial wastewater were outlined (Chapter 4), and methods for setting up an industrial waste survey identified (Chapter 5). Various industrial wastewater control technology alternatives were investigated (Chapter 6), and methods for developing solutions to various pollution problems outlined (Chapter 7). Finally, the economics of various industrial wastewater treatments were analyzed and example calculations set up (Chapter 8).

1-5. Mode of technology transfer

It is recommended that the information in this report be issued as a DA Pamphlet and also incorporated into Technical Manual 5-814-3, *Domestic Wastewater Treatment*, and into other Technical Manuals of the 5-814 series. The report can also be used in its current form as a reference volume.

Table 1-1

Undesirable characteristics and effects of industrial wastes

<u>Constituent</u>	<u>Undesirable Characteristics</u>
Soluble degradable organics	Depletion of dissolved oxygen in streams, leading in severe cases to fish kills, development of anaerobic conditions, evolution of malodorous gases, and unsightly environment.
Toxic materials and elements	Adverse effects on aquatic life; accumulation of toxic materials and their transfer to man via food chains; introduction of toxic materials to domestic water supply systems.
Color and turbidity	Aesthetically undesirable; increased demands on water treatment plants; harboring of bacteria and viruses.
Refractory organics	Persistence in the environment for long periods; cause aesthetic (e.g., foam) or public health (e.g., chlorinated hydrocarbons) problems.
Oil and floating materials	Aesthetically undesirable; may interfere with natural stream reaeration.
Nutrients (nitrogen and phosphorus)	Enhance eutrophication (e.g., blooms of algae in lakes and ponded areas); critical in recreational areas.
Suspended solids	Create sludge deposits in streams which may result in malodorous and anaerobic conditions.
Acids and alkalis	Alter the natural buffer system in streams; endanger aquatic life; adversely affect water quality for domestic, industrial, and navigational use.
Heat	Thermal pollution causing depletion of dissolved oxygen; thermal barriers restrict movement of aquatic organisms and cause a shift in biotic composition.
Dissolved salts	Increase the salinity of receiving fresh water; impair reuse of water supplies (i.e., brackish water).

Chapter 2

Industrial Wastewater Regulations

2-1. Legislation

a. **National Environmental Policy Act.** The National Environmental Policy Act (NEPA) established environmental protection as a national goal. Key points of NEPA legislation were (1) requirement of Environmental Impact Statements (EIS) for all Federal projects and for all state or local projects funded or regulated by a Federal agency, and (2) establishment of the Council on Environmental Quality.

b. **Federal Water Pollution Control Act.** The 1972 amendments to the Federal Water Pollution Control Act (FWPCA) (commonly called the Clean Water Act) established national goals for eliminating all pollutant discharges by 1985 and called for attaining interim water quality standards to provide "fishable and swimmable" waters by July 1, 1983. This legislation also established requirements for:

- (1) Providing a permit system to restrict discharge of pollutants from point sources.
- (2) Developing technology to eliminate the discharge of pollutants into navigable waters.
- (3) Federal financing programs for construction of publicly owned treatment works.
- (4) Developing area-wide waste treatment management programs to ensure pollution control in each state.
- (5) Control of toxic pollutants.
- (6) Federal facility compliance with Federal, State, and local requirements.

Figure 2-1 summarizes other provisions of the legislation. Later, Congress passed the 1977 Amendments to the Federal Water Pollution Control Act; the most important changes were:

- (1) More time was allowed for compliance with certain regulations.
- (2) There was increased emphasis on controlling toxic pollutants.
- (3) EPA was authorized to issue "best management practices" regulations for controlling toxic and hazardous pollutants contained in industrial plant site runoff, spills or leaks, and discharges from other activities ancillary to industrial operations.
- (4) Requirements for pretreating industrial wastes before discharge to municipal sewage treatment systems were modified.
- (5) Federal facilities were required to investigate new pollution control technology before constructing new facilities.

c. Resource Conservation and Recovery Act of 1976. The Resource Conservation and Recovery Act (RCRA) of 1976 required controlling the handling and disposal of hazardous wastes. Figure 2-2 summarizes the features of RCRA. The Act's requirements for developing regulations for hazardous waste handling practices has probably had the greatest impact on water pollution control, especially with respect to industrial waste treatment. One of the most important features of RCRA is its establishment of a "cradle-to-grave" concept for handling of hazardous wastes. Generators of hazardous wastes will be required to initiate documentation regarding the transport, handling, and disposal of these wastes. Permits will be required in each step of the handling and disposal processes, and records will be kept by the waste generator to identify all persons having responsibility for transportation and disposal of a particular waste. Chapter 3 has additional guidance on hazardous waste.

d. Safe Drinking Water Act of 1974. The Safe Drinking Water Act (SDWA) required the establishment of national standards for all public water supplies. Figure 2-3 summarizes highlights of this law. The major impact of the Act's requirements on industrial waste management is the restriction it puts on underground injection of wastes. The regulations protect all aquifers or portions of aquifers which are drinking water sources and any aquifer which can yield water containing 10,000 mg/L or less of total dissolved solids. Permits will be required for all wells used for injection of industrial wastes. Permit holders must maintain the wells so as to prevent the contamination of drinking water supplies.

e. Other pertinent federal legislation. The Toxic Substances Control Act (TSCA) of 1976 requires control of chemicals which have a known adverse effect on human health. Some provisions of this Act relate specifically to the handling of polychlorinated biphenyls (PCBs). Pesticides are specifically regulated under provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended by the Federal Environmental Pesticide Control Act (FEPCA) of 1972 and the FIFRA Amendments of 1975. This Act requires registration of all new pesticide products and provides for Federal control of pesticide use. Although the direct implications of these laws with respect to industrial water pollution control are minor, some provisions may affect certain activities on military bases.

2-2. Summary

a. Summary. Environmental laws and associated industrial waste discharge criteria are in an evolutionary stage. Federal, State, and local requirements are in a constant state of refinement. For this reason, a detailed discussion of regulations promulgated under the Federal statutes would be obsolete before publication of this document. Furthermore, a discussion of potentially applicable State and local regulations, which in many cases prevail over Federal criteria, would be far too cumbersome to present within the scope of this report. For these reasons, the reader is referred to USA-CERL Technical Report N-56¹ which describes the Computer-Aided Environmental Legislative Data System (CELDS), for evaluation of pertinent environmental legislation and regulations.

b. CELDS was developed to respond to the Army's need for rapid, easy access to environmental legislation relevant to a specific project or activity, including industrial

¹J. van Weringh, et al., *Computer-Aided Environmental Legislative Data System (CELDS) User Manual*, Technical Report N-56/ADA061126 (U.S. Army Construction Engineering Research Laboratory, 1978).

waste treatment. This system, a collection of current Federal and State environmental laws, regulations, and standards has been developed for use by nonlawyers. Abstracts of the legislation are written in a straightforward narrative style. These abstracts are not intended to replace the original documents or resolve complex legal problems; their purpose is to provide quick access to current controls on activities that may influence the environment, and to supply informative data for environmental impact analysis and quality management.

c. Presently, the CELDS retrieval system contains legislation from all states and the Federal Republic of Germany. CELDS is continuously updated, and direct correspondence with the administering agencies is maintained to ensure the currentness and completeness of the abstracted environment legislation.

FEDERAL WATER POLLUTION CONTROL ACT

1972 AMENDMENTS - CLEAN WATER ACT

1. Water Quality goals established
2. Established NPDES Permit System for Discharges
3. Permits to be based on technology based effluent limits
4. Federal financial assistance provided for publicly owned treatment works
5. Regional administration of Federal Policy be established
6. Major research and demonstration efforts be made to develop treatment technology
7. Federal facilities shall comply with all Federal, State, and Local requirements

1977 AMENDMENTS

1. Increased Emphasis on Control Toxic Pollutants
2. Compliance date modified
3. Best Management Practice regulations to be issued
4. Modifications in Industrial Pretreatment Program
5. Federal facilities must investigate innovative pollution control technology

Figure 2-1. Highlights of the Federal Water Pollution Control Act.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

1. Established office of Solid Waste within EPA
2. Requires Hazardous Waste Management regulations including manifest system and permit requirements
3. Requires guidelines for Solid Waste Management
4. Provide technical and financial assistance to maximize the conservation and utilization of valuable resources
5. Developed criteria for landfill design and operation
6. Provide technical assistance to state and local governments

Figure 2-2. Features of RCRA.

SAFE DRINKING WATER ACT

1. Established national standards for public water supplies
2. Restricted underground injection of wastewaters

Figure 2-3. Highlights of Safe Drinking Water Act.

Chapter 3

Handling and Disposal of Hazardous Wastes

3-1. Hazardous waste characteristics

Hazardous wastes are those which "may significantly contribute to an increase in mortality, or an increase in serious irreversible or incapacitating reversible illness," whether properly or improperly managed. Full definition is in 40 CFR 261.3. Many discharged substances with various physical, chemical, biological, or radiological properties are considered hazardous, and diverse factors affect how hazardous such wastes are. They may occur as raw materials, as byproducts of industrial operations, or as a result of peripheral process activities (air pollutant scrubbers, equipment cleanup, etc). Regulations have established criteria for identifying hazardous wastes using specific physical and chemical characteristics, lists of known hazardous substances, and knowledge of industrial processes producing the wastes.

3-2. Regulations

Transport, storage, treatment, and disposal of hazardous wastes are regulated principally by the Environmental Protection Agency (EPA) and the Department of Transportation (DOT). The U.S. Coast Guard has regulations regarding planned and unplanned discharges of hazardous substances into navigable waters. To ensure compliance with the most current regulations, regulatory agencies should be consulted. Federal, State, and local regulatory agencies should be consulted. The 10 regional EPA offices would be likely first candidates.

3-3. Identification of regulated hazardous wastes

Regulations have established criteria for identifying hazardous wastes using specific physical and chemical characteristics, lists of known hazardous substances, and/or knowledge of processes generating the wastes. 40 CFR 261.6 should be consulted for regulations which apply to re-used, recycled, or reclaimed materials.

a. Hazardous waste characteristics. Wastes with one or more of the following characteristics should be considered hazardous and managed accordingly:

- (1) Ignitability: has a high potential for causing fire (see 40 CFR 261.21).
- (2) Corrosivity: can destroy human skin or corrode steel (see 40 CFR 261.22).
- (3) Reactivity: exhibits instability or undergoes violent or dangerous reaction (see 40 CFR 261.28).
- (4) Toxicity: when subjected to the EPA Extraction Procedure (EP), produces extract containing contaminants in concentrations exceeding maximum extract levels established by EPA (table 3-1). Suspect wastes should be analyzed for these properties as described in table 3-2. Material could also be assessed for infectious, radioactive, and other properties, if amendments to existing regulations designate these parameters as characteristic of hazardous wastes. Waste materials which are suspected of being radioactive should be tested and handled according to Nuclear Regulatory Commission (NRC) regulations. Infectious wastes should be handled according to Federal and/or local public health regulations.

b. Hazardous waste lists. There are several criteria for determining which materials may be included on hazardous waste lists. They may exhibit one or more hazardous characteristics, or they may be described as "acutely hazardous" or "toxic."

(1) Toxicity is a measure of the harmful, poisonous, or deadly effects of various agents on test organisms. Toxic wastes can cause fatality, serious irreversible illness, or incapacitating reversible illnesses in humans and/or laboratory test animals. Some substances, such as cyanide compounds and phosgene gas (COCl_2) are acutely toxic and are fatal to humans in low doses and over brief exposure periods. Other wastes cause adverse health effects only after long (chronic) exposures to low doses. For example, DDT and many other pesticides can accumulate to toxic levels in the body. However, the levels at which many substances exhibit chronic toxicity to humans are unknown.

(2) Criteria for listing "toxic" wastes include assessments of their toxic, carcinogenic (cancer-producing), mutagenic, teratogenic (malformation-producing), phytotoxic (plant-poisoning) aspects, and their effects on aquatic species. A substance's acute toxicity is evaluated in the laboratory. The degree of toxicity is usually expressed as the LD_{50} (the median dose required to kill, within a specified exposure period, 50 percent of all animals exposed to the agent). Based on results of mammalian studies, substances designated by EPA as "acutely hazardous" include:

(a) An oral LD_{50} toxicity of less than 50 milligrams per kilogram of tissue (using rats as test animals).

(b) An inhalation of LD_{50} toxicity of less than 200 milligrams per liter (using rabbits as test animals).

(c) A dermal LD_{50} toxicity of less than 200 milligrams per kilogram (using rabbits as test animals).

The EPA can provide lists of hazardous chemicals and chemical intermediates. Hazardous wastes are considered as either all waste streams containing one or more of these substances, or as uncleaned containers and inner liners for these waste streams.

c. Hazardous waste source lists. Many wastes have been designated as hazardous and listed according to specific or non-specific industrial sources, such as those from the production of iron, steel, pesticides, explosives, various organic chemicals, etc. These include process residues, emission control dusts, wastewater treatment sludges, spent solvents, spill residues, process intermediates, or by-products. The EPA can provide current lists of specific and non-specific source hazardous wastes. All the waste streams listed, plus wastes derived from handling or treatment of listed waste streams, are considered to be hazardous. References for hazardous waste lists are 40 CFR 261.30-33.

3-4. Nonregulated wastes

a. Some wastes, such as the following solid wastes, are not subject to control by EPA's hazardous waste regulations:

(1) Household wastes - garbage, refuse of sanitary wastes.

(2) Agricultural wastes - crop residues returned to the soil as fertilizers.

(4) Mining overburden - returned to the mine site.

(5) Drilling wastes - from the exploration of crude oil, natural gas, or geothermal energy.

Other nonregulated materials include untreated domestic sewage discharged to sewer systems of municipal wastewater treatment plants, point-source industrial discharges (wastewater treatment effluents) regulated by the Clean Water Act, irrigation return flows, or source, special nuclear, or by-product materials regulated by the Atomic Energy Act of 1954. Refer to 40 CFR 261.4.

Exclusions are regulated by the NRC, which has issued other disposal regulations. Transportation information should be obtained from the DOT Hazardous Materials Transportation Office. 40 CFR 261.4(6) also excludes some specific chrome-bearing wastes.

b. Wastes produced by "small quantity generators" are not regulated, with special exceptions. "Small quantity generators" are those producing fewer than 1000 kilograms of hazardous waste, or less than 1 kilogram of "acutely hazardous" or "toxic" waste, in a calendar month.

c. A waste may be temporarily excluded from regulation if the generator (not just "small quantity generators") requests a review of the waste's characteristics or of the testing methods which established the waste as hazardous. Persons seeking these reviews should consult the EPA or appropriate regulatory agency for information.

3-5. The manifest system

a. The EPA manifest is a control measure which accounts for the movement of a hazardous waste from its generation site to ultimate disposal, forming the basis for "cradle to grave" management of these wastes. A shipping document is also required by DOT for all hazardous materials. A manifest:

(1) Serves as a tracking device for hazardous wastes; the cradle-to-grave reporting system is designed to help protect human health and the environment during the transport of these wastes.

(2) Provides a base for recordkeeping and report requirements.

b. Manifests must be prepared by waste generators and submitted to transporters whenever hazardous wastes are sent off-site. A generator who accumulates hazardous waste for more than 90 days is regarded as operating a storage facility and must comply with 40 CFR 264, 265, and 270. The manifests must travel with the waste until it is delivered to a storage, treatment, or disposal facility. Generators must designate one facility which is permitted to handle the wastes; an alternate facility may be designated if an emergency prevents delivery to the primary facility. Specific information required on the manifest includes:

(1) A manifest document number.

(2) EPA identification numbers for the generator, transporter, and receiving facility.

(3) Waste description, including volume or weight of the waste, and type and number of containers (according to DOT specifications Title 49, Code of Federal Regulations, Parts 171-179; "Subchapter C, Hazardous Material Regulations" [November 1983]).

(4) Certification by the generator that all materials are prepared for transport in accordance with DOT requirements Title 49, Code of Federal Regulations, Parts 171-179; "Subchapter C, Hazardous Material Regulations" (November 1983).

c. Manifests must be signed by each person handling the waste, and copies returned to the generator when the waste is delivered to a storage, treatment, or disposal facility. Any changes in original delivery instructions must be included on the manifest.

3-6. Guidelines for generators and transporters

a. EPA regulations require all generators and transporters to follow acceptable management practices for handling hazardous wastes (Title 40, Code of Federal Regulations, Parts 261-265). Current titles are:

- 40 CFR 261 Identification and listing of hazardous wastes
- 262 Standards applicable to generators of hazardous waste
- 263 Standards applicable to transporters of hazardous waste
- 264 Standards for owners and operators of hazardous waste treatment storage, and disposal facilities
- 265 Interim status standards for owners and operators of hazardous waste treatment, storage, and disposal facilities.

Generators must determine whether their wastes are hazardous by testing, consulting the EPA's "Hazardous Waste List," or studying the waste-generation process. Wastes from different DOT hazard classes should not be mixed in the same container. Generators must have an EPA identification number before sending any hazardous wastes off-site for storage, treatment, or disposal. Transporters must also have identification numbers. Generators should not keep hazardous wastes on-site for more than 90 days, because then they become subject to storage facility regulations. Both generators and transporters are responsible for insuring that hazardous wastes sent off-site are properly prepared for transport according to DOT requirements for packaging, marking, labeling, and placarding (Title 49, Code of Federal Regulations, Parts 171-179; "Subchapter C, Hazardous Material Regulations" [November 1983]).

b. The Department of Defense (DOD) has appointed the Defense Property Disposal Offices (DPDOs) as its hazardous waste disposal agents. All wastes that are not internally recyclable should be presented to the local DPDO for disposal. Arrangements should be made with the local DPDO prior to shipping any hazardous wastes. The shipper should determine if the DPDO has the required permit and facilities for receipt and handling of the specific waste.

c. Both generators and transporters must keep records of all hazardous waste shipments for 3 years, starting when a transporter first accepts a waste from a generator. Generators should also keep results of all tests performed on wastes to assess their hazardous properties. Generators must notify EPA of all shipments failing to reach a designated facility. There is a 35-day period before notification is required. The EPA requires annual reports for both generators and transporters, which should include a waste's DOT hazard class, its EPA-listed waste category, and its hazardous characteristics. Table 3-2 gives an example of DOT hazard classes and respective codes. DOT sometimes changes its classification system; therefore, a current list should be obtained

from DOT, the EPA, or State Department of Solid Waste. Reports should also include information on lost manifests and international hazardous waste shipments (Title 40, Code of Federal Regulations, Parts 261-265, listed in paragraph 3-6a).

3-7. Guidelines for owners and operators of storage, treatment, and disposal facilities

a. **General management.** EPA's general facility standards (Title 40, Code of Federal Regulations, Parts 261-265) listed in paragraph 3-6a apply to all facilities that store, treat, or dispose of hazardous wastes, with a few exceptions. For example, publicly owned treatment works (POTWs), underground injection control programs (regulated by the Safe Drinking Water Act), and ocean disposal programs (regulated by the Marine Protection, Research and Sanctuaries Act) are not controlled by these standards, even though they may be handling hazardous wastes. Like generators and transporters, facility owners and operators must have EPA identification numbers to handle hazardous materials.

b. **Analytical requirements.** Facility owners and operators must obtain physical and chemical analyses of representative samples of all wastes received at the facility before wastes can be stored, treated, or disposed of. Such analyses must also be repeated when changes in the waste-generating processes have (or are thought to have) occurred. Any waste which appears to be different from what is designated on accompanying manifests should be analyzed. Facility owners and operators should outline sampling and testing procedures and sampling schedules in a general waste analysis plan which summarizes this information for all hazardous wastes received.

c. **Security.** To protect the public from potential health hazards, all storage, treatment, and disposal facilities should use basic security measures to guard against unauthorized entries to the facility. These measures should include provisions for: surveillance systems; artificial or natural barriers surrounding the facility; controlled entry at access points to the facility regulated by electronic devices, guards, etc.; and posted warnings against unauthorized entry (in appropriate languages for states bordering Canada or Mexico).

d. **Records.** Facilities must sign all manifests accompanying hazardous waste shipments and return appropriate copies to the generators. Facility owners and operators must keep records describing the characteristics, quantities, and locations of all hazardous wastes received. These records should also include methods of storage, treatment, or disposal of wastes, as well as inspection records, monitoring, analytical results, etc. When a facility is closed, these records should be forwarded to the EPA and local land management officials.

e. **Groundwater monitoring.** Owners and operators of facilities that treat, store, or dispose of hazardous wastes in surface impoundments, waste piles, landfills, or land treatment units must conduct a monitoring and response program to ensure protection of groundwater from contamination. Groundwater sampling systems must include enough wells, typically at least three, strategically located to provide a typical sample of water from the top aquifer. 40 CFR 265.91 requires one monitoring well upgradient and three wells downgradient. Sampling must be done at least twice a year during the active life and post-closure period of the facility. The following should be measured: pH, specific conductance, total organic carbon (TOC), total organic halogens (TOH), and concentrations of specific contaminants. Normal background levels for these parameters must be established using analytical well data. All samples must be carefully compared with background data to determine if leachate from the facility has caused a statistically

significant degradation in groundwater quality. Groundwater monitoring program requirements for a particular facility are enumerated in the facility's operating permit, issued by the EPA Regional Administrator.

f. Closure of facilities. EPA regulations define specific measures which must be taken before and after closure of storage, treatment, and disposal facilities. These include:

- (1) Installation of a final cover to prevent leachate generation.
- (2) Facility maintenance to minimize potential for release of wastes to the environment. Both the Interim and Permanent standards require postclosure care for 30 years.
- (3) Removal or final disposal of all waste inventory, including all equipment used to handle hazardous wastes.
- (4) Notification of generators and transporters of the final date for receiving hazardous wastes.
- (5) Notification of regional authorities about projected facility closure date.
- (6) Provisions for post-closure groundwater monitoring system in compliance with existing regulations.

g. Corrective action programs. If a facility exceeds the groundwater protection standard established in its operating permit, the owner or operator must begin a corrective action program. This program must treat or remove hazardous constituents. More vigorous monitoring, including a larger number of wells and more frequent sampling, may be required to demonstrate the effectiveness of actions taken. Corrective action programs cannot be stopped until groundwater protection standards have not been exceeded for at least three consecutive years. All corrective action programs must be established and operated according to guidelines specified by the EPA Regional Administration in the facility's permit.

3-8. Hazard reduction techniques

Two major problems which may occur from improperly designed or managed facilities:

- Fires, explosions, or production of toxic fumes caused by violent reactions of ignitable, reactive, or incompatible wastes.
- Contamination of the environment by hazardous pollutants. EPA regulations require special considerations to get rid of these hazards.

a. Guidelines for storage tanks and containers. Proper management of hazardous waste tanks and containers minimizes potential health and environmental hazards. Examples of possible measures include:

- (1) Containers constructed of materials compatible with wastes stored in them, particularly if the wastes are highly corrosive.
- (2) Compliance with DOT regulations for tank and container reuse.

- (3) Routine, frequent inspections for leaks or ruptures.
- (4) Safe locations, well inside the facility's boundaries, for all hazardous waste storage vessels.
- (5) Adequate cutoff devices for emergency shutdown of waste feed to tanks.
- (6) Maintenance of adequate freeboard in uncovered tanks, unless equipped with drainage controls or surrounded by dikes to contain any spills.

b. Special considerations for highly reactive wastes. Special management procedures are required of facilities handling ignitable, explosive, reactive, or incompatible wastes. Storage tanks, containers, and waste piles should not be placed in areas in which conditions would cause them to undergo violent reactions. Ignitable and explosive wastes should not be stored near machinery which gives off sparks or large quantities of heat. Incompatible or reactive wastes should not be stored in adjacent containers or placed in the same pile. Ignitable or explosive wastes should not be stored in waste piles unless they are protected from conditions which encourage fires or explosions. When possible, all ignitable, explosive, reactive, or incompatible wastes should be pretreated to render them unreactive before storage or disposal. Table 3-3 gives examples of incompatible wastes and hazards produced by certain waste combinations. Regulatory agencies must be consulted regarding specific applications to ensure compliance.

c. Selection of facility sites. Site selection for hazardous waste management facilities is a critical factor in minimizing the potential for groundwater contamination by leachate and runoff. These guidelines are discussed in 40 CFR 264.18(a). General areas to be avoided include:

- (1) Limestone or highly fractured rock quarries and most sand and gravel pits, which are usually good aquifers.
- (2) Swampy areas, unless adequately drained to get rid of standing waters.
- (3) Floodplains with a high potential for inundation by surface waters.
- (4) Any permeable material with a high water table.

Good sites include areas such as:

- (1) Clay pits if they are kept dry.
- (2) Flat upland areas with a great enough impermeable layer of soil, such as clay, overlying aquifers.
- (3) Regions near the heads of gullies in rough topographical regions where there is very little surface water.

3-9. Contingency plans

a. Storage, treatment, and disposal facilities require careful management to avoid the release of hazardous materials to the air, soil, or water. Contingency plans must be prepared for use in emergencies such as fires, explosions, or unplanned releases of hazardous materials. The guidelines for developing and the requirements for the

necessary contingency plans are found in 40 CFR 264.30-56. Actions must be designed to minimize or eliminate long- and short-term dangers to humans and the environment.

b. Generators and transporters of hazardous wastes, as well as owners and operators of storage, treatment, and disposal facilities, must have effective emergency plans ready to implement immediately if fire or explosion occurs or hazardous materials are released.

c. The plan should contain emergency procedures, locations of emergency equipment, notification numbers for local emergency response teams, and shutdown and evacuation procedures for personnel. Examples of required emergency equipment are:

(1) Communications or alarm systems, including an internal system for warning personnel and an external system to summon emergency response teams (fire and police, other rescue and specialized clean-up crews).

(2) Portable fire extinguishers.

(3) Spill control and decontamination equipment.

(4) Adequate water supply for sprinkler systems, etc.

The plan must designate an emergency coordinator to direct emergency operations and coordinate response team activities. He/she must identify the released waste and assess its potential hazard, considering the nature, quantity, source, and exposed area of the release. The emergency coordinator is responsible for notifying the authorities designated in the contingency plan.

d. Hazardous waste spills posing serious health hazards must be reported immediately to designated on-the-scene regional coordinators. Such spills might also be reported to the National Response Team. The report should include information such as:

(1) Name and telephone number of the reporter.

(2) Location of the spill (facility address or geographic region).

(3) Time and type of incident (discharge, fire, explosion, etc.)

(4) Extent of injuries, if any.

(5) Name and quantity of material involved.

(6) Possible environmental or health hazards resulting from release of hazardous material.

e. Transporters must take immediate action to protect human health and the environment when a hazardous waste spill occurs. Actions might include immediate removal or containment with temporary dikes.

f. Transporters having hazardous spills must submit written reports containing information specified in DOT regulations to:

The Director, Office of Hazardous Materials Regulations
Materials Transportation Bureau
Department of Transportation
Washington, D.C. 20790

3-10. Storage, treatment, and disposal methods

Storage facilities hold wastes until they are treated, disposed of, or stored elsewhere. Treatment processes change the physical, chemical, or biological characteristics of a hazardous waste to render it less hazardous, reduced in volume, or easier to recover or store. Disposal facilities are those in which hazardous wastes are permanently placed into land or water, where the waste will remain after facility closure. Table 3-4 summarizes typical storage, treatment, and disposal options, applications, and special operating considerations. These are based on existing EPA regulations and could be subject to change.

a. Surface impoundments

(1) Surface impoundments are natural topographic depressions or man-made excavations of diked areas, formed mainly of earthen materials or lined with man-made materials. Examples include holding, storage, settling, and aeration pits, ponds, and lagoons. Since impoundments usually hold collections of liquids or liquid-bearing wastes, they can pose serious health or environmental hazards if leakage to groundwaters occurs. Other potential problems include air emissions of volatile wastes or spills from overtopped basins (pits, ponds, etc). NPDES requirements regulate all discharges from surface impoundments.

(2) Hazardous wastes may be stored or treated in surface impoundments designed to prevent releases to the environment. The impoundment must have a liner to prevent migration of wastes to adjacent soil, groundwater, or surface water. A minimum freeboard of 60 centimeters (2 feet) is needed to prevent spillage. Natural covers, such as rock, shale, or grass, must be used to protect the structural integrity of earthen dikes. Freeboard and dikes must be inspected weekly and after storms for evidence of deterioration, malfunction, or improper operation. Surface impoundments may be used for hazardous waste disposal if closure and post-closure procedures are observed. Detailed regulations on the design and operation of surface impoundments are found in 40 CFR 265.220-250.

b. Waste piles

(1) A waste pile is a collection of noncontainerized dry materials that is often used to treat or store hazardous wastes. Although liquid-bearing wastes may not be placed in waste piles, contaminated runoff or leachate can be hazardous if it leaks to groundwater. Wind dispersal of dry waste components can also be hazardous.

(2) Waste piles must have a liner to prevent migration to adjacent soil, groundwater, or surface waste. Runoff and leachate collection systems are also required, as well as run-on diversion systems. All release control systems must be inspected weekly and after storms for evidence of deterioration, malfunction, or improper operation.

(3) Detailed regulations regarding design and operation of waste piles, as well as closure and post-closure care and special requirements for ignitable, reactive, or incompatible wastes, are given in 40 CFR 265.250-258. Closure rules are in 40 CFR 264.220. Run-on and runoff controls are discussed in 40 CFR 264.272.

c. Land treatment

(1) A land treatment facility is one in which the hazardous wastes are applied onto or incorporated into the soil by tilling, contouring, or other typical farming techniques. Wastes which can be biologically degraded by soil microorganisms or made less hazardous or nonhazardous by chemical reactions in the soil may be suitable for land treatment. This technique is used primarily for oily wastes, but may be appropriate for other wastes. Potential health and environmental problems include groundwater and soil contamination from inadequately degraded wastes and degradation reaction by-products. Before land application, the owner or operator of a land treatment facility must demonstrate that candidate hazardous wastes can be completely degraded, transformed, or immobilized in the treatment-zone soils. Land treatment facilities must provide for both unsaturated (aeration) zone monitoring and groundwater monitoring. Soil core and soil pore samples taken in the unsaturated zone provide information about the degree of treatment which wastes have received; groundwater monitoring provides a basis for detecting contamination.

(2) Crops may be grown on land treatment facilities; however, facility owners and operators must test them to ensure that they will not pose a health hazard. These tests should include:

(a) Analysis for cadmium, lead, mercury, and arsenic.

(b) Analysis for the toxic contaminants listed in table 3-1.

(c) Field tests demonstrating that cadmium, lead, mercury, or arsenic will not be taken up by crops or by food-chain animals.

(3) EPA regulations restrict application rates of wastes with significant levels of cadmium; the rates vary with respect to soil exchange capacity, soil pH, and cadmium concentrations. Current regulations should be reviewed before growing food-chain crops on land treatment facilities.

d. Landfills

(1) A landfill is a collection of dry waste material which is disposed of on or in the ground. Waste piles used as disposal facilities are considered landfills. Although liquid-bearing wastes may not be put in waste piles, contaminated runoff or leachate can pose health and environmental hazards if it leaks to groundwater. Wind disposal of dry waste components can also be hazardous.

(2) Landfills used for final disposal of hazardous wastes must be designed to prevent releases to the environment. They must have a liner to prevent contaminants from migrating to adjacent soil, groundwater, or surface water. Besides provisions for preventing wind dispersal of dry wastes, general operating conditions require runoff and leachate collection systems and run-on diversion systems. During the active life of the facility, all release control systems must be inspected weekly and after storms for evidence of deterioration, malfunction, or improper operation.

(3) Upon closure, the landfill must be capped with a final cover to prevent migration of liquids. Liquid management and groundwater monitoring systems must be maintained during the post-closure care period.

(4) Detailed regulations on the design and operation of landfills are given in 40 CFR 264.300-316.

e. Thermal treatment

(1) Thermal treatment is defined as treatment "in a device which uses elevated temperatures as the primary means to change the chemical, physical, or biological character or composition of the hazardous wastes." Such processes include incineration, molten salt pyrolysis, and calcination. EPA standards prohibit thermal treatment by open burning; however, open burning or detonation of waste explosives is permitted in accordance with the Department of Defense explosives minimum separation distances (tab 3-5).

(2) Incinerators, which are used mostly to treat hazardous wastes rather than to provide steam (power boilers), are regulated by EPA standards. They must be operated within limits set forth in permit specifications, based on case-by-case trial burn performance data. Continuous monitoring is required for important process control variables, including combustion temperature, waste feed rate, air feed rate, and emissions. There should be steady-state operation of the combustion or other thermal processes before introducing hazardous waste to the system.

(3) Detailed regulations on the design and operation of incinerators are given in 40 CFR 264.340-382.

f. Underground injection wells

(1) Underground injection, or deep-well disposal, involves the injection of a waste into a confined permeable rock layer, usually more than 1000 meters below the surface. These wells should be located in regions that are isolated from freshwater aquifers to prevent contamination of existing or potential public water supplies. Other potential problems with deep-well disposal are earthquakes, activation of faults, or pressurized release of wastes from the wells into the atmosphere. Careful selection of sites should prevent these problems.

(2) Generally, the most favorable sites for underground injection are along synclinal basins and coastal plains, which usually have thick layers of sedimentary rock containing salt deposits. Recommended would be areas of unconsolidated sedimentary rock and occasional salt deposits. Geological considerations require that injection zones:

(a) Have sufficient porosity, thickness, permeability, and aerial extent to ensure safe injection (for example, sandstone or fractured limestone), or

(b) Are below the level of freshwater aquifers and confined by a relatively impermeable rock (for example, salt or shale and clay).

Other factors important in the selection of a site include considerations of:

(a) Physical and chemical properties of waste to determine compatibility with the receiving rock; for example, injection of acidic wastes into a limestone reservoir increases the rock's permeability, and consequently, the storage volume.

(b) The well's depth, the thickness of the injection zone, and the reservoir's fluid pressure, permeability, porosity, etc., which influence the rate at which a reservoir rock accepts a waste.

A monitoring system is needed to determine direction and rate of waste movement away from the point of injection and the stability of the reservoir rock. Deep observation wells in the disposal aquifer near the injection well provide information about the movement of waste; shallow observation wells permit water quality monitoring to detect any upward movement of wastes. The location of all old or abandoned oil or gas wells, as well as freshwater-bearing zones, is needed to help define the geology of a proposed injection site before beginning this type of disposal program. Figure 3-1 shows how liquid wastes could potentially enter freshwater aquifers through abandoned wells.

(3) EPA regulates underground disposal of hazardous wastes in Class I and Class IV underground wells. The Underground Injection Control Program also regulates underground injections, particularly to protect underground drinking water sources. Therefore, owners or operators of underground injection wells used to dispose of hazardous wastes must coordinate with appropriate regulatory agencies.

g. Chemical, physical and biological treatment. Various biological processes, as well as many physical-chemical processes, including filtration, ion exchange, reverse osmosis, centrifugation, distillation, and neutralization may be used to treat hazardous wastes (chap 6). Facilities which use these processes should provide for routine inspection of all process monitoring, discharge control, and safety equipment. The structural integrity of all materials supporting process equipment and discharge confinement structures should routinely be evaluated for deterioration.

Table 3-1

Maximum concentration of contaminants for characteristics of toxicity
 (From Title 40, Code of Federal Regulations, "Identification and Listing of
 Hazardous Waste" [July 1983].)

EPA Hazardous Waste Number	Contaminant	Maximum Concentration (milligrams per liter)
D004	Arsenic.....	5.0
D005	Barium.....	100.0
D006	Cadmium.....	1.0
D007	Chromium.....	5.0
D008	Lead.....	5.0
D009	Mercury.....	0.2
D010	Selenium.....	1.0
D011	Silver.....	5.0
D012	Endrin (1, 2, 3, 4, 10-hexa- chloro-1, 7-epoxy-1, 4, 4a, 5, 6, 7, 8, 8a-octahydro-1, 4-endo, endo-5, 8-dimethano naphthalene).....	0.02
D013	Lindane (1, 2, 3, 4, 5, 6 - hexa-chlorocyclohexane, gamma isomer).....	0.4
D014	Methoxychlor (1, 1, 1-Trichloro-2, 2-bis [p-methoxyphenyl] ethane).....	10.0
D015	Toxaphene (C ₁₀ H ₁₀ Cl ₈ , Technical chlorinated camphene, 67-69 percent chlorine).....	0.5
D016	2, 4-D, (2, 4-Dichlorophenoxyacetic acid).....	10.0
D017	2, 4, 5-TP Silvex (2, 4, 5- Trichlorophenoxypropionic acid).....	1.0

ble 3-2

ardous properties of wastes

Hazard	Hazardous Property Description	Determination Procedure Reference	Examples
Ignitability	(a) Liquids: flash point less than 60°C (140°F) (exception: aqueous solutions with less than 24% alcohol by volume)	(1)	gasoline, rocket propellant
	(b) Non-Liquids: produce fire by friction, moisture absorption, or spontaneous chemical change; "when ignited, burn so vigorously and persistently that they create serious hazards"		calcium carbide -- general acetylene gas when exposed to water
Corrosivity	(c) Ignitable gases: flammable		hydrogen, acetylene, propane, butane
	(d) Oxidizers		nitric acid, potassium permanganate
	(a) Aqueous Solutions: pH less than or equal to 2.0, or greater than or equal to 12.5	(2)	battery acids, caustic (sodium hydroxide)
	(b) Liquids: corrode steel (SAE 1020) at rate exceeding 6.35 mm (.25 inch) per year at 55°C (130°F), by NACE standards	(3)	sulfuric acid, sodium hydroxide, ferric chloride

ASTM Standards for Ignitability, ASTM, 1916 Race St., Philadelphia, PA 19103.
Test Methods for the Evaluation of Solid Wastes, Physical/Chemical Methods, Solid Waste Information (USEPA), as reported in 40 CFR, part 261.
National Association of Corrosion Engineers, P.O. Box 986, Katy, TX 74450.

-2 (Cont'd)

Hazardous Property Description	Determination Procedure Reference	Examples
activity (a) exhibits instability: tending to undergo violent change without detonating		
(b) undergoes violent reaction with water		lithium; metallic sodium
(c) forms explosive mixtures with water		lithium; hydride
(d) can generate toxic gases, vapors, or fumes		calcium hypochlorite + acid --> chlorine gas
(e) contains sulfide or cyanide, which can generate toxic gases at pH less than 2.0 or greater than 12.5		spent cyanide bath solution from metals recovery operation
(f) can detonate or explode when subjected to irritant or heat under confinement		
(g) can detonate or explode at normal temperature and pressures		
(h) contains a class A or class B explosive		Class a: dynamite, TNT, nitroglycerine Class B: rocket propellant, military ammunition

2 (Cont'd)

ard	Hazardous Property Description	Determination Procedure Reference	Examples
city	contains contaminants in concentration exceeding maximum contaminant levels.	(4)	see table 3-1

Toxicity Test Procedure, available from Solid Waste Information, USEPA, 26 W. St. Clair St., Cincinnati, OH 45268.

Table 3-3

Examples of hazards from potentially incompatible* wastes
 (From Title 40, Code of Federal Regulations, 265, App. V.,
 "Interim Status Standards for Owners and Operators of
 Hazardous Waste Treatment, Storage, and Disposal Facilities"
 [July 1983].)

Sub-Group	Hazard	Group A Wastes	Group B Wastes
I	Heat generation; violent reaction	Acetylene sludge Alkaline caustic liquids Alkaline cleaner Alkaline corrosive liquids Alkaline corrosive battery fluids Caustic wastewater Lime sludge and other corrosive alkalies Lime wastewater Lime and water Spent caustic	Acid sludge Acid and water Battery acid Chemical cleaners Electrolyte, acid Etching acid liquid or solvent Pickling liquor and other corrosive acids Spent acids Spent mixed acid Spent sulfuric acid
II	Fire or expulsion; generation of flammable hydrogen gas	Aluminum Beryllium Calcium Lithium Magnesium Potassium Sodium Zinc Other reactive metals and metal hydrides	Any waste in Groups I-A or I-B
III	Fire, heat, or heat explosion	Alcohols Water	Any concentrated waste in Groups I-A or I-B, metal hydrides, calcium, lithium, potassium, SO_2Cl_2 , $SOCl_2$, PCl_3 , CH_3SiCl_3 ; other water-reactive waste

Table 3-3 (Cont'd)

Sub-Group	Hazard	Group A Wastes	Group B Wastes
IV	Fire, explosion, or violent reaction	Alcohols Aldehydes Halogenated hydrocarbons Nitrated hydrocarbons Unsaturated hydrocarbons Other reactive organic compounds and solvents	Concentrated Group I-A or I-B wastes, Group II-A wastes
V	Generation of toxic hydrogen cyanide or hydrogen sulfide gas	Spent cyanide and sulfide solutions	Group I-B wastes
VI	Fire, explosion, or violent reaction	Chlorates, chlorine, chlorite Chromic acid Hypochlorites Nitrates Nitric acid, fuming Perchlorates Peroxides Other strong oxidizers	Acetic acid and other organic acids Concentrated mineral acids Group II-A wastes Group IV-A wastes Other flammable and combustible wastes

*Potential hazards created by mixing Group A wastes with Group B wastes of that subgroup, or other combinations as indicated.

Table 3-4

Examples of storage, treatment, and disposal methods for hazardous wastes and special considerations for each method

Method	Application			Special Considerations
	Storage	Treatment	Disposal	
Surface Impoundments	X	X	X	Minimum freeboard - 60 centimeters (2 feet); grass, shale, rock, etc. - protective covers for earthen dikes. Both 40 CFR 26.4 and 265 require removal of all waste residues and contaminated soil at closure of a surface impoundment.
Waste Piles	X	X		May be managed as a landfill; adequate protection from wind dispersal, run-on diversion and run-off collection systems; dikes, walls, etc., separating piles of incompatible wastes.
Land Treatment		X		Unsaturated zone (soil core and soil pore monitoring); groundwater monitoring; run-on/runoff controls; special restrictions for cadmium, arsenic, mercury, and lead in facilities growing food chain crops.
Incinerators		X	X	Steady-state operation required prior to waste treatment startup; combustion and emission control; equipment monitoring.
Thermal Treatment		X		Steady-state (normal) operation before introducing hazardous waste with modification for batch processes; open burning banned with exception of open detonation of explosives - DOD regulations; monitoring inspections - instruments, emissions, thermal process.
Chemical, Physical and Biological Treatment		X		Routine inspections of all discharged control and safety equipment, monitoring equipment data, construction materials of process equipment and areas surrounding discharge confinement structures; cut-off or by-pass system required on continuous-feed tanks.
Underground Injection			X	Hazardous waste regulations apply to Class I and Class IV wells; standards - under development.
Landfills			X	Run-on diversion system runoff collection systems controls to minimize wind dispersal of waste; records, including location, contents and dimensions of all cells with benchmarks indicated. Special closure considerations: (1) controls for pollution migration into groundwater, surface, air, etc.; (2) controls for surface water infiltration; (3) controls to prevent erosion; (4) maintenance of final cover; (5) maintenance of leachate collection and monitoring systems; (6) maintenance and monitoring of gas collection systems; (7) restricted access with respect to intended use after closure.

Table 3-5. Department of Defense minimum distance guidelines for open detonation of waste explosives (From Title 40, Code of Federal Regulations, 265.382, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities" [July 1983].)

Pounds of Waste Explosives or Propellents	Minimum Distance From Open Burning or Detonation to the Property of Others
0 to 100	204 meters (670 feet)
101 to 1,000	380 meters (1,250 feet)
1,001 to 10,000	530 meters (1,730 feet)
10,001 to 30,000	690 meters (2,250 feet)

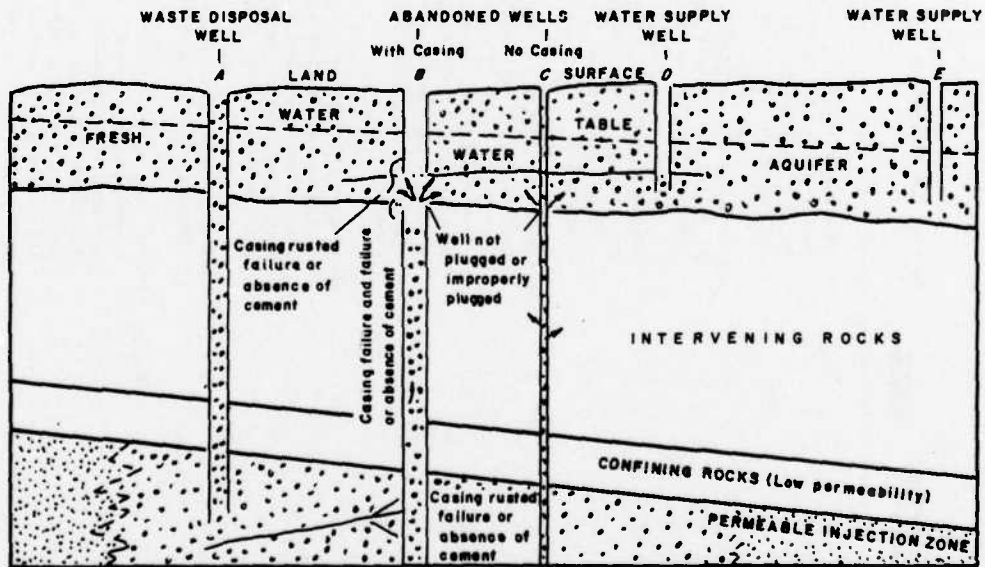


Figure 3-1. An idealized diagram showing potential ways for liquid wastes to enter freshwater aquifers through abandoned wells.

Chapter 4

Nature and Origin of Industrial Wastewater

4-1 Industrial wastewater characteristics

a. General description. The Environmental Protection Agency has defined three categories of pollutants:

(1) Conventional, which include pH, biochemical oxygen demand (BOD), total suspended solids (TSS), oil, and grease.

(2) Nonconventional, which include chemical oxygen demand (COD), total organic carbon (TOC), and ammonia-nitrogen.

(3) Toxics, which include an EPA list of pollutants consisting primarily of heavy metals and organic materials.

In industrial wastewaters, these pollutants consist of a complex mixture of constituents (organics, inorganics, particulates, and biological) or consist of a single component. Many analytical tests have been developed to define the constituent makeup to determine a wastewater's impact on the environment or the treatment required. Figure 4-1 shows a hierarchy of these analytical procedures. Most of the analytical techniques discussed in this chapter are in *Standard Methods*.²

b. Organic constituents. Biodegradation consumes dissolved oxygen in water; this typically reduces aquatic diversity and thereby reduces the water's biological and aesthetic quality. Four tests are used to measure organic material in wastewater for the equivalence of oxidizing agents reacting with organic substances: the conventional pollutant parameter, BOD; the non-conventional pollutant parameters COD and TOC; and total oxygen demand (TOD).

(1) Biochemical oxygen demand (BOD). The BOD test indirectly measures biodegradable organic material. The test does not measure specific organic materials, but instead indicates how much oxygen is needed to stabilize the biodegradable organic fraction. This test simulates the impact of a wastewater on the dissolved oxygen level in the receiving waters. Enough dissolved oxygen must be provided to maintain aquatic life. The BOD test measures the oxygen depleted after 5 days within a closed system containing a mixture of wastewater and an acclimated seed of microorganisms. The test may also measure a quantity of reduced inorganic materials such as ammonia or sulfites.

(2) Chemical oxygen demand (COD). COD indirectly measures organic material. The COD does not necessarily indicate the potential impact on the receiving waterway since it does not consider biodegradability. COD measures the oxygen equivalent of the organic material oxidized by dichromate or permanganate during acid digestion. This parameter was developed to substitute for the more time-consuming BOD test.

(3) Total organic carbon (TOC). The TOC test also indirectly measures organic material; however, it does not necessarily indicate potential impact on receiving stream quality. The test simply measures the quantity of carbon dioxide freed during

²*Standard Methods for the Examination of Water and Wastewater*, 15th ed. (APHA-AWWA-WPCF, 1981).

combustion of the wastewater sample. TOC is the amount of carbon present in the organic molecules in the sample.

(4) Total oxygen demand (TOD). The TOD test is somewhat like the TOC test in that it is an indirect way to measure organic concentrations. However, TOD, which is the difference in the oxygen content of a sample before and after combustion, is the most direct measurement of oxygen demand. TOD measures how much oxygen is needed to burn the contaminants in the wastewater sample.

(5) Organic parameter relationships. A preliminary step in developing treatment alternatives should be to analyze the wastewater's organic parameter relationships with the above four tests. This analysis will provide a general idea of the treatment technologies most likely to be effective.

(a) Figure 4-2 shows the theoretical oxygen demand (ThOD), TOD, COD, BOD, theoretical organic carbon (ThOC), and TOC yields for a hypothetical wastewater. This figure demonstrates the relative biodegradability of a wastewater and shows qualitatively how the characteristics are related. These data are only for the example in the figure and should not be applied elsewhere. Since the relative ratios are wastewater-dependent, they must be determined in the laboratory for each specific case.

(b) In general, one would expect the stoichiometric COD/TOC ratio of a wastewater to approximate the molecular ratio of oxygen to carbon ($32/12 = 2.66$). Actually, the ratio limits would range from zero when the organic material is resistant to dichromate oxidation, to 5.33 for methane, or higher when inorganic reducing agents are present. The BOD/TOC ratio of an industrial waste would be subject to many variables and could not be expected to follow any pattern. This variance is the result of the COD yield of the compounds; wastestreams containing some of these substances would be subjected to a fluctuating COD/TOC ratio if the component concentration changes. The more an industrial wastestream varies, the more its COD/TOC ratio will change. This is a good indicator of how consistent wastewater constituents are and can be helpful in predicting the design organic load applied to a biological treatment facility.

(c) TOC and COD are both valid measures of pollution, and both can be correlated to BOD values in many applications. The conjunctive use of these parameters in terms of BOD, COD, TOC, and TOD ratios can help evaluate the organic nature of an unknown waste properly. There are several other important organic evaluation parameters, such as oil and grease content, phenols, and organics containing toxic functional groups. Oil and phenol analyses are very significant when evaluating unit processes for treating chemical, petrochemical, and refinery wastewaters. Quantities of toxic organic compounds, such as pesticides and other haloforms that are present in wastewaters entering the environment are very significant and require control.

(6) Oil and grease. Oil and grease in wastewater is usually a characteristic of petroleum-based chemical manufacturing, machining, vehicle maintenance, kitchen, and restaurant wastes. Oil and grease is an indirect measurement defined and quantified by an analytical procedure. Oil and grease is not an absolute quantity of a specific substance but rather is an expression of all substances extracted by the organic solvent (Freon) used in the test procedure. Thus, oil and grease may include hydrocarbons, fatty acids, soaps, fats, waxes, oils, and any other Freon-extractable substance that will not volatilize during the test procedure. Oil and grease is an obnoxious, and in large quantities, a dangerous environmental pollutant. It is hard to remove by conventional treatment processes such as anaerobic or aerobic biological processes and is an interference in

most physical-chemical treatment processes. Oil and grease treatment usually consists of removal by skimming or flotation and disposal by reuse, incineration, or landfilling.

(7) Phenol. Phenol is found most often in the petroleum-refining and chemical-processing industries. It is soluble in water, oils, carbon disulfide, and numerous organic solvents. The wet chemical analysis of phenol directly measures a variety of phenolic compounds. In high concentrations, phenol is a toxic and mutagenic substance and may be absorbed through the skin. Most phenolic compounds can be treated in acclimated biological treatment systems.

(8) Cyanide. Cyanide is found in metal plating, petroleum-refining, plastics, and chemical manufacturing wastewaters. The cyanide ion is highly toxic to aquatic life and humans at low concentrations. Most cyanide appears as a chemical complex, often in an organo-metallic complex, rather than the simple cyanide ion, CN. Thus, cyanide toxicity depends on the species of the complex. Typically, cyanide-contaminated wastewaters require treatment using alkaline chlorination or electrolytic destruction. At low concentrations, biological treatment units can provide some treatment; however, toxicity to the biomass from cyanide spills can be a problem with this type of system. Ferro-cyanides are the most difficult to destroy.

(9) Surfactants. Surfactants are found in industrial cleaning agents which may make up part of the wastewater. Their presence is indicated when colloidal particles are dispersed and will not settle, or when substantial foaming occurs in the aeration basin.

(10) Other organic compounds of significance. Many wastewaters contain toxic organic compounds that may be identified only by direct measurement using specialized analytical techniques such as infrared spectrophotometry, gas chromatography, and/or mass spectrometry. Other analytical methods may be required, depending on the substance. The need to analyze or treat these organic compounds is site-specific. If a substance is used or manufactured in a chemical process or other industrial activity, it may be present in the wastewater. Typically, candidate compounds are defined by evaluating the chemicals used and/or formed in the industrial process.

c. Inorganic parameters. Many inorganic parameters are important when assaying potential toxicity, general characterization, or process evaluation.

(1) Acidity. A wastewater's acidity is important because an acceptable environment for biological treatment requires a neutral or near-neutral water. Regulatory authorities typically have criteria which establish strict pH limits to final discharges. Acidity is due to the un-ionized portions of weakly ionizing acids, hydrolyzing salts, and certain free mineral ions. The latter is probably the most significant, since it is hard to predict neutralization requirements when diverse forms of mineral acidity are prevalent. Microbial systems may sometimes reduce acidity through biological degradation of organic acids or increase it through nitrification or other biochemical processes. Acidity is expressed as milligrams/liter CaCO_3 .

(2) Alkalinity. Alkalinity, which may be considered the opposite of acidity, is also expressed as milligrams/liter CaCO_3 . Alkalinity is provided by carbonate, bicarbonate, and hydroxide components of natural water supplies. Industrial wastes often contain these species. Alkalinity determinations are required in maintaining pH control and for determining chemical requirements for various unit processes such as chemical coagulation.

(3) pH. pH represents the negative logarithm of the hydrogen (H^+) ion concentration. The pH of water at $25^\circ C$ has a concentration of 10^{-7} moles/liter H^+ and 10^{-7} moles/liter hydroxide (OH^-) ions; thus, the standard scale of pH units ranges from 0 to 14 units. Acid solutions have a pH from 0 to 7. Alkaline or basic solutions have a pH of 7 to 14. pH is a very important wastewater parameter that affects the solubility of metals, salts and organic chemicals, oxidation-reduction potential, and rate of chemical reaction in wastewater solutions. Gross wastewater characteristics affected by pH include toxicity, corrosivity, taste, odor, and color.

(4) Nitrogen. In wastewater treatment, the nitrogen forms of primary concern are: total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrate-nitrogen (NO_3-N), and nitrite-nitrogen (NO_2-N).

(a) Total Kjeldahl nitrogen represents the organic-nitrogen plus ammonia-nitrogen indicated by the Kjeldahl test procedure. The organic nitrogen in the wastewater sample is changed to ammonia-nitrogen by catalyzed acid digestion of the wastewater. The resulting NH_3-N is then analyzed and reported as the organic nitrogen fraction. However, not all organic nitrogen compounds will yield ammonia-nitrogen under catalyzed acid digestion. Acrylonitrile and cyanuric acid are examples of compounds that are only partially hydrolyzed by the Kjeldahl test procedure.

(b) Both ammonia-nitrogen and organic-nitrogen are present in most natural waters in relatively low concentrations, but industrial streams may have large amounts. Concentrations as low as 0.5 milligrams/liter have been reported to be toxic to some fish; concentrations as high as 1,600 milligrams/liter have proved to be inhibitive to biological waste treatment plant microorganisms. The toxicity of ammonia varies as a function of pH. Ammonia-nitrogen is also an essential nutrient in biological waste treatment systems.

(c) Nitrate-nitrogen may appear in wastewaters as dissociated nitric acid (HNO_3), or may result from the biological nitrification of ammonia to nitrate.

(d) Nitrite nitrogen is most commonly found in treated wastewaters or natural streams at very low concentrations (<0.5 milligrams/liter). Nitrite is a metabolic intermediate in the nitrification process. It is rapidly converted to NO_3-N by nitrifying organisms. Fixed nitrogen compounds (ammonia, nitrate, nitrite, and organic nitrogen) are essential nutrients for biological wastewater treatment. A typical minimum BOD/nitrogen ratio for a biological reactor would be 20:1. If sufficient fixed nitrogen is not present, the reactor will become nutrient limited, and performance will be reduced. Fixed nitrogen compounds may be regulated in the wastewater discharge and therefore require treatment.

(5) Phosphorus. Phosphorus occurs naturally in rivers and streams as compounds of phosphate. Elemental phosphorus does not persist naturally in aquatic systems since molecular oxygen quickly oxidizes it to phosphate. Phosphates are commonly found in industrial wastestreams from corrosion inhibitors, detergents, process chemical reagents, and sanitary wastes. Phosphorus is an essential nutrient in biochemical mechanisms. A BOD/phosphorus ratio of about 100:1 is required for most biological treatment systems. Like fixed nitrogen, phosphorus may be regulated in the wastewater discharge and thus require treatment.

(6) Sulfur. Sulfur occurs naturally in rivers and streams as compounds of sulfur. Elemental sulfur does not persist naturally in aquatic systems, since molecular oxygen oxidizes it to sulfate. The sulfate anion (SO_4^-) is one of the most common ionic species

in natural waters and industrial wastestreams. In some industrial wastestreams, sulfate and sulfur compounds are present in high concentrations and may be a major part of Total Dissolved Solids (TDS) and conductivity. Sulfates can cause odor and can corrode sewer pipes if they form sulfuric acid. The bad-smelling gas, hydrogen sulfide (H_2S), is produced by the anaerobic biological reduction of sulfate to H_2S . As pH increases, the chemical equilibrium favors the ionization of sulfur and prevents the formation of H_2S . As pH decreases, the formation of H_2S is favored. When the H_2S rises to the crown of the sewer, it combines with condensed water to form sulfuric acid; the acid reacts with the concrete and corrodes it.

(7) Chlorine. Chlorine is widely used to disinfect treated wastewaters. In sufficient concentrations, chlorine is toxic to all forms of life; however, it does not persist in aquatic systems. It does react with other chemical compounds such as ammonia and certain hydrocarbons to form the toxic chloramines and potentially toxic or mutagenic chlorinated hydrocarbons. Thus, chlorination is not recommended for certain industrial wastestreams. Chlorides occur both in natural water systems and many industrial wastestreams. Chloride concentrations of 8000 to 15,000 milligrams/liter have been reported to adversely affect biological waste treatment systems.

(8) Heavy metals. Heavy metals may be toxic, carcinogenic, or both. They may cause great problems in biological treatment systems that can range from mild inhibition to complete destruction of the biological reactor biomass. They tend to concentrate in the sludge, and adversely affect anaerobic systems if digestion is used. The heavy metals of concern include arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, platinum, rare earths, selenium, silver, tin, and zinc. These elements can typically be measured using atomic adsorption or analytical chemistry techniques.

(a) Arsenic and arsenical compounds occur in industrial wastewaters of the metallurgical industry, glassware and ceramic production, tannery operations, and dye and pesticides manufacturing. The highest wastewater concentrations occur in the manufacture of Paris green and calcium meta-arsenate. However, these insecticides are no longer produced in great amounts. Softening, carbon adsorption, reduction, coagulation, and precipitation have all been used effectively to remove various arsenic compounds from industrial wastewater streams.

(b) Barium-contaminated wastewater is a problem in the explosives manufacturing industries. The most often used treatment has been co-precipitation with sodium sulfate. This process is effective for barium reductions to about 1.4 milligrams/liter, which is the solubility of barium sulfate. Coagulation of suspended solids in the wastewater (including the non-settleable barium sulfate particles) with ferric sulfate provides solids removal.

(c) When present in the air, beryllium and its compounds are of concern. Beryllium is one of the most toxic and hazardous non-radioactive substances used by industry. Since beryllium is an ideal metal for surfaces that receive heat and abrasion (such as aircraft brakes), industry has taken steps to reduce airborne emission. Thus, most machining operations are done under water; however, the machined particles then become a water pollution problem. Removal from liquid waste streams is typically done by alkaline precipitation or ion exchange.

(d) Boron is not a major toxic component in industrial wastewater discharges. However, it may prevent wastewater reuse for irrigation because of plant toxicity. Sources of boron-contaminated wastewaters include detergent manufacture, weather-

proofing, wood processors, fireproofing, fabric processors, glassware and porcelain manufacture, leather finishing, carpet manufacture, cosmetics, photographic processing, and rocket fuels. Treatment is typically done by precipitation or ion exchange.

(e) Cadmium and cadmium compounds are always toxic, producing acute or chronic symptoms which vary from irritations to death. Exactly how it affects humans and animals is not well understood. Experiments have also shown cadmium to be carcinogenic. The primary industries that produce cadmium-laden wastewaters include metallurgical alloying, ceramics, electroplating, photography, pigment works, textile printing, chemical industries, and lead mine drainage. Treatment processes for cadmium are typical of those used for most heavy metals. Successful processes include chemical precipitation, ion exchange and, to a lesser degree, coagulation.

(f) Many industries use chromium for electroplating, and in process chemicals, corrosion inhibitors, pigments, and tanning agents. The toxicity is a function of valence with Cr^{+6} highly toxic and Cr^{+3} only mildly toxic. Typically, treatment processes use reduction to convert Cr^{+6} to Cr^{+3} . This is done at a pH of < 3.0 , using a reducing agent such as sodium bisulfite, sulfur dioxide, or ferrous sulfate. After reduction, the Cr^{+3} is removed by precipitation, ion exchange, or reverse osmosis. Chrome may be recovered from pure systems using either reverse osmosis or ion exchange.

(g) Copper is not typically a problem. It is often used in the form of copper sulfate to control algae in lakes. The primary sources of copper in industrial waste streams are metal process pickling baths and plating baths. Brass and copper metalworking requires periodic oxide removal which is done by immersing the metal in strong acid baths. Solution adhering to the metal surface (dragout) is rinsed from the metal and contaminates the waste rinsewater. Jewelry manufacturers use copper plating either directly or as a base metal for silver and other precious metal surfaces. Copper is also used in the alkaline Bemberg rayon process as cupro-ammonium salts. As with most heavy metal wastes, treatment processes used to reduce soluble copper in wastewaters may be destructive, involving precipitation and disposal of resulting solids, or a recovery process, such as ion exchange, evaporation, and electrolysis. The value of copper metal frequently makes recovering it more attractive than for many heavy metals.

(h) Iron is not toxic in normal doses. The potential industrial sources of dissolved iron species include mining operations, ore milling, chemical industries, dye industries, metal processing industries, textile mills, food canneries, tanneries, and titanium dioxide production. The primary industrial wastewater unit process used for iron reduction/removal is converting ferrous iron to the ferric state, and then precipitation of ferric hydroxide near a pH of 7, where its solubility is minimal. The conversion occurs readily upon aeration at pH 7.5. Spontaneous formation of ferric hydroxide then removes iron by precipitation.

(i) Lead is a moderately toxic, cumulative heavy metal. Industrial wastewaters from battery manufacture, printing, paint and dyeing processes, photographic materials, and explosives manufacturing often contain lead. Treatment processes for lead are typically alkaline precipitation at a pH of 9.5 to 10. The alkaline source is normally sodium hydroxide or lime. For high levels of treatment (< 1.0 milligrams/liter), precipitation is sometimes followed with ion exchange.

(j) The major source of manganese in wastewaters is the iron and steel industry. The chemistry, toxicity, and treatment strategies for manganese are the same as those for iron.

(k) Mercury in wastewaters results from the manufacture of photographic chemicals, electrical and electronic components, explosives, preservatives, and pesticides. Mercury is highly toxic and cumulative in the food chain. In man, it can be absorbed both through the skin or by ingestion. Typical industrial waste treatment strategies for treatment of mercury-contaminated wastewaters include ion exchange, co-precipitation with sulfur in the form of mercury sulfide, or conversion to the mercuric form and the precipitation as mercuric sulfate using hydrogen sulfide as the sulfide donor.

(l) The electroplating industry is the primary source of nickel-contaminated wastewater. Toxicity in water is not a major problem at concentrations below 10 milligrams/liter. Treatment is typically lime or sodium hydroxide precipitation followed by sedimentation and filtration if required.

(m) Platinum and the rare earth metals, although in some forms highly toxic, are not a significant problem as industrial wastewater contaminants, since they are valuable and therefore removed before they enter the wastestream.

(n) Selenium is highly toxic to humans mostly from food chain accumulation. Selenium is generated by the paint, pigment, dye, glass, and insecticide industries. Treatment techniques and effluent concentration data are sparse. However, coagulation with lime, followed by sand filtration, activated carbon, and ion exchange has been shown to be 99+ percent effective for removing selenium in selected process wastestreams.

(o) Silver is a relatively toxic metal; however, due to its value, it is rarely a big problem in industrial wastewaters because it is removed for reuse. Trace levels of silver ions are often found in wastewaters from the porcelain, photographic, electroplating, and ink manufacturing industries. Typical removal/reduction processes include precipitation, ion exchange, reductive exchange, and electrolytic recovery.

(p) Tin and zinc are emitted mostly from electroplating industries. They are toxic only at high concentrations and are easily removed by precipitation or ion exchange.

(9) Toxicity. In industrial waste treatment, toxicity is most often related to aquatic organisms such as fish, arthropods, shellfish, and microorganisms. The toxicity bioassay test is used to evaluate a wastewater's relative toxicity. The test determines the lethal concentration of pollutant that will kill 50 percent of the test organisms (LC₅₀) in a given period of time. The LC₅₀ is an indirect method of measuring toxicity.

d. Biological constituents. Wastewaters that contain biological components can originate from domestic wastes, hospitals, livestock production, slaughterhouses, tanneries, pharmaceutical manufacturers, and food-processing industries. The major pathogens include certain bacteria, viruses, and parasites.

(1) The coliform group of bacteria indicates the bacterial pollution of water and wastewater. Total coliform and fecal coliform are widely used as test parameters for water quality. The total coliform test includes organisms other than those found in gastrointestinal tracts of mammals. These "woodland coliforms" may also be counted in the total coliform test, although they represent organisms associated with insects, soils, and plants. The fecal coliforms are differentiated from the total coliforms by incubation at an elevated temperature in a temperature-, growth-specific medium.

(2) The viruses found in wastewater that are of most concern are of the Polio

(3) Parasites and protozoa are widely found in sanitary wastewaters. Few of these organisms directly cause death, but some weaken the host and promote the possibility of contracting infectious disease.

e. Physical constituents

(1) Temperature. The chemical equilibrium of complex wastewaters is very temperature-dependent. Waste treatment system efficiency is affected by temperature extremes. At low temperatures (4°C, for example), biochemical and chemical reaction rates are extremely slow, and waste treatment operations are often severely limited. At high temperatures (greater than 110°F), waste treatment plants may have operating problems due to mesophilic-thermophilic transfer. When this occurs, biological processes are impaired, air and oxygen solubility becomes limited, and other physical properties, such as sludge density and settling rate, adversely affect overall waste treatment.

(2) Tastes and odors. Dissolved inorganic salts of iron, zinc, manganese, copper, sodium, and potassium can be detected by taste. Tastes and odors may also be associated with decaying organic matter, living algae and other microorganisms containing essential oils and other odorous compounds, specific organic chemicals such as phenols and mercaptans, chlorine and its substitution compounds, and many other chemical materials. Petrochemical discharges and liquid wastes from the paper and synthetic rubber industries often cause taste and odor problems. Sulfides from these sources cause odors in concentrations of less than a few hundredths of one part per million.

(3) Color. Color in water and wastewaters may result from metallic ions such as chromium, platinum, iron, or manganese, and from humus and peat materials such as tannin and algae. Color caused by suspended matter is said to be "apparent color." Color caused by soluble materials is said to be "true color." True color is the parameter by which color is evaluated. An arbitrary standard is used to evaluate color. The color produced by 1 milligram/liter of cobalt-platinum reagent is taken as one color unit. Dilutions of cobalt-platinum reagent are made in the 0 to 70 unit range and placed in special comparison tubes (Nessler tubes). Water samples are then compared and matched to the cobalt-platinum standard dilutions.

(4) Radioactivity

(a) Regulatory agencies have established standards for the maximum allowable concentrations of some radioactive materials in surface waters. There are three types of radioactivity: alpha, beta, and gamma rays. Alpha rays consist of a stream of particles (doubly charged ions of helium with a mass of four) projected at high speed from radioactive matter. Once emitted in air at room temperature, alpha particles do not travel much more than 10 cm. These particles are stopped by an ordinary sheet of paper.

(b) Beta particles consist of a stream of electrons moving at speeds ranging from 30 to 90 percent of the speed of light; their penetration power varies with their speed. These particles normally travel several hundred feet in air and may be stopped by aluminum sheeting a few millimeters thick.

(c) Gamma rays are true electromagnetic radiation and therefore travel at the speed of light. They are similar to X-rays, but have shorter wavelengths and greater

penetrating power. Proper shielding from gamma rays requires several centimeters of lead or several feet of concrete.

(d) The isotopes of carbon (C^{14}) and iodine (I^{125}) are radioactive materials which are commonly used in tracer studies for research in biology, chemistry, and medicine. Certain isotopes, such as radioiodine and radiophosphorus, can collect in biological slimes and sludges in sewers and waste treatment plants.

(4) Wastewater solids. Wastewater solids are present in nearly all wastewater discharges. They occur as a result of stormwater runoff, sanitary discharge, chemical precipitation reactions in the waste, and direct discharge of solid materials. Waste solids are classified according to their state (dissolved or suspended), and subsequently, according to their physical and chemical characteristics. Suspended solids are made up of two physical categories: colloidal and settleable. Settleable solids will typically settle under laminar conditions as a function of Stokes' Law. Conversely, colloidal solids will not settle because they are in equilibrium with the system. Specifically, their surface to volume ratio is high enough that due to particle mass, Stokes' Law forces are insignificant relative to stabilizing forces, such as surface charge and Brownian motion. Dissolved solids are nonvolatile impurities that remain in a water after the suspended solids have been removed. They may be either inorganic salts or nonvolatile organic complexes. The concentration of suspended and dissolved solids in an industrial wastewater is determined from gravimetric analysis. The procedures for these analyses are defined in *Standard Methods*.³

4-2 Sources of industrial wastewater

Industrial wastewaters are generated by industrial processes and include appurtenant sanitary wastewaters. At a typical military facility, these wastes may be produced by water treatment plant sludges and backwash, vehicle washracks, electroplating operations, boiler blowdown, cooling towers, paint shops, metal finishing operations (nonplating), food processing operations, hospitals, photographic processing, munitions manufacture, laundries, vehicle service and maintenance, and others. Because of their process-dependent character, industrial wastewaters cannot be characterized by either generic municipal or industrial wastewater information, thus they often require specifically designed treatment facilities that reduce/remove the contaminants of concern. Since industrial wastewaters are often single-component systems, the opportunity for water reuse and material recovery is often economically viable. Domestic or municipal wastewaters are made up mostly of both soluble and suspended organic matter. These wastes vary somewhat among locations; however, they are well-defined in terms of components and range of strength. A sampling program is required to define a wastewater's characteristics; often, a treatability study is needed to best define the unit processes for mitigating pollutants.

a. Water treatment. Water treatment plants commonly use chemical precipitation, sand filtration, carbon adsorption, and chlorination for treatment. Sludges produced from precipitation have high concentrations of minerals such as calcium, iron, and aluminum. These sludges vary in solids content from 1 to 5 percent and are often discharged to a municipal sewage treatment plant. The carbon columns and sand filters are periodically backwashed to remove solids. The sand filter backwash is sometimes chlorinated to prevent biological growth in the beds. Column backwashes are commonly done

b. **Vehicle washracks.** Nearly all military installations have washracks for vehicle cleaning and maintenance. The washwaters contain grit, soil, grease, metal oxides, salt, and detergents. Washing is normally done by pressure spraying with water or cleaning compounds to remove surface films; this is followed by scrubbing with brushes and cleaners to loosen foreign matter, and finally rinsing thoroughly with water to remove emulsified oils and dirt. An alkaline, water-based cleaner is normally used. Many Army facilities have converted to or are converting to integrated washracks with high-pressure hoses to eliminate the use of solvents. Wastewater flows and concentrations vary greatly due to the type of vehicle being washed, type of washing operation, amount of water used, inclusion or exclusion of stormwater, variation in type of cleaning agents, and sampling procedures. Automobile and ground vehicle washing requires 30 to 50 gallons (114 to 189 liters) of water per vehicle. Table 4-1 gives washwater characteristics for ground vehicles. The major components include free and emulsified oils, suspended dirt, metal oxides, phosphates, detergents, and surfactants. Aircraft are routinely washed to remove foreign material from the aircraft surface. One to two 55-gallon drums of organic solvent, 25 gallons of alkaline cleaner, and 3000 gallons of water are used to wash one B-52 aircraft. Table 4-2 shows how the properties of effluents from aircraft washracks vary; the table shows that they have greater potential for much higher waste loads than ground vehicles.

c. **Electroplating wastewaters**

(1) The Army uses two basic types of electroplating which yield vastly different wastewater streams. The first - often called decorative plating - is used mostly for corrosion prevention. It deposits a thin coat of the plating metal on the part's surface. The other procedure - hard plating - requires a long plating time and high amperages to deposit thick layers of the plated metal on a bearing surface for wear resistance. Hard plating emits more wastewater per unit area of plated surface. Emissions may possibly be related as a function of amp-hours required for deposition; however, the procedure is complex, and sampling of specific waste streams is far more comprehensive. Commonly plated metals include copper, cadmium, chromium, nickel, silver, tin, and zinc. The surface to be plated serves as a cathode. An electrode made of the metal being deposited usually acts as the anode. With some metals, such as chromium, an inert anode is used, and the plating bath supplies the metal deposited. Nonmetallic surfaces to be plated must be made conductive by applying a material such as graphite. Metal stripping, cleaning, pickling, and phosphatizing are preparation steps. Anodizing of aluminum in a chromate bath is considered a related operation, since it produces a waste similar to plating waste.

(2) A typical plating operation includes the following steps:

- (a) Cleaning by solvent degreasing and/or alkaline cleaner.
- (b) Rinsing.
- (c) Acid cleaning or pickling.
- (d) Rinsing.

(g) Principal plating.

(h) Rinsing.

(i) Drying.

(3) The major waste sources are rinse water overflow; fume-scrubber water; batch-dumps of spent acid, alkali, or plating bath solutions; dragout; and spills of the concentrated solutions. Important parameters include pH, cyanides, emulsifying and wetting agents, and heavy metals. Cyanide is converted to highly toxic hydrogen cyanide gas at low pH; therefore, cyanide-plating solutions must not be mixed with acid-cleaning or acid-plating solutions. If a mass balance of a plating facility is considered, the key losses are scrubbers, rinse tanks, and dragout. The metals plated onto the parts are not significant relative to these other losses.

d. Boiler blowdown. Boiler waters must be chemically stabilized to simultaneously control scale and corrosion. This is done with buffer solutions (typically phosphate compounds), and dispersants (typically organics). Maintenance of the boiler water characteristics requires blowdown of some fraction of the flow to reduce dissolved solids loading. Silicates are the most damaging dissolved solids and are usually the blowdown rate determining parameter. Boiler blowdown waters are typically high in total dissolved solids, especially silicates and phosphates, and may also contain moderate levels of organics used to stabilize suspended solids.

e. Cooling towers. Industrial cooling towers recycle cooling waters used within the industrial process. They may operate on an untreated or slightly treated basis with a high blowdown rate, or on a high recycle ratio with lime softening to reduce suspended solids buildup. Blowdown from a cooling tower is similar to boiler blowdown, but is normally not as high in total dissolved solids. Due to the nature of cooling water use, there is always the potential of contamination from process chemicals when piping failure occurs. Thus, conductivity monitoring is often used to prevent uncontrolled discharge of process chemicals in case a system failure occurs.

f. Paint shop

(1) Paint-associated operations can produce complex industrial wastewaters. They include cleaning, stripping, surface preparation, and re-painting. Although most wastewater is generated during stripping, a lot is also generated during surface preparation and re-painting.

(2) Paint stripping of vehicles is a periodic maintenance procedure to prevent corrosion of metallic surfaces. Stripping is often done in the same facility as washing; however, due to the characteristics of the wastewater generated, this practice should be avoided. Most washracks are not equipped with the treatment flexibilities to treat the wastewater generated from paint stripping. The best data available are from Air Force aircraft stripping operations. These data should be generally applicable to other vehicles, varying only as a function of surface area. In the de-painting process, paint stripper is brushed on and allowed to set on the painted surfaces; this causes the paint to swell and blister. The loosened paint is removed with a high-pressure water spray. Modern paints are stripped with a phenolic paint remover, while the older paints are removed by strippers containing mostly methylene chloride (dichloromethane) and hexavalent chromium with additional surfactants, thickeners, and wetting agents. Flows and characteristics are highly variable. For example, about 3350 gallons of paint-stripper, of which 715 gallons are phenolic paint-stripper, are used for a B-52 aircraft; smaller air-

craft may require only about 300 gallons. An estimated 45 to 75 gallons of water are required to rinse each gallon of paint-stripper. Table 4-3 lists major pollutants from a phenolic aircraft paint-stripping wastewater and their ranges of concentration.

(3) Industrial wastewaters generated by surface preparation and painting operations are of two primary forms: spills/discards and water-wall wastes. Spills/discards are highly concentrated wastes that are normally captured and treated separately, reprocessed, or turned over to a hazardous waste disposal contractor. Paint shop water-walls are typically recycled water systems that are drained on a scheduled basis to the industrial wastewater treatment facility. These waters are typically high in heavy metals, solvents, suspended solids, and dissolved solids. Although usually toxic, their volume is low enough that treatment with a mixed industrial waste is not normally a problem. Some facilities pre-treat water-wall wastes to remove the heavy metals by precipitation before discharge into the mixed industrial waste stream.

g. Metal refinishing and machining. Metalizing and machining of metal parts for military hardware often generate substantial industrial wastewater flows. The contaminants include noncontact cooling waters and cooling/lubricating waters. The primary contaminants associated with the contacted waters include petroleum, oils, and lubricants (POLs), solvents and degreasers, acids, pickling solutions (some of which may contain cyanides), metal ions, and base metal particulates. The wastewaters are typically pre-treated for POLs and solvent removal using gravity separation with deemulant chemicals and/or dissolved air flotation.

h. Food processing. Food processing wastewaters are not normally considered to be industrial wastewaters; however, on posts with large troop concentrations, these wastes can become incompatible with normal domestic wastewater treatment. This is due mostly to the efficiencies in water use common to large operations which produce a high-strength organic wastewater. The primary contaminants of concern are oils and greases, suspended solids from grinders, and starch wastes from potatoes, rice, and beans. These waters should be pre-treated for oil and grease removal; the suspended solids and BOD loading should be given adequate consideration at the treatment plant.

i. Hospital. Hospital wastes are not normally considered to be industrial wastewaters. However, they may produce problems in the sanitary waste treatment system. They typically contain high per capita BOD and suspended solids loadings. Unauthorized disposal of radioactive substances is sometimes a problem in hospital wastewaters. A wastewater radioactive monitoring program should be established to identify and control any unauthorized disposal.

j. Photographic wastes

(1) Most military bases have one or more photographic laboratories. Photographic wastes are normally a small fraction of a facility's waste load when silver recovery is practiced. In larger operations, separate treatment of these wastes is normally required to remove toxic materials.

(2) There are several types of photochemical processes. Each results in a different type of wastewater; for example, color processes produce more pollutants than black and white ones. Photographic wastes are a mixture of spent process chemicals and washwater. Spent fixing agents are treated separately for silver recovery. The three most common types of silver recovery are: metal replacement, electrodeposition, and precipitation. Metal replacement involves passing the wastewater through a fine steel wool screen. The iron in the steel wool replaces the silver in solution, resulting in a

settled silver-rich sludge. Electrodeposition involves plating nearly pure silver on the cathode of an electrolytic cell. Silver is usually precipitated when chlorine and sulfide are added to form insoluble silver chloride or sulfide.

(3) Table 4-4 lists the other constituents of a typical combined photographic process chemical and wash wastewaters. The toxic chemicals of concern include silver, chromium, cyanide, and boron.

(a) Silver ion is highly toxic to aquatic organisms. However, silver chloride or silver sulfide provides minimal risk of toxicity.

(b) Chromium is present in the hexavalent form (C_r^{+6}) in some bleach solutions. However, hexavalent chromium is reduced to a trivalent form (C_r^{+3}) by strong reducing agents present in photographic wastewaters.

(c) Cyanide is present in bleaching solutions as potassium ferricyanide. Chemical action by other reducing agents and by silver oxidation forms complex insoluble cyanide compounds. These are potentially dangerous, because degradation releases toxic cyanide gas at low pH.

(d) Boron occurs in small quantities and is usually precipitated as calcium borate.

k. Wastes from munitions manufacture

(1) Wastes generated from munitions manufacture originate from manufacturing areas and from loading, assembling, and packaging (LAP) areas. Wastewaters are generated from the manufacture and use of explosive chemicals such as trinitrotoluene (TNT), nitroglycerine, Cyclonite (RDX), Methenamine (HMT), Octogen (HMX), and nitramine (Tetryl). The amount and composition of munitions wastewaters varies with the explosive being produced.

(2) In TNT production, toluene is reacted with nitric acid in a three-step process, using fuming sulfuric acid as a catalyst and drying agent. Excess acids wash away from the crude TNT, and form a waste stream known as "yellow water." Unwanted beta- and gamma-TNT isomers are selectively removed from the desired alpha-TNT in a solution of sodium sulfite (sellite). This purification step generates a dark red-colored waste known as "red water." The purified TNT is then recrystallized, dried, and flaked. The wash-down water from processing areas contains suspended TNT and is known as "pink water." Conventional production is normally a batch-type operation, but many plants are changing to continuous-type operation. The continuous operations normally use chemical recycle and produce a smaller quantity of more concentrated waste than the batch-type operations. Table 4-5 gives typical wastewater characteristics from both types of operations.

(3) Production of nitroglycerine involves mixing glycerine with concentrated nitric and sulfuric acids, and is much like the TNT manufacturing process. The acids are decanted, and the nitroglycerine is washed with water and soda ash to remove any remaining acids. The two main wastewaters are the waste acid and the soda ash; both contain nitroglycerine. Table 4-6 lists typical wastewater characteristics.

(4) HMX and RDX are very similar compounds. They are made by nearly the same process; however, the operating temperatures and raw material feed ratios differ. The raw materials (hexamine, acetic anhydride, nitric acid, and ammonium nitrate) are

fed into a reactor, forming crude HMX or RDX; this mixture is then aged, filtered, decanted, and washed with water. Wastewaters result from spillage of raw materials or product; discharge of cooling water, washwater, and filtered water; and flows from equipment and floor cleanup operations. HMX and RDX wastes typically have a BOD₅ of 900 to 1,000 milligrams/liter and a pH ranging from 1.6 to 6.0. Wastewater must be analyzed to determine specific treatment needs.

(5) To produce Tetryl, dimethylaniline (DMA) is diluted with sulfuric acid to control the reaction rate; this is followed by nitration with nitric acid. The crude Tetryl is then neutralized, washed, and recrystallized with an acetone solvent. These wastes are characterized by low pH and high concentrations of sulfates, total solids, and nitrates. Table 4-7 summarizes the important wastewater characteristics.

(6) To produce nitrocellulose, purified cellulose in the form of cotton-linters or wood-cellulose is treated with a mixture of sulfuric acid, nitric acid, and water. The nitrated cellulose is purified by a combination of centrifugation, boiling, macerating, solvent extraction, or washing operations. The nitrocellulose ("green powder") is then mixed with other explosive materials for processing into various propellants. Waste materials produced include the cellulose- and nitrocellulose-contaminated acid waters from the nitrification and purification steps, alcohol and ether solvents, and other waste material from the refining and processing steps.

(7) Small arm bullet jackets and casings are normally brass (copper and zinc alloy), although either may be made of steel. Larger artillery shells are usually steel. The manufacturing processes used for both brass and steel are nearly the same; they consist of stamping out plugs from metal sheets, then drawing, trimming, tapering, and shaping the plugs into either a shell, bullet jacket, or casing. Conventional metal conditioning operations, such as alkaline cleaning, pickling, phosphatizing, and metal coating, occur between steps. One quality control check involves using a mercurous nitrate solution; however, this can cause mercury pollution. Total wastes have widely fluctuating pH with heavy metals (mercury, copper, zinc, lead, and iron), oils, and surfactants. Table 4-8 lists typical munitions metal parts wastewater characteristics.

(8) Production of lead slugs, bullet jackets, and shell casings generates wastewaters that differ from those of explosives manufacture. Wastes include heavy metals, oils and grease, soaps and surfactants, solvents, and acids.

(9) Lead slugs are manufactured by extruding lead wire, then cutting and forming the lead for insertion in the bullet jacket. Alkaline cleaners, soluble oils, and cooling waters make up the wastewater flow. Typical characteristics include a pH of about 11 and a COD of 286 milligrams/liter.

(10) The main LAP operations that produce wastewaters are explosives receiving and melting operations, cartridge and shell-filling operations, and shell-renovation. Wastewater is generated from four sources: air-scrubbing, shell-filling, shell-washout water, and cleanup water. Dust from the unloading operation and fumes from the molten explosive are scrubbed from the air with water. When the shells are being filled with explosives, any spillage or over-filling will contaminate the water bath unless the water is covered. The washout water from rejected or renovated shells is heavily contaminated with explosives. The metal-cleaning and metal-treating rinse waters are contaminated with alkali soaps and surfactants, as well as dissolved copper. A complete washdown of all areas and equipment which could be contaminated with explosives is usually done at least weekly, resulting in large flows of highly contaminated water. Table 4-9 gives typical total wastewater characteristics.

l. Laundry. Most military posts have a large central laundry facility to clean uniforms and working clothes. Wastewaters from laundries vary by type of laundry operation, type of detergents used, the use of dyes, and the condition of the clothing being laundered. Table 4-10 lists typical laundry wastewater characteristics. Laundry washwaters are a large source of BOD and flow volume. Wastewater is usually filtered through a lint screen and sometimes cooled for heat recovery before discharge into the sewer. Dry cleaning solvents are normally recycled, but a small volume may enter the wastewater effluent.

m. Vehicle service and maintenance. Most military posts perform general maintenance on equipment and vehicles. Most of the wastewater from these shops is from vehicle motor and coachwork maintenance. These wastes include condensate from engine steam cleaning, hydraulic, engine, and transmission oils, battery wastes, fluids from radiator cleaning, and waste fuel from defueling operations. The primary contaminants in the waste flow include POLs, phenols, surfactants, acids, ethylene glycol, and solvents. Although most POLs are segregated for recycle, spills are typically washed down into floor drains connected to the industrial waste sewer.

n. Other. Due to the nature of the Department of Defense mission, industrial operations are often begun to meet a specific military need. Thus, the Facilities Engineer should look at each case individually. The standard should be evaluation of the wastewater effluent as a function of raw material components and processes involved. There is no pre-set way to estimate generic characteristics of industrial wastewaters. The only pragmatic approach is to conduct a laboratory investigation of the wastewater, or to project its characteristics, based on a review of similar operations for new facilities.

Table 4-1. Washwater effluent quality*

<u>Parameter</u>	<u>Range</u>
Crease and Oil (milligrams/liter)	25 - 3096
pH	7.0 - 8.1
TSS (milligrams/liter)	30 - 15700
BOD ₅ (milligrams/liter)	8 - 1078
Flow Rate (gallons per minute) for 24-hour period	4 - 1795**

*From Lubieniecki, Jr., E., et al., "Sand Filtration of Wastewater from Military Vehicle Washing Facilities," Unpublished report, 1979.
**Storm runoff.

**Table 4-2. Properties of aircraft washrack effluent
(based on grab samples)**

<u>Parameter</u>	<u>Concentration (milligrams/liter)</u>
COD	46 - 24,048
Oils and Grease	0.4 - 4,400
Surfactants	0.2 - 213
Phosphates	1 - 3,800

Table 4-3. Characteristics of phenolic aircraft paint-stripping wastewater* (milligrams/liter unless noted otherwise)

<u>Parameter</u>	<u>Concentration</u>
Phenols	1,000 - 3,000
Methylene Chloride	1,000 - 3,000
COD	5,000 - 30,000
Chromium	50 - 200
Suspended Solids	100 - 1,000
Oils	100 - 2,000
pH (units)	8.5

*Based on data from two Air Force facilities.

Table 4-4. Analysis of photographic processing wastewater discharge

<u>Constituent</u>	<u>Concentration (milligrams/liter)</u>
COD	2,234
Dissolved Solids	5,942
Suspended Solids	70
Oils and Grease	22
Surfactants (as LAS)	13
Phenols	0
Nitrates	48
Phosphates	380
Sulfates	1,100
Cyanides	260
Silver	6.70
Iron	1.96
Zinc	0.20
Copper	0.08
Manganese	0.05
Chromium	0.05
Lead	<0.05
Cadmium	0.065
Thiosulfate	68
Hydroquinone	48
Boron	12.8
Bromide	6
Potassium	56
Sodium	61

Table 4-5

Typical TNT wastewater characteristics
(milligrams/liter unless noted otherwise)

Parameter	Continuous-Type Process		Batch-Type Process
	24-Hour Composite Sample	Grab Sample	
TNT	20.3	145	--
pH (units)	2.5	2.05	2.6
COD	64	274	673
Nitrate (as N)	213	53	107
Sulfate (as SO ₄)	1,821	842	638
Color (units)	161	228	6,700
Total Solids	2,792	1,160	2,048
Volatile Solids	1,377	960	850
Suspended Solids	619	224	98
Temperature (°F)	95	--	--
(°C)	35	--	--
Flow (gallons/pound of TNT)	--	--	11.2
(cubic meters/100 kilograms of TNT)	--	--	9.27

Table 4-6

Typical nitroglycerine wastewater characteristics
(milligrams/liter unless noted otherwise)

Parameter	Maximum	Minimum
Nitroglycerine	315	0
pH (units)	9.9*	1.7
COD	340	10
Nitrate (as N)	1,920	0.5
Sulfate (as SO ₄)	470	15
Color (units)	80	5
Total Solids	25,000	110
Suspended Solids	40	1
Temperature (°F)	80	50
(°C)	27	10
Flow (mgd)	0.17	0.04
(cubic meters/day)	643	151

*High values indicate a dump of the soda ash washing solution.

Table 4-7

Typical tetryl wastewater characteristics
(milligrams/liter unless noted otherwise)

Parameter	Maximum	Average	Minimum
Temperature (°F)	84	78	75
(°C)	29	26	24
pH (units)	6.6	3.1	2.2
Acidity (as CaCO ₃)	430	314	162
Color (units)	100	70	30
Total Solids	3,012	1,565	941
Suspended Solids	96	37	4
Nitrate (as N)	54	37	22
Sulfate (as SO ₄)	1,220	779	580

Table 4-8

Typical munitions metal parts wastewater characteristics
(milligrams/liter unless noted otherwise)

Parameter	Maximum	Minimum
Temperature (°F)	120	65
(°C)	49	18
pH (units)	9.2	3.3
Alkalinity (as CaCO ₃)	370	0
Total Solids	5,000	650
Suspended Solids	725	27
Zinc	18	7
Copper	32	0.6
Lead	<0.2	--
Iron	21	<3.0
Oil	168	0

Table 4-9

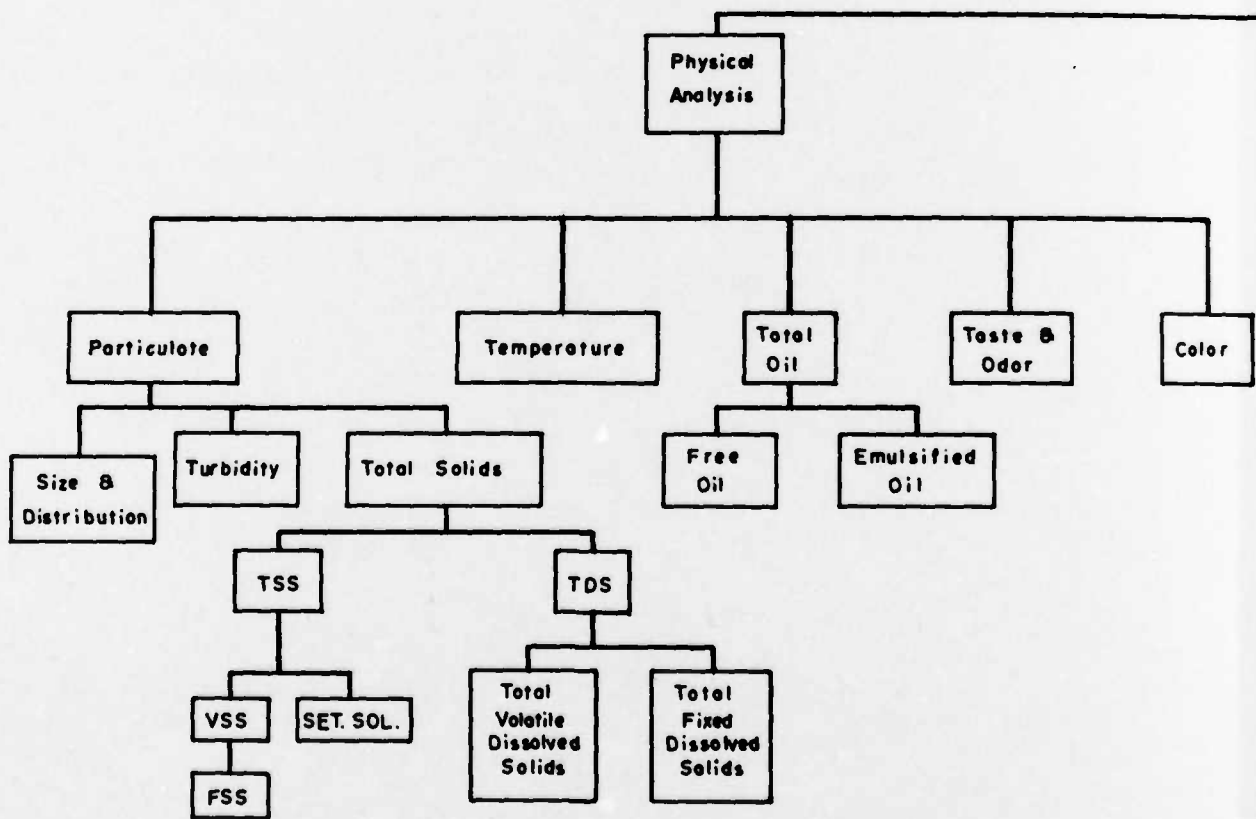
Typical LAP facility industrial wastewater characteristics
(milligrams/liter unless noted otherwise)

Parameter	Maximum	Average	Minimum
pH (units)	8.4	7.9	6.8
Total Solids	1,790	1,401	903
Suspended Solids	336	138	22
Total Volatile Solids	956	548	426
Total (Kjeldahl) Nitrogen	25	17	10
TNT	235	178	156
RDX	180	145	88

Table 4-10

Typical laundry wastewater characteristics
(milligrams/liter unless noted otherwise)

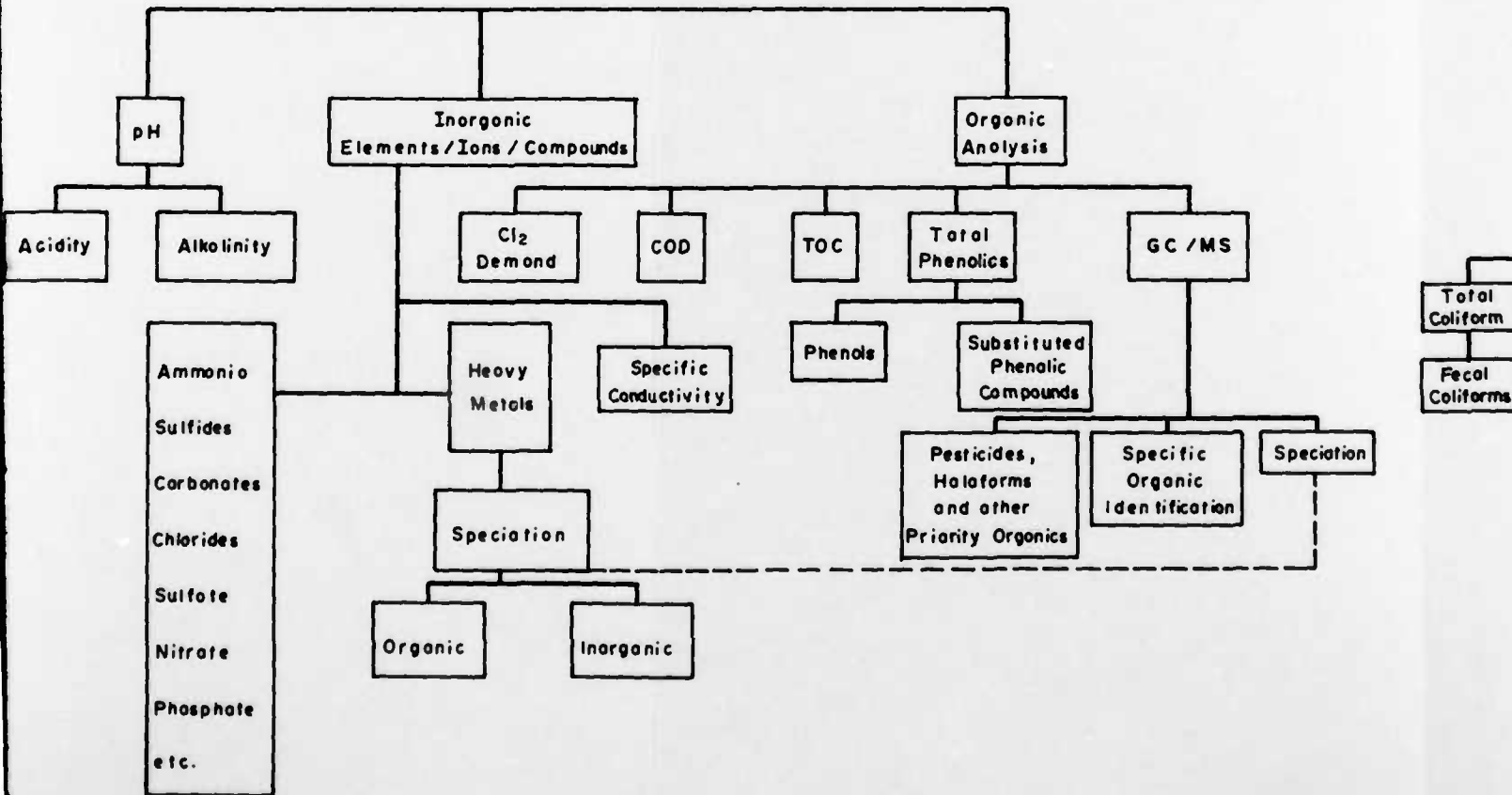
Parameter	Maximum	Average	Minimum
pH (units)	11	8	5.1
Temperature (°F)	140	100	50
(°C)	60	38	10
BOD ₅	3,810	700	45
Grease and Oil	1,410	800	150
Total Solids	3,310	1,700	120
Suspended Solids	784	160	15
Detergents (as ABS)	126	55	3
Phosphates	430	150	1
Free Ammonia	--	3	--

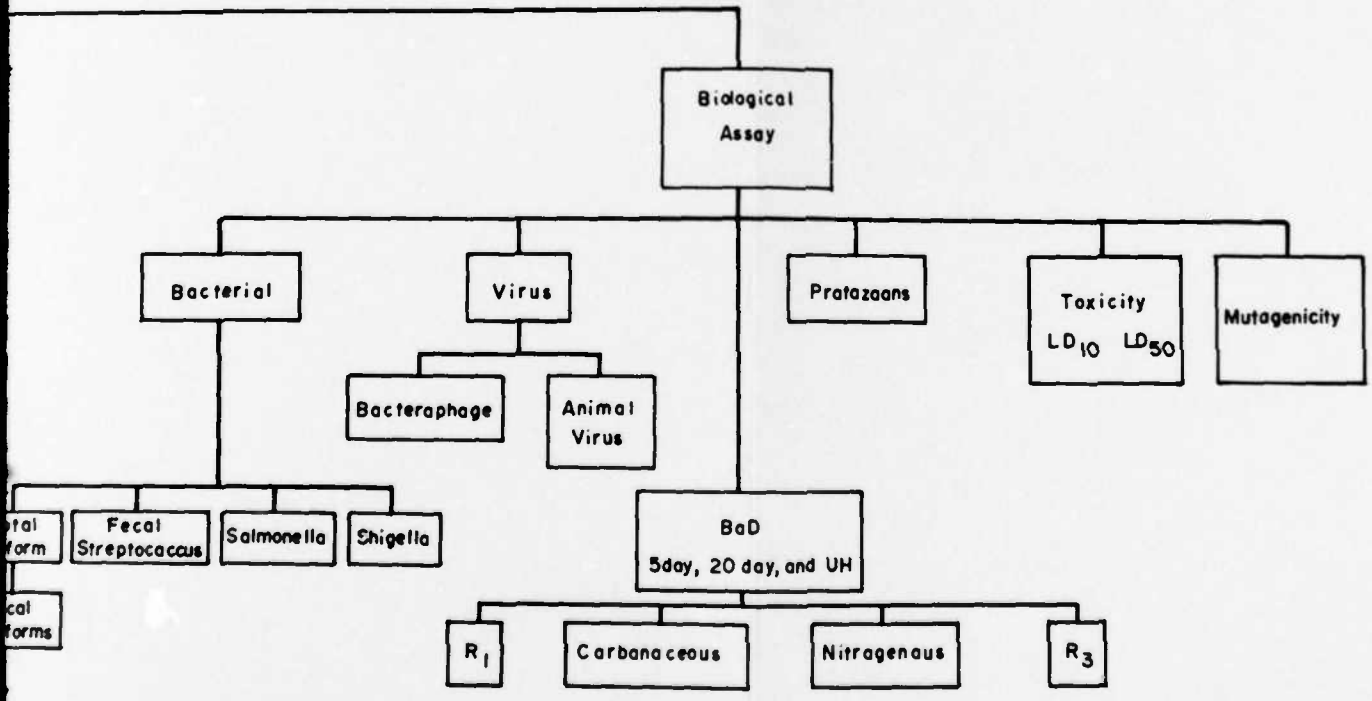


Ac

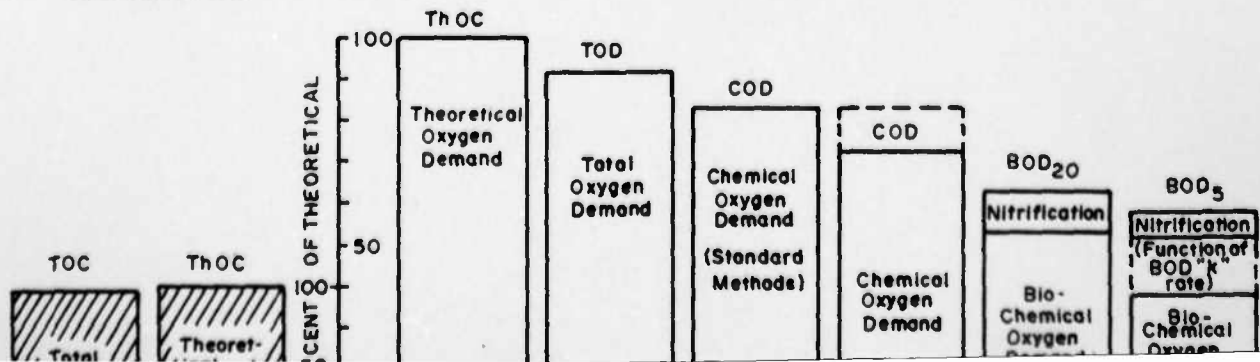
Waste water Sample

Chemical Analysis





ORGANIC CARBON CONCENTRATION OXYGEN DEMAND



Chapter 5

The Industrial Waste Survey

5-1. Waste survey objectives

a. An industrial waste survey characterizes various wastestreams for flow rate, concentration of pollutants, and source. This information is needed to develop a treatment or abatement strategy. Such surveys also indicate which wastestreams contain valuable chemicals that should be recovered, which are hazardous or toxic, and which can be recycled or reused. The survey also indicates if there are problems with sewers or drains.

b. The importance of the industrial waste survey requires that the information it provides be accurate, complete, and reliable. Therefore, the survey team should always consider the survey's objectives:

- (1) To inventory and locate the waste sources and define their fate.
- (2) To quantify the waste sources in terms of pollutant concentrations, flows, and mass loadings, and especially in terms of the variability of the waste stream quantities.
- (3) To classify the waste stream as:
 - (a) Low-strength (suitable for reuse or untreated discharge).
 - (b) Valuable for recovery.
 - (c) Amenable to or requiring treatment.
 - (d) Complex and/or high-strength.
 - (e) Incompatible or hazardous.
- (4) To identify problem areas.
- (5) To develop preliminary control philosophies and alternatives.

c. To determine treatment and disposal alternatives, the survey must identify specific characteristics of an industrial wastewater. First the waste stream's broad category is defined. For example, low-strength wastewaters may be reused with or without treatment or may be discharged with little or no treatment. Incompatible or hazardous waste streams should also be identified. The consequences of mixing waste streams should always be considered, since it may often be more cost-effective to treat a concentrated, single-component waste than a dilute, multicomponent waste.

d. Since industrial wastewater characteristics reflect the industrial process, the potential for material recovery should always be considered. Recovered raw materials or products can help offset the cost of waste treatment and sometimes make a profit. It may also be possible to reuse the water in the industrial process after material recovery; this will further reduce treatment and raw water costs.

e. High-strength wastewaters may be single- or multicomponent; thus, several unit processes may be needed. The survey should try to evaluate these waste streams as far

back into the industrial process as practical. Treatment, material recovery, and water reuse all become more complex and less cost-effective as the number of waste components from mixing various process waste streams increases. Definition of the wastes should help identify problem areas. The waste survey must also:

- (1) Determine flow patterns and sewer layout.
- (2) Confirm engineering drawings to as-built facilities.
- (3) Inspect existing waste conveyance systems.
- (4) Examine industrial operations generating wastes.

5-2. Survey organization

The organization of the waste survey will depend on the problems being addressed, the resources available to the installation being surveyed, and the structure of the facility command. Some facilities may lack capabilities in one or more technical areas (for example, the laboratory capabilities required to analyze wastewater samples). Sampling equipment and adequate survey manpower may not be available. If in-house resources are not adequate, outside help is required, and will be an important factor in organizing the survey. A team should then set up to perform the waste survey in accordance with AR 420-47. The team may consist of an Army engineer or a civilian designated to manage the survey and several task forces to conduct work in specific disciplines. Work tasks are assigned within the team, and efforts are coordinated through review meetings and reporting procedures. The survey team leader, who is responsible for overall coordination and direction of the project, should represent the Army facility. Appendix B provides an example survey.

a. Survey preparation

(1) Description of industrial operations. The various industrial and maintenance operations generating wastewater are evaluated to determine the potential for wastewater reuse and material recovery and to identify chemicals used in the process which are or could become a wastewater component. Several factors must be considered in reviewing industrial processes:

- (a) A site map of the installation.
- (b) Aerial photographs.
- (c) Potential for wastewater reuse and material recovery. Waste loads may be reduced by reusing or recovering valuable components from the wastewater. Wastewater which contains low concentrations of pollutants may be used as utility water for washing operations or for irrigation. Wastewater which is recirculated in this manner should be positively isolated from potable water supplies. Recovery of valuable materials from wastewater is becoming increasingly attractive as the price of certain raw materials continues to rise. Metals, solvents, and acids are the most widely recovered materials. Silver recovery from x-ray and photographic laboratories is also popular. Chromium and other metals found in metal plating and similar wastes may be recovered. Solvents such as acetone and trichloroethane which are used in cleaning and degreasing operations may be separated from wastewater by distillation. Waste acids may be sold to independent users or recovered by evaporation.

(d) Segregation of contaminated stormwater. Clean or contaminated stormwater runoff will often enter the industrial process sewer system and combine with concentrated wastewater. This may cause significant problems in downstream treatment operations. The waste surveyor should be aware of the need to segregate noncontaminated stormwater from wastewater and should try to detect points of inflow and infiltration. A good way to detect infiltration is to observe flow monitoring data before and during a rainfall. Chart flow recorders clearly document changes in flow rate which may be from rainfall. Dye tablets may be placed on the ground to trace surface runoff and infiltration. Often, the stormwater runoff may be excluded from the wastewater by regrading and ditching. Stormwater which falls on an industrial process area and becomes contaminated requires treatment if the source of contamination cannot be removed. In this case, extra grading, ditching, and storage may be required before the contaminated runoff is introduced into the industrial sewer for treatment.

(e) Waste production records. If water is purchased from a municipal supply, a record of water use is easily obtainable. Intake water records alone are not enough to determine wastewater flow, but can often indicate approximate flow. Waste production record figures should be evaluated for accuracy before they are incorporated into the waste survey. Flow meters should be checked or calibrated, and samples taken to ensure the accuracy of past waste production records.

(f) A list of chemicals used in each area. Whenever possible, a list of chemical additives and raw materials entering an industrial or maintenance process should be obtained. The fate of these substances should be traced through the industrial process and places noted where wastewater is generated. The chemical list will be useful in determining which chemicals or other wastewater components require analysis. Often, the chemicals in use will be reported by trade name. In this case, the chemical container should be checked for a listing of chemical content. If the containers do not list the contents, the manufacturer must be contacted.

(g) A description of each process that generates wastewater.

(h) Industrial, sanitary, and storm sewer drawings.

(i) Copies of any previous environmental studies, surveys, or other related documents.

(j) Descriptions of current or planned construction which could impact the survey results. The industrial, sanitary, and storm sewer drawings are very useful for identifying waste sources, selecting sampling points, and producing a block flow diagram. Many sewer drawings, especially on older sites, are incomplete or misleading. Often, drawings are not updated as new sewers are built or to reflect new construction or rework. Thus, they should be confirmed by inspection and tracing. A list of chemicals and a process description of the areas generating wastewater is useful in determining components that may be in the wastewater. A site map with aerial photographs can show stormwater collection and discharge areas. Stormwater discharges are of concern if they become contaminated from area sources or if they enter the industrial or sanitary sewer system. Water use records provide important background information on water use. They are often a valuable point of reference in the water use and mass balance assessment. Old reports prevent duplication of prior efforts to trace sewers or identify sources.

(2) Block flow diagram. The block flow diagram provides a graphic summary of the waste survey. It shows wastewater sources in and out of industrial areas, points out

discharge volumes and/or water use, and serves as a place to express mass balances and other survey findings. Figure 5-1 is an example block flow diagram. The block diagram helps the surveyor locate and document waste sources and provides an updated record on the progress of the waste survey. It tells what information has been developed and what must be gathered. It serves as a check in developing material balances when summing tributary contribution, and provides a format for presenting the material balance.

(3) Analytical considerations. Prompt and accurate analysis of wastewater samples is desirable to maintain survey efficiency and accuracy. The laboratory providing the service should be able to offer other services if required. These may include sample collection, sample pickup and delivery, equipment rental, special investigations, and data evaluation. Often, the military base doing the survey will not have the laboratory capability for the survey project. In this case, the Army Environmental Hygiene Agency (AEHA) or a commercial laboratory may provide the needed sampling and analytical services. Considerations for evaluating a laboratory include:

- (a) Location.
- (b) Cost for analysis.
- (c) Ability to provide services as needed.
- (d) Reporting time for analytical results.
- (e) Experience and certification.
- (f) Sample shipping and handling.

(4) Sampling considerations. Equipment needed for the waste survey may include samplers; sample containers; refrigerators; flow-measuring devices; pH, specific ion and temperature monitors; chemicals; and safety equipment. The type of equipment needed will depend on the survey application. When evaluating equipment requirements, one must look at the type of sample or measurement required and the method needed to obtain it at each sample point. Based on the analyses requested, the laboratory should specify sample containment, preservation, and shipping requirements well before the survey.

b. Assignment of tasks. Figure 5-2 is a typical survey organization chart showing general responsibilities and lines of communication. The survey coordinator is responsible for most of the work. He/she must plan and supervise all areas of sampling, monitoring, sample analysis, and data evaluation. This person will obtain or produce sewer maps and block diagrams as required and will perform material balances where needed. The survey coordinator reports to the Facility Engineer or his/her designee regularly. The Facility Engineer helps gather background information such as sewer maps and data, finds an on-site work area, locates wastestreams, and authorizes the work.

5-3. Wastewater sources

A preliminary site inspection is done to acquaint the surveyor with the facility layout. The surveyor will visit each sampling location identified on the sewer layout drawing and inspect each industrial process contributing wastewater to the sewer. The purpose is to

trace flows, confirm drawings, inspect flow channels, and determine sampling and monitoring requirements; good notes are essential.

a. **Flow tracing.** Flow tracing determines the accuracy of existing sewer maps and identifies waste sources. The first step is to visually compare the sewer map to the site. This requires looking into each collection point or manhole, and identifying any tributary pipes. The incoming pipes are then traced to the waste source. This ensures that unknown interceptions have not been made. Four techniques are commonly used in flow tracing. These techniques should be compared before making a selection.

(1) **Smoke.** Smoke is used to trace the direction that is opposite that of the liquid flow. A smoke bomb or smoke generator placed at an outlet is allowed to produce smoke until it begins to appear at the wastewater source. Smoke may only be used in partially filled pipes.

(2) **Floats.** Wood chips, ping pong balls, packaging materials such as polystyrene, corks, oranges, and many other floatable materials are used to trace flow path in an open channel or partially filled pipe sewer. However, this is not recommended for small-diameter pipes. The use of floats is simple and quite effective. By knowing the travel time and distance between points, the flow can also be estimated. Consideration should also be given to the ultimate fate of the floats; a screen should be placed at the outfall or before the treatment equipment inlets. There should be no inactive high points in the sewer lines in order to avoid trapping the floats.

(3) **Dyes.** Many different dyes are available in liquid, powder, and tablet form for tracing flows in closed pipes, open channels, and partially filled sewers. Flow patterns are determined by observing the path of the dye at manholes and outlets. Sewer time-of-travel can also be determined with dyes. Care should be taken to coordinate dye-tracing activities, because after the flow is dyed, it may not be possible to detect other downstream sources. Methyl orange, nigrosine, fluorescein, and rhodamine B are commonly used dyes. Methyl orange is red in acid solutions and yellow in alkaline solutions. Nigrosine gives a black color to acid and alkaline solutions. Fluorescein sodium salt, also known as acid yellow 73, gives no color in acid solutions, but becomes brilliant green in alkaline solutions and yellowish-red in water. With no interference, fluorescein fluorescence is detectable at concentrations as low as 0.02 parts per million with a UV fluorimeter. In high concentrations, rhodamine B turns reddish in water. Rhodamine is detectable by fluorometric techniques at concentrations in the parts per billion range. Dyes are easy to use, but should be selected carefully, since some are toxic to aquatic life. Dyes may also temporarily change the color of small, natural, streams.

(4) **Salts.** Sodium chloride and lithium chloride salts may be used to trace or measure flows in closed-pipe sewer systems. In open channels or partially filled sewers, one of the other methods is recommended. Sodium chloride (NaCl) is usually practical at total sewer flow rates of less than 200 gallons per minute. A concentrated NaCl solution is metered into the wastestream. The presence of NaCl is determined by a conductivity meter at a point downstream. The change in conductivity can be used to determine flow. Lithium chloride is useful for flows of up to several million gallons per day. It is introduced in the same manner as sodium chloride. After the estimated time of travel has passed, downstream samples are periodically withdrawn and analyzed for lithium using atomic absorption. Atomic absorption analysis may be expensive.

b. **Confirmation of drawings.** Background information is first collected and reviewed to determine the scope of the sampling and analytical program. Old sewer and piping diagrams are seldom updated for new construction or modification. However, an old

drawing can be used as a starting point. The sewer drawing should be a plan view of the facility showing the industrial sources, gross flow patterns of the sewer, manhole locations, and pipe sizes (fig 5-3). The hydraulic grade for each sewer segment is also required. These may be obtained either from existing as-built profile drawings or by field measurements of manhole inverts. The surveyor and the utility engineer will compile what is known about the various flows and wastewater characteristics from each work area. After an initial site inspection and sewer map validation, more sampling points within selected process areas will be chosen for further evaluation. Confirmation of drawings is a primary objective of the flow tracing studies. As the tracing studies progress, the results are compared to the existing sewer map, and modifications are made as required. Several pipes are often not recorded on the sewer map, especially at older sites. Leaks, blocked lines, or damage to sewers may be observed and should be noted on the updated sewer map.

c. **Flow channel inspection.** During the site inspection, flow channels should be examined to determine sampling and monitoring requirements. The first consideration is to get a sample that truly represents the wastestream. Secondary considerations include ease of access, presence of electricity, and type of sampling and monitoring equipment needed at that location. The checklist in table 5-1 details sampling and monitoring requirements. The flow channels are also examined to assess the sewer's structural integrity. If the sewers and pipes appear to be in good condition with no significant damage, this should be noted. If corrosion has damaged piping, sewers are clogged with debris, or structural fatigue or failure is evident, this should also be noted and reported.

d. **Safety.** Injury may result from falls, chemical contact, burns, or other causes. Protective clothing and equipment should be used in potentially dangerous areas. The survey team should be aware of site safety regulations, evacuation routes, and alarm signals. No sewer should be entered until repeated tests indicate the absence of explosive or poisonous gases. Even then, the sewers should be ventilated by mechanical blowers, and workers should be equipped with gas detectors, portable air supplies, and a safety harness. At least two persons are always required.

5-4. Location of sampling and monitoring stations

The proper location of sampling and monitoring stations is very important in developing an effective waste survey. Nonrepresentative sampling and monitoring stations will result in inaccurate data which could seriously compromise waste treatment activities. Care and attention is required when locating sampling and monitoring stations. Locations should be scouted during the site and flow channel inspection. The checklist presented in table 5-1 should be reviewed to help select sampling and monitoring sites. It is desirable to locate sampling and monitoring stations at the same point; however, this is not always possible and may lead to erroneous results. In either case, the station should be located to:

- Ensure that the sample or measurement taken is representative of the wastestream.
- Ensure that proper sampling or monitoring techniques are used.
- Provide adequate safety and access for waste surveyors and operators.

a. **Point source discharges.** A point source discharge is a discharge flow through a flow channel or conduit, usually manmade. Such a discharge would be one flowing through a pipe, sewer, or ditch. This is the easiest type of flow to sample. Location of

sampling and monitoring stations for point source discharges depends on the type of flow channel.

(1) Closed pipes. Sampling wastewater from closed pipes requires a sample port. The port is positioned in the middle of the pipe for pressurized flow and at the bottom of the pipe when flow only partially fills the pipe. The ports should be located so as to ensure that the waste flow is well mixed. If sedimentation or other separation of wastewater constituents is known to occur, the sample port should be located downstream of an elbow in the pipe or at a pump discharge. For some sampling situations, a static mixer may be needed in the pipe to ensure a representative sample.

(2) Sewers. Sewer sampling is often very hard because of the danger involved. It is usually best to locate the sampling and monitoring equipment outside the sewer and to have only the sample pump intake line and monitoring sensor actually in the sewer. This is to minimize climbing in and out of the sewer. Care must be taken to place the intake line or sensor in the center of the stream and to avoid contact with the sides and bottom. If large solid particles are present, a coarse screen may have to be placed over the sample intake line to prevent clogging. Quantities of large solids can be estimated by grab sampling. If the flow in the sewer is slow and it is apparent that oils are separating and floating on the liquid surface or solids are settling in the stream, the stream must be mixed ahead of the sampling point. This may be done by placing baffles ahead of the sample point. Bricks or solid concrete blocks may be arranged to produce turbulence in the wastestream. Baffles must be secure to prevent them from washing away if a sudden high flow occurs.

(3) Trenches. Concrete or earthen trenches are relatively easy to sample. As with closed pipe or sewer flow channels, the sample point must provide an adequately mixed, representative sample. Baffling or weirs should be provided to produce turbulence in the stream if mixing is required. The sample point should be located in the center of the stream with no bottom contact. The sample intake or sensor may be positioned in a wastestream by connecting it to the leg of a "T." The arms of the "T" rest against the top sides of the trench and position the leg in the trench. With both concrete and earthen trenches, it is usually possible to locate a weir or other flow-monitoring device near the sampling equipment.

b. In-plant waste sources. The desired location of sampling points at process units and machinery will largely be indicated by the process block diagram. The actual location will be determined by the structure and arrangement of the process equipment. The following are suggestions for sampling certain process wastestreams.

(1) Tank overflows. A plastic bucket may be placed beneath the overflow or may receive overflow through a piece of tubing or pipe connected to the overflow pipe.

(2) Pump discharges. Many pumps have pressure gauges or blank plugs on their discharge side. The gauge or plug can be replaced with a fitting and valving to allow either grab or composite sampling.

(3) Open vessels. In the absence of any sample ports or downstream access, sampling must be done from the top of the vessel. Several samples at different locations and depths should be composited in unmixed vessels. In mixed vessels, samples should be taken at mid-depth.

(4) Pressurized pipes and vessels. To avoid splashing and possible injury, extra care should be taken in sampling pressurized pipes and vessels. Gloves, safety glasses, and an apron may be required. When sampling from a spigot, the initial flow should be discarded to avoid accumulations of solids in the spigot. When sampling from a pressurized spigot, the top of the sample container should be covered to prevent splashing and should have openings for the spigot and for air displacement. Special sampling equipment which is available for sampling pressurized pipes is recommended.

(5) Open channels. Open channels are usually covered by an expanded metal walking surface. This can easily be removed or cut to provide sampling access. Most industrial open channels are ideally suited to flow measurement by weir or velocity methods. Open channels may be used to convey wastes from process areas or buildings. Obtaining a representative sample may require baffling to increase flow velocity. Often, the sample collection and flow measurement can be co-located.

c. Coordination with process operators. A sample will often have to be taken by process operators in an area being surveyed. This is particularly true when process flows occur at late hours, when the stream is intermittent, or when a spill occurs. The process operators are a valuable source of information and assistance, and have an important role in the waste survey. The operators can locate most wastestreams and can be most helpful in locating sampling and monitoring points.

5-5. Measurement of wastewater flow

Flow measurement is a basic part of the industrial waste survey. Total discharge flow (24-hour average) and flow variability (maximum and minimum) must be determined to provide adequate waste characterization data. The flow data may be used for treatment facility design, manufacturing process modification, or waste discharge permit application.

a. Description and selection of method. The type of flow-measuring device or method used should be chosen carefully, depending on the given flow channel. Selection of the proper method depends on:

- (1) Type of flow channel.
- (2) Variability of flow.
- (3) Accessibility of monitoring point.
- (4) Use of the flow data (accuracy required).
- (5) Hydraulic head available.
- (6) Type and character of the fluid.

Four basic types of flow conduits frequently require flow measurement: open channels, sewers, free discharge pipes, and pressured pipes. The type of flow conduit and the accessibility to the conduit will greatly influence the type of flow measurement used. Flow variability will greatly affect the measurement accuracy. Highly variable flows will require a flow recording device to compute average, peak, and minimum flows. Steady flows can be checked when samples are collected. In both gravity flow and pressurized pipes, the available head must be considered in selecting most flow measurement techniques. The head loss required is indicated or can be readily available calculated

from the data provided in this chapter and in appendix B. Compatibility with wastewater solids, grit material, solvents, temperature, etc., should be considered for wetted elements of flow measurement devices. Most sewer survey flow measurements are temporary; therefore, long-term compatibility is usually not important. The sections below describe the most commonly used wastewater flow measurement methods. Appendix C describes several less commonly employed methods.

b. Methods and devices for measuring the flow in open channels. Open channel flows and gravity sewers flowing partially full are commonly used to convey industrial wastes. Both can be described using open-channel hydraulics. Various methods for measuring flow in open channels may be used, depending on the geometry of the sewer, accessibility, and the range of expected waste flows. Common techniques for measuring open-channel flow include velocity and depth measurement, weir measurements, dilution methods, pumping rates, and drainage rates. Specific equipment and techniques are discussed below. Appendix C provides further detail.

(1) Measuring the surface velocity and depth. When the wet cross-sectional area and the average velocity are known, flow (Q) in a sewer may be obtained by the formula $Q = AV$. The wet area (A) is determined by measuring the depth and diameter of the pipe. The average velocity (V) can be estimated by measuring the surface velocity. There is a relatively constant relationship between the surface velocity and the average velocity of a stream; the average velocity is about 85 percent of the surface velocity.

(a) The surface velocity can be measured by placing floating material in the sewer and measuring the time it takes for the float to travel a measured distance downstream. A straight length of sewer line, free of obstructions, is required for good results. Any floating material can be used, such as cork, wood, oranges, or a stoppered bottle. It is important to allow the float a few seconds to reach the same velocity as the current in the wastestream. The process should be repeated four to five times and the average surface velocity obtained. If time differences between runs vary much, 20 to 30 floatings should be made to obtain a distribution curve. The mean of this curve should then be used to determine the mean surface velocity.

(b) The depth and velocity of flow should be measured at the same time. The wet cross-sectional area of a circular sewer can be obtained from the depth measurement by using figure 5-4. The surface velocity method is not very accurate, but is useful in preliminary surveys and in sizing flow-measuring devices. When the sewer is flowing too full to use a weir and a current meter is not available, this method is probably the most practical.

(c) The current velocity meter consists of a rotating element whose rotation speed varies with flow velocity. Current meters must be calibrated; the calibration table is usually provided with the instrument. To measure flows in a closed channel, access must be provided. Current meters may be used to measure the velocity of flow in both open and closed channels.

(d) An approximate average velocity is measured when the current meter is placed at 60 percent of the water depth from the water surface in an open channel. Another method is to take the average of the velocity at depths of 20 percent and 80 percent. The velocity should be measured at several places within the cross-sectional area.

(2) Weirs. The weir is a commonly used device for measuring waste flows because

placed in a partly filled pipe, channel, or stream. The water level at a given distance upstream from the weir is proportional to the flow. Commercially available weirs consist of a vertical plate with a sharp crest; the top of the plate is either straight or notched. Weirs can be installed at pipe outlets, in manholes, or in open drains. Figure 5-5 shows four common types of sharp crested weirs and gives the discharge formula for each type of weir. Proper crest formation and accurate point of measurement of the flow height, H , are important for determining flow accurately. Figure 5-6 is a typical profile of a sharp-crested weir. The water flowing over the crest is called the nappe. The main problem associated with rectangular weirs is that the flow contracts when it passes over the weir. Thus, the effective width of the nappe is smaller than the width of the crest. The Cipolletti weir, which has sloping sides, was developed to compensate for this contraction and to be able to use the width of the crest for flow calculation. Ventilation of the nappe must also be considered for good formation of the crest. Without ventilation, the nappe adheres to the face of the weir. Since the flow contracts both horizontally and vertically, the height of flow over the weir should be measured at least 2.5 times H upstream. Appendix C discusses flow measurement calculations for each type of weir. Each formula is qualified for the specific application. To design a satisfactory weir, the following general requirements should be met.

(a) The weir should consist of a thin plate about 1/8 to 1/4 inch thick with a straight edge or a thick plate with a knife edge; the sharp edge is to prevent the nappe from sticking to the crest. The height of the weir from the bottom of the channel to the crest should be at least two times the expected head of water above the crest; this ratio is necessary to lower the velocity of approach. Also, the upstream velocity of flow should be greater than 0.3 feet/second.

(b) The weir should be ventilated to prevent a vacuum from forming under the falling water.

(c) The connection between the weir and the channel should be waterproof. Therefore, the joint between the weir plate and channel should be packed with a chemically inert cement or asphalt type roofing compound. Grease compounds should not be used if oil concentrations are to be measured.

(d) The weir must be level to ensure a uniform depth of flow.

(e) The crest of the weir must be kept clean. Fibers, stringy materials, and larger particles tend to cling to the crest and should be removed periodically. In water with high suspended solids concentrations, considerable sedimentation in the channel of approach will occur. Sediment influences the measurements and makes representative sampling harder.

(f) The device for measuring the head should be placed upstream at least 2.5 times the head on the weir, and should be placed in a quiet section of the sewer.

(g) The weir should be located at the end of a straight stretch of the sewer with little or no slope. The velocity of approach should be low and uniformly divided over the channel; however, the weir will usually lower the velocity enough for measurement. For added accuracy, and when the sewer is flowing full, the weir should be placed at the end of the line in a weir stilling box as shown in figure 5-7. However, for fully flowing sewers, other methods of flow measurement are recommended. It should be

(h) The weir size should be selected after the preliminary surveys have determined the expected flow rates in the sewer. Permanently installed weirs should be calibrated after installation, inasmuch as coefficients in the weir formulas may vary. However, reasonable flow estimates can be obtained without calibration when weirs are used properly.

(3) Pumping rates. When the water in a sewer is pumped into another sewer or if the wastewater is pumped out of a reservoir or sump on a time or level controller, the flow may be estimated by recording the time of pumping. The capacity of the pump at the discharge pressure can be determined from head-versus-capacity curves supplied by the manufacturer. On older pumps, it is recommended to check the pump curves at one point near the operating pressure. Section 5-5d(2) below provides more details about this method.

c. Methods for computing the flow from freely discharging pipes. Freely discharging pipes are either pumped or gravity-flow pipes which discharge to the open air. The major factor affecting flow measurement is whether the pipe is full or partially full. The following sections discuss three of the most commonly used flow measurement methods. Appendix C discusses the use of orifices and flow nozzles.

(1) Bucket and stopwatch. The simplest measurement method for a full or partially full freely discharging pipe is the bucket and stopwatch. The bucket must be of a known volume and require at least 10 seconds to fill. Several timed fillings should be made. The average filling time divided into the bucket volume gives the flow rate. This method can be accurate to within 15 percent of the time flow.

(2) Trajectory method. Flow from filled or partly filled pipes may be estimated by measuring the trajectory of the stream after it has left the pipe and is freely discharging into the air. This situation is common for the outfall of elevated sewers. The trajectory method lacks the precision and accuracy of conventional meters or weirs, but is often accurate enough for rough flow estimates and is relatively inexpensive. Flows can be measured within 20 to 30 percent with this method. Figure 5-8 shows a partially filled sewer freely discharging into the air. The two characteristic distances to be measured are X and Y. The X-axis should always be parallel to the line of the sewer; the Y-axis should be perpendicular to the ground. The formula for calculated flow is:

$$Q = \frac{1.800A X}{Y} \quad (\text{Eq 5-1})$$

where:

Q = flow in gallons per minute

A = wet cross-sectional area of liquid in the pipe in square feet

X = distance between end of pipe and the vertical gauge in feet measured parallel to the pipe

Y = vertical distance from water surface at discharge end of the pipe and intersection of water surface with the ground

When the pipe is flowing full, A equals the cross-sectional area of the pipe. A modification of this method is shown in Figure 5-9 where Y is measured from the mid-depth of the liquid and is equal to 1 foot. X is measured to the center of the stream, and the velocity of the liquid leaving the sewer is:

$$V = 4.0 X \text{ (feet per second)} \quad (\text{Eq 5-2})$$

The flow of water discharged from the pipe is determined from:

$$Q = 450 AV \text{ (gallons per minute)} \quad (\text{Eq 5-3})$$

where:

A = wet cross-sectional area in square feet.

This method is known as the coordinate or trajectory method.

(3) California pipe method. The California Pipe Method is used to measure the rate of flow in a partly filled horizontal pipe having free discharge. The horizontal part of the pipe must be at least six times the diameter. If the pipe is not horizontal, a horizontal section can be added as shown in figure 5-10. Once the diameter of the pipe is known, only the distance from the top of the sewer to the water surface at the mouth of the pipe is needed to obtain the flow rate. The flow may be calculated by

$$Q = TW \text{ (gallons per minute)} \quad (\text{Eq 5-4})$$

where:

$$T = 3,900 \left(1 - \frac{a}{d}\right) 1.88$$

d = diameter of sewer, in feet

a = d minus water depth, in feet

$$W = d^{2.48}$$

Values for T and W may be obtained from tables 5-2 and 5-3. An air bubbler or other water level recorder may be used to continuously measure the water surface elevation. A ruler is used for instantaneous measurements.

d. Flow measurements in pressurized pipe systems. There are a number of invasive and noninvasive techniques for flow measurement in pressurized pipes. Invasive measurements require either inserting a probe into the pipe, or replacing a pipe section with a flow-measuring device. Noninvasive techniques measure flow by positioning flow sensors outside of the pipe. The more easily used methods are the noninvasive methods because they do not require interruption of the flow to install a flow element. Appendix C discusses invasive techniques.

electronically. Ultrasonic flow meters can be either portable or fixed. The portable model is best for sewer surveys. It can be carried easily and clamped to pipes. If properly used, its accuracy is about ± 10 percent or better.

(2) Pump curves. Pump discharge curves are primarily used with centrifugal pumps where the output flow is a function of the total dynamic head (TDH) of the pump. Figure 5-11 shows a typical pump curve. The TDH is easily measured by a pressure pump gauge on the pump discharge. The flow is then determined from the pump curve. Many sewer pumps operate on level controls in the wet well. When the level rises to a set point, the pump turns on and runs until the water level reaches a lower set point and the pump is turned off. A timer attached to the pump circuit can be used to determine the minutes per day the pump has operated at the discharge flow rate determined from the pump curve. Pump curves can be obtained from the pump manufacturer. At least one point on the curve should be verified by another flow measurement method. Using a calibrated pump curve, accuracy of ± 10 percent can be obtained. Accuracy using pump curves is usually about ± 15 percent.

(3) Tracers or dyes. Appendix C describes the use of tracers and dyes. A chemical feed pump which can deliver at the operating pressure is needed to use this method on a pressurized pipe. A tap or spigot downstream of the injection point is also needed to collect a sample of the diluted tracer.

e. Miscellaneous flow-measuring methods

(1) Measuring level changes in tank. For a batch-operated system, it may be convenient to determine the amount of waste flow by measuring the change in level of an isolated reservoir with time. The surface area of the vessel must be known. For large volumes, the wastewater flows can be diverted into a holding tank. Several fillings should be used to get a good average flow.

(2) Water meters on incoming lines. The amount of wastewater generated by an operation may be estimated if the water consumption of the area under consideration is known. Thus, a materials balance should be made of the incoming and outgoing flow to check the accuracy of each method and to determine if an important discharge or source has been left out. There may be a problem in performing a water balance because of the water losses from steam lines, evaporation, and other losses. The water content of the product is usually known. The flow of the incoming water lines can be obtained with a variety of flow meters. On larger lines, it is convenient to measure the flow by a venturi tube, an orifice plate, or a current meter. Current meters are easily installed in the lines to the different production processes.

5-6. Wastewater sampling

Wastewater sampling during the course of an industrial waste survey is concerned mostly with characterizing wastewater components such as BOD, COD, pH, solids, heavy metals, and organics. This is to classify the wastewater or obtain treatment facility design data. Survey sampling also detects industrial product losses and process spills, documents recyclable stream characteristics, and ensures awareness of industrial plant dis-

a. Types of samples. The purpose of sampling is to obtain a representative portion or composite of the stream being surveyed. Two different types of samples may be collected: the grab or discrete sample, and the composite sample.

(1) Grab samples. A grab sample may be taken manually or automatically from wastestreams. Each sample reflects the waste characteristics at the time it is taken. Automatic sampling is about the same as taking a series of grab samples at regular intervals. The volume of a grab sample depends on the total number of separate analyses that must be made. A grab sample may be preferred over a composite sample when:

(a) The water to be sampled does not flow on a continuous basis (for example, as occurs at an intermittently dry discharge outlet or when contaminated process tanks are dumped periodically). A grab sample from such a discharge is enough to obtain the waste characteristics of a batch dump. It is important to ensure that the intermittent dump is well mixed when the sample is taken.

(b) The waste characteristics are relatively constant. In this case, a complex sampling program is not needed since an occasional grab sample may be enough to establish waste characteristics.

(c) It is necessary to determine whether or not a composite sample obscures extreme conditions of the waste; a classic example is variation of pH. A composite sample may have a neutral pH, while individual grab samples may exhibit a wide pH range. It may be impossible to treat a widely varying waste biologically without pretreatment equalization and/or neutralization; however, these characteristics may not be apparent from a properly composited sample. An example of pH variation with time occurs in the textile industry where the pH in the morning may be as low as 3.5, while in the afternoon, it may be as high as 11.

(d) Analysis of wastewaters for parameters such as dissolved gases, residual chlorine, soluble sulfides, temperature, and pH is required. Wastewater variability is determined by analyzing grab samples taken regularly during a manufacturing period. Sampling intervals may be about one sample per hour, depending on plant operations. Intervals of one sample per hour are usually used as a starting point for variability analysis.

(2) Composite samples. Composite samples may be taken from the wastestream on a continuous or intermittent basis. Continuous samples may be taken either without regard to flow, or may be flow-proportional. With nonproportional continuous samples, the rate of sample flow remains unchanged over a sampling period. However, flow-proportional continuous samplers are integrated with a flow-monitoring device; sample volume is adjusted to conform to changes in wastewater flow rate. On a highly variable wastestream, flow-proportional sampling is required to collect representative composite samples. Intermittent composite samples may be taken by hand or automatically with or without flow-proportioning. Manually derived composite samples are usually developed from samples taken at regular intervals. Equal volumes of sample taken at each interval

b. Sampling for variability analysis. Industrial wastestreams often require variability analysis of flow and waste concentration to meet the survey objectives. Treatment plant design requires waste variability analysis to determine peak loading factors and the need for equalization facilities. Municipalities often limit contributor waste variability to prevent treatment plant upset. Variability analyses on industrial wastestreams are very useful for showing product losses and plant spills, as well as variations in process performance.

(1) Sampling frequency. Variability analysis defines the significant variation in flow and waste concentration. Sampling intervals are chosen to indicate waste variability. Wastestreams typically low in waste concentration variability but high in flow variability may only require grab sampling every 4 hours, with a 24-hour continuous composite for comparison. In preparing a survey for an industrial area, the activities involved in each operation and their contribution to individual streams must be considered. Sampling frequency may then be estimated based on process operation. Intervals of one composite sample per hour are usually employed as a starting point for streams of high variability. Streams of moderate variability may require composite samples of only 4- or 5-hour intervals.

(2) Duration of the variability analysis. An analysis will generally last from 5 to 21 days of normal plant operation, depending on how the data will be used and the findings. The plant should operate during the survey under normal conditions, and it is important to consider seasonal variations caused by weather or manufacturing demand.

c. Equipment available for sampling

(1) Manual sampling. Manual sampling equipment used in the waste survey is often made at the survey site. Usually, when sampling the surface of a stream or tank it is easy to make a pole dipper or to use a rope and bucket. However, sampling below the liquid surface or in inaccessible locations requires special fabrication or the use of commercially available equipment.

(a) A hand-operated pump may be useful for sampling areas of limited access if the intake line can be properly placed. The pump should be self-priming and easy to clean. Pumps contaminated by sampling process wastestreams should not be used to sample less polluted waters.

(b) The Bacon bomb sampler is a device that is lowered into the wastestream on a line attached to the sampler housing. Another line is attached to a trip valve. When the desired sampling location is reached, the trip valve line is pulled, filling the bomb with wastewater. This sampler is of limited use in high-flow streams since the bomb spins and entwines the carrier and trip valve lines.

(c) The Kemmerer sampler is widely used to sample water at various depths in lakes and rivers. This device is a section of pipe with spring-loaded caps on both ends. The sampler is set in the open position and lowered into the stream. At the desired position, a weighted brass messenger is sent down the line to activate the spring trigger. When activated, both cap ends of the sampler spring shut and the sample is taken.

(2) Automatic sampling. Many types of automatic sampling are available for survey work. Selection will depend on application requirements and costs. Four factors should be considered when assessing application requirements.

(a) Intake and transport system. Intakes connected to flexible hosing must be weighted or otherwise positioned in the flow channel. Most wastestreams will require a coarse solid screening device over the intake to prevent plugging. Piping and plumbing construction materials should be considered in terms of compatibility with the wastewater and maintenance requirements.

(b) Pumping system. The sampler pumping system should be able to adequately transport the sample from intake to sample container. A sample lift of more than 20 feet requires special or heavy-duty pumping systems. The sampling situation may require that the sample line be purged with fresh sample or air before collecting a new sample. The pump should not grind, aerate, or otherwise affect sample make-up. The pump should be compatible with flow-proportioning equipment if required.

(c) Control system. The control system should have dependable timing or flow-proportioning capability. It should be flexible to permit different intervals or sample volumes to be collected.

(d) Storage system. The storage system should be able to store the required sample volume and should provide refrigeration if needed. Figure 5-12 gives examples of various types of automatic samplers and basic sampler parts.

(3) Nonproportional samplers. Most waste survey samples will be taken by nonproportional sampling equipment. If flow fluctuates greatly, the samples can be proportioned manually if the flow rate is known. When the flow is of low variability, the nonproportional sampler is adequate for collecting composite samples. All samplers designed for flow-proportional sampling may also be used in nonproportional applications. A common nonproportional composite sampler is the continuous fixed-flow-rate sampler. This device samples continuously, at a rate of 15 milliliters per minute or less, without regard to waste flow rate. Figure 5-13 compares sample composition between proportional and nonproportional samplers.

(4) Proportional samplers. There are two basic types of proportional samplers. One collects a definite volume at irregular time intervals; the other collects a variable volume at equally spaced time intervals. Both types are flow-dependent; one dictates the time interval, and the other regulates the sample volume. A sampler based on flow may be similar to the scoop-type sampler shown in figure 5-14. The scoop rotates at a constant velocity. After a predetermined period of time, the scoop takes a sample. The volume of the sample depends on the water level in the channel. The scoop-type sampler is limited to wastewater without high-suspended or floating solids, and must be installed where the flow has a known relationship with depth. Another automatic sampler consists of a motor-driven wheel or disc, mounted on a frame and supporting a number of freely suspended buckets. The small buckets are mounted along the spokes of the wheel at varying distances from the axis. An increase in the water level will cause more buckets to be filled and thus proportionally increase the amount of sample being collected. A very simple proportional sampling device is a tipping bucket. The bucket empties itself when it is filled. An indicator records the number of times the bucket empties. The tipping bucket can be used for flows in the range of 0.1 to 20 gallons per minute. The flow-proportional sampler may be connected to a flow measurement device. Figure 5-15 shows a typical flow-proportional system. The flow-measuring device may be an electric probe, a bubbler system, or a float. Appendix D presents other types of composite samplers.

d. Sample handling. To get a representative sample, many precautions are necessary:

-- The sample should be taken at a place where the wastewater is well mixed, such as near a Parshall flume or where there is hydraulic turbulence. Weirs tend to enhance the settling of solids immediately upstream. Such locations should be avoided as a sample source.

-- The sample should be taken in the center of the channel of flow where the velocity is highest and the possibility that solids have settled is minimal. To avoid a lot of floating materials, the mouth of the collecting container or pump intake should be put at least a few inches below the water surface.

-- Sampling wastestreams with immiscible fluids, such as mixture of oil and water, needs special attention. In areas where oil is floating, it is simple to get a sample to analyze; the difficulty is determining how much oil flows per day. A common method of estimating total volume is to divert the wastestream into a container. After separating the two fluids, the thickness of the oil layer can be measured and the volume of oil present ascertained. Another problem with oil is adherence to the sampling device; this requires use of glass containers and frequent cleaning.

-- The sample volume obtained should be enough for all the required analyses, plus some extra for repeating any doubtful analyses. The minimum volume of a grab sample should be between 1 and 2 liters. The lower value is for concentrated wastestreams. Individual portions of a composite sample should be at least 25 to 100 milligrams/liter. Depending on the frequency of sampling and the individual sample volume, the total composited sample should be between 4 and 15 liters.

-- Sometimes it may be desirable to gather a number of samples for compositing at one time, such as at the end of a work shift or the end of a work day. It would be possible to use only part of each aliquot to make up the total; however, it is better to mix the entire volume of all samples and then use a part of the mixture for analysis. Either way, the individual samples must represent the flow at the time it was collected to maintain the integrity of the total composited sample.

-- The samples should be stored to ensure that the characteristics to be analyzed are not changed. Refrigeration may be necessary. When storage interferes with an analysis, separate samples should be taken for analyses that may require special preservation techniques.

-- The sample container and sampling device should be clean and uncontaminated. Before the sample is taken, the container should be rinsed several times with the wastewater.

-- Each sample should be labeled with an identification card containing, as a minimum, the following information:

- Sample location and/or station number.
- Date and time of collection.
- Sample type: Grab - with conditions, flow, etc., Composite - duration, frequency, etc.
- Preservation technique, if applicable.

- Any field analysis of sample pH, temperature, DO, etc.
- Volume collected.
- Other data that may be required (unusual plant conditions, problems in taking sample, etc).
- Name of sample taker.

(1) Sample containers and identification. Sample containers must be compatible with the wastewater being stored and the wastewater components subject to analysis. Sample containers should be selected to prevent leaks and to ensure that there is no chemical interaction between the sample and sample container. Table 5-4 lists container materials recommended for sample storage. Certain organic solvents will dissolve plastic sample bottles and plastic bottle caps. Some plastic sample containers will turn yellow and become brittle when exposed to strong mineral acids. Hot wastewater samples will create a vacuum upon cooling and may implode sealed glass or collapse plastic containers. Samples which generate gas, such as biological sludges, should be vented and refrigerated to prevent container rupture if analysis is delayed more than a few hours. Glass containers are required for most samples containing oil or organics. Analysis of volatile organic substances such as haloforms require special air displacement glass containers with septum seals. Hazardous materials of any kind require care in handling. Call the Army Environmental Hygiene Agency (301) 671-3554 or Chemtrec (800-424-9300) for help in responding to chemical spills or handling hazardous materials. Samples should be clearly identified; all data pertinent to sampling and analysis should appear on the sample label. All samples taken should be identified and recorded in a sample logbook. The sample log documents all samples, shipping instructions, and analyses to be performed. Also noted are any unusual characteristics such as appearance or odor.

(2) Sample preservation. It is not possible to stop all chemical activity in a sample container by adding preservatives, but it is sometimes possible to slow the reaction rate or complex the chemical constituents of interest. Most preservation techniques are intended to retard biological activity, dampen volatility, and control hydrolysis of chemical compounds. When in doubt about the proper preservation technique, it is best to at least refrigerate the sample because this slows chemical and biological reactions. Table 5-4 lists recommended preservation techniques for planning purposes on selected analyses. Samples should be analyzed as soon as possible after collection; however, it is seldom feasible to do the analyses immediately. Therefore one should be aware of certain time-dependent chemical changes which can occur in samples, such as:

- (a) Metal cations may precipitate as hydroxides or form complexes.
- (b) The valance state of the ions may change by oxidation or reduction.
- (c) Metal cations may be absorbed on the surface of glass, plastic, or quartz containers.
- (d) Organic compounds may hydrolyze or volatilize.

Microbial activity may also change the characteristics of the sample:

- (a) Cell lysis may increase the BOD and COD.
- (b) Cell productivity may change the BOD and COD.
- (c) The organic nitrogen and organic phosphorus content may be changed.
- (d) The pH may change.

Preservatives that do not influence the analyses should be added as soon as the sample is collected. To deal with preservation requirements, the sample may have to be split and portions preserved as a function of analytical requirements.

(3) Sample shipment. Most wastewaters require no special shipping precautions other than careful packing to avoid breakage and spillage. However, the EPA and the Department of Transportation regulate hazardous waste shipment. Special shipping containers, labels, and shipping certification are required to ship some wastewaters. Sample shipment by air is regulated by the Federal Aviation Administration (FAA) and by the International Aviation Transportation Administration (IATA) for international shipments. Before shipping any hazardous materials or wastewater, the EPA and DOT should be consulted about shipping requirements.

5-7. Data evaluation

Analytical techniques for data evaluation consist of physical and statistical methods. Physical techniques examine mathematical relationships derived from analyzing actual field data. These include averages, ratios, percentages, extremes, and mass loadings. Statistical techniques examine the probability of occurrence of a given value or event and the confidence which can be placed on specific values or events. Data from the sewer survey can be used to evaluate and possibly change in-plant and wastewater treatment practices; it may also influence the commitment of large capital expenditures. Preliminary alternatives should be selected using the information gathered. Such decisions should be based on good technical data. Thus, the parameters monitored and the significance of results obtained must first be critically evaluated for accuracy. In general, the tasks of data evaluation, in sequence, are data compilation, data editing, and data computation and reporting.

a. Data compilation. Data must be compiled and edited before it can be used. Compilations or data summaries are usually produced in tabular form on the computer or on accountant or engineering graph tables. Compilation allows the editor easy access to and control over the numbers. Weekly and monthly averages can be made, minimum and maximum values selected, and the data reviewed for editing.

b. Data editing. Editing insures that the data are accurate. Data editing for an industrial waste survey can be very difficult. The first requirement is to reject any data known to result from analytical or sampling error. An example of this would be a chemical oxygen demand (COD) analysis in which the soluble COD value was higher than the total COD value. Since total COD values are always higher than soluble COD values, it can be assumed that the data are in error or that the waste mix was highly unusual. These data should be evaluated for dispensation as errors or identification of re-sampling needs. Highly variable data or a group of data with a few erratic data points should be looked at carefully during editing. The reviewer must decide whether erratic data are the result of analytical or sampling error, or whether they accurately reflect process

operations. One way to decide is by making a chronological data plot. Regular, periodic process discharges can often be identified by such analysis. If these processes are known to be changed for some reason, such as recycling, then the data may be considered separately. After preliminary editing by visual comparison, a more rigorous editing practice is often needed. This would involve curve fitting and stochastic modeling techniques.

(1) Averages and extremes. On a simple level, average, minimum, and maximum data values can be compared to look for the development of a trend or to indicate random variation. Long-term averages can be compared to period averages to see if they are comparable. For example, 10 months of data may be averaged to produce a long-term average value. Each month could be averaged separately and compared to the 10-month average. For example, some months might have higher discharges than others, and the reason would have to be ascertained. However, if each monthly average was similar to the long-term, 10-month average, it could be concluded that there was very little waste load variation on a monthly basis.

(2) Ratios and percentages. Relationships between certain parameters may be compared during editing. For example, consider the analysis of a wastewater with a BOD of 400 milligrams/liter and a COD of 800 milligrams/liter. The resulting BOD/COD ratio is calculated to be 0.5 or 50 percent. If this relationship is reasonably stable, it may be used to evaluate erratic data. If analysis of that same wastewater sampled a day later indicated a BOD of 700 milligrams/liter and a COD of 600 milligrams/liter, the resulting ratio would be 1.2 or 120 percent. This ratio indicates a probable error in analysis or an extremely rare condition. These data should not be used without confirming analysis.

(3) Statistics. Statistical analysis of data is a very useful tool for data evaluation. Mean, variance, and standard deviation are used to determine the variability of waste characterization parameters. The variability of the measured parameters may result from various phenomena, such as:

- (a) In-plant spills or poor housekeeping practices.
- (b) Temporary modification of in-plant processes or an unusual activity in the industrial area.
- (c) Chemical reactions resulting from various combinations of waste discharges.
- (d) Nonrepresentative samples due to improper maintenance and/or operation of monitoring equipment.
- (e) Improper preservation of samples.
- (f) Errors in calculations or in analysis of measured parameters.
- (g) Lack of cooperation by plant personnel.

Variability of waste parameters can be graphically expressed by entering survey data on a chronological plot of survey parameters. Thus, variability can often be identified with process operations. Chronological plots are very useful for identifying routine process discharges and process spills.

c. Data computation and reporting. The use of the waste survey data governs the method and extent of computation. For example, the data requirements for the design of treatment facilities are far more involved than for discharge into a Public Owned Treatment Work (POTW).

(1) Mass loading and concentration calculations. Analytical results for most chemical analyses are expressed in metric units of milligrams per liter, which is about one part per million. Concentration may be directly converted to mass loading if the flow rate is known. Thus:

Mass Loading, kg/day = (concentration, mg/L) x (flow, l/d) ÷ (1 x 10⁶ mg/kg) and,

Mass Loading, lb/day = (concentration, mg/L) x (flow, mgd) x (8.34 lb/gal)

Most NPDES permits have discharge limitations for BOD, COD, TSS, NH₃-N, and other parameters expressed as mass loadings to the receiving stream. Some permits have limitations on discharge concentration as well as mass loading. Military installations which discharge into a regional or municipal waste treatment plant typically pay for this service on a dollar per pound of pollutant basis. Therefore, it is important to be able to accurately quantify pollutant loadings.

(2) Running averages. Running averages are usually conducted on 7- or 30-day data periods. A group of consecutive data is averaged to produce a running average value. The next sequential data point is added and the oldest data point deleted. The group of sequential data is averaged after having discarded an old datum and incorporated a new one. Running averages are particularly useful for determining maximum, minimum, or average flow or production rates on a consecutive-day basis.

(3) Application of statistics. The probable major use of statistics in a waste monitoring program is to develop the data needed to construct a reliable flow and materials balance diagram. Statistical correlation of the data will allow a choice of average values; it will also provide a procedure for determining the range of values for a specific parameter. Probability plots can be developed which will help define the values and confidence limits to use for design purposes. Also, the standard deviation and variances can be calculated to define the range and variability of the data. This information is valuable, for example, in determining equalization requirements for specific treatment processes or for evaluating the operational effectiveness between different production shifts. A wide difference in standard deviation or variance between shifts with the same production schedule may imply a different degree of operational care with regard to discharge requirements or a different production procedure. Inefficient operation and frequent spillages can often be determined by comparing the appropriate statistical parameters for various operating periods or shifts.

5-8. Safety

a. One important aspect of the monitoring program, especially in the initial surveys, is protecting the people who collect the samples. Sample gauging points are sometimes established in manholes or other potentially dangerous locations. In the absence of proof acquired by repeated testing of the air in such locations for explosive or dangerous gases, a hazard should be assumed to exist. The types and nature of toxic materials which could be produced by the industrial activities or as a result of the mixing of wastes from different areas should be established. These hazards may be poisonous gases, such as hydrogen sulfide, chlorine, carbon monoxide, or hydrogen cyanide, or explosive gases, such as methane or gasoline vapor. Also, the atmosphere might not have enough oxygen to sup-

port life. Inert and nonexplosive gases, such as nitrogen and carbon dioxide, may readily produce a deadly atmosphere in a manhole or other poorly ventilated structure by diluting the oxygen. A conventional gas mask is of no value in this situation. Self-contained breathing equipment would be acceptable, but generally, a hose mask which is suited for unlimited time against any poisonous gas or oxygen-deficient atmosphere is the best equipment. It is sometimes possible to create a safe atmosphere by providing artificial ventilation in the form of portable blowers or air compressors. A safety harness, rope, and explosion-proof light in addition to gas-protective equipment are essential when entering unventilated structures. A minimum two-man team is required for all sampling operations. The danger of contact with liquid wastes should also be recognized and safety procedures established.

b. Every effort should be made to select sample points which do not endanger personnel. Personnel should also be aware of the safety measures recommended for treatment facilities and plant sewage pumping stations and call management's attention to any unsafe conditions. The following points are of value in setting a safety program.

(1) Avoid crowded underground structures for pumping equipment. Use of above-ground stations is best.

(2) Use stairs rather than vertical ladders for access to pump rooms. Where space is critical, a spiral stairway may be used, but even a ship's ladder is preferable to a vertical ladder. When vertical ladders cannot be avoided and their depth exceeds 10 feet, they should be equipped with a hoop cage or offset landings.

(3) Specify guards for all exposed moving parts of pumps and equipment.

(4) Specify explosion-proof wiring, lighting switches, and other electrical equipment in all locations where potentially explosive atmospheres of flammable gas or vapor with air may collect. Specify moisture-proof equipment for damp areas, but where there is no possibility of flammable gas accumulation. The basic standard of practice is the National Electrical Code.

(5) Specify that all electrical wiring be properly insulated and grounded. No exposed wiring should be permitted. Control circuits should not be more than 110 V.

(6) Provide natural or artificial lighting throughout the structure, especially in the wet and dry wells.

(7) Provide hoists and rails to remove heavy equipment, such as screenings, cans, or pumps needing repair.

(8) Furnish a water supply under sufficient pressure for hosing wet wells and dry wells.

(9) Prohibit all potential cross connections between a potable water supply and the sewage pumping equipment.

(10) Assure adequate natural or mechanical ventilation in both wet wells and dry wells. The best mechanical ventilation in deep wet or dry wells is by an air inlet near the ceiling and an exhaust duct, connected to an exhaust fan, located just above the maximum sewage level in wet wells or near the floor of dry wells. The fan should be able to completely change the air in 2 to 5 minutes. Ventilation in wet wells is sometimes done

wet well. Combustible and toxic gas indicators and alarms are sometimes desirable in large wet wells.

(11) Segregate wet wells completely from dry wells and provide entrance from the outside atmosphere only.

(12) Post warning signs and use red paint for hazards such as steep stairs or projecting objects (for example, valve wheels or ceiling space heaters). To avoid head injuries, allow enough headroom; personnel should wear hard hats.

(13) Stand-by gasoline engines should be fueled by a fuel pump; a shutoff valve should be provided for small elevated gasoline storage tanks mounted on the engine to prevent the continuous discharge of gasoline through a defective carburetor. Large elevated gasoline storage tanks located inside structures should not be used.

(14) The telephone number for help in responding to dangerous chemical spills should be posted.

3-1. Checklist for location of sampling and monitoring equipment

Sample Location _____

yes no Is location accessible from road? _____

yes no Is flow channel accessible? Explain _____

is out Is location inside or outside building? _____

yes no Is source of discharge known? Specify _____

yes no Are there any other sources at this point? Specify _____

yes no Does sampling/monitoring equipment require housing? _____

yes no Is electricity available? _____

yes no Is there explosive or other hazard? Specify. _____

open closed Is flow channel open or closed? Specify type. _____

grab comp Type of sample to be taken. Specify _____

Volume _____ Volume of sample required per day or sampling period.

Location _____ Location of sample point in flow channel. Specify. _____

man auto Type of sampling equipment needed. Specify. _____

instant. cont. Type of flow measurement to be taken.

type _____ Flow monitoring technique to be used. Specify. _____

type _____ Other monitoring to be done at this location. Specify. _____

yes no Special safety precautions needed? Specify. _____

yes no Unusual characteristics of waste? Specify (not, high suspended solids, etc.) _____

Table 5-2

Values of T for California pipe flow formula (From Planning and Making Industrial Waste Surveys [Ohio River Valley Water Sanitation Commission, April 1952].)

$$T = 3,900 \left(1 - \frac{a}{d}\right) 1.88$$

$\frac{a}{d}$	T	$\frac{a}{d}$	T	$\frac{a}{d}$	T
0.00	3,900	0.35	1,740	0.70	410
0.01	3,830	0.36	1,690	0.71	380
0.02	3,760	0.37	1,640	0.72	360
0.03	3,690	0.38	1,590	0.73	330
0.04	3,610	0.39	1,540	0.74	310
0.05	3,540	0.40	1,490	0.75	290
0.06	3,470	0.41	1,450	0.76	270
0.07	3,400	0.42	1,400	0.77	250
0.08	3,330	0.43	1,350	0.78	230
0.09	3,260	0.44	1,310	0.79	210
0.10	3,200	0.45	1,270	0.80	100
0.11	3,130	0.46	1,230	0.81	170
0.12	3,070	0.47	1,180	0.82	160
0.13	3,000	0.48	1,140	0.83	140
0.14	2,930	0.49	1,100	0.84	125
0.15	2,870	0.50	1,060	0.85	110
0.16	2,810	0.51	1,020	0.86	97
0.17	2,750	0.52	930	0.87	85
0.18	2,690	0.53	915	0.88	73
0.19	2,630	0.54	905	0.89	61
0.20	2,570	0.55	870	0.90	51
0.21	2,510	0.56	830	0.91	42
0.22	2,450	0.57	800	0.92	34
0.23	2,390	0.58	760	0.93	26
0.24	2,330	0.59	730	0.94	20
0.25	2,270	0.60	700	0.95	14
0.26	2,210	0.61	660	0.96	9
0.27	2,160	0.62	630	0.97	5
0.28	2,100	0.63	600	0.98	3
0.29	2,050	0.64	570	0.99	1
0.30	1,990	0.65	540		
0.31	1,940	0.66	510		
0.32	1,890	0.67	480		
0.33	1,840	0.68	450		

Table 5-3

Values of W for California Pipe Flow Formula
(From *Planning and Making Industrial Waste Surveys* [Ohio River Valley Water
Sanitation Commission,
April 1975].)

Pipe Diameter (inches)	$W = d^{2.48}$	
	d feet	W
3	0.25	0.032
4	0.33	0.064
6	0.50	0.179
8	0.67	0.370
10	0.83	0.630
12	1.00	1.00
14	1.17	1.48
15	1.25	1.74
16	1.33	2.03
18	1.50	2.73
20	1.67	3.57
21	1.75	4.01
22	1.83	4.48
24	2.00	5.58
27	2.25	7.47
30	2.50	9.70
33	2.75	12.29
36	3.00	15.25

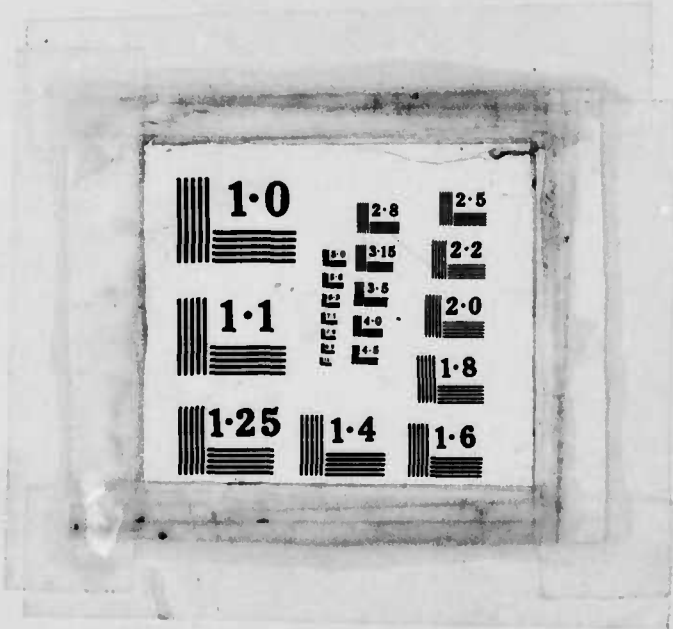
ion and handling requirements

Container*	Minimum Sample Size, milliliters	Storage and/or Preservation**
P,C(B)	100	24 hour; refrigerate
P,C(B)	200	24 hour; refrigerate
P,C	1,000	6 hour; refrigerate
P	100	--
G(brown)	100	Analyze as soon as possible; refrigerate or add HCl to pH 2
P,C	100	Analyze immediately
P,C	100	Analyze as soon as possible; H ₂ SO ₄
P,C	500	Analyze immediately
P,C	500	Analyze immediately
P,C	500	10 days in dark; freeze
G	500	--
P,C	500	24 hour; add NaOH to pH 12; refrigerate
P	300	--
G, wide-mouth calibrated	1,000	Add HCl to pH
P,C	500	Analyze immediately
P,C	--	For dissolved metals separate by filtration immediately; add 5 milligrams/liter conc HNO ₃ /liter
P,C	500	Analyze as soon as possible; add 0.8 milligrams/liter conc H ₂ SO ₄ /liter; refrigerate
P,C	100	Analyze as soon as possible; add 0.8 milligrams/liter conc H ₂ SO ₄ /liter; refrigerate
P,C	100	Analyze as soon as possible; add 40 mg HgCl ₂ /liter and refrigerate (4°C) or freeze
P,C	500	Analyze as soon as possible; refrigerate or add 0.8 milligrams/liter conc H ₂ SO ₄ /liter
G	500	Analyze as soon as possible; refrigerate

and handling requirements (continued)

Container*	Minimum Sample Size, milliliters	Storage and/or Preservation**
G, BOD bottle	300	Analyze immediately
C	1,000	Analyze immediately
G(S)	--	--
P, G(B)	--	--
G	500	24 hour; add H ₃ PO to pH 4.0 and 1 g CUSO ₄ ·5H ₂ O/liter; refrigerate
G(A)	100	For dissolved phosphates separate by filtration immediately; freeze and/or add 40 mg HgCl/liter
P, G(B)	--	--
G, wax seal	240	Analyze immediately or use wax seal
P	--	--
G, gas bottle	--	--
P, G	--	Refrigerate
P, G	100	Add 4 drops 2M zinc acetate/100 milligrams/liter
P, G	--	Analyze immediately
G	500	Analyze as soon as possible; refrigerate
--	--	Analyze immediately
P, G	--	Analyze same day; store in dark for up to 24 hours

ene or equivalent); G = glass, G(A) or P(A) = rinsed with 1 + 1 HNO₃.
 illicate; G(S) = glass, rinsed with organic solvents.
 planning only; refer to Standard Methods for the Examination of Water
 h ed., AWWA, APHA, WPCF (1981) for procedure.



1.0

1.1

1.25

1.4

2.8

2.0

1.6

2.5

2.2

2.0

1.8

F
F
F
F
F

2.8

3.15

3.5

4.0

4.5

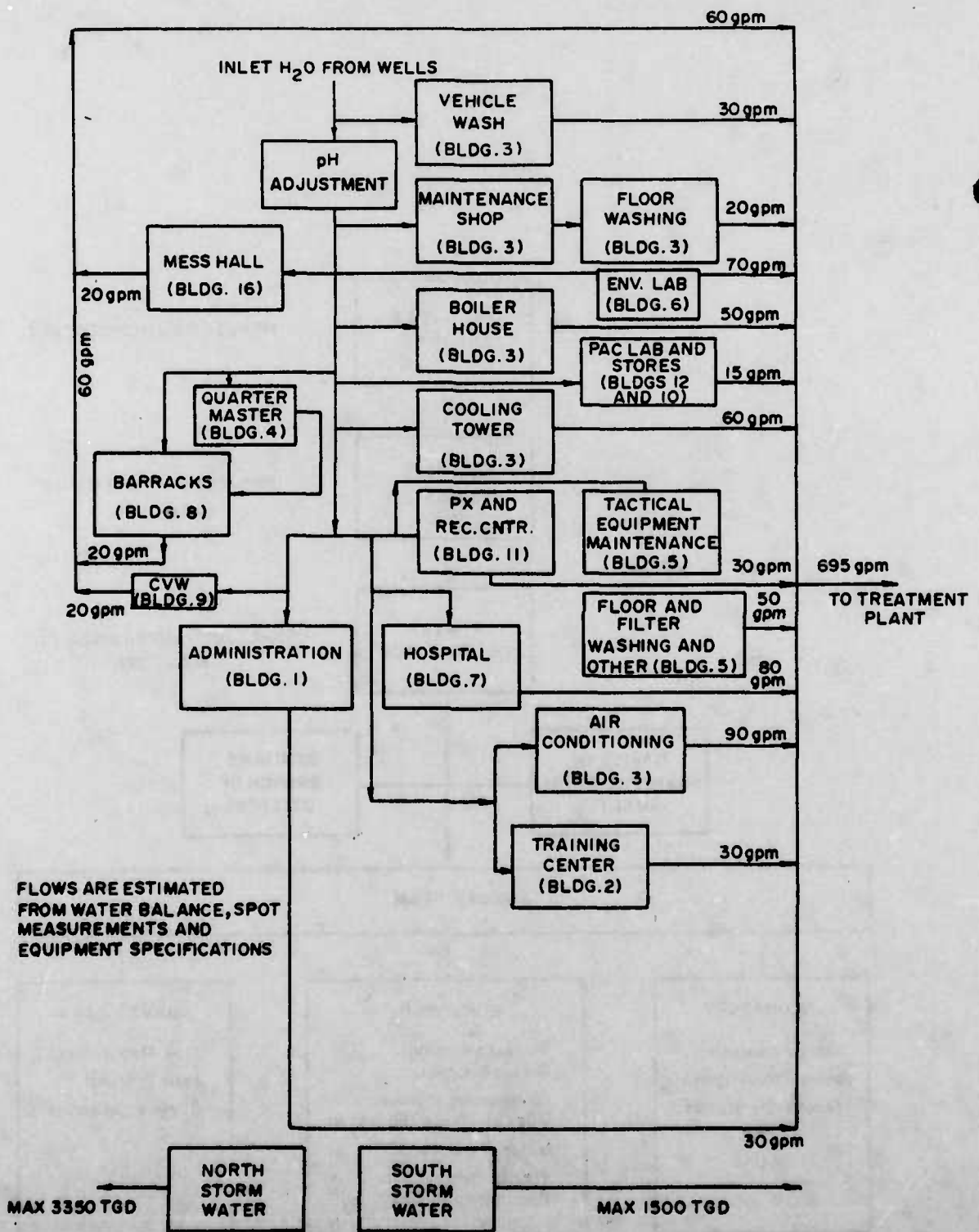


Figure 5-1. Example block flow diagram.

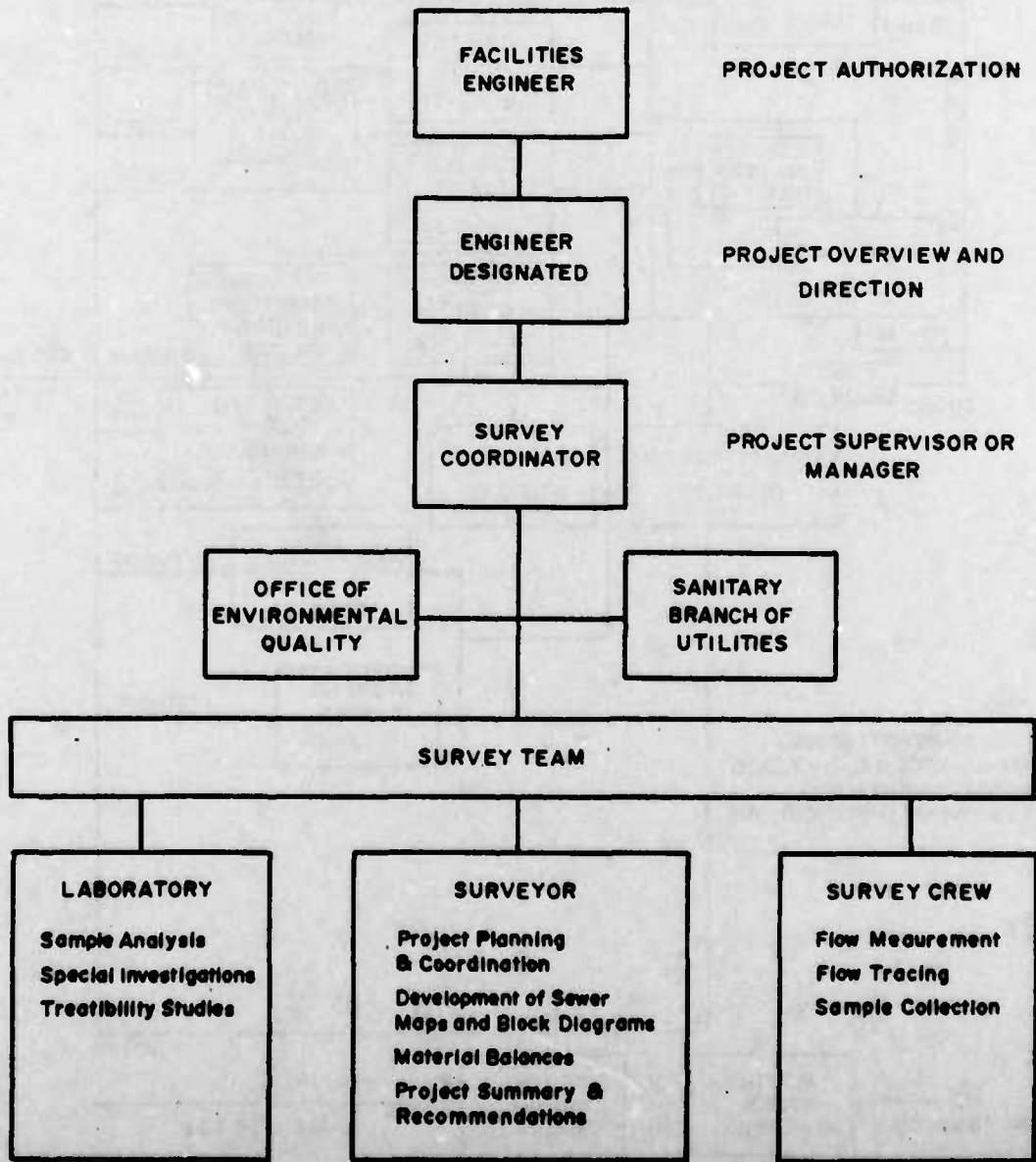


Figure 5-2. Survey organization chart.

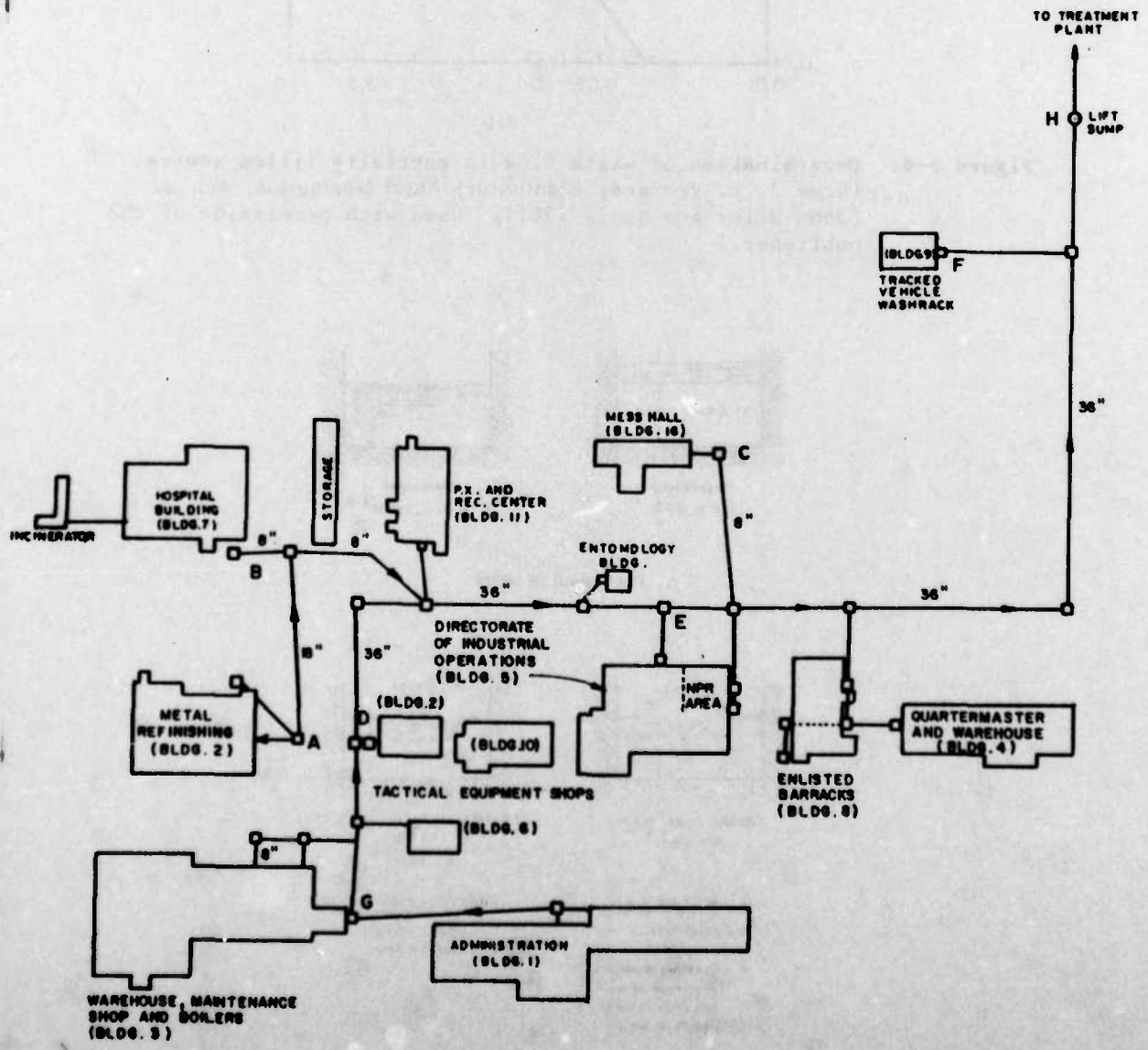


Figure 5-3. Sewer plan view.

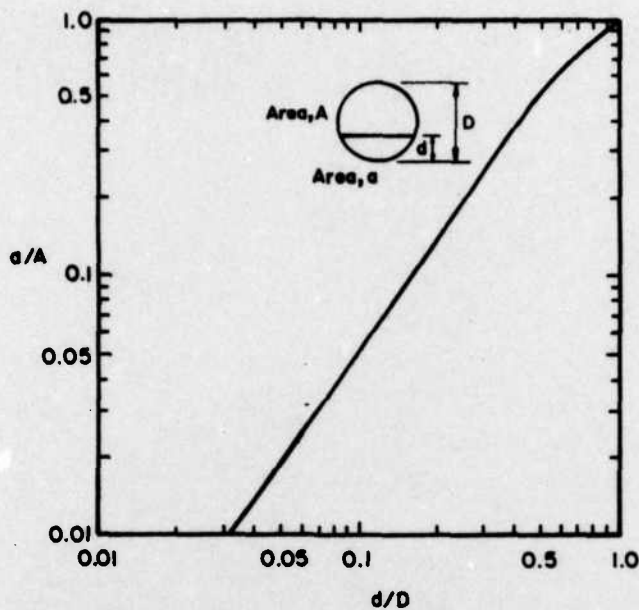
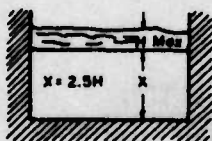
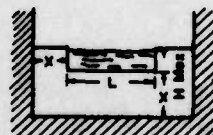


Figure 5-4. Determination of waste flow in partially filled sewers. (From J. K. Vennard, *Elementary Fluid Mechanics*, 4th ed. [John Wiley and Sons, 1961]. Used with permission of the publisher.)

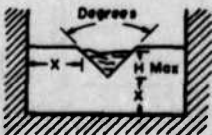


Suppressed
 $Q = K L H^{1.5}$

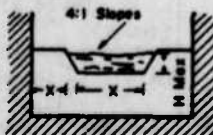


Contracted
 $Q = K(L - 2M) H^{1.5}$

RECTANGULAR WEIRS



TRIANGULAR WEIR
 $Q = K H^{2.5}$



TRAPEZOIDAL (CIPOLLETTI) WEIR
 $Q = K L H^{1.5}$

FLOW FORMULA

- Q = Flow Rate
- H = Head on weir
- K = Constant dependent upon type of weir and units of measure
- L = Length of weir

CONSTRUCTION GUIDE

- L at least 3H Max
- X at least 2H Max

Figure 5-5. Various types of sharp-crested weirs.

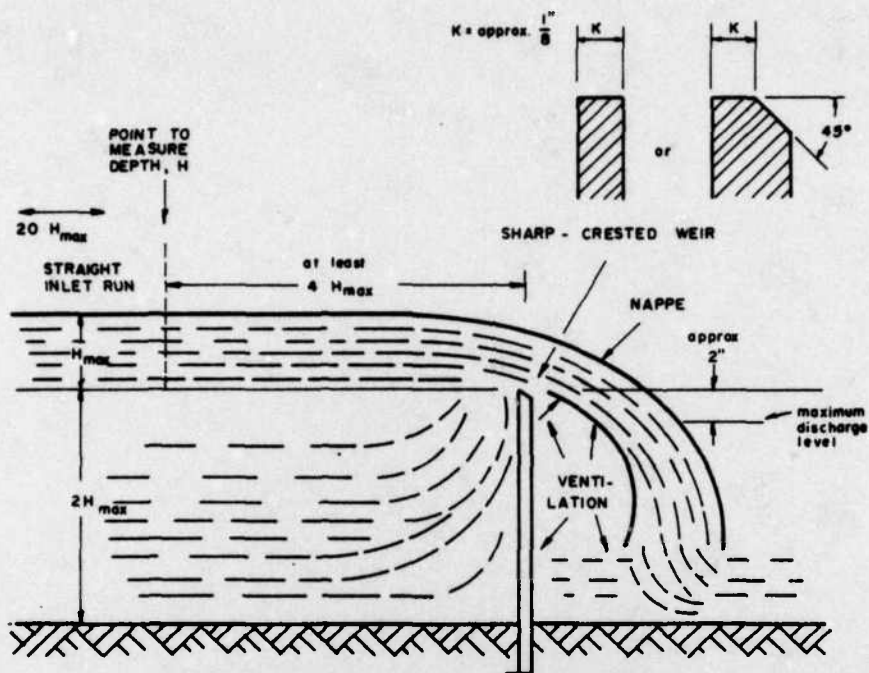
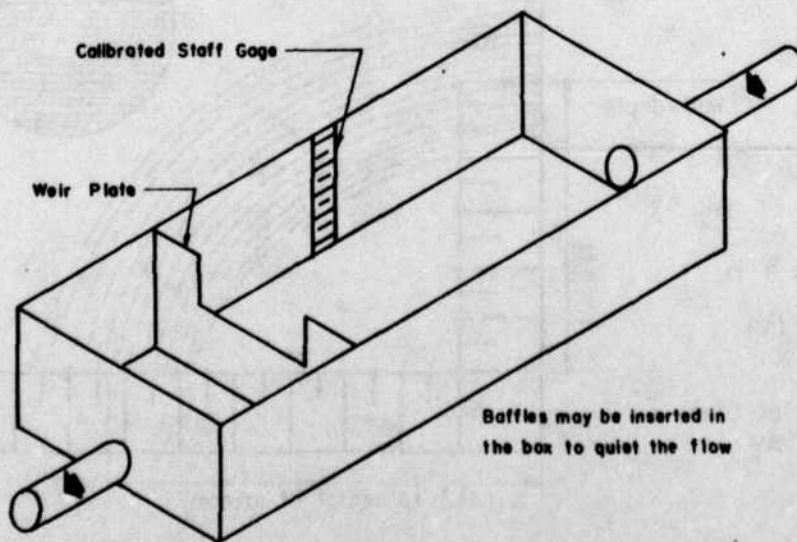


Figure 5-6. Profile of sharp-crested weir.



Typical weir - stilling box. Dimensions can be varied to suit plant conditions so long as quiet flow can be effected.

Figure 5-7. Weir stilling box.

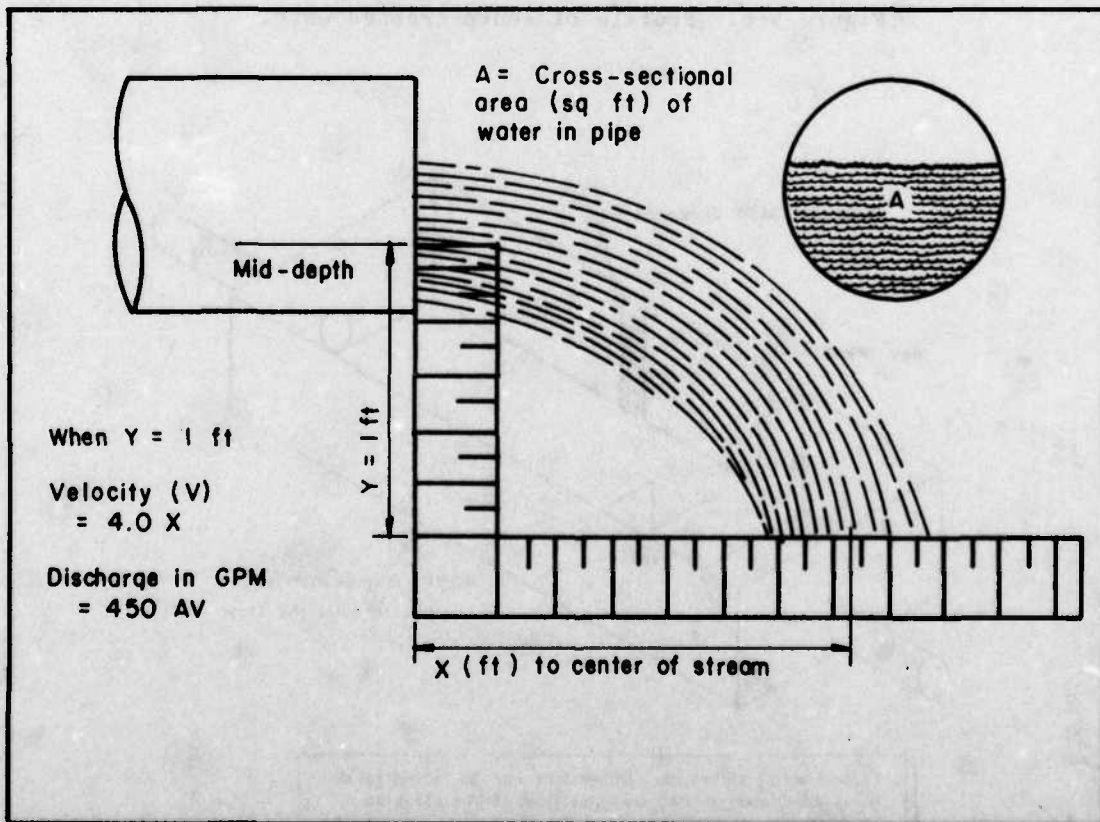


Figure 5-8. How to measure discharge from a pipe.

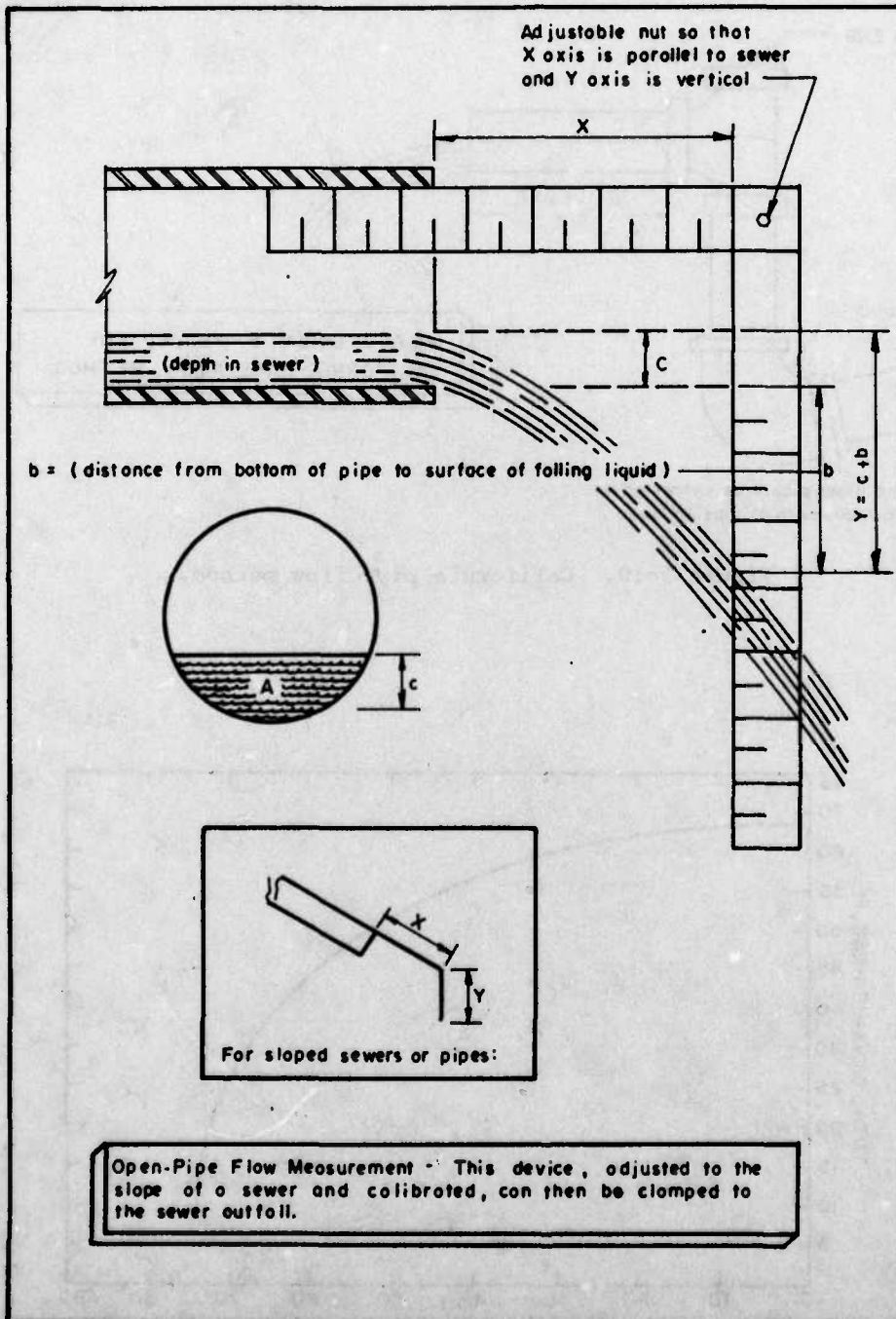


Figure 5-9. Open pipe flow measurement.

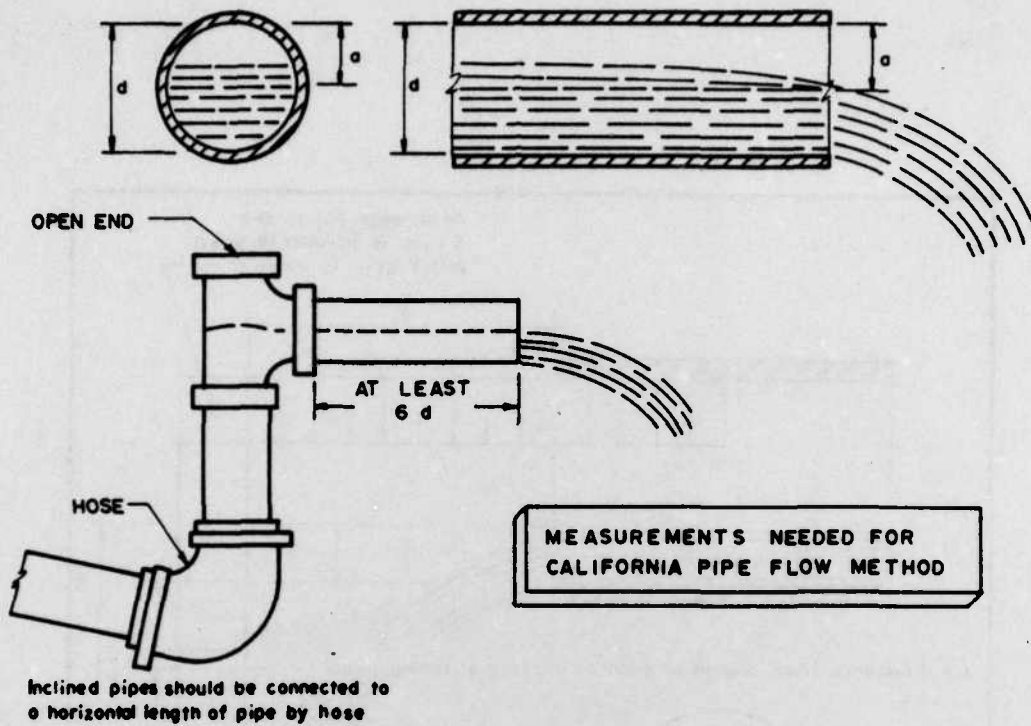


Figure 5-10. California pipe flow method.

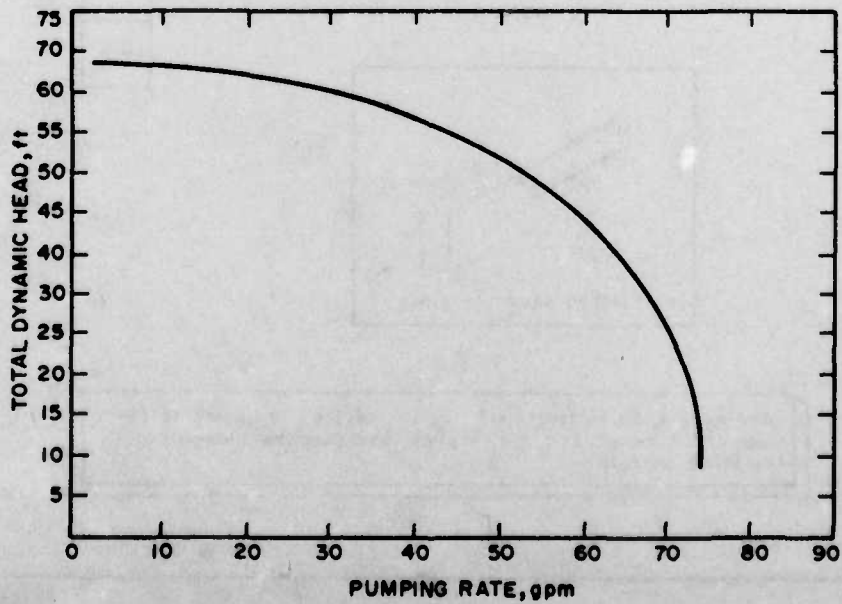


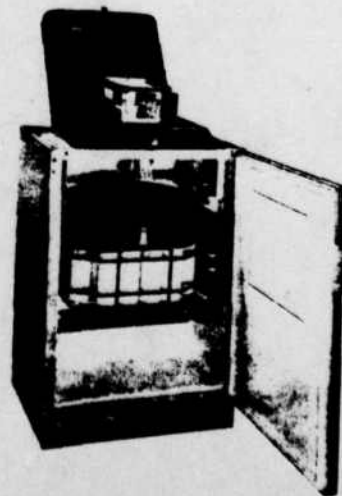
Figure 5-11. Example pump curve.



Discrete



Composite



Refrigerated Discrete

Figure 5-12. Examples of various types of automatic samplers.

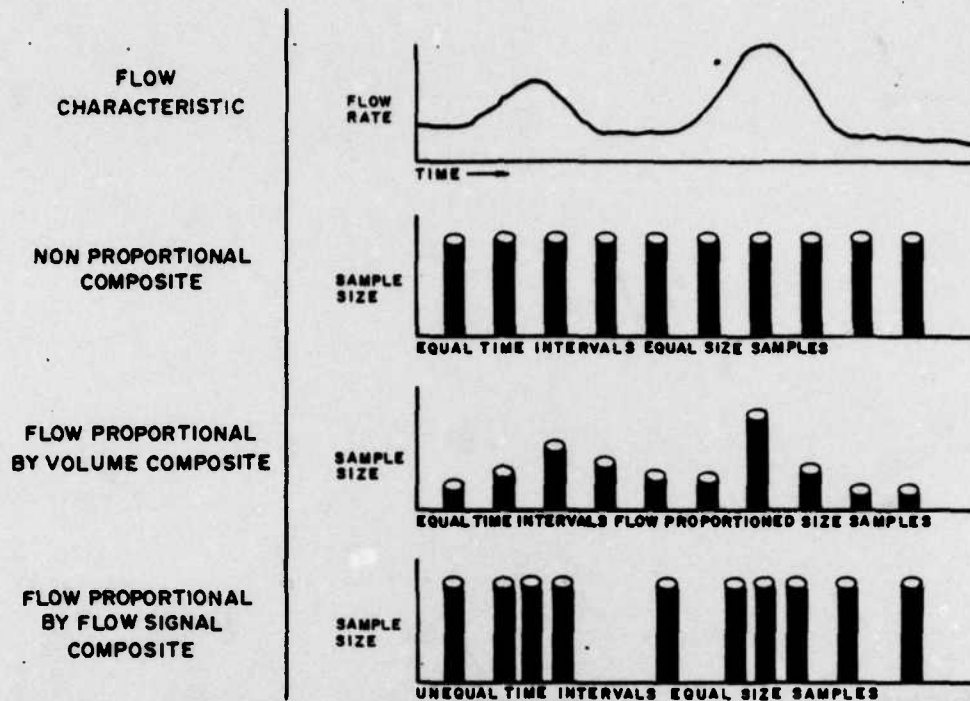


Figure 5-13. Comparison of various sampling methods.

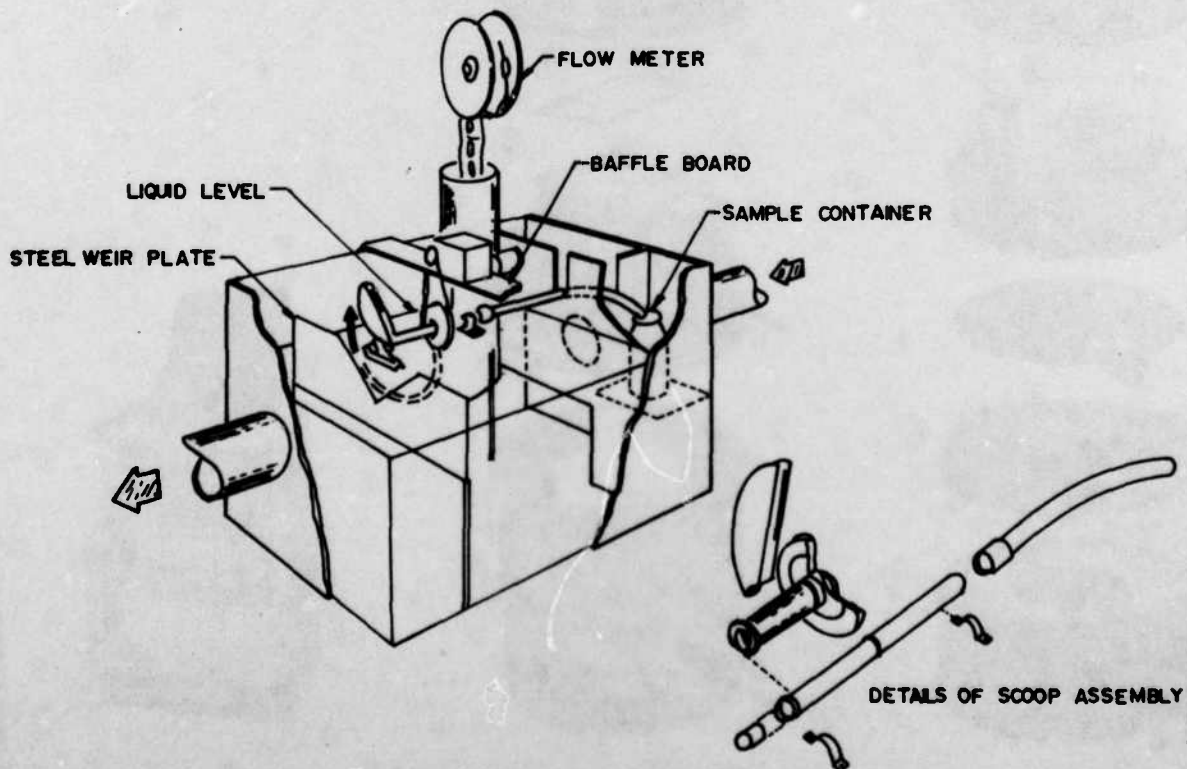


Figure 5-14. The "scoop" installation and detail of assembly. (From J. K. Vennard, *Elementary Fluid Mechanics*, 4th ed. [John Wiley and Sons, 1961]. Used with permission of the publisher.)

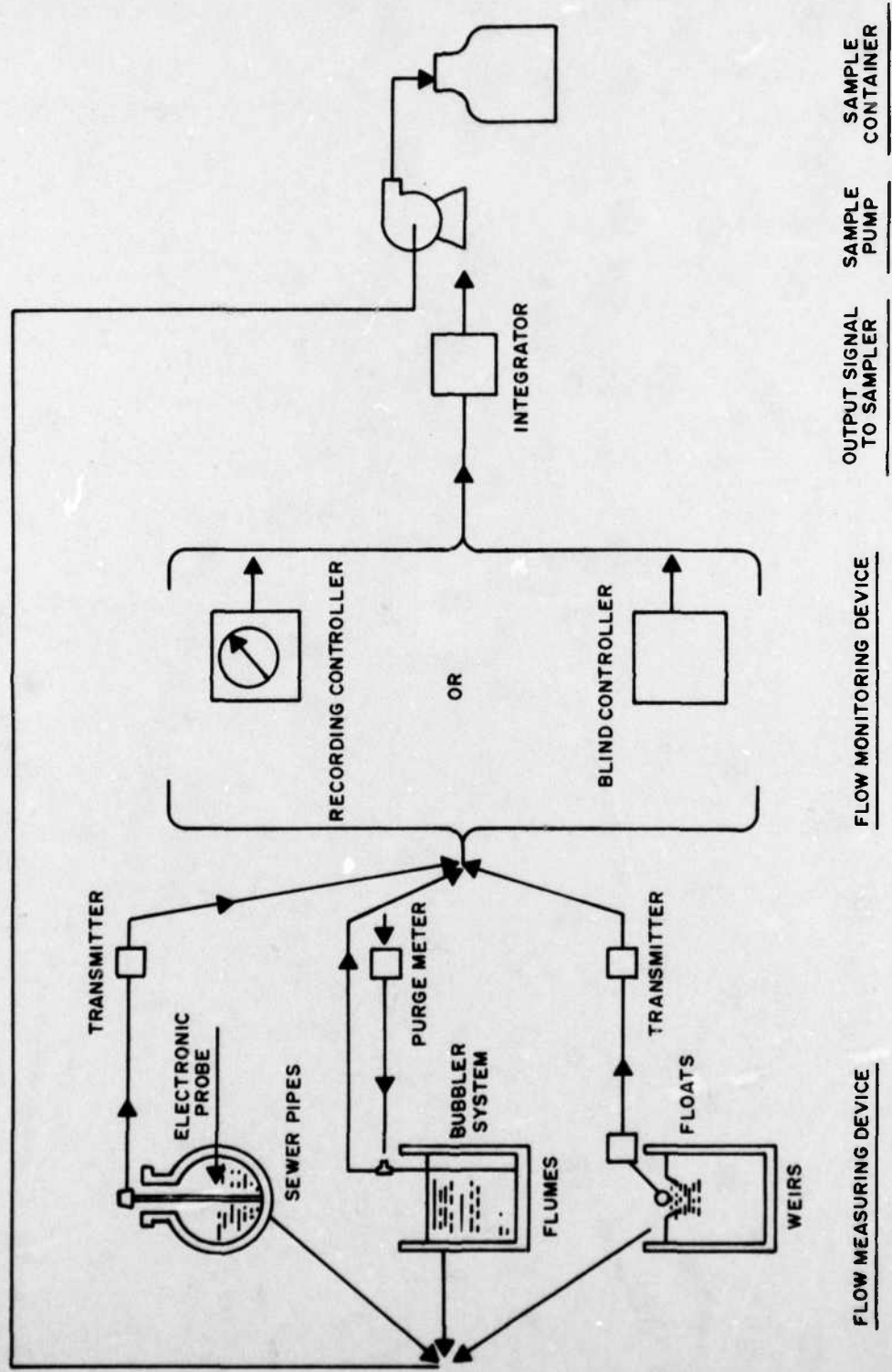


Figure 5-15. "flow-proportional" sampler control systems.

Chapter 6

Industrial Wastewater Control Technologies

6-1. Treatment systems terminology

a. The purpose of wastewater treatment systems is to upgrade the quality of the plant effluent to a level that will meet the requirements of the intended disposal scheme. A treatment system generally consists of unit operations, with each designed to remove one or more pollutants. Depending on the quality of the wastewater and the desired effluent characteristics, a series of unit operations can be selected. Generally, the complexity of the treatment system will be in direct proportion to the complexity of the raw wastewater quality and the stringency of the effluent quality requirements.

b. Wastewater treatment systems may be classified either by the nature of the removal mechanism or by the extent of treatment. Based on the principal removal mechanism, treatment processes may be categorized as physical, chemical, or biological. In most cases, more than one removal mechanism is used in a single treatment unit or in a process train.

(1) Physical treatment refers to operations in which pollutants are separated from the wastewater by physical or mechanical means, such as simple settling of suspended solids, or straining of solids in a microstrainer.

(2) Chemical treatment includes processes in which removal depends on a chemical reaction, such as precipitation of heavy metals with lime or oxidation of ammonia with chlorine.

(3) Biological treatment refers to processes in which the main removal mechanism involves breakdown and destruction of organic material by living microorganisms. Biological treatment processes include the breakdown of carbonaceous organic matter by microorganisms in an activated sludge reactor or anaerobic digestion of an organic sludge. In most cases, more than one removal mechanism is relied upon in a single treatment unit or in a process train. Thus, combinations of physical/chemical or physical/chemical/biological processes are frequently encountered in practice.

c. Historically, treatment systems for municipal and combined municipal/industrial wastes have been classified into four major categories (in progressively intensive order): pretreatment, primary treatment, secondary treatment, and advanced waste treatment (tertiary treatment). These categories refer to both the degree and type of contaminants removed from the wastewater; however, they are not in rigid sequence for industrial wastewaters. The order in which unit processes are applied in industrial waste treatment is a function of the contaminants in the waste. Therefore, it would not be unusual for an advanced waste treatment process to be applied for removal of a toxic component prior to biological treatment.

d. Industrial wastewater treatment facilities generate residuals or sludge as treatment byproducts. The characteristics of these residuals must be evaluated to determine their ultimate disposition. The three primary alternatives are treatment, dewatering, and disposal; processing and disposal as a hazardous material; and material recovery. Each category contains a variety of unit processes. Figure 6-1 illustrates the various treatment classes in their logical sequence and the unit processes and operations included in each.

6-2. Preliminary treatment

Preliminary treatment refers to the initial treatment operations conducted at wastewater treatment plants. The major objectives of these methods are to protect plant equipment from damage; to remove inert solids of high density; to convert wastewater to a form more amenable to treatment; and to dampen flow, pH, toxicity, or organic load variations. Although each method does not fulfill all of these objectives, several methods may be used together to produce the desired effects. In some cases, preliminary treatment methods may remove enough contaminants to allow discharge without further treatment.

a. Bar racks and screens. Most bar racks and screens are prefabricated units for which the manufacturer has developed removal, flow, and headloss characteristics. The design information provided by the manufacturers should be evaluated in detail to assure comparison on an equal basis among different suppliers. These data should be further compared with design calculations from standard reference sources to assure accuracy of claimed performance levels. All industrial wastewater treatment plants should have a bar rack on the influent channel. Subsequent finer screens should be added as required by the character and concentration of the suspended solids. All bar racks and screens should be fitted with headloss alarms to prevent hydraulic overloads to the plant or wastewater spills at the intake structure.

(1) Bar racks and screens are the first unit processes in most industrial wastewater treatment plants. They remove large solids from the wastewater that would damage other plant equipment. Large solids such as lumber, bottles, rags, cardboard, and dead animals are typically removed on the bar rack. Subsequent screens are sometimes used if the large solids loading is high. When racks and screens are used in series, the screen opening is reduced for each successive screen. In some industrial processes, the suspended solids represent a valuable raw material or product. In these cases, selective screening can sometimes be used to recover materials for reuse.

(2) Screenings or rakings (the solids removed) should be evaluated for content and reuse potential. If the materials are not hazardous and have no salvage value they are typically landfilled. If they contain hazardous materials, they must be treated as such under the Resource Conservation and Recovery Act (RCRA) and properly handled. If they have salvage value or reuse potential, storage and implementation procedures must be considered.

(3) Bar racks are the most frequently used screening device. They trap relatively large objects on parallel bars which are mounted vertically on a steel frame. The rack is set perpendicular to the flow in a channel and is tilted in the direction of the flow. Trapped solids are removed from the rack either manually or mechanically. Manually cleaned racks are tilted more than mechanically cleaned racks to allow easier access to the bars with a cleaning rake. Fine screens are often preceded by a bar rack. Figure 6-2 shows a schematic of mechanically cleaned bar screens.

(4) Static screens remove fine solids with screen spacings in the range of 0.01 to 0.10 inch. A concave screen is placed horizontally in a channel. The flow is forced over a barrier and down onto the screen, perpendicular to the flow. As the flow travels through the screen, solids are captured and roll down into a collection hopper. Figure 6-3 shows a typical static screen.

(5) A rotary drum screen is a metallic or synthetic cloth-covered drum rotating on a horizontal axis. The wastewater enters one end of the drum and exits through the cloth into a collection well. Cloth media are available with a variety of spacing sizes from 0.01 to 0.75 inch. Figure 6-4 shows a rotary drum screen. Rotary drum screens with very fine screening cloths (down to 1 micron) are classified as microscreens. These are sometimes used as a polishing step in industrial wastewater treatment plants that have rigid effluent suspended solids criteria.

(6) Vibrating screens use high-speed vibration and/or rotation to improve capture and drying of solids on flat screens. The screen is placed horizontally in a vertical channel, allowing the wastewater to fall by gravity through the screen. The solids captured by the screen are moved by the vibration to a common collection/drainage location. Vibrating screens are available in sizes ranging from No. 3 mesh to No. 200 mesh.

b. Comminutors

(1) Comminutors are an alternative to screens. Comminutors grind ("comminute") the solids and leave them in the wastestream. Both devices prevent large solids from entering the plant and damaging equipment. Comminutors reduce the size of the solids, but they do not decrease the solids load to the plant as screens do. Comminutors eliminate the need to dispose of screen material separately and improve the treatability of the solids by making them more manageable in size.

(2) Comminutors are usually located in a channel at the influent of a wastewater treatment plant behind a bar rack. Large solids are trapped on a stationary screen; cutting teeth pass across the screen and chop the solids into small enough pieces to pass through it. Figure 6-5 provides plan and cross-section views of a comminutor installation.

(3) Comminutors are sized by hydraulic capacity. Design data and required channel size may be obtained from comminutor manufacturers for standard-sized comminutors. Typically, the influent channel of a plant should be designed to accommodate the comminutor. A bypass channel and stopgates should always be provided to allow maintenance and repair. Rough bar screens and sometimes grit chambers precede comminutors to prolong the life of the equipment.

(4) Comminutors may be used in the preliminary treatment stage of plants receiving stormwater runoff or wastestreams containing large amounts of fibrous material, rags, cardboard, or other solids which could damage equipment or interfere with later operations.

(5) Barminutors have received large amounts of attention recently. They combine the best features of bar screens and comminutors in one piece of equipment.

c. Grit chambers

(1) Heavy inorganic solids in wastewater cause excessive wear on treatment plant equipment. Specifically, sand or other dense inorganic grit increases wear on pump impellers or pipes, and may sometimes clog channels and drains where velocities are low enough to permit sedimentation. If grit is removed in the primary clarifier with the primary sludge, it will reduce sludge digestion capacity. Therefore, industrial wastewaters with significant grit loadings typically undergo grit removal in the pretreatment segment of the treatment facility. The grit normally can be discarded in a sanitary landfill; how-

ever, if the industrial wastewater contains significant quantities of hazardous materials, the grit should be evaluated as a hazardous material and handled accordingly.

(2) Grit is typically differentiated from other suspended solids by its terminal settling velocity. Since grit removal is a physical process, using selective settling, selection of an overflow rate for the grit chamber balances collection of high-density particles against loss of low-density organics. Discrete settling velocity can be calculated from Stokes law:

$$v_o = \left[\left(\frac{4}{3} \right) \frac{g (S_s - 1) d^{1/2}}{C_D} \right] \quad (\text{Eq 6-1})$$

where:

- v_o = terminal settling velocity (cm/sec)
- g = acceleration due to gravity (cm/sec²)
- S_s = specific gravity of the grit (dimensionless)
- d = diameter of the grit particle (cm)
- C_D = drag coefficient (dimensionless)

The drag coefficient, C_D , is a function of the Reynolds number:

$$C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$$
$$0.5 < R_e < 10^4$$

where R_e = Reynolds Number.

(3) Typically, grit chambers are designed with a surface overflow rate of 4000 gallons/square foot/hour. This represents a terminal settling velocity of 4.5 centimeters/second, which would be the approximate settling rate of 65-mesh silica sand. Thus, at these design rates, all particles with sizes and densities greater than 65-mesh silica sand would be collected.

(4) Horizontal flow and aerated grit chambers are the two most common designs. Both use surface overflow rate as the primary design variable; however, they use different techniques to scour the grit for trapped organics. In the horizontal chamber, a minimum 1 foot/second horizontal velocity is maintained to scour the grit; in the aerated system, diffused air creates the turbulence needed for scouring.

(5) Most grit chambers are drop-in package units, although manufacturers will develop designs to fit specific needs. However, their products should be compared on an equivalent basis, considering overflow rate, horizontal flow velocity, mixing intensity, and grit collection system. Both capital and operational costs should be evaluated to assure the most cost-effective system.

d. Skimmers and grease traps

(1) Skimmers and grease traps remove floatables from the wastestream at the source. These materials include POLs, foam, cooking grease, and other debris. If these materials are not removed at their source, they could cause problems in both the wastewater collection system and the treatment plant. POLs can become emulsified by turbulence in the sewer or during pulping and cause treatment problems in both physical/chemical and biological treatment systems.

(2) Skimmers and grease traps work on the principle of gravity (or density) separation. Grease traps are small catch tanks usually placed close to the wastewater source. Enough detention time (typically 10 to 30 minutes) is provided to cool and float most of the oil and grease and other floatable organics; this prevents them from entering the main sewer collection system. Grease traps must be cleaned regularly.

(3) Skimming "tanks" are short-detention-time holding basins, where rake mechanisms or skimming blades skim substances from the top into a collection hopper. Effluent exits below the water surface, either under a baffle or through submerged outlets. This process may be done in a separate tank or combined with a primary sedimentation process.

(4) Materials removed by grease traps and skimmers should be evaluated to determine their composition. Industrial wastes reflect the industrial process; therefore, floatables may contain recoverable raw materials or hazardous materials that may require special handling. The final disposal procedure for floatables should be based on the analysis results.

(5) Grease traps are typically designed to have a hydraulic detention time of 10 to 30 minutes. They should be sized to handle surges of oily wastes and should be easy to clean and maintain.

(6) Skimming tanks are usually designed for a hydraulic time of 1 to 15 minutes, or an average of about 5 minutes. Collection hoppers should be sized to hold the skimmings for an amount of time based on the desired cleaning schedule. Skimming depth should be adjustable to allow operators to set the scraper level for maximum oil and floatable removal but minimum removal of the aqueous phase.

(7) Grease traps are useful when much of the oil and grease entering a waste treatment plant is from one or two sources. By catching the oil and grease before it enters the main sewer system, separate disposal or recycle may be provided and wastewater treatment plant operating problems minimized. This practice can extend the organic loading capacity of the plant. Food processing, mess halls, vehicle maintenance, and motor pools are common applications of "at-source" oil and grease removal. Skimmers are typically used at the industrial treatment plant to remove floatables from the combined waste stream. Sometimes, however, where an industrial process generates large amounts of floatables or product recovery potential exists, skimmers are a viable in-plant process.

e. Equalization

(1) Equalization is used to dampen fluctuations in waste strength and flow. It improves the performance of later treatment processes by reducing sudden or large variations in wastewater characteristics; this gives more consistent, controllable operating conditions.

(2) There are two types of equalization: that used chiefly to dampen flow variations, and that used to dampen waste load excursions, such as organic, pH, or toxic concentration peaks. This is done by providing a holding basin large enough for the effluent to equalize flow or waste load changes before exiting the basin. Mixing should be provided for waste load equalization. Flow equalization basins do not require mixing unless solids settling or septic conditions pose a problem. Where needed, mixing is provided by mechanical mixers, diffused air, baffling, or distribution of inlet flows.

(3) Equalization system design is based on influent characteristics and sensitivity of the treatment processes. Influent characteristics may vary in flow and/or loading. Treatment plants vary in sensitivity. Some units, such as clarifiers and flotation units, are sensitive to hydraulic over- or under-loads. Others, such as trickling filters and activated sludge systems, are more sensitive to organic loadings, although they still require continuous flow.

(4) Equalization must be designed to coordinate influent characteristics and treatment plant tolerances. Two simple forms of equalization basins are used. Flow equalization basins accept variable flows, but discharge at a constant rate. These basins operate at variable levels. Waste load equalization basins accept a constant flow and discharge at the same rate. The basin level is constant.

(5) Equalization basins are usually designed by a statistical procedure using a comparative analysis of the wastewater characteristics for a series of samples, an acceptable basin effluent characteristics range, and a specified degree of confidence for equalization system performance.

(6) Mixing systems designed for equalization basins are usually based on a range of 15 to 20 horsepower per million gallons for mechanical mixers and 1.5 cubic feet per minute per 1000 gallons for diffused air mixing. Design values may be obtained from manufacturers of this equipment or may be estimated from statistical design methods. Placement of baffles, mixers, or aerators must also be considered.

(7) Most industrial wastewater treatment plans should have an equalization basin. It gives operators time to react to slug discharges or process upsets. This flexibility is often critical in operating a complex industrial wastewater treatment system properly.

f. Neutralization

(1) The pH of an industrial wastewater is a function of the processes that generate it. Thus, the influent pH varies as a function of ongoing upstream processes. If the influent pH varies widely over a diurnal cycle, or is consistently outside the acceptable range for treatment, it must be neutralized. The degree of pH adjustment required depends on subsequent unit processes in the wastewater treatment plant, since most physical/chemical and biological processes operate only within a specific pH range. If operation is attempted beyond the acceptable range for a unit process, efficiency is typically reduced greatly. Furthermore, shock loading biological reactors with extreme pH changes can kill the biomass; this will cause a longer-term problem while the biomass is re-acclimated.

(2) Neutralization is often done in the equalization basin or in a separate basin at the front of the treatment plant. It may also be required at other locations in the plant to offset pH changes caused by treatment processes. A final pH adjustment may also be

required before discharge. Regardless of the location in the treatment chain, the procedures are analogous. There are several common methods of pH adjustment.

(a) **Chemical addition systems.** These systems add chemicals, acids, and alkalis in a mixing basin which adjust the pH to the desired set point. The systems are considered either one-sided or two-sided. One-sided systems add only acid or alkali. They are used when the waste is consistently on one side of the set point before adjustment. Two-sided systems use an acid and an alkali to adjust a waste which varies on both sides of the set point. Many adjustment systems are automatically operated by pH sensors which trigger pumping of desired reagents. Batch systems are sometimes used for flows of up to 100,000 gallons per day. The wastewater fills the basin, the pH is measured, and appropriate chemicals are added. The basin is mixed well, and the contents provided an adequate reaction time; the pH is then rechecked. If necessary, more chemicals are added until the desired pH is attained and the waste is discharged. The pH adjustment for batch systems may be manual or automatic. Continuous pH adjustment units are usually either one-stage or two-stage. One-stage systems are used with low variability wastes. The low variability makes one-step pH adjustment relatively easy. The pH probe measures influent pH and triggers addition of chemicals in the mixing basin. A stilling basin allows complete reaction. The pH is checked again as the mixture exits, and an impulse provides feedback to the reagent pumps if dosages must be adjusted. Figure 6-6 illustrates a two-sided, one-stage continuous system. Two-stage systems are used for highly variable wastes. The first mixing basin roughly adjusts the pH, and the second basin fine-tunes it to the set point. The pH sensors are used in the influent pipe, the first stage, and the stilling well. Signals coming from the first stage and the stilling well sensors provide feedback to the first and second set of chemical addition controls, respectively. Figure 6-7 illustrates a two-sided, two-stage continuous pH adjustment system.

(b) **Mixing acidic and alkaline wastestreams.** This process requires enough equalization capacity to produce the desired adjustment and to allow for flow variation.

(c) **Passage through limestone.** Acid waste pH can be adjusted by downflow or upflow passage through limestone beds.

(d) **Mixing acidic wastes with lime slurries.** In lime-slaking operations, the reaction is speeded up by heat and physical agitation.

(3) **The design of pH adjustment facilities requires consideration of several factors.**

(a) **Waste characteristics.** The pH, acidity, alkalinity, variability, volume, potential by-products of neutralization, and toxic by-products of waste involved must be determined.

(b) **Equalization facilities.** Equalization may be designed to dampen pH fluctuations; this will minimize adjustment requirements.

(c) **Choice of method.** The method used is determined by the degree of adjustment required, available resources, responsiveness of the wastestream, subsequent treatment processes, and economic factors. Bench-scale testing is usually needed to determine the feasibility of the method chosen. Chemical addition is the most commonly used method of pH adjustment. The sections below outline some of the important factors in designing these methods. Each waste responds differently so testing must be conducted to determine these parameters.

-- Type and dosage. For chemical addition systems, laboratory tests relating pH and chemical dosages are used to determine the chemical type and quantity for the individual waste stream to be treated. Economic considerations typically control choices among several successful chemicals.

-- Mixing. Adequate mixing must be provided to allow maximum chemical dispersion and efficient chemical use.

-- Reaction time. Sufficient hydraulic retention time must be provided to assure complete chemical reactions.

-- Sludge Volume. Chemical addition often results in precipitation of solids. For these cases, pH adjustment designs must consider sludge removal and disposal.

(d) Materials of construction. The extremely acidic or caustic nature of some chemicals used in pH adjustment may require specific corrosion-resistant materials be used to construct the facilities. Many industrial wastes are highly acidic, such as electroplating wastes, or highly alkaline, such as some pesticide and laundry wastes. Adjustment of waste pH is often used as an "in-plant" pretreatment step on a segregated stream.

6-3. Primary treatment

Primary treatment processes generally address removal of suspended and floatable materials. The processes used are emulsion breaking, oil and water separation, air flotation, and primary clarification.

a. Emulsion breaking

(1) Emulsion breaking processes are used to break water-oil bonds ("emulsions"), so POLs can be removed from wastewater. Emulsified POLs require special treatment so that the materials will be freed for separation by gravity, coagulation, or air flotation. Emulsion breaking is complex and requires thorough bench-scale and pilot plant investigations before final process selection.

(2) Substances which create or stabilize emulsions may be classified as ionic or nonionic; they generally are of a colloidal nature or consist of solid particles which are surface-active. Hydrated gels or gums, soaps, sulfonated oils, asphaltic residues, waxes, silt, finely divided coke, and sanitary sewage solids are typical.

(3) Common emulsion-breaking methods are:

(a) Physical methods: heating, distillation, centrifugation, and precoat filtration.

(b) Electrical methods.

(c) Chemical methods: polymers, metal hydroxides, and chelating agents.

(4) Emulsions are present in many wastewaters. Machinery lubricants and coolants are common examples of emulsified POLs found in industrial wastes. Emulsions are

often created in POL-contaminated wastewaters which come in contact with steam, soap, caustic streams, or vigorous agitation. Emulsions occur on Army bases in discharges from steam washracks for equipment or vehicle cleaning. Petrochemical wastes can also contain high concentrations of emulsions. Emulsion breaking would commonly be used as pretreatment in-plant for wastes from a specific source, such as an engine pack steam-cleaning area.

b. Oil and water separators

(1) Oil and water separators selectively remove oil and grease as a function of buoyant velocity. The removal of POLs in preliminary stages of treatment prevents emulsification and inhibition of treatment processes.

(2) The two most common types of POL and water separators are the API separator and the CPI separator. The API separator was developed by the American Petroleum Institute to capture particles with a rise velocity (negative settling velocity) greater than 0.15 centimeter per second. This value is calculated from the laminar flow form of Stokes Law:

$$V_o = \frac{g}{18} (S_s - 1) d^2 \text{ for } R_e < 1.0 \quad (\text{Eq 6-2})$$

where:

- V_o = terminal settling velocity (cm/sec)
- g = acceleration due to gravity (cm/sec²)
- S_s = specific gravity of the oil (dimensionless)
- d = oil droplet diameter (cm)
- v = viscosity (g/cm sec)
- R_e = Reynolds number (dimensionless)

For a typical lubricating oil with a specific gravity of 0.85, this converts to removal of all oil particles with diameters greater than 0.015 centimeters. Design is based on surface overflow rate; however, since V_o is negative this value is actually expressed as gallons/square foot/hour underflow. Surface skimming mechanisms remove the floated oil. The oil may sometimes be recycled. Sludge rakes can be included in the design to conduct any settleable solids into a sludge hopper, which is emptied periodically. Figure 6-8 illustrates an API separator design.

(3) To improve the removal efficiency, inclined parallel corrugated plates were added to API separators. In this CPI separator, wastewater is directed down the inclined parallel plates and exits from the lower side of the plates. Oil globules rise along the corrugated plates and join into larger drops. The oil is skimmed into a collection hopper at the top of the tank. Figure 6-9 shows a cross-section of a CPI separator.

(4) The tradeoff between API and CPI separators is operating cost. The CPI separator takes advantage of increased surface area to reduce the unit volume required to meet overflow rate requirements; thus, the unit size is smaller and requires a lower capital investment. However, CPIs are harder to clean and may clog if the wastewater is highly contaminated with emulsified oil or other floatables.

(5) It is preferable to install oil and water separators on segregated wastestreams before discharge to the main sewer systems. APIs and CPIs are often used in Army tactical equipment areas to recover usable oils and gasoline; they are also used in vehicle and equipment rework facilities, in vehicle wash areas to remove oils from the wash-water discharge, and for area sources runoff from airfields.

c. Dissolved air flotation (DAF)

(1) DAF is sometimes an alternative to clarification for suspended solids removal. DAF removes fibers and low-density materials which do not settle well. DAF speeds up the rise rate and removal of floatable materials such as oil, grease, and fine particles.

(2) DAF is similar to clarification; however, solids are floated to the top and skimmed off, instead of settling to the bottom to be raked out. This is done by means of fine air bubbles which adhere to particles in the wastewater. The specific gravity of the air/solid globule is much less than the wastewater; this allows the globule to rise to the surface. There are three standard flotation systems:

(a) Full pressurization DAF without recycle.

(b) Partial pressurization DAF with recycle.

(c) Induced air flotation.

Full pressurization DAF systems pressurize the influent waste flow, which supersaturates the wastewater with air. The pressurized flow is released into a basin which is open at atmospheric pressure. Fine bubbles form in the wastewater as the air is released from the supersaturated air/water solution. Partial pressurization is based on the same principle; however, part of the effluent is supersaturated with air and then recycled to mix with the influent in the basin. Figure 6-10 illustrates these two systems. Induced air flotation (IAF) uses mechanical mixers to force air bubbles into the wastewater. Typically, four stages or cells are used. These systems have lower capital cost than DAF systems. However, the skimming volume from IAF systems is generally 3 to 7 percent of the influent flow; with DAF systems, it is less than 1 percent. In some applications, flotation systems can remove solids more efficiently than clarifiers, but require frequent operator attention for adjustments and maintenance.

(3) For either DAF or induced flotation, the most important design parameter is the air-to-solids ratio. There must be a balance between the amount of air needed to properly float solids and an excess which would cost more in operator expenses. The air-to-solids (A/S) ratio is expressed in pounds of air released per pounds of solids fed. The A/S ratio must be determined for a wastewater by bench- and pilot-scale tests. Typical ratios range from 0.01 to 0.10 pounds-air/pounds-solids.

(4) Specific DAF design variables include pressure, recycle ratio, overflow rate, and hydraulic retention time. The following ranges are typical:

Pressure = 25 to 70 pounds per square inch gage

Recycle Ratio = 5 to 120 percent

Overflow Rate = 500 to 4,000 gallons per day/square foot

Hydraulic Retention Period = 20 to 60 minutes

(5) Flotation units treat wastewaters with low-density solids and/or POLs. Combined with chemical addition, they can often remove emulsified oils. Table 6-1 gives typical industrial process wastes with associated DAF performance.

d. Primary clarifiers

(1) Primary clarification is used to remove settleable solids, insoluble BOD, and floatable material. It is the most commonly used preliminary step to decrease the organic and solids loadings on biological treatment units. Clarification is also used in secondary and tertiary treatment.

(2) Sedimentation (or clarification) is done in large basins or "clarifiers." The wastewater enters the basin and is given enough time for quiescent settling of particles before the clarified wastewater passes over weirs to leave the basin. Sludge formed by the settled particles collects in the bottom of the clarifier and is drawn off periodically. There are four settling classifications:

(a) Discrete settling is the settling of separate particles with no interaction. This is also called "free settling." Primary clarification is usually of this type.

(b) Flocculant settling is the settling of particles which join with other particles as they descend; this increases the total particle weight and the settling rate.

(c) Zone settling is the settling of a mass of particles as a unit; it produces a distinct solids-liquid interface.

(d) Compression settling occurs when particles have settled sufficiently to form a structure; further settling results from compression by the weight of more particles.

(3) Settling occurs in consecutive stages or zones. Figure 6-11 shows these stages and the associated type and rate of settling. Discrete settling of particles from the upper layers of a clarifier first produces a clarified water zone from which effluent is drawn. The discrete particles descend to the individual particle zone where flocculant settling starts. The flocculated particles ("floc") agglomerate and form a lattice which settles as a unit. This produces a distinct interface between the settling solids and the liquid above. The descent of the interface through the hindered zone represents zone settling. Eventually, solids buildup from the floor of the clarifier interferes with the descent of the solids lattice in the transition zone. As solids continue to build up, water is squeezed out of the sludge by the increasing weight. This accounts for compression settling in the compression zone.

(4) Sedimentation clarifies effluent (overflow) and concentrates sludge (underflow). These are often done in separate units. Discrete and flocculant settling occur in units which emphasize clarified effluent, such as primary clarifiers. Zone and compression settling are the predominant settling types in units emphasizing thickened underflow; these include activated sludge clarifiers and gravity sludge thickeners.

(5) Clarifiers are circular or rectangular basins equipped with overflow weirs for effluent and underflow ports for sludge withdrawal. They may also be equipped with

baffles to prevent floatable materials from going over the weirs and skimmers to remove these materials. Sludge rakes help with sludge collection and removal. Rectangular clarifiers provide the economic advantage of common-wall construction if more than one unit is to be used. Figure 6-12 shows a rectangular clarifier. Circular clarifiers are classified as centerfeed, peripheral feed, and peripheral feed/draw. Centerfeed clarifiers receive influent waste in the middle of the clarifier and remove effluent around the perimeter. Peripheral feed units receive wastewater from the perimeter and remove wastewater through a collection area in the center. Influent wastewater enters and effluent exits from the perimeter of peripheral feed/draw clarifiers. These units often have center effluent draw-off capabilities. Figure 6-13 illustrates one type of circular clarifier.

(6) The most important clarifier design parameter is the surface loading rate or overflow rate. This rate depends on the type of wastewater, the solids characteristics, and the chemicals added, if any. For primary clarification of untreated wastewater, average overflow rates of 600 to 1200 gallons per day/square foot are common.

(7) Overflow rate (OR) is a different way of expressing the terminal settling velocity of the solids. Zone settling velocity (ZSV), refers to the settling rate of solids (in feet/hour). This term may be converted to the overflow rate as:

$$\left(\text{ZSV ft/hr} \times \left(\frac{24 \text{ hr}}{\text{day}} \times \frac{7.48 \text{ gal}}{\text{cu ft}} \right) \right) = \text{OR, gallons per day/square foot.}$$

Therefore, lab settling test results may be easily changed to design overflow rates. (Use of scale-up factor is highly recommended.) Figure 6-14 shows examples of the effect of changing overflow rates on TSS and BOD removal.

(8) Weir loading is the volume of water flowing over a weir per day per unit length and is expressed in gallons per linear foot. Weir loading rates to municipal primary clarifiers are restricted by law in some parts of the country to a maximum of 10,000 to 15,000 gallons per day/linear foot. Primary clarifiers are typically designed to provide 90 to 150 minutes detention time for the average flow. Shorter detention times (30 to 60 minutes) may be used when the clarifier precedes a biological treatment unit.

(9) Primary clarification is important when the wastewater to be treated contains a large amount of settleable solids and when the loading to a secondary treatment system must be decreased. Wastewaters containing stormwater runoff and comminuted solids have high organic solids contents; they should be treated by primary clarification before secondary treatment. Primary clarification is sometimes enough to be the final treatment process before discharge. Removal of soil from vehicle wastewater and removal of suspended solids from laundry wastes are typical examples.

6-4. Biological treatment - basic concepts

a. Biological treatment has become the most natural treatment philosophy in wastewater treatment. The process uses micro-organisms to decompose organic wastes in the same way that they would be decomposed naturally. The major difference between naturally occurring biodegradation and biological treatment systems is the environment under which the reaction occurs. In natural systems, the reaction is rate-limited due to oxygen transfer; in treatment, the reaction is normally growth-rate-limited. Thus, biological treatment systems try to provide an "ideal" environment for the micro-organisms to decompose the organic waste. Since industrial wastewater is a function of the industrial process, it can lack essential nutrients or contain contaminants that are toxic to the biological reactor.

b. The basic premise of biological wastewater treatment is removal and/or stabilization of organics in the wastewater. This process may be extended to oxidize oxygen-demanding chemicals, such as ammonia, to a less reactive chemical form such as nitrate or nitrogen gas.

c. Aerobic and anaerobic are the two main types of biological treatment systems. Aerobic systems use free oxygen to oxidize organic materials; anaerobic systems oxidize in the absence of free oxygen. Aerobic treatment has been the preferred technique for municipal wastewater; anaerobic treatment has been used to treat organic sludges generated by the aerobic processes as well as wastewater.

d. Many different biological treatment processes are now in use. All have three basic requirements:

(1) A means of providing contact between "bugs" (microorganisms) and organic matter (the substrate).

(2) A means of providing the electron donor (usually oxygen) for metabolism.

(3) A means of harvesting "bugs" for clarification of effluent and of providing recycle solids where necessary.

e. Two ways to provide contact between microorganisms and organic matter in the water are suspended growth systems, and fixed or attached growth systems. A slurry or suspended growth method may be used where the bugs and wastewater are blended in a basin. In a fixed film or attached growth method, bugs are grown on a medium; the wastewater is then passed over the medium, or the medium passed through the wastewater.

f. Aerobic systems require molecular oxygen as the electron donor for metabolism. Several means of providing oxygen are used. In biological treatment ponds, photosynthesis by algae and other aquatic plants provides oxygen. Fixed-film systems may pass or hold bio-media in the air. Blowers may also be used to improve circulation around the medium, thus increasing microorganism/air contact. For slurry systems, either compressed air is bubbled into the wastewater, or mechanical induction of oxygen (by throwing wastewater into the air) is used.

g. Diffused aeration, surface aeration, and turbine aeration are three important means of providing oxygen required for metabolism.

(1) Diffused aeration. Diffused aeration devices are usually classified into two categories: coarse bubble diffusers and fine bubble diffusers. Coarse bubble diffusers pass air through large-diameter submerged orifices or use hydraulic shear devices to produce large bubbles. This type of diffuser requires little maintenance but does not provide a high rate of oxygen transfer due to the large bubble size. Static aerators, a modification of the standard coarse bubble diffusers, are vertical, cylindrical tubes placed on the bottom of a basin over coarse bubble orifices. Air rises through the tube, causing an air-lift effect, which results in better mixing than conventional diffused-air systems. Elements in the tube cause turbulence and break up air bubbles to insure complete mixing and maximum air/water contact. These aerators have very high oxygen transfer efficiencies in comparison to most diffused-air systems. Fine bubble diffusers force air through porous media situated at the bottom of biological treatment basins. Fine bubbles are formed, providing good oxygen transfer; however, the system also requires air filters

and, in some applications, considerably more maintenance than coarse bubble diffusers due to clogging problems with the fine porous media.

(2) **Surface aeration.** Surface aerators or mechanical aerators consist of partially or completely submerged impeller blades spinning at speeds which can splash the wastewater into the air to provide air/water contact. Surface aerators are designed as low-speed or high-speed units, depending on the rotational speed of the blades. Usually surface aerators are placed so as to rotate in a horizontal plane around a vertical shaft. Brush aerators are placed so as to rotate in a vertical plane around a horizontal shaft. Surface aerators provide moderate to good oxygen transfer and require only a little maintenance. Although this type of aeration has the advantage of mechanically mixing basin contents, it results in a high degree of heat loss from evaporation during the winter and is applicable only to a limited range of basin depths.

(3) **Turbine aeration.** Turbine aerators are a combination of diffused and surface aerators. Air is pumped out of a sparger ring above the basin floor. Impellers over the sparger ring spin to break large bubbles into much smaller bubbles and to provide mixing. Many turbine aerators have additional impeller blades on the same shaft just below or at the surface of the wastewater for further aeration. The oxygen transfer efficiency of these units is very high, but maintenance is also high, since both the compressed air blower and the mechanical mixer systems must be maintained.

(4) Figure 6-15 illustrates some of these aeration systems. Table 6-2 rates various devices on the basis of maintenance requirements and oxygen transfer efficiency. These ratings are very general because wastewater characteristics greatly affect the maintenance and transfer efficiencies. Thus, each case should be assessed before selecting aeration equipment.

(5) Heat loss caused by aeration devices may drastically decrease lagoon operating temperatures in cold weather. This is another factor which must be considered when selecting an aeration system. Table 6-2 summarizes relative heat loss ratings for several aerator types.

h. The five most common types of aerobic biological treatment are waste stabilization ponds, aerated lagoons, activated sludge systems, trickling filters and rotating biological contactors. The first three are slurry systems, and the last two are fixed-film methods.

(1) **Stabilization ponds.** Waste stabilization ponds, or "oxidation ponds," are generally found where large areas of low-cost land are available and very high-quality effluent is not required. They are very simple flow-through systems consisting of a basin or a series of basins in which the wastewater is acted on by microorganisms before discharge. Mixing may be provided for proper solids and oxygen distribution, but no mechanical aeration methods are involved. Aerobic systems rely on aquatic plants (particularly algae) to provide oxygen as needed. Depending on the quality of the receiving stream, algae may have to be removed from the effluent before discharge. Since waste stabilization ponds are unmixed systems, a separate clarification system is not needed to remove effluent solids. However, solids buildup may decrease the pond volume enough to require occasional dredging. Due to the large area involved, waste stabilization ponds are very susceptible to changes in weather conditions, such as temperature, solar radiation, and ice formation. Cold weather conditions usually greatly decrease removal efficiencies. The key parameters in designing waste stabilization ponds are depth and organic loading. Table 6-3 provides typical ranges of design parameters for waste stabilization

ponds, including values for pond sizes, pH, temperature, and algae concentrations. There are two types of waste stabilization ponds; they differ by the microorganisms used.

(a) Aerobic algae ponds are maintained in a completely aerobic state by photosynthesis and mixing. Algae provides oxygen for aerobic microorganisms which oxidize organics. Since the ponds depend on algal photosynthesis, their depth is limited to the depth of light penetration, usually about 2 feet. Therefore, they are usually designed with 2- to 4-foot depths. Aerobic ponds are designed in 60- to 120-pounds BOD/acre-day.

(b) Facultative ponds are probably the most common waste stabilization pond. A shallow aerobic layer is maintained on top of an anaerobic layer. Anaerobic activity in the bottom layer produces by-products which are oxidized in the aerobic layer. These ponds are usually designed 3 to 8 feet deep. Anaerobic layers may be much deeper, since they do not depend on photosynthesis for electron donor production. Facultative basins are used for wastes with a mixture of soluble and suspended BOD. Facultative ponds are designed on a 30 to 100 pounds BOD/acre-day range.

(2) Aerated lagoons. Aerated lagoons are flow-through basins. Solids recycle is not provided, but mechanical aerators supply oxygen and mixing. Two types of aerated lagoons are used: aerobic and facultative (fig 6-16). These are analogous to the waste stabilization ponds of the same names; however, the volumes involved may be greatly decreased for the same degree of treatment because the use of mechanical aeration allows for higher concentrations of microorganisms and, therefore, higher activity per volume of basin. Aerobic aerated lagoons remain well mixed due to the aeration systems. This causes the effluent suspended solids to be equal to the suspended solids in the basin. To decrease the effluent solids concentration, solids separation systems (usually settling basins) are used. The resulting sludge is then disposed of with no sludge recycle to the lagoon. Therefore, the basin suspended solids operate at an equilibrium concentration which depends on influent BOD, temperature, and wastewater detention time. Aerated lagoons are often used in series. One example is a three lagoon series consisting of a high-rate aerobic lagoon, a low-rate facultative lagoon, and a settling lagoon. The high-rate aerobic lagoon employs a high organic loading, higher temperatures, and a short retention time to maintain rapid biological oxidation. The second lagoon, a low-rate facultative pond, uses a longer retention time and lower organic loadings for continued treatment. The third basin is a settling lagoon or "polishing pond" used to remove solids from the effluent before discharge. The most important aerated lagoon design parameters are basin suspended solids concentrations (usually operating at an equilibrium range of 200 to 500 milligrams per liter), detention time (usually ranging from 3 to 10 days), and temperature. Table 6-4 lists other design parameters and typical ranges.

(3) Activated sludge. Activated sludge systems use various forms of aerated reactors followed by sludge separation and solids recycle facilities which return much of the settled solids (biomass) to the biological reaction basin and waste the remainder. The major difference between aerated lagoons and activated sludge units is the use of controlled solids recycle allowing the maintenance of high basin biomass concentrations. The biomass concentration in activated sludge systems is referred to as "mixed liquor." The higher the biomass concentration of the mixed liquor, the more rapid the biological oxidation process. Typically, clarification is used to separate the solids from basin effluent. Since some wastage is required for proper functioning, settled sludge is disposed. The amount which exceeds what is needed to maintain the requisite sludge concentration in the mixed liquor is the amount disposed. The remaining sludge is recycled to the basin. The major differences in various activated sludge systems are the method of influent addition, mixing, and the length of reaction time provided. Five common activated sludge systems are conventional, completely mixed, step aeration, extended

aeration, contact stabilization, and pure oxygen. Figure 6-17 diagrams several of the basic activated sludge systems.

(a) **Conventional.** Conventional activated sludge systems operate in long rectangular tanks on a plug-flow basis. Wastewater travels through as a "plug" instead of being completely mixed with the entire basin contents. This results in a high oxygen demand at the beginning of the aeration basin, decreasing oxygen demand as organic removal progresses, and low oxygen demand for the endogenous growth stage at the end of the aeration basin.

(b) **Completely mixed.** Completely mixed activated sludge systems quickly disperse the influent into the basin. This results in uniform oxygen demand throughout the basin and allows the basin to serve as an equalization tank.

(c) **Step aeration.** Step aeration combines conventional and completely mixed systems. The wastewater enters at intervals in the basin, allowing partial mixing or distribution, but travels in a plug-flow manner between inlet ports. The oxygen demand is staggered; demand is high at inlet ports, but decreases with flow away from that point until another inlet port is reached.

(d) **Extended aeration.** Extended aeration systems employ the same plug-flow scheme used in conventional activated sludge systems; however, sufficient aeration time and low organic loading are used to cause the system to reach a completely endogenous stage by the end of the aeration tank. This results in high effluent quality and low sludge production. Unfortunately, the high oxygen requirements and the need for a lot of space restrict use of the system to fairly small plants (less than 1 million gallons per day). This system is often used in package treatment plants.

(e) **Contact stabilization.** This process takes advantage of the two-phase nature of BOD removal in activated sludge activities. The first stage is the absorption of organic material by microorganisms. This requires about 30 to 90 minutes. The second stage is the oxidation of the organics by the microorganisms' metabolic processes. This phase takes several hours. In contact stabilization systems, these two phases occur in separate tanks. Influent wastewater is mixed with microorganisms (recycled activated sludge) in the first tank for 30 to 90 minutes. Clarification separates solids from the effluent. The solids, organisms with absorbed organics, are discharged into a second tank where they are aerated for enough time to stabilize--usually 3 to 6 hours. The "hungry bugs," having metabolized the available organics, are then recycled to the first tank. Some of this recycled activated sludge is wasted as needed before going back to the first tank. Use of this system is restricted to wastes in which the microorganisms absorb organics rapidly.

(f) **Pure oxygen system.** A pure oxygen activated sludge system combines conventional and complete-mix systems. It uses pure oxygen in aeration to greatly increase the biological oxidation rate. Pure oxygen systems are usually built with three or four stages in an airtight basin for better oxygen use. All the influent wastewater enters at one point in the first stage of the airtight basin and is mixed with the wastewater by mechanical aerators. The somewhat depleted oxygen then passes over baffles into the second stage. Wastewater passes under a baffle into the second stage and is completely mixed with the contents of that stage. The oxygen mixes with the wastewater again. This process continues through each stage. Decreasing oxygen demand in the plug flow nature of the stages is accommodated by the maximal oxygen requirements in the first stage and the gradual depletion of oxygen use rates through the remaining stages as the organics are stabilized. The oxygen-depleted gas (usually about 50 percent

O₂) is vented from the end of the airtight basin. The wastewater goes to a clarification unit from which activated sludge is recycled to the first stage. Figure 6-18 illustrates a pure oxygen system.

(g) Activated sludge design considerations. Activated sludge basins are designed using five basic design components: hydraulic load, BOD removal, oxygen requirements, sludge production, and solid/liquid separation. The size of a biological reactor and associated appurtenances is governed by both the hydraulic and organic load on the plant. Design of a facility without consideration of both parameters is poor design. During aerobic biological treatment, the major portion of the substrate is converted into new cell mass; the remainder is oxidized to CO₂, H₂O, and other metabolic end products. The fraction of organic constituents converted to cell mass is relatively constant for a particular waste. At the same time, a fraction of the biological solids is continuously destroyed. This endogenous oxidation is a function of the quantity of biological solids in the system and of the aeration basin temperature. The equations used to develop solids balances are available in wastewater treatment textbooks. Further calculations may be used to compare the quantity of excess biological sludge (waste-activated sludge) generated and to use in designing sludge-handling facilities. Separation of biological solids from the treated wastewater in the activated sludge process is usually done by gravity sedimentation in a clarifier. To adequately separate the biological solids from the supernatant liquid, the sludge in this system must be maintained so that the solids readily flocculate and settle from the liquid.

(4) Trickling filters. A trickling filter is a fixed-film process made by filling a standing tank with a packing medium of crushed rock or plastic used to provide growth sites for microorganisms. Nearly all new trickling filters use synthetic media, primarily that of the stacked variety. New developments such as cross-flow media and the trickling filter/solids contact process have enabled trickling filter plants to produce advanced quality effluent. Wastewater is "trickled" over the medium. Microorganisms develop a "slime growth" on the medium, (a film population of microorganisms), which absorbs organics, nutrients, and oxygen from the air and wastewater passing through the filter. Carbon dioxide and by-products are released from the film. As the depth of the bio-growth increases, two layers develop: an anaerobic layer against the medium, and an aerobic layer over the anaerobic layer. Two types of trickling filters are commonly used: a high rate filter, and a low rate filter. The low rate filter is a simple flow-through system with raw influent fed into the top, and with effluent drawn from the bottom, sent to solids separation (usually clarification), and discharged. High rate systems recycle part of the effluent to allow higher organic loadings to be used. Trickling filters are popular in small combined municipal/industrial systems, typically 5 million gallons per day or less. Figure 6-19 shows a typical packed media trickling filter. The key parameters in trickling-filter design are the hydraulic and organic loading rates. High rate filters usually employ hydraulic loading rates of 10 to 40 million gallons per acre/day; low rate filters typically use a range of 1 to 4 million gallons per acre/day. Organic loading rates range from 1000 to 5000 pounds BOD/acre day for high rate filters, and from 300 to 1,000 pounds BOD/acre day for low rate filters. Table 6-5 gives these design values and typical values for other design parameters for high and low rate filters.

(5) Rotating biological contactor. Rotating biological contactors (RBCs) are fixed-film processes. The medium is a series of large plastic discs rotating in a vertical plane around a horizontal axis submerged about halfway (roughly 40 percent) into a basin of wastewater. The medium passes through the wastewater, and then through the air which provides oxygen for oxidation. Diffused air is sometimes used in the wastewater basin to provide more oxygen and/or the driving force for the rotation. Slime generally grows from 1 to 4 millimeters thick on the medium. Shear forces slough off excess

slime. This slime is removed in a clarifier following the RBC before the effluent is discharged. Figure 6-20 illustrates RBC units. RBCs have smaller space and power requirements than activated sludge systems. Also, insulated covers may be used to maintain heat in the winter and provide efficient year-round operation. The four most important parameters in a rotating biological contactor's design are hydraulic loading, rotational speed, staging, and temperature. Hydraulic loadings of RBCs used for secondary treatment usually range from 2 to 4 gallons per day/square foot of medium, although actual rates in industrial applications should be determined from pilot-scale testing. The disc rotational speed is usually 1 to 2 revolutions per minute or up to 60 feet/minute for the perimeter of the medium disc. Higher rotational speeds may produce excessive shear forces and strip the medium's biogrowth. Staging or separation of a number of disc series into successive basins maximizes the efficiency of the disc surfaces. Typically, two to four stages are used for progressive biological treatment. The number of stages depends on characteristics of the wastewater and the degree of treatment required. For optimal performance, the temperature of the biodisc system should remain between 55°F and 85°F (13°C-29°C).

(6) General design considerations. Several factors are vital to the design of any aerobic biological treatment process: pH control requirements, nutrient requirements, and mixing requirements. The pH of a wastewater influent to a biological treatment system should remain between 6.5 and 8.5. Microorganisms function best in near neutral pH conditions. They are less susceptible to upset by alkaline conditions than by acid conditions; therefore, more tolerance is allowed on the alkaline side of a neutral pH. The wastewater pH may be neutralized by equalization or by chemical addition. Organisms in biological treatment systems need nutrients to grow and to synthesize the organic substrate. Nutrient requirements may be grouped into two categories:

(a) Major nutrients. The two major nutrients required are nitrogen and phosphorus. Nitrogen requirements are commonly estimated to be 5 percent of the influent BOD concentration; phosphorus requirements are typically 1 percent. These estimates are typically more than the true needs of the biomass. If nutrient augmentation is required, the 100:5:1 (carbon:nitrogen:phosphorus) ratio is a good starting point. Once operation has been stabilized, nutrient levels can be reduced to determine the true requirements. Nutrient deficiency is a common problem in treating organic industrial wastewaters.

(b) Micronutrients. Most organisms require trace quantities of certain inorganics. These include boron, copper, manganese, iron, zinc, vanadium, cobalt, molybdenum, iodine, and selenium. Slightly larger quantities of some other inorganics may also be required, including calcium, magnesium, sodium, potassium, SO_4 , and HCO_3 . Most domestic wastes contain these ions, but industrial wastes may need to be supplemented for healthy biological growth. Aerobic biological treatment systems apply to almost any biodegradable waste (one with a moderate to high BOD) which has relatively little or no toxic characteristics. Some nutrient content in the waste is preferable but not necessary, since supplemental nutrients may be provided. Table 6-6 provides guidance about the types of wastes which would be most applicable to each biological treatment system. Generally, low-strength wastes or applications requiring only low-quality effluent are good candidates for waste stabilization pond treatment. Variable, moderate-strength wastes are amenable to aerated lagoon treatment. Activated-sludge systems can handle a variety of wastes, from readily degradable to high-strength inhibitory wastes, depending on the system configuration. Trickling filters and RBCs typically provide adequate treatment of moderate-strength non-variable wastes. All of the systems except activated sludge can be used as roughing or polishing processes for other biological systems. Table 6-7 provides typical performance data for waste stabilization ponds. The variety

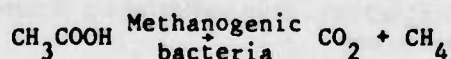
of wastes and loading rates makes the information hard to assess; however, the facultative pond system appears to be the most successful. Figure 6-21 shows the effect of organic loading rate changes. This figure shows that for a variety of food wastes, increasing the organic loading decreases the BOD removal rate.

i. Anaerobic treatment^a

Anaerobic treatment^{*} is utilized for wastewaters as well as for digestion of sludges. The end products of anaerobic degradation are gases, mostly methane (CH₄), carbon dioxide (CO₂), and small quantities of hydrogen sulfide (H₂S) and hydrogen (H₂). The process comprises two stages: (1) acid fermentation and (2) methane fermentation.

In the *acid fermentation stage*, the complex organic compounds in the wastewater (proteins, fats, and carbohydrates) are first hydrolyzed to yield smaller molecular units, which in turn are subject to biooxidation being converted mainly to short-chain organic acids, such as acetic (CH₃COOH), propionic (CH₃CH₂COOH), and butyric (CH₃-CH₂-CH₂-COOH). A heterogeneous population of facultative and anaerobic bacteria is responsible for these hydrolytic and oxidation reactions. Essentially, no COD reduction does occur in the acid fermentation stage since primarily what occurs is conversion of complex organic molecules to short-chain organic acids which also exert an oxygen demand.

In the *methane fermentation stage*, "methanogenic microorganisms," which are strictly anaerobic, convert the longer chain acids to methane, carbon dioxide, and organic acids having a shorter carbon chain. The acid molecules are repeatedly broken down yielding finally acetic acid, which is then converted to CO₂ and CH₄:



The group of facultative and anaerobic bacteria, which is responsible for the acid fermentation stage, has a much faster rate of growth than the methanogenic bacteria responsible for the methane fermentation stage. As a result, the acid fermentation stage is relatively rapid so the methane fermentation stage is the rate-controlling step in anaerobic processes.

Since methane fermentation controls the process rate, it is important to maintain conditions of effective methane fermentation. Detention time for methane microorganisms must be adequate or they are washed out from the system. Experimental data show that the required detention time varies from 2 to 20 days. Optimum pH range is 6.8 to 7.4.

^aR. S. Ramalho, *Introduction to Wastewater Treatment Processes*, 2nd ed. (Academic Press, Inc., 1983), pp 419, 420, 421, 422, 423, 433.

^{*}This process is usually more economical than aerobic treatment of high-strength industrial organic waste.

Some of the advantages of anaerobic over aerobic treatment are as follows:

1. Since aeration equipment is not utilized, this represents savings in capital costs as well as power consumption for the anaerobic treatment.
2. The biomass yield coefficient γ for anaerobic processes is much lower than that for aerobic systems. This means that less biomass is produced per unit of substrate removal and consequently there may be considerable savings in the processes for handling and disposal of excess sludge (wastage). This also means a lower requirement for nutrients (nitrogen and phosphorus).
3. For anaerobic processes it is possible to operate at higher influent organic loading than for the case of aerobic processes. This fact results from the limitation in the rate of oxygen transfer for the case of aerobic processes.
4. The production of methane in anaerobic processes is advantageous owing to its fuel value. A substantial part of the energy requirements for anaerobic processes may be obtained from the exhaust gases.

Some of the disadvantages of anaerobic over aerobic treatment are as follows:

1. Higher detention times are required. Consequently, the capital investment in vessel volume is higher for anaerobic treatment.
2. Bad odors associated with anaerobic processes, due mainly to production of H_2S and mercaptans, may constitute a serious limitation, particularly in urban areas.
3. Higher temperatures are required to insure anaerobic processes to proceed at reasonable rates. Usually the optimum temperature for anaerobic processes is around $35^\circ C$, which means that preheating of the feed or heating the anaerobic reactor may be required. This energetic requirement may not be, however, a serious disadvantage if a substantial part of it can be supplied from the methane gas produced.
4. Sedimentation of anaerobic biomass in the secondary clarifier is more difficult than the settling of biomass in the activated sludge process. This means that capital costs for clarification are higher. If, however, the wastewater being treated in the anaerobic process contains a high concentration of suspended solids to which the biomass can become attached, good settling conditions may be obtained in the secondary clarifier. This is the case with some industrial wastewaters such as for meat packing, slaughterhouse, brewing, and fish canning operations for which anaerobic treatment is often utilized.

5. Operation of anaerobic units is more difficult than that of aerobic ones, the process being more sensitive to shock loads.

The main process for anaerobic treatment of wastewaters is the so-called *anaerobic contact process*, which is diagrammatically represented in Figure 6-22. This is a *suspended growth* type of process.

The notation utilized in the flow diagram in Figure 6-22 is basically similar to that for the activated sludge plant. The only difference resides in the notation for the anaerobic biomass concentrations. X_F , X_Q , X_V , and X_U are utilized for the concentrations (mg/liter) in fresh feed, combined feed, reactor (and reactor effluent), and clarifier underflow, respectively.

Recycle ratios, $r = Q_F/Q_R$ are usually in the range 2-4. The MLVSS concentration X_V in the anaerobic reactor is usually controlled to a level of 3000-4000 mg/liter.

A vacuum degasifier is usually placed following the anaerobic digester to eliminate gas bubbles which would tend to float the suspended solids in the clarifier.

For the anaerobic contact process, the sedimentation of suspended biomass in the secondary clarifier is usually difficult unless the wastewater contains a large suspended solids concentration. In this case (e.g., wastewaters from meat packing plants, fish canning operations), the microorganisms become attached to the solids and are readily separated in the secondary clarifier.

When wastewaters containing mostly soluble BOD are to be treated, the anaerobic contact process is not indicated since a substantial concentration of biomass is lost in the secondary clarifier overflow. In this case, instead of utilizing a suspended media system like the anaerobic contact process, it may be indicated to utilize an anaerobic treatment with attached growth.

Anaerobic filters, also referred to as submerged filters, are systems designed to perform anaerobic treatment employing attached growth biomass. A flow diagram of an anaerobic filter is shown in Figure 6-23.

The anaerobic filter is similar to an aerobic trickling filter except that the wastewater feed enters at the bottom of the unit and leaves at the top. As a result, the packing material is completely submerged in the wastewater and since there is essentially no air within the system, the process is anaerobic. Gravel or synthetic packing may be utilized.

The anaerobic filter constitutes an effective system for anaerobic treatment of soluble wastes. No recycle is required since the biomass remains attached to the filter packing and therefore is not lost in the effluent.

It is possible to operate anaerobic treatments at temperatures lower than the operation of the anaerobic contact process, owing to the high biomass concentration present in the filter.

The anaerobic filter is not indicated for treatment of wastewater containing high concentration of suspended solids owing to clogging problems.

The design of anaerobic filters is so far mostly based upon empirical loading considerations.

6-5. Stabilization

Stabilization of organic sludges is required to decrease odors, kill pathogenic bacteria, and decrease the biodegradable content of the sludge. Putrescible, odorous sludge can be a health hazard as well as a nuisance to the community near the final disposal location. Several sludge stabilization processes provide side benefits, such as decreasing the volatile suspended solids content or producing a more easily dewatered sludge. Five common methods of sludge stabilization are anaerobic digestion, chlorine addition, heat treatment, lime addition, and aerobic oxidation.

a. Anaerobic digestion.

(1) Several steps are involved in changing the organic solids to the end products. Insoluble organic material is hydrolyzed by enzymes to soluble organic material (fig 6-24). Acid-forming bacteria then change this material to volatile acids, carbon dioxide, hydrogen, bacterial cells, and other products. Methane-producing bacteria use the first three materials to form methane, carbon dioxide, and additional cells. The bacterial cells undergo endogenous respiration and eventually degrade to inert end products.

(2) Changing volatile acids to methane is a much slower process. The methane-formers are inhibited by low pH; thus, the system may be easily upset if volatile acid production is too rapid and the pH decreases too much. The digester must be controlled to balance the volatile acid and methane production.

(3) There are two types of anaerobic digestion systems: conventional and high rate (fig 6-25). Conventional or low-rate digesters are unheated and unmixed stratified systems with detention times of 30 to 60 days. High-rate digesters are heated and mixed. These may be stabilized after a 10- to 20-day detention time (fig 6-26) and can handle much higher organic loading rates than conventional digesters.

(4) Although anaerobic digestion requires energy for heating the sludge, collection of the methane it produces is economically advantageous. The methane may be used to heat the influent sludge, maintain heat in the digesters, provide mixing, and often to provide much of the power needed in the rest of the plant.

(5) The disadvantages of anaerobic digesters are high capital costs, the tendency of anaerobic digesters to upset easily, and the problems associated with the poor-quality supernatant.

(6) Anaerobic digesters are designed primarily by detention time and solids loading rate. Both parameters depend on the type of digester (low- or high-rate) to be designed and the sludge to be digested. Table 6-8 gives typical values specific to the two types.

Bench- or pilot-scale tests are required to develop anaerobic digester designs with nondomestic wastes. Typical operating ranges for anaerobic digesters are: volatile acids--200 to 400 milligrams per liter; bicarbonate alkalinity--1500 to 3000 milligrams per liter; volatile acid/bicarbonate alkalinity ratio--0.05 to 0.3; and pH range--6.6 to 7.6. Industrial organic wastes with little or no toxicity (or heavy metals), a high volatile solids level, and a high concentration of soluble organics are good anaerobic digestion candidates.

b. Chlorine addition.

(1) Chlorine stabilization is used to reduce putrescibles, odors, and pathogens, and to improve dewaterability of the sludge. The primary mechanisms for chlorine stabilization are oxidation, addition of chlorine to unsaturated compounds, and replacement of hydrogen by chlorine. Chlorine stabilization reduces the number of organisms which create unpleasant or malodorous conditions and makes organic substrates less suitable for bacterial metabolism and growth. Figure 6-27 shows a simple schematic of the system. The system pressurizes the sludge, adds chlorine to it, and allows time for complete reaction.

(2) The system has three major advantages. It may be operated intermittently and does not require a constant flow rate. It is insensitive to toxicity and to variations in sludge characteristics. The disadvantages include: corrosion problems caused by the low pH (2 to 3) and high levels of hydrochloric acid in the discharge; there is no reduction in sludge mass; high chemical costs; and problems with resulting toxic chlorinated compounds in the sludge.

(3) The design of a chlorine addition system is based on laboratory or pilot tests to determine chlorine requirements and reaction time. Chlorine requirements may be estimated, but depend on sludge characteristics. Table 6-9 gives some estimated values.

(4) The system has been used to stabilize sludges from primary and secondary processes and to stabilize supernatants from digesters and dewatering processes. It has also been used in industrial applications to control odors.

c. Heat treatment.

(1) Heat treatment is a method of stabilization and conditioning used to eliminate pathogens, reduce odors, and produce a highly dewaterable sludge. Two commercial processes have been developed to heat treat the sludge for short periods under pressure. In the Zimpro process, air is injected to the reactor. Heat treatment coagulates the solids, breaks down the gel structure, and reduces the hydration and hydrophilic nature of the solids. This permits rapid dewatering without chemical additives.

(2) In the Porteus process, sludge is passed through a heat exchanger into a reaction vessel, where steam is injected directly into the sludge. The retention time is 30 minutes at 350° to 390°F (188° to 199°C), and 180 to 210 pounds per square inch (1240 to 1450 kilonewtons per square meter). After heat treatment, the sludge passes back through the heat exchanger into a thickener-decanter. For sewage sludge, a cake from a filter press of about 40 percent moisture is obtained. The decant and press liquor is high in BOD and requires return to the treatment process.

(3) The low-pressure Zimpro system operates with pressures in the range of 150 to 300 pounds per square inch (kilonewtons per square meter). Sludge and air are heated by an exchanger to 250° to 300°F (149° to 167°C) before entering the reactor. Steam injection maintains reactor temperatures at 300° to 350°F (167° to 177°C). The exhaust gases are water-scrubbed. The treated sludge is disposed of by vacuum filtration or on sand beds. The filtrate normally contains 2000 to 3000 milligrams per liter of BOD and requires biological treatment. Figure 6-28 shows the Zimpro process.

(4) The main advantages of heat treatment are that the sludge is sterilized, substantially deodorized, and dewatered readily on vacuum or pressure filters. The supernatant, high in BOD, is returned to the treatment plant. The solids are dewatered by vacuum filtration; this usually produces 40 to 50 percent cake solids.

(5) Heat treatment may be used to stabilize sludges which do not digest well (especially toxic sludges), or for which there is very limited sludge disposal area. Minimizing the final sludge volume is very important in some systems.

d. Lime stabilization.

(1) Lime stabilization raises raw sludge pH to a level hostile to biological activity. Adding lime reduces odors, gets rid of pathogenic bacteria, and improves vacuum filter performance. Lime is added to the sludge until the pH is more than 12; this pH is maintained for 2 hours, and inhibits or destroys pathogens and odor-producing microorganisms. Chemical reactions between the lime and the sludge also provide further stabilization by breaking down cellular structure. Lime-stabilized dewatered sludge may be suitable for landfill or land application disposal methods if toxic organics or heavy metals are not controlled under Resource Conservation and Recovery Act requirements.

(2) The major problem with this system is that it does not greatly reduce organic content. If the pH of the sludge decreases to less than 11, biological activity will resume. Also, the solids quantity is not reduced, but rather increased.

(3) The design parameters for a lime addition system are pH, contact time, and lime dosage (a function of acidity). This system has limited applicability because the increase in sludge volume caused by adding the lime prevents its use in areas where sludge disposal is expensive. Problems which occur when the pH is less than 11 further reduce its successful application.

e. Aerobic oxidation.

(1) Aerobic oxidation may be defined as the destruction of degradable organic sludges by aerobic, biological mechanisms. Generally, aerobic oxidation applies to excess biological sludges. If there is no external substrate, microorganisms enter the "endogenous" phase of the life cycle and deplete internal cellular carbon sources. This may be done on a continuous or batch basis, depending on sludge flow. Figure 6-29 shows a typical decrease in VSS over time for a batch aerobic sludge digester. The temperature of oxidation may be increased to improve the rate of organic consumption.

(2) Aerobic oxidation has the advantages of low capital costs, easy operation, minimal odors, and reduction of BOD, volatile suspended solids levels, and pathogens.

The disadvantages include high power costs and poor dewaterability of the digested sludge.

(3) Table 6-10 lists typical design parameter ranges for aerobic oxidation. These design values can be set for a particular waste through laboratory studies and standard design equations. Other design considerations include: configuration - continuous or batch, temperature, solids reduction, mixing, desired solids content of final sludge, pH level, sludge age, surface area, and nutrient concentration. Aerobic oxidation is common in many industries with organic wastes having little or no toxic content. The operation is normally simpler than alternative systems and better lends itself to industrial applications when low-sludge volumes are encountered.

6-6. Physical and chemical treatment processes

Since industrial wastewaters reflect the industrial processes, organic components may not be the primary contaminants of concern. Thus, many industrial wastewaters require approaches to facilitate treatment that are not amenable to classical pollution control techniques. Several physical and chemical processes are used to address treatment of nonbiodegradable industrial wastes: coagulation/flocculation/sedimentation, flotation, evaporation, distillation, filtration, carbon adsorption, resin adsorption, ion exchange, air stripping, steam stripping, reverse osmosis, ultra-filtration, chlorination, ozonation, precipitation, chemical reaction, and electro dialysis. Table 6-11 lists several treatment methods and the pollutants they remove.

a. Coagulation/flocculation/sedimentation. Coagulation, flocculation, and sedimentation (or flotation) are methods used to enhance suspended solids removal and some incidental removal of dissolved phosphorus and heavy metals.

(1) Coagulation is adding chemicals to wastewaters to agglomerate particles into globules ("floc") which would be easier to settle (or float). Table 6-12 lists typical chemicals used for coagulation and their applications. The most commonly used coagulants are alum, ferric salts (FeCl_3 or $\text{Fe}_2(\text{SO}_4)_3$), lime, and polymers. Weighting agents such as diatomaceous earth and bentonite are also used sometimes. Coagulants are usually added in a flash mix tank with high mixing intensity to insure complete distribution for maximum solids/coagulant interaction. A short detention time prevents shearing of any floc formations before waste enters the later flocculation stage.

(2) Flocculation refers to gentle mixing or agitation of wastewater to encourage inelastic collision of floc particles. As floc particles grow, their settling velocity increases; therefore, they are easier to separate from the liquid phase. Flocculation usually follows a flash mix tank; it is done in a separate tank or in the centerwell of an upflow clarifier. Paddles are used to gently stir the wastewaters and aid floc formation. Paddle speed and power are critical design parameters for flocculation mixing. There must be enough agitation to maintain solids in suspension and provide adequate solids contact; however, the mixing must not be so intense that it causes shear of the flux.

(3) Sedimentation theories for coagulated and flocculated wastes are similar to those for untreated wastestreams; however, higher loading rates are generally acceptable. Figure 6-30 shows the combination of the three stages involved: separate flash mix, flocculation, and sedimentation. Coagulation and flocculation are also used to enhance removal performances of flotation and filtration systems.

(4) Design parameters are best determined for industrial wastes by laboratory and pilot-scale studies. Initial wastewater characterization and bench-scale "jar tests" must be done to find out which types of coagulants are best for getting the desired effluent characteristics. Jar tests using a series of samples in beakers to which varying amounts of different chemicals are added provide data on electrophoretics, settling rates, and removal efficiencies. Laboratory-scale dosage, pH, settling column, and zone-settling velocity tests may be used for design; however, because of problems in scale-up, pilot-scale verification and design flexibility are recommended. Sizing of flash mix tanks should allow a detention time of 30 seconds to 3 minutes. The mixing power in the flash mix tank is determined by specific design calculations available in wastewater treatment textbooks. Flocculation tanks should allow from 15 to 45 minutes detention time. Calculations for proper paddle power and size design have been developed and are available in wastewater treatment text books and in TM 5-814-3, pages 8-11 to 8-13. This TM is currently being updated and is in the review state. Table 6-13 gives typical design factors listed in the technical manual.

(5) The design of a sedimentation facility is governed by the more conservative of two design approaches: one based on achieving some effluent standard and the other on attaining a certain sludge or underflow thickness. Determinations for the two designs require data from zone settling velocity tests, settling column tests, and settling curves. Design parameters to be developed include overflow rates, solids loading, depth, and detention time.

(6) Chemical coagulation, flocculation, and sedimentation are common treatment strategies for reducing suspended solids in industrial wastewaters. Table 6-14 gives data for treatment of textile and pulp and paper effluents; although these are not typical Army industrial processes, the table may be treated as an example.

b. Flotation

(1) Flotation is a means of removing suspended solids and thickening sludges by introducing fine air bubbles into the wastewater and floating materials to the surface, where they are skimmed off.

(2) Section 6-3c above provides a general description and design guidelines for DAF (dissolved air flotation) and IAF (induced-air flotation) units.

(3) Flotation devices are occasionally used following biological treatment systems to remove biogrowths and to concentrate sludges as necessary for activated-sludge recycle.

c. Evaporation

(1) The feasibility of partial or complete treatment of industrial wastewaters using evaporation is a function of the treatment objective and the wastewater characteristics. The primary objectives of evaporation treatment may include volume reduction or total evaporation, volatile contaminant removal, and material recovery. The unit process feasibility is a function of climate, temperature, air pollution potential, material recovery potential, and land cost.

(2) There are two types of evaporation systems: evaporation ponds and forced evaporation.

(a) With an evaporation pond, waste is issued to an open air basin; solar evaporation leaves a smaller volume of concentrated waste. This is sometimes done in arid climates where the decrease is enough to allow smaller treatment facilities. In some areas large enough lagoons have been built to eliminate the need for further treatment. A "dead-end" evaporation pond provides enough capacity to allow evaporation at an average rate equivalent to or greater than the rate of feed to the lagoon. Nonvolatile residues buildup in the bottom and are removed as needed. Climatic conditions and land areas are the major factors in evaluating evaporation pond feasibility. Evaporation rates are a function of many variables, including solar radiation, relative humidity, rainfall, ambient temperature, wind velocity, and pond depth. Published Type A evaporation pan data, with appropriate adjustments for location and pond characteristics are typically used for design (available from U.S. Weather Service). When A-data are not available, evaporation rate data can be developed from variables from many other formulas. If the wastewater of concern contains toxic or hazardous components, the impact of volatiles and residuals must be considered. The volatiles may generate an air pollution problem, and the residuals may pollute groundwater or require special handling as a hazardous material. The air pollution problem may preclude use of the technology; however, several measures can be taken to mitigate the residuals problem. Soil characteristics can be evaluated to determine the potential for groundwater problems; impermeable liners can also be added to prevent infiltration. However, these measures may make the system too expensive.

(b) Industrial wastewaters with large amounts of recoverable materials, either volatile or nonvolatile, may be subjected to forced evaporation. This process injects heat energy into the wastewater to recover volatiles or concentrate nonvolatiles. Design of forced evaporation systems is based on the wastewater's mass transfer and heat transfer characteristics. The required heat input is that required to raise the wastewater to the boiling point, plus the heat of vaporization. Due to the large energy requirement, forced evaporation systems are not common except in residual material recovery operations.

d. Distillation. Distillation is the combination of forced evaporation and a vapor condensation system. It can be used to recover valuable volatiles or to purify water. It is rarely used for wastewater treatment unless recoverable materials are of sufficient value or there is no other method of treatment available. In steam distillation, selective vaporization may be used to draw off specific compounds at different temperatures. It may be used to remove compounds "lighter" than water from a wastestream, or to draw water out of a stream of concentrated nonvolatile wastes. In industries, distillation is used for solvent stripping and for pretreating solvent-laden wastestreams; it is also used to regenerate activated carbon beds from vapor solvent recovery systems. Ammonia is often distilled from wastestreams as a form of pretreatment. Design of distillation systems is similar to that of forced evaporators with the addition of condensing units.

e. Filtration

(1) Filtration is used to remove particles from wastewater. Wastewater is passed through a porous medium which retains the particles. Three primary micro-mechanisms are involved in filtration: impaction, interception, and diffusion. Impaction occurs when the particle is carried out of the flow streamline and collides inelastically with the medium because of inertia. Interception occurs when the particle passes within one-half its diameter to the medium while following the flow streamline. Diffusion occurs when very small particles collide with the medium because of random motion induced on a molecular level.

(2) Modern industrial wastewater filters should be designed as a function of the particles in the wastewater, using either deep-bed theory or pilot-scale testing. The original wastewater treatment filters were downflow sand filters. Problems with blinding on the surfaces of these filters led to the development of dual or multimedia filters, in which two or more types of media are packed in a column, and are graded from coarse grains on top to fine grains at the bottom. This allows removal of the larger particles first and smaller particles further down. Dual-media filters usually use anthracite coal (specific gravity 1.4 to 1.6) over silica sand (specific gravity 2.65). Multi-media filters add a bottom layer of garnet sand (specific gravity 4.2) or ilmenite (specific gravity 4.5). The gradation of specific gravities allows the particles to remain in the original order even though backwashing (backflow cleaning of media) occurs. Use of varying media greatly improves system efficiency, the length of run before backwash, and the head loss through the system.

(3) An upflow sand filter consists of several media layered in a bed, from gravel on the bottom to fine sand on top. The wastewater is forced up through the filter from the bottom, to a multimedia downflow filter. In some cases, upflow sand filters allow the use of raw water for backwashing.

(4) To improve filtration, a modification was developed in which pressure was applied to the influent side of filter; this increased the filtration rate and decreased the frequency of backwashing. Pressures of about 150 psig are commonly used.

(5) Figure 6-31 illustrates typical commercial filtration systems. Table 6-15 lists some of the process variables to be considered in filtration design. These design variables should be determined by pilot-scale tests of the wastewater. Required effluent quality and the economics of various filter configurations should be considered. Table 6-16 provides typical ranges for some design variables in dual and multi-media filters.

(6) Filtration is sometimes used in preliminary treatment systems for wastes low in suspended solids. Generally though, preliminary treatment by filtration is not cost-effective. More often, filtration is used as a polishing process following biological treatment or physical/chemical treatment by coagulation. Table 6-17 provides some typical performance data for filtration of biologically treated wastes.

f. Carbon adsorption

(1) Carbon adsorption is used mostly to remove organic materials from wastewaters. It is especially useful in removing refractory organics and for polishing water to remove odor or color caused by microgram-per-liter concentrations of some organics.

(2) The carbon adsorption process places organics in contact with granular or powdered activated carbon. Attractive forces between the surface of the adsorbent (the carbon) and the adsorbate (the molecules in solution) pull the molecules out of solution and onto the carbon. The need for molecule attachment sites makes surface area an important factor in carbon adsorption. The high porosity of activated carbon provides a large amount of surface area per unit volume. There are two categories of carbon: granular and powdered. Granular carbon particles are much larger.

(a) Granular carbon is generally used in column configurations similar to filtration columns. The wastewater is passed through the beds of carbon in a series of columns, allowing organics to be in contact with carbon for adsorption. Some filtration also occurs due to configuration. The carbon often develops a biogrowth which may

provide further organic removal. Figure 32 is a flow diagram of a carbon column adsorption process.

(b) Powdered activated carbon is mixed in a slurry with the wastewater; after sufficient contact time, it is removed by settling and/or filtration. This may be done in a one- or two-stage system. In two-stage systems, the fresh carbon is usually added to the second stage and mixed with wastewater from the first stage. The carbon is then settled and recycled to the first stage. It is most effective to add the slightly spent carbon in the first stage, where the maximum waste load exists. Also, polishing of the wastewater in the second stage is more effective when fresh carbon is used.

(3) Granular or powdered carbon may be used once and thrown away, or it may be reactivated (regenerated) for reuse. There are many methods of regeneration; however, most methods applicable to wastewater treatment heat the spent carbon to burn off the organics. This leaves the attachment sites on the carbon available for reuse.

(4) Construction of on-site regeneration facilities is rarely economical for plants in the size range used for industrial waste. Central regeneration facilities are provided by some carbon vendors; however, transportation costs must be considered if the carbon is to be hauled a great distance. Laboratory tests, including activated carbon adsorption isotherms, should be done to determine the feasibility of carbon adsorption for an application.

(5) Design parameters of importance to carbon adsorption systems include: Carbon size and type; carbon quantities; contact time; column characteristics (pretreatment requirements, hydraulic loading, column configuration, backwash rate), and settling rates (for powdered carbon systems).

(6) Industrial wastewater response to carbon adsorption varies. Table 6-18 lists the results of carbon isotherm tests on a series of industrial wastes. The variability of carbon adsorption effectiveness for different wastes is indicated by the range of removal rates (from 25 to 99 percent). Specific industrial applications for carbon adsorption systems include use with paper, plastics, organic chemicals, and refinery industry wastes.

g. Resin adsorption

(1) Resin adsorption is a unit process used to remove and/or recover dissolved organic compounds from wastewaters. The resins used are spherical beads, and may be generally classed as either polymeric adsorbents or carbonaceous adsorbents. The polymeric adsorbents are made up of either styrene-divinylbenzene copolymers or acrylic esters, and are generally used to remove compounds of high molecular weight. The carbonaceous adsorbents combine the properties of the polymeric adsorbents and activated carbon; thus, they may be effective for removing compounds of both low and high molecular weight.

(2) These resins are most often used in fixed-bed columns, with either a single column or stage columns in series. Resin column operations involve three major modes: adsorption, backwashing, and resin regeneration. During adsorption, wastewater is passed through the resin bed until the effluent organic concentration reaches an unacceptable level (breakthrough) or in staged systems, until the first bed is exhausted. The adsorption column is taken off-line; the bed is then backwashed with water in an upflow direction which greatly expands the bed and removes suspended matter from it. The bed is then ready for regeneration; this may be done by steam, organic solvents, acids, or bases. The regenerant is applied slowly, freeing the adsorbed organics from the

resin and preparing the resin for another adsorption cycle. The chemical regenerants, especially the organic solvents, are expensive and represent a disposal problem; therefore, they are usually processed by steam distillation for contaminant concentration and, in some cases, product recovery.

(3) The critical design parameters for resin adsorption systems are similar to those for activated carbon adsorption systems; however, the numerical values will be different. The adsorbent capacity of the resin (pound pollutant/pound resin) as a function of resin bed contact time is very important. Pretreatment may be needed before resin adsorption to remove suspended matter and other interfering substances. Other important considerations include loss of resin adsorbent capacity upon multiple regeneration cycles; resin fouling or poisoning; physical attrition of resin; swelling of resin during adsorption or regeneration; and efficiency of regenerant recovery procedures. Surface and volumetric loading rate design ranges for some existing full-scale resin adsorption systems are summarized below:

Surface Loading Rate, gallons per minute/square foot	1-6
Volumetric Loading Rate, gallons per minute/cubic foot	0.2-2
Backwash Bed Expansion, percent	100
Backwash Surface Loading Rate, gallons per minute/ square foot	3-12
Regeneration Volumetric Loading Rate, gallons per minute/ cubic foot	0.1-0.5

Resin adsorption may be used to remove a wide spectrum of organic compounds from industrial wastes, such as halogenated hydrocarbons, aromatics, and some organic nitrogen compounds. The process offers low (parts per billion) effluent concentration values; it may allow for product or byproduct recovery, and may be used to remove nonbiodegradable materials from wastewater. The chemicals, plastics, synthetics, and pharmaceutical industries use full-scale applications of resin adsorption systems. Table 6-19 lists several of these applications.

h. Ion exchange

(1) Ion exchange replaces certain ions from industrial wastestreams with less polluting ones. The process removes ions from wastewater passing through media in a column by exchanging ions in the waste with ions in the media solids (ion exchange resins). Resins are categorized as cation-selective or anion-selective. Depending on the treatment needs, a single resin may be used to remove either cations or anions from a waste stream. Alternatively, a two-stage system may be used to remove cations in one stage (or resin bed) and anions in a second stage. In a mixed-resin system, resins are combined to provide cation and anion removal in the same bed. Cationic resins exchange cations in solution for hydrogen or sodium ions in the resin. Anionic resins exchange anions in solution with hydroxide ions in the resin. This process is reversible, so resins can be regenerated and reused.

(2) Regeneration is done by running a strong acid through cation resins, using the hydrogen ions or salt brine to replace sodium, and by passing a strong base through anion resins to replace hydroxide ions. Typically, ion exchanges operate cyclically, running until the resin is spent; they are then taken out of the line for regeneration and rinsing before further service. Figure 6-33 is a flow diagram of an ion exchange system.

(3) Bench and pilot-scale tests are recommended to determine appropriate resin type and other design parameters. Factors of importance include pH, hydraulic loading,

resin size, resin exchange capacity, pretreatment, wastewater composition, desired effluent quality, bed depth, and regeneration efficiency.

(4) Ion exchange is widely used as an in-process waste treatment/ material recovery system in electroplating and metal finishing. Contaminated rinse waters in electroplating can be cleaned and reused using ion exchange; the regenerant can be processed for metal recovery.

i. Air stripping

(1) The major use of air stripping in industrial wastewater treatment is for ammonia removal. Lime pushes the pH above 7.0 to shift the equilibrium of the ammonia-ammonium ion toward ammonia. The high-pH, ammonia-laden water is then passed through a conventional cooling tower where aeration and agitation strip the ammonia from the water into the air.

(2) Problems caused by ammonia removal include calcium carbonate scaling in tower and feed lines, poor cold weather performance, and fixed nitrogen air pollution with the conversion of NH_3 to NO_2 . Therefore, an acid scrubber for tower off-gases may have to be installed. Air stripping of ammonia is most efficient when the waste has a high pH; however, due to operating problems, ammonia stripping is also done with close to neutral pH solutions.

(3) Design of an air stripping system depends on many factors, such as wastewater characteristics; pretreatment requirements; pH; hydraulic loading; air requirements; temperature effluent requirements; and local air pollution restrictions. Table 6-20 provides some typical design ranges for a high-pH wastewater.

(4) Air stripping of ammonia works best as an "in-plant," pretreatment method. Refineries and chemical plant wastes may require ammonia removal before discharge.

j. Steam stripping

(1) Steam stripping is typically used to remove ammonia from ion exchange regenerants and some concentrated industrial waste streams. Steam stripping is much like air stripping, except that steam is substituted for the air flow and the system is contained in a distillation tower instead of an adapted cooling tower. Steam is injected into the tower counter-current to the downward flow of waste. The steam may be condensed after it leaves the tower in an air-cooled plate and tube condenser. The condensate may contain high concentrations of aqueous ammonia which can be sold to fertilizer manufacturers.

(2) Steam stripping allows ammonia recovery and eliminates nitrogen air pollution problems; however, its use is limited to small-volume and high-pH systems because of costs. It is best used in an industry as a pretreatment method rather than in a combined wastewater treatment plant.

k. Reverse osmosis

(1) Reverse osmosis separates water from dissolved salts and organics. It uses the concept of osmotic pressure to separate salt or organic molecules from water molecules. In the unit process, osmotic pressure is overcome and exceeded mechanically; water molecules are forced to flow through a semipermeable membrane from a high concentration of salts or organics to a lower concentration. This concentrates the

impurities and produces a good-quality process effluent. Figure 6-34 shows this concept. Membranes are usually made of cellular acetates or nylon polymers. They are formed into tubular, spiral-wound, or hollow-fiber units. The U.S. Army Engineering Center recommends the use of only spiral-wound modules. Figure 6-35 is a basic flow diagram for reverse osmosis. Pretreatment is almost always required to prevent clogging of the membrane.

(2) The key parameter in reverse osmosis design is pressure, which usually ranges from 400 to 1000 pounds per square inch gauge. Table 6-21 lists reverse osmosis design ranges and typical values for pressure and several other parameters.

(3) Reverse osmosis is often used for desalination. It has also been used successfully to treat electroplating wastes (for removal of cadmium, copper, nickel, and chromium) and pulp mill wastes. "In-plant" uses include color removal in textile mills and treatment of cheese whey wastes. Pilot-scale investigations are required for industrial wastes, since some waste streams may rapidly degenerate the membranes.

l. Ultrafiltration

(1) Ultrafiltration removes finely divided colloids and suspended solids. The major difference between ultrafiltration and reverse osmosis is the type of membrane and the pressure used. Ultrafiltration membranes allow the passage of much larger particles, although the openings are still quite small. Some ultrafiltration membranes can remove particles from 0.002 to 10.0 microns in size. Typically, the pressures used are relatively low (50 pounds per square inch gauge) as compared to the high pressures (400 to 1000 pounds per square inch gauge) of reverse osmosis. Construction of ultrafiltration units is similar to that of reverse osmosis units.

(2) Major design parameters for ultrafiltration include membrane area, configuration, material, and driving force. Table 6-22 provides typical design data for these parameters. (See *EPA Process Design Manual for Suspended Solids Removal*, Section 8.6, for a discussion of these factors.) Ultrafiltration has been used primarily as a particle removal system for polishing other industrial wastewater unit process effluents.

m. Chlorination

(1) Chlorination is a multipurpose unit operation. It was first used to disinfect water supplies, but now is used as a disinfectant and oxidant for both water and wastewater systems. In current practice, chlorination is used for disinfection and in-plant control of algae, bacteria, odor, and color control. It is also used in a cyanide treatment process. Table 6-23 lists application points, purposes, and representative dosages for chlorination.

(2) The main disinfecting agent in chlorination is hypochlorous acid (HOCl); its concentration depends on wastewater pH. Figure 6-36 illustrates the ionization shift with pH. Thus, lower-pH waters will allow better chlorine disinfection because more HOCl is available.

(3) Chlorine is commercially available as calcium or sodium hypochlorite, or as chlorine gas. Use of hypochlorite is more expensive, but safer. Calcium hypochlorite may be obtained in a stable, dry, granular form or in a wet form. Sodium hypochlorite is sold in 1.5 to 15 percent strength. Chlorine gas is sold in 100- to 150-pound cylinders and 1-ton cylinders as a liquid gas under high pressure.

(4) Most states require chlorination of industrial wastewaters with an organic content. The effective dose requirements are a function of the effluent's coliform bacteria characteristics. Chlorine is also widely used during early stages of treatment for in-plant control of algae and other growth.

(5) Two specific groups of compounds identified in chlorinated discharges may have adverse environmental effects. Chloramines, with their residual disinfectant capabilities, have been observed in the benthic deposits of some receiving water bodies. These compounds alter the species diversity of the benthos. The other group of compounds of concern are the trihalomethanes (THMs). THMs have been regulated in drinking water supplies because they are suspected carcinogens. The primary source of THMs in natural water systems is chlorinated industrial wastewaters.

(6) When designing chlorine contact chambers, the following factors must be considered: chlorine addition system, chlorine/wastewater mixing system, contact time, prevention of short-circuiting, prevention of solids settling in chlorination channels, and by-pass capabilities. Chlorine gas is very poisonous and corrosive. If it is used, facility design should include appropriate safety devices and precautions.

n. Ozonation

(1) Ozonation has become increasingly popular in industrial treatment systems. It has been used for pesticide wastes, disinfection, odor removal, organic oxidation, color removal from dye and tobacco wastes, paint wastes, cyanide reduction, phenol removal, virus destruction, and COD reduction from organic chemical plant wastes. Ozone (O_3), a strong oxidizing agent, has become a popular substitute for chlorine.

(2) Ozone is generated from dry air or liquid oxygen ("LOX") by a high-voltage electric discharge. The system is expensive, power-intensive, and inefficient. The amount produced is less than 15 percent of the theoretical yield. A typical ozone generator makes only 150 grams of ozone per kilowatt hour of electrical energy. Ozone cannot be stored easily; thus, production must match demand.

(3) Ozone has been used successfully to control odor-causing substances in effluents from preliminary treatment and for color removal in effluents from biological treatment units. Ozone decomposition may also change biological refractory organics to biodegradable organics; this sometimes increases the wastewater's biodegradability.

(4) Ozone has been used to treat cyanide wastes from electroplating and metal-finishing operations. In the oxidation process the nitrogen is replaced with hydrogen and oxygen; this produces bicarbonate and nitrogen gas in an alkaline environment. Although effective as a unit process, ozonation for cyanide waste treatment is normally not cost-competitive with alkaline chlorination.

(5) Ozonation may be more effective when used with ultraviolet radiation. "Ozone-UV" has been shown to be effective for breaking down some pesticides to CO_2 and H_2O . "Ozone-UV" has also been used to oxidize several priority pollutants to nonreactive end products.

(6) Although ozonation offers promise, its economic feasibility is usually poor compared to other treatments. However, environmental restrictions on the use of chlorine may make ozonation more practical in the future.

(7) To disinfect wastes low in organics and relatively free of suspended matter, ozone dosages should provide a residual of 0.1 milligram per liter 5 minutes after contact. The dosage required depends on the wastewater's organic content. Laboratory tests should be used to determine required dosages. Several manufacturers make ozone-generating systems for on-site production.

o. Chemical reduction and precipitation

(1) Heavy metals are typically removed from industrial wastewater using solubility-pH relationships. Most heavy metals are in hydroxide equilibrium. Therefore, as the pH increases and more hydroxyl ions become available, solubility decreases and the metal hydroxide (or other complex) precipitates. In conjunction with precipitation, some heavy metals such as chromium (Cr^{+6}) are reduced to a lower valence state; this reduces activity and often toxicity. Before reduction and precipitation, interfering substances such as cyanides should be addressed. Cyanide can be treated using alkaline chlorination, electrolysis, or ozonation.

(2) Reduction of valence is most commonly done on chrome electroplating wastes. To maximize electroplating efficiency, hexavalent chromium is used in plating baths. Wastes from rinse tanks, dragout, and spills therefore contain Cr^{+6} . Reduction of hexavalent chromium to the trivalent form decreases reactivity and toxicity and enhances precipitation. It is typically done with a sulfur-base reducing agent, such as sodium bisulfite, sulfur dioxide, or ferric sulfate. The chromium-laden wastewater is mixed with a stoichiometric excess of the reducing agent at a pH of about 3.0. Figure 6-37 is a schematic of a typical sulfur dioxide reduction system.

(3) Precipitation is done on pretreated, heavy-metal wastewater. Metal solubility generally decreases as pH increases. Once the minimum solubility point is reached, a further increase in the pH increases solubility and reduces process efficiency. Figure 6-38 shows solubility curves for various heavy metals of concern in industrial wastewater treatment.

(4) Many chemicals may be mixed with the wastewater to adjust the pH. Lime, sodium hydroxide, and carbonates are the most commonly used. Carbonates are more popular because they form less soluble compounds. They also produce sludges that are easier to dewater.

(5) Only two tanks are usually required in a continuous treatment system. The wastewater is mixed with the precipitating chemicals in the first tank; it then flows to a second tank, which acts as a settling basin or clarifier. Batch systems may use one tank for both mixing and settling.

(6) Heavy metals can cause precipitation problems. The process often forms finely divided solids which are hard to settle. The high pH values required to precipitate some metals may cause severe corrosion problems. Toxic materials and poisonous gases, such as H_2S , are sometimes formed, causing health hazards. However, precipitation is usually successful and is still the most common method used.

(7) Table 6-24 lists removal efficiencies for lime precipitation of various heavy metals. Table 6-25 lists metals removed by precipitation, the precipitated compounds, and effluent concentrations.

(8) In designing collection and treatment facilities, it is very important to segregate cyanide or sulfide waste streams from acidic waste streams until the cyanides or sulfides have been removed. Combining of these streams before treatment could release cyanide or sulfide gases, which are highly poisonous.

p. Alkaline chlorination

(1) Alkaline chlorination is the most often used treatment for cyanide-bearing wastewaters. The three-step process occurs under alkaline conditions to prevent generation of toxic hydrogen cyanide gas or cyanogen chloride gas. In the first step, cyanide-laden wastewaters are mixed with chlorine; this oxidizes cyanide to cyanogen chloride. The second step, which occurs almost instantly when pH levels exceed 10.5, is the hydrolysis of the cyanogen chloride to cyanate. The third step converts cyanate to carbon dioxide and nitrogen. This step occurs most quickly at lower pH values, preferably 7.5 to 8.0 for a reaction time of 10 to 15 minutes. (This step takes roughly 30 minutes at pH levels of 9.0 to 9.5.) The entire process uses 8.0 parts chlorine and 7.3 parts sodium hydroxide per part of cyanide.

(2) The process is carried out in a series of three tanks for continuous treatment systems. The first reaction tank is used to mix the wastewater, chlorine and caustic (used to maintain a pH of 10.5) and to change cyanides to cyanates. The second tank is an interim tank used to add and mix in mineral acid; this lowers the pH to 7.5 to 8.0. There is complete destruction of cyanates when the pH-adjusted waste reaches the third tank. Figure 6-39 shows a continuous cyanide treatment system.

q. Electrodialysis. In electrodialysis, a solution's ionic components are separated by semipermeable ion-selective membranes. Applying an electrical potential between the two electrodes passes an electric current through the solution, which causes cations to migrate toward the negative electrode and anions to migrate toward the positive electrode. The alternate spacing of cation- and anion-permeable membranes forms cells of concentrated and dilute salts.

(1) Wastewater is pumped through the membranes. The membranes are separated by spacers and assembled into stacks. The wastewater is usually retained for about 10 to 20 seconds in a single stack or stage. Dissolved solids removals vary with (a) wastewater temperature, (b) amounts of electrical current passed, (c) type and amount of ions, (d) permselectivity of the membrane, (e) fouling and scaling potential of the wastewater, (f) wastewater flowrates, and (g) number and configuration of stages.

(2) This process may be operated in either a continuous or a batch mode. The units can be arranged either in parallel or in series. Makeup water, usually about 10 percent of the feed volume, washes the membranes continuously. A portion of the concentrate stream is recycled to maintain nearly equal flowrates and pressures on both sides of each membrane. Sulfuric acid is fed to the concentrate stream to minimize scaling.

(3) Problems with this process include chemical precipitation of salts with low solubility on the membrane surface and clogging of the membrane by residual colloidal organic matter. Membrane fouling may be reduced by carbon pretreatment, possibly preceded by the chemical precipitation and some form of multimedia filtration.

6-7. Sludge dewatering and disposal

Most treatment processes normally used in water pollution control yield a residual from a solids-liquid separation process (sedimentation, flotation, etc.) or produce a sludge as a

result of a chemical (coagulation) or biological reaction. These solids undergo a series of treatment steps for volume reduction (dewatering) before final disposal. Figure 6-40 is a substitution flow sheet for the various alternatives available for sludge thickening, dewatering, and disposal. Process selection depends on sludge characteristics, viable final disposal alternatives, economic assessments, and other considerations.

a. **Thickening.** The first steps in a sludge treatment system is thickening. Thickening is advantageous because it: improves digester operation and reduces capital cost where stabilization will be used; reduces sludge volume for disposal; and increases economy and performance of sludge-dewatering systems. The three common methods of thickening are gravity thickening, flotation thickening, and centrifugation. Disc-nozzle centrifuges are commonly used for thickening. Chemical addition may be used in any of the three systems to improve operating efficiency.

(1) Gravity thickening

(a) Gravity thickening, or type IV compression settling, is done in a clarifier-type settling tank with a slowly rotating rake mechanism. A picket rake mechanism breaks up particle bridging and promotes settling and compaction. Figure 6-41 is a cross-sectional diagram of a gravity thickener.

(b) Design of a gravity thickener is usually governed by mass loading (solids flux pounds per square foot day) to the tank. This can be determined in the laboratory by developing the batch flux relationships for a specific sludge. The design is based on the flux rate needed for a specified underflow concentration. Table 6-26 provides typical solids flux ranges and subsequent thickened sludge concentrations. Parameters of concern are: configuration (circular or rectangular basin); surface overflow rate; drive torque requirements for sludge rakes; tank depth (freeboard plus settling zone plus compression zone); floor slope; chemical addition; skimmers; pickets or rake configuration; septicity; denitrification; and storage capacity.

(c) Gravity thickeners are very common in industrial sludge-handling facilities, especially for primary sludges. Table 6-26 gives examples of industrial applications and operations efficiency.

(2) **Sludge flotation.** The same unit process used for particulate removal is used for sludge thickening, with minor operational modification. When the process is used as a sludge concentration procedure, the underflow is pressurized and then mixed with the sludge stream at atmospheric pressure. The rest of the unit process configuration is like that used for particulate removal. Figure 6-42 illustrates a DAF sludge unit. The DAF approach to concentrate sludge is effective for most sludges of low specific gravities (<1.2).

b. **Dewatering.** Reducing the moisture content (dewatering) in a sludge is essential for volume reduction if ultimate disposal is by incineration, landfill, or requires transport of any great distance. Selection of the dewatering process is normally based on type of disposal to be used, sludge characteristics, the plant's operating and maintenance capabilities, and economics. Several of the more common dewatering methods are centrifugation, vacuum filtration, belt filtration, pressure filtration, and drying beds. Dewatering processes concentrate the solids level of the sludge and decrease the percentage of water in it. Chemicals such as lime, ferric chloride, alum, and polymers may be used to condition the sludge and aid in dewatering.

(1) Centrifugation

(a) Centrifugation is a form of solids-liquid separation in which centrifugal forces are used to accelerate separation. Three types of centrifuges are used to process sludges: solid bowl decanter, basket type, and disc-nozzle separator. The major differences among these is the method by which solids are collected in and discharged from the bowl.

(b) The solid bowl decanter operates in a continuous mode. It is made of an imperforate cylindrical-conical bowl with an internal helical conveyor. The feed sludge enters the cylindrical bowl through the conveyor discharge nozzles. Centrifugal force compacts the sludge against the bowl wall; the internal scroll or conveyor, which rotates just slightly more slowly than the bowl, conveys the compacted sludge along the bowl wall toward the conical section and out.

(c) The basket centrifuge operates in a batch mode and is very similar to a washing machine on a spin cycle. The solids enter the basket through a port in the top and are directed to the bottom. Centrifugal forces hurl the solids against the walls and allow the concentrate to reach up to and over the lip of the basket. When the basket is filled with solids, the centrifuge is stopped and a knife edge used to remove them. This requires a downtime of about 10 percent of the total cycle time.

(d) In a disc-nozzle centrifuge, the feed enters at the top and is distributed among many channels, or spaces, between the stacked, conical discs. Solid particles settle through the liquid layer which flows in these channels to the underside of the disc and then slide along the underside to a sludge compaction zone. The thickened sludge is then flushed out of the bowl with part of the wastewater; this limits the solids concentration to 10 to 20 times the feed concentration. Discharge of the sludge through nozzle orifices puts an upper limit on the size of particles that can be handled by the disc centrifuges. However, they are very efficient in thickening waste-activated sludge up to 6 percent at high feed rates.

(e) Centrifuges are used for both thickening and dewatering. The disc-nozzle centrifuge is normally used for thickening; the solid-bowl and basket are used for thickening and dewatering. Table 6-27 lists some of the advantages and disadvantages of the different types of centrifuges. Centrifuged sludge may range in solids concentration from 10 to 40 percent; however, 25 percent solids typically is the maximum practicable concentration.

(f) Design of centrifuges should be defined by pilot-scale tests and manufacturer's guidelines. Feed rates are usually restricted to 0.5 to 2.0 gallons per minute/horsepower.

(g) Centrifugal dewatering of sludges has become less popular due to its high energy and maintenance requirements; however, industries have found the systems to work well when proper maintenance is available. Some of the industrial applications include: metals plant, board mill, kraft mill, pulp mill, and textile mill sludges. Table 6-28 presents data from industrial and domestic dewatering applications.

(2) Vacuum filtration

(a) Vacuum filtration is used to dewater wastewater sludges. Water is removed under an applied vacuum through a porous medium which retains the solids.

Media used may include nylon or dacron cloth, steel mesh, or tightly wound stainless steel coil springs.

(b) Figure 6-41 is a schematic of a vacuum filter arrangement. The rotating drum with an applied vacuum passes through a slurry tank; solids stay on the drum. The amount of drum submerged in the slurry tank may vary from 10 to 60 percent. During submergence, solids are retained on the filter medium, and the water is removed by filtration. This period of the filtration cycle is called the form time. After the drum emerges from the slurry tank, the deposited cake is further dried by liquid transfer to air drawn through the cake by the applied vacuum. At the end of the filter cycle, the cake is removed onto a conveyer belt which may go to a collection hopper, trucks for hauling, or directly to incineration. The filter medium is washed with a water spray before being immersed in the slurry tank.

(c) Variables which affect the dewatering process include:

- Sludge feed solids concentrations, which are determined by the nature of the sludge and by the preceding thickening processes.
- Sludge and filtrate viscosity, which may be the same as that of the liquid (usually water) at similar temperatures or may vary widely as a function of chemical and particle characteristics.
- Sludge compressibility, which relates to the nature of the sludge particles.
- Chemical and physical composition, including particle size and shape, water content, etc.

(d) Vacuum filter design depends on the characteristics of the sludge to be dewatered. Bench-scale and/or pilot-scale tests should be done to determine sludge treatability characteristics, the chemical conditioning requirements, the type of medium required, and the pressure needed. Filter operating parameters include:

- Operating vacuum, which varies from 10 to 20 inches of mercury. (Higher vacuums are more effective with incompressible cakes.)
- Drum submergences, which vary from 10 to 60 percent. High porosity sludges will use higher submergences.
- Sludge conditioning by chemical addition. Many sludges require chemical addition (ferric chloride, lime, or polyelectrolyte) to condition smaller particles and to minimize fine-particle migration, which results in blinding of the filter media and cake. Media blinding will markedly reduce the filtration rate.
- Type and porosity of the filter medium. Where filtrate solids are not significant, high-porosity media can be used, resulting in lower cake water content and higher filtration rates.⁵

⁵Process Design Techniques for Industrial Waste Treatment, C. E. Adams, Jr., and W. W. Eckenfelder, Jr., eds., Associated Water and Air Resources Engineers, Inc. (Enviro Press, 1974).

Vacuum filters are commonly used to dewater industrial sludges.

(3) Belt filter

(a) With a belt filter, chemically conditioned sludge is fed onto a filter belt. The sludge is then squeezed between two filter belts. These belts are made of a filter medium which allows the water to pass through when pressure and shearing forces are applied. The dewatered sludge remains on the filter medium and is removed from the belts by gravity or by a scraper. Figure 6-44 shows the process. The systems are easier to operate than some of the alternatives, but require chemical addition. Belt filters obtain a dewatered solids level of 12 to 30 percent. The controlling parameters are filter media, belt speed and width, applied roller pressure, and chemical addition.

(b) Manufacturers usually perform bench-scale dewatering tests for these units. The tests are used to design the belt filter system. The design parameters which are normally evaluated include chemical dosage, hydraulic and solids loading, washwater requirements, and sludge cake solids content.

(c) Belt filters are being used more often due to improvements in design and growing acceptance of this relatively new technology. Industrial applications include dewatering of biological and chemical sludges.

(4) Filter press

(a) A filter press is a batch dewatering process using a continuous makeup system for supply. Sludge is withdrawn continuously from the clarifiers, thickeners, digesters, or holding tanks; it is then conditioned for dewatering, if necessary, and supplied to the filter under pressure by pump or by air pressure. The sludge is dewatered by filtration of the solids-bearing slurry through the filter medium which may be precoated. The high pressures allow thick cakes to build up inside the filter chamber. The filtrate flows from behind the filter medium through flow passages formed in the plate surface, or in open mesh underdrainage members to outlets on the filter plate. The outlet from the plate may be "open," discharging from each plate directly to a collecting trough or tray, or "closed," discharging through enclosed piping to a drainage system.

(b) After the cake is completely formed at the final filtration pressure, the flow of material into the filter decreases significantly, indicating the end of the effective filtration cycle. The filter is then opened, one chamber at a time, allowing the filter cakes to discharge. The filter is then ready to "turn around" and be put back on-stream.

(c) The pressure exerted on the cake during formation is limited only to the pumping force and basic filter closing system design. The filter cake dryness results partly from the applied pressure. Filters can be designed at pressures ranging from 50 to as high as 225 pounds per square inch gauge. As the final filtration pressure increases, there is a corresponding increase in cake dry solids.

(d) Filtrate quality is a function of filter media, conditioning, and the decision to precoat. Precoated filters obtain clarity down to 10 milligrams per liter suspended solids. Unprecoated filters will have suspended solids levels of 50 to 500 milligrams per liter, depending on media, type of solids, and type of conditioning used.

(e) One of the main considerations for using a filter press is the high-density and high dry-solids content of the filter cake. Filter cakes with 50 percent dry solids will have a density of 80 to 100 pounds per cubic foot, depending on the conditioning used and the final filtration pressure. When filter presses are used, the quantity of solids requiring landfill is reduced as much as 60 percent compared to a 20 to 25 percent solids cake with a density of 65 pounds per cubic foot obtained with other dewatering devices. Thus, the cost of disposal (by volume) is only 40 percent of what it would be for a system producing 20 to 25 percent solids.

(f) There are various means of conditioning sludges for dewatering. These include chemicals such as lime (hydrated, or quick lime after slaking, or recalcined lime after slaking), ferric chloride (liquid solution); polymers (anionic, cationic, or nonionic, depending on the sludge); physical admix materials such as ash (power plant fly ash, multiple hearth or fluidized-bed incinerator ash); and other wastes (cement kiln dust, lime kiln dust, coke breeze, carbon, soot, and other similar particle-size material, wet or dry).

(g) The variables which affect dewatering are:

- Sludge feed solids concentration, which is determined by the nature of the sludge and by the preceding thickening processes.
- Sludge and filtrate viscosity, which may be the same as water or may vary if the sludge is non-Newtonian.
- Sludge compressibility, which relates to the nature, size, etc., of the sludge particles.
- Chemical and physical composition, including particle size and shape, water content, oil content, etc.

(h) The operating variables which affect dewatering are:

- Operating pressure or final filtration pressure.
- Filter chamber cake thickness.
- Filtration time recycle.
- Type of sludge conditioning (chemical addition, admix addition, combination of above, or other).
- Temperature of the sludge slurry (for example, oil-bearing sludges can be greatly affected by higher temperatures).
- Precoat. The performance of systems which run without precoating tends to decrease with time until the medium has been washed.
- Type and porosity of filter medium. This will affect the filtrate solids, cake release, and media blinding characteristics.

(i) Since filter presses were developed for industrial product dewatering, meaningful, dynamic equations for sludge dewatering design have not been developed. The size of most plants is based on pilot experience and basic parameters of the filter equipment. These include:

- The total amount of sludge solids to be dewatered per day, calculated in terms of gallons of sludge to be handled and pounds of dry solids to be disposed of.
- The amount of conditioning needed (either physical or chemical), which is added to the dry solids to account for all material being fed to the filter.
- The filter cake volume, based on the expected percent solids in the final filter cake, which has been determined by pilot testing, existing plants, or other information.
- The total volume of filter chambers required per day.
- The number of filter chambers per day based on the actual cubic feet in each filter chamber.

(j) The number of chambers in each filter cycle can be calculated based on the number of cycles per day. The number of cycles per day is determined by pilot test data or actual operating plants. Due to the expansion characteristics and other considerations, a larger filter with a smaller number of plates may be selected for the initial stage, and the expansion capabilities of the filter will be used to take up additional plant capacity in the future⁶

(k) Figure 6-45 shows how the solids build up in the filter press and the filtrate passes through. Figure 6-46 shows a full-scale system.

(l) The following information is needed for design:

- (a) Total sludge feed solids in suspension.
- (b) Concentration of slurry entering the system.
- (c) Type and amount of conditioning materials required.
- (d) Cake thickness which can be produced with the required filter pressure.
- (e) Length of filter cycle which can be expected when filtering this sludge, conditioned as required.
- (f) Total dewatering time available.⁷

Primary and secondary sludges from industrial wastes can be dewatered successfully using pressure filters. Filter press dewatering applies to almost all wastewater sludges

⁶Process Design Techniques for Industrial Waste Treatment.

⁷Process Design Techniques for Industrial Waste Treatment.

and can usually provide better high cake solids content than centrifuges or belt filters. However, its capital and operating costs are higher. The use of a filter press may be economically feasible when transportation and sludge volume disposal cost dominate the anticipated expenditures.

(5) Drying beds

(a) The most common method of sludge dewatering is drying on open or covered sand beds. Sludge drying occurs by sedimentation, filtration, and evaporation. The proportion of the water removed by filtration may vary from 20 to 55 percent, depending on the sludge's initial solids content and on the solids characteristics. Climate (rainfall and evaporation) affects the design and use of drying beds. Sludge-drying beds usually consist of 4 to 9 inches of sand over 8 to 18 inches of graded gravel or stone. The sand has an effective size of 0.3 to 1.2 millimeters and a uniformity coefficient less than 6.0. Gravel is graded from 1/8 to 1 inch. The beds have underdrains spaced from 9 to 20 feet apart. The underdrain piping may be vitrified clay laid with open joints having a minimum diameter of 4 inches and a minimum slope of about 1 percent. The filtrate is returned to the treatment plant.

(b) Wet sludge is usually applied to the drying beds at depths of 8 to 12 inches. Removal of the dried sludge in a "liftable state" varies with both individual judgment and final disposal means, but usually involves sludge of 10 to 60 percent solids.

(c) Bed turnover can often be substantially increased by using chemicals. Ferric chloride treatment can reduce the sludge drying time by up to 50 percent. Polymers can increase both the rate of bed dewatering and the depth of application.

(d) Table 6-29 presents the advantages and disadvantages of using sand drying beds. Figure 6-47 shows a plan and cross section of a drying bed.

(e) A rational sludge-drying method has been developed⁸ based on the observed dewatering characteristics of a variety of industrial waste sludges. Sludge after drainage (usually 18 to 24 hours) is air-dried to the desired consistency. The moisture difference (initial-final) is that which must be evaporated. Depending on the cumulative rainfall and evaporation for the geographical area in question, the time needed at various times of the year to evaporate this moisture is obtained. The required bed area may then be determined.

(f) Sand drying beds are relatively common in small treatment plants or where large amounts of land are available. Table 6-30 presents several industrial applications and the associated drying characteristics.

(g) Drying beds may also be constructed with paved surfaces, usually asphalt, which makes lifting easier. Vacuum filtration has also been applied to drying beds where a vacuum is pulled on the complete bed through a porous medium or wedge wire screen. Effective sludge drying time is reduced to 24 to 48 hours.

c. Disposal. The objective of a sludge-handling system is to prepare the sludge for disposal. There are three disposal alternatives: disposal in or on the land, disposal in

⁸Current and Potential Utilization of Nutrients in Municipal Wastewater and Sludge, Volume 2, (U.S. Environmental Protection Agency [USEPA], Office of Water Program Operations, July 21, 1978).

the sea (ocean dumping), and disposal by incineration. Ocean dumping is being discouraged because of pollution problems. Several disposal methods are landfilling, lagooning, composting, land application, and incineration.

(1) Landfilling. Landfilling is the planned burial of wastewater solids, including processed sludge, screenings, grit, and other waste solids which cannot be recovered or used. This process involves placing the solids in a prepared site or excavated trench and covering them with a layer of soil so that dewatered sludge may be entirely buried below the ground surface. Trench fills normally have daily cover. There are four types of landfilling:

(a) The sludge-only trench fill, which involves excavating trenches.

(b) The sludge only area-fill, which mixes the sludge with the soil. The mixture is then placed on the original ground surface. This method can be used where there is high groundwater or bedrock. A final layer of soil is added to prevent odors and nuisance.

(c) Codisposal with refuse, in which the sludge is mixed with either soil or refuse and disposed at a refuse landfill. Refuse fills mix roughly a 9 to 1 combination of refuse with sludge. A standard trench landfill method is used for burial.

(d) Hazardous landfills, in which hazardous sludges are buried in lined and controlled landfill areas. Groundwater and leachate are controlled and treated if required. Extensive Federal and State regulations apply to all landfill designs, particularly hazardous landfills. The design of a hazardous landfill requires special leachate testing and control measures. The regulations provide specifications for construction and operation of different types of landfills, and require permits for building and operating a landfill. Project specific design and permit requirements are available from the Army's Computer-Aided Environmental Legislative Data System data base for specific locations. Industrial sludges which are nonhazardous and have a solids content greater than 15 percent may be disposed of in sludge-only or codisposal landfills. Nonhazardous sludges with solids content greater than 3 percent may be disposed of in a codisposal landfill. Hazardous sludges must be disposed in a hazardous waste landfill. Table 6-31 describes some of the considerations for determining acceptable options for landfill/sludge combinations.

(2) Lagooning

(a) Sludge lagoons are basins designed to store waste sludge for future disposal. However, they are not an ultimate disposal technique. A sludge lagoon has many simultaneous ongoing functions: sludge is decomposing (if organic) under both aerobic and anaerobic conditions; suspended solids are undergoing type IV settling; excess water is evaporating; and rainfall is accumulating.

(b) Design of sludge lagoons is based on solids loading rate, total flow, supernates recycle capabilities, rainfall/evaporation data, other climatic data, soil characteristics, and the availability of land.

(c) Lagooning has received widespread industrial acceptance because it is inexpensive and delays expenditures of capital funds. However, the sludge must ultimately be placed elsewhere; thus, lagooning only defers the disposal cost.

(3) Composting

(a) Composting disinfects and disposes of organic nontoxic sludges and provides soil conditioners and nutrients. It converts organic sludges into humus for use as soil conditioners and as nutrients for plants. The method of conversion involves aerobic thermophilic decomposition (decomposition in the presence of free oxygen at high temperatures--45 to 70°C). To degrade properly, the sludge must have a moisture content of 50 to 60 percent and a carbon/nitrogen ratio of less than 35. Sludges from fruit and vegetable processing plants, such as peels and sugar cane wastes, are well suited for composting.

(b) The most common composting method is the windrow process in which sludge is stacked in long parallel rows, typically 15 feet wide and 3 to 7 feet deep. Machinery mixes and aerates the stacks, usually two or three times per day for the first 5 days, and once for the next 30 days.

(c) Composting design is based on a variety of parameters, including sludge characteristics, composting method, time of digestion, availability of land, pH, and climatic conditions. The *EPA Process Design Manual on Sludge Treatment and Disposal* contains a more complete discussion of this method.

(4) Land application

(a) In land application, sludge is used to promote agricultural growth. Liquid sludge (2 to 5 percent solids) is applied to the soil to provide basic nutrients for plant growth and soil conditioning.

(b) Land application processes include spray irrigation, overland runoff, ridge and furrow irrigation, or soil infiltration. The sludge is dispersed by evaporation to the atmosphere, adsorption by the plants, or percolation into the soil. Figure 6-48 illustrates spray irrigation.

(c) Several factors must be considered in designing a land application system: character of the soil, depth of groundwater, initial moisture content, terrain and ground cover, pre-application treatment, sludge application mode, sludge storage requirements, and toxic contaminants in the sludge. Typical application rates vary from 0.2 to 6 inches per week with 2 inches per week representing an average rate.

(d) Land application is a viable process for sludges with few toxic or hazardous materials. Land application is being used by an increasing number of industries (tanning, food processing, chemicals, etc.), especially those with organic wastes which contain plant nutrients and little or no toxic materials. Table 6-32 presents operating data for some industrial and municipal applications of spray irrigation.

(5) Incineration

(a) Incineration is used for ultimate disposal of organic sludge and for destruction of toxic materials to an inert ash product. This process involves both drying and combustion. The variables to be considered in incineration are the moisture and volatile content of the sludge cake and the thermal value of the sludge solids. The moisture content is very significant because it dictates whether the combustion process will be self-supporting or whether supplementary fuel will be required. Table 6-33 shows the thermal value of several sludges.

(b) Various types of single or combined incineration units are available. In the incineration process, the sludge temperature is raised to 212°F, at which moisture evaporates. The water vapor and air temperature are increased to the ignition point. Some excess air is required for complete combustion of the sludge. Self-sustaining combustion is often possible with dewatered waste sludges once the auxiliary fuel raises incinerator temperature to the ignition point. The primary end products of combustion are carbon dioxide, sulfur dioxide, and ash.

(c) Incineration can be done in multiple-hearth furnaces in which the sludge passes vertically through a series of hearths. In the upper hearths, moisture is vaporized and exhaust gases are cooled. The volatile gases and solids are burned in the intermediate hearths. The total fixed carbon is burned in the lower hearths. Temperatures range from 1000°F at the top hearth to 600°F at the bottom. The exhaust gases pass through a scrubber to remove flyash and other volatile products. Figure 6-49 shows a typical furnace.

(d) In the fluidized bed, sludge particles are fed into a bed of sand fluidized by upward-moving air. A temperature of 1400°F to 1500°F in the bed rapidly dries and burns the sludge. Upward-flowing combustion gases remove the ash from the bed.

(e) Design considerations for sludge incineration include sludge, moisture content, volatile content, oxygen required for complete combustion, air pollution control requirements, and sludge thermal energy. Incinerator manufacturers can operate bench- or pilot-scale incineration systems using a specific sludge to develop design data. Based on these tests, manufacturers can determine the best type and size of incinerator and establish operating parameters such as feed rate and air flow rate.

(f) Most Army installations do not produce enough sludge to justify an incineration system. However, the need to dispose of hazardous materials may modify incinerator economics. Installations have used codisposal facilities where sewage sludge, primarily domestic, has been combined with refuse and incinerated with heat recovery.

Table 6-1

Air flotation treatment of oily wastewater (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinold Co., Inc., 1980], p 168, Copyright 1980. Used with permission of the publisher.)

Industrial Source	Alum (milligrams per liter)	Oil Concentration (milligrams/liter)		
		Influent	Effluent	Percent Removal
Refinery	0	125	35	72
	100	100	10	92
Oil tanker ballast water	100 (+1 milligram per liter polymer)	133	15	89
Paint manufacturer	150 (+1 milligram per liter polymer)	1,900	0	100
Aircraft maintenance	30 (+10 milligrams per liter activated silica)	250-700	20-50	90+
Meat packing		3,830	270	93
Meat packing		4,360	170	96

Table 6-2

Aeration device rating*

Aeration Device	Maintenance Rating	Transfer Rating	Heat Loss Rating
Diffused Air			
Coarse Bubble - Standard	2	7	4
Coarse Bubble - Static Aerators	4	4	4
Fine Bubble	3	1	2
Surface Aerators			
Low Speed	6	2	5
High Speed - Solid Shaft	1	5	7
High Speed - Coupling	5	5	7
Turbine Aerators	7	3	4

*Rating numbers go from best to poorest, with No. 1 as best and No. 7 as poorest.

Table 6-3

Design parameters for stabilization ponds
 (From Metcalf & Eddy, Inc., Wastewater Engineering: Collection, Treatment, Disposal
 [McGraw-Hill Book Co., 1972]. Used with permission.)

Parameter	Type of Pond		
	Aerobic	Aerobic-Anaerobic	Anaerobic
Flow regime	Intermittently mixed		Mixed Surface Layer
Pond size, acres	<10 multiple	2-10 multiple	2-10 multiples
Operation**	Series or parallel	Series or parallel	Series or parallel
Detention time, days†	10-40	7-30	7-20
Depth, feet	2-4	3-6	3-8
pH	6.5-10.5	6.5-9.0	6.5-8.5
Temperature range, °C	0-40	0.50	0-50
Optimum temperature, °C	20	20	20
BOD ₅ loading, pounds/acre/day	60-120	15-50	30-100
BOD ₅ conversion	80-95	80-95	80-95
Principal conversion products	Algae, CO ₂ , bacterial cell tissue	Algae, CO ₂ , CH ₄ , bacterial cell tissue	CO ₂ , CH ₄ , bacterial cell tissue
Algal concentration, milligrams/liter	80-200	40-160	10-40
Effluent suspended solids, milligrams/liter††	140-340	160-400	110-340

*Conventional aerobic ponds designed to maximize the amount of oxygen produced rather than the amount of algae produced.

**Depends on climatic conditions.

†Typical values (much higher values have been applied at various locations). Loading values are often specified by state control agencies.

††Includes algae, microorganisms, and residual influent suspended solids. Values are based on an influent soluble BOD₅ of 200 milligrams/liter end, with the exception of the aerobic ponds, an influent suspended-solids concentration of 200 milligrams/liter.

Table 6-4

Design parameters for aerated lagoons
 (From Metcalf & Eddy, Inc., *Wastewater Engineering: Collection, Treatment, Disposal* [McGraw-Hill Book Co., 1972]. Used with permission.)

Parameter	Aerated Lagoons
Flow regime	Completely mixed
Pond size, acres	2-10 multiples
Operation*	Series or parallel
Detention time, days*	3-10
Depth, feet	6-20
pH 6.5-8.0	
Temperature range, °C	0-40
Optimum temperature, °C	20
BOD ₅ conversion	80-95
Principal conversion products	CO ₂ , bacterial cell tissue
Effluent suspended solids, milligrams/ liter**	260-300

*Depends on climatic conditions.

**Includes algae, microorganisms, and residual influent suspended solids. Values are based on an influent soluble BOD₅ of 200 milligrams/liter and an influent suspended solids concentration of 100 milligrams/liter. Values represent effluent before clarification.

Table 6-5

Comparison of low-rate and high-rate trickling filters
 (From Metcalf & Eddy, Inc., *Wastewater Engineering: Collection, Treatment, Disposal* [McGraw-Hill Book Co., 1972]. Used with permission.)

	Low-Rate Filter	High-Rate Filter
Hydraulic loading, mgad	1 to 4	10 to 40
Organic loading, lb BOD ₅ /acre-foot-day	300 to 1,000	1,000 to 5,000
Depth, feet	6 to 10	3 to 8
Recirculation	None	1:1 to 4:1
Rock volume	5 to 10 times	1
Power requirements	None	10 to 50 horsepower/ million gallons
Filter flies	Many	Few; larvae are washed away
Sloughing	Intermittent	Continuous
Operation	Simple	Some skill
Dosing interval	Not more than 5 minutes (generally intermittent)	Not more than 15 seconds (continuous)
Effluent	Fully nitrified	Nitrification at low loadings

Table 6-6

Industrial application of biological treatment systems

Biological Treatment Process	Applicable Waste
Waste Stabilization Ponds	Low-strength wastes; applications requiring only low-quality effluent; may be used for polishing.
Aerated Lagoons	Variable moderate-strength wastes; roughing or polishing application.
Activated Sludge Conventional Complete Mix	Readily degradable, nontoxic wastes Inhibitory wastes, high-strength, variable characteristics
Step Aeration	Readily degradable, nontoxic
Contact Stabilization	Readily degradable; consistent-strength wastes
Extended Aeration	Difficult-to-degrade wastes, slightly toxic or inhibiting
Pure Oxygen	High-strength, readily degradable wastes
Trickling Filter	Moderate-strength, nonvariable wastes; roughing or polishing for another biological process
Rotating Biological Contactors	Moderate-strength, nonvariable wastes; roughing or polishing for another biological process

Table 6-7

Summary of average performance data from stabilization basins
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 349. Copyright 1980. Used with permission of the publisher.)

Industry	Area, acres	Depth, feet	Detention Time, days	Loading, pounds/acre-day	BOD Removal, percent
(a) Anaerobic Ponds					
Canning	2.5	6.0	15.	392	51
Meat and poultry	1.0	7.3	16.	1,260	80
Chemical	0.14	3.5	65.	54	89
Paper	71.	6.0	18.	347	50
Textile	2.2	5.8	3.5	1,433	44
Sugar	35.	7.0	50.	240	61
Wine	3.7	4.0	8.8	--	--
Rendering	1.0	6.0	245.	160	37
Leather	2.6	4.2	6.2	3,000	68
Potato	10.	4.0	3.9	--	--
Average value				860	60
(b) Facultative - Aerobic Ponds					
Meat and poultry	1.3	3.0	70	72	80
Canning	6.9	5.8	37	139	98
Chemical	31.	5.0	10	157	87
Paper	84.	5.0	30	105	80
Petroleum	15.5	5.0	25	28	76
Petrochemical	--	--	--	100	95
Wine	7.	1.5	25	221	--
Dairy	7.5	5.0	98	22	95
Textile	3.1	4.0	14	165	45
Sugar	20.	1.5	2	86	67
Rendering	2.2	4.2	48	86	76
Hog feeding	0.6	3.0	8	356	--
Laundry	0.2	3.0	94	52	--
Miscellaneous	15.	4.0	88	56	95
Potato	25.3	5.0	105	111	--
Average value				114	81
(c) Combined Anaerobic - Aerobic Ponds					
Canning	5.5	5.0	22	617	91
Meat and poultry	0.8	4.0	43	267	94
Paper	2,520.	5.5	136	28	94
Leather	4.6	4.0	152	50	92
Miscellaneous					
Industrial wastes	140	4.1	66	128	--
Resins, alcohols, amines, esters, styrene, ethylene	760	--	--	41	99
Olefins, glycols, aldehydes, polyolefins	470	--	240	41	99
Average value				167	95

Table 6-8**Typical values for low- and high-rate digesters**

Parameter	Low-Rate	High-Rate
Detention Time, days	30-60	10-15 (min)
Solids Loading Rate, lb VSS/cu ft/day	0.03-0.1	0.10-0.50
Temperature, °C	Ambient	32-35

Table 6-9

Estimated chlorine requirements for sludge and sidestream processing
 (From *Water Pollution Research Report 1973* [Her Britannic Majesty's Stationery Office, London, England, 1963]. Used with permission of the Controller.)

Feed Stream	Suspended Solids Percent	Chlorine Requirements Pounds/1000 gallon*
Primary sludge	4.0	17
Waste-activated sludge		
With prior primary treatment	0.7	7
No primary treatment	0.7	7
From contact stabilization	0.7	7
Sludge from low- and high-rate trickling filters	1.0	10
Digester supernatant	0.3	2-10
Septage	1.2	6

*1 pound/1000 gallons = 0.12 kilograms/liter.

Table 6-10

Design criteria for aerobic digesters
 (From Metcalf & Eddy, Inc., *Wastewater Engineering: Collection, Treatment, Disposal* [McGraw-Hill Book Co., 1972]. Used with permission.)

Parameter	Value
Hydraulic detention time, days at 20°C*	
Activated sludge only	12 to 16
Activated sludge from plant operated without primary settling	16 to 18
Primary plus activated or trickling-filter sludge	18 to 22
Solids loading, pounds volatile solids/cubic foot/day	0.1 to 0.20
Oxygen requirements, pound/pound destroyed	
Cell tissue**	≈2
BOD ₅ in primary sludge	1.6 to 1.8
Energy requirements for mixing	
Mechanical aerators, horsepower/1,000 cubic feet	0.5 to 1.0
Air mixing, scfm/1000 cubic feet	20 to 30
Dissolved oxygen level in liquid, milligrams/liter	1 to 2

*Detention times should be increased for temperatures below 20°C. If sludge cannot be withdrawn during certain periods (weekends, rainy weather), additional storage capacity should be provided.

**Ammonia produced during carbonaceous oxidation oxidized to nitrate.

Table 6-11

Tertiary treatment processes for the removal of specific pollutants
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], copyright 1980. Used with permission of the publisher.)

Unit Process	Major Elements Removed	Additional Features	Type Treatment
Filtration - sand, diatomite, or mixed media	Suspended solids	Removal of BOD, COD, PO ₄ in suspended form	Physical
Filtration plus coagulation - mixed media	Suspended solids and phosphate, color, and turbidity	As above, plus colloidal solids	Physical/chemical
Coagulation	Color, turbidity, suspended solids, and PO ₄	Some COD and BOD removed	Chemical
Air stripping	NH ₃	High pH required	
Carbon adsorption	COD, TOC, BOD ₅ , specific organics	Reduction in color and residual suspended solids	Physical
Ion exchange	Nitrogen, total dissolved solids, PO ₄	Resins selected for specific purposes	Physical
Reverse osmosis	Organics and inorganics	Pretreatment required to avoid membrane fouling; treatment or disposal of residue	Physical

Table 6-12

Chemical coagulant applications

Chemical	Typical Dosage Range (milligrams/liter)	pH	Comments
Line	150-500	9.0-11.0	For colloid coagulation and P removal. Wastewater with low alkalinity, and high and variable P.
Alum	75-250	4.5-7.0	For colloid coagulation and P removal. Wastewater with high alkalinity and low and stable P.
FeCl ₃ , FeCl ₂	35-150	4.0-7.0	For colloid coagulation and P removal.
FeSO ₄ , 7H ₂ O	70-200	4.0-7.0	Wastewater with high alkalinity and low and stable P. Where leaching of iron in the effluent is allowable or can be controlled. Where economical source of waste iron is available (steel mills, etc.)
Cationic Polymers	2-5	No change	For colloid coagulation or to aid coagulation with a metal. Where the buildup of an inert chemical is to be avoided.
Anionic and some nonionic polymers	0.25-1.0	No change	Used as an aid to speed flocculation settling and to toughen floc for filtration.
Weighting aids and clays	3-20	No change	Used for very dilute colloidal suspensions for weighting.

Table 6-13

Typical design factors for flocculation tanks

Design Factor	Less Than 0.1	0.1 to 1.0	Greater Than 1.0
Detention time (min) t	30	20	15
Depth (ft), d	8	10	12
Velocity gradient, g (sec^{-1})	20-40	30-50	40-60

Table 6-14

Effect of coagulation on selected industrial wastewaters

Plant # - Coagulant	Dosage (milligrams/liter)	pH	Color		COD	
			Influent	% Removal	Influent	% Removal
Textile Manufacturers						
1. Fe ₂ (SO ₄) ₃ Alum	250	7.5-11.0 5-9	0.25*	90	584	33
	300			86		39
2. Fe ₂ (SO ₄) ₃ Alum	1,200	3-4/9-11 8.5-10	0.74*	68	840	30
	500			89		49
3. Fe ₂ (SO ₄) ₃ Alum	500	9.5-11 6-9	1.84*	89	825	40
	2,000			65		40
4. Fe ₂ (SO ₄) ₃ Alum	250	9-11 5-6	4.60*	95	1,570	38
	250			95		31
5. Fe ₂ (SO ₄) ₃ Alum	600	—	—	78	—	50
	1,000			87		31
6. Fe ₂ (SO ₄) ₃ Alum	750	—	—	89	—	44
	2,500			87		44
Pulp and Paper Mill						
1. Fe ₂ (SO ₄) ₃ Alum	500	3.5-4.5 4.0-5.0	2,250**	92	776	60
	400			92		53
2. Fe ₂ (SO ₄) ₃ Alum	1,500	3.5-4.5 4.0-5.5	1,470**	92	480	38
	275			91		53
3. Fe ₂ (SO ₄) ₃ Alum	250	—	940**	93	468	48
	1,000			85		45
4. Fe ₂ (SO ₄) ₃ Alum	250	4.5-5.5 5.0-6.5	—	85	—	53
	250			91		44
5. Fe ₂ (SO ₄) ₃ Alum	1,000	—	—	85	—	40

*Color sum of absorbances at wave lengths of 450, 550, and 650 nm.

**APHA units.

Table 6-15

Process variables for filtration design

(From G. Tchobanoglous, "Filtration Techniques in Tertiary Treatment," *J. WPCF*, Vol 42, No. 4 [*J. WPCF*, 1970]. Used with permission of the publisher.)

1. Filter-media grain size, shape, density, and composition
2. Filter-media porosity
3. Media head loss characteristics
4. Filter-bed depth
5. Filtration rate
6. Allowable head loss
7. Fluid characteristics
8. Influent characteristics
 - a. Suspended-solids concentration
 - b. Floc or particle size and distribution
 - c. Floc strength
 - d. Floc or particle charge

Table 6-16

Typical design data for dual-media and multi-media filters
 (From G. Tchobanoglous, "Filtration Techniques in Tertiary Treatment,"
 J. WPCF, Vol 42, No. 4 [J. WPCF, 1970]. Used with permission of the
 publisher.)

Characteristic	Value	
	Range	Typical
Dual-media		
Anthracite:		
Depth, inches	8-24	18
Effective size, millimeters	0.8-2.0	1.2
Uniformity coefficient	1.4-1.8	1.5
Sand:		
Depth, inches	10-24	12
Effective size, millimeters	0.3-0.8	0.5
Uniformity coefficient	1.2-1.6	1.4
Filtration rate, gallons per minute/square foot	2-10	6
Multi-media		
Anthracite:		
Depth, inches	8-20	15
Effective size, millimeters	1.0-2.0	1.4
Uniformity coefficient	1.4-1.8	1.5
Sand:		
Depth, inches	8-16	12
Effective size, millimeters	0.4-0.8	0.6
Uniformity coefficient	1.2-1.6	1.4
Garnet:		
Depth, inches	2-4	3
Effective size, millimeters	0.2-0.6	0.3
Uniformity coefficient		1.0
Filtration rate, gallons per minute/square foot	2-12	6

Table 6-17

Reported filtration performance
 (From W. W. Eckenfelder, Jr., Principles of Water Quality Management [Van Nostrand Reinhold Co., Inc., 1980], p 501, copyright 1980. Used with permission of the publisher.)

Filter Type	Feed Type ^a	Media Size (millimeters)	Filter Depth (feet)	Hydraulic Loading (gallons per minute/square foot)	SS Removal (percent)	MOO ⁵ Removal (percent)	Eff. SS (milligrams/liter)	Eff. MOO ⁵ (milligrams/liter)
Gravity downflow	TF Eff.	1.0-2.0	--	6	70	55	5-7	--
Gravity downflow	TF Eff.	0.9-1.7	2-3	3	67	58	--	2.5
Pressure upflow	TF Eff.	0.9-1.7	5	3	85	74	5.0	2.5
Pressure upflow	AS Eff.	0.9-1.7	5	3	77	--	--	--
Pressure upflow	AS Eff.	1.0-2.0	5	2.2	50	62	7.0	6.4
Pressure upflow	AS Eff.	1.0-2.0	5	4.0	67	73	4.9	6.4
Pressure upflow	AS Eff.	1.0-2.0	5	4.9	56	65	5.7	7.1
Mixed media	EA Eff.	0.25-2.0	2.5	5.0	74	88	4.6	2.5
Mixed media	AS Eff.			2.0	73	74	3.8	6.0
Mixed media	AS Eff.			4.0	73	85	4.3	3.9
Mixed media	AS Eff.	0.25-2.0	2.5	2.5				

^aTF denotes trickling filter; "AS" denotes conventional activated sludge; "EA" denotes extended aeration.

Table 6-18

Results of adsorption tests on different industrial wastes
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 539, copyright 1980. Used with permission of the publisher.)

Type of Industry	Initial TOC (or phenol), (milligrams/liter)	Initial Color O.D.	Average % Reduction	Carbon Exhaustion Rate, (pounds/1000 gallons)
Food and kindred products	25-5,300	-	90	0.8-345
Tobacco manufacturers	1,030	-	97	58
Textile mill products	9-4,670	-	93	1-246
	-	0.1-5.4	97	0.1-83
Apparels and allied products	390-875	-	75	12-43
Paper and allied products	100-3,500	-	90	3.2-156
	-	1.4	94	3.7
Printing, publishing, and allied industries	34-170	-	98	4.3-4.6
Chemicals and allied products	19-75,500	-	85	0.7-2,905
	(0.1-5,325)	-	99	1.7-185
	-	0.7-275	98	1.2-1,328
Petroleum refining and related industries	36-4,400	-	92	1.1-141
	(7-270)	-	99	6-24
Rubber and miscellaneous plastics products	120-8,375	-	95	5.2-164
Leather and leather products	115-9,000	-	95	3-315
Stone, clay, and glass products	12-8,300	-	87	2.8-300
Primary metal industries	11-23,000	-	90	0.5-1,857
Fabricated metal products	73,000	-	25	606

Table 6-19

Summary of existing or potential resin adsorption applications

Principal Compounds in Wastewater	Resin Regenerant
Chloroform	Steam
Dieldrin, aldrin, endrin, DDT	Acetone, methanol
Phenol	Acetone, methanol, caustic soda
Chlorinated pesticides	Isopropanol
Ethylene dichloride	Steam
Benzene, toluene, xylene	Steam

Table 6-20

Design ranges for high-pH air-stripping system
(From *Process Design Manual for Nitrogen Control* [USEPA, October 1975].)

Parameters	High pH Requirements
Hydraulic Loading	2-3.5 gallons per minute per square foot
Air-Liquid Ratio	150-800 cubic feet per gallon
Temperature	25°C
pH	10.7-11.0
Tower Packing Depth	<u>+24</u> feet

Table 6-21

Summary of reverse osmosis system operational parameters
 (From F. J. Agardy, "Membrane Process," *Process Design in Water Quality Engineering*, E. L. Thackston and W. W. Eckenfelder, Jr., eds. [Jenkins Publishing, 1972]. Used with permission of the publisher.)

Parameter	Range	Typical Value
Pressure	400 to 1000 pounds per square inch gauge	600 pounds per square inch gauge
Temperature	60°F to 100°F	70°F
Packing Density	50 to 500 square feet per cubic foot	-
Flux	10 to 80 gallons per day per square foot	12 to 35 gallons per day per square foot
Recovery Factor	75 to 95%	80%
Rejection Factor	85 to 99.5%	95%
Membrane Life	-	2 years
pH	3 to 8	4.5 to 4.5
Turbidity	-	1 JTU
Feedwater Velocity	0.04 to 2.5 feet per second	-
Power Utilization	9-17 kilowatts per hour per 1000 gallons	

Table 6-22

Typical ultrafiltration design parameters
 (From *Process Design Manual for Suspended Solids Removal*, 625/1-75-003a [USEAP, 1975].)

Parameter	Values
Membrane Area	Sufficient to provide flux rate of 8 gallons per day per square foot
Membrane Configuration	Storage battery, tubular or spiral-wound
Membrane Material	Two layers 1. Surface 0.1 to 10 micros 2. Surface support - open cell 5- to 10-mil thickness
Driving Force	25 to 50 pounds per square inch

Table 6-23

Chlorination applications in wastewater collection, treatment, and disposal
 (From Metcalf & Eddy, Inc., *Wastewater Engineering: Collection, Treatment, Disposal* [McGraw-Hill Book Co., 1972]. Used with permission.)

Application	Dosage Range, (milligrams per liter)	Remarks
Collection:		
Slime-growth control	1-10	Control of fungi and slime-producing bacteria
Corrosion control (H ₂ S)	2-9*	Control by destruction of H ₂ S in sewers
Odor control	2-9*	Especially in pump stations and long flat sewers
Treatment:		
Grease removal	2-10	Added before aeration
BOD reduction	0.5-2**	Oxidation of organic substances
Ferrous sulfate oxidation end	+	Production of ferric sulfate
Filter ponding control	1-10	Residual at filter nozzles
Filter fly control used	0.1-0.5	Residual at filter nozzles, during fly season
Sludge bulking control	1-10	Temporary control measure
Digester supernatant oxidation	20-140	
Digester and Imhoff tank foaming control	2-15	
Nitrate reduction ammonia	Variable	Conversion of nitrate to ammonia
Disinfection:		
Untreated wastewater	6-25	Prechlorination
Plant overflows, stormwater	2-20	Bacterial reduction
Primary Treatment	5-20	After sedimentation
Physical-chemical treatment	2-6	After coagulation
Trickling-filter plant	3-15	
Activated-sludge plant	2-8	
Tertiary treatment plant	1-5	After multimedia filter

*Per milligram per liter of H₂S

**Per milligram per liter of BOD₅ destroyed

+ $6\text{FeSO}_4 \cdot 7\text{H}_2\text{O} + 3\text{Cl}_2 - 2\text{FeCl}_3 + 2\text{Fe}_2(\text{SO}_4)_3 + 42\text{H}_2\text{O}$.

Table 6-24

Removal of heavy metals by lime, coagulation, settling, and recarbonation
 (From Y. Argaman, and C. L. Waddle, "Fate of Heavy Metals in Physical/Chemical
 Treatment Process," *Water-1973*, AIChE Symposium Series, 70, 136:400 [1974].)

Metal	Concentration Range (milligrams per liter)		Removed (%)
	Influent	Effluent	
Ag	0.24-1.51	0.01-0.02	96-99
As	7.00-8.40	0.20-0.30	96-97
Ba	0.36-1.08	0.04-0.14	87-89
Cd	0.54-5.78	0.01-0.19	95-99
Co	0.42-1.29	0.04-0.09	90-96
Cr ⁺⁶	0.45-1.40	0.30-1.25	11-33
Cu	0.60-1.47	0.04-0.23	84-93
Hg	3.26-4.45	0.29-0.61	86-91
Mn	1.37-2.26	0.01-0.02	99
Ni	0.75-1.36	0.11-0.20	85
Pb	0.41-1.21	0.04-0.05	90-96
Zn	7.34-9.61	0.12-0.18	97-99

Table 6-25

Removal of heavy metals by precipitation

Metal	Process	Effluent Level	Constraint
Arsenic	Prec. with $S^{=}$ pH 6-7	0.05 milligrams per liter	
	Carbon Adsorption (low levels)	0.06 milligrams per liter	
	$Fe(OH)_3$ coprec.	0.05 milligrams per liter	
Barium	$BaSO_4$ prec.	0.5 milligrams per liter	
Cadmium	$Cd(OH)_2$ ppt (pH 10.0)	0.1 milligrams per liter	Complexing ions (for example, requires pre- treatment) Oxidizes CN^- and Cd to oxide
	$Fe(OH)_3$ coprec. pH 8.5 H_2O_2 oxidation	none	
Copper	$Cu(OH)_2$ prec.	0.2 milligrams per liter	pH 9.0-10.3
	$Fe(OH)_3$ coprec.	0.3 milligrams per liter	pH 8.5
Lead	$Pb(OH)_2$ prec.	0.5 milligrams per liter	pH 10.0
	$Pb(OH)_3$ ppt	0.001 milligrams per liter	pH 8.0-9.0
	Pb S	--	pH 7.5-8.5
Mercury	$Fe(OH)_3$; $Al(OH)_3$ coprec.	0.1 milligrams per liter	Na_2S added
Nickel	$Ni(OH)_2$	0.15 milligrams per liter	pH 10.0
Selenium	SeS prec.	0.05 milligrams per liter	pH 6.5
Zinc	$Zn(OH)_2$	--	pH 8.5

Table 6-26

Surface loadings and performance data from gravity thickening
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], copyright 1980. Used with permission of the publisher.)

Description of Sludge	Solids Loading Rate (Pounds per square foot-day)	Influent Sludge Solids Concentration (percent)	Thickened Sludge Solids Concentration (percent)
Separate Sludges			
Primary	20-30		8-10
Modified Activated	15-25		7-8.5
Activated	5-6		2.5-3
Trickling Filter	8-10		7-9
Combined Sludges			
Primary and Modified Activated	20-25		8-12
Primary and Activated	6-10		5-8
Primary and Trickling Filter	10-12		7-9
Pulp and Paper			
(53% Primary, 47% Activated)	25.0	2.0	4.0
(67% Primary, 33% Activated)	25.0	2.0	6.0
(100% Primary)	25.0	2.0	9.0
Brewery - Domestic		2.0	8.0
Carbon Processing	18-76	0.2-0.5	5.0
Lime Softening		4.5	18.7

Table 6-27

Advantages and disadvantages of various centrifuges
 (From Process Design Manual for Sludge Treatment and Disposal, EPA 625/1-79-011 [USEPA].)

Advantages	Disadvantages
<p>Solid Bowl Centrifuge</p> <ol style="list-style-type: none"> 1. Centrifuges have clean appearance, little to no odor problems, and fast startup and shutdown capabilities. 2. Easy to install. 3. Provides high throughput in a small surface area. 4. Gives for many sludges a cake as dry as any other mechanical dewatering process except for pressure filtration systems. 5. Has one of the lowest total capital-cost-versus-capacity ratios. 6. Does not require continuous operator attention. <p>Basket Centrifuge</p> <ol style="list-style-type: none"> 1. Same machine can be used for both dewatering and thickening. 2. May not require chemical conditioning. 3. Centrifuges have clean appearance, little to no odor problems, and startup and shutdown capabilities. 4. Basket centrifuge is very flexible in meeting process requirements. 5. Is an excellent dewatering machine for hard-to-handle sludge. 6. Has low total operating and maintenance costs. 7. Does not require continuous operator attention. <p>Nozzle Disk Centrifuge</p> <ol style="list-style-type: none"> 1. Yields highly clarified centrate without the use of chemicals. 	<ol style="list-style-type: none"> 1. Scroll wear potentially a high maintenance item. 2. Requires grit removal or possibly a grinder in the feed stream. 3. Requires skilled maintenance personnel. <ol style="list-style-type: none"> 1. Requires special structural support. 2. Except for vacuum filter, consumes more direct horsepower per unit of product processed. 3. Skimming stream could produce significant recycle load. 4. For easily dewatered sludges, has the highest capital cost versus capacity ratio. 5. For most sludges, gives the lowest cake solids concentration. <ol style="list-style-type: none"> 1. Can only be used on sludges with particle sizes of 400 or less.

Table 6-28

Centrifuge application to various wastewaters
 (From Process Design Techniques for Industrial Waste Treatment, C. E. Adams, Jr., and W. W. Eckenfelder, Jr., eds, [Enviro Press, 1974]. Used with permission of the publisher.)

Effluent	Application Treatment	As Fed	Solids As Discharged	Cake (% Solids)	Polymer Added* (pounds/ton)
SOLID-BOWL CENTRIFUGE					
Paper mill; paper	Primary; primary, secondary	Coarse, fibrous, claylike	Relatively dry	28-40	None
Refinery	—	Gritty, coarse	Dry to pudding	20-25	None
Paper mill, municipal	—	Slimy, thickened	Thick pudding	18-22	10-20
Paper mill, water treatment	Lime sludge; water softening	Claylike	Dry	40-60 (depends on % hydroxide)	None
Steel mill	Pickle liquor, neutralized	Some floccy, some clay	Very thick pudding (can be shoveled)	20-30	1-2
DISC-TYPE CENTRIFUGE WITH NOZZLES					
Paper, municipal	Waste-activated	Slimy	Thickened (for further dewatering or digestion)	6-7	None (or <1)
Refinery	Liquid-liquid solids	Oil-water emulsion; some fine, clay-like solids	Oil-water emulsion split; solids concentrated	011 (<1% water); solids (7-10%)	None
Water treatment plant	Alum floc	Slimy, floccy	Thin, floccy	5-7	<1
SOLID BOWL BASKET (IMPERFORATE) CENTRIFUGE					
Water treatment chemical waste	Alum floc, hydroxide sludge	Floccy	Very thick pudding	15-25	None (or <1)

*Recovery, 85-90 percent.

Table 6-29

Advantages and disadvantages of using sludge drying beds
(From *Process Design Manual for Sludge Treatment and Disposal*, EPA 625/1-79-011 [USEPA, 1979].)

Advantages	Disadvantages
1. When land is readily available, this is normally the lowest capital cost.	1. Lack of a rational engineering design approach allowing sound engineering economic analysis.
2. Small amount of operator attention and skill is required.	2. Requires more land than fully mechanical methods.
3. Low energy consumption.	3. Requires a stabilized sludge.
4. Less sensitive to sludge variability.	4. Must be designed with careful concern for climatic effects.
5. Low to no chemical consumption.	5. May be more visible to the general public.
6. Higher dry cake solids contents than fully mechanical methods.	6. Removal usually labor-intensive.

Table 6-30

Waste-sludge drying characteristics
 (From *Water Pollution Research Report 1963* [Her Britannic Majesty's Stationary Office, London, England, 1963]. Used with permission of the Controller.)

Source of Type of Sludge	Solids Applied (X)	Vol. (X)	Depth Applied (centimeters)	Period to Liftable State (days)	Solids Content Removed (X)	Specific Resistance x 10 ³ , eec ² /g (500 grams per square centimeter)	Coefficient of Comp.
1. Steam peeling of carrots	1.91	74.3	39.4	25	7.0	0.46	1.02
2. Lime neutralization of pickling liquor	2.46	16.9	48.3	25	10.5	0.30	0.63
3. Vegetable tanning	6.79	43.5	19.5	20	20.0	0.15	0.79
4. Lime neutralization of regenerant liquors from ion-exchange demineralization of plating wastes	7.05	19.8	17.5	20	18.0	0.19	0.55
5. Alum sludge	4.82	44.1	26.9	50	14.5	5.30	0.31
6. Digested sewage sludge	4.28	56.8	30.5	74	25.0	13.50	0.60

Table 6-31

Suitability of sludges for landfilling
 (From Process Design Manual for Sludge Treatment and Disposal, EPA 625/1-79-011 [USEPA, 1979].)

Type of Sludge	Sludge Only Landfilling		Co-disposal Landfilling	
	Suitability	Reason	Suitability	Reason
Liquid - unetabilized				
Gravity-thickened primary, WAS and primary, and WAS	NS	OD, OP	NS	OD, OP
Flotation-thickened primary and WAS, and WAS without chemicals	NS	OD, OP	NS	OD, OP
Flotation-thickened WAS with chemicals	NS	OP	NS	OD, OP
Thermal-conditioned primary or WAS	NS	OD, OP	MS	OD, OP
Liquid - stabilized				
Thickened anaerobic digested primary and primary, and WAS	NS	OP	MS	OP
Thickened aerobic digested primary and primary, and WAS	NS	OP	MS	OP
Thickened lime stabilized primary and primary, and WAS	NS	OP	MS	OP
Dewatered - unetabilized				
Vacuum-filtered, lime-conditioned primary	S	-	S	-
Dewatered - stabilized				
Drying bed digested and lime-stabilized	S	-	S	-
Vacuum-filtered, lime-conditioned digested	S	-	S	-
Pressure-filtered, lime-conditioned digested	S	-	S	-
Centrifuged, digested, and lime-conditioned digested	S	-	S	-
Heat-dried				
Heat-dried digested	S	-	S	-
High-temperature-processed				
Incinerated dewatered primary and primary, and WAS	S	-	S	-
Wet-air oxidized primary and primary, and WAS	NS	OD, OP	MS	OD, OP
WAS - Waste-activated sludge NS - Not suitable MS - Marginally suitable S - Suitable OD - Odor problems OP - Operational problems				

Table 6-32

Operating data for selected land application systems
 (From W. W. Eckenfelder, Jr., Principles of Water Quality Management [Van Nostrand Reinhold Co., Inc.,
 1980], p 659, copyright 1980. Used with permission of the publisher.)

Waste	Soil	Cover	Organic (pounds/acre day)	Hydraulic (inches/acre day)	Duration	Type	Removal efficiency (%)
Cannery	—	Grass	183 COD	0.88	—	Spray	81
Cannery	—	Grass	102 COD	0.49	—	Spray	81
Domestic	—	Forest	—	0.20	June-Dec	Spray	80
Domestic	Silt loam	Grass	35 COD	1.32	223 days	R&F**	65
Domestic	Silt loam	Grass	46 COD	1.72	235 days	R&F	65
Cannery	Sandy silt	Grass	—	3.90	—	Spray	—
Cannery	Clay	Grass	218 BOD	0.88	Year-round	Spray	—
Cannery	—	—	74 COD	0.44	Year-round	Spray	98
Cannery	—	—	238 BOD	1.80	57 days	R&F	—
Cannery	—	—	2,020 BOD*	1.25	35 days	R&F	—
Cannery	—	—	1,360 BOD**	2.86	120 days	R&F	—
Milk	—	—	58 BOD	0.86	—	R&F	95
Meat	Sand	—	100 BOD	1.47	Year-round	R&F	91
Cannery	—	—	413 BOD	2.96	—	—	—
Cannery	—	—	864 BOD	3.35	—	—	—
Cannery	—	—	22 BOD	3.50	—	—	—
Cannery	—	—	40 BOD	0.37	—	—	—
Cannery	—	—	65 BOD	0.37	—	—	—
Cannery	—	—	807 BOD	3.61	—	—	—

*Exceed 30 ton/yr loading

**Ridge and furrow

—Not given in literature source.

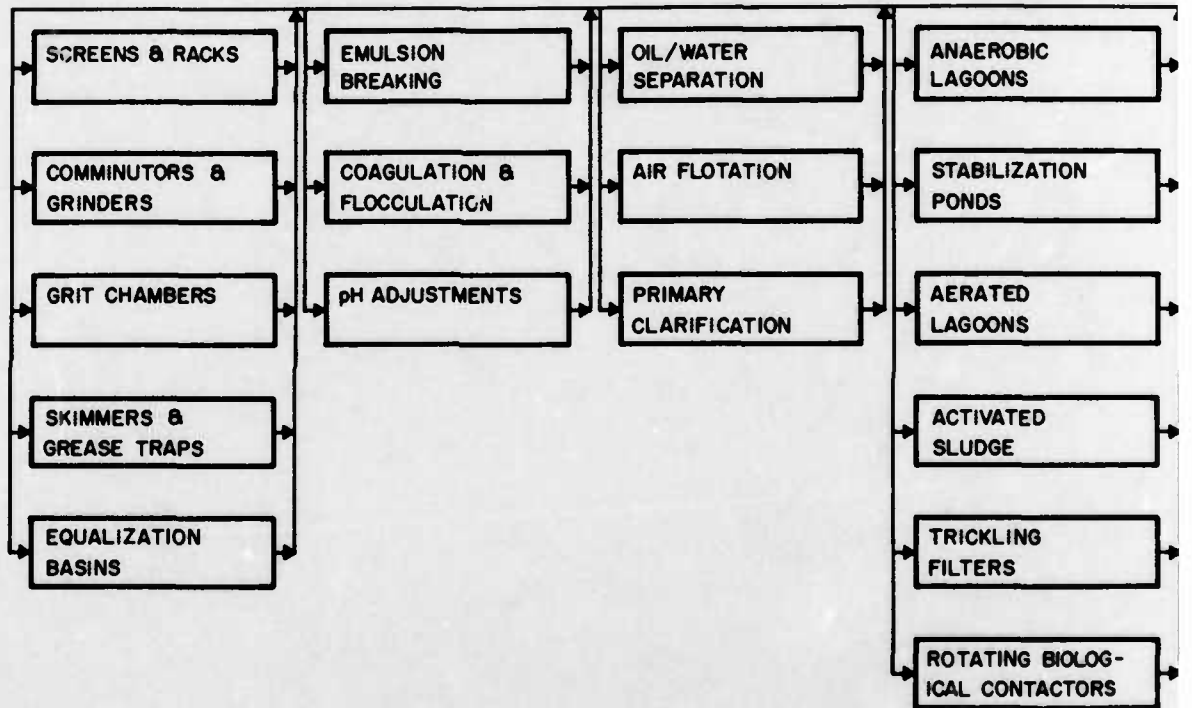
Table 6-33

Heat values of sampled sludges

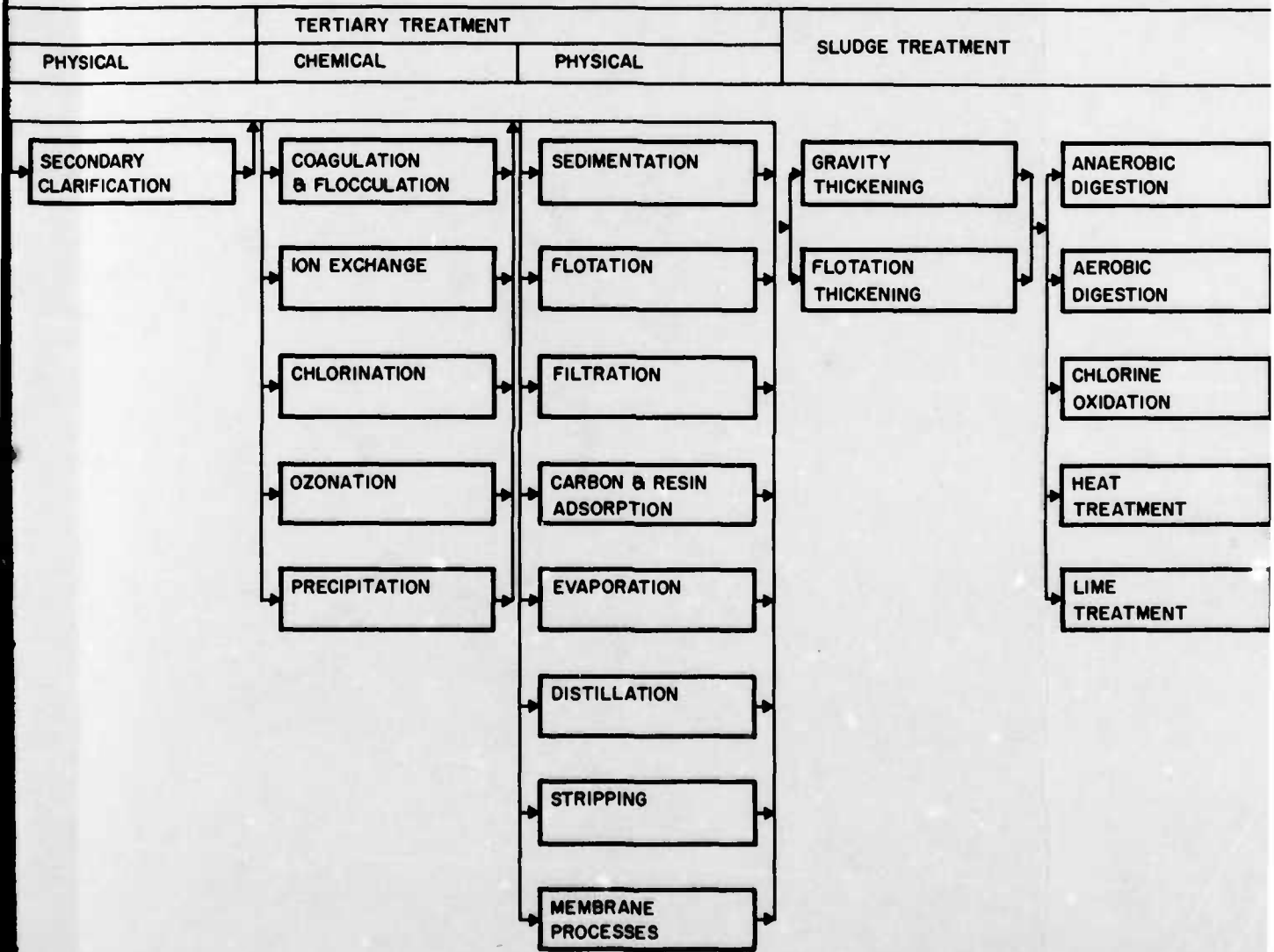
(From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 650, copyright 1980. Used with permission of the publisher.)

Tested Sludge	Com- bustibles (percent)	Ash (percent)	Sludge Heat Value (BTU/pound)
Oil			17,500
Grease and scum	88.5	11.5	16,750
Raw wastewater	74.0	26.0	10,285
Fine screenings	86.4	13.6	7,820
Waste sulfite liquor solids			7,900
Primary wastewater sludge			8,990
Activated wastewater sludge			6,540
Semichemical pulp solids			5,812
Digested primary sludge	59.6	40.4	5,290
Grit	33.2	69.8	4,000

PRETREATMENT	PRIMARY TREATMENT		SECONDARY TREATMENT
	CHEMICAL	PHYSICAL	BIOLOGICAL

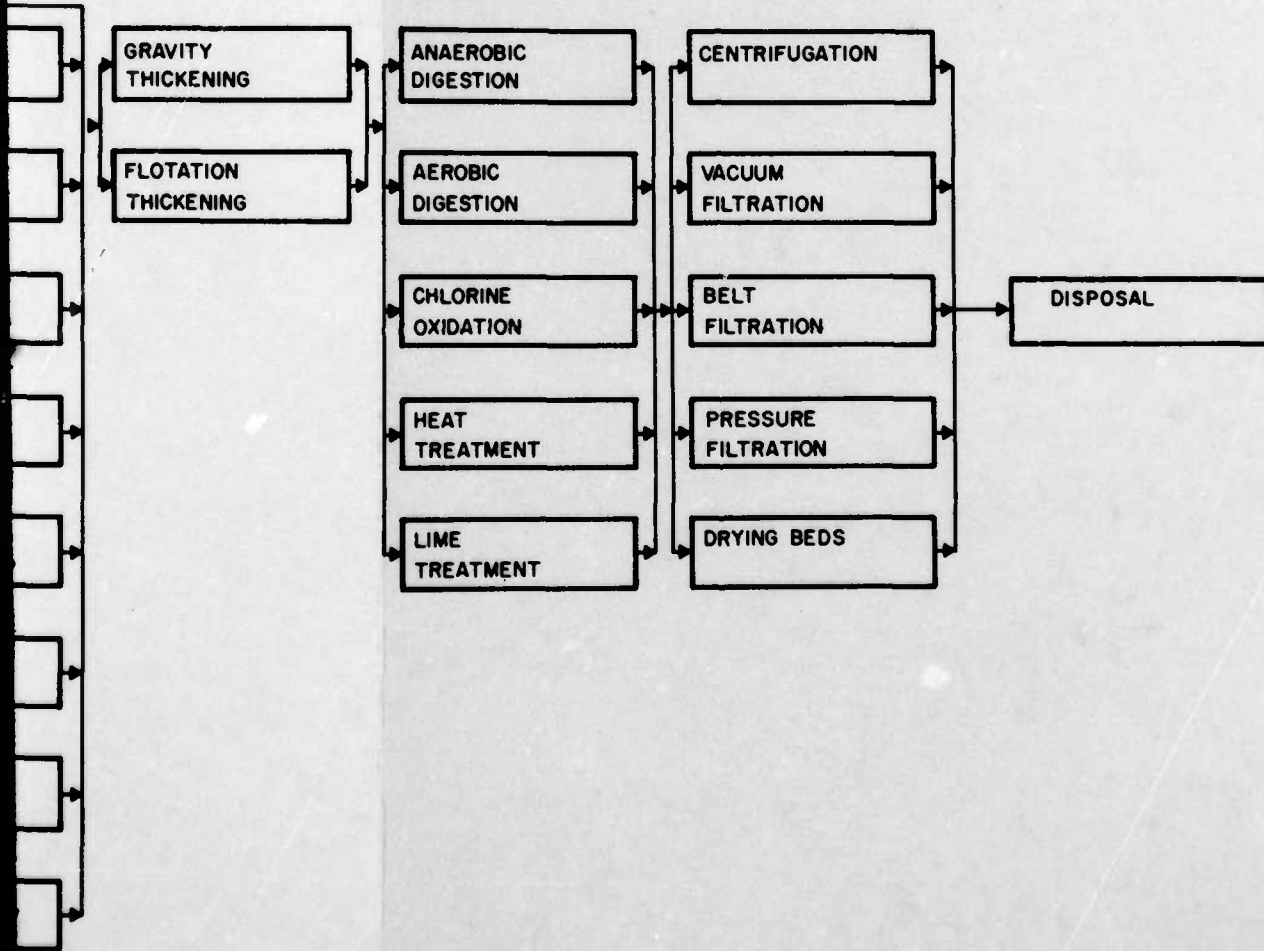


Figure



1. Wastewater treatment sequence--process substitution diagram. (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 131, copyright 1980. Used with permission of the publisher.)

SLUDGE TREATMENT



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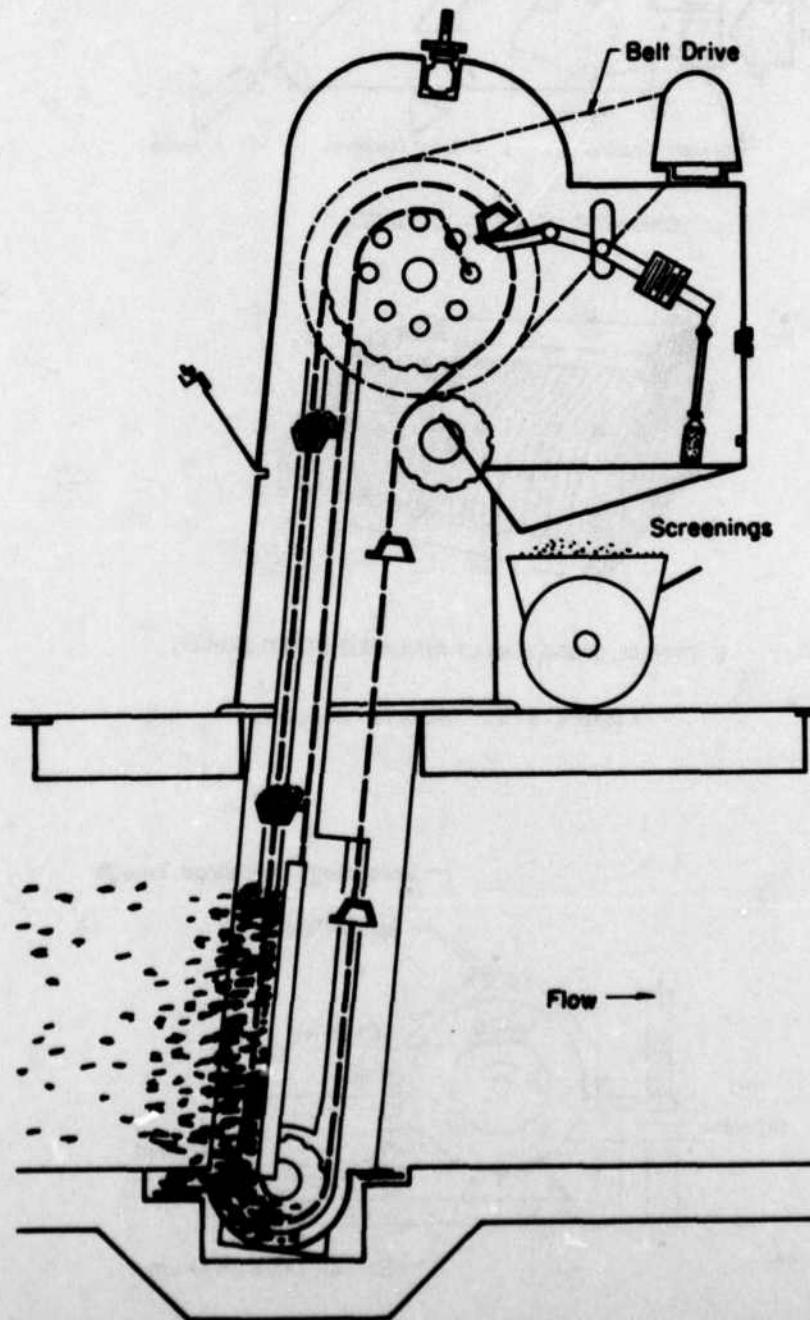
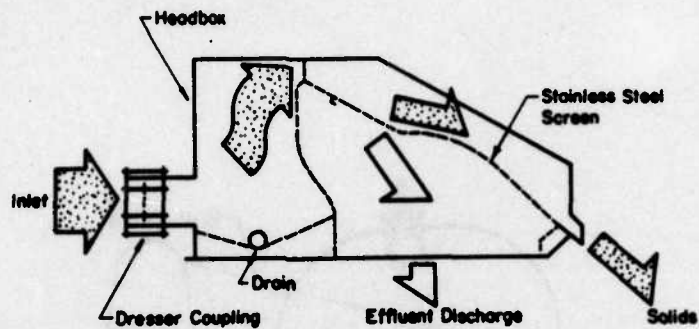
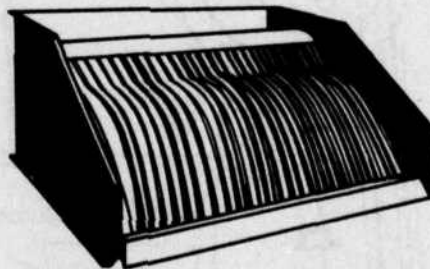


Figure 6-2. Schematic of a mechanically cleaned bar rack.



a. SCHEMATIC OF A STATIC SCREEN



b. TYPICAL COMMERCIALY AVAILABLE STATIC SCREEN

Figure 6-3. Static screen.

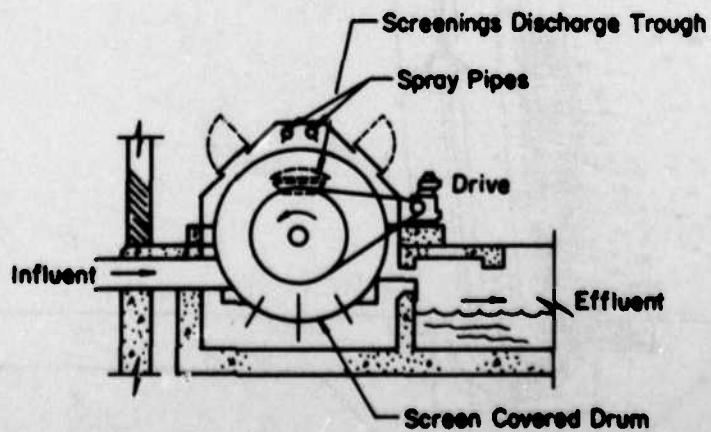
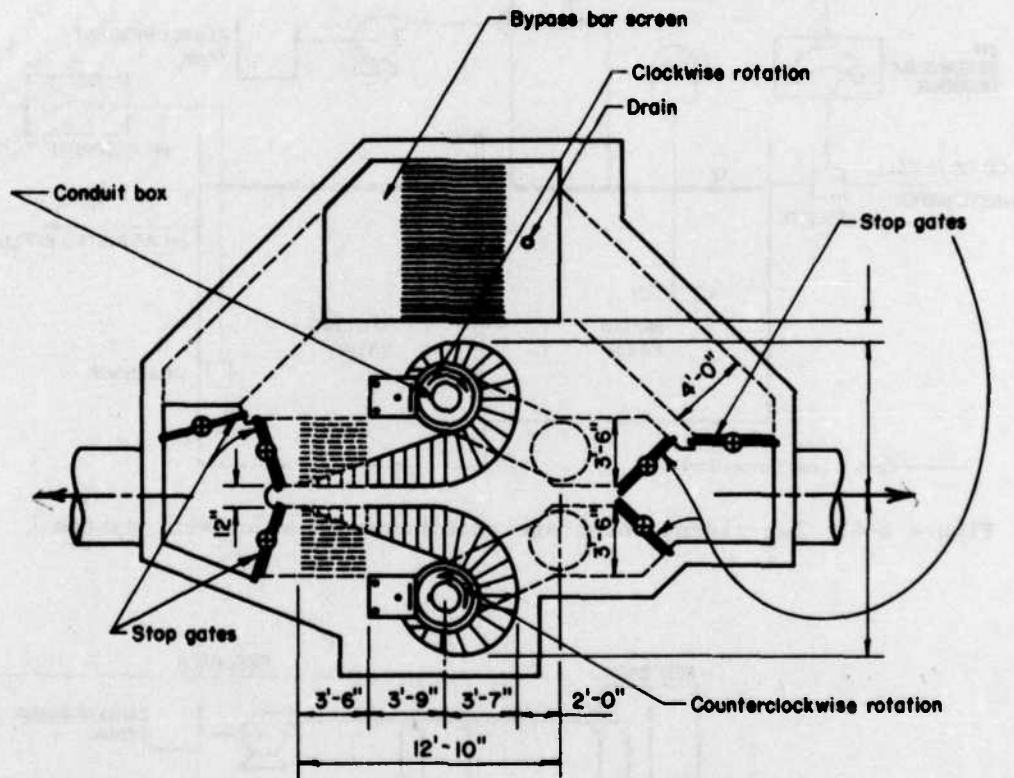


Figure 6-4. Rotary drum screen schematic.
 (From Metcalf and Eddy, Inc., *Wastewater Engineering: Collection, Treatment, Disposal* [McGraw-Hill Book Co., 1972]. Used with permission.)



PLAN

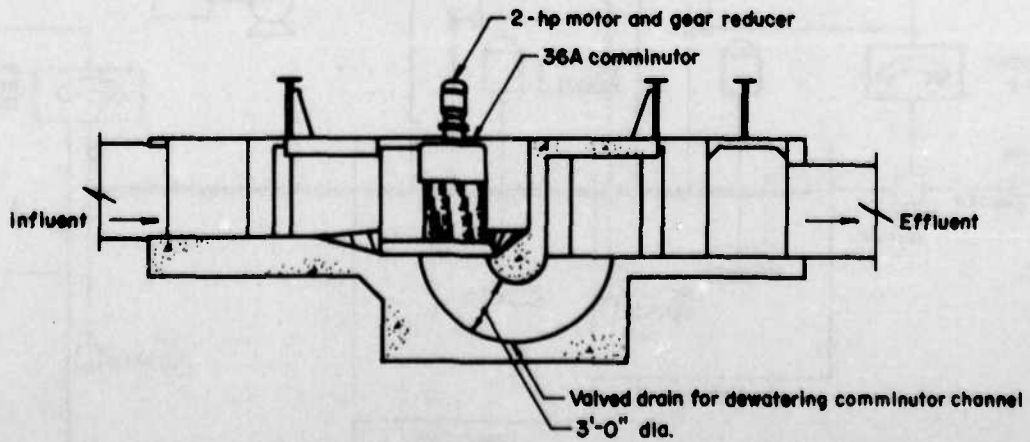


Figure 6-5. Plan and cross-sectional views of a comminutor installation.

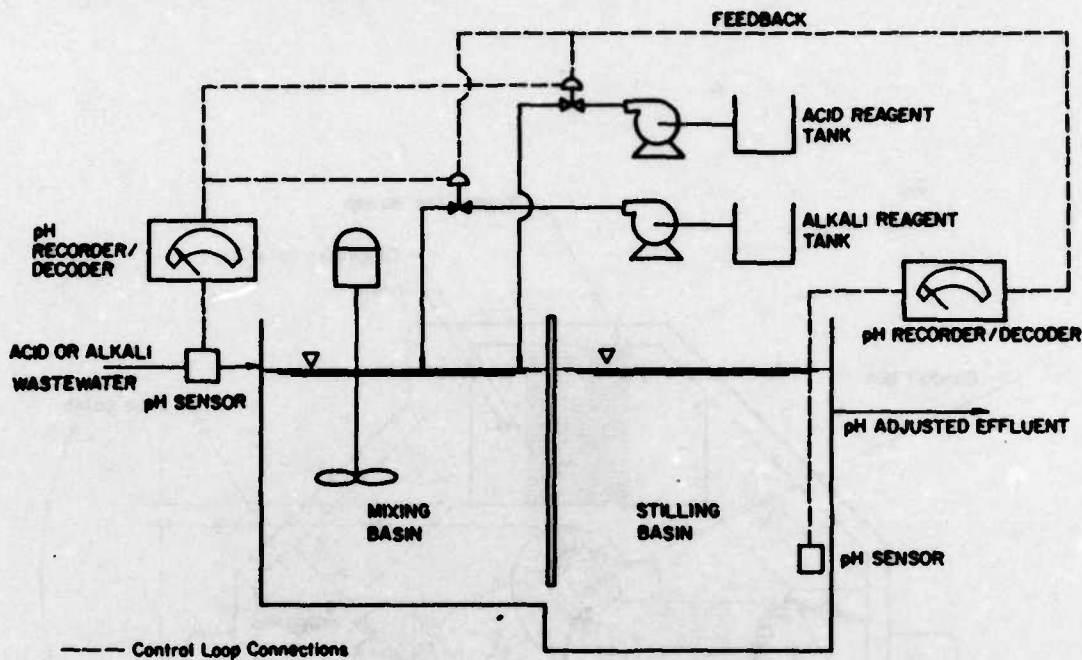


Figure 6-6. Two-sided, one-stage continuous pH adjustment system.

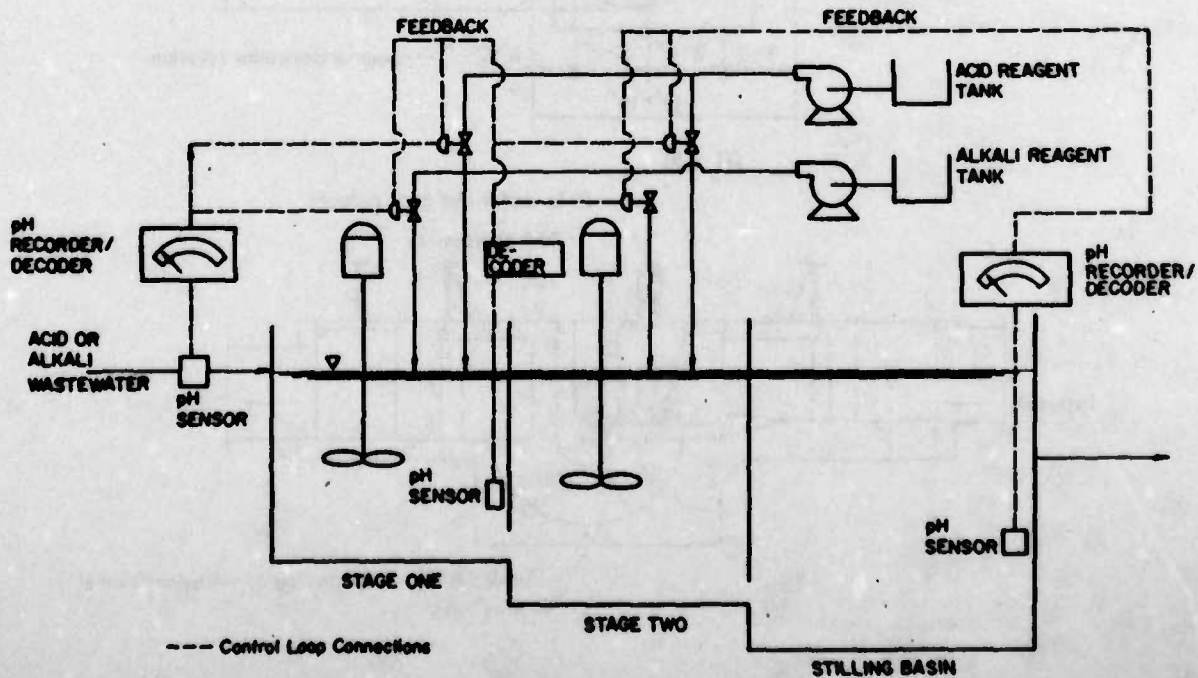


Figure 6-7. Two-sided, two-stage continuous pH adjustment system.

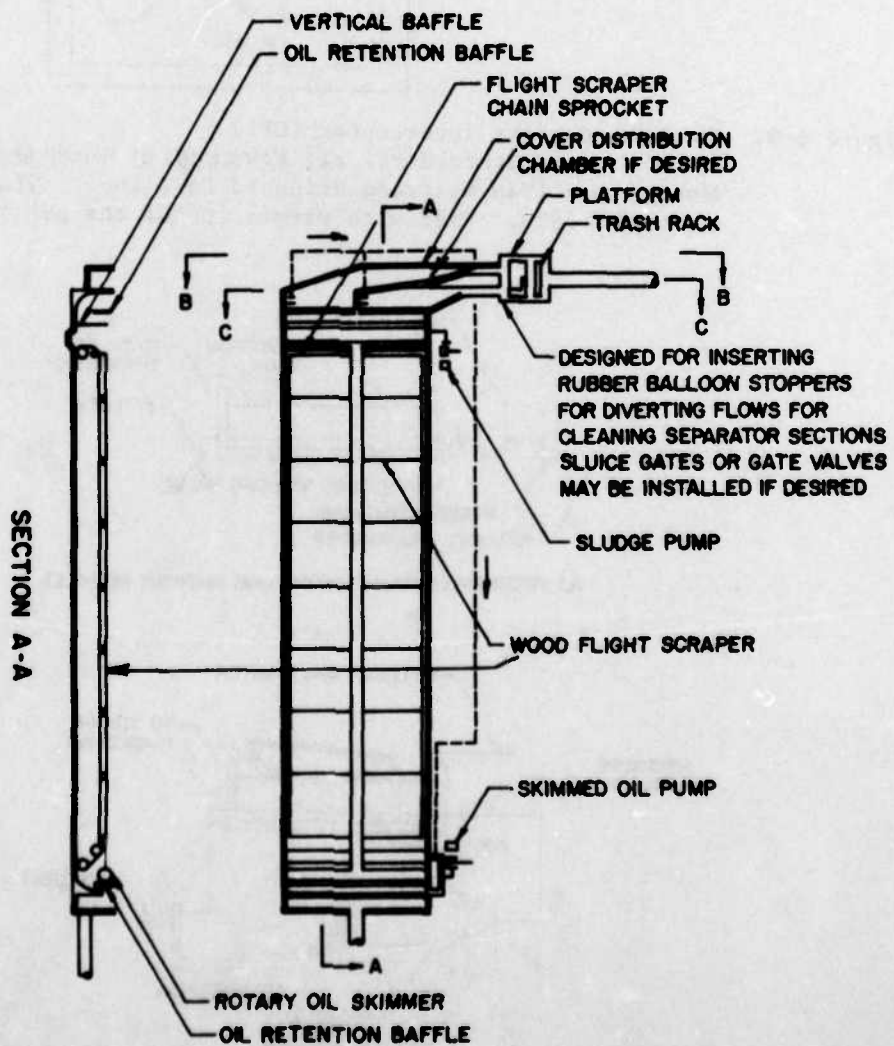


Figure 6-8. Example of general arrangements for API. (From *Manual on Disposal of Refinery Wastes*, Volume on Liquid Wastes, Chapter 6, 1st ed. [American Petroleum Institute, 1969]. Used with permission of the publisher.)

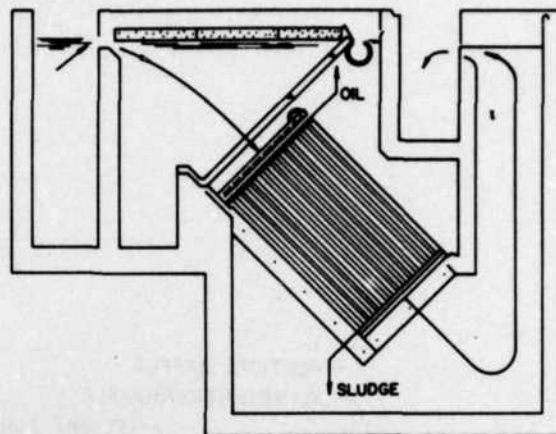
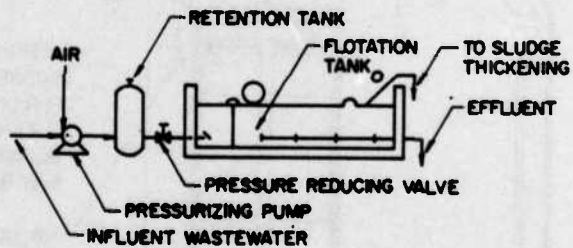
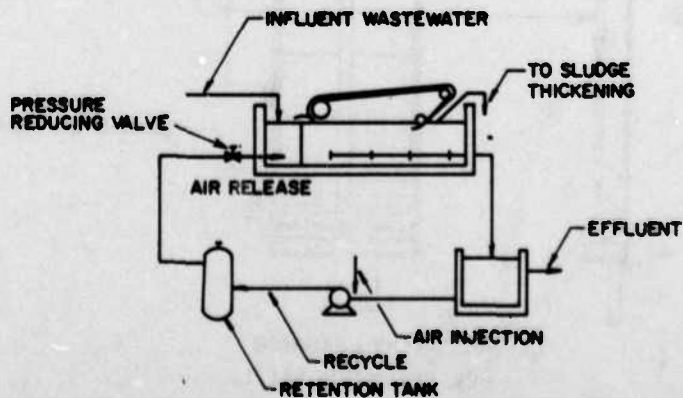


Figure 6-9. Corrugated plate interceptor (CPI)
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 163, copyright 1980. Used with permission of the publisher.)



(a) PRESSURIZED FULL FLOW DAF UNIT (WITHOUT RECYCLE)



(b) PRESSURIZED RECYCLE DAF UNIT

Figure 6-10. Pressurized dissolved air flotation (DAF) systems.
 (From W. W. Eckenfelder, Jr., *Industrial Water Pollution Control*, [McGraw-Hill Book Co., 1966], p 657. Used with permission of the publisher.)

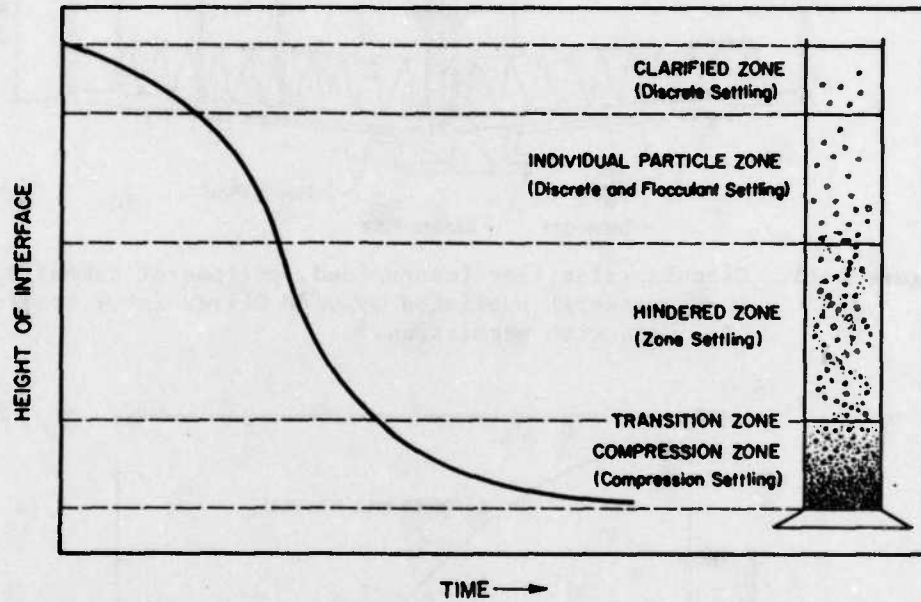


Figure 6-11. Settling zones.

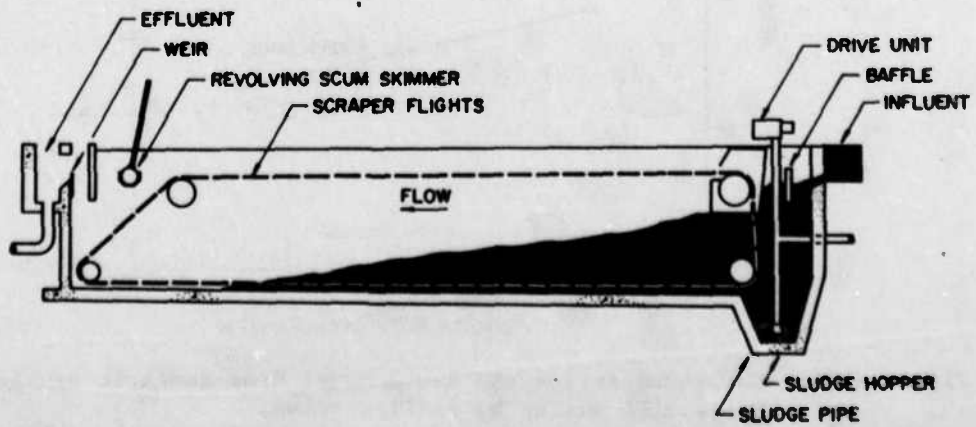


Figure 6-12. Rectangular clarifier.

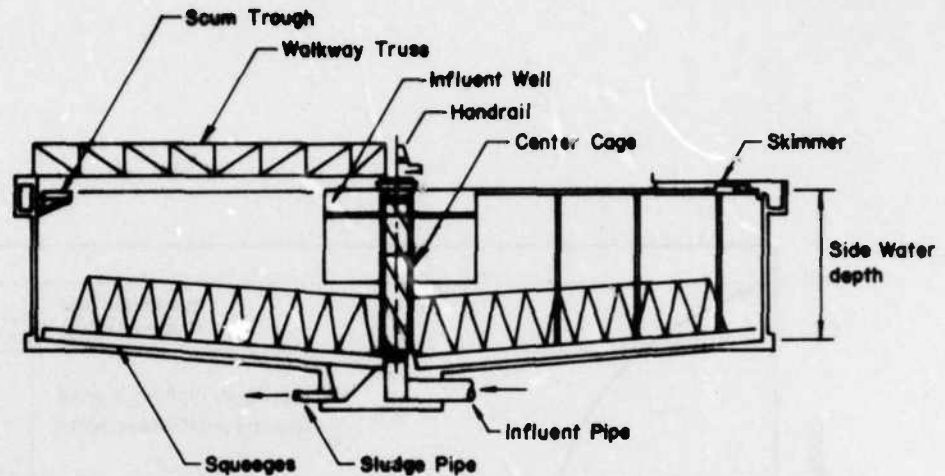


Figure 6-13. Circular clarifier (centerfeed, peripheral takeoff). (From material published by Dorr Oliver Inc., Stamford, CT. Used with permission.)

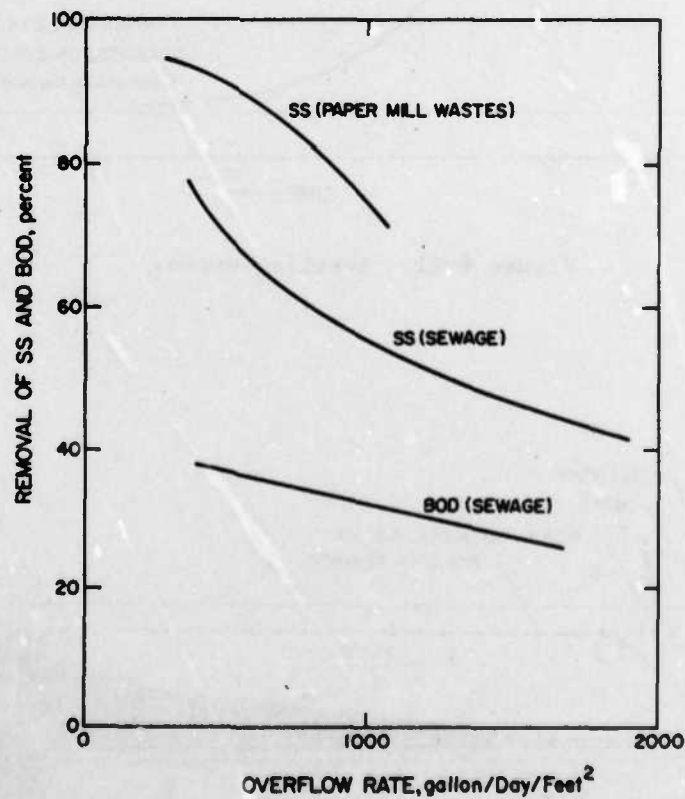


Figure 6-14. Suspended solids and BOD removal from domestic sewage and paper mill wastes by sedimentation. (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 143, copyright 1980. Used with permission of the publisher.)

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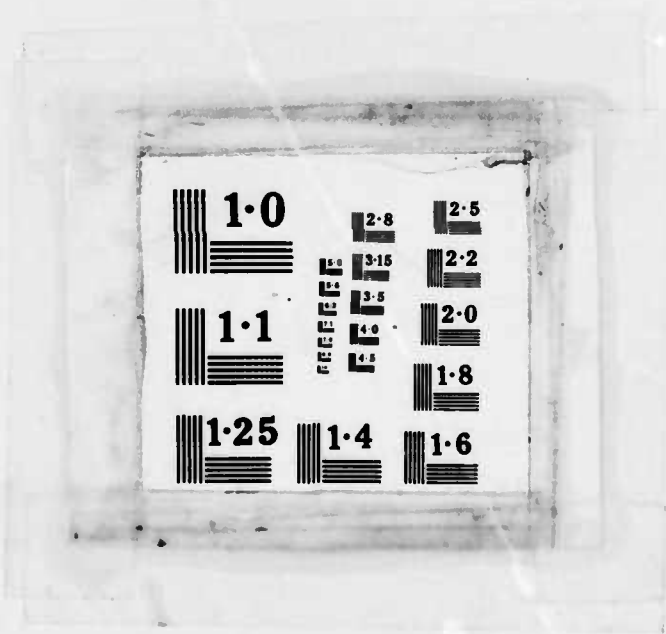
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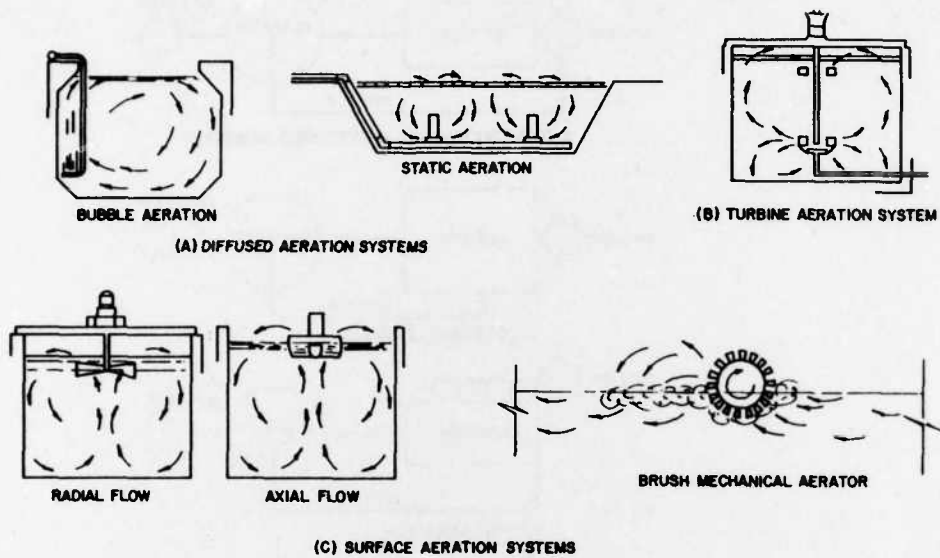


Figure 6-15. Schematics of selected aeration equipment.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 217, copyright 1980. Used with permission of the publisher.)

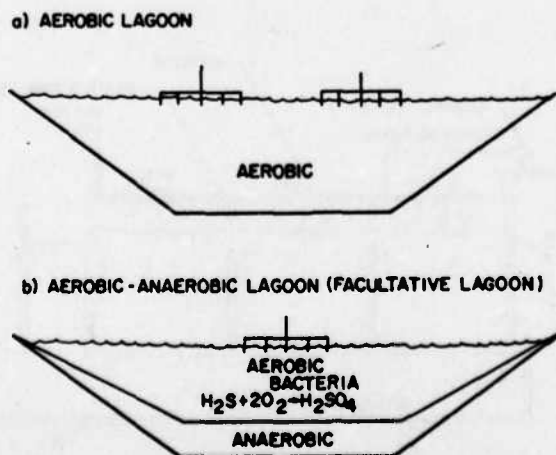


Figure 6-16. Comparison of alternative aerated lagoon systems.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 356, copyright 1980. Used with permission of the publisher.)

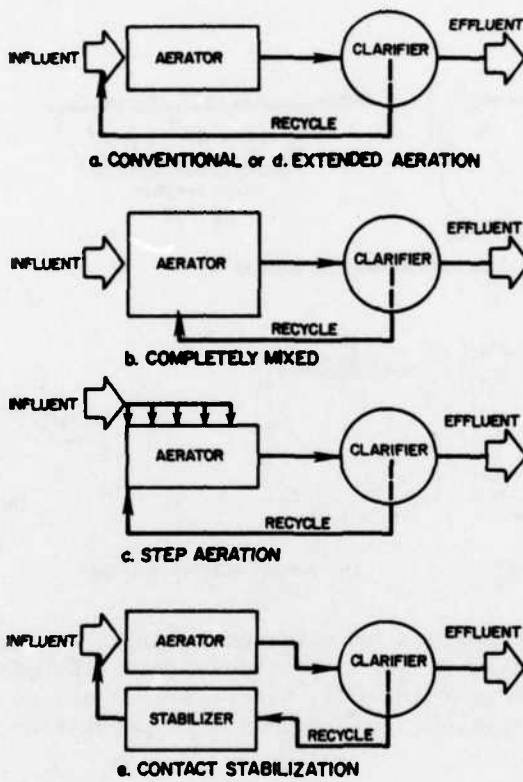


Figure 6-17. Activated sludge systems.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 391, copyright 1980. Used with permission of the publisher.)

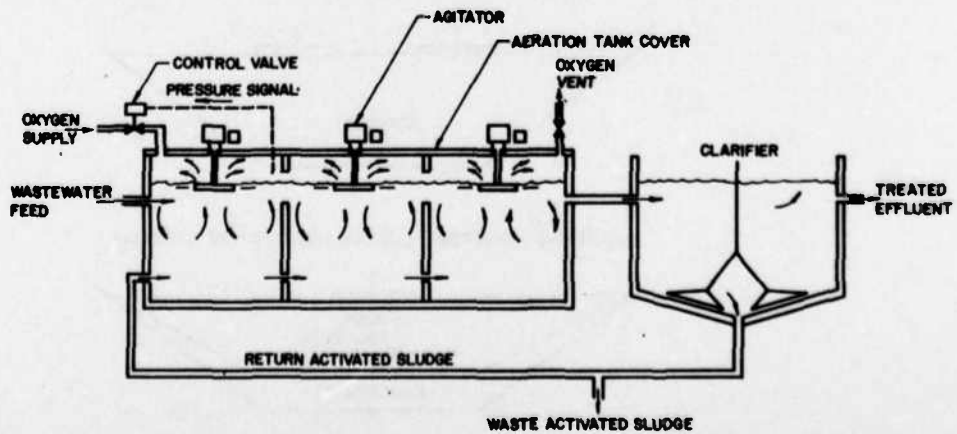


Figure 6-18. Schematic diagram of three-stage pure oxygen system.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 407, copyright 1980. Used with permission of the publisher.)

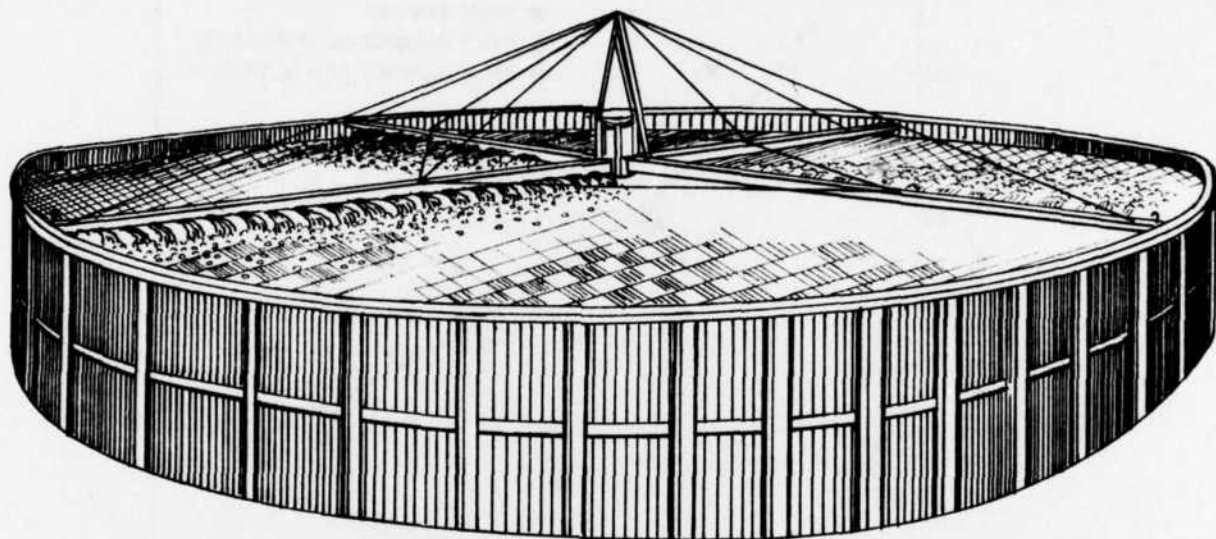


Figure 6-19. Plastic packed trickling filter.

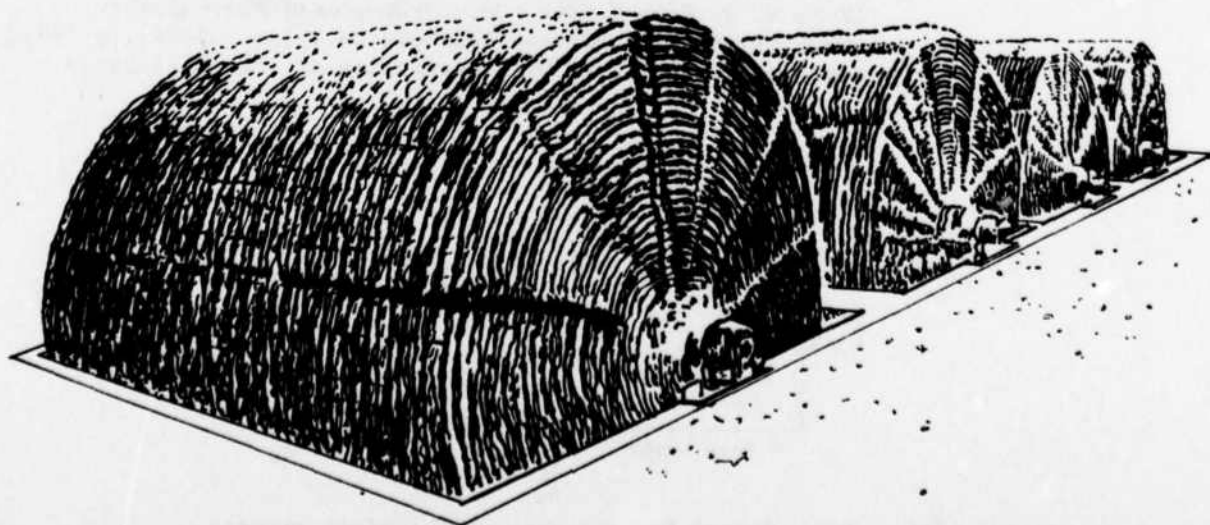


Figure 6-20. Rotating biological contactor.
(From material published by Envirex, Inc., a Rexnord Co.,
Waukesha, WI. Used with permission.)

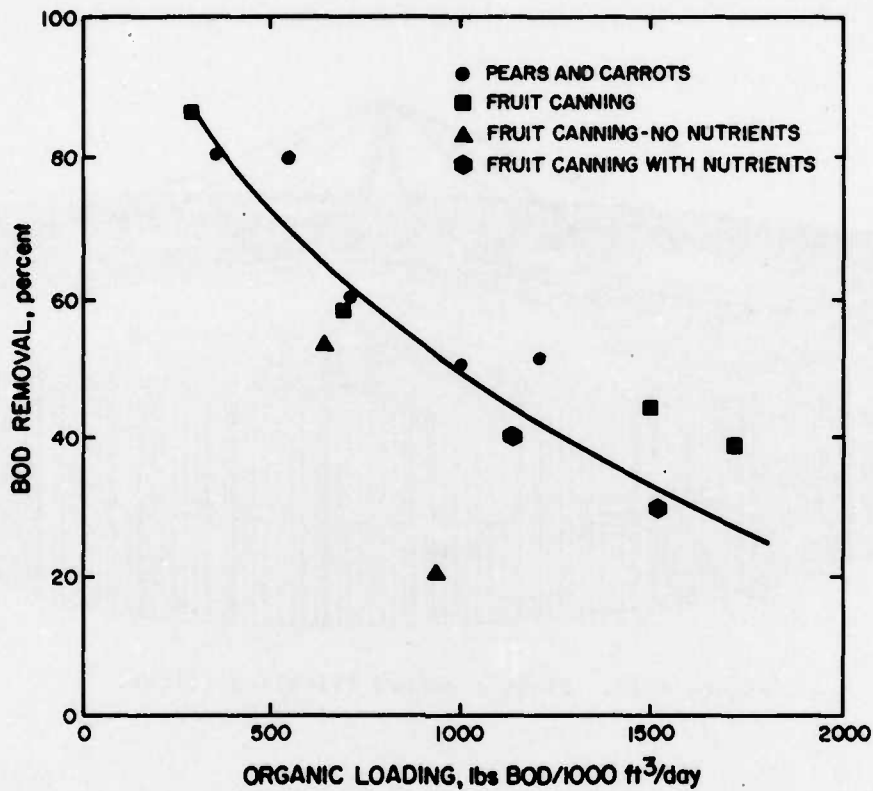


Figure 6-21. Treatment of food processing wastewater on high-rate trickling filter.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 390, copyright 1980. Used with permission of the publisher.)

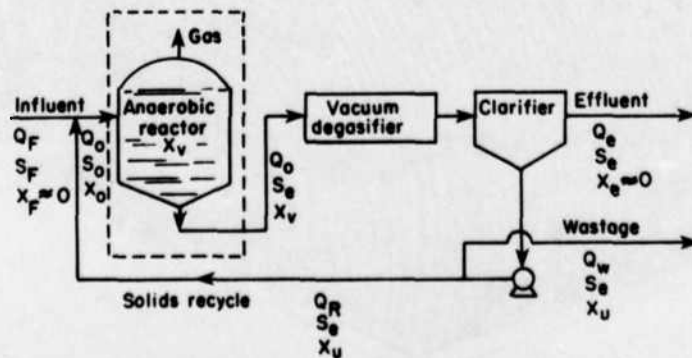


Figure 6-22. Flow diagram for the anaerobic contact process.
 (From R. S. Ramalho, *Introduction to Wastewater Treatment Processes*, 2nd ed. [Academic Press, Inc., 1983], pp 419, 420, 421, 422, 423, 433, copyright 1983. Used with permission of the publisher.)

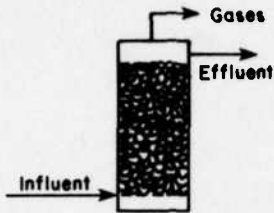


Figure 6-23. Diagram of an anaerobic filter.
 (From R. S. Ramalho, *Introduction to Wastewater Treatment Processes*, 2nd ed. [Academic Press, Inc., 1983], pp 419, 420, 421, 422, 423, 433, copyright 1983. Used with permission of the publisher.)

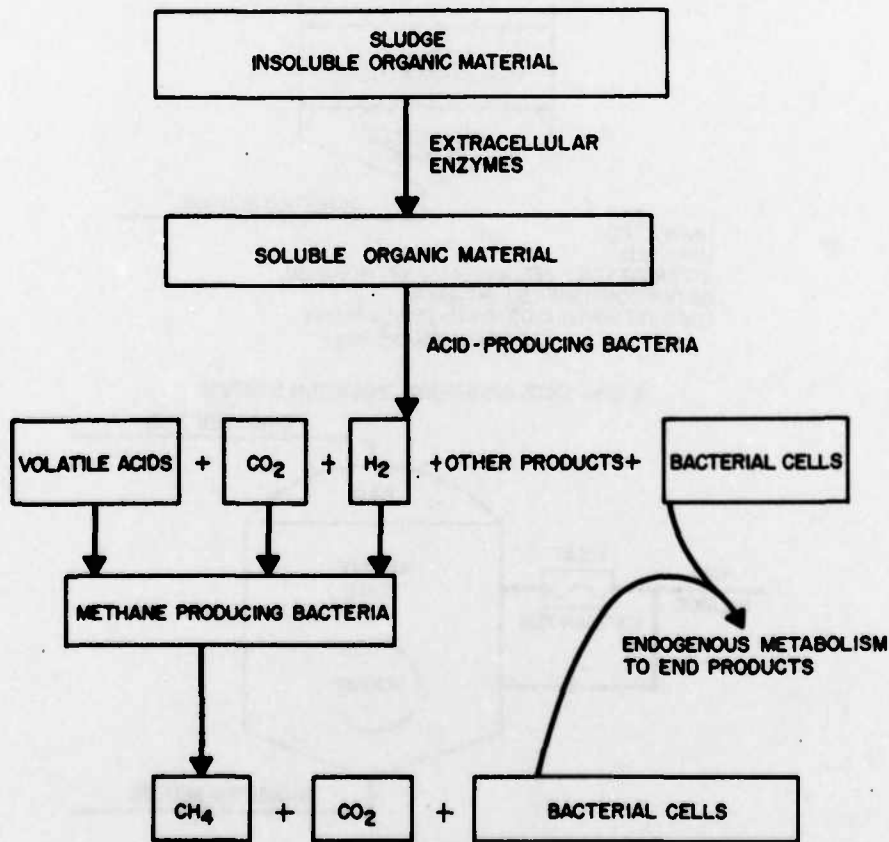
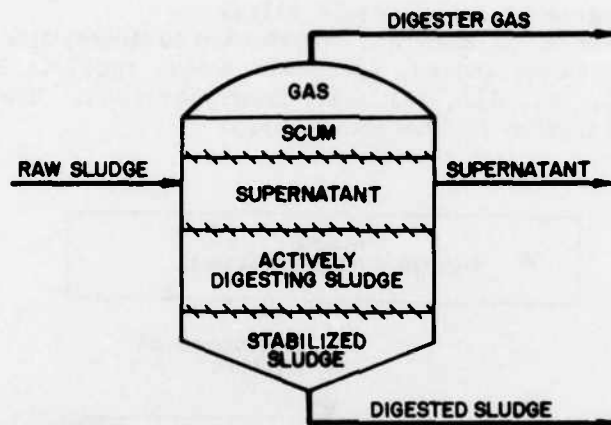
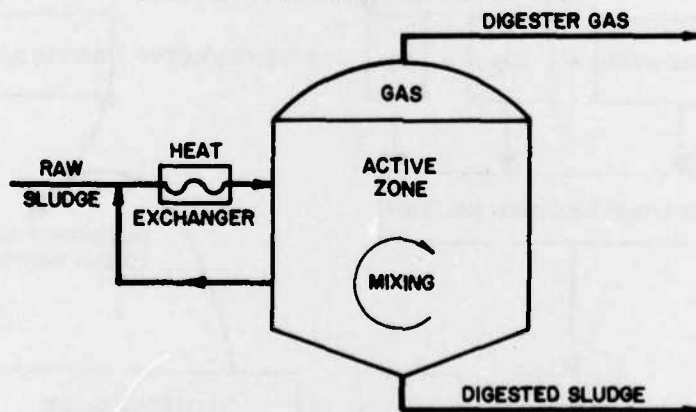


Figure 6-24. Mechanism of anaerobic sludge digestion.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 335, copyright 1980. Used with permission of the publisher.)



UNHEATED
UNMIXED
INTERMITTENT FEEDING AND WITHDRAWAL
DETENTION TIME: 30-60 DAYS
LOADING RATE: 0.03-0.10 lb VSS/cu ft/day
(0.4-1.6 kg VSS/m³/day)

a. LOW-RATE ANAEROBIC DIGESTION SYSTEM



HEATED TO CONSTANT TEMPERATURE
MIXED
CONTINUOUS FEEDING AND WITHDRAWAL
DETENTION TIME: 10-15 DAY MINIMUM
LOADING RATE: 0.10-0.50 lb VSS/cu ft/day
(1.6-8.0 kg VSS/m³/day)

b. SINGLE-STAGE, HIGH-RATE ANAEROBIC DIGESTION SYSTEM

Figure 6-25. Anaerobic digestion systems.

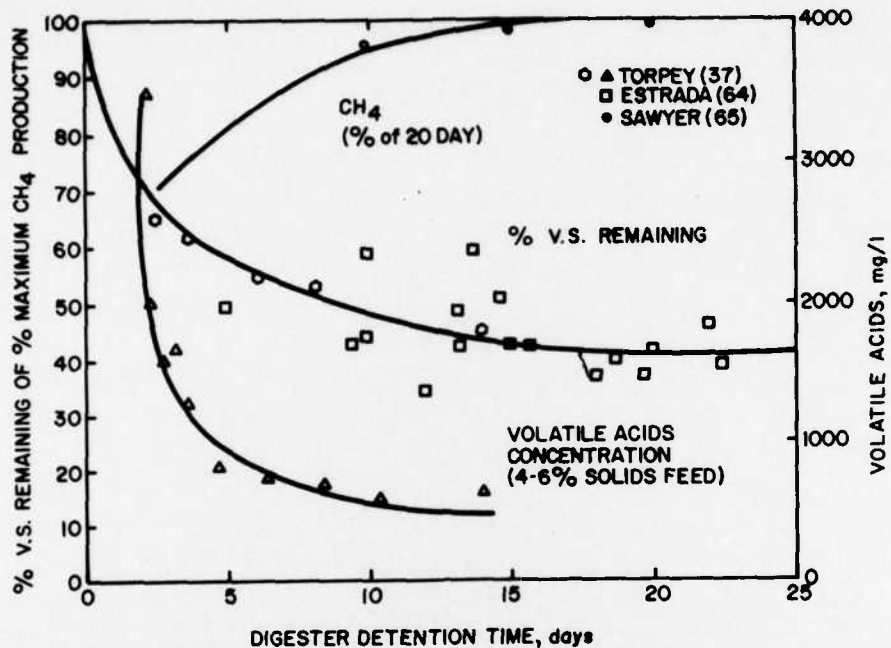


Figure 6-26. High-rate anaerobic digester performance. (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 447, copyright 1980. Used with permission of the publisher.)

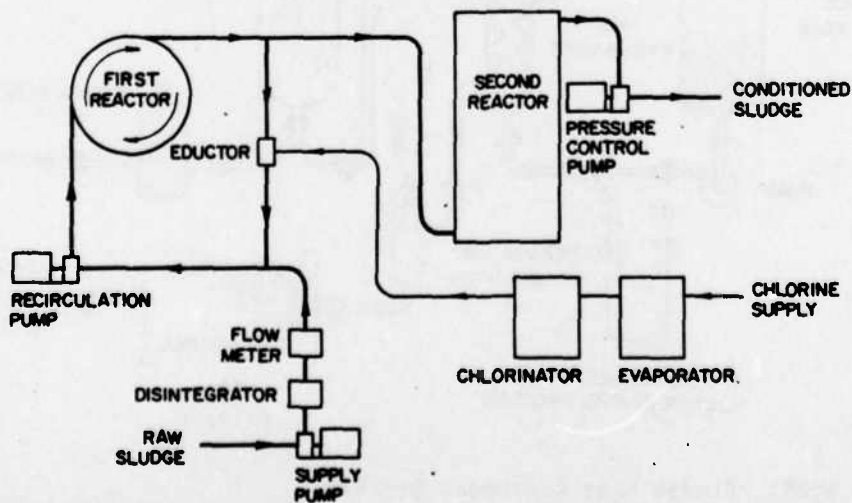


Figure 6-27. Schematic of a chlorine oxidation system.

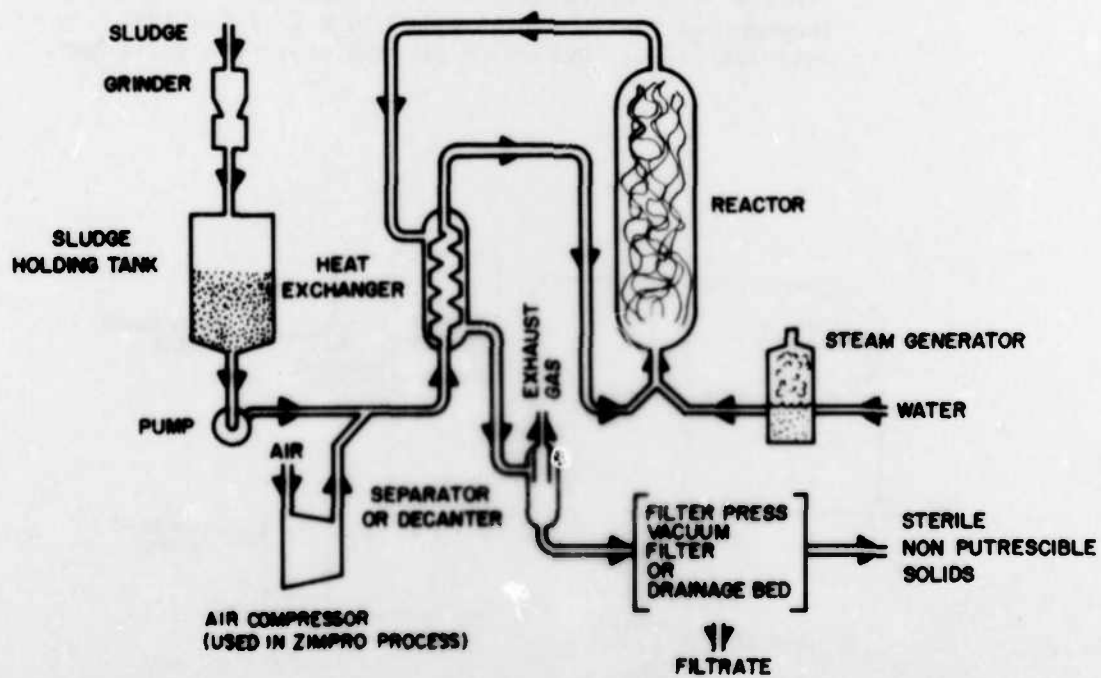
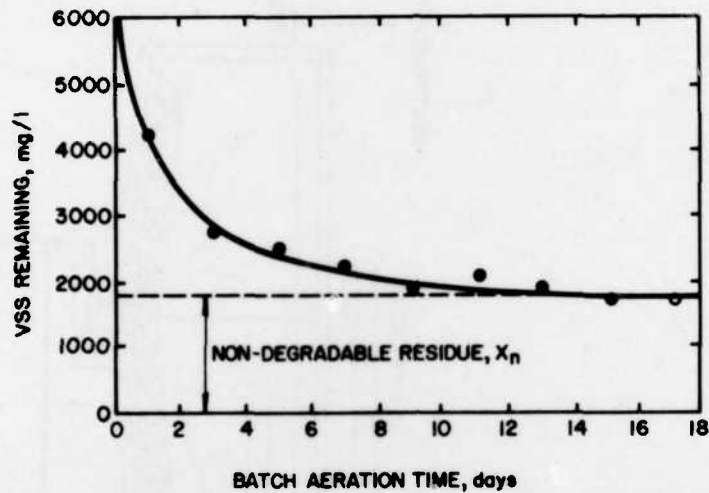
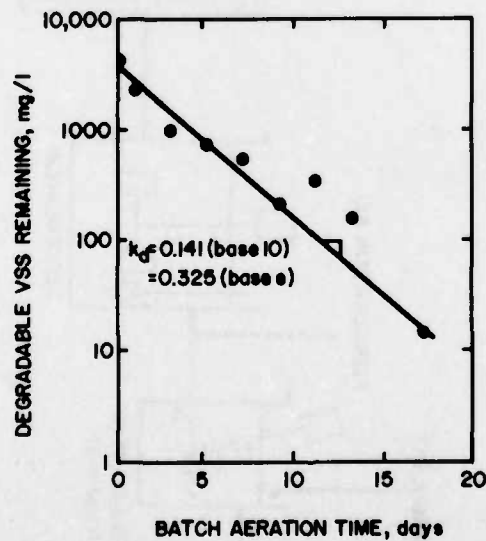


Figure 6-28. Sludge heat treatment process.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], copyright 1980. Used with permission of the publisher.)



(a) CHRONOLOGICAL DESTRUCTION OF VSS IN BATCH REACTOR

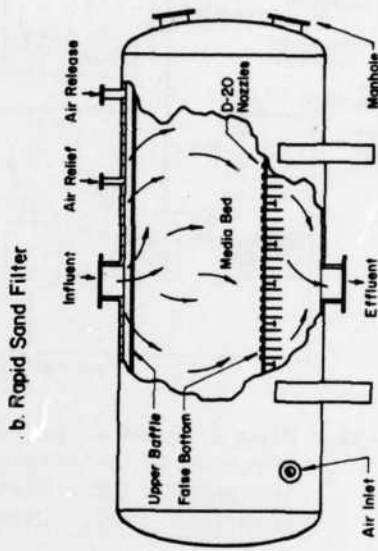
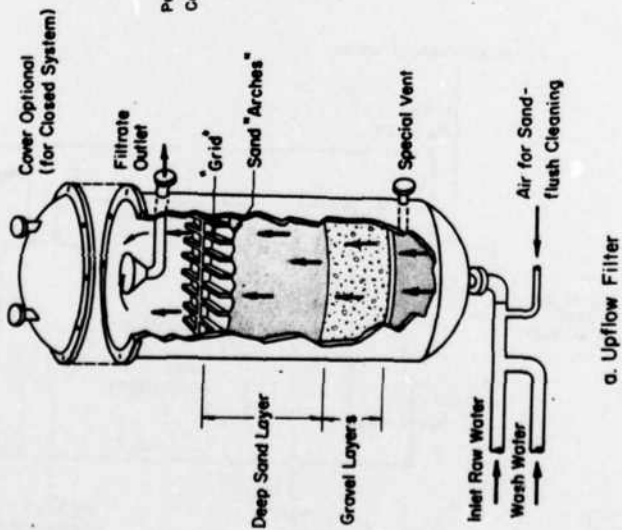
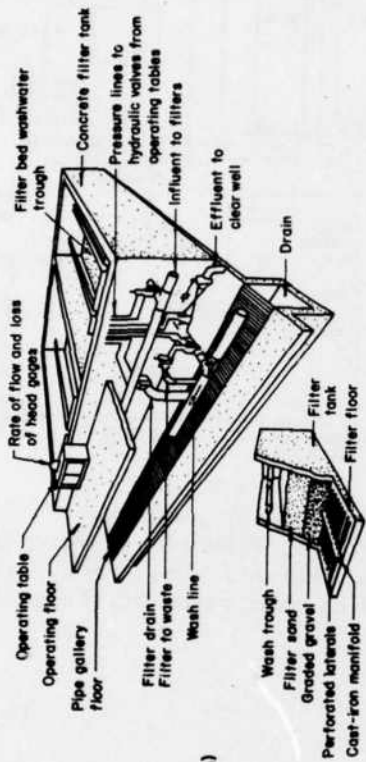


(b) CORRELATION OF DEGRADABLE VSS WITH DETENTION TIME

Figure 6-29. Kinetics of aerobic sludge digestion.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 438, copyright 1980. Used with permission of the publisher.)



Figure 6-30. Three-stage coagulation/flocculation/sedimentation. (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 471, copyright 1980. Used with permission of the publisher.)



c. Horizontal Pressure Filter

Figure 6-31. Typical commercial filtration systems.

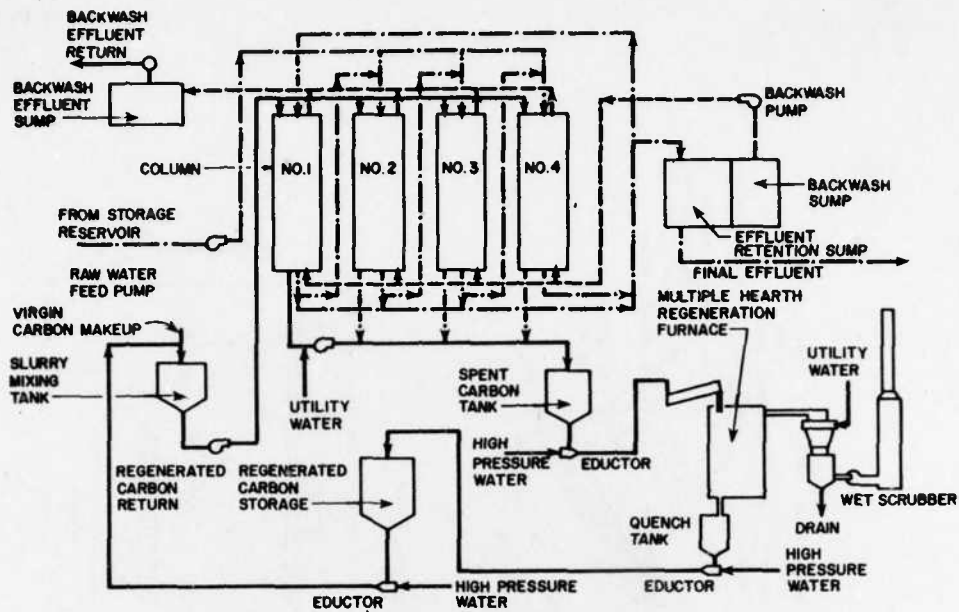


Figure 6-32. Flow diagram of carbon adsorption process.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 525, copyright 1980. Used with permission of the publisher.)

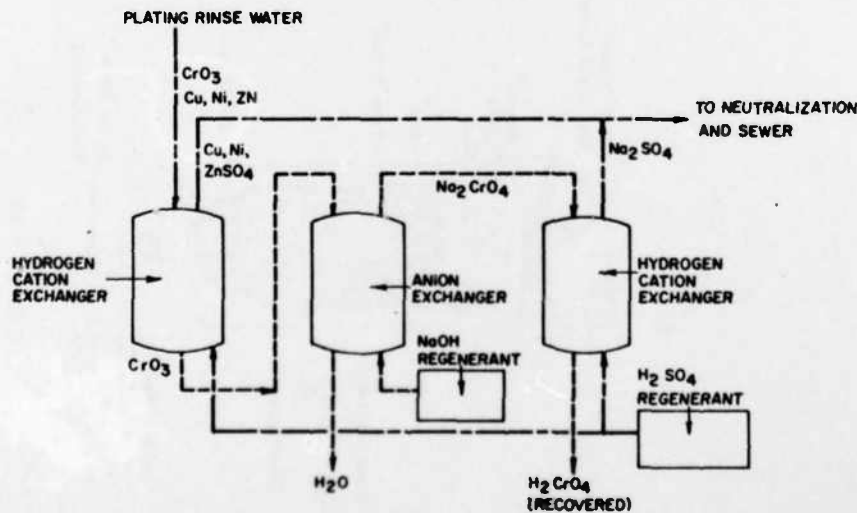


Figure 6-33. Ion exchange flow diagram.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 540, copyright 1980. Used with permission of the publisher.)

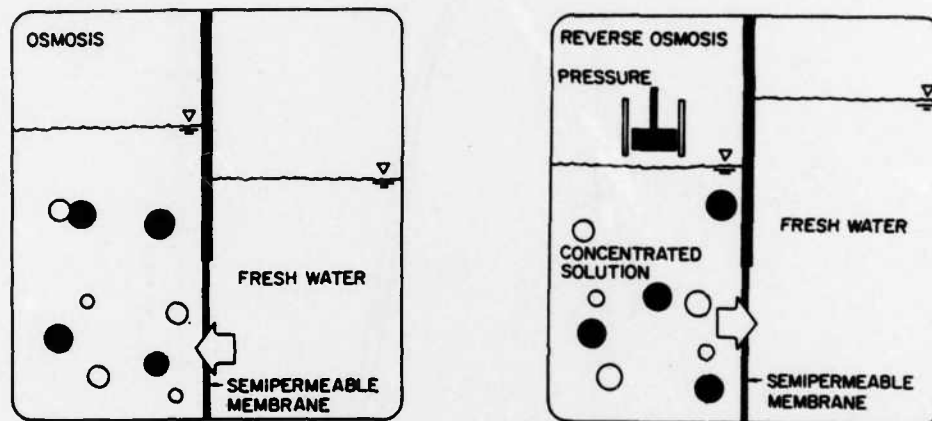


Figure 6-34. Osmosis and reverse osmosis.
 (From S. S. Kramer, "Reverse Osmosis Makes High Quality Water Now," *Environmental Science Technology*, 9:314 [American Chemical Society, 1975]. Used with permission of the publisher.)

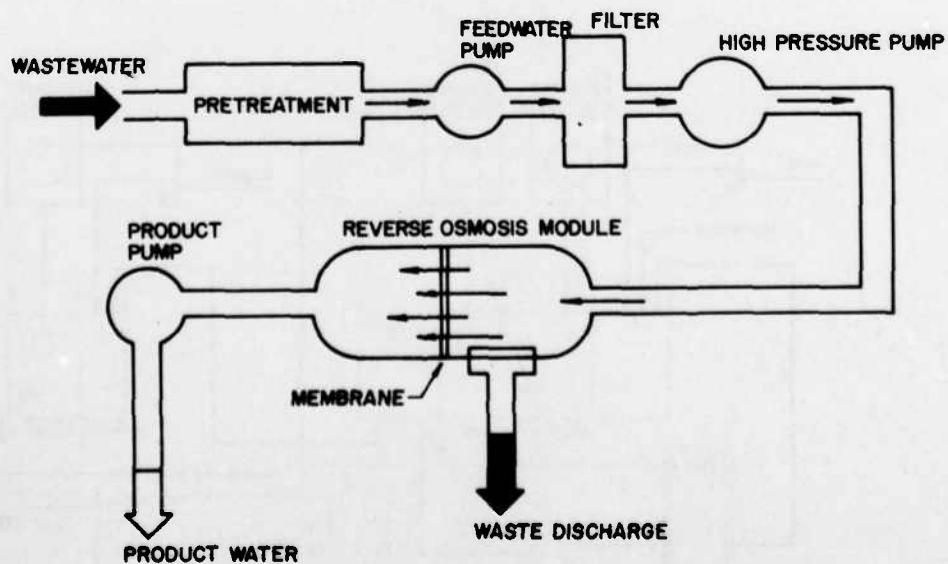


Figure 6-35. Basic reverse osmosis process schematic.
 (From F. J. Agardy, "Membrane Process," *Process Design in Water Quality Engineering*, E. L. Thackston and W. W.

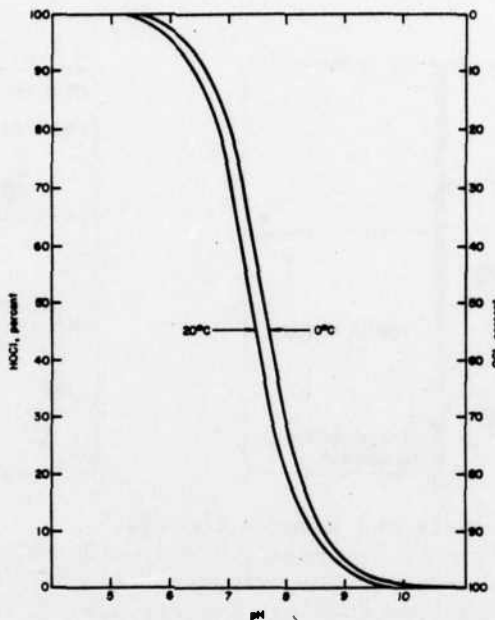


Figure 6-36. Relative amounts of HOCl and OCl at various pH levels. (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 550, copyright 1980. Used with permission of the publisher.)

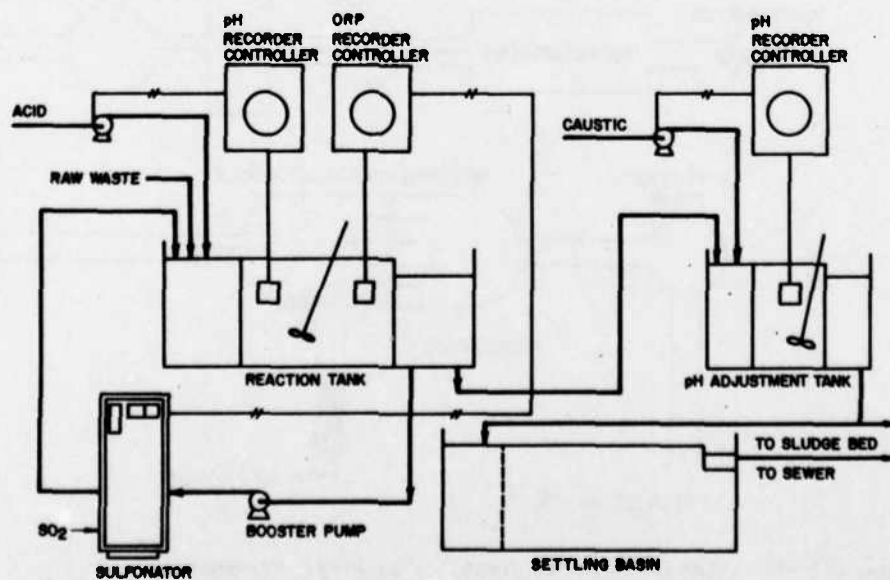


Figure 6-37. Continuous chrome-wastes treatment system. (From material published by Fischer and Porter Co., Warminster, PA. Used with permission of publisher.)

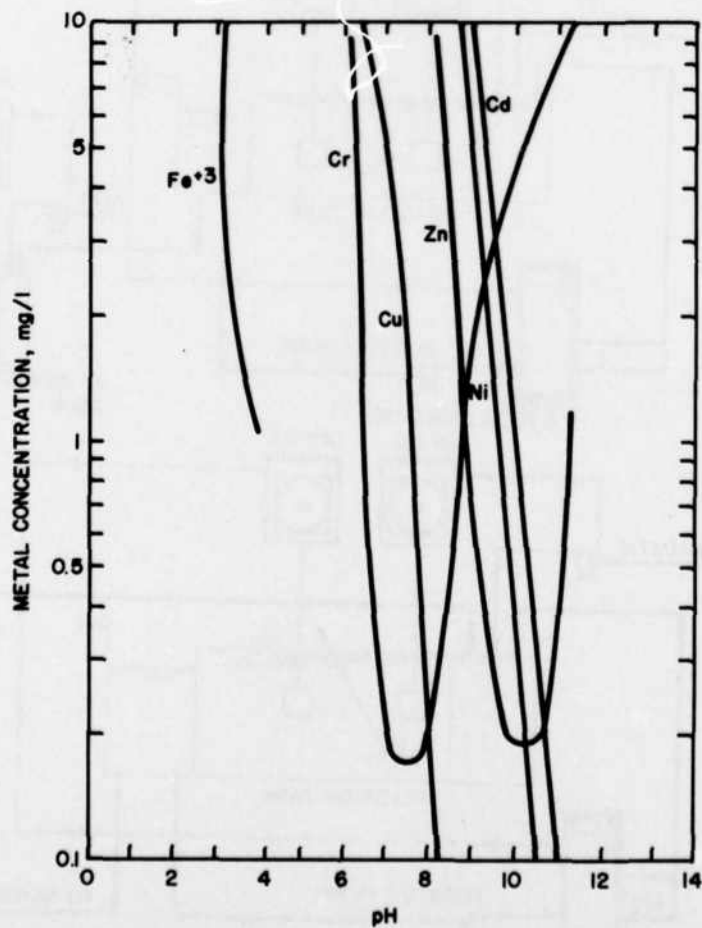


Figure 6-38. Solubility of metals versus pH
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 480, copyright 1980. Used with permission of the publisher.)

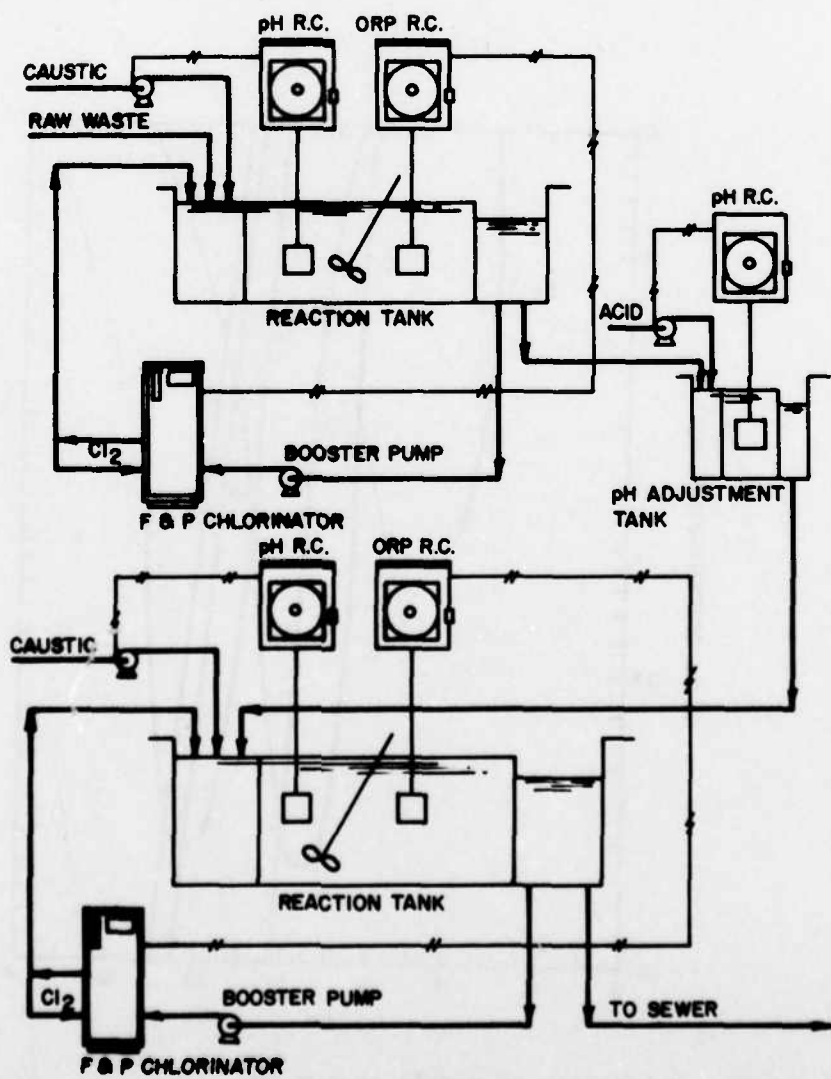


Figure 6-39. Continuous cyanide treatment system.
 (From material published by Fischer and Porter Co.,
 Warminster, PA. Used with permission of the publisher.)

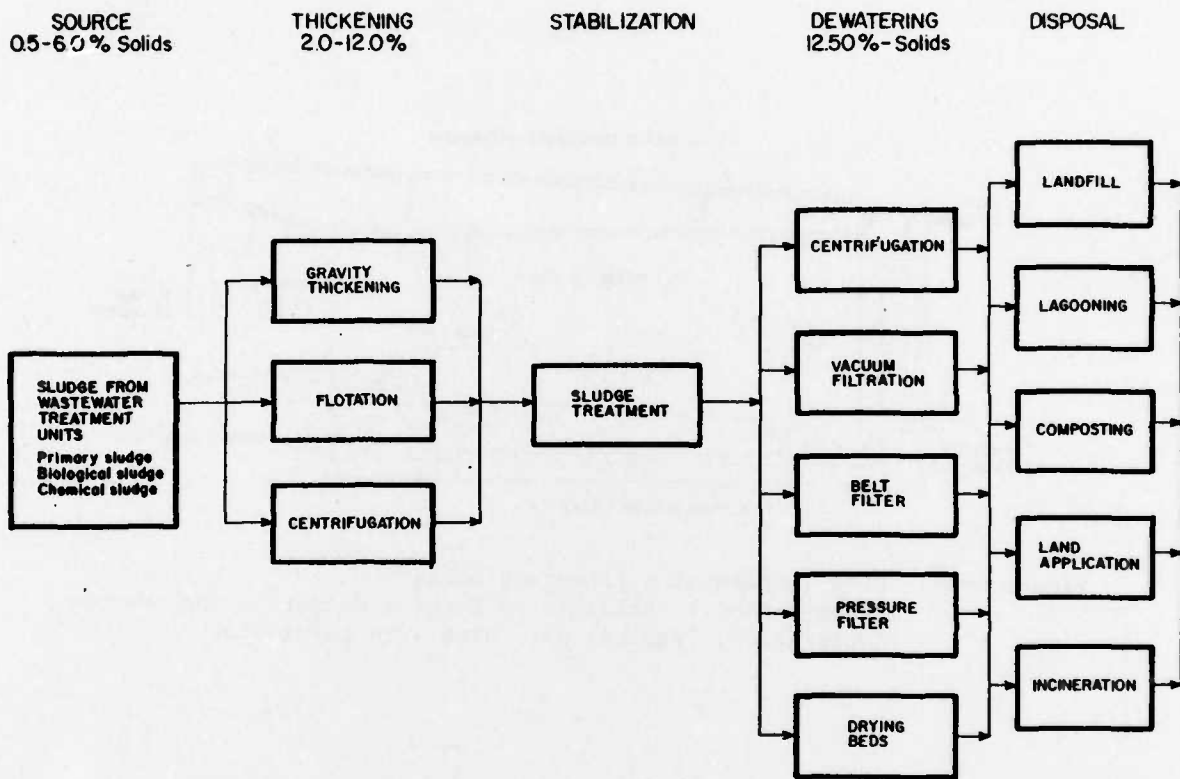


Figure 6-40. Sludge handling and disposal processes.

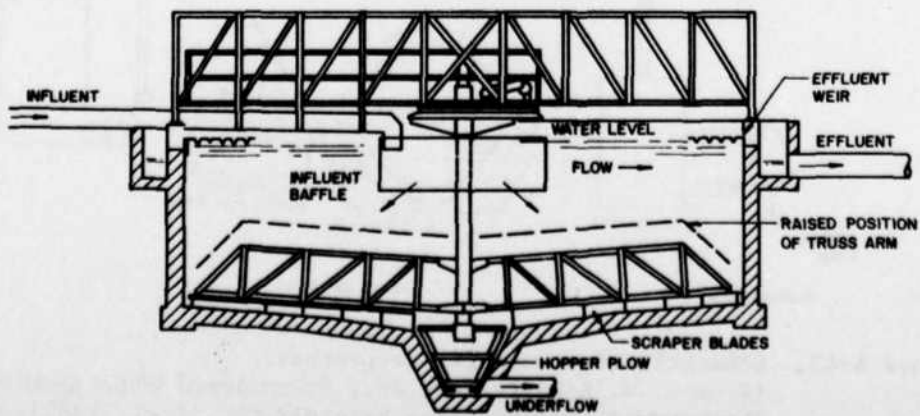


Figure 6-41. Gravity thickener.

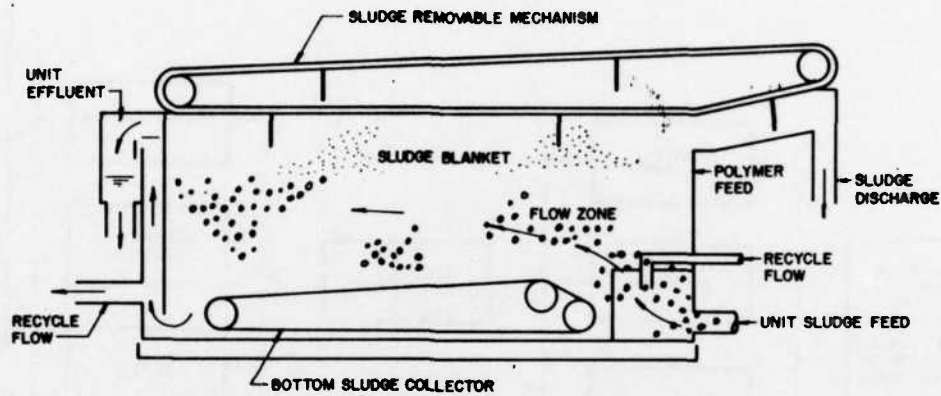


Figure 6-42. Flow diagram of a flotation unit.
 (From material published by Kombine Sanderson Engineering Corporation, Peapock, NJ. Used with permission.)

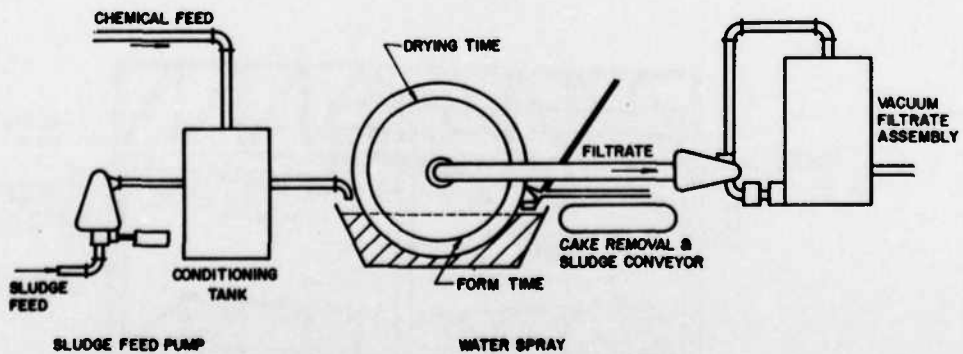


Figure 6-43. Schematic of vacuum filter process.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 618, copyright 1980. Used with permission of the publisher.)

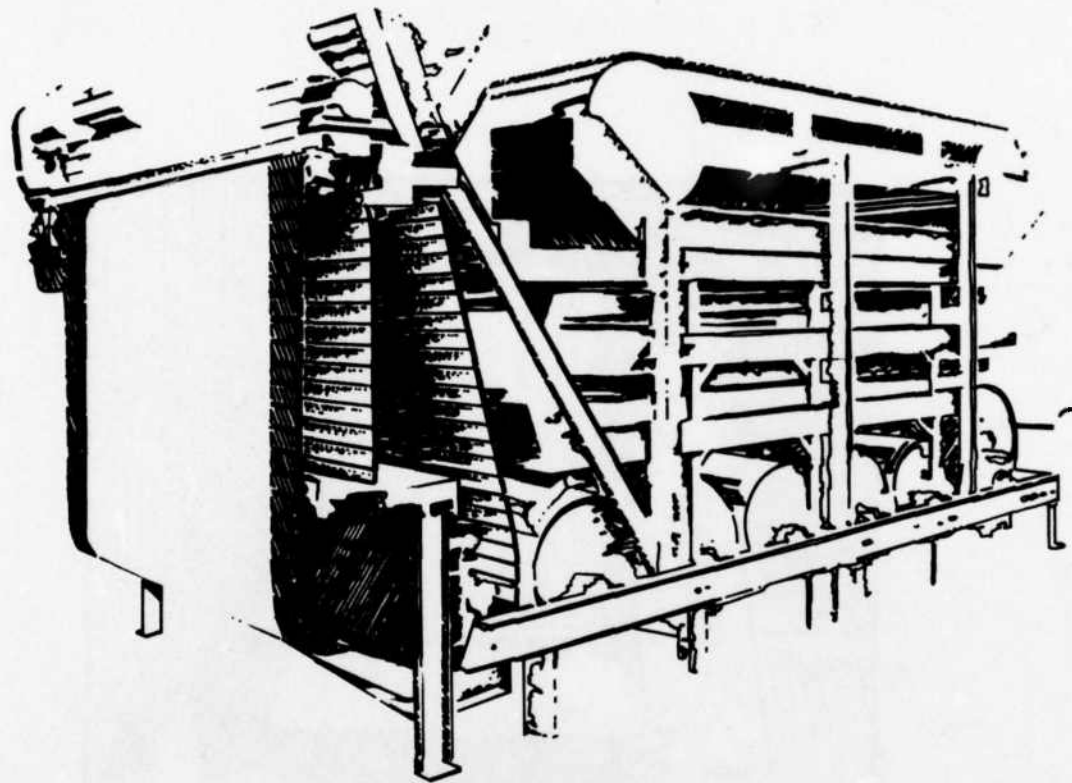


Figure 6-44. Typical belt filter.

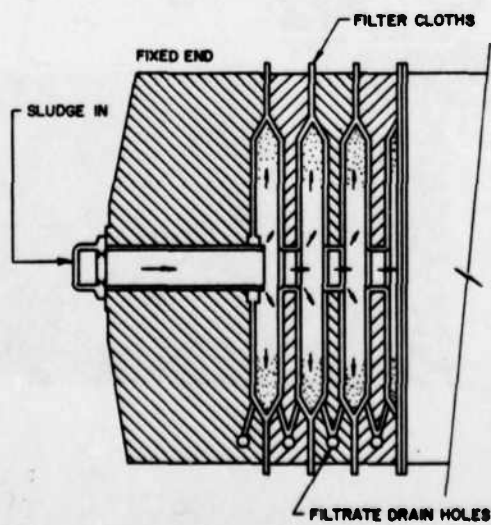


Figure 6-45. Cutaway view of a filter press.

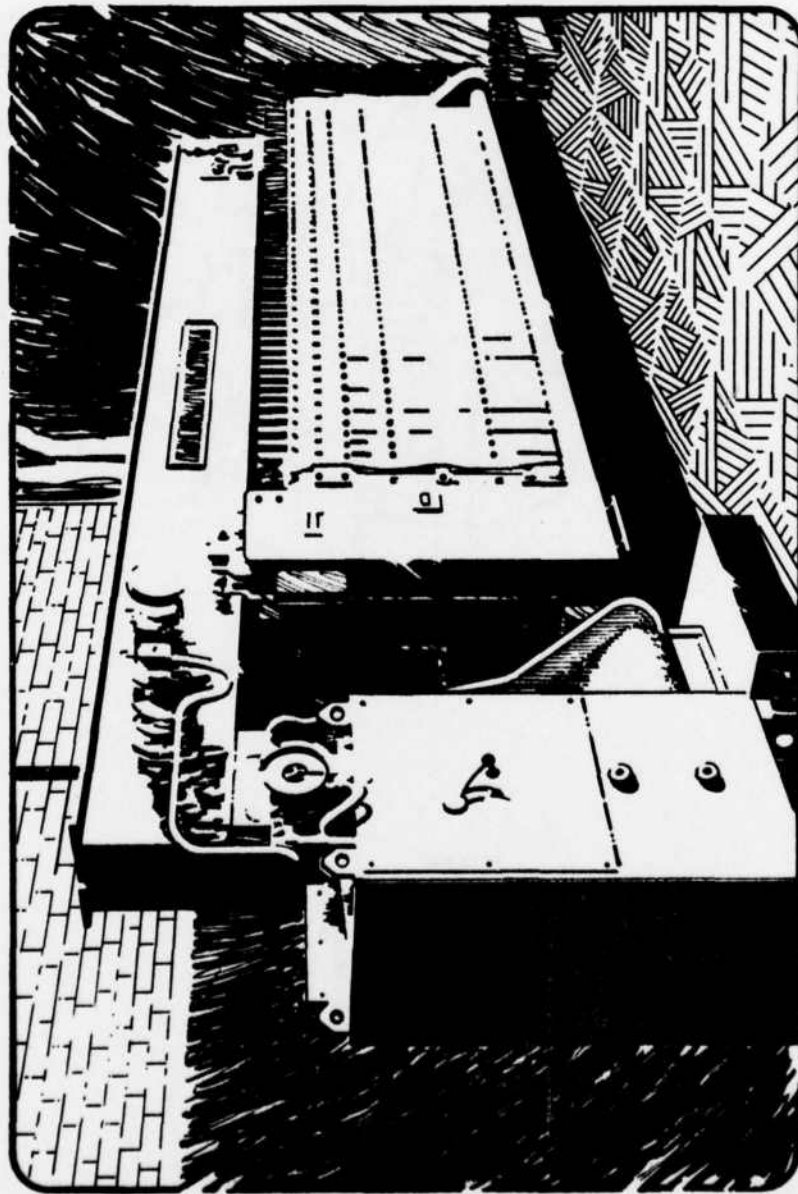


Figure 6-46. Typical filter press.
(From W. W. Eckenfelder, Jr., Principles of Water Quality Management [Van Nostrand Reinhold Co., Inc., 1980], p 633, copyright 1980. Used with permission of the publisher.)

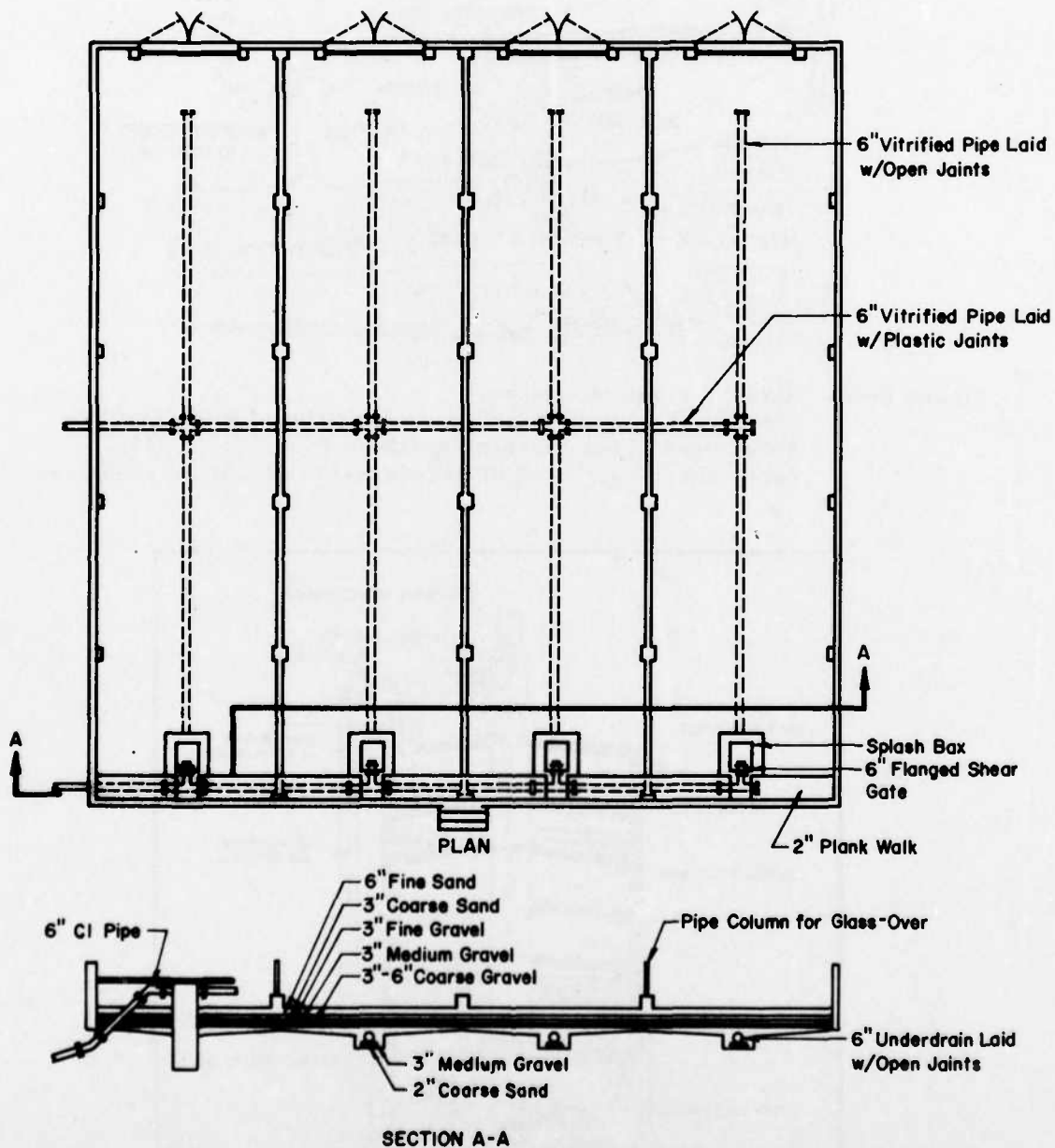


Figure 6-47. Plan and section of a typical sludge drying bed.
 (From Metcalf and Eddy, Inc., Wastewater Engineering: Collection, Treatment, Disposal [McGraw-Hill Book Co., 1972]. Used with permission.)

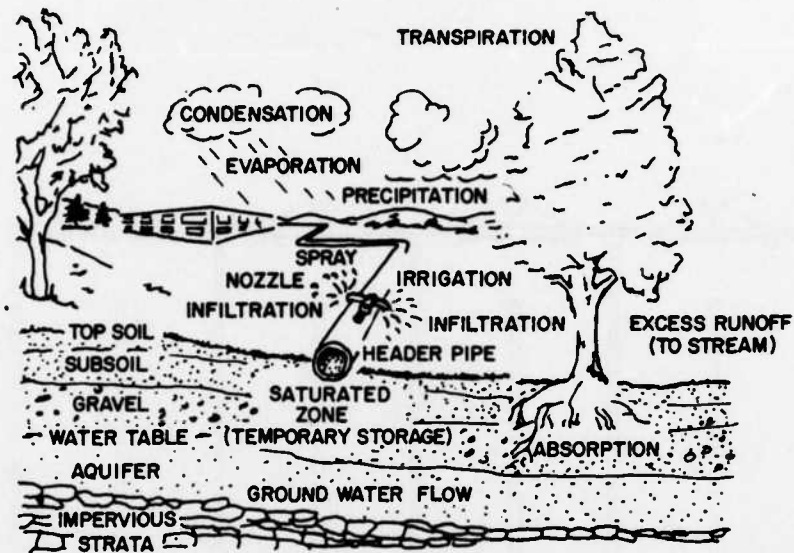


Figure 6-48. Spray irrigation system.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], copyright 1980. Used with permission of the publisher.)

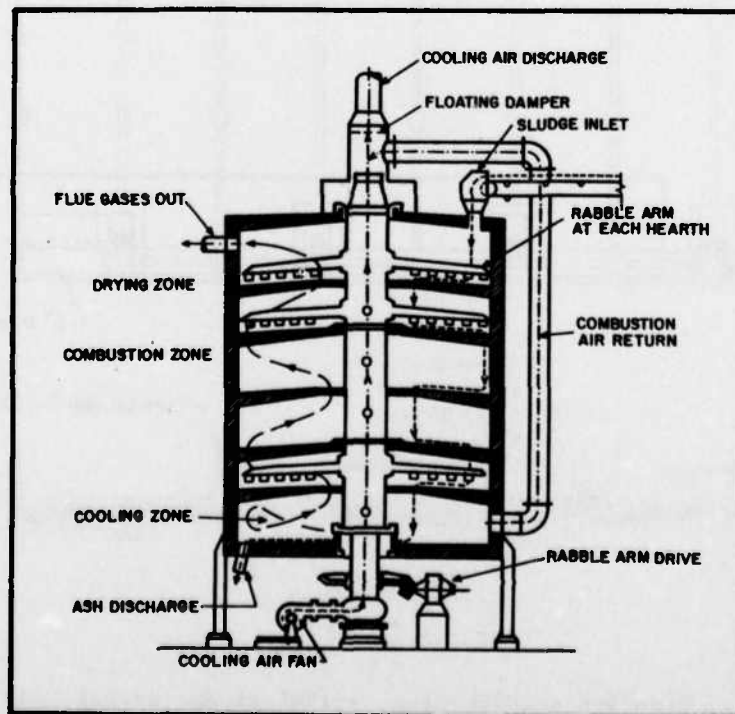


Figure 6-49. Cross-section of a typical multiple-hearth incinerator.
 (From W. W. Eckenfelder, Jr., *Principles of Water Quality Management* [Van Nostrand Reinhold Co., Inc., 1980], p 651, copyright 1980. Used with permission of the publisher.)

Chapter 7

Solution Development Methodology

7-1. Abatement philosophies

Two approaches or abatement philosophies are commonly used for industrial waste problems: end-of-pipe control and in-plant control. End-of-pipe control usually involves collecting all wastes into one wastestream and designing treatment processes to remove the undesirable portions. In-plant control involves handling wastes at their source, either by modifying the source or by removing undesirable portions while they are most concentrated. Often, the most attractive solution will be a combination of both philosophies.

a. In-plant control. In-plant control techniques are usually geared toward a single source. Each solution must be handled on a case-by-case basis. In general, in-plant control consists of one or more of the following: segregation, recirculation and recycling, disposal of concentrated residuals, pretreatment, reduction in volume or waste load, or process modification.

(1) Segregation. Segregation means isolating certain wastestreams from others. It usually involves controlling how wastes are collected. Often, segregation is the key to in-plant control because each source may have to be surveyed. Segregation may be needed before any other in-plant controls can be used. Segregation may be undesirable when two complementary streams are separated. For example, when an acidic and basic streams are segregated, pH adjustment problems may increase. Also, warm and cold streams are sometimes better treated when combined due to temperature effects on treatment efficiency. A nutrient-containing wastestream is desirable in a mixture of predominantly carbonaceous waste and should not be segregated.

(2) Water recirculation and recycling. This is the reuse of wastewaters. Recirculation and recycling may require some form of local treatment. In multi-process industrial complexes, it is often possible to develop a cascade approach to wastewater reuse. Developing this type of approach requires evaluating both requisite process water quality and process-specific contamination. Then occasions for using effluent from one process as raw water for another can be evaluated. This strategy can be further enhanced by implementing specific contaminant treatment systems for process waste streams. A typical application of this approach might be use of a chrome electroplating rinse water as chrome plating air pollution scrubber makeup. This would reduce water demand by eliminating two waste streams (rinse water and scrubber blowdown); it would also recover the chrome both from the rinse tanks and the aerosols collected in the wet scrubber system.

(3) Disposal of concentrated residuals. Sometimes, industrial wastes can be gathered in a semi-dry or otherwise concentrated state and recovered for reuse or separate disposal. This practice can reduce the pollution load or eliminate toxic or hazardous materials. Also, some of these residuals can be sold.

(4) Pretreatment. Before discharge to the main collection system, isolated wastestreams may be treated locally for specific constituents. In a vehicle maintenance area, such pretreatment is possible by installing an oil/water separator on the sewer which collects floor washings. Table 7-1 lists several pretreatment processes.

(5) Reduction in volume or waste load by better housekeeping. Most industrial processes result in unnecessary dumping to sewers. Needless flushing of spilled materials, emptying of old or used containers, running of unused hoses, and leaking of worn equipment are all examples where reduction can be effective. Good housekeeping practices, proper management, adequate supervision, and common sense can often reduce waste discharges. Reduction techniques can be very effective when an end-of-pipe treatment facility is heavily loaded or overloaded. Both the volume and quantity of material being disposed must be considered when setting priorities for reducing industrial wastes entering the sewer.

(6) Process modification. A frequently overlooked control method is modifying the waste-generating operation. This can be done by either changing or replacing the equipment or materials used. Equipment modification could involve repair, renovation, or replacement of existing machinery. Replacing chemicals and materials with ones that cause less pollution can also be a significant in-plant control.

(7) Examples. The use of centralized vehicle wash facilities is a good example of in-plant control. The centralized wash facility is used by many tactical and industrial operations and employs water conservation by treatment and recycle of washwater. Segregation is done in a covered, centralized wash facility which isolates washwater from storm runoff, vehicle maintenance activities which generate oily wastes and any other incompatible wastewater source. Recycling and pretreatment are done by collecting washwater, passing it through an intermittent sand filter, chlorinating it, and storing it for reuse. The volume of washwater can be minimized by automated wash equipment designed specifically for the facility and by using automatic shut-off nozzles on all wash hoses. Process substitution can be done with detergents that are readily biodegradable and effective at low concentrations. Table 7-1 gives another example of an in-plant control approach. Using in-plant control, a chemical plant reduced BOD waste load by 33 percent and flow by 25 percent. Process modification and segregation for special disposal played key roles in attaining the reduction. The in-plant controls decreased the size of the end-of-pipe treatment facility required.

b. End-of-pipe control. An end-of-pipe pollution control method means treating discharges from many operations after these wastes have been combined in a common sewer. End-of-pipe control usually addresses removal of a large variety of wastewater constituents. Many processes can be used in a treatment sequence to obtain an acceptable discharge quality. From a management point of view, this approach is best, since all operations are done in a single, central location. Technologically, however, the end-of-pipe alternative may pose severe treatment problems, because the number of pollutants and the wastewater characteristics vary.

c. Factors for consideration. Any abatement policy should be chosen carefully because it can greatly affect the cost and complexity of the control techniques used. Many factors must be considered in developing an abatement strategy.

(1) The nature of the industrial wastes should be recognized. Some wastes are readily amenable to in-plant control, while others may be treated equally well at end-of-pipe facilities. In-plant control of a source could greatly affect requirements for end-of-pipe treatment. A waste survey defines the waste characteristics and is useful in determining how to approach controlling the various waste sources.

(2) The potential impact of the waste on the environment and on sewer and treatment unit construction materials should be examined. A highly toxic or corrosive waste would best be handled by some in-plant control that would neutralize its hazardous

properties before discharge to the sewer system and end-of-pipe treatment. For example, spent battery acid could easily be neutralized at the source and rendered harmless to pipes and concrete. Left untreated, it could severely damage these structures.

(3) The location of the waste source is another key factor. Waste sources that are close together in confined quarters are not easily controlled in-plant because adding equipment or changing piping in congested areas is difficult. End-of-pipe treatment generally requires more land area and a collection system to bring the wastes to the treatment units.

(4) Operation and maintenance of the control system is very important. Few treatment systems can operate continually without routine maintenance. In-plant control units can usually be operated and maintained by the regular staff. However, end-of-pipe treatments often require specialized operators and routine scheduled maintenance.

(5) Installation and operating cost is a very important factor in choosing an abatement policy. From a life-cycle cost analysis approach, in-plant control can often be justified because of lower capital costs and less intensive operational requirements. However, the cost and complexity of any solutions should always be considered. When all factors are considered, the most logical abatement philosophy may be an approach which combines both in-plant and end-of-pipe control principles. Policies should be assessed before programs to develop solutions have started.

7-2. Disposal alternatives

A major factor in solving an industrial waste problem is how the treated wastewater will be disposed. Very often, there is more than one disposal alternative, and the engineer must choose the most suitable one. There are six general disposal alternatives for industrial wastewaters: discharge to a domestic wastewater treatment plant; dilution in surface waters, including fresh water and ocean disposal; land disposal; deep well injection; evaporation; and reuse.

a. Discharge to a domestic wastewater treatment plant. Army installations may be located in or near a civilian community which owns a treatment plant, or they may have their own treatment system for domestic wastes. In both cases, the industrial wastewater may be discharged to the existing plant for treatment with the domestic wastewater. Design and operation of domestic or municipal treatment works typically differ from that of industrial waste treatment facilities. Although some industrial wastes are compatible with municipal plants, special consideration is needed before requesting a discharge permit or entering into a contract for combined treatment. For combined treatment of domestic and industrial waste to be fully successful, only compatible industrial waste can be discharged. Non-compatible materials must either be treated before discharge (pretreated) or eliminated. There are national industry-based limitations and specific prohibitions for industrial users of municipal plants. Normally, municipal plants develop a comprehensive sewer use ordinance or industrial user permit system to protect the combined wastewater treatment facility. Before proceeding with combined treatment, the wastestream components, or operational situations which could upset municipal facilities, including the wastewater conveyance system, must be identified and controlled.

(1) Impact of industrial wastewaters on domestic wastewater treatment systems. Assuming that the domestic wastewater treatment plant can handle the additional hydraulic, organic, nitrogen, and suspended solids loading from the industrial discharge

and that the plant is operated and maintained properly, most industrial wastes can be treated effectively in the combined facility. However, noncompatible materials which can result in hazards to life, damage the sewage system, upset or reduce plant performance, or cause adverse changes in municipal plant sludge characteristics must be pretreated. Noncompatible industrial discharges can be identified based on physical and chemical wastewater parameters which damage or make the sewage treatment facilities inoperative. Some parameters may also damage the collection system or upset the treatment plant performance. For example, industrial discharges can reduce the biochemical reaction rates or decrease the sludge settling velocity for biological treatment systems. Municipal plants are not built or operated to deal effectively with complex and varied industrial compounds. Sludge-handling problems commonly result from poor settleability and dewaterability of combined industrial/municipal sludges. Also, toxic compounds, such as heavy metals, may render the municipal plant's sludge unacceptable for common disposal methods and require special incineration systems or hazardous waste landfills. Industrial wastes may vary much more than municipal wastes. Variations in the amount or type of waste generated can greatly affect municipal plant operation and performance. Batch processes or changes in production methods result in organic, hydraulic, and toxic loading variations which municipal systems have difficulty anticipating and responding to. Industrial waste spills and sludge discharges, such as during washdowns, often cause upsets.

(2) Pretreatment control technologies.

(a) The applicable pretreatment control technologies can be defined only after a complete assessment of the industrial waste characteristics, discharge limitations, and alternative generation and treatment techniques. Besides end-of-pipe treatment, in-plant control should be considered. Sometimes, the non-compatible waste component can be eliminated by process changes in the production method. Production or maintenance schedules can often be adjusted to minimize discharges or reduce the impact on municipal plants during process modifications. Table 7-2 gives examples of in-plant and end-of-pipe techniques for potentially noncompatible discharges. Consideration must be given to the industrial waste generation rate and how it relates to municipal plant operation; this is especially true when the industrial waste is a significant portion of the total hydraulic or organic loading.

(b) Selection of the pretreatment control technology should also consider reducing the amount and concentration of compatible pollutants. Such consideration can often greatly reduce sewer use and the surcharge cost for industrial discharges. Sometimes, installing simple aerated lagoon or anaerobic pretreatment systems can provide large savings. Biological systems can also be used to reduce waste loads discharged to a physical-chemical treatment system (which may not be able to remove the industrial organics satisfactorily).

(c) Many control technologies are used for industrial pretreatment. The most commonly used physical/chemical pretreatment methods are screening, emulsion breaking, oil/water separation, sedimentation, equalization, and neutralization. The most commonly used biological pretreatment methods are aerated lagoons, rough trickling filters, and rotating biological contactors.

(d) Some pretreatment methods used at Army installations before discharge to municipal sewers are: screens used for lint collection in laundries; oil/water separators for removal of oil and grease from washrack wastes; sedimentation of solids from washrack wastes; and gravity separation of oils and wastes from motor pool maintenance facilities.

b. Discharge to surface waterways

(1) Discharge of industrial wastewater to surface waterways is the most common ultimate disposal method. Both the location of discharge point and the type of dispersal mechanism are important for protecting water quality. A properly designed subsurface dispersal system will allow full use of the receiving water's assimilative capacity.

(2) Federal, State and local governments have restricted wastewater discharge quality to control the adverse effects of contaminants. These restrictions may require a certain type of treatment system, or they may specify concentration limits on certain parameters, regardless of the treatment system used. Typically, the quality of the receiving stream or body of water is considered, along with the intended use of the water after the discharge. Each state has classified its major streams and bodies of water. Table 7-3 lists some typical classifications. Water quality regulations are being revised. Thus, specific regulations should be obtained from the responsible regulatory agency before making a decision.

(3) Oxygen-depleting compounds are primarily soluble organics and fixed nitrogen compounds; their discharge could greatly damage the receiving stream. "Oxygen Sag Curves" have been developed to show the relationship between oxygen content in the stream and the distance or time the discharge has traveled downstream. Two major factors which determine the curve's shape are the rate of decrease of BOD and the natural stream reaeration capabilities. Figure 7-1 is a hypothetical oxygen sag curve which also provides theoretical values for these two major factors. A more complex version of this analysis can be used to consider nitrification and carbonaceous reactions simultaneously. The effects of oxygen depletion on aquatic life can be drastic. If dissolved oxygen (DO) decreases too much, the stream will not be fit for higher forms of life. Fish and many large aquatic life-forms will disappear. The stream population will change from a variety of relatively advanced species to a large population of fairly simple species which can live in low DO conditions. As natural reaeration gradually overcomes the effects of oxygen depletion, the oxygen content will increase. Given enough time, the DO should reach predischARGE levels, and the previous stream population will return. Figure 7-2 shows the population changes resulting from changes in DO content as the water travels from the point of wastewater discharge.

(4) Toxic materials and heavy metals such as cadmium, lead, mercury, and zinc may greatly inhibit or kill organisms in the receiving waters. Many of these substances may concentrate in aquatic organisms. Small concentrations in the stream can be stored and concentrated in aquatic animals (bioaccumulation) to extremely high levels; they may eventually be passed to man through the food chain. This type of toxic migration has occurred for several toxic compounds such as polychlorinated biphenyls (PCBs) and DDT.

(5) Color and turbidity reduce light penetration of the water. This decreases both the rate of photosynthesis and the stream population of algae and aquatic plants. This reduces food supply for animals, possibly causing growth inhibitions or death of higher forms of life.

(6) When present at too high a concentration, nutrients cause algal blooms, in which algae reproduce very quickly, covering water surfaces with large floating colonies. Although algae produce oxygen in sunlight by photosynthesis, they also use oxygen for respiration. Therefore, at night, algae are an additional oxygen sink. Dying and decomposing algae also consume large quantities of dissolved oxygen.

(7) Oil and floating materials are aesthetically undesirable; they are typically high in BOD and may suffocate aquatic life by blanketing gills, leaves, and other oxygen transfer surfaces. Floating substances may also have a capping effect on the stream, decreasing or destroying the stream's natural reaeration abilities.

(8) Acids and alkalis may shock receiving streams if the waste's pH differs enough from the stream's pH. Most localities require that discharges to natural waters be neutralized to within a pH range of 6.0 to 9.0. Some restrictions are even stricter.

(9) Substances which cause atmospheric odors, such as sulfides and mercaptans, are aesthetically unappealing and should be eliminated before discharge.

(10) Suspended solids produce many damaging effects. These include an increase in turbidity and its associated problems. The high organic content of some suspended solids greatly increases the water's BOD and depletes oxygen. Sedimentation causes solids to collect on the bottom of a receiving body of water. This sludge bank may alter the habitat of the bottom-dwelling (benthic) organisms enough to decrease or kill off some species. Biological activity within the sludge bank may also produce gases which lift masses of decomposing sludge to the surface; this causes an unsightly and bad-smelling problem.

(11) Discharge of wastewaters that are much warmer than the receiving stream may raise the stream's temperature. This will decrease the dissolved oxygen content, since gases are less soluble in warmer water. Increased biological activity typical of higher temperatures also further speeds up oxygen depletion.

c. Discharge to oceans

(1) Within environmental constraints, either barge transport or an outfall pipe can be used for ocean disposal of industrial wastes. The former is primarily used to dispose of low-volume concentrated wastewater; the latter is better for large volumes of diluted wastewater.

(2) A rational approach to developing an ocean outfall solution for a particular waste should include the following steps:

(a) Define the beneficial uses of the marine waters at the disposal site and its vicinity. These may include commercial fishing, marine recreation, navigation, fishery propagation and migration, and industrial use.

(b) Define the water quality criteria pertinent to the relevant beneficial uses. Areas of concern include public health, aesthetic nuisances, toxicity to marine biota, stimulation of planktonic blooms, and oxygen depletion.

(c) Define the oceanographic characteristics of the disposal site. This includes water circulation patterns, currents and dispersion, density and temperature profiles, and submarine topography.

(d) Evaluate the regulatory posture relative to ocean disposal quality criteria.

(3) The main objective in designing an ocean outfall is to enhance wastewater dilution in marine waters. This is done by installing a multiple port diffuser through which wastewater is discharged. The wastewater jets get energy from the diffuser and rise to the ocean surface because of density differences. Along their path, the jets are

progressively diluted with ambient seawater. Called "initial dilution," it depends mostly on the depth of sea at the discharge point. Typical values of initial dilution range from 10 to 100.

(4) The wastewater plume which forms at the sea surface above the diffuser is subject to ocean currents, turbulent mixing, and wave and wind effects. This results in further dilution, called "turbulent dilution." Its intensity depends mainly on the ocean's natural turbulence. Typical values at distances of 1 to 5 miles from the discharge point range from 1.5 to 10. Thus, the overall physical dilution - the product of initial and turbulent dilutions - that can be achieved in an ocean outfall ranges from 50 to 500.

(5) The USEPA closely regulates ocean dumping of industrial waste. Several studies, including biological and oceanographic, must be conducted before permits are issued. Thus, this approach should be considered carefully because it will be hard to carry out.

d. Land applications of industrial wastewater

(1) Land application of wastewater is a treatment system in which the soil-plant receiver changes wastewater characteristics by microbial stabilization, absorption, immobilization, and crop recovery. Industrial wastes are applied to the land at rates low enough not to exceed the soil-plant system's assimilative capacity. Pretreatment processes are often needed to reduce toxic or pollutant species that increase land requirements.

(2) Due to wastewater complexity and the lack of standard off-the-shelf designs, land treatment has not previously been widely used for industrial wastes. However, an environmentally acceptable rate of application can now be determined for all industrial waste constituents except radioactive materials.

(3) A rational approach to developing a land-disposal solution should be as follows:

(a) Determination of the controlling parameter in the wastewater based on the plant-soil system's assimilative capacity and the waste load's constituents. The controlling parameter is the constituent that requires the greatest land area.

(b) Design and economical evaluation of all components required for the land application system under various levels of the land-limiting constituent (LLC).

(c) Selection and economical evaluation of pretreatment or in-plant modifications for reducing the concentration of the land-limiting constituent.

(d) Selection of the most cost-effective combination of a pretreatment system and land disposal system.

(4) The most complex and difficult phase involved in the overall design is determining the land-limiting constituent. Land application design has a highly site-specific character; this requires careful development of an individual solution rather than using arbitrary application rates for all sites. Past system failures have most often been attributed to not considering the site-specific nature of this disposal method.

(5) Eight broad categories of pollutants have been established to help with consideration of the many constituents in industrial wastes: water; phosphorus and sulfur; oil and grease; specific organics; salts, acids, and bases; anionic species; heavy metals;

and nitrogen. There are many compounds and species within each category; each one should be considered alone. The broad category can be used to note overall response.

(6) Determining the land application rate for any industrial waste constituent is based on calculating its mass balance in the plant-soil system. The result is the application rate, expressed in pounds/acre-year, that will not exceed the environmentally accepted levels of pollutant in any part of the system. There are no standard application rates for all types of soils; however, each case should be treated individually. Table 7-4 gives some examples of assimilative capacities determined for different sites.

e. Deep well injection of industrial wastewater

(1) Deep well injection is a disposal method in which industrial wastes are stored in proper subsurface strata. Deep wells have been widely used for many years in oil-producing fields to return large quantities of saline water underground. However, due to the uncertainties involved and the regulatory constraints (which are becoming more strict), they have not been widely used for industrial waste disposal.

(2) Approval of a new injection well for industrial waste disposal requires that all alternatives be less satisfactory environmentally. Drilling of a preinjection test well, monitoring provisions, contingency plans, and provisions for capping of wells after shut-down are also required. For a specific industry, this may be the most environmentally acceptable practice available.

(3) The most important aspect of developing deep well injection is protecting underground water resources from contamination. The discharged wastes must remain confined in a specified zone and not be allowed to diffuse into strata that were not designated for wastewater storage. The well area and its casing must be designed and built to avoid upward migration of fluid from the injection well. A comprehensive monitoring program must be established for the injection area.

(4) The wastewater's compatibility with the water in the injection zone must be studied carefully. The reaction between the wastewater constituents and the salinity of the groundwater may cause mineral salts to precipitate or may cause formation of gases; in both cases, the strata will be made impermeable. Organic material in the wastewater may cause extensive biological growth and rapid plugging of the aquifer pores.

f. Evaporation of industrial wastewaters. Wastewater evaporation can be used in certain climatic regions for many types of industrial wastewaters. The major criteria are the absence of toxic or controlled volatile substances that would create an air pollution problem; an impervious soil layer (or artificial liner) to prevent groundwater contamination; and enough land area to provide the large surface area needed for evaporation. If the wastewater contains high concentrations of solids, there must be some provision for sludge removal and disposal. The major advantages of total evaporation systems are the elimination of the liquid discharge, low operation/maintenance cost, and low pretreatment unit process cost.

g. Reuse of industrial wastewaters. To attain high levels of treatment for surface water discharge, industrial wastewaters are often subjected to complex treatment unit processes. The requisite treatment levels for surface water discharge often exceed the raw water quality criteria of the industrial process. Thus, it may be cost-effective to remove only those contaminants that exceed the raw water criteria of the industrial process and reuse the water. The decision-maker should compare the tradeoff between (1) the cost of industrial wastewater treatment to meet discharge criteria, and (2) the cost

of treatment for reuse less the cost of the raw water saved and any process materials that may be recovered.

7-3. Process selection guidelines

This section presents a rational, systematic approach for solving an industrial waste disposal problem.

a. Process selection procedure

(1) A rational approach to an industrial waste disposal problem should proceed as follows:

- (a) Conduct a comprehensive industrial wastewater survey.
- (b) Evaluate all available disposal alternatives.
- (c) Establish discharge criteria for each disposal method.
- (d) Assess opportunities for in-plant control, material recovery, water reuse.
- (e) Assess and screen treatment processes.
- (f) Conduct laboratory evaluation of treatment processes.
- (g) Select treatment alternatives.
- (h) Develop process designs.
- (i) Construct economic analysis of alternatives.
- (j) Evaluate institutional considerations.

(2) An industrial wastewater survey (chap 5) will provide data on the quality of the wastewater from the plant and its various streams.

(3) All candidate disposal alternatives must be considered at the early stages of the solution development. This includes discharge to municipal plants, land disposal, dilution in surface waterways, ocean disposal, deep well injection, evaporation, and water reuse. Consideration of all disposal alternatives will increase the number of variables in the design process; however, it is essential if the most cost-effective solution is sought.

(4) To establish the level of treatment required, the discharge criteria must be known. Sometimes, it is not possible to totally quantify the discharge criteria; if so, acceptable discharge criteria may be assumed, based on water quality limitations, the size of the waste load, or USEPA guidelines for the industrial activity. An assumed level of treatment will have to be justified when negotiating a permit according to the Federal, State, and local guidelines.

(5) Potential in-plant waste load reductions can be assessed based on the wastewater survey. Factors to be included in this assessment are: the magnitude of waste load reduction achievable, an estimated cost (order of magnitude) for implementing in-plant control, and the impact of the reduction on end-of-pipe treatment processes in

terms of performance and cost. The assessment culminates in establishing a revised waste load which reflects in-plant controls that are practical.

(6) A preliminary screening of treatment processes based on typical performance characteristics is conducted, using the revised waste load and the expected discharge requirements.

(7) Treatment processes which appear feasible in the preliminary assessment become candidate methods for laboratory screening. The screening refines the design parameters and verifies the capability of the process to meet discharge criteria. Some candidate processes may not require laboratory screening, since personnel may be familiar with processes used at other installations; however, a process should usually be verified before being implemented.

(8) Process designs are then prepared for each viable candidate system. This allows a comparative economic analysis to be developed, based on life-cycle cost estimates.

(9) Other considerations which may influence process selection are:

(a) Future upgrading of water quality standards. In the long run, it may be most cost-effective to design in the flexibility to upgrade the treatment process for meeting future, more stringent discharge criteria. The potential for tightening permit criteria can be evaluated while establishing current criteria.

(b) Future changes in plant activities such as types of products or level of production must be accounted for when selecting a treatment process. The possibility for expansion or process modification to meet future needs should be considered. Future production plans are often unknown at the time of design. Thus, processes with higher flexibility and those that can be expanded more readily should receive higher priority.

(c) Complexity of the process. Although a candidate process may technically be highly efficient, it may not be feasible to train operators within the institutional constraints of the organization.

(d) Land restrictions. The available land area and the soil's characteristics may severely impact the economic analysis. Some alternatives may not be applicable.

(e) Weather constraints, winter temperatures, precipitation, and other meteorological characteristics of the proposed site may influence the viability of candidate methods. Examples include: the relationship between removal efficiency and operating temperature in biological processes; the impact of precipitation, cloud cover, and freezing weather on air-drying of sludges; and the need to enclose processes in harsh climates so that they receive proper operator attention.

(f) Air pollution and aesthetic nuisances that may be associated with industrial wastewater treatment must be considered. A mere shift of an environmental pollution problem from the aquatic phase to the atmosphere or to land is not an acceptable solution.

(g) Appendix E is an example of a design problem using this methodology.

b. Abatement capability of various treatment processes

(1) A preliminary screening of the available processes is based on a general overview of process capabilities (tab 7-5). In most industrial cases, more than one constituent must be removed; thus, several processes must be selected. The appropriate combination will be based on the relative significance of each pollutant and the applicability of each process for removing each one. Hence, a wastewater that contains mostly biodegradable organics will be treated biologically; one with mostly refractory organics will be treated by physical-chemical methods.

(2) The effluent quality attainable by any treatment process depends on the influent characteristics and on the design and operation parameters of the treatment facilities. Although treatment efficiencies of industrial wastes may vary widely, there are practical limits of attainability for each process. Table 7-6 lists typical attainable concentrations of various pollutants for selected processes. (The data in this table are intended only for a preliminary process screening. In the more advanced stages of design, effluent quality characteristics should be established using previous experience with the specific wastewater or using the results of treatment testing.)

c. Process design data

(1) Before developing a process design for an industrial waste treatment plant, the engineer must obtain all the pertinent data: wastewater characteristics, discharge permit, site of treatment plant, climatic conditions, process design criteria, and cost of construction, operation, and maintenance.

(2) A process design checklist should be prepared to account for all pertinent design data (tab 7-7). The example in the table relates to a specific treatment plant consisting of preliminary flocculation/sedimentation, activated sludge, granular media filtration, gravity thickening of sludge, and vacuum filtration. Similar checklists can be developed for other process trains.

d. Environmental factors at industrial waste treatment plants. Environmental factors such as malodorous gases, unsightliness, dust, and land pollution must be considered during treatment plant design. These adverse environmental factors must be prevented or controlled to minimize health hazards and objections to the plant.

(1) Atmospheric pollution considerations

(a) Many areas and processes in wastewater treatment facilities are a potential source of airborne pollutants. These include odors, noxious or toxic gases, particulates, and aerosols. Industrial wastes may contain a variety of volatile solvents which may cause severe odor problems if not controlled properly. Removal of such volatiles by air stripping without sufficient controls on the air stream is not an environmentally acceptable process.

(b) The most common aesthetic problem in a wastewater treatment plant is odor. Many compounds generate odor; therefore, this discussion will be limited to only industrial wastewater pollutants that may generate odors.

(c) The odors most often emitted from wastewater treatment plants are from hydrogen sulfide, methylmercaptans, methylsulfides, amines, indole, and skatole. Table 7-8 lists the most common odorous vapors found at wastewater treatment facilities and some of their characteristics.

(d) The following odor controlling methods have been applied successfully in treatment plants:

- Oxidation of odor-producing compound by agents such as chlorine, chlorine dioxide, hydrogen peroxide, or ozone.
- Control of the oxidation/reduction potential (ORP) to prevent anaerobic conditions and associated odor development by use of air, pure oxygen, or nitrates.
- Adjustment of pH to a level which will avoid formation of volatile species.
- Elimination of odor-producing compounds by in-plant control.

(e) Explosive, noxious, and toxic gases which may be found in treatment plants include chlorine, methane, ammonia, hydrogen sulfide, and carbon monoxide. Precautions must be taken to prevent such gases from escaping in hazardous or nuisance concentrations.

(2) Solid waste originating from wastewater treatment

(a) A large portion of the pollution load in the industrial wastewater may end up as a semisolid sludge. These include all nondegradable pollutants which are not volatilized in the treatment process. Much of the degradable organics in the raw wastewater is converted to a biological mass which is disposed of as sludge.

(b) Sludge-handling operations are intended to reduce the sludge's quantity and volume. The end product of these operations must eventually be disposed of in an environmentally acceptable manner. The most common disposal method is application to land.

(c) Selection of a land disposal site should avoid environmental nuisances. These include: contamination of surface water by storm runoff; contamination of groundwater from leachates; evolution of toxic or obnoxious gases from continuing decomposition; and unsightly operation.

(d) Industrial waste sludges will contain many compounds; some of these may be hazardous. Thus, proper handling of this sludge is a problem that must be addressed during the facility design.

7-4. Upgrading of existing facilities

The material presented above is geared toward the design of new facilities. However, these principles also apply to upgrading and modifying existing facilities.

a. Reasons for upgrading existing systems

(1) Upgrading of existing systems refers to many design and operational techniques for improving plant performance. Some may not be performing well. Others may not be able to handle increased waste or hydraulic loads. In both cases, upgrading may be the answer. Upgrading may be done for one or several of the following reasons:

(a) To improve performance of facilities with operational deficiencies (facilities which perform poorly due to operational difficulties.)

(b) To improve performance of facilities with design deficiencies (facilities which perform poorly due to design inadequacy).

(c) To increase hydraulic capacity to lessen hydraulic overloads from infiltration and expansion of services.

(d) To increase organic capacity to compensate for overload caused by the number of connections or high-strength contributions.

(e) To comply with stricter standards. Tighter discharge limitations may require that treatment processes be upgraded to obtain higher removal efficiencies; this could be done either by improving performance of current facilities and/or by building more facilities.

(2) The USEPA surveyed 103 wastewater treatment plants to identify and rank the major causes of poor plant performance. (The survey did not consider plants with hydraulic or organic overloading problems.) Table 7-9 lists and ranks 70 potential problem areas. The first 16 problems are classified as operational or design deficiencies. Table 7-10 lists and gives a short explanation of the first 10 problem areas in the ranking. It is apparent from this survey that operation and design are often the two most important areas to consider during upgrade.

b. Upgrading techniques. Methods or techniques used in upgrading depend on the problems to be solved. Often, several problems are involved; therefore, several techniques must be used to provide the required level of performance. For simplicity, the various approaches discussed below will be addressed separately; however, combined use is encouraged where necessary.

(1) Upgrading of poorly operated facilities. One of the most common reasons for poor plant performance is poor operation. Thus, consideration of the operating techniques used in a plant should always be the first step in system upgrade. To verify performance, operations should be optimized before any other upgrading technique is applied. Specific operating problems are listed and briefly discussed in the USEPA survey noted above. These and other problems may be categorized into three basic areas typical of operating deficiencies.

(a) Improper application of process control methods. This is the most common source of operational problems in existing treatment plants. It stems from the inability or lack of ability or interest by plant operators to apply learned techniques for correct process control. This often results from severe manpower shortages for plant operation and maintenance. Lack of motivation may be due to inadequate recognition of operators' achievements by plant management. Thus, the key to solving these problems is plant manager's awareness of the wastewater treatment system's importance and difficulties.

(b) Inadequate training or guidance of plant operators. Operating personnel must understand the processes involved, recognize problems as they develop, and know the ways to correct them. According to the USEPA survey, there are several reasons for inadequate training and poor application of concepts. Some plants do not offer training programs. Others provide misleading or incorrect information. Operation and maintenance (O&M) manuals are often so poorly written that the operators do not understand

them or are not given the information they need. Proper training programs and guidance by qualified personnel can solve these problems.

(c) Improper testing and data analyses. Proper sampling and analyses are very important to controlling plant operations. One of the major reasons is insufficient numbers and training of laboratory personnel. Improper sampling, such as sampling at the wrong time or wrong place, using an inappropriate collection method, or not taking enough samples can result in erroneous or insufficient data. Improper analyses caused by inadequate lab facilities, poor sample preservation or analytical techniques, and obsolete or poorly calibrated instrumentation also lead to erroneous data. Delinquent recordkeeping and data analyses may allow to go unnoticed vital information that indicates the need for operational adjustment. Good sampling and analysis techniques are worthless if the results are not used properly. There are many ways to approach these problems. The staffing and training of operators and laboratory personnel should be analyzed, and proper corrective hiring, firing, and training should be conducted. Discussions with current plant operators could provide considerable insight into training and into O&M manual deficiencies which should be corrected. Updating of sampling and analytical techniques and equipment would also help. Finally, the importance of properly applying manual and laboratory information to maintaining stable process operations should be impressed on the operators. Operators often have a lot of knowledge to offer and should be involved with treatment process design in the early stages to get their viewpoints.

(2) Upgrading poorly designed facilities. Many plants have sizing or process design deficiencies relating to hydraulic or organic overloading problems. Many detail design problems also result in poor performance. The major ones include:

(a) Insufficient flexibility in pumping rates or in preventing proper control of plant processes during times of high or low flow.

(b) Inadequate bypasses for repair and maintenance of equipment, resulting in entire processes being taken out of service unnecessarily.

(c) Lack of standby equipment, causing possible loss of process operation while replacements are ordered.

(d) Poor hydraulic and solids distribution to parallel units, resulting in over- or underloading of different portions of the process.

(e) Lack of flexibility in process instrumentation and equipment, resulting in poor low-flow or low-load operation.

(f) Poor accessibility of equipment for repair and maintenance, often resulting in repair problems and neglectful maintenance practices. The remedies for most of these problems are self-explanatory. Correction of these deficiencies may improve plant performance enough to remove the need for further upgrading.

(3) Upgrading to provide increased hydraulic capacity

(a) Although units based on flow rates are operable when hydraulically overloaded, their removal efficiencies are greatly reduced. Some of the units most adversely affected by hydraulic overload are equalization basins, primary clarifiers, dissolved or induced air flotation systems, filtration units, and oil/water separators.

(b) Efforts to correct hydraulic overloading should first be directed at eliminating excessive flows by modifying the influent hydraulic characteristics. Hydraulic overloading may result from peak flows in excess of plant design or by average flows exceeding plant design capacity. Peak flows may be remedied by installing equalization basins which dampen the peaks to acceptable average flow levels. Equalization facilities may be established at the treatment plant; if the peak loading is caused by an isolated source, such as an industrial batch process, they can provide equalization at the source. Average loading in excess of hydraulic capacity may often be remedied by eliminating infiltration and inflow. Leaking sewers and stormwater runoff connections are the principal hydraulic sources which should be addressed. Decreased industrial "in-plant" water use or "in-plant" water recycle may also help get rid of hydraulic overloading where excessive quantities of water are discharged from industrial sources.

(c) If hydraulic overloads cannot be eliminated, process modifications may be used to increase the system's hydraulic capacity. Adding chemical coagulants greatly improves the efficiency of most hydraulic-based units; this increases hydraulic capacity. Special devices have been developed to increase hydraulic capacity in some units; these include tube settlers in clarifiers (currently rarely used) and corrugated plate interceptors in oil/water separators. If none of these methods provides enough increase, parallel units may have to be built.

(4) Upgrading to provide increased organic loading capacity

(a) Biological units are most affected by organic overloading. Waste stabilization ponds, activated sludge systems, trickling filters, and rotating biological contactors are among the more easily affected. Organic overloading often results in poor sludge settleability, sludge bulking, and odor problems. Increased secondary sludge production caused by overloading causes problems with sludge thickeners, digesters, and dewatering and disposal facilities. When overloaded, many biological systems exhibit decreased removal efficiencies; in severe organic overloading situations, they may fail completely. For example, aerobic systems may become anaerobic, and/or the organisms may become completely unsettlable due to sludge bulking. In activated-sludge systems, organic overloading may sometimes result from inadequate mixing, which leads to sludge settling in the aeration basin; this reduces the effective biomass in the system. This problem can be solved by increasing the mixing level by adding of mixing equipment, draft tubes, or hydraulic modifications.

(b) As with hydraulic overloading, organic overloads may be caused by either peak loads or excessive average loads. Peak loads may be dampened by equalization at the source or at the treatment plant. If the average load is an organic overload, other correctional methods must be used. In activated-sludge systems with low DO concentrations, increasing aeration capacity may provide the oxygen required by the bacteria to properly assimilate excessive quantities of organic matter. Also, enrichment with pure oxygen may also work. If the problem is not insufficient oxygen, increasing the biological solids retention time would provide a larger biological population, which could then oxidize more organic matter. This plan depends on the secondary clarifier's ability to accommodate higher solids loadings. A similar effect can be achieved by increasing the volume of the aeration basin. In terms of the previously discussed activated sludge design relationships, both solutions will result in a lower food-to-microorganism ratio and an increase in BOD removal efficiency.

(c) One important factor in all biological treatment systems is operation at low temperatures. Since all biological reactions slow down as temperature drops, many plants have operational difficulties during the winter. Upgrading methods are directed

toward better heat conservation within the treatment plant. Among the possible winter upgrading methods are reduced mixing in equalization basins, bypassing equalization basins, covering equalization basins, and a shift from surface to diffused air aeration.

(d) Finally, the addition of supplementary organic load reduction units, such as roughing trickling filters before biological systems or polishing filters following biological systems, may be necessary for proper upgrade. Trickling filters can handle increased organic overloads when rock media are replaced by synthetic media.

(5) Upgrading to meet more stringent standards. Many plants will soon have to meet more stringent standards than those originally designed for. Compliance may require building more units, depending on the parameters which must be met. When this decision is reached, the entire facility should be evaluated relative to the requisite discharge criteria. In-place processes and new processes should be integrated to meet the new needs and to maintain operational integrity.

Table 7-1

Example of wasteload reductions by in-plant control in a chemical plant

In-plant Control Method	Description of Modification	Flow Reduction		BOD Load Reduction	
		mgd	Percent	pounds/day	Percent
Segregation and special disposal	Incineration of high-strength organic streams	0.04	0.4	6,510	11.7
	Wet scrubber replaced with afterburner	0.30	2.7	560	1.0
Process modification	Repair and replacement of process equipment	1.60	14.4	4,650	8.3
	Unit shutdowns due to the age of the process or product*	0.25	2.2	1,860	3.3
Substitution	Use of raw materials with less pollutant load	0	0	560	1.0
Recycling	Reprocessing of specific wastestreams to recover more product and concentrate waste	0.01	0.1	560	1.0
Reduction	A number of small, varied projects	<u>0.60</u>	<u>5.4</u>	<u>3,900</u>	<u>7.0</u>
Totals		2.8	25.2	18,600	33.3

*These were not caused by environmental considerations, but they were a factor.

Table 7-2

Potential noncompliance materials and example control measures*

Component	In-plant Control	End-of-Pipe Control
Physical Constituents		
1. Suspended Solids	Clarifier	Primary clarifier
2. Floating Material	Separators	Separators
3. Fiber	Screen	Screens, primary clarifier
4. Temperature	Cooling tower	Combine w/other wastes
5. Oily material	Separator, segregation	Separator
Chemical Constituents		
1. Organics		
a. Complex	Activated carbon, ozone	Activated carbon
b. Toxic	Activated carbon, special disposal	Activated carbon
c. Surfactants	Activated carbon, special disposal, process substitution	--
d. Colored waste	Activated carbon	--
e. pH	Neutralization	Neutralization
2. Inorganic		
a. Total dissolved fixed solids	Special disposal	Ion exchange
b. Heavy metals	Precipitation	Precipitation

*The waste generation rate must also be considered in terms of the diurnal discharge of domestic wastewater into the POTW.

Table 7-3

Stream classification for water quality criteria*

Class	Quality Criteria	Required Treatment
A**	Water supply, recreation Coliform bacteria, color, turbidity, pH, dissolved oxygen, toxic materials, taste- and odor-producing chemicals, temperature	Secondary (tertiary in some cases to meet criteria) plus disinfection
B**	Bathing, fish life, recreation Coliform bacteria, pH, dissolved oxygen, toxic materials, color and turbidity (at high levels), temperature	Secondary plus disinfection
C	Industrial, agricultural navigation, fish life Dissolved oxygen, pH, floating and settleable solids, temperature	Primary and, in some cases, secondary
D	Navigation, cooling water Nuisance-free conditions, floating material, pH	Primary

*Based upon data from R. E. Leffel, Direct Environmental Factors at Municipal Wastewater Treatment Works, EPA-430/9-76-003 (USEPA, 1976) and F. L. Evans, III, EPA Technology Transfer: Summary of National Operational and Maintenance Cause and Effect Survey (USEPA Environ. Res. Info. Center, July 1979).

**May require nutrient (nitrogen and phosphorus) removal.

Table 7-4

Assimilative capacities of selected constituents at four different land disposal sites
 (From M. R. Overcash and D. Pal, *Design of Land Treatment Systems for Industrial Wastes - Theory and Practice* [Ann Arbor Science Publishers, Inc., of Butterworth Publishers, 1979]. Used with permission of the publisher.)

Parameter	Rate of Application, pounds/acre-year			
	Site A	Site B	Site C	Site D
Nitrogen	536	603	946	--
Phosphorus	1,072	572	189	--
COD	62,580	152,000	97,890	--
Copper	4.47	3.39	28.0	2.23
Zinc	8.94	6.70	56.1	--
Lead	17.88	13.41	117.4	8.83
Cadmium	0.45	0.13	1.14	0.09
Water*	65.0	93.70	54.6	40.9

*Inches/year.

Table 7-5

Applicability of processes to wastewater treatment

Application or Pollutant	Candidate Process
Biodegradable organics (BOD, COD)	Aerobic biological treatment, anaerobic biological treatment, land treatment
Refractory organics (TOC, COD)	Carbon adsorption, resin adsorption, wet oxidation, ozonation, reverse osmosis
Suspended solids (TSS)	Clarification, filtration, flotation, screening, coagulation, microscreening
Ammonia-nitrogen ($\text{NH}_3\text{-N}$)	Aerobic treatment, anaerobic treatment, ion exchange, air stripping, steam stripping, algae ponds, land treatment
Nitrate-nitrogen ($\text{NO}_3\text{-N}$)	Aerobic methanol denitrification, ion exchange, chemical reduction, land treatment
Phosphorus ($\text{PO}_4\text{-P}$)	Chemical precipitation, algae ponds, ion exchange, land treatment
Heavy metals	Reduction/precipitation, ion exchange, recovery/reuse, carbon absorption, reverse osmosis, land treatment
Dissolved solids (TDS)	Evaporation, ion exchange, reverse osmosis, chemical precipitation, electrodialysis
Oil and grease	Skimming, emulsion breaking, gravity separation, dissolved air flotation
Sulfides	Precipitation, stripping, oxidation
Product recovery	All non-disposal technologies

Table 7-6

Typical attainable effluent quality from selected treatment processes*

Process	Typical Attainable Effluent Concentration, milligrams per liter					
	BOD	COD	SS	N	P	Oil & Grease
Primary sedimentation w/flocculation	-	-	20	-	-	-
Air flotation	-	-	-	-	-	10
Anaerobic lagoon	100	-	100	-	-	-
Aerated lagoon	50	-	50	-	-	-
Activated sludge	20	-	30	-	-	-
Nitrification/ denitrification	-	-	-	2	-	-
Ammonia stripping	-	-	-	5	-	-
Carbon adsorption	-	10	-	-	-	-
Chemical precipitation	-	-	-	-	1	-

*Significant deviations can be expected for industrial wastes of an unusually complex nature.

Table 7-7

Example of a process design checklist

(Processes included are primary flocculation, clarification, activated sludge, granular media filtration, gravity thickening, and vacuum filtration.)

A. Wastewater Characterization

1. Flow rate - average and peak flows (gallons/day)
stormwater contribution, peak rate (gallons/minute)
2. Quality - average and range of concentrations (milligrams/liter) of all constituents affecting the discharge permit or the treatability of the wastewater
average and range of pollutional loads (pounds/day) of all constituents affecting the discharge permit or the treatability of the wastewater
3. Individual Stream Characterization - flows and main quality characteristics of major wastewater

B. Discharge Permit

1. Average and peak concentration levels (milligrams/liter) of permit parameters and/or
2. Average and peak pollutants loads (pounds/day) of permit parameters
3. Minimum treatment requirements (percent removal), if any

C. Site of Treatment Plant

1. Land availability
2. Site topography
3. Geological data

D. Climatic Data (for temperature or weather-sensitive processes)

1. Average, maximum, and minimum daily air temperature on a monthly basis
2. Winds - direction and velocity
3. Relative humidity
4. Intensity of clear-sky solar radiation
5. Cloud coverage
6. Precipitation

E. Process Design Parameters

1. Primary treatment
 - a. Flocculant type and dose (milligrams/liter)
 - b. Rapid mixing power level and residence time (horsepower/1000 gallons, minute)
 - c. Flocculation basin power level and residence time (horsepower/1000 gallons, minute)
 - d. Primary clarifier overflow rate (gallons per day/square foot)

Table 7-7

Example of a process design checklist--continued

2. Biological treatment
 - a. Biodegradation rate coefficients as a function of temperature and biological solids retention time
 - b. Minimum effluent concentration (milligrams per liter)
 - c. Sludge production and decay coefficients
 - d. Oxygen utilization coefficients
 - e. Biodegradable sludge fraction as related to a process loading rate
 - f. Sludge settleability characteristics
 - g. Oxygen transfer and saturation coefficients
 - h. Aerators standard oxygen transfer efficiency
3. Granular media filtration
 - a. Influent SS concentration - average and range (milligrams per liter)
 - b. Effective size and uniformity coefficient of filter media
 - c. SS removal efficiency as a function of hydraulic loading rate
 - d. Headloss characteristics as a function of solids retention
 - e. Backwash requirements - bed expansion and time
 - f. Bed expansion as a function of backwash rate
4. Gravity thickening of sludge
 - a. Flow rate and solids content of raw sludge (gallons/day and milligrams per liter)
 - b. Batch flux data
 - c. Desired sludge concentration (milligrams per liter or percent)
5. Vacuum filtration
 - a. Thickened sludge flow rate and concentration (gallons/day and percent)
 - b. Specific resistance of sludge at various polymer dosages
 - c. Sludge cake constants
 - d. Solids concentration and form time exponents
 - e. Desired cake concentration
6. Cost of construction and O&M
 - a. Unit cost for individual treatment processes
 - b. Additional costs for pumping equipment, piping, and electrical work required
 - c. Land cost
 - d. Contingencies, engineering administration, and miscellaneous costs

Table 7-7

Example of a process design checklist--continued

- e. Staffing requirements
- f. Labor cost for different levels of technical, general maintenance, and administrative personnel
- g. Cost of chemicals
- h. Cost of materials for general maintenance or replacements
- i. Power cost
- j. Transportation cost

Table 7-8

Odorous vapors found at wastewater facilities
(From R. E. Leffel, Direct Environmental Factors at Municipal Wastewater Treatment Works, EPA-430/9-76-003 [USEPA, 1976].)

Municipal Wastewater Treatment Works, EPA-430/9-76-003 [USEPA,

Substance (Odor Description)	Formula	Molecular Weight	Odor Threshold (micrograms per liter of air)	Normal Boiling Point, °C at 760 mm Hg
Ammonia (sharp and pungent)	NH ₃	17.03	37	-33
Ethyl mercaptan (decayed cabbage and garlic)	C ₂ H ₆ S	62.1	0.2	23
Hydrogen sulfide (rotten eggs)	H ₂ S	34.1	1.1	-62
Indole (excreta)	C ₈ H ₆ NH	117.1	--	254
Methyl mercaptan (decayed cabbage and onions)	CH ₃ SH	48.1	1.1	8
Skatole (fecal, pungent, and irritating)	C ₉ H ₉ N	131.2	9.0	266
Dimethyl amine	(CH ₃) ₂ NH	45.08	4.7	7
Methyl amine	CH ₃ NH ₂	31.06	21.0	-7
Dimethyl sulfide	(CH ₃) ₂ S	62.13	2.5	37
Chlorophenol (medicinal)	ClC ₆ H ₅ O	128.56	0.18	214
Chlorine (pungent, irritating)	Cl ₂	70.91	10	-34
Allyl mercaptan (garlic)	CH ₂ :CH·CH ₂ ·SH	74.15	0.05	67
Diphenyl sulfide (unpleasant)	(C ₆ H ₅) ₂ S	186.28	0.05	296
n-butyl mercaptan (skunk)	CH ₃ ·CH:CH·CH ₂ ·SH	90.19	0.03	98
Ozone (slightly pungent, irritating)	O ₃	48	1	-111.3

Table 7-9

Collective ranking of factors limiting plant performance

(From F. L. Evans III, *EPA Technology Transfer: Summary of National Operational and Maintenance Cause and Effect Survey* [USEPA Environ. Res. Info. Center, July 1979].)

Factor	Limiting Factor		No. of Times	
	Area	Description	Factor was Ranked #1	Factor was Noted
1	Operation	Operator Application of Concepts and Testing to Process Control	24	89
2	Operation	Process Control Testing	0	67
3	Design	Infiltration/Inflow	9	56
4	Operation	Sewage Treatment Understanding	9	50
5	Operation	Technical Guidance	7	47
6	Design	Sludge Waste and Return Capability	9	43
7	Design	Secondary Process Controllability	3	55
8	Design	Secondary Process Flexibility	3	37
9	Operation	O&M Manual Inadequacy*	0	40
10	Design	Aerator	6	27
11	Design	Sludge Treatment*	3	36
12	Design	Industrial Loading	4	27
13	Operation	Staff Training	0	31
14	Design	Secondary Clarifier	3	26
15	Operation	Performance Monitoring	0	31
16	Design	Ultimate Sludge Disposal	1	30
17	Administration	Plant Administration, Familiarity with Needs	2	21
18	Design	Disinfection*	1	20
19	Administration	Plant Staff - Number	2	22
20	Design	Plant Hydraulic Loading	0	18
21	Administration	Plant Staff - Plant Coverage	0	26
22	Maintenance	Spare Parts Inventory	0	23
23	Design	Laboratory Space and Equipment	0	30
24	Design	Return Process Stream	1	18
25	Operation	Equipment Malfunction	2	17
26	Maintenance	Lack of Preventive Maintenance Program	1	20
27	Design	Alternative Power Source	0	24
28	Design	Organic Loading	7	13
29	Maintenance	General Housekeeping	0	17
30	Maintenance	Maintenance Scheduling and Recording	0	19
31	Administration	Administration Policies	2	15
32	Administration	Plant Staff Productivity	0	17
33	Administration	Insufficient Funding	1	18
34	Maintenance	Manpower	0	14
35	Design	Preliminary Unit Design*	0	20
36	Administration	Staff Motivation	0	19
37	Administration	Working Conditions	0	18
38	Design	Alarm Systems	0	19

Table 7-9

Collective ranking of factors limiting plant performance--continued

Factor	Limiting Factor		No. of Times	
	Area	Description	Factor was Ranked #1	Factor was Noted
39	Maintenance	Critical Parts Procurement	0	14
40	Design	Flow Proportioning to Units	0	12
41	Operation	Staff Aptitude	0	13
42	Design	Inoperability Due to Weather	0	12
43	Administration	Staff Supervision	0	13
44	Design	Primary Units*	1	9
45	Maintenance	Equipment Age	0	14
46	Operation	O&M Manual - Use by Operators*	0	12
47	Administration	Salary	0	12
48	Design	Lack of Standby Units for Key Equipment		9
49	Design	Lack of Unit Bypass	0	12
50	Maintenance	Technical Guidance - Emergencies	0	10
51	Maintenance	Availability of Preventive Maintenance Ref.	0	10
52	Design	Flow Backup	0	7
53	Operation	Staff - Level of Education	0	9
54	Design	Toxic Loading	1	8
55	Design	Submerged Weirs	0	6
56	Design	Plant Location	0	6
57	Operation	Staff Level of Certification	0	8
58	Operation	Staff - Insufficient Time on Job	0	7
59	Maintenance	Staff Expertise - Emergencies	0	9
60	Design	Seasonal Variation Loading	0	7
61	Administration	Unnecessary Expenditures	0	7
62	Design	Process Automation for Control	1	6
63	Administration	Personnel Turnover	0	4
64	Operation	Shift Staff Adequacy	0	3
65	Design	Unit Accessibility	0	3
66	Design	Process Accessibility for Sampling	0	4
67	Design	Process Automation for Monitoring	0	2
68	Design	Equipment Accessibility for Maintenance	0	2
69	Administration	Bond Indebtedness	0	0
70	Design	AWT Units*	0	0

*Not included in every plant evaluated.

Table 7-10

Ten top-ranked causes of poor plant performance

(From F. L. Evans III, *EPA Technology Transfer: Summary of National Operational and Maintenance Cause and Effect Survey* [USEPA Environ. Res. Info. Center, July 1979].)

The 10 major causes of poor plant performance are described as follows:

1. Operator Application of Concepts and Testing to Process Control - This factor was ranked as the most severe deficiency and leading cause of poor performance at 23 facilities and was a high-ranked factor at a total of 89 out of the 103 plants evaluated. It occurs when a trained operator in a satisfactorily designed plant permits less than optimum performance. This factor was ranked when incorrect control adjustment or incorrect control test interpretation occurred, or when the use of existing inadequate design features continued when seemingly obvious operations alternatives or minor plant modifications could have been implemented to improve performance. The lack of testing and control was not necessarily the result of inadequate training or comprehension in these areas, but simply the lack of or inability to apply learned techniques.
2. Process Control Testing Procedures - Inadequate process control testing involves the absence or wrong type of sampling or testing for process monitoring and operational control. This deficiency leads to making inappropriate decisions. Standard unit process tests such as mixed liquor suspended solids, mixed liquor dissolved oxygen, mixed liquor settleable solids, and return sludge suspended solids for activated sludge processes were seldom or never conducted. Also, important operating parameters such as sludge volume index, F/M ratio, and mean cell retention time in suspended growth systems or recirculation rates in trickling-filter plants were usually not determined. This factor adversely impacted performance at 67 of the 103 plants evaluated.
3. Infiltration/Inflow - The results of this widespread problem are manifested by severe fluctuations in flow rates, periods of severe hydraulic overloading, and dilution of the influent wastewater so that both suspended and fixed biological systems are loaded to less than optimal values. The extreme result is the "washout" of suspended growth systems as a result of the loss of solids from the final clarification stage during high-flow periods. This factor was ranked first at nine plants and was an adverse factor at 56 facilities.
4. Inadequate Understanding of Wastewater Treatment - This factor is distinguished from Factor #1 in that it is defined as a deficiency in the level of knowledge that individual staffs at various facilities exhibit concerning wastewater treatment fundamentals. On occasion, an operator's primary concern is simply to keep the equipment functional rather than to learn how the equipment relates to the processes and their control. This factor adversely affected performance at 50 plants and was the leading cause of poor performance at nine facilities.

Table 7-10

Ten top-ranked causes of poor plant performance--continued

5. Technical Guidance - Improper technical guidance includes misinformation from authoritative sources, including design engineers, State and Federal regulatory agency personnel, equipment suppliers, operator training staff, and other plant operators. At any one plant, improper technical guidance was observed to come from more than one source. This factor was ranked as the most severe deficiency at seven plants and was an adverse factor at 47 facilities.
6. Sludge Wasting Capability - This factor was ranked as the leading cause of poor performance at nine facilities and was a factor at 43 plants studied. This factor includes inadequate sludge-handling facilities and the inability to measure and control the volume of waste sludge. Either one or both of these conditions was noted as having a major impact on performance at several plants.
7. Process Controllability - The lack of controllability was evident in the inability to adequately measure and control flow streams such as return sludge flow and trickling-filter recirculation rates. While measurement and control of return activated sludge flow were the most frequent reasons for rating this factor, process controllability was not a major cause of poor performance. It prevented an operator from "tuning" the treatment system to the varying demands which were placed on it by hydraulic and organic loading fluctuations. This factor occurred at 55 plants and was the leading factor at three facilities.
8. Process Flexibility - Lack of flexibility refers to the unavailability of valves, piping, and other appurtenances required to operate in various modes or to include or exclude existing processes as necessary to optimize performance. Poor flexibility precludes the ability to operate an activated-sludge plant in the contact stabilization, step-loading, or conventional modes and the ability to bypass polishing ponds or other downstream processes to discharge high-quality secondary clarifier effluent. Either the lack of or inadequate process flexibility was noted as the leading cause of poor performance at three plants and was a factor at 37 facilities.
9. Ineffective O&M Manual Instruction - This situation, existing at 40 plants, was judged serious, although the adverse effect was moderate. The poor quality of most plants' O&M manuals undoubtedly has contributed to operators' general lack of understanding of the importance of process control and the inability to practice it, but a competent staff could use other available information sources.
10. Aerator Design - Deficiencies in aerator design were the major cause of poor performance at six facilities and were less significant factors at an additional 21 plants. Deficiencies were noted in the type, size, shape, capacity, and location of the unit and were of such a nature as to hinder adequate treatment of the waste flow and loading and stable operation.

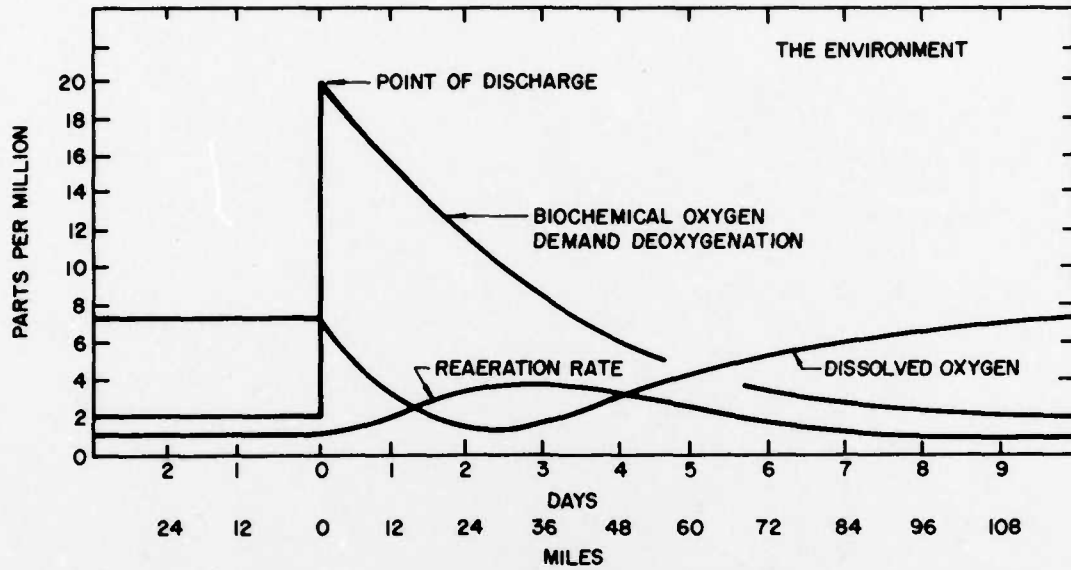


Figure 7-1. Typical oxygen sag curve.

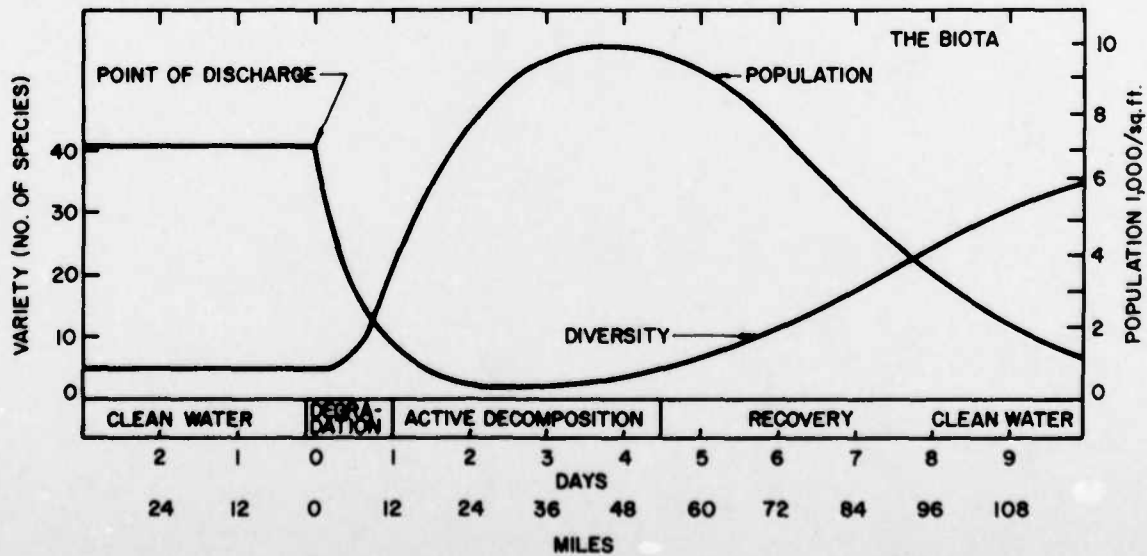


Figure 7-2. Effect of oxygen sag curve on aquatic life.

Chapter 8

Economics of Industrial Wastewater Treatment

8-1. Overview of economic analysis

The success of engineering projects is usually measured in terms of financial efficiency. Since the engineer is most likely the one who understands the technical requirements of a project, he/she is often asked to analyze the technical and financial details of a project. For waste treatment management systems, a cost-effective solution is one which minimizes total resource costs spent to meet the Federal and State water quality standards and treatment requirements. Resource costs include capital; operation, maintenance, and replacements; social; and environmental.

a. Purpose. Cost evaluation information is provided to help water quality management planners, decision-makers, and design engineers evaluate the cost-effectiveness of alternative wastewater treatment systems.

b. Types of estimates. Several methods have been developed to help meet the practical problems of cost estimation. However, some of these techniques are not applied as often as others. There are five basic cost-estimating procedures.

(1) Cost curves. Cost curves for constructing and operating wastewater treatment plants have been developed for municipal and industrial wastewater treatment facilities. These cost data are available for: total plant construction costs based on types of treatment units; and unit process cost and construction component cost. The cost curves are developed using a linear regression equation of available and past control data and are checked for statistical validity. The resultant plots of unit construction cost against design flow on a log-log paper are used to determine treatment facility cost. This is the easiest method to use.

(2) Detailed engineering estimate - construction quantity takeoff. These estimates are based on actual cost of equipment, material, and the cost of labor for constructing and installing equipment. The cost of all major equipment is determined from vendors. Quantities of all foundation material, excavation, formed concrete, poured concrete, steel, pipes, fittings, and mechanical and electrical equipment are computed from design drawings. A unit cost is then applied to each item to include materials of construction or equipment cost and installation labor. Table 8-1 summarizes selected unit costs from May 1980. Due to inflation and changing market conditions, these costs must be adjusted to reflect the projected cost at the time of construction. This type of estimate is most commonly used when an accuracy of ± 10 percent is desired.

(3) Cost per unit pollutant loadings. Engineers have correlated construction and operating costs with the size of treatment facilities in terms of flow, BOD, and suspended solids loading. Because construction costs obtained by this method are not reliable, published costs are not available. This approach is not recommended for industrial waste treatment systems due to the complexity of the systems and the variables in the database.

(4) Analogy method - comparison with similar existing facility. If more formal techniques cannot be applied, a specialized method of judgment may be used to estimate costs by making direct comparisons with historical information from similar existing facilities. The major problem of the analogy method is that it is basically a judgment process and therefore requires a great deal of experience and expertise. Estimates of

operating and maintenance costs or recurring annual costs also lend themselves to the analogy method. Such estimates will depend on expert judgment and experience and are not useful for developing sophisticated cost estimates.

(5) CAPDET model. The U. S. Army Corps of Engineers and the USEPA have refined the Corps' CAPDET model (Computer-Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems). The updated CAPDET can be used to estimate the capital costs for wastewater treatment plants to within ± 10 percent. Required inputs are detailed designs of the unit processes, calculation of construction labor and material quantities, and application of unit prices to these take-offs. Operations and maintenance costs must also be considered.

(6) Summary. Providing good cost data is often the most demanding and time-consuming task in an economic analysis. Even with the application of one or more of the techniques outlined above, the results are still uncertain. Use of cost curves, which were prepared using the costs of other facilities, is a reasonable and relatively easy cost estimation alternative.

c. Components of cost estimates. Cost-estimating procedures give the construction cost of treatment facilities. However, certain other cost components, such as engineering, administrative, inflation, and other nonconstruction costs, must be developed to determine the total project costs.

(1) Capital cost. Capital cost is the first or one-time cost of the treatment facility. It includes initial investment in construction costs, engineering costs, legal and administrative costs, and other nonconstruction costs and construction contingencies. These costs must be updated to reflect the time of construction, using an inflation index.

(a) Engineering. Engineering for wastewater treatment facilities consists of two elements: basic services and specialized services. Basic engineering services include preliminary design reports, detailed design, and certain office and field engineering services required during project construction. Specialized services include comprehensive improvement studies, resident engineering, soils investigation, land surveys, O&M manual, plant startup and other miscellaneous support services.

(b) Legal and administrative costs. Legal and administrative costs related to planning and construction of wastewater treatment works can be substantial. Assistance may be required to prepare legal documents and construction contracts, and for land acquisition. Even though consultants are used, the administration of design and construction may require a great deal of time. The total cost of these items may also be related to the project size.

(c) Inflation/deflation. In practice, the proper treatment of inflation should address two separate time periods: the interval between the preparation time of the analysis (present cost) and the anticipated time of construction; and project life analysis. Cost indices can be used to update the initial investment cost. Costs incurred during the project life of an economic analysis are discounted to their "present worth" equivalents. The discount factors automatically adjust for a normal price/cost growth rate during the period for which they are applied. However, since it is hard to predict inflation over the 15-, 20-, or 25-year periods common in an economic analysis, straightforward escalation techniques cannot be directly applied to recurring annual operations and maintenance costs.

(d) Cost indices. There are several cost-indexing systems; each type is directed to a specific user. Generally, input for index development consists of a mix of materials and labor costs. The composition of this mix determines the relevance of a given index to a particular construction-estimating requirement.

-- Construction cost indices. Various indices used for updating treatment plant costs include the Engineering News Record (ENR) Building Cost Index, the ENR Construction Cost Index, the Chemical Plant Cost Index, the Bureau of Reclamation Index, the EPA Treatment Plant Indices, and Contractor Cost Indices.

-- Operation and maintenance cost indices. Several indices can be used to convert the O&M wastewater treatment plant costs to a common dollar base. Some of the indices used in cost updating include the EPA operation and maintenance cost index, the fuel and utilities component of the National Consumer Price Index (CPI), the Bureau of Labor Statistics (BLS) Water and Sewerage service index, the BLS industrial commodity wholesale price index, factory maintenance cost index (Factory Magazine), and the Business Week price index.

(e) Nonconstruction costs. A large percentage of the total expense of a wastewater treatment project results from non-construction cost items. This category includes legal/administrative cost, architect/engineer fees, construction inspection expense, and contingency allowance. These costs can account for up to 30 percent of the construction cost.

(2) Operation and maintenance costs. Operation and maintenance costs are costs for the normal functioning of wastewater treatment facilities. Amortization of capital costs are not included in the O&M costs. O&M costs are recurring annual costs; they can be estimated by cost curves and other methods.

8-2. Economic principles

The decision about which treatment alternative to select will depend on the economic consequences over a long period of time. Some unit processes are capital-cost-intensive; others are operating- and maintenance-cost-intensive. To compare these alternatives in one time frame (present-worth analysis), it is important to understand the *value of money* at different points in time. The equivalence relationship allows a present sum of money to be related to future sums for various alternatives.

a. Present worth analysis. Present-worth analysis is most often used to determine the present value of future expenditures and receipts. In present-worth analysis, annual operations and maintenance costs are converted to present value and added to construction costs to obtain the total present worth of project costs. Careful consideration is given to the economic and service life of each alternative to be evaluated. Any salvage value remaining after the planning period must be subtracted from the present-worth cost. Table 8-2 summarizes compound interest formulas. Tables 8-3 and 8-4 give values of the factors for 7 and 10 percent interest rates (i) over n years.

b. Economic life

(1) The economic life of a project is the period of time during which it provides a positive benefit to the owner. The factors limiting the duration of economic life are:

(a) Mission life or period over which a need for the project is anticipated.

(b) Physical life or period over which the project may be expected to last physically.

(c) Technological life or period before obsolescence would dictate replacement of the existing or proposed facilities.

(2) There may be significant *lead time* between the initial investment and the beginning of the economic life. Economic life starts only when the alternative begins to yield tangible benefits to the owner. To provide a basis for comparing alternatives, the USEPA has defined economic lives as follows:

Permanent Structures:

30 to 50 years

(includes plant buildings, concrete process tankage, basins, etc.; sewage collection and conveyance pipelines; lift station structures; tunnels; outfalls)

Process Equipment:

15 to 30 years

(includes major process equipment such as clarifier mechanism, vacuum filters, etc.; steel process tankage and chemical storage facilities; electrical generating facilities on standby service)

Auxiliary Equipment:

10 to 15 years

(includes instruments and control facilities; sewage pumps and electric motors; mechanical equipment such as compressors, aeration systems, centrifuges, chlorinators, etc.; electrical generating facilities on regular service)

(3) Land for treatment works, including land used as part of the treatment process or for ultimate disposal of residues, is assumed to have a salvage value at the end of the planning period equal to its prevailing market value at the time of economic analysis. Structures are assumed to have salvage value if there is a use for them at the end of the planning period. Salvage value is estimated using straight-line depreciation during the service life of treatment works.

8-3. Treatment plant cost estimate

a. Capital costs

(1) It is usually difficult and time-consuming to develop detailed engineering cost estimates for actual quantities of labor, materials, and equipment. Detailed and accurate engineering estimates are possible only after the completion of construction drawings and specifications.

(2) The construction and operation costs have been developed for municipal and industrial facilities. Cost data are available for: total plant construction cost based on types of treatment units used; and unit processes construction cost. A reliable source of the construction cost curves is the USEPA report *Construction Costs for Municipal Wastewater Treatment Plants: 1973-1977*⁹ This report, using data on the cost of con-

⁹*Construction Costs for Municipal Wastewater Treatment Plants: 1973-1977*, 430/9-77-013, MCD-37 (USEPA, January 1978).

structing wastewater treatment facilities in the recent past, attempts to set an empirical base from which future costs can be estimated; it assumes that past costs can be adjusted for inflation, material, and labor cost fluctuations and for various other influences to provide an estimate of what similar facilities will cost in the future.

(3) The use of past construction cost information to predict future costs in an empirical approach (cost curves) hinges on the ability to place each planned treatment facility in a precise category of similar plants. This can be by wastewater characteristics, design flow, unit processes used, level of treatment, location, or any combination of these. There must also be enough data to define average cost relationships for particular classifications; as with any cost-estimating tool, there must be an attempt to predict changes in cost parameters and to quantify the effect of these changes on treatment plant construction costs. For example, applying aeration basin cost curves developed for treatment of low-strength municipal wastewater to a high-strength industrial wastewater may result in misleadingly low capital and operation costs.

b. Operation and maintenance costs. Most wastewater treatment facilities spend more for operation and maintenance and for repair over the lifetime of a given facility than on initial capital cost. Operating cost of a treatment facility is the sum of costs for personnel, power, utilities, chemicals, equipment, and materials.

c. Presentation of cost data. Cost comparisons for alternatives can be expressed in several ways. The most commonly used method is total present-worth cost. In this method, all costs over the economic life of the facility (both capital and operating) are computed at their total present worth. Thus, the life-cycle cost of the alternative is expressed in terms of its present value. Another method is comparison in terms of the annual cost. This is computed by dividing the total present-worth cost by the economic life of the alternative in years. Similarly, alternatives can be compared based on daily equivalent costs. When dealing with unusual treatment schemes, it is sometimes helpful to express present-worth costs in terms of unit costs (cost per 1000 gallons treated or cost per pound of BOD removed). Costs can then be readily compared to unit costs for conventional treatment schemes. Table 8-5 shows an example of the different ways to express alternative costs. The cost information is taken from the example in paragraph 8-4c below.

8-4. Example calculations

a. Example: present-worth analysis. Determine the present worth of a treatment plant designed to treat 5 mgd, with a present average daily flow of 4 mgd. Initial construction cost of the plant was \$3,000,000; the average annual O&M cost is \$190,000, and the annual interest rate is 10 percent. The planning period is 20 years, and the salvage value at the end of the period will be \$0.

- (1) Present worth equals initial cost plus present worth of the operating and maintenance costs.
- (2) Equivalent annual cost equals the present worth times the appropriate capital recovery factor.

Solution:

- (1) Initial cost = \$3,000,000.

- (2) Determine the present worth of annual O&M by applying the uniform series present-worth factor for 20 years at 10 percent interest.
 - (a) Uniform series present worth factor = 8.514 (from tab 8-4).
 - (b) Annual O&M = \$190,000.
 - (c) O&M present worth = $\$190,000 \times 8.514$
= \$1,618,000.
- (3) Total present worth = initial cost + O&M present worth
= $\$3,000,000 + \$1,618,000$
= \$4,618,000.
- (4) Determine the equivalent annual cost by applying the capital recovery factor to the total present worth.
 - (a) Capital recovery factor = 0.1175 for 20 years at 10 percent (from Table 8-4).
 - (b) Equivalent annual cost = $\$4,618,000 \times 0.1175$
= \$542,000.

b. Example: present-worth analysis involving varying O&M costs, phased construction, and salvage value. Determine the present worth and annual equivalent cost of a treatment plant for a 20-year period at an interest rate of 7 percent. The average daily flow to the plant will increase linearly over the 20 years from 2 mgd to 5 mgd. The design capacity of the plant will be 3 mgd for the first 10 years of service, and then expanded to 5 mgd.

- (1) Initial cost of the plant is \$2,000,000, and the cost to upgrade to 5 mgd at year 10 is \$1,500,000.
- (2) Salvage value at the end of year 20 is \$750,000.
- (3) Constant annual O&M cost is \$80,000 for years 1 to 10, and \$170,000 for years 11 to 20.
- (4) Variable annual O&M costs increase linearly from \$0 to \$30,000 for years 1 to 10, and again from \$0 to \$30,000 for years 11 to 20.

Solution:

- (1) Initial cost = \$2,000,000; this cost requires no adjustment for the present-worth analysis.
- (2) Determine the present worth of the O&M costs.
 - (a) Determine the present worth of the constant O&M for years 1 to 10. The present-worth factor = 7.024 for 10 years at 7 percent interest (from tab 8-5).

$$\text{Present worth} = \$80,000 \times 8.024 = \$641,920.$$

- (b) Determine the present worth of the variable O&M for years 1 to 10. The gradient present-worth factor = 27.716 for 10 years at 7 percent (from tab 8-3).

$$\text{Present worth} = \frac{\$30,000}{10} \times 27.716 = \$83,000.$$

- (c) Determine the present worth of the constant O&M for years 11 to 20. The uniform payment present-worth factor = 7.024 for 10 years at 7 percent (from tab 8-3). The single payment present-worth factor = 0.5083 for 10 years at 7 percent (from tab 8-3).

$$\text{Present worth} = \$170,000 (7.024) (0.5083) = \$607,000.$$

- (d) Determine the present worth of the variable O&M for years 11 to 20. The gradient present-worth factor = 27.716 for 10 years at 7 percent. The single-payment present-worth factor = 0.5083 for 10 years at 7 percent (from tab 8-3).

$$\text{Present worth} = \frac{\$30,000}{10} (27.716) (0.5083) = \$42,000.$$

- (3) Determine the present worth of the upgrading costs that occur at year 10. The upgrading cost is \$1,500,000 and the single-payment present-worth factor = 0.5083 for 10 years at 7 percent (from tab 8-3).

$$\text{Present worth} = \$1,500,000 (0.5083) = \$762,000.$$

- (4) Determine the present worth of the salvage value at the end of 20 years. Salvage value is \$750,000 and the single-payment present-worth factor = 0.2584 for 20 years at 7 percent (from tab 8-3).
Present worth = \$750,000 (0.2584) = \$194,000.

- (5) Determine the total cost by adding each cost from steps 1 through 3, and subtract the salvage value at the end of 20 years.

Initial cost	\$2,000,000
Constant O&M (year 1-10)	562,000
Variable O&M (year 1-10)	83,000
Constant O&M (year 11-20)	607,000
Variable O&M (year 11-20)	42,000
Upgrade (at year 10)	762,000
Salvage value	<u>-(194,000)</u>
Total cost	\$3,862,000

- (6) Determine the average equivalent cost of the plant over 20 years at 7 percent interest. The uniform payment capital recovery factor = 0.0944 for 20 years at 7 percent (from tab 8-3).

$$\text{Annual cost} = \$3,862,000 (0.0944) = \$365,000.$$

c. Example: cost estimating using cost curves. Estimate the construction cost of a 1.0-mgd activated-sludge treatment facility for fourth-quarter 1979 dollars using cost

curves. Also, estimate the total capital cost of the project. The 1.0-mgd activated-sludge treatment facility includes the following processes: preliminary treatment (screens and grit removal), influent pumping, primary sedimentation, activated sludge, secondary settling, disinfection, outfall, sludge thickening (gravity), aerobic digestion, sludge handling, dewatering, and landfilling of sludge. The plant also contains a combined laboratory, control, and maintenance building.

Solution:

- (1) Determine the construction cost of each unit process using the cost curve. Only the cost curve for preliminary treatment is included (fig 8-1). Table 8-6 summarizes the remaining costs.
- (2) Determine the construction cost of other miscellaneous construction-related costs, also using cost curves.
- (3) Total each cost as presented in table 8-9. This is the construction cost, second-quarter 1978.
- (4) Determine the nonconstruction cost by taking 22.5 percent of the construction cost (6 percent engineering, 16.5 percent legal, planning, supervision, and contingencies).

Nonconstruction cost = \$1,775,000 (0.225) = \$399,000.

- (5) Determine the total project cost by totaling the construction and nonconstruction costs, and adjusting these costs to fourth-quarter 1979 using the SCCT cost index. The second-quarter 1977 SCCT Index = 123; the fourth-quarter 1979 SCCT Index = 158. Table 8-7 summarizes these costs.

Table 8-1

Unit cost for construction items*

<u>Construction Item</u>	<u>Unit Amount</u>	<u>Unit Cost, \$</u>
Granular Foundation Material	cubic yard	8
Rock Excavation	cubic yard	10-15
Concrete Cradle or Encasement	cubic yard	125
Floor Concrete	cubic yard	200
Formed Concrete	cubic yard	300
Ductile Iron Pipe	pound	1.75
Fittings	pound	1.75
Structural Steel	pound	900

*Estimated May 1980 costs.

Table 8-2

Compound interest formulas

Single Payment Formulas

$$\text{Compound Amount } F = P(1+i)^n = P(F/P, i\%, n) = \text{CAF}$$

$$\text{Present Worth } P = F(1+i)^{-n} = F(P/F, i\%, n) = \text{PWF}$$

Uniform Series Formulas

$$\text{Compound Amount } F = A \frac{(1+i)^n - 1}{i} = A(F/A, i\%, n) = A(\text{SCAF})$$

$$\text{Sinking Fund } A = F \frac{i}{(1+i)^n - 1} = F(A/F, i\%, n) = F(\text{SSF})$$

$$\text{Capital Recovery } A = P \frac{i(1+i)^n}{(1+i)^n - 1} = P(A/P, i\%, n) = P(\text{CRF})$$

$$\text{Present Worth } P = A \frac{(1+i)^n - 1}{i(1+i)^n} = A(P/A, i\%, n) = A(\text{SPWF})$$

Gradient Series Formulas

$$\text{Gradient to Uniform Series } A = G \frac{1}{i} - \frac{n}{(1+i)^n - 1} \quad (A/G, i\%, n) = G(\text{GSUF})$$

$$\text{Gradient Present Worth } P = \frac{G}{i} \frac{(1+i)^n - 1}{i} - n \frac{1}{(1+i)^n} = (P/G, i\%, n) = G(\text{GPWF})$$

Table 8-3

Compound interest factors for 7 percent

n	SINGLE PAYMENT		UNIFORM PAYMENT SERIES				GRADIENT SERIES	
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth
	Find F Given P F/P	Find P Given F P/F	Find A Given F A/F	Find A Given P A/P	Find F Given A F/A	Find P Given A P/A	Find A Given G A/G	Find P Given G P/G
1	1.070	.9346	1.0000	1.0700	1.000	.935	0	0
2	1.145	.8734	.4831	.5531	2.070	1.808	.483	.873
3	1.225	.8163	.3111	.3811	3.215	2.624	.955	2.506
4	1.311	.7629	.2252	.2952	4.440	3.387	1.416	4.795
5	1.403	.7130	.1739	.2439	5.751	4.100	1.865	7.647
6	1.501	.6663	.1398	.2098	7.153	4.767	2.303	10.978
7	1.606	.6227	.1156	.1856	8.654	5.389	2.730	14.715
8	1.718	.5320	.0975	.1675	10.260	5.971	3.147	18.789
9	1.838	.5439	.0835	.1535	11.978	6.515	3.552	23.140
10	1.967	.5083	.0724	.1424	13.816	7.024	3.946	27.716
11	2.105	.4751	.0634	.1334	15.784	7.499	4.330	32.466
12	2.252	.4440	.0559	.1259	17.888	7.943	4.703	37.351
13	2.410	.4150	.0497	.1197	20.141	8.358	5.065	42.330
14	2.579	.3878	.0443	.1143	22.550	8.745	5.417	47.372
15	2.759	.3624	.0398	.1098	25.129	9.108	5.758	52.446
16	2.952	.3387	.0359	.1059	27.888	9.447	6.090	57.527
17	3.159	.3166	.0324	.1024	30.840	9.763	6.411	62.592
18	3.380	.2959	.0294	.0994	33.999	10.059	6.722	67.622
19	3.617	.2765	.0268	.0968	37.379	10.336	7.024	72.599
20	3.870	.2584	.0244	.0944	40.995	10.594	7.316	77.509
21	4.141	.2415	.0223	.0923	44.865	10.836	7.599	82.339
22	4.430	.2257	.0204	.0904	49.006	11.061	7.872	87.079
23	4.741	.2109	.0187	.0887	53.436	11.272	8.137	91.720
24	5.072	.1971	.0172	.0872	58.177	11.469	8.392	96.255
25	5.427	.1842	.0158	.0858	63.249	11.654	8.639	100.676
26	5.807	.1722	.0146	.0846	68.676	11.826	8.877	104.981
27	6.214	.1609	.0134	.0834	74.484	11.987	9.107	109.166
28	6.649	.1504	.0124	.0824	80.698	12.137	9.329	113.226
29	7.114	.1406	.0114	.0814	87.347	12.278	9.543	117.162
30	7.612	.1314	.0106	.0806	94.461	12.409	9.749	120.972
31	8.145	.1228	.0098	.0798	102.073	12.532	9.947	124.655
32	8.715	.1147	.0091	.0791	110.218	12.647	10.138	128.212
33	9.325	.1072	.0084	.0784	118.933	12.754	10.322	131.643
34	9.978	.1002	.0078	.0778	128.259	12.854	10.499	134.951
35	10.677	.0937	.0072	.0772	138.237	12.948	10.669	138.135

Table 8-3 (Cont'd)

n	SINGLE PAYMENT		UNIFORM PAYMENT SERIES				GRADIENT SERIES	
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth
	Find F Given P F/P	Find P Given F P/F	Find A Given F A/F	Find A Given P A/P	Find F Given A F/A	Find P Given A P/A	Find A Given G A/G	Find P Given G P/G
40	14.974	.0668	.0050	.0750	199.635	13.332	11.423	152.293
45	21.002	.0476	.0035	.0735	285.749	13.606	12.036	163.756
50	29.457	.0339	.0025	.0725	406.529	13.801	12.529	172.905
55	41.315	.0242	.0017	.0717	575.929	13.940	12.921	180.124
60	57.946	.0173	.0012	.0712	813.520	14.039	13.232	185.768
65	81.273	.0123	.0009	.0709	1146.755	14.110	13.476	190.145
70	113.989	.0088	.0006	.0706	1614.134	14.160	13.666	193.519
75	159.876	.0063	.0004	.0704	2269.657	14.196	13.814	196.104
80	224.234	.0045	.0003	.0703	3189.063	14.222	13.927	198.075
85	314.500	.0032	.0002	.0702	4478.576	14.240	14.015	199.572
90	441.103	.0023	.0002	.0702	6287.185	14.253	14.081	200.704
95	618.670	.0016	.0001	.0701	8823.854	14.263	14.132	201.558
100	867.716	.0012	.0001	.0701	12381.662	14.269	14.170	202.200

Table 8-4

Compound interest factors for 10 percent

n	SINGLE PAYMENT		UNIFORM PAYMENT SERIES				GRADIENT SERIES	
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth
	Find F Given P F/P	Find P Given F P/F	Find A Given F A/F	Find A Given P A/P	Find F Given A F/A	Find P Given A P/A	Find A Given G A/G	Find P Given G P/G
1	1.100	.9091	1.0000	1.1000	1.000	.909	0	0
2	1.210	.8264	.4762	.5762	2.100	1.736	.476	.826
3	1.331	.7513	.3021	.4021	3.310	2.487	.937	2.329
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.800
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583
20	6.727	.1486	.0175	.1175	57.275	8.514	6.508	55.407
21	7.400	.1351	.0156	.1156	64.002	8.649	6.719	58.109
22	8.140	.1228	.0140	.1140	71.403	8.772	6.919	60.689
23	8.954	.1117	.0126	.1126	79.543	8.883	7.108	63.146
24	9.850	.1015	.0113	.1113	88.497	8.985	7.288	65.481
25	10.835	.0923	.0102	.1102	98.347	9.077	7.458	67.696
26	11.918	.0839	.0092	.1092	109.182	9.161	7.619	69.794
27	13.110	.0763	.0083	.1083	121.100	9.237	7.770	71.777
28	14.421	.0693	.0075	.1075	134.210	9.307	7.910	73.650
29	15.863	.0630	.0067	.1067	148.631	9.370	8.049	75.415
30	17.449	.0573	.0061	.1061	164.494	9.427	8.176	77.077
31	19.194	.0521	.0055	.1055	181.943	9.479	8.296	78.640
32	21.114	.0474	.0050	.1050	201.138	9.526	8.409	80.108
33	23.225	.0431	.0045	.1045	222.252	9.569	8.515	81.486
34	25.548	.0391	.0041	.1041	245.477	9.609	8.615	82.777
35	28.102	.0356	.0037	.1037	271.024	9.644	8.709	83.987

Table 8-4 (Cont'd)

n	SINGLE PAYMENT		UNIFORM PAYMENT SERIES				GRADIENT SERIES	
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth
	Find F Given P F/P	Find P Given F P/F	Find A Given F A/F	Find A Given P A/P	Find F Given A F/A	Find P Given A P/A	Find A Given G A/G	Find P Given G P/G
40	45.259	.0221	.0023	.1023	442.593	9.779	9.096	88.953
45	72.890	.0137	.0014	.1014	718.905	9.863	9.374	92.454
50	117.391	.0085	.0009	.1009	1163.909	9.915	9.570	94.889
55	189.059	.0053	.0005	.1005	1880.591	9.947	9.708	96.562
60	304.482	.0033	.0003	.1003	3034.816	9.967	9.802	97.701
65	490.371	.0020	.0002	.1002	4893.707	9.980	9.867	98.471
70	789.747	.0013	.0001	.1001	7887.470	9.987	9.911	98.987
75	1271.895	.0008	.0001	.1001	12708.954	9.992	9.941	99.332
80	2048.400	.0005		.1000	20474.002	9.995	9.961	99.561
85	3298.969	.0003		.1000	32979.690	9.997	9.974	99.712
90	5313.023	.0002		.1000	53120.226	9.998	9.983	99.812
95	8556.676	.0001		.1000	85556.761	9.999	9.989	99.877
100	13780.612	.0001		.1000	137796.123	9.999	9.993	99.920

Table 8-5

Example computation of expressing cost estimates

	Estimated Cost	PW Factor	Present-Worth* Cost
Capital Cost (1977, 2nd Quarter)	\$2,174,000	$\frac{158}{123}$	\$2,793,000
O&M Cost	130,000/year	8.514	1,107,000
Salvage Value (estimate)	(502,000)	0.1486	<u>(75,000)</u>
Total Life-Cycle Cost			3,975,000
Annual Cost**			467,000
Daily Cost			1,280
Unit Cost per 1000 gallons			1.28

*4th quarter, 1979.

**A discount rate of 10 percent is used over an economic life of 20 years.

Table 8-6

Construction cost of 1.0 million gallons per day treatment plant
(Second quarter 1977 costs)

Unit Process/Component	Estimated Cost (thousands of dollars)
Preliminary treatment	\$ 58
Influent pumping	147
Primary sedimentation	69
Activated sludge	227
Secondary settling	109
Disinfection	53
Outfall	74
Gravity thickening	33
Aerobic digestion	147
Sludge handling	43
Dewatering	34
Sludge disposal	--
Laboratory and Control Building	<u>165</u>
Mobilization	48
Sitework	112
Excavation	138
Electrical	136
Instrumentation and control	51
Yard piping and miscellaneous	100
HVAC	<u>31</u>
Total estimated construction cost	\$ 1,775 - second quarter 1977

Table 8-7

Estimated total project (capital) costs

	Second quarter 1977*	Fourth quarter 1979**
Estimated construction cost	$\$1,775,000 \times \frac{158}{123} =$	$\$2,280,000$
Nonconstruction cost (22.5% of construction cost)	$\frac{399,000}{123} \times \frac{158}{123} =$	$\frac{513,000}{123}$
Total estimated project cost	$\$2,174,000$	$\$2,793,000$

*Second-quarter 1977 SCCT Index = 123

**Fourth-quarter 1979 SCCT Index = 158

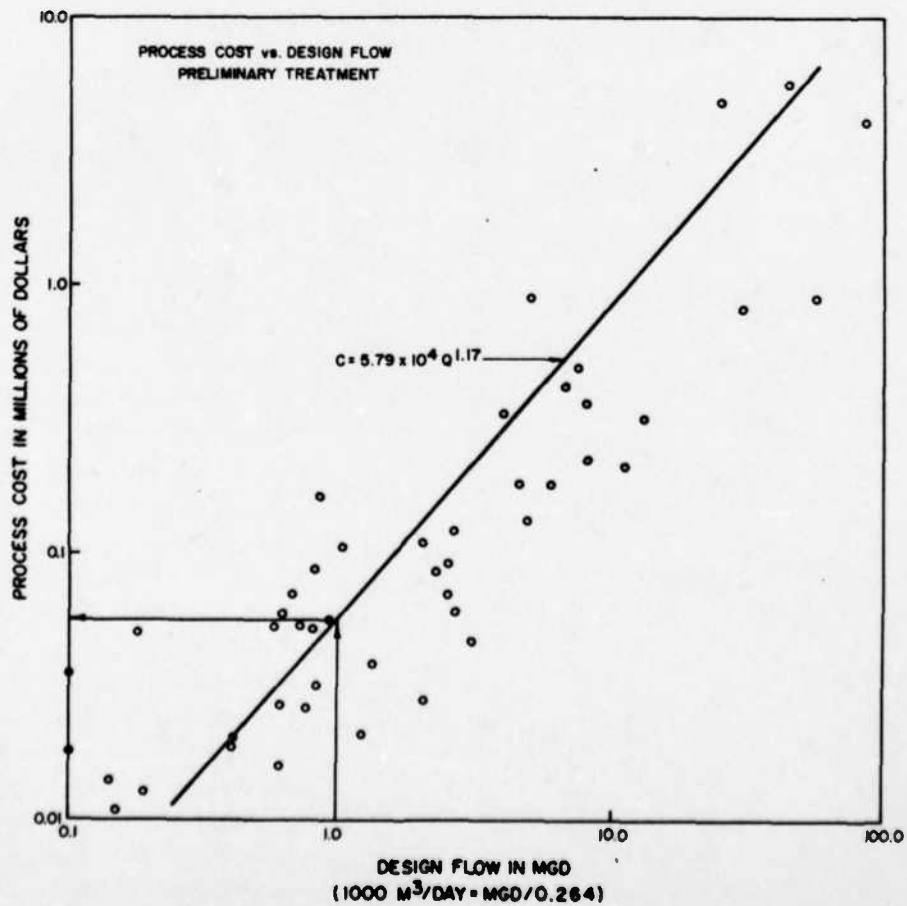


Figure 8-1. Preliminary treatment cost curve.

Chapter 9

Summary

This report has provided a general reference guide for identifying, designing, and reviewing industrial water pollution abatement projects.

Industrial wastewater regulations have been summarized that provide the regulatory background for treating wastewaters generated by military industrial operations. Methods for handling and disposing of hazardous wastes have been identified. These include methods for identifying regulated and nonregulated hazardous wastes, hazard reduction techniques, contingency plans, and storage, treatment, and disposal techniques. Guidelines have been provided for generators, transporters, and owners and operators of storage, treatment, and disposal facilities.

The characteristics and sources of industrial wastewaters have been identified and methods for performing an industrial waste survey outlined. Survey methods discussed include objectives, organization, identification of sources, location of sampling and monitoring stations, measurement of wastewater flow, sampling, data evaluation, and safety factors.

Industrial wastewater control technologies have been summarized for preliminary treatment, primary treatment, biological treatment, stabilization, physical and chemical treatment, and sludge dewatering and disposal. Methods for solving industrial wastewater problems have been investigated, and various philosophies for pollution abatement outlined. Various disposal alternatives have been discussed and process selection guidelines provided. Methods for upgrading existing facilities have also been given.

One of the most important aspects of pollution control is an abatement method's cost-effectiveness. This report provided an overview of economic principles used to analyze a solution's costs. Example cost calculations have been provided for several alternatives in order to provide a basis for user applications of the economic principles.

Appendix A

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Appendix B

Example Waste Survey

B-1. Background

The following example waste survey is given for a fictional Army base; the example is intended to represent procedures that would typically apply, in general, to many military installations. Eagle Army Base operates a primary treatment plant to treat sanitary wastewater discharges and discharges from vehicle maintenance operations. The Directorate of Engineering and Housing was informed that secondary treatment would be required for the discharges within 3 years; therefore, Directorate personnel decided to conduct a waste survey from which treatment options could be developed. The Director of Utilities was instructed to devise a plan for conducting the survey. The Director of Utilities determined that the following steps would provide the needed information:

- Define scope of survey.
- Assemble survey team.
- Assign tasks and implement logistics.
- Conduct preliminary survey.
- Determine survey requirements.
- Implement waste survey.
- Assemble survey data.
- Develop and summarize survey findings.
- Develop and summarize waste treatment and waste recovery options.

A consultant was hired to perform the survey under the supervision of the Director of Utilities.

B-2. Scope of survey

Military installations normally have only two acceptable options for managing sanitary and industrial process discharges. The generally preferred option of discharging all facility wastes to a local, publicly owned treatment facility is not available to Eagle Army Base because of its remote location. Therefore, the survey will collect data on waste recovery and the design of treatment facilities. To this end, the consultant was tasked with:

- Assembling survey team and establishing lines of communication.
- Inspecting existing sewers and confirming drawings.
- Measuring flow rate and pollutant concentration in major flow tributaries.
- Computing average and extreme pollutant loadings.

-- Indicating areas where waste reduction and recovery should be practiced.

-- Producing a report summarizing survey findings.

B-3. The survey team

Personnel were organized into a survey team as shown in figure B-1. Lines of communication were established to allow for management and supervision of the project, to facilitate use of Army facilities, and to provide access to restricted areas by the surveyor.

B-4. Preliminary site inspection

A preliminary site inspection was conducted to identify sampling stations and determine sampling requirements. Upon completion of the preliminary site inspection, sampling and monitoring requirements were defined. For example, table B-1 illustrates sampling and monitoring requirements for sample point F, TAC Bldg. 9 effluent. Eight sampling points were identified as major waste sources requiring the installation of sampling and monitoring stations as itemized in table B-2. The preliminary inspection confirmed that the sewer layout drawing (fig B-2) was accurate. The drawing shows sample points itemized in table B-2. During the preliminary inspection, sampling requirements were defined and flow measurement techniques selected. It was determined that grab sampling of sample points A, B, and C would be adequate for these waste streams. Composite samples were required for all other waste streams. Twenty-four-hour composite samplers were installed at points H (lift sump) and D. Samples for stations C, E, and F were composited manually.

B-5. The waste survey

The preliminary site inspection provided the information needed to detail a sampling and analytical program. Use of table B-1 allowed the surveyor to determine sampling logistics and meet sampler installation requirements.

a. **Sampling and analytical program.** It was determined that sanitary waste discharges could be adequately characterized by grab sampling. These discharges include the training center (Building 2), the Hospital (Building 7), the PX and Rec Center (Building 11), the Enlisted Barracks (Building 8), and the Quartermaster Warehouse building (Building 4). Composite samples were determined to be necessary for the Mess Hall (Building 15), Maintenance Shop and tributaries (Buildings 3, 6, 12, 10, 1), the Tactical Equipment Motor Pool (Building 5), the Centralized Vehicle Washrack (Building 9), and the lift sump. When it was known that heavy waste discharges could be expected from a work area, more samples and measurements were taken to identify peak loadings. The sampling and analytical program was conducted for 6 weeks. Table B-3 shows the sampling and analysis schedule.

b. **Water balance.** A mass balance of water flows was conducted to trace water flow from the origin to the lift sump. Flow measurements in the main trunk and in tributary sewers were made by frequent spot measurements, using the velocity and depth-of-flow method. These measurements were summed and found comparable to measurement of total facility discharge. Total facility discharge was measured by the Parshall flume continuous-flow monitor at the primary treatment plant. Figure B-3 is a schematic of the water balance. Flow measurements in process areas were made by the bucket-and-stopwatch method, equipment specifications, and the velocity and depth-of-flow method.

c. Wastewater characterization. All sample points were analyzed for BOD, COD, TSS, flow rate, and pH. Discharges from sample points D, E, and F were also analyzed for oil and grease (O/G). Table B-4 gives the results of these analyses. EPA-approved analytical procedures were used in all analytical testing.

B-6. Wastewater survey findings

a. The Eagle Army Base produces industrial and domestic wastewater discharges from several sources. The industrial discharges are primarily from vehicle washrack and vehicle maintenance operations. There are seven major waste source areas on the facility, all of which discharge wastestreams at one or more points.

b. The seven major waste sources combine with several minor sources to produce the total facility discharge at the lift sump (sample point H). The pumping station at the lift sump transports the total facility discharge to the primary treatment plant. After primary treatment, the wastewater flows by gravity to the Trace River.

c. A chemical and flow analysis of the various wastestreams was conducted to define the total pollutants discharged and the quantity of pollutants emanating from each area. Table B-5 presents the results of these investigations.

d. The data show that most wastewaters are sanitary in nature and are considered to have no recovery value. Wastewaters associated with vehicle maintenance (Buildings 1, 3, 5, 7, 9) were found to contain relatively low concentrations of BOD and COD, but high quantities of dirt and grit and some oil.

e. The total facility discharge produces about 1100 pounds/day BOD, 2510 pounds/day COD, and 1560 pounds/day TSS at a flow rate of 0.89 million gallons per day. Of this total, about 50 pounds/day BOD, 580 pounds/day COD, 500 pounds/day TSS, and 0.14 million gallons per day of flow are due to vehicle maintenance and washing. Vehicle maintenance and washing make up only 5 percent of the total BOD loading, but provide 23 percent of the COD loading and 36 percent of the TSS loading, most of which is dirt and grit.

f. Because of the large contribution of TSS and COD to the total facility waste load from vehicle maintenance, special consideration should be given to future design of pretreatment facilities.

g. Oil and grease waste loadings total about 20 pounds/day, or 2.9 milligrams per liter. While these loadings are relatively low, the potential for much higher loadings from spills is very high. Consideration should be given to installing oil separators at all machine shop locations.

Table B-1

Checklist for location of sampling and monitoring equipment

Date	_____	Sample Location	_____
1	yes no	Is location accessible from road?	_____
2	yes no	Is flow channel accessible? Explain	_____
3	in out	Is location inside or outside building?	_____
4	yes no	Is source of discharge known? Specify	_____
5	yes no	Are there any other sources at this point? Specify	_____
6	yes no	Does sampling/monitoring equipment require housing?	_____
7	yes no	Is electricity available?	_____
8	yes no	Is there explosive or other hazard? Specify.	_____
9	open closed	Is flow channel open or closed? Specify type. Concrete floor truck 12"L x 12" D x 12"W	_____
10	grab comp	Type of sample to be taken. Specify 24 hr comp	_____
11	Volume 5 gal	Volume of sample required per day or sampling period.	_____
12	Location	Location of sample point in flow channel. Specify. Immediately before sewer inlet	_____
13	man auto	Type of sampling equipment needed. Specify. ISCO 1680	_____
14	instant. cont.	Type of flow measurement to be taken.	_____
15	Type V-notch when diurnal	Flow monitoring technique to be used. Specify. 60°V-Notch Weir	_____
16	Type sampling	Other monitoring to be done at this location. Specify. Diurnal: 1 grab/hour	_____
17	yes no	Special safety precautions needed? Specify.	_____
18	yes no	Unusual characteristics of waste? Specify (not, high suspended solids, etc.)	_____

COMMENTS: 1. Need Electrical Extension Cord to Sampling Station
 2. Weir must be fabricated

Table B-2

Identification of sample point tributaries

Sample	Point	Tributary	Type of Sample
1.	A	Training Center (Bldg. 2) Hospital (Bldg. 7)	Grab
2.	B	PX and Rec Center (Bldg. 11)	Grab
3.	C	Mess Hall (Bldg. 15)	Composite
4.	D	Maintenance Shop (Bldg. 3) Env. Lab (Bldg. 6) Pac. Lab (Bldg. 12) Stores (Bldg. 10) Administration (Bldg. 1)	Composite
5.	E	Tactical Equipment Motor Pool (Bldg. 5)	Composite
6.	F	Centralized Vehicle Washrack (Bldg. 9)	Composite
7.	G	Barracks (Bldg. 8) Quartermaster (Bldg. 4)	Grab
8.	H	Lift Sump	Composite

Table 2-3

Sampling and analytical schedule

Sample Point	Type of Sample	Analysis and Frequency								
		BOD ₅ (milligrams/liter)	BOD ₅ (milligrams/liter)	COD _{Cr} (milligrams/liter)	COD _{Cr} (milligrams/liter)	TSS/VSS (milligrams/liter)	Set. sol. (milliliters)	pH (Units)	O & C (milligrams/liter)	Flow (gallons per day)
A	Grab	MWF	W	MWF	W	MWF	MWF	Daily	Th	Daily
B	Grab	TuTh	Tu	TuTh	Tu	TuTh	TuTh	Daily	Th	Daily
C	Comp	MWF	MW	MWF	MW	TuTh	TuTh	Daily	TuTh	Daily
D	Comp	Daily	MW	Daily	MW	MWF	MWF	Daily	TuTh	Daily
E	Comp	TuTh	Tu	TuTh	Tu	TuTh	TuTh	Daily	TuTh	Daily
F	Comp	TuTh	Tu	TuTh	Tu	MTuTh	MTuTh	Daily	TuTh	Daily
G	Grab	TuTh	Tu	TuTh	Tu	TuTh	TuTh	Daily	Th	Daily
H	Grab	Daily	MWF	Daily	MWF	MWF	MWF	Daily	TuTh	Daily

Table B-4

Characterization of tributary wastestreams

Parameter	Sample Identification													
	A	B	C	D	E	F	G							
	Bldg 2,7		Bldg 11		Bldg 16		Location Bldg 1,3,6,12,10		Bldg 5		Bldg 9		Bldg 4,8	
BOD (milligrams/liter)	210	260	410	125	60	30	200							
COD (milligrams/liter)	300	450	800	300	400	560	300							
TSS (milligrams/liter)	230	300	540	100	120	1,900	230							
FLOW (gallons per minute)	110	30	20	365	50	20	20							
pH (units)	7.5	7.2	7.2	6.0	6.5	7.5	7.2							
O/C (milligrams/liter)	--	--	--	2	15	11	--							

Table B-5

Wastewater flow and material balance
Eagle Army Base

Parameter	Sample Identification								
	A	B	C	D		E	F	G	H
	Bldg	Bldg	Bldg	Location		Bldg	Bldg	Bldg	Lift
	2,7	11	16	1,3,6,12,10		5	9	4,8	Sump
BOD (pounds/day)	277	94	98	548		36	7	48	1,110
COD (pounds/day)	396	162	192	1,315		240	135	72	2,510
TSS (pounds/day)	304	108	130	438		72	456	55	1,560
FLOW (gallons/minute)	110	30	20	365		50	20	20	615

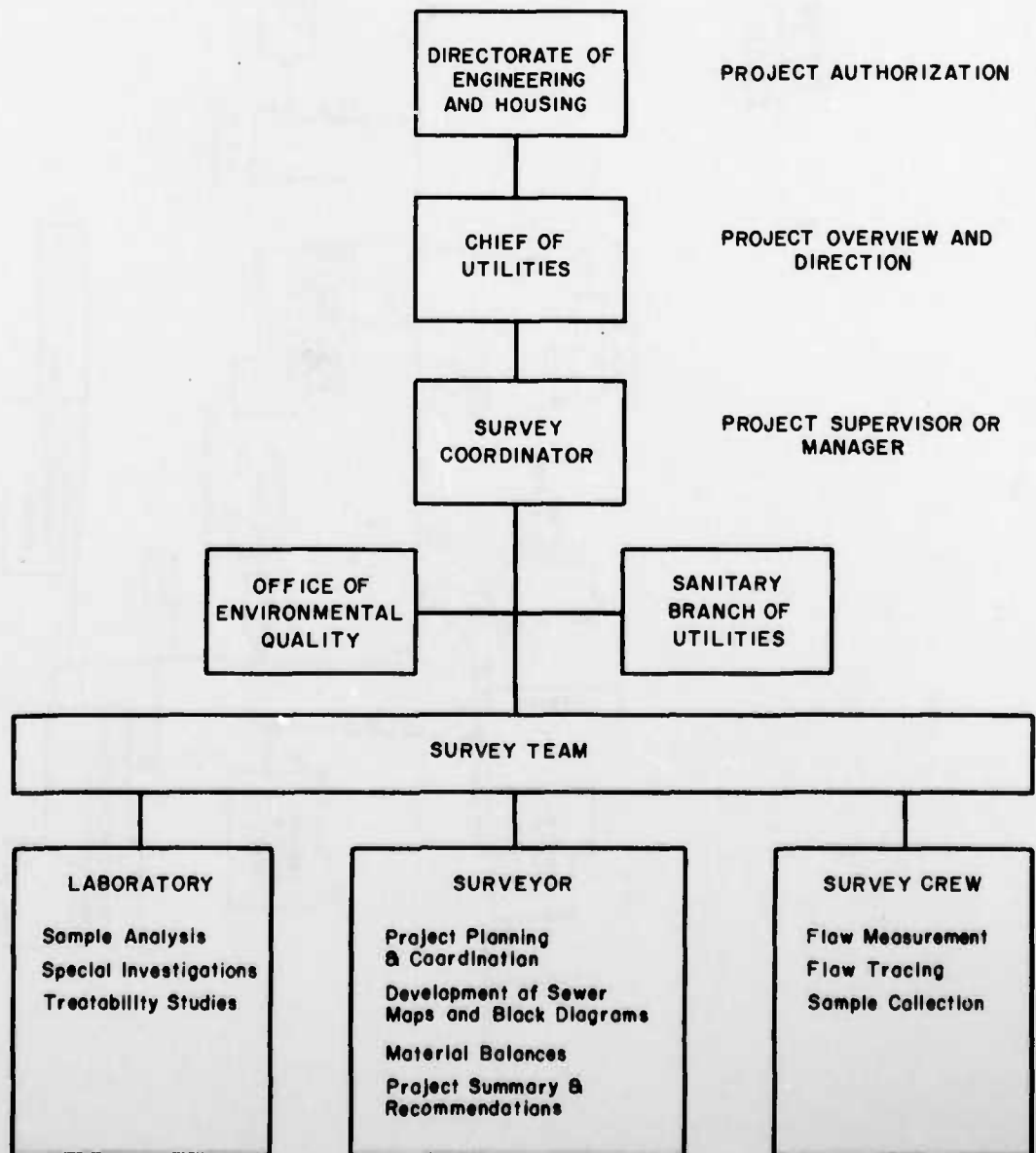


Figure B-1. Eagle Army Base survey organization chart.

Appendix C

Flow Measuring and Sampling Techniques

C-1. Primary flow measuring devices

There are several methods and devices for measuring flow in pressurized pipes. These include: venturi meter, flow nozzle, orifice meter, magnetic meter, pitot tube, and rotameter.

a. Venturi meter

(1) The venturi meter (fig C-1) is a pipe segment consisting of a converging section, a throat, and a diverging section. In venturi tubes and similar devices, a part of the static head (pressure) is transferred into the velocity head. Therefore, the static head in the throat of the tube is less than the static head in the channel. This difference in head is related directly to the flow.

(2) Instruments which use this differential head technique are called headloss devices. The general equation for calculating the flow in a headloss device is:

$$Q = CAK \sqrt{H} \quad (\text{Eq C-1})$$

For a venturi meter, the equation becomes:

$$q = 440AK \sqrt{H} \quad (\text{Eq C-2})$$

or

$$Q = 0.98AK \sqrt{H} \quad (\text{Eq C-3})$$

where:

q = volume of water, in gallons per minute

Q = volume of water, in cubic feet per second

C = discharge coefficient, about 0.98 for venturis

A = throat area, in square feet

H = $H_2 - H_1$, differential head, in feet of water

H_1 = pressure head at center of pipe in inlet section, in feet of water

H_2 = pressure head at throat, in feet of water

$$K = \frac{2g}{1 - \left(\frac{d_2}{d_1}\right)^4} \quad (\text{obtain values of } K \text{ from fig C-2}) \quad (\text{Eq C-4})$$

where:

g = gravity constant, 32.2 feet per second

d_2 = throat diameter, in feet

d_1 = diameter of inlet pipe, in feet

Using figure C-2, the flow through the meter can be calculated when the differential pressure is measured.

(3) Venturi tubes are often used where high-pressure recovery is essential, or where large amounts of solids in the flow stream would tend to collect in front of an orifice plate.

(4) To obtain accurate measurements, the meter must be installed downstream from a section of straight and uniform pipe. The required length of straight section depends on the ratio of throat diameter to pipe diameter. Typically, 5 to 15 pipe diameters of straight run are required before the venturi. Manufacturers of venturi meters routinely size their meters for a specific use. Therefore, it is important that the meter be installed according to their instructions.

b. Flow nozzle

(1) A flow nozzle is a hybrid device whose characteristics are between those of a venturi meter and an orifice. Figure C-3 shows an installed flow nozzle. Flow nozzles create more headloss than venturi meters but less than orifices. Their cost is also between that of venturi meters and orifices. The flow-measuring principles are the same, inasmuch as static pressure is transferred into velocity. The flow formula for the venturi tube also applies to the nozzle because the discharge coefficients are about the same. Flow nozzles can be used in wastewater flows having moderate amounts of suspended solids.

(2) Many flow nozzles are available commercially. Each manufacturer uses a slightly different nozzle form, ranging from a venturi to an orifice. A nozzle's characteristics can be predicted according to whether they most resemble the venturi or the orifice.

c. Orifice meter

(1) An orifice meter is a relatively inexpensive, easy-to-install, and reliable flow-measuring device. It is basically an obstacle placed in the path of flow. The thin-plate orifice is most commonly used.

(2) The principles for operating an orifice are the same as for nozzles and venturi meters. The stream lines of the flow and the basic formula are of the same form as for a venturi meter:

$$Q = CAK H \quad (\text{Eq C-5})$$

(3) Figure C-4 illustrates the coefficient, C, for several forms of orifices. The nominal coefficients apply to relatively large orifices operating under comparatively large heads of water.

(4) Variations in flow are accommodated by varying the throat width. The main disadvantage of the orifice is the large headloss that occurs across the section. Figure C-5 compares the relative permanent pressure loss for the primary flow elements.

d. Pitot pipe. Figure C-6 is a schematic diagram of a simple pitot tube. In operation, the velocity of the flow is calculated from the difference in head measured on the manometer. The pressure in the left tube measures the static pressure in the pipe; the right tube measures the stagnation pressure, or the pressure where the velocity is zero. Pitot tube measurements should be made in a straight section upstream that is free of valves, tees, elbows, and other fittings. A minimum upstream distance of 15 to 50 diameters of straight pipe is recommended. When a straight section is not possible, a velocity profile should be determined experimentally. Pitot tubes create a minimal amount of headloss. They are not practical for use with liquids having large amounts of suspended solids because of the possibility of plugging. In large pipes, the pitot tube is one of the most economical means of measuring flows.

e. Magnetic flow meters

(1) Several manufacturers supply magnetic flow meters that can be used successfully in places where other types of meters would become clogged by solids. The magnetic flow meter (fig C-7) operates according to Faraday's Law of Induction: the voltage induced by a conductor moving at right angles through a magnetic field will be proportional to the velocity of the conductor through the field. With magnetic flow meters, the water flowing in the pipe is the conductor, and a set of electromagnetic coils in the flow meter produces the field. The induced voltage is drawn off through the flow meter electrodes, which are in contact with the liquid, and then transmitted to a converter for signal conditioning. The voltage is proportional to the average velocity in the pipe cross-section. The flow can be readily calculated if the pipe diameter is known.

(2) In a given meter, the induced voltage is a function only of liquid velocity, and is not affected by temperature, viscosity, turbulence, or conductivity (above a minimum threshold of 5 micro-ohms). For liquids with conductivity values of 0.1 to 5 micro-ohms, a special signal converter is needed. The magnetic flow meter can be used in pipes with a diameter as small as 0.1 inch.

(3) The accuracy of the meter increases with increases in velocity. An accuracy of 1 percent can be obtained for flow velocities from 3 to 30 feet per second. The magnetic flow meter does not cause headloss, because the pressure loss is not greater than for flow through an equivalent length of straight pipe.

f. Rotameters. Rotameters are tapered tubes in which the fluid flows vertically upward. A metal float in the tube comes to equilibrium at a point where the annular flow area is such that the velocity around the float keeps it suspended. Rotameters are simple, inexpensive, and accurate devices for measuring relatively small flow rates of clear, clean liquids. Thus, they are often used to measure the water flow rate into individual processing steps in manufacturing operations. To maintain accuracy in a rotameter, both the tube and float must be kept clean.

C-2. Weirs

Various weirs are used to measure flow in open channels. These include the Cipolletti, triangular, and rectangular weirs.

a. Common flow formula. The common formula for flow over a weir is:

$$\frac{2}{3} \sqrt{2g} H^{3/2} \quad (\text{Eq C-6})$$

where

q = flow per unit of width, cubic feet per second

g = gravity (32 feet per second squared)

H = head above crest (upstream), feet

A coefficient, C , is usually included to compensate for the nonuniformity of flow. Thus, the equation for the flow per unit of width becomes:

$$C_w \frac{2}{3} \sqrt{2g} H^{3/2} \quad (\text{Eq C-7})$$

where:

C_w = nonuniformity coefficient (less than or equal to 1).

Permanently installed weirs should be calibrated after installation, since coefficients in the weir formulas may vary due to many factors. However, reasonable flow estimates can be obtained without calibration when weirs are used properly.

b. Velocity head correction. When the velocity of approach for a suppressed, contracted, or Cipolletti weir is too high to neglect, a correction factor can be introduced into the flow equation. The correction factor extends the use of the basic formula for weirs to include the velocity head as follows:

$$h = \frac{V^2}{2g} \quad (\text{Eq C-8})$$

where:

h = velocity head, feet

V = approach velocity, feet per second

g = gravity (32 feet per second squared)

Then the term $H^{3/2}$ in the basic equation is converted to:

$$H^{3/2} = (H + h)^{3/2} - h^{3/2} \quad (\text{Eq C-9})$$

c. Cipolletti weir. The Cipolletti weir has a trapezoidal form; it has end slopes of one horizontal to four vertical, which corrects for the horizontal contraction of the nappe. Thus, no correction is needed for the crest width. The general equation for the Cipolletti weir is:

$$Q = 3.367 LH^{3/2} \quad (\text{Eq C-10})$$

where:

Q = discharge, cubic feet per second

L = length of the weir opening at the base, feet

H = measured head above crest, feet

d. Rectangular weirs

(1) Rectangular weirs may be straight or notched. A straight weir, also called a suppressed weir, has no end contractions. A notched weir may have one or two end contractions, and if the crest height is greater than 5H (where H = head above crest), the approach velocity may be neglected. However, with a suppressed weir, the water flows over the full width of the weir and problems may develop when a vacuum forms under the nappe.

(2) The most common type of rectangular weir is the notched weir with end contractions. If the end contractions are standard (that is, the width of each end contraction is at least 2.0 times the head above the crest), the Francis formula applies in computing the flow:

$$Q = 3.33 LH^{3/2} \quad (\text{Eq C-11})$$

where:

Q = flow, cubic feet per second

L = effective width of the weir, feet

H = head above crest, feet

(3) Figure C-8 presents a nomograph of the Francis formula which can be used for either suppressed weir or one with standard end contractions. These conventional calculations do not apply when estimating discharges with very low heads that cause the nappe to cling to the weir face.

e. Triangular weirs. The triangular weir or V-notch type is of value for measuring low flows. It should be used for flows less than 1 cubic foot per second (450 grams per minute) and is not recommended if the flow is greater than 2 cubic feet per second. The V-notch weir may be constructed with any angle, the most commonly used angle is 90 degrees. Another common V-notch weir has an angle of 60 degrees. The end contraction on each side of the weir should be at least $\frac{3}{4}L$, where L is the width of the water surface at maximum elevation. Figure C-9 is a nomograph for determining flow rates for 60-degree and 90-degree V-notch weirs. The formula for the 90-degree notch weir is:

$$Q = 2.49H^{2.5} \quad (\text{Eq C-12})$$

where:

Q = flow in cubic feet per second

H = head over weir in feet

V-notch weirs are not recommended if H is less than 0.3 feet, since the possibility of the nappe adhering to the weir plate becomes too great. Table C-1 gives the minimum discharge without nappe adherence for heads lower than 0.3 feet.

f. Broad-crested weir. The flow formula for a broad-crested weir is:

$$Q = 2/3L \sqrt{2g} E^{3/2} \quad (\text{Eq 13})$$

where:

Q = flow, cubic feet per second

L = length of weir crest

$$E = H + \frac{V^2}{2g}$$

The term $V^2/2g$ can be neglected for low-approach velocities. This type of weir is usually made of concrete. The advantage of the broad-crested weir is that the surface elevation upstream is not influenced by the downstream water surface; thus, it operates accurately with submerged flow.

C-3. Flumes

This section discusses the use, dimensions, and capacities of the commonly used flumes: Parshall and Palmer-Bowlus.

a. Parshall flume

(1) The Parshall flume is a convenient device for measuring the flow in sewers. It consists of three parts: a converging section, a throat section, and a diverging section. Figure C-10 presents a plan and cross-section view of a Parshall flume. Note that the floor of the flume in the converging section is higher than the floor in the throat and diverging sections.

(2) The elevation of the water surface should be measured back from the crest of the flume at a distance equal to two-thirds of the length of the converging section. The crest is located at the junction of the throat and converging section. The head should be measured in a stilling well instead of in the flume itself, since sudden changes in flow are dampened in a stilling well. The size of the Parshall flume should be determined during the preliminary survey. Figure C-10 shows typical dimensions and capacities of Parshall flumes. The general formula for computing the free discharge from a Parshall flume is:

$$Q = 4WH^n \quad (\text{Eq C-14})$$

where:

Q = discharge, cubic feet per second

W = throat width, feet

H = head of water above the level floor in feet in the converging section

$$n = 1.522W^{0.026}$$

(3) Figure C-11 presents flow curves for various sizes of Parshall flumes. The flume may be built of wood, fiberglass, concrete, plastic, or metal, and can be installed at a convenient location, such as a manhole. Many prefabricated models are available. The Parshall flume is used for sewer lines where continuous-flow measurements are desirable. Its main advantage over a weir is the self-cleaning properties of the flume.

(4) Accurate measurements can be made, even if the flow is submerged, as indicated by the water levels in figure C-11. The flow can become submerged due to high water elevations downstream. If the flow is submerged, there will be a velocity reduction in the throat. The degree of submergence must be determined to measure the flow accurately, since the flume is calibrated for free-flow conditions. The condition of submerged flow is indicated by a ripple or wave formed just downstream from the end of the throat. A reduction in the velocity of water leaving the flume may be desirable, because it lessens the erosion downstream.

b. Palmer-Bowlus flume

(1) The Palmer-Bowlus flume may be nothing more than a level section of floor placed into a sewer. In effect, this is a special broad-crested weir. Its simplicity is a major advantage over the Parshall flume. The length of the floor should be about the same as the diameter of the conduit. Figure C-12 shows a few possible configurations of the Palmer-Bowlus flume. The materials used to build the flume may be cast iron, stainless steel, fiberglass, grout, or concrete. This type of flume is easily installed in existing sewers, since no drop in head is required. The flume is designed so that critical depth will occur in the level floor section.

(2) The accuracy of this device is comparable to that of a Parshall flume; no field calibration is necessary. A reasonably accurate measurement of flow can be obtained with upstream depths as great as 0.90 of the sewer capacity.

c. Summary of specific weirs and flumes. Table C-2 compares headloss encountered with various flow-measuring devices. Head losses are generally much higher with weirs than flumes.

C-4. Open-flow nozzles

For accurate and continuous measurement of flow, the open-flow nozzle shown in figure C-13 is quite practical. The Kennison nozzle and the parabolic flume are two common types of open-flow nozzles. These nozzles are attached to the end of the pipe or channel. Each nozzle is rated according to the relationship between the water level in the nozzle and the flow. These devices can register the flow continuously if a float is placed in the nozzle or in a separate stilling tank attached to a recorder. Table C-3 gives the dimensions and approximate maximum capacities for various sizes of parabolic flumes and Kennison nozzles.

C-5. The Manning flow formula

a. Besides using a flow-measuring device, flow in a sewer can also be calculated by measuring the water depth and by using a flow equation, such as the Manning formula, to determine the mean velocity. The flow may be obtained by the continuity equation. The disadvantage of this method is that the coefficient of roughness and the slope of the sewer must be estimated. The Manning formula can be used for open channel flow, such as partly filled sewers, as well as for closed conduits under pressure flow. The Manning formula is:

$$V = \frac{1.486}{n} (R^{2/3} S^{1/2}) \quad (\text{Eq C-15})$$

where:

V = average velocity, feet per second

n = coefficient of roughness

R = hydraulic radius, feet = $\frac{\text{cross-sectional area}}{\text{wetted perimeter}}$

S = slope of energy grade line, feet per foot

b. Figure C-14 is an alignment chart for the Manning formula for circular pipes flowing full. This chart can be used for other shapes of closed circuit and open channels if the discharge scale is ignored and the diameter scale is taken to represent values equal to four times the hydraulic radius of the actual cross-section. When the pipe is not flowing full, the ratios shown in table C-4 should be used.

c. The following procedure is used to find the flow in a partially filled sewer:

(1) Measure water depth in the sewer.

(2) Calculate the ratio d/D, where D is the diameter of the sewer, and d is the water depth in the sewer.

(3) With this ratio, use table C-4 to find the corresponding ratios of the volume and velocity for the partially filled sewer for use with figure C-14.

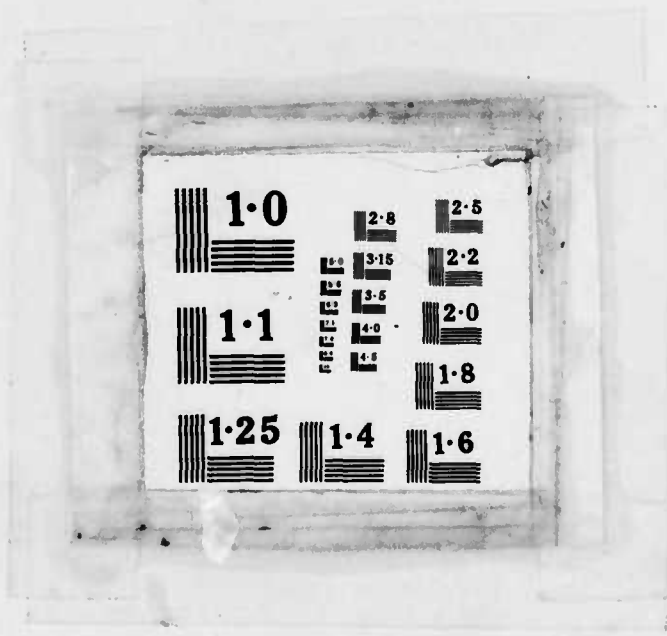
d. Table C-5 can be used to estimate the coefficient of roughness for the Manning formula; the coefficient of roughness can increase with time due to erosion, settled solids, and corrosion. The choice of a reasonable value for n is important. The slope of the sewer can usually be found on construction drawings or by measuring elevations between manholes. For a constant cross-section with no obstructions, the velocity should be fairly uniform; therefore, the energy grade line has the same slope as the sewer. Even though the use of this formula for flow measurements may not be very accurate, it is useful for estimating ranges of flow.

C-6. Measurement by dilution of chemicals

Wastewater flow rates may be estimated by adding a known concentration of chemicals to the wastewater and then measuring the diluted concentration of chemical downstream. The quantity of water required for that dilution is then calculated. Two groups of chemicals--metallic salts and fluorescent compounds--are often used.

a. Metallic salts

(1) Sodium and lithium chloride salts are most often used. Lithium can be detected at concentrations as low as 0.1 milligrams per liter, using the appropriate atomic absorption technique. Lithium analysis is subject to few interferences, and background levels of lithium are usually low. Chloride may be analyzed at levels as low as the 0.3 to 20 milligrams per liter range, depending on the method and presence of interferences. Chloride may be present in large quantities in some waste streams.



1.0

2.8

2.5

3.15

2.2

3.5

2.0

4.0

1.8

4.5

1.1

1.25

1.4

1.6

(2) A known concentration of salt is continuously pumped into the wastestream. At a point downstream where the salt and wastewater are completely mixed a sample is analyzed for the salt constituent. Flow rate can then be determined by:

$$Q = \frac{Q_t (C_t - C)}{C - C_o} \quad (\text{Eq C-16})$$

where:

Q = stream discharge, gallons per minute

Q_t = tracer addition rate, gallons per minute

C_t = concentration of tracer

C_o = background concentration of tracer in wastestream before injection

C = concentration of tracer in stream after injection.

b. Fluorescent chemicals. Certain fluorescent chemical dyes such as Rhodamine WT may be detected in concentrations as low as 0.1 ppb, depending on the diluent. The technique for flow determination is similar to the salt technique. Rhodamine is analyzed by fluorometric techniques. Fluorescent tracers are not suitable for wastewaters which have high concentrations of solids, oxidizing or reducing agents, or organic chemicals. Fluorescent tracers are used mostly for storm sewer surveys, river and stream flow determinations, and clean process water flow determinations.

C-7. Measurement of liquid depth in flow channels

The liquid depth or head in a flow channel must be known to calculate flow rate for a number of flow-measuring techniques, which include weirs, flumes, current meters, and the calculation methods. There are several methods of measuring liquid depth for weirs and flume arrangements.

a. Hook gauge. The hook gauge (fig C-15) is one of the least expensive and simplest methods for measuring liquid depth in a flow channel. The gauge is mounted above the flow channel measuring point; the hook is lowered to where the point just pierces the water surface. The liquid level is read from the calibrated vernier at the gauge. Hook gauges are usually installed in a stilling well. This method is used only for instantaneous manual measurements and is not connected to continuous-monitoring or automatic control systems.

b. Measuring with a calibrated rule. A ruler or other calibrated rule can be used to take instantaneous measurements of liquid depth. The rule must be kept level (at a 90-degree angle to the liquid surface) when measurements are taken. Care must be taken to compensate for the wake formed by inserting the ruler in fast-moving streams.

c. Air bubbler. The air bubbler (fig C-16) may be used to measure flows in either channels or pipes. A bubbler tube is placed in the bottom of the flow channel. Air is bubbled at a controlled rate into the liquid. As the liquid level changes, the static pressure on the escaping air changes. This pressure change is sensed by a pressure detector which then translates pressure change in the flow channel to liquid depth. These units may be made portable by using an air cylinder for the air supply.

d. Floats. Floats may be used to measure water depth as shown in figure C-17. Figure C-18 shows the installation of a float in a manhole. Floats are most commonly protected from floating debris by placing them in a stilling well connected to the flow channel.

e. Pressure chambers. A pressure sensing chamber (fig C-19) is used to measure flow at the water surface. The wastewater should be relatively free of suspended or floating material.

f. Ultrasonic sensors. Ultrasonic sensors are mounted above the flow channel measuring point. The sensor generates a series of ultrasonic waves which are reflected from the water surface. The difference in time between emission and detection of the wave is proportional to the liquid level in the flow channel.

Table C-1

Practical minimum discharge for 90-degree V-notch weirs

Weir Head (feet)	Discharge (gallons per minute)
0.02	0.049
0.03	0.160
0.04	0.380
0.05	0.755
0.075	1.964
0.10	4.00
0.15	10.47
0.20	20.95
0.25	35.45
0.30	55.50

Table C-2

Head losses in weirs and flumes (in feet)

Flow Q	Parshall Flume 1-foot Throat	Palmer-Bowlus Flume	Rectangular Weir	Cipolletti Weir	V-Notch Weir
0.5	0.08	0.04	0.29	0.28	0.52
1.0	0.14	0.08	0.46	0.44	0.69
1.5	0.38	0.17	0.75	0.69	0.92

Table C-3

Open flow nozzles - dimension and approximate capacities

Nozzle Diameter (inches)	Nozzle Length (inches)		Capacity (gallons per minute)	
	Parabolic	Kennison	Parabolic	Kennison
6	28	12	190	190
8	35	16	395	313
10	43	20	675	587
12	50	24	1,040	869
16	66	32	2,030	1,880
20	81	40	3,410	3,130
24	96	48	5,190	5,180
30	119	60	8,700	8,050
36	142	72	13,500	13,500

Table C-4

Ratios to relate flow in sewers flowing full to flow in sewers partly full

<u>Ratio of:</u>	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
<u>Depth of Flow</u> <u>Sewer diameter</u>	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.00
<u>Cross-section of flow</u> <u>Cross-section of sewer</u>	0.05	0.14	0.25	0.37	0.50	0.63	0.75	0.86	0.95	1.00
<u>Volume flowing partly full</u> <u>Volume flowing full</u>	0.02	0.08	0.18	0.33	0.49	0.67	0.84	0.98	1.07	1.00
<u>Velocity flowing partly full</u> <u>Velocity flowing full</u>	0.33	0.56	0.74	0.87	0.98	1.07	1.13	1.16	1.13	1.00

Table C-5

Values of effective absolute roughness and friction formula coefficients

Conduit Material	Manning n
Closed conduits	
Asbestos-cement pipe	0.011-0.015
Brick	0.013-0.017
Cast iron pipe	
Uncoated (new)	--
Asphalt dipped (new)	--
Cement-lined and seal coated	0.011-0.015
Concrete (monolithic)	
Smooth forms	0.012-0.014
Rough forms	0.015-0.017
Concrete pipe	0.011-0.015
Corrugated-metal pipe	
(1/2-inch x 2 2/3-inch corrugations)	
Plain	0.022-0.026
Paved invert	0.018-0.022
Spun asphalt lined	0.011-0.015
Plastic pipe (smooth)	0.011-0.015
Vitrified clay	
Pipes	0.011-0.015
Liner plates	0.013-0.017
Open channels	
Lined channels	
a. Asphalt	0.013-0.017
b. Brick	0.012-0.018
c. Concrete	0.011-0.020
d. Rubble or riprap	0.020-0.035
e. Vegetal	0.030-0.040
Excavated or dredged	
Earth, straight and uniform	0.020-0.030
Earth, winding, fairly uniform	0.025-0.040
Rock	0.030-0.045
Unmaintained	0.050-0.140
Natural channels (minor streams, top width at flood stage <100 feet)	
Fairly regular section	0.03-0.07
Irregular section with pools	0.04-0.10

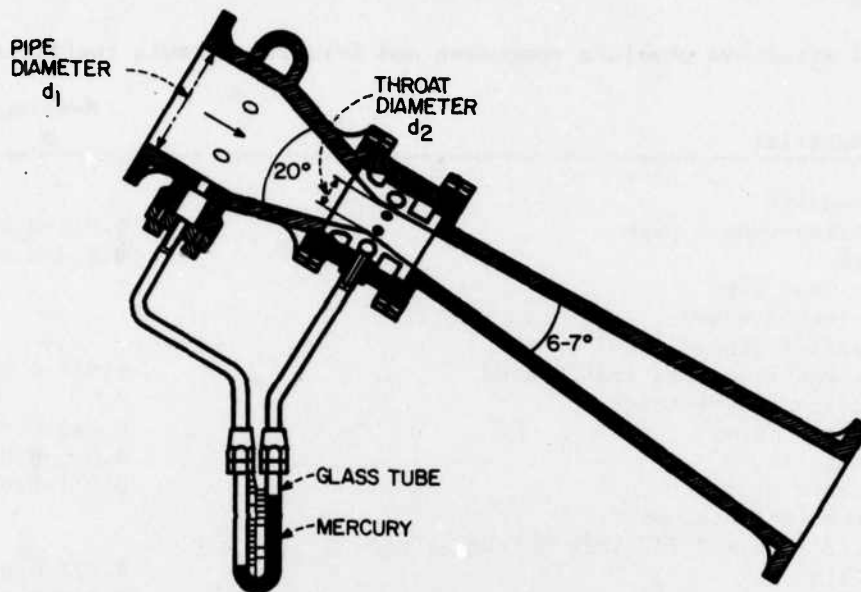


Figure C-1. Venturi meter.

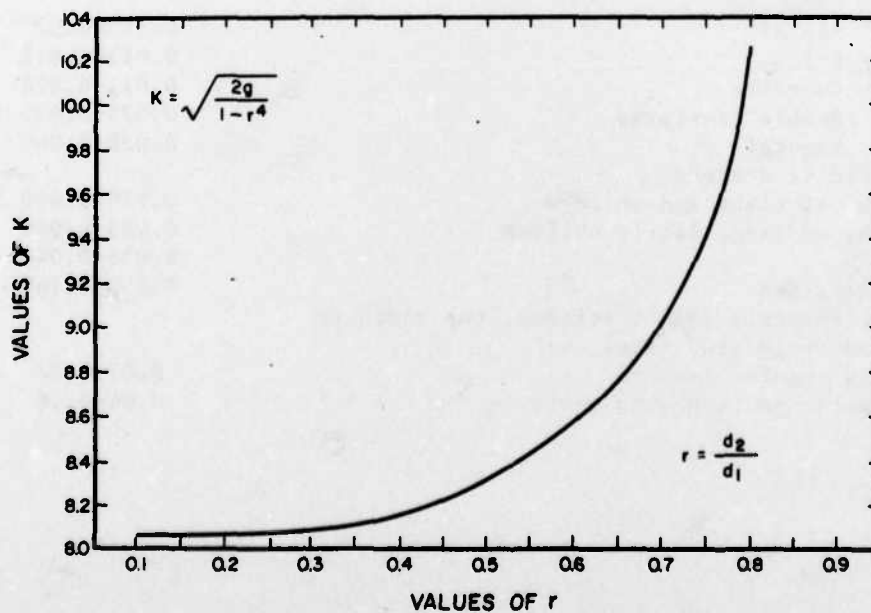


Figure C-2. Curve for determining the values of K used in the orifice, venturi, and flow nozzle equations.

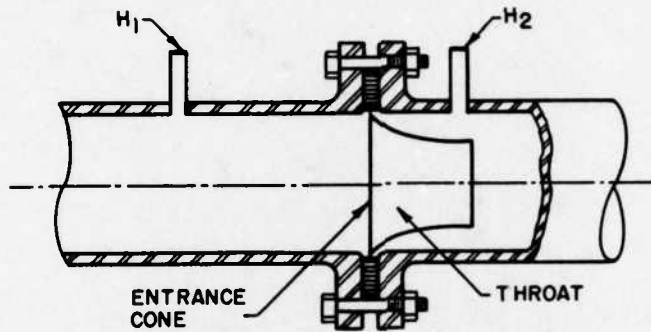


Figure C-3. Flow nozzle in pipe.

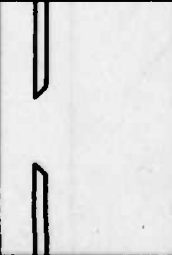
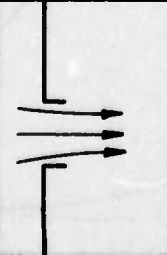
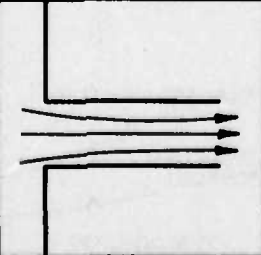
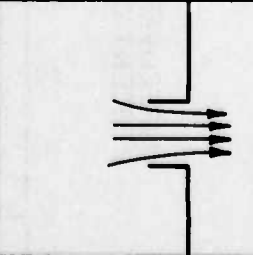
ORIFICES AND THEIR NOMINAL COEFFICIENTS				
	SHARP EDGED	ROUNDED	SQUARE EDGED	RE-ENTRANT TUBE
				
C	0.61	0.98	0.82	TUBE FLOWS FULL 0.52

Figure C-4. Coefficients of several types of orifices.

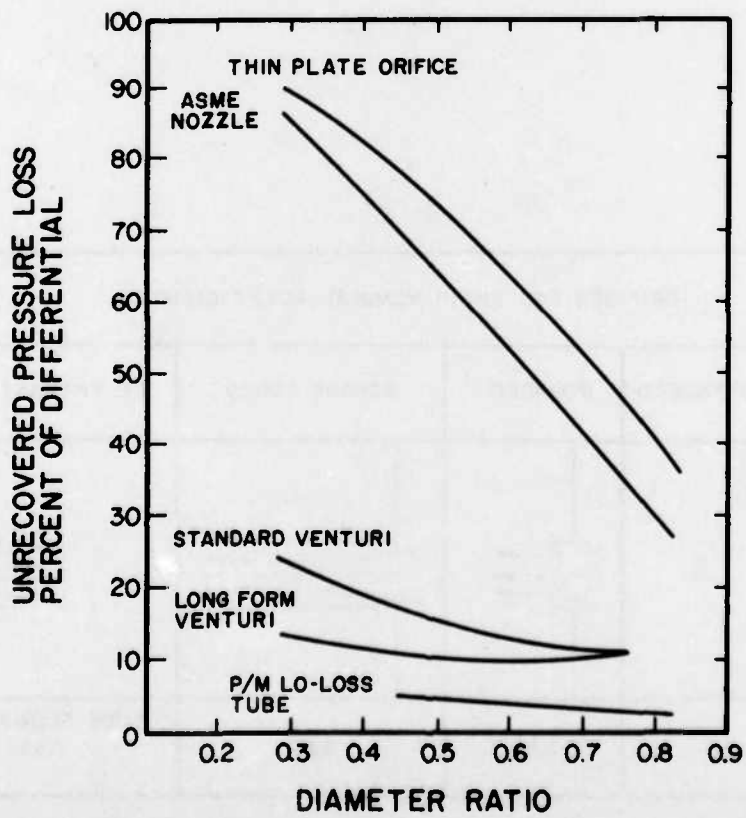


Figure C-5. Relative permanent pressure loss of primary flow elements.

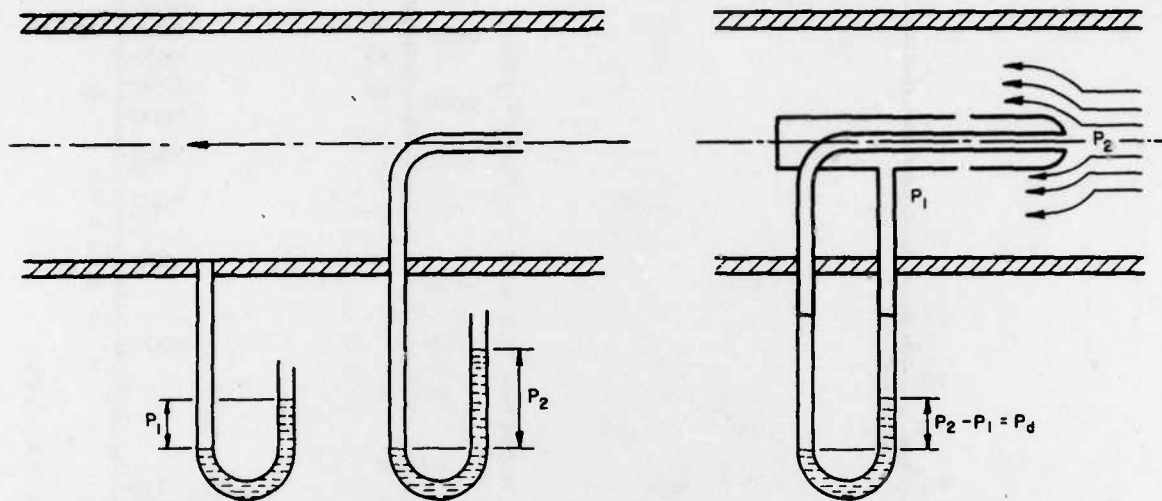


Figure C-6. Typical arrangements for pitot tube pressure measurements.

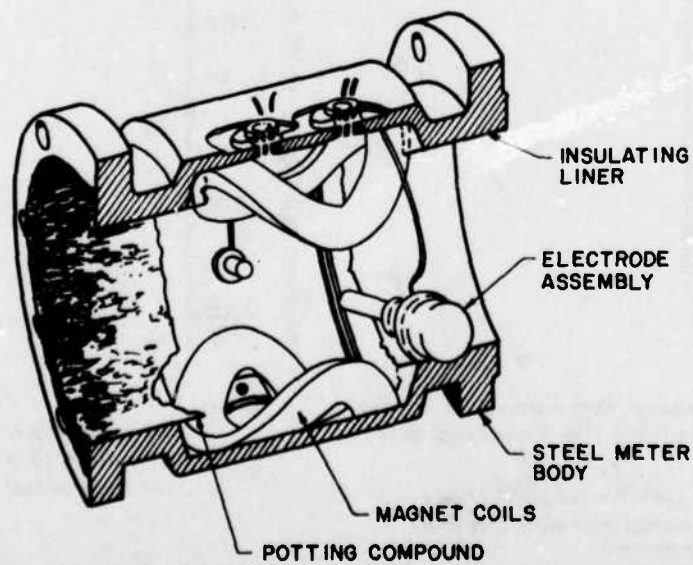
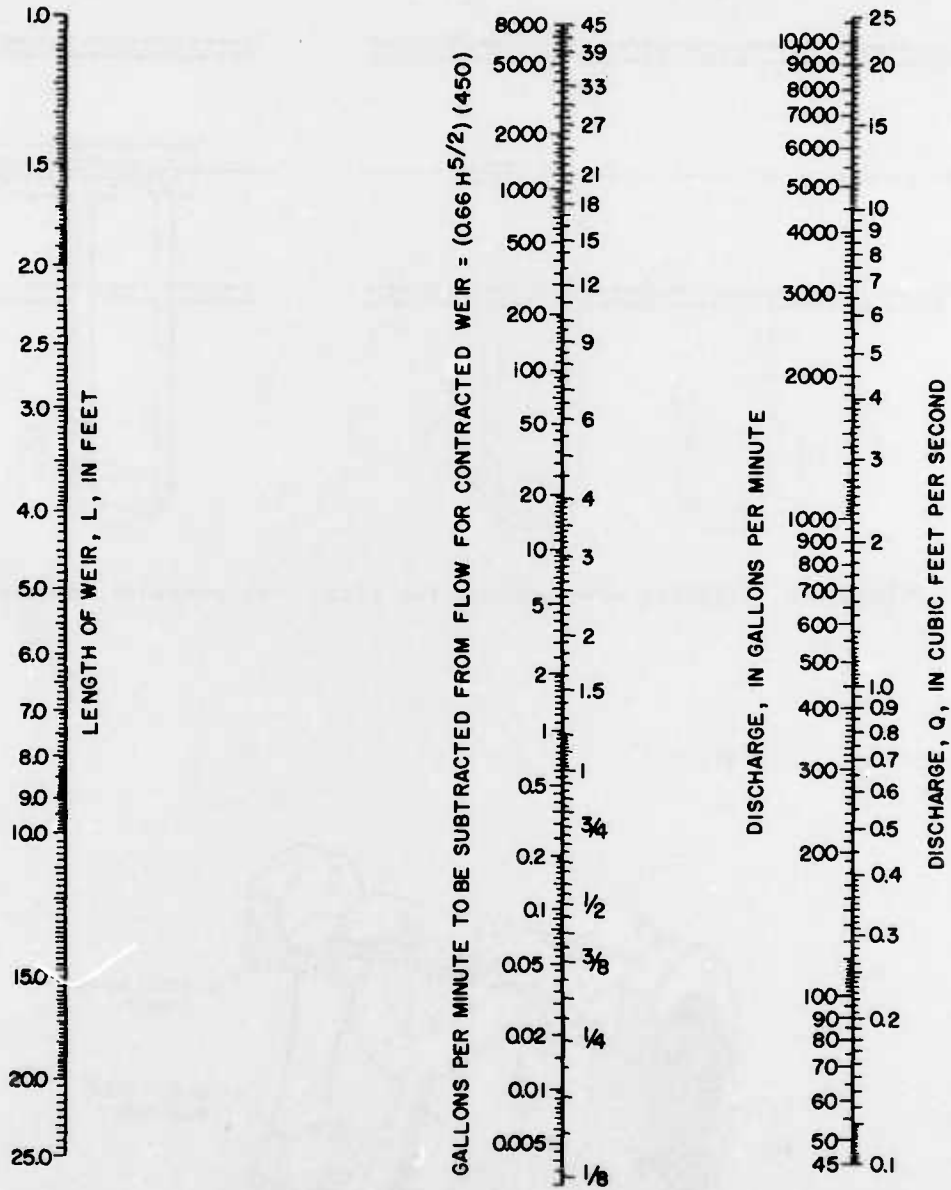


Figure C-7. Magnetic flow meter.



Note: Based on Francis Weir Formula as Follows:

$$Q = 3.33 LH^{3/2} \text{ (Far Suppressed Weir)}$$

or

$$Q = 3.33 (L - 0.2H) H^{3/2}$$

$$= 3.33 LH^{3/2} - 0.66 H^{5/2} \text{ (Far Contracted Weir with Two End Contractions)}$$

Where:

Q = Discharge in cubic feet per second

L = Length of Weir in feet

H = Head in feet

Figure C-8. Nomograph for capacity of rectangular weirs.

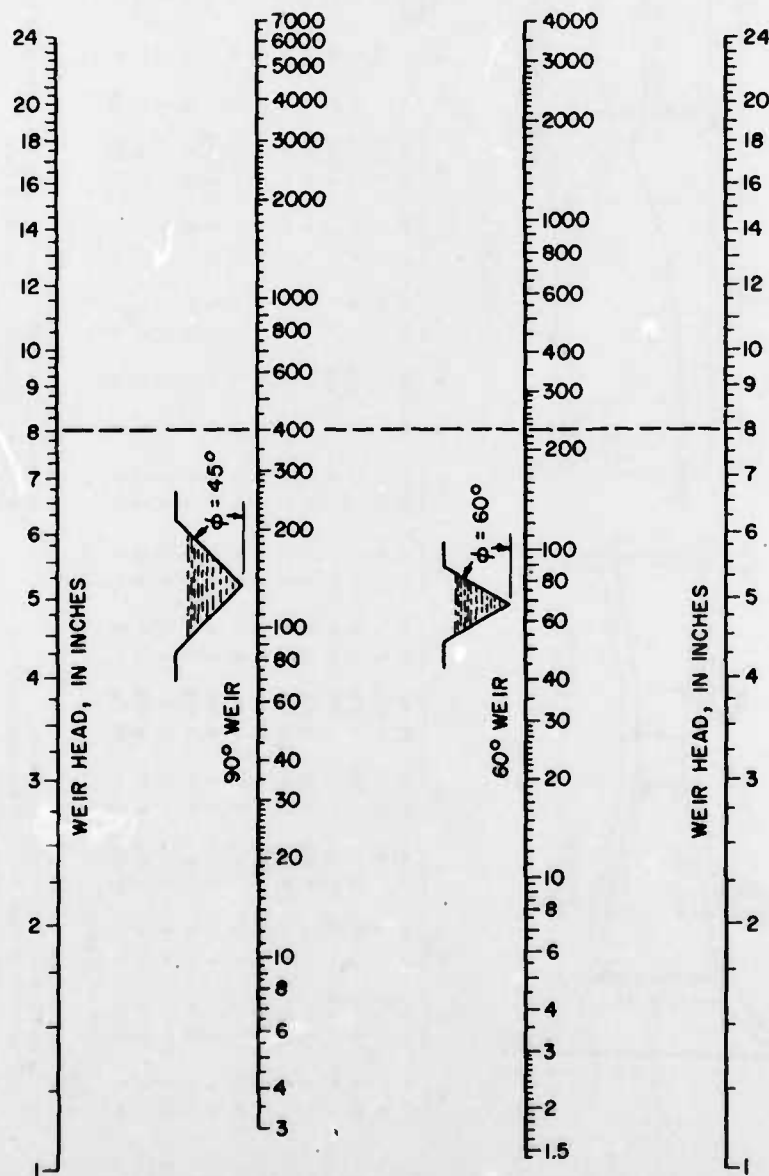
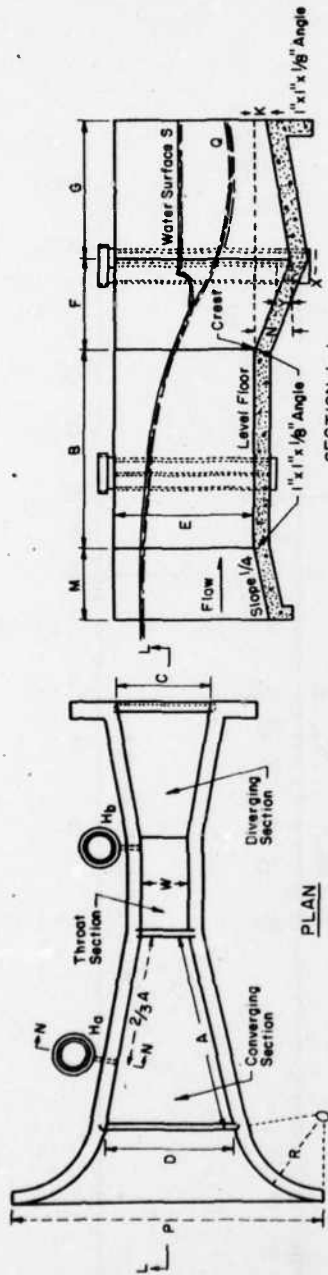


Figure C-9. Flow rates of nomograph for 60-degree and 90-degree V-notch weirs (gallons per minute).



W	A	2/3A	B	C	D	E	F	G	K	N	R	M	P	X	Y	Free-Flow Capacity (Second-Foot*)	
																Minimum	Maximum
0.3	1.6%	1 1/8	1.6	0.7	0.10 7/8	2.0	0.6	1.0	1	2 1/4	1.4	1.0	2.6 1/4	1	1 1/2	0.03	1.9
0.6	2 1/8	1 4 3/8	2.0	1.3 1/2	1.3 5/8	2.0	1.0	2.0	3	4 1/2	1.4	1.0	2.11 1/2	2	3	0.05	3.9
0.9	2 10 3/8	1 11 1/8	2.10	1.3	1.10 3/8	2.6	1.0	1.6	3	4 1/2	1.4	1.0	3.6 1/2	2	3	0.09	8.9
1.0	4.6	3.0	4.7 1/8	2.0	2.9 1/4	3.0	2.0	3.0	3	9	1.8	1.3	4.10 7/8	2	3	0.11	16.1
1.6	4.9	3.2	4.7 1/8	2.6	3.4 3/8	3.0	2.0	3.0	3	9	1.8	1.3	5.6	2	3	0.15	24.6
2.0	5.0	3.4	4.10 7/8	3.0	3.11 1/4	3.0	2.0	3.0	3	9	1.8	1.3	6.1	2	3	0.42	33.1
3.0	5.6	3.8	5.4 7/8	4.0	5.1 1/4	3.0	2.0	3.0	3	9	1.8	1.3	7.3 1/4	2	3	0.61	50.4
4.0	6.0	4.0	5.10 3/8	5.0	6.4 1/8	3.0	2.0	3.0	3	9	2.0	1.6	8.10 7/8	2	3	1.3	67.9
5.0	6.6	4.4	6.4 1/8	6.0	7.6 3/8	3.0	2.0	3.0	3	9	2.0	1.6	10.1 1/4	2	3	1.6	86.6
6.0	7.0	4.8	6.10 3/8	7.0	8.9	3.0	2.0	3.0	3	9	2.0	1.6	11.3 1/2	2	3	2.6	103.5
7.0	7.6	5.0	7.4 1/8	8.0	9.11 1/8	3.0	2.0	3.0	3	9	2.0	1.6	12.6	2	3	3.0	121.4
8.0	8.0	5.4	7.10 3/8	9.0	11.1 3/8	3.0	2.0	3.0	3	9	2.0	1.6	13.8 1/4	2	3	3.5	136.5

Figure C-10. Dimensions and capacities of the Parshall measuring flume, for various throat widths (From ORSANCO, 1952.)

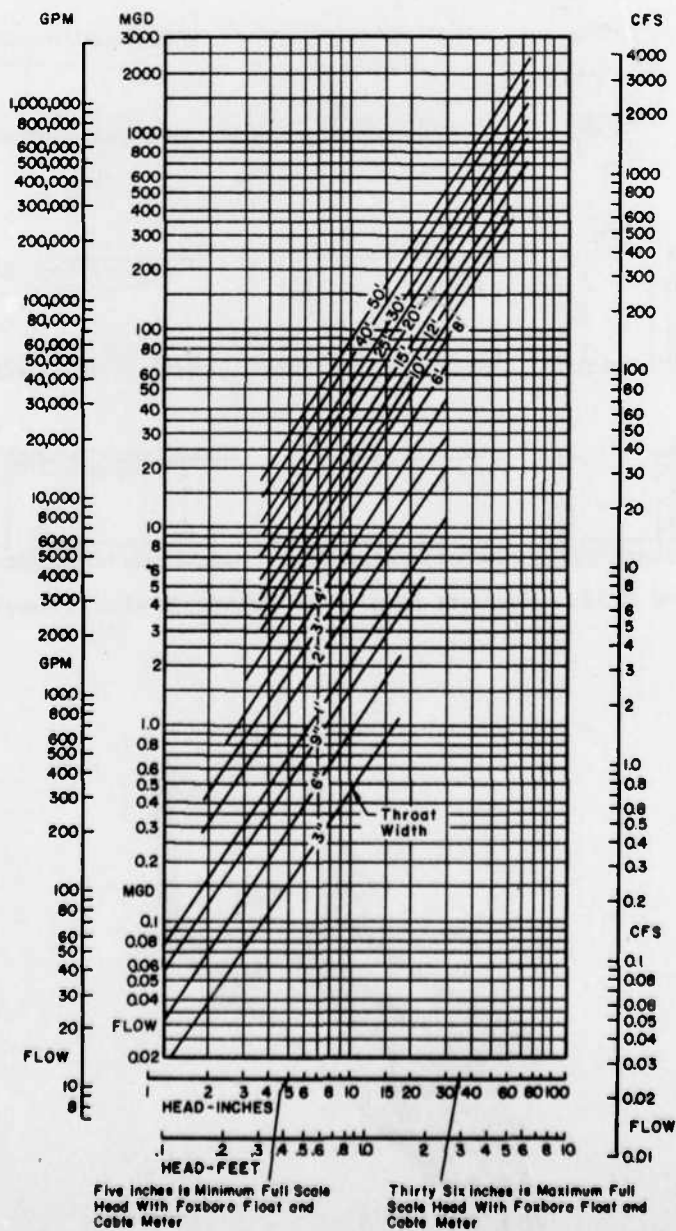


Figure C-11. Flow curves for Parshall flumes.

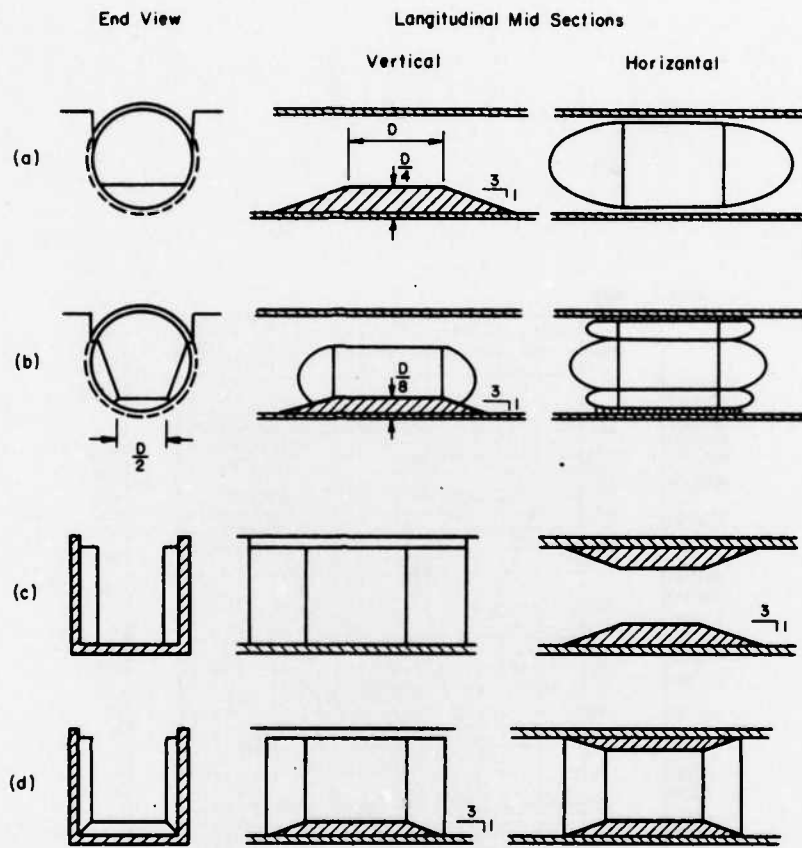


Figure C-12. Various shapes of Palmer-Bowlus flumes.

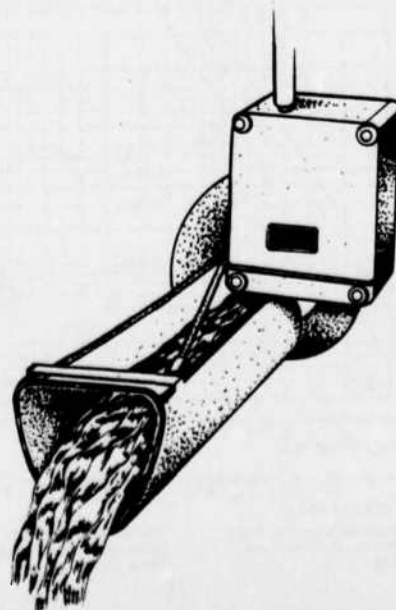


Figure C-13. Open-flow nozzle with in-stream transmitter.

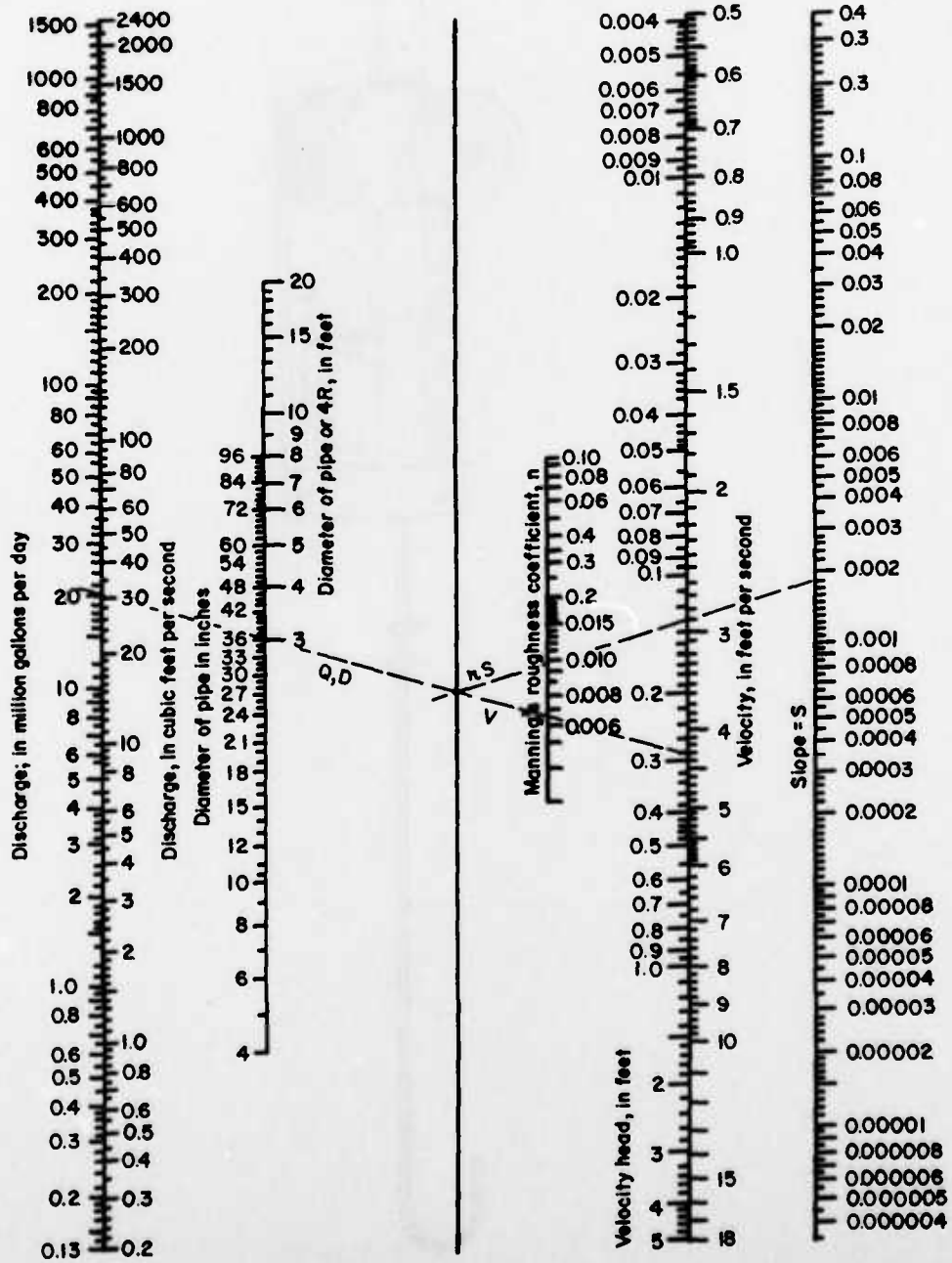


Figure C-14. Alignment chart for Manning formula for pipe flow.

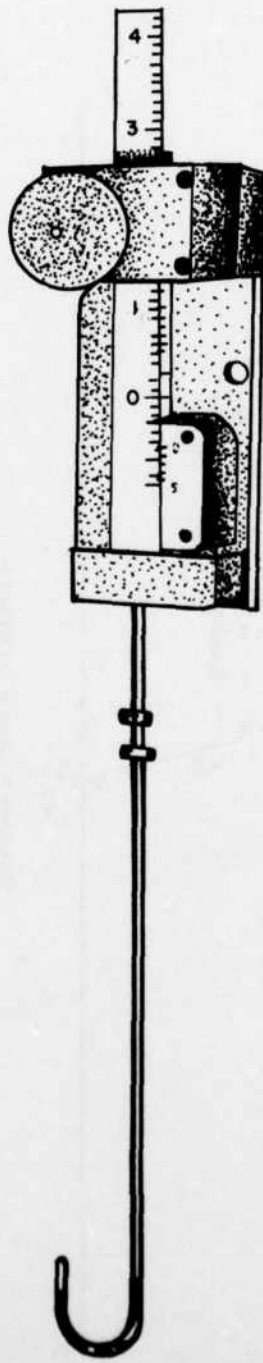


Figure C-15. Hook gauge.

An air bubbler will measure water depth in pipes and channels. The recorder gauges for the bubbler must be selected for the depth of flow because of low air back-pressure.

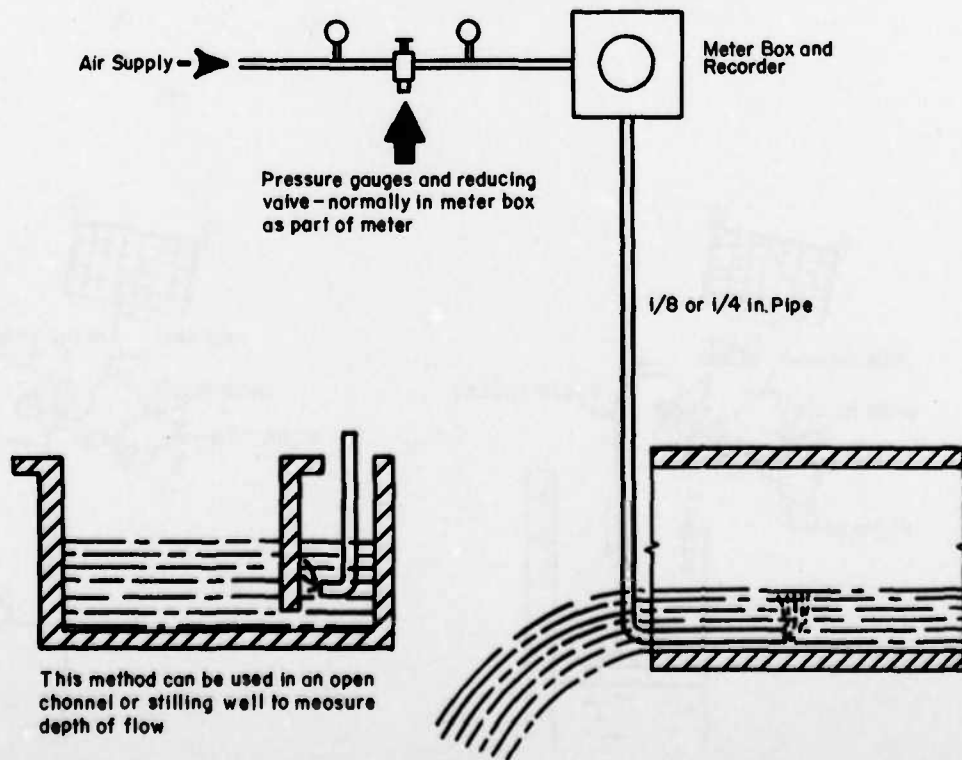


Figure C-16. Air bubbler for measuring water depth.

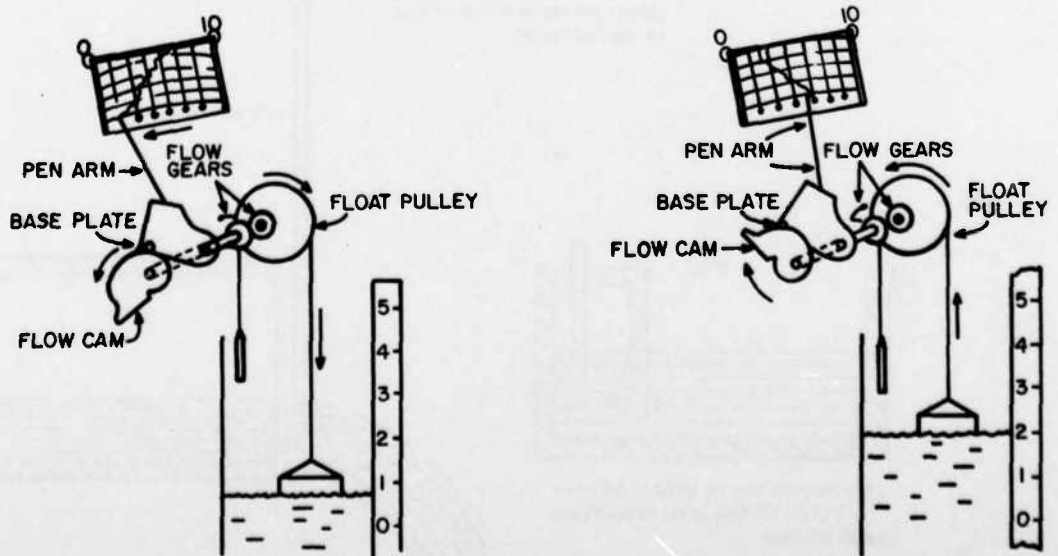
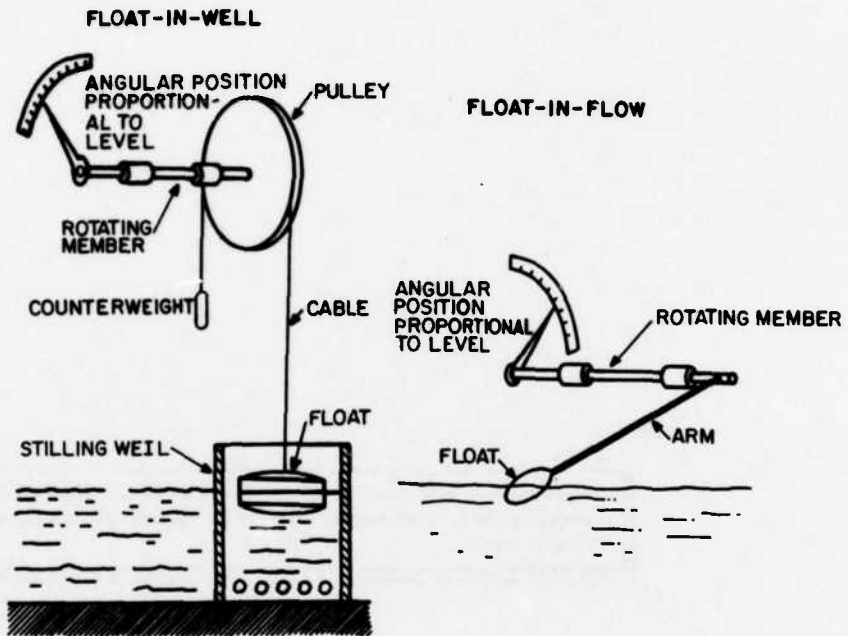


Figure C-17. Various floating water elevation measuring devices.

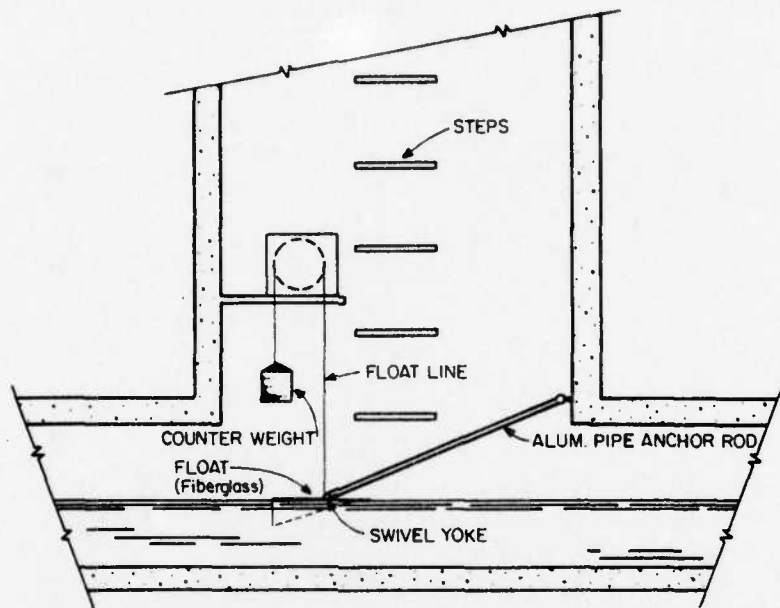


Figure C-18. Recorder and scow float used in sewer manhole.

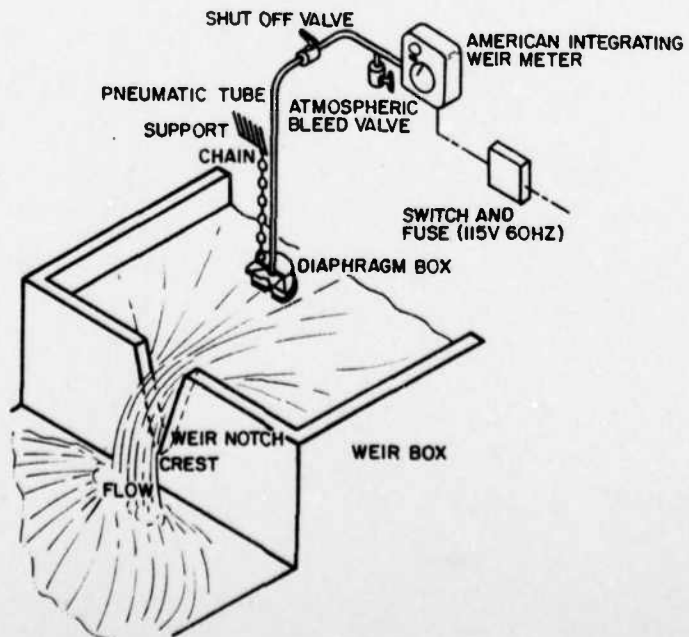


Figure C-19. Pressure sensor.

Appendix D

Sampling Equipment and Supplies

D-1. Types of sampling equipment

a. Air-activated samplers are most often used when an explosive or highly corrosive atmosphere prevents the use of electrically operated pumps. Figures D-1 and D-2 show an air-lift automatic sampler. In figure D-1, a solenoid valve controls air flow to an airlift pump. Figure D-2 shows the air-lift sample pump. When the compressed air supply is shut off, the spring in the sampler raises the piston; this opens the inlet so that part of the wastewater enters the sampler. The air valve is then opened and the piston is forced down; this closes the inlet. Compressed air then passes through the air escape port into the main chamber of the sampler and forces the liquid up the sample line to the collection container. The air supply is then cut off, and the cycle is repeated.

b. A vacuum can be used to obtain samples for water with a high suspended solids content or corrosive characteristics. Figure D-3 shows a vacuum-type automatic sampler. A timer activates the vacuum system which lifts liquid through a suction line into the sample chamber. When the chamber is filled, the vacuum is automatically closed. The pump then shuts off, and the sample is drawn into the sample container. A secondary float check prevents any liquid from reaching the pump. The suction line drains by gravity back into the source line. With the vacuum system, no pockets of fluid remain to contaminate later samples. An optional feature provides pressurized purge of the suction lines just before sampling; this assures that no old material, which might contaminate the new sample, remains in the submerged end of the tube to cause plugging. This system can operate on a time interval basis or on a signal from flow meters or other external control or monitoring devices. The maximum lift attainable under normal conditions is limited to about 20 feet. Figure D-4 shows a simple vacuum-type sampler.

c. A different system (fig D-5) is used where suspended solids in the wastewater may cause problems with other samplers. Samples are actually blown out of the wastestream with compressed air by the "Duckbill," which acts as a check-valve at the inlet; this prevents air from escaping back through the inlet. Compressed air, which comes into the top fitting, forces the waste sample through the bottom fitting into the collecting bottle. When the top fitting is vented to the atmosphere, hydrostatic pressure of the liquid wastestream forces a fresh sample up the vertical inlet and through the "Duckbill." A trapped air pocket in the dome keeps the sampler from filling completely. A burst of compressed air then takes another sample to the collecting station. Reverse leakage of the sample back through the rubber "Duckbill" is impossible. This sampler may be used to take composite samples proportionate or nonproportionate with flow.

D-2. Travelling cup samplers

a. Another type of sampler consists of a stainless steel cup mounted on an endless chain. When activated by an interval time control, the sampling cup is carried down through the wastewater; it returns around the upper sprocket filled with sample and is discharged into a suitable container. The unit then rests until the next sample is required. Controls are available for flow-proportional operation. The chain-type sample (fig D-6) is designed for permanent installations with depths of wastewater between 4 and 15 feet. This sampler is designed to collect proportionate and nonproportionate samples with or without refrigeration.

b. In another type of cup sampler (fig D-7), the sampling cup travels through a perforated guide tube into the effluent. The cup within the guide takes a sample while traversing the depth of the fluid. On its return, the cup empties the sample into a receiver. The device is motor-controlled and can be regulated by a timer or a flow-proportional recorder.

D-3. Peristaltic samplers

A variety of automatic samplers are equipped with peristaltic tubing-type pumps. These samples may be portable or line-powered. The sampler jar may be refrigerated and the pump controlled by a timer or flow integrator. Two types of pumps are available: one for relatively clear wastewater, and one for sampling effluents with long fibers and larger particles. The maximum lift of the pumps is limited to about 22 feet.

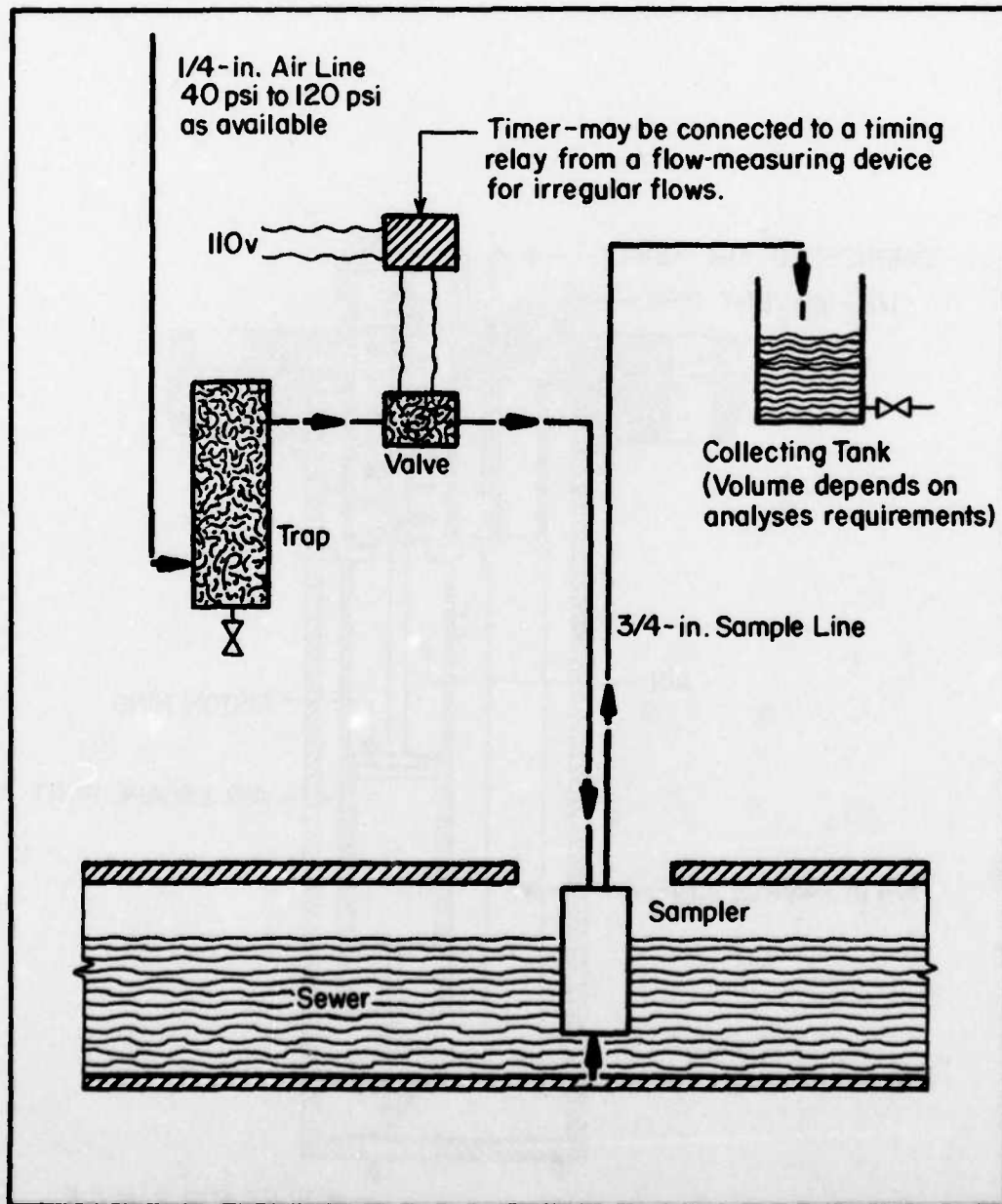


Figure D-1. Air-lift automatic sampler system.

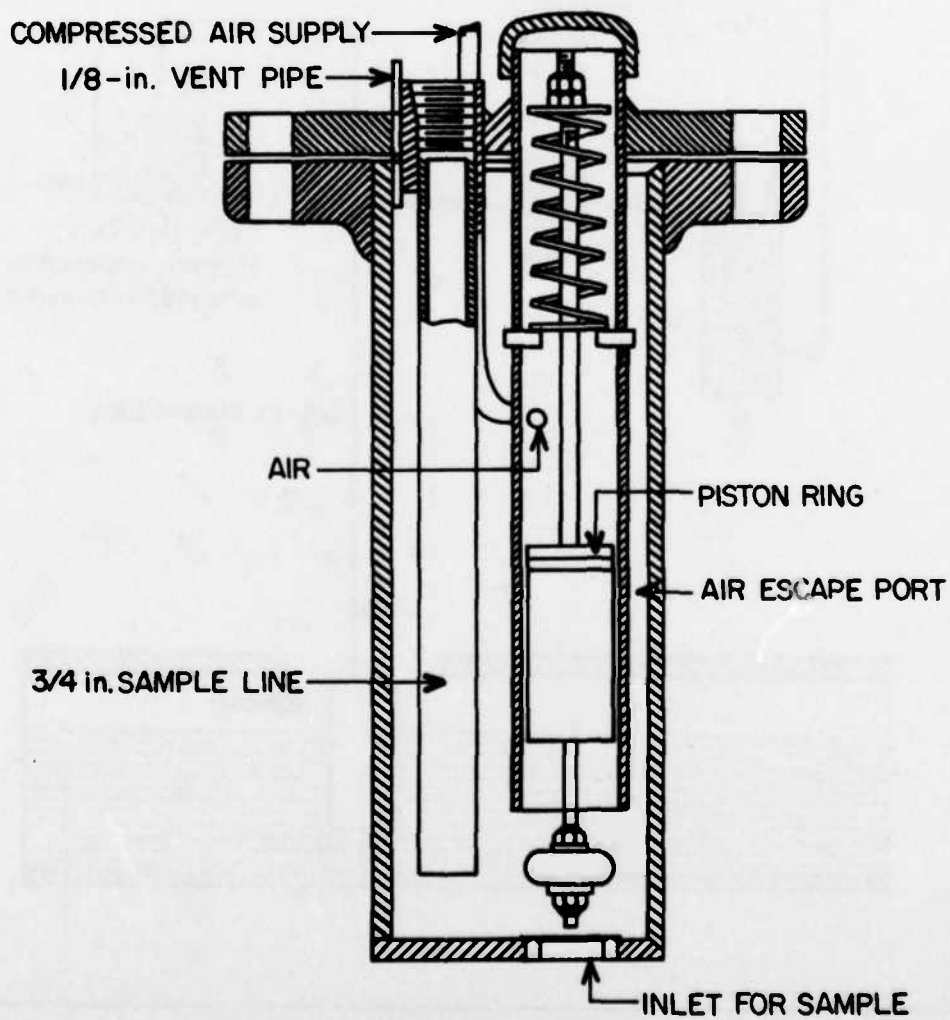


Figure D-2. Air-lift automatic sampler.

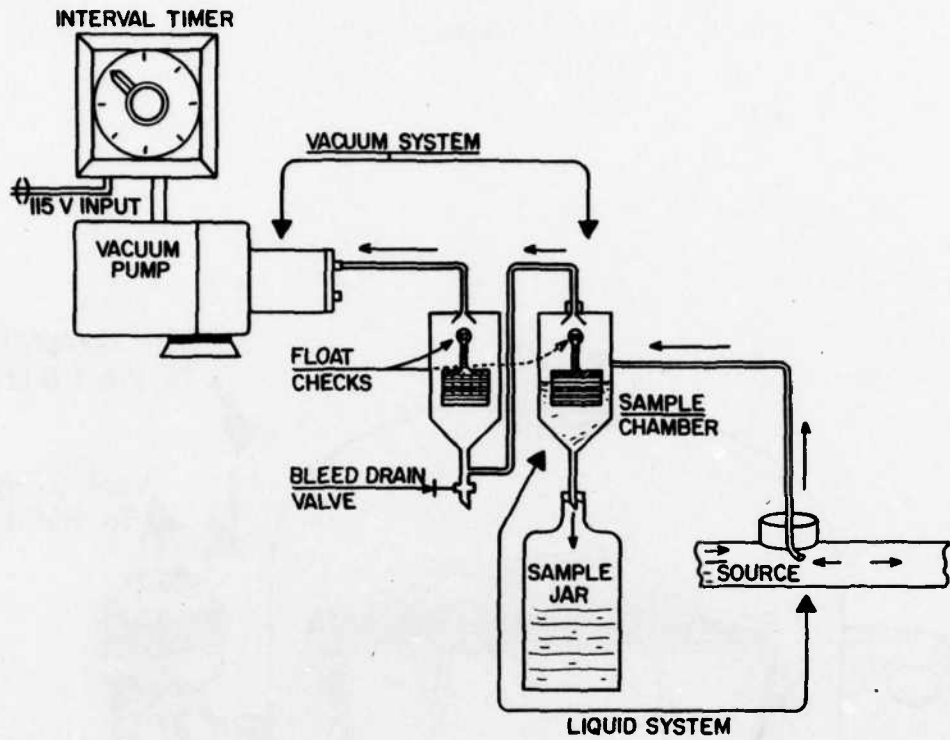


Figure D-3. Vacuum-type automatic sampler system schematic.

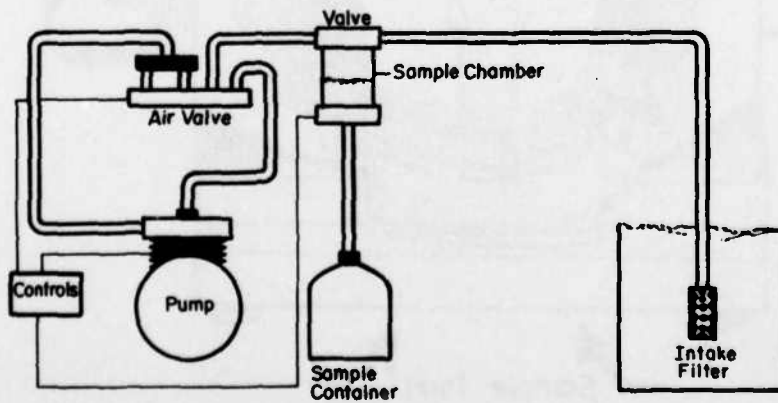


Figure D-4. "UES" sampler.

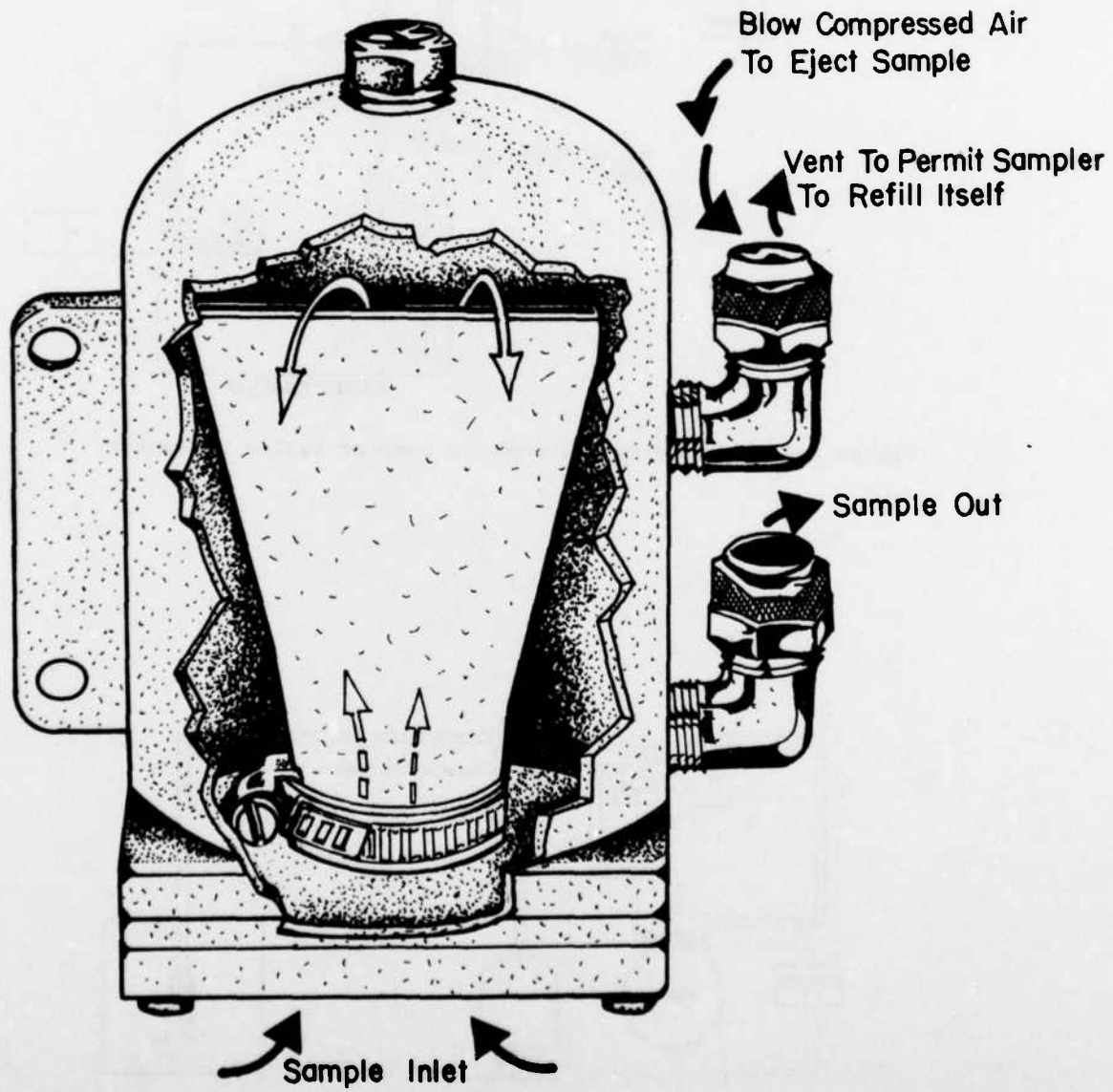


Figure D-5. Markland "Duckbill" sampler.

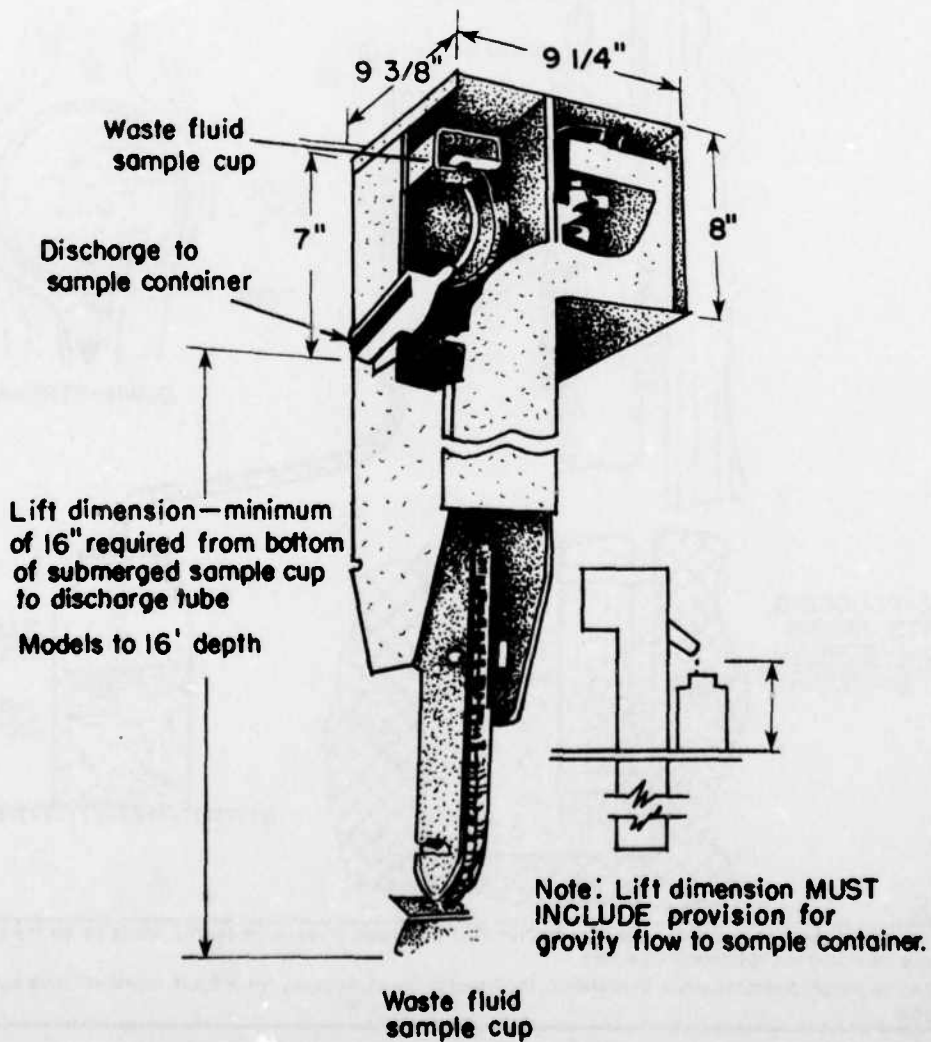


Figure D-6. Chain-type sampler.

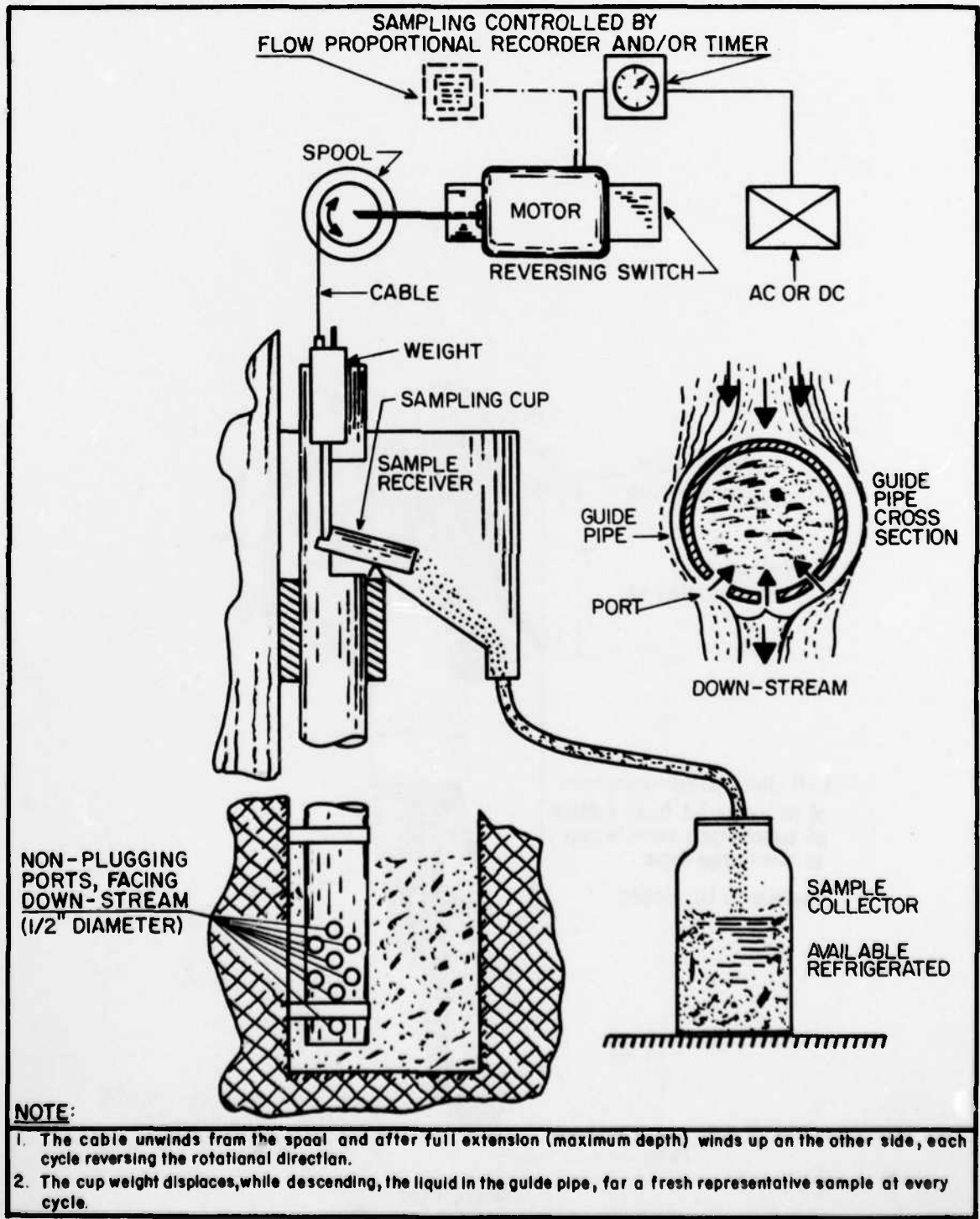


Figure D-7. Nonplugging effluent sampler.

Appendix E

Example Process Selection

E-1. Statement of problem

This example illustrates a vehicle washrack which will be used at a hypothetical installation (Eagle Army Post) to wash 54 tanks and 10 trucks during an 8-hour period daily. Water will be obtained from local wells. Besides the wastewater generated at the washing operation, the facility will treat the first flush of storm runoff from a nearby 10-acre vehicle parking area.

E-2. Solution

a. Wastewater characterization

(1) A survey was conducted of the wastewater from several nearby washrack facilities. Table E-1 summarizes the results. The data show that the wastewater contains mostly inorganic suspended solids and a relatively small concentration of oil and grease.

(2) Runoff water samples from parking areas similar to the one designed for Eagle Army Post were collected during a rainstorm and composited. The samples were analyzed for SS and oil and grease (tab E-1). It was found that most pollutants are carried in the first 0.25 inches of rain. Assuming a runoff coefficient of 0.8, the volume of stormwater that must be treated is 54,000 gallons, and the average flow rate is 900 gallons per minute.

b. Disposal alternatives. Three disposal alternatives were considered: discharge to a nearby stream, land disposal, and reuse. No municipal treatment facilities in the area could accommodate the wastewater from the washrack operation.

c. Discharge criteria for disposal alternatives

(1) An NPDES discharge permit was issued by the state regulatory agency for disposal to the nearby stream. Table E-2 lists the permit limits. Since the washrack wastewater does not contain sanitary wastes, there is no concern over fecal coliforms. Also, the BOD of the wastewater is lower than the permit limitation, and it is free of phenols. Hence, the only two parameters that must be treated are SS and oil and grease.

(2) The assimilative capacities of various constituents were compiled for the land disposal solution (tab E-3).

(3) Water quality criteria (tab E-4) were established for the treated water which would be reused in the washing operation.

d. Assessment and screening of treatment processes

(1) Discharge to stream. Treatment objectives for this solution are removal of TSS and oil and grease. Based on the data of table E-5, a system consisting of primary sedimentation and oil separation would be able to produce an effluent of the desired quality. Since a major part of the TSS is coarse sand particles, a grit chamber was proposed as a pretreatment device. Oil separation and TSS settling can be done in the same basin. Flocculation will be needed to enhance the removal of colloidal TSS.

(2) Land disposal. The area required for land disposal of this wastewater without pretreatment was calculated on the basis of raw waste loads and the soil assimilative capacity (tab E-5). The volume of water to be treated was calculated assuming a 7-day per week operation of the washrack and two rainstorms' runoff to be treated per week. Hence, the total volume of water to be treated is calculated as follows:

Tank wash: (54 tanks/day)(2600 gallons/tank)
(7 days/week) = 982,800 gallons/week

Truck wash: (10 trucks/day)(700 gallons/truck)
(7 days/week) = 49,000 gallons/week

Total washrack: = 1,032,000 gallons/week

Rainstorm runoff: (2 storms/week)(54,500 gallons/storm) = 109,000 gallons/week

Total volume of wastewater and rainstorm runoff = 1,141,000 gallons/week

or = 41.9 acre-inch/week

The yearly pollutant discharge was calculated on the basis of flow rate and concentration. The land area required was calculated for each constituent by dividing the raw waste load by the assimilative capacity. As shown in Table E-5, the required area is about 34 acres, with oil and grease being the land-limiting constituent. Land requirements based on the hydraulic and iron loadings are very close to those for oil and grease. Therefore, no benefit would be gained by pretreating for oil and grease removal.

(3) Wastewater reuse. More intensive treatment must be used to obtain the effluent quality required for reuse. Some of the emulsified oil and the soluble organics (COD) must be removed, and better removal of TSS will be required. A possible treatment scheme for these goals would be a grit chamber, followed by air flotation and granular media filtration. It is assumed that 15 percent of the water used in the washrack is lost by evaporation and other means. Then the total volume of water lost is (15/100) (147,500 gallons per day) = 22,100 gallons per day. The quantity of makeup water is calculated by:

$$Q_o = Q_e \frac{\alpha}{\alpha - 1} \quad (\text{Eq E-1})$$

where:

Q_o = makeup flow rate, gallons per day

Q_e = evaporative and other loss, gallons per day

α = ratio of maximum TDS in washwater to TDS of makeup water.

Hence:

$$\alpha = 3500/1200 = 2.92$$

and

$$Q_o = 22,100 \frac{2.92}{1.92} = 33,600 \text{ gallons per day}$$

and the effluent, or blowdown, flow rate is:

$$Q_B = Q_o - Q_e$$

$$Q_B = 33,600 - 22,100 = 11,500 \text{ gallons per day.}$$

e. Design of treatment facilities. Based on results of laboratory treatability studies, treatment systems for the three alternative solutions were designed. Figure E-1 shows schematics of the three treatment and disposal alternatives.

(1) Handling of stormwater stream. The average flow rate of wastewater from the washrack is 310 gallons per minute. Assuming a rainfall intensity of 0.5 inches per hour, the storm runoff flow rate is 1800 gallons per minute. Since storm runoff needs to be treated only once or twice per week, a collection basin for this water is proposed; the water would be fed gradually to the treatment plant when the plant is not loaded with washwater. With this arrangement, the treatment plant can be designed for a flow rate of 310 gallons per minute and operated between 8 to 24 hours per day, depending on the frequency of rainstorms.

(2) Discharge to stream. The grit chamber is designed to remove settleable solids with no concern for organic SS. Thus, it is a sedimentation tank rather than a grit chamber. It is designed for a lower overflow rate, as compared to conventional grit chambers, and with no flow control or turbulence-generating devices. The rapid mixer flocculation tank and primary sedimentation tank are designed according to standard procedures. Table E-6 summarizes all pertinent design criteria and main dimensions.

(3) Land application. Only a grit chamber has to be designed for the land application alternative. However, there will be additional capital investments for land acquisition, site preparation, piping, and pumping.

(4) Water reuse. The treatment system for this alternative consists of a grit chamber, a dissolved air flotation package, and a granular media filter. Table E-7 gives a design summary.

f. Economic analysis of alternatives. Selection of the most attractive solution is based on an economic analysis of the proposed alternatives. For this analysis, base unit capital costs have been considered. It was assumed that the differences in O&M costs for these systems would be minor. Table E-8 includes estimated capital costs for the various treatment units for the three alternatives. The amortized costs were based on a 7 percent interest rate and 15-year life for all units except land disposal where a 35-year life was assumed. In the reuse alternative, water use is reduced by 113,000 gallons per day. Assuming a water cost of \$0.25/1000 gallons, this is an annual savings of \$10,390. Table E-9 gives a cost comparison which shows that the most economical solution is land disposal.

Table E-1

Vehicle washrack wastewater characterization

Parameter	Parking Area Washrack Effluent	Runoff
Water Usage		
gallons/tank	2,600	--
gallons/truck	700	--
gallons/day	147,400	54,000
Total Suspended Solids (TSS), milligrams/liter	4,800	320
Total Dissolved Solids (TDS), milligrams/liter	1,200	--
Biochemical Oxygen Demand (BOD), milligrams/liter	23	--
Chemical Oxygen Demand (COD), milligrams/liter	560	--
Oil and Grease, milligrams/liter*	20	8
Settleable Solids, milliliters/liter	16	--
Cu, milligrams/liter	0.04	--
Fe, milligrams/liter	11	--
Pb, milligrams/liter	0.01	--
Al, milligrams/liter	25	--

*80 percent is free oil, 20 percent emulsified.

Table E-2

NPDES permit discharge limitations

<u>Characteristic</u>	<u>Limitation</u>	<u>Daily Average</u>	<u>Daily Maximum</u>
Oil and grease, milligrams/liter		10	15
Total suspended Solids (TSS), milligrams/liter		25	40
Phenol, milligrams/liter		1	2
BOD, milligrams/liter		30	45
Fecal coliforms, per 100 milliliters		200	--

Table E-3

**Assimilative capacities for land disposal site
(in pounds/acre-year except where otherwise indicated)**

<u>Constituent</u>	<u>Assimilative Capacity</u>
Water, inches/week	65
COD 65,000	
Oil and grease	15,000
Cu 5.0	
Pb 15.0	
Fe 45.0	

Table E-4

Water quality criteria for recycled vehicle washwater

<u>Parameter</u>	<u>Maximum Level</u>
TSS, milligrams/liter	15
Oil and grease, milligrams/liter	1
COD, milligrams/liter	100
pH	6.5-9.0
TDS	3,500

Table E-5

Calculation of required area for land disposal

<u>Parameter</u>	<u>Raw Waste Load (pounds/year)</u>	<u>Assimilative Capacity (pounds/acre-year)</u>	<u>Required Area (acres)</u>
Water	41.9*	1.25**	33.5
COD	249,900	65,000	3.8
Oil and grease	9,299	270	34.3
Cu	17.8	5.0	3.6
Pb	4.5	15.0	0.3
Fe	4,908	145.0	33.8

*In acre-inches/week.

**In inches/week.

Table E-6

Design summary for treatment system I - discharge to stream

Treatment Unit	Design Criteria	Dimensions
Grit Chamber (horizontal flow, constant elevation)	Overflow Rate = 10 gallons per minute/square foot	Area = 31 square feet Length = 10 feet Width = 3.1 feet Depth = 4.0 feet
Rapid Mixing	Detention Time = 60 seconds Alum dose = 40 milligrams/liter	Volume = 41 cubic feet Alum Required = 55 pounds/day
Flocculation	Detention Time = 45 minutes Velocity Gradient = 35 seconds ⁻¹	Volume = 2000 cubic feet
Oil Separation and Settling	Rise Rate = 0.20 feet per minute Overflow Rate = 0.15 cubic feet/ square feet-minute Horizontal Velocity = 2.5 feet per minute	Area = 275 square feet Width = 6 feet Length = 46 feet Depth = 2.8 feet

Table E-7

Design summary for treatment system III - water reuse

Treatment Unit	Design Criteria	Dimensions
Grit Chamber	Overflow Rate = 10 gallons per minute/square foot	Area = 31 square feet Length = 10 feet Width = 3.1 feet Depth = 4.0 feet
Dissolved Air Flotation	Overflow Rate = 1.5 gallons per minute/square foot Pressurization Level = 60 pounds per square inch Retention Time: 30 minutes	Area = 208 square feet Depth = 6.0 feet
Granular Media Filter	Hydraulic Loading = 3.0 gallons per minute/square foot Backwash Rate = 15 gallons per minute/square foot	Area = 103 square feet Depth of Media = 40 inches

Table E-8

Estimated costs of treatment units*

Unit	Capital Cost (\$)	Amortized Cost (\$/year)
Grit Chamber	18,000	1,980
Flocculation	60,000	6,590
Oil Separation and Sedimentation	56,000	6,150
Dissolved Air Flotation	90,000	9,880
Granular Media Filtration	150,000	16,470
Land Disposal Area (Acquisition and Application System)	140,000	10,800

*For comparative use only.

Table E-9

Comparative costs for three treatment alternatives

Alternative	Capital Cost (\$)	Amortized Cost (\$/year)	Value of Water Saved (\$/year)	Net Cost (\$/year)
I Discharge to Stream	134,000	14,720	0	14,720
II Land Disposal	158,000	10,800	0	12,780
III Treatment and Reuse	258,000	28,330	10,390	17,940

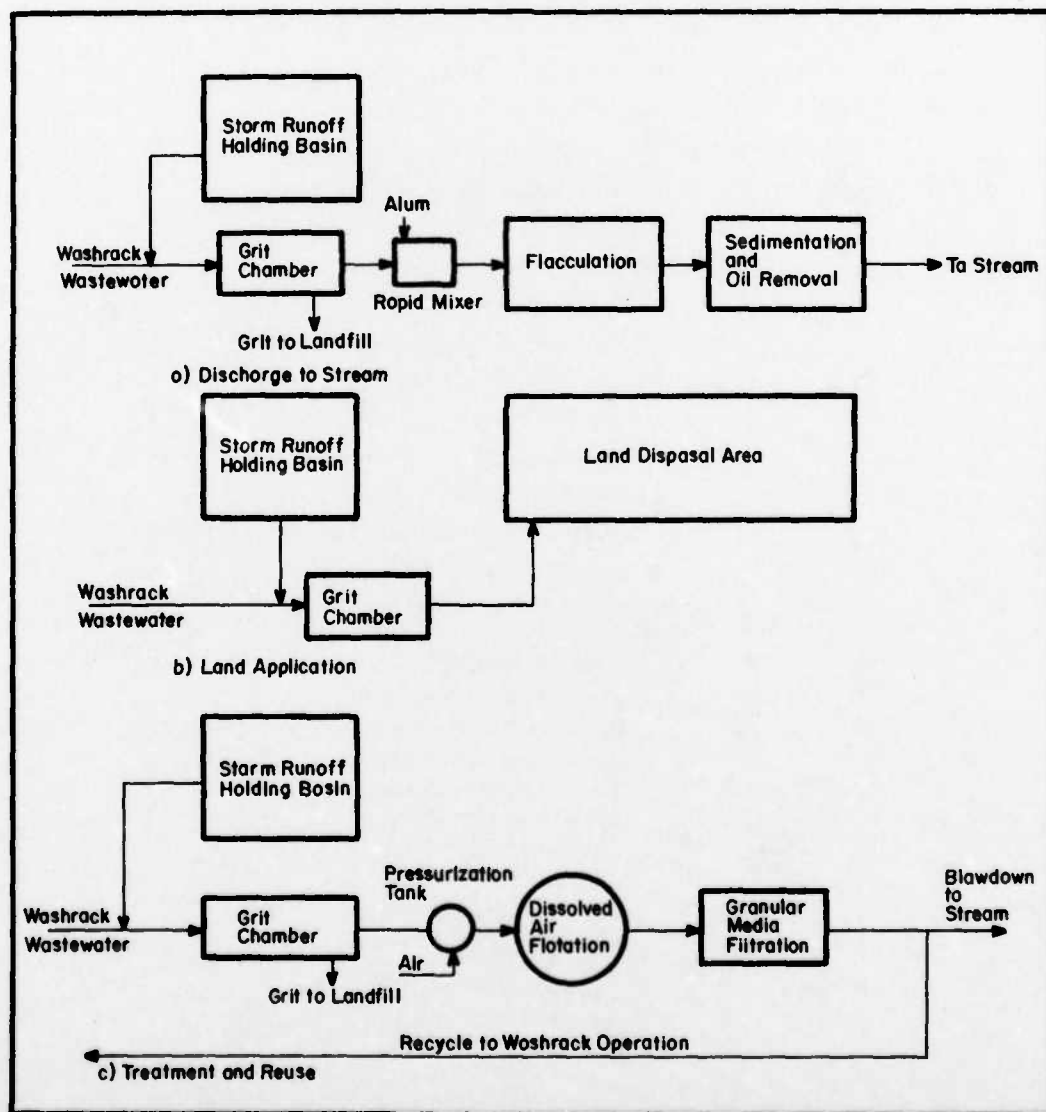


Figure E-1. Flow diagram for alternative solutions.

Appendix F

Conversion Factors for Units of Measurement of Physical Properties of Water, Dissolved Oxygen Solubility Data

F-1. Conversion factors

The following are U.S. customary, metric (SI), and British units of measurement.

a. Length

1 inch = 2.54 centimeters
1 foot = 0.3048 meters
1 yard = 0.915 meters
1 mile (U.S. statute) = 1.6093 kilometers
1 micron = 39.37 microinches
1 millimeter = 0.0394 inches
1 centimeter = 0.394 inches
1 meter = 1.093 yards
1 kilometer = 0.6214 mile

b. Area

1 square inch = 6.4516 square centimeters
1 square foot = 0.0929 square meters
1 square yard = 0.8361 square meters
1 square mile (U. S. statute) = 2.59 square kilometers
1 acre = 4046.8 square meters
1 square centimeter = 0.155 square inches
1 square meter = 1.196 square yards
1 hectare = 2.471 acres
1 square kilometer = 0.386 square mile

c. Volume

1 cubic inch = 16.39 cubic centimeters
1 cubic foot = 0.0283 cubic meters
1 cubic yard = 0.7645 cubic meters
1 acre-foot = 1233.5 cubic meters
1 U.S. gallon = 3.79 liters
1 U.K. gallon = 4.55 liters
1 cubic centimeter = 0.061 cubic inches
1 cubic meter = 1.307 cubic yards
1 liter = 0.26 U.S. gallons = 0.22 U.K. gallons

d. Mass

1 ounce (avoirdupois) = 28.35 grams
1 pound (avoirdupois) = 0.4536 kilogram
1 ton (short, 2000 pounds) = 907.185 kilograms
1 ton (long, 2240 pounds) = 1016.05 kilograms
1 gram = 0.0352 ounces
1 kilogram = 2.2 pounds

e. Pressure

1 pound per square inch = 6894.757 Pascals
1 pound per square foot = 47.88026 Pascals
1 atmosphere = 1 kilogram/square centimeter
1 kilogram per square centimeter = 14.697 pounds per square inch

f. Velocity

1 inch per second = 2.54 centimeters/second
1 foot per second = 0.3048 meter/second
1 centimeter per second = 0.394 inches/second
1 meter per second = 1.093 yards/second

g. Power

1 horsepower = 0.7457 kilowatts
1 British thermal unit (Int. Table) = 1055.056 joules
1 kilowatt = 1.341 horsepower

h. Miscellaneous

1 cubic foot per second = 28.3 liter/second
1 million gallons per day (U.S.) = 3780 cubic meters/day
1 million gallons per day (U.K.) = 4550 cubic meters/day
1 pound per cubic foot = 16.0185 kilograms/cubic meter
1 milligram per liter = 0.000138 ounces/gallon (U.S.)
1 centipoise = 0.001 Pascals-second
1 pound BOD/acre/day = 1.12 kilograms BOD/hectare/day
1 degree Fahrenheit = 5/9 degree Celsius

To obtain Celsius (C) temperature readings from

Fahrenheit (F) readings, use the following equation:

$$C = (5/9)F - 32.$$

F-2. Physical properties of water

Temperature °F	Specific Weight	Density	Viscosity	Kinematic Viscosity	Surface Tension	Vapor Pressure
	γ pounds/ cubic foot	ρ slug/ cubic foot	$\mu \times 10^5$ pound- second/ square foot	$\nu \times 10^5$ square feet/ second	σ pounds/ foot	p_v pounds per square inch absolute
32	62.42	1.940	3.746	1.931	0.00518	0.09
40	62.43	1.940	3.229	1.664	0.00514	0.12
50	62.41	1.940	2.735	1.410	0.00509	0.18
60	62.37	1.938	2.359	1.217	0.00504	0.26
70	62.30	1.936	2.050	1.059	0.00498	0.36
80	62.22	1.934	1.799	0.930	0.00492	0.51
90	62.11	1.931	1.595	0.826	0.00486	0.70
100	62.00	1.927	1.424	0.739	0.00480	0.95

F-3. Dissolved-oxygen solubility data

Temperature °C	Dissolved Oxygen, milligrams/liter				
	Chloride Concentration, milligrams/liter				
	0	5,000	10,000	15,000	20,000
0	14.62	13.79	12.97	12.14	11.32
1	14.23	13.41	12.61	11.82	11.03
2	13.84	13.05	12.28	11.52	10.76
3	13.48	12.72	11.98	11.24	10.50
4	13.13	12.41	11.69	10.97	10.25
5	12.80	12.09	11.39	10.70	10.01
6	12.48	11.79	11.12	10.45	9.78
7	12.17	11.51	10.85	10.21	9.57
8	11.87	11.24	10.61	9.98	9.36
9	11.59	10.97	10.36	9.76	9.17
10	11.33	10.73	10.13	9.55	8.98
11	11.08	10.49	9.92	9.35	8.80
12	10.83	10.28	9.72	9.17	8.62
13	10.60	10.05	9.52	8.98	8.46
14	10.37	9.85	9.32	8.80	8.30

Glossary

Absorption

The taking up of one substance into the body of another.

Acid

- a. A substance that tends to lose a proton.
- b. A substance that dissolves in water with the formation of hydrogen ions.
- c. A substance containing hydrogen which may be replaced by metals to form salts.

Acidity

The quantitative capacity of aqueous solutions to react with hydroxyl ions. It is measured by titration with a standard solution of a base to a specified end point. Usually expressed as milligrams per liter of calcium carbonate.

Activated carbon

Carbon particles usually obtained by carbonization of cellulosic material in the absence of air and possessing a high adsorptive capacity.

Activated sludge

Sludge floc produced in raw or settled wastewater by the growth of zoogical bacteria and other organisms in the presence of dissolved oxygen and accumulated in sufficient concentration by returning floc previously formed.

Adsorption

- a. The adherence of a gas, liquid, or dissolved material on the surface of a solid.
- b. A change in concentration of gas or solute at the interface of a two-phase system. Should not be confused with absorption.

Advanced wastewater treatment

Those processes that achieve pollutant reductions by methods other than those used in conventional treatment (sedimentation, activated sludge, trickling filter, etc.). It employs a number of different unit operations, including lagoons, post-aeration, micro-straining, filtration, carbon adsorption, membrane solids separation, phosphorus removal, and nitrogen removal.

Aeration

The bringing about of intimate contact between air and a liquid by one or more of the following methods: (1) spraying the liquid in the air, (2) bubbling air through the liquid, (3) agitating the liquid to promote surface absorption of air. See following terms modifying aeration: diffused-air, mechanical.

Aerator

A device that promotes aeration.

Aerobic

Requiring, or not destroyed by, the presence of free elemental oxygen.

Aerobic bacteria

Bacteria that require free elemental oxygen for their growth.

Agglomeration

The coalescence of dispersed suspended matter into larger flocs or particles which settle rapidly.

Agitator

- a. Mechanical apparatus for mixing and/or aerating.
- b. A device for creating turbulence.

Air

The mixture of gases that surrounds the earth and forms its atmosphere, composed primarily of oxygen and nitrogen. It also contains carbon dioxide, some water vapor, argon, and traces of other gases.

Algae

Primitive plants, one- or many-celled, usually aquatic, and capable of elaborating their foodstuffs by photosynthesis; used as an oxygen producer in some bodies of water.

Alkali

Any of certain soluble salts, principally sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical processes such as water or wastewater treatment.

Alkaline

The condition of water, wastewater, or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

Alkalinity

The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

Alum

A common name, in the water and wastewater treatment field, for commercial-grade aluminum sulfate.

Aluminum sulfate

A chemical, formerly sometimes called "waterworks alum" in water or wastewater treatment, prepared by combining a mineral known as bauxite with sulfuric acid.

Ammonia

A chemical combination of hydrogen (H) and nitrogen (N) occurring extensively in nature. The combination used in water and wastewater engineering is expressed as NH_3 .

Anaerobic

Requiring, or not destroyed by, the absence of air or free elemental oxygen.

Anaerobic bacteria

Bacteria that grow only in the absence or in very low levels (roughly 1 milligram/liter) of free elemental oxygen.

Anion

A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of electric potential.

Anthracite

Hard coal.

Average daily flow

The total quantity of liquid tributary to a point divided by the number of days of flow measurement.

Average flow

Arithmetic average of flows measured at a given point.

Backwash

The reversal of flow through a filter to wash clogging material out of the filtering medium and reduce conditions causing loss of head.

Backwash bed expansion

The expansion that occurs when a filter bed is being backwashed, usually expressed as a percentage of the backwashed and settled bed.

Bacteria

A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll. Bacteria usually appear as spheroid, rodlike, or curved entities, but occasionally appear as sheets, chains, or branched filaments. Bacteria are usually regarded as plants. See following terms modifying bacteria: aerobic, anaerobic, facultative anaerobic.

Baffles

Deflector vanes, guides, grids, gratings, or similar devices constructed or placed in flowing water, wastewater, or slurry systems to check or effect a more uniform distribution of velocities; absorb energy; divert, guide, or agitate the liquids; and check eddies.

Bar screen

In a waste treatment plant, a screen that removes large suspended solids.

Basin

- a. A natural or artificially created space or structure, surface or underground, which has a shape and character of confining material that enable it to hold water. The term is sometimes used for a receptacle midway in size between a reservoir and a tank.
- b. The surface area within a given drainage system.
- c. A small area in an irrigated field or plot surrounded by low earth ridges and designed to hold irrigation water.
- d. An area upstream from a subsurface or surface obstruction to the flow of water.
- e. A shallow tank or depression through which liquids may be passed or in which they are detained for treatment or storage. Also see tank.

Biochemical action

Chemical change resulting from the metabolism of living organisms.

Biochemical oxygen demand

A standard test used in assessing wastewater strength. See BOD.

Biodegradation (biodegradability)

The destruction or mineralization of either natural or synthetic organic materials by the microorganisms populating soils, natural bodies of water, or wastewater treatment systems.

Biological filtration

The process of passing a liquid through the medium of a biological filter, thus permitting contact with attached zoogeal films that adsorb and absorb fine suspended, colloidal, and dissolved solids and release end products of biochemical action.

Biologically active floc

Floc formed by the action of biological agencies; for example, activated sludge.

Biological oxidation

The process whereby living organisms in the presence of oxygen convert the organic matter contained in wastewater into a more stable or a mineral form.

Biological slime

The gelatinous film of zoogeal growths covering the medium or spanning the interstices of a biological bed. Also called microbial film.

Biological treatment systems

"Living" systems which rely on mixed biological cultures to break down waste organics and remove organic matter from solution.

Biological wastewater treatment

Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Trickling filters and activated sludge processes are examples.

BOD

a. Abbreviation for biochemical oxygen demand. The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions.

b. A standard test used in assessing wastewater strength.

BOD load

The BOD content of wastewater passing into a waste treatment system or to a body of water, usually expressed in pounds per unit of time.

Breakpoint chlorination

Addition of chlorine to water or wastewater until the chlorine demand has been satisfied and further additions result in a residual that is directly proportional to the amount added beyond the breakpoint.

Buffer

Any of certain combinations of chemicals used to stabilize the pH values or alkalinities of solutions.

Cake solids

Percent dry solids in wet sludge cake discharged from a dewatering device. As commonly reported, this includes the weight of sludge-conditioning chemicals which may comprise 5 to 15 percent of the dry sludge solids.

Calcium hypochlorite

A dry powder consisting of lime and chlorine combined in such a way that, when dissolved in water, it releases active chlorine.

Cation

The ion in an electrolyte which carries the positive charge and which migrates toward the cathode under the influence of a potential difference.

Centrate

The effluent or liquid portion of a sludge removed by or discharged from a centrifuge.

Centrifugal dewatering of sludge

The partial removal of water from wastewater sludge by centrifugal action.

Centrifuge

A mechanical device in which centrifugal force is used to separate solids from liquids and/or to separate liquids of different densities.

Channel

A perceptible natural or artificial waterway which periodically or continuously contains moving water or which forms a connecting link between two bodies of water. It has a definite bed and banks which confine the water.

Chemical coagulation

The destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical. See flocculation.

Chemical oxygen demand (COD)

A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC; oxygen consumed and dichromate oxygen consumed, respectively.

Chemical precipitation

- a. Precipitation induced by addition of chemicals.

b. The process of softening water by the addition of lime or lime and soda ash as the precipitants.

Chemical sludge

Sludge obtained by treatment of wastewater with chemicals.

Chemical treatment

Any process involving the addition of chemicals to obtain a desired result.

Chlorination

The application of chlorine to water or wastewater, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.

Chlorination chamber

A detention basin provided primarily to secure the diffusion of chlorine through the liquid. Also called chlorine contact chamber.

Chlorine

An element ordinarily existing as a greenish-yellow gas about 2.5 times as heavy as air. At atmospheric pressure and a temperature of -30°F , the gas becomes an amber liquid about 1.5 times as heavy as water. The chemical symbol of chlorine is Cl, its atomic weight is 35.457, and its molecular weight is 70.914.

Chlorine demand

The difference between the amount of chlorine added to the wastewater and the amount of residual chlorine remaining at the end of a specific contact time. The chlorine demand for a given water varies with the amount of chlorine applied, time of contact, temperature, pH, nature, and amount of impurities in the water.

Chlorine residual

The total amount of chlorine (combined and free available chlorine) remaining in water, sewage, or industrial wastes at the end of a specified contact period following chlorination.

Clarification

Any process or combination of processes which reduces the concentration of suspended matter in a liquid.

Clarified wastewater

Wastewater from which most of the settleable solids have been removed by sedimentation. Also called settled wastewater.

Clarifier

A unit which secures clarification. Usually applied to sedimentation tanks or basins. See sedimentation tank.

Coagulant

A chemical added to wastewater or sludge to promote agglomeration and flocculation of suspended solids to induce faster settling or more efficient filtration. Typical coagulants are polyelectrolytes, alum, and ferric chloride.

Coagulation

In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

Coagulation basin

A basin used for the coagulation of suspended or colloidal matter, with or without the addition of a coagulant, in which the liquid is mixed gently to induce agglomeration with a consequent increase in settling velocity of particulates.

COD

Symbol for chemical oxygen demand. See chemical oxygen demand.

Colloidal matter

Finely divided solids which will not settle but may be removed by coagulation or biochemical action or membrane filtration. See colloids.

Colloids

- a. Finely divided solids which will not settle but may be removed by coagulation or biochemical action or membrane filtration; they are intermediate between true solutions and suspensions.
- b. In soil physics, discrete mineral particles less than 2 microns, (μ)n diameter.
- c. Finely divided dispersions of one material, called the dispersed phase; with another, called the dispersion medium.
- d. in general, particles of colloidal dimensions are about 10A to 1 μ n size. Colloidal particles are distinguished from ordinary molecules by their inability to diffuse through membranes that allow ordinary molecules and ions to pass freely.

Color

Colors in water are usually due to the decomposition of organic matter of vegetable or soil origin. Color caused by suspended matter is referred to as "apparent color"; color due to colloid vegetable or organic extracts is called "true color."

Comminuted solids

Solids which have been divided into fine particles.

Comminution

The process of cutting and screening solids contained in wastewater flow before it enters the flow pumps or other units in the treatment plant.

Comminutor

A device for catching and shredding heavy solid matter in the primary stage of waste treatment.

Concentrate

To increase the proportion of solids in a sludge or wastewater.

Concentration

- a. The amount of a given substance dissolved in a unit volume of solution.
- b. The process of increasing the dissolved solids per unit volume of solution, usually by evaporation of the liquid.

Conduit

Any artificial or natural duct, either open or closed, for conveying liquids, or possibly other fluids.

Contact tank

A tank used in water or wastewater treatment to promote contact between chemicals or other materials and the body of liquid treated.

Current

- a. The flowing of water or other fluid.
- b. That portion of a stream of water which is moving with a velocity much greater than the average or in which the progress of the water is principally concentrated.

Dechlorination

The partial or complete reduction of residual chlorine in a liquid by any chemical or physical process.

Decomposition

The breakdown of complex material into simpler substances by chemical or biological means.

Depth of side water

The depth of a liquid measured along the inside of the vertical exterior wall of a tank.

Detention time

The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Dewatering

Any process of water removal or concentration of a sludge slurry, as by filtration, centrifugation, or drying. (A dewatering method is any process which will concentrate the sludge solids to at least 15 percent solids by weight.)

Diatomaceous earth

A fine, siliceous earth consisting mainly of the skeletal remains of diatoms (unicellular organisms).

Diffusion aerator

An aerator that blows air under low pressure through submerged porous plates, perforated pipes, or other devices so that small air bubbles rise through the water or wastewater continuously.

Digester

A tank in which sludge is placed to permit digestion to occur. Also called sludge digestion tank. See sludge digestion.

Digestion

a. The biological decomposition of organic matter in sludge, resulting in partial gasification, liquefaction, and mineralization.

b. The process carried out in a digester. See sludge digestion.

Diluent

A diluting agent.

Dilution

Disposal of wastewater or treated effluent by discharging it into a stream or body of water.

Discharge

- a. As applied to a stream or conduit, the rate of flow or volume of water flowing in the stream or conduit at a given place and within a given period of time.
- b. The passing of water or other liquid through an opening or along a conduit or channel.
- c. The rate of flow of water, silt, or other mobile substance which emerges from an opening, pump, or turbine, or passes along a conduit or channel, usually expressed as cubic feet per second, gallons per minute, or million gallons per day.

Disinfectant

A substance used for disinfection, such as chlorine or ozone.

Disinfection

The killing of the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

Dissolved air flotation

A process that adds energy in the form of air bubbles which become attached to suspended sludge particles, increasing the buoyancy of the particles and producing more positive flotation.

Dissolved oxygen (DO)

The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.

Dissolved solids

Theoretically, the anhydrous residues of the dissolved constituents in water. Actually, the term is defined by the method used in determination. In water and wastewater treatment, the Standard Methods tests are used.

Ditch

A small artificial open channel or waterway constructed through earth or rock to convey water.

Domestic wastewater

Wastewater derived principally from dwellings, business buildings, institutions, and the like. It may or may not contain groundwater, surface water, or storm water.

Dose

- a. The quantity of substance applied to a unit quantity of liquid for treatment purposes. It can be expressed in terms of either volume or weight (for example, pounds per

million gallons, parts per million, grains per gallon, milligrams per liter, or grams per cubic meter).

- b. Generally, a quantity of material applied to obtain a specific effect.

Drum screen

A screen in the form of a cylinder or truncated cone which rotates on its axis.

Drying bed

A wastewater treatment unit usually consisting of a bed of sand and gravel on which sludge is placed to dry by evaporation and drainage.

Efficiency

- a. The relative results obtained in any operation in relation to the energy or effort required to achieve such results.
- b. The ratio of the total output to the total input, expressed as a percentage.

Effluent

- a. A liquid which flows out of a containing space.
- b. Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof.

Endogenous respiration

An auto-oxidation of cellular material, which takes place in the absence of assimilable organic material, to furnish energy required for the replacement of protoplasm.

Environment

The physical environment of the world consisting of the atmosphere, the hydrosphere, and the lithosphere.

Equalization

A process by which variations in flow and composition of a waste stream are averaged in an equalizing unit.

Equalizing basin

A holding basin in which variations in flow and composition of a liquid are averaged. Also called balancing reservoir.

Eutrophication

- a. The normally slow aging process by which a lake evolves into marsh and ultimately becomes filled with detritus and disappears.
- b. The intentional or unintentional enrichment of water.

Evaporation

- a. The process by which water becomes a vapor at a temperature below the boiling point.
- b. The quantity of water that is evaporated; the rate is expressed in depth of water, measured as liquid water, removed from a specific surface per unit of time, generally in inches or centimeters per day, month, or year.

Evapotranspiration

Water withdrawn from soil by evaporation and/or plant transpiration. Considered synonymous with consumptive use.

Excess sludge

The sludge produced in an activated-sludge treatment plant that is not needed to maintain the process and is withdrawn from circulation.

Facultative anaerobic bacteria

Bacteria which can adapt to growth in the presence, as well as in the absence, of oxygen. May be referred to as facultative bacteria.

Ferric chloride

A chemical (FeCl_3) often used for sludge conditioning.

Filter

A device or structure for removing solid or colloidal material, usually of a type that cannot be removed by sedimentation from water, wastewater, or other liquid. The liquid is passed through a filtering medium, usually a granular material, but sometimes finely woven cloth, unglazed porcelain, or specially prepared paper. There are many types of filters used in water or wastewater treatment.

Filtrate

The liquid which has passed through a filter.

Final effluent

The effluent from the final treatment unit of a wastewater treatment plant.

Fine screen

A relative term, usually applied to screens with openings of less than 1 inch, but in wastewater treatment, often reserved for openings that may be 1/16 inch.

Five-day BOD

That part of oxygen demand associated with biochemical oxidation of carbonaceous, as distinct from nitrogenous, material. It is determined by allowing biochemical oxidation to proceed, under conditions specified in Standard Methods, for 5 days.

Floc

Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto, through biochemical processes, or by agglomeration.

Flocculating tank

In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means. In biological wastewater treatment where coagulation is not used, agglomeration may be done biologically.

Flocculation agent

A coagulating substance which, when added to water, forms a flocculent precipitate which will entrain suspended matter and expedite sedimentation; examples are alum, ferrous sulfate, and lime.

Flocculator

- a. A mechanical device to enhance the formation of floc in a liquid.
- b. An apparatus for the formation of floc in water and wastewater.

Flotation

The raising of suspended matter to the surface of the liquid in a tank as scum -- by aeration, the evolution of gas, chemicals, electrolysis, heat, or bacterial decomposition -- and the subsequent removal of the scum by skimming.

Flowing-through time

- a. The time required for a volume of liquid to pass through a basin, identified in terms of the characteristic being measured, such as mean time, modal time, minimum time.
- b. The average time required for a small volume of liquid to pass through a basin from inlet to outlet.

Flow rate

The rate at which a substance is passed through a system.

Flow regulator

A structure installed in a canal, conduit, or channel to control the flow of water or wastewater at intake or to control the water level in a canal, channel, or treatment unit.

Flume

- a. An open conduit of wood, masonry, or metal constructed on a grade and sometimes elevated. Sometimes called aqueduct.

- b. A ravine or gorge with a stream running through it.
- c. To transport in a flume, as logs.

Food-to-microorganism ratio (F/M)

An activated sludge basin loading parameter, usually expressed as pounds BOD/pound MLVSS-day.

Grease

In wastewater, a group of substances including fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and certain other nonfatty materials. The type of solvent and method used for extraction should be stated for quantitation.

Grit

The heavy suspended mineral matter present in water or wastewater, such as sand, gravel, cinders.

Grit chamber

A detention chamber or an enlargement of a sewer designed to reduce the velocity of flow of the liquid to permit the separation of mineral from organic solids by differential sedimentation.

Grit collector

A device placed in a grit chamber to convey deposited grit to a point of collection.

Groundwater

Subsurface water occupying the saturation zone, from which wells and springs are fed. In a strict sense, the term applies only to water below the water table. Also called phreatic water, percolic water.

Gutter

An artificially surfaced, and generally shallow, waterway provided at the margin of a roadway for surface drainage.

Halogen

Any one of the chemically related elements -- fluorine, chlorine, bromine, and iodine.

Hardness

A characteristic of water, imparted by salts of calcium magnesium, and iron such as bicarbonates, carbonates, sulfates, chlorides, and nitrates, that causes curdling of soap and increased consumption of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes objectionable taste.

Head loss

The loss in liquid pressure resulting from the passage of the solution through a pipe, a channel, or a treatment unit.

Heavy metals

Metals that can be precipitated by hydrogen sulfide in acid solution, for example, lead, silver, gold, mercury, bismuth, copper.

Hydraulic loading

The flow (volume per unit time) applied to the surface area of the clarification or biological reactor units (where applicable), usually expressed in gallons per day/square foot.

Hydraulic loss

The loss of head attributable to obstructions, friction, changes in velocity, and changes in the form of the conduit.

Impeller

A rotating set of vanes designed to impel rotation of a mass of fluid.

Impervious

Not allowing, or allowing only with great difficulty, the movement of water; impermeable.

Incineration

Burning sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash. The ash can then be disposed of safely on land, in some waters, or into caves or other underground locations.

Industrial wastes

The liquid wastes from industrial processes, as distinct from domestic or sanitary wastes.

Infiltration

- a. The flow or movement of water through the interstices or pores of a soil or other porous medium.
- b. The quantity of groundwater that leaks into a pipe through joints, porous walls, or breaks.
- c. The entrance of water from the ground into a gallery.
- d. The absorption of liquid of the soil, either as it falls as precipitation or from a stream flowing over the surface. See percolation.

Influent

Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

Inhibitory toxicity

Any demonstrable inhibitory action of a substance on the rate of general metabolism (including rate of reproduction) of living organisms.

Inorganic matter

Chemical substances of mineral origin, or more correctly, not of basically carbon structure.

ion

a. A charged atom, molecule, or radical, the migration of which affects the transport of electricity through an electrolyte or, to a certain extent, through a gas.

b. An atom or molecule that has lost or gained one or more electrons. By such ionization it becomes electrically charged. An example is the alpha particle.

ion exchange

a. A chemical process involving reversible interchange of ions between a liquid and a solid but no radical change in structure of the solid.

b. A chemical process in which ions from two different molecules are exchanged.

Ion-exchange treatment

The use of ion-exchange materials, such as resin or zeolites, to remove undesirable ions from a liquid and substitute acceptable ions.

Isotherm

A line drawn through all points having the same temperature.

Land disposal

Disposal of wastewater onto land.

Lime

Any of a family of chemicals consisting essentially of calcium hydroxide made from limestone (calcite), which is composed almost wholly of calcium carbonate or a mixture of calcium and magnesium carbonate.

Loading

The time rate at which material is applied to a treatment device involving length, area, or volume, or other design factor.

Mechanical aeration

a. The mixing, by mechanical means, of wastewater and activated sludge in the aeration tank of the activated-sludge process to bring fresh surfaces of liquid into contact with the atmosphere.

b. The introduction of atmospheric oxygen into a liquid by the mechanical action of paddle, paddle wheel, spray, or turbine mechanisms.

Microbial activity

Chemical changes resulting from the metabolism of living organisms. Biochemical action.

Microbial film

A gelatinous film of microbial growth attached to or spanning the interstices of a support medium. Also called biological slime.

Micron

Unit of length: 1^{-6} meters; 39×10^{-6} inches

Microorganism

Minute organism, either plant or animal, invisible or barely visible to the naked eye.

Milligrams per liter

A unit of the concentration of water or wastewater constituent. It is 0.001 grams of the constituent in 1000 milliliters of water. It has replaced the unit formerly used commonly, parts per million, to which it is about equivalent, in reporting the results of water and wastewater analysis.

Minimum flow

The flow occurring in a stream during the driest period of the year. Also called low flow.

Mixed liquor

A mixture of activated sludge and organic matter undergoing activated sludge treatment in the aeration tank.

Mixed-liquor volatile suspended solids (MLVSS)

The concentration of volatile suspended solids in an aeration basin. It is commonly assumed to be equal to the biological solids concentration in the basin.

Municipal waste

The combined residential and commercial waste materials generated in a given municipal area.

Natural water

Water as it occurs in its natural state, usually containing other solid, liquid, or gaseous materials in a solution or suspension.

Neutralization

Reaction of acid or alkali with the opposite reagent until the concentrations of hydrogen and hydroxyl ions in the solution are about equal.

Nitrification

- a. The conversion of nitrogenous matter into nitrates by bacteria.
- b. The treatment of a material with nitric acid.

Nitrosomonas

A genus of bacteria that oxidizes ammonia to nitrate.

Nonbiodegradable

Incapable of being broken down into innocuous products by the actions of living beings (especially microorganisms).

Nonpotable water

Water which is unsatisfactory for consumption.

Nonsettleable matter

That suspended matter which does not settle or float to the surface of water in 1 hour.

Nutrient

- a. Any substance assimilated by organisms which promotes growth and replacement of cellular constituents.
- b. A chemical substance (an element or an organic compound, for example, nitrogen or phosphate) absorbed by a green plant and used in organic synthesis.

Odor control

- a. In water treatment, the elimination or reduction of odors in a water supply by aeration, algae elimination, superchlorination, activated carbon treatment, and other methods.
- b. In wastewater treatment, the prevention or reduction of objectionable odors by chlorination, aeration, or other processes or by masking with chemical aerosols.

Organic loading

Pounds of BOD applied per day to a biological reactor.

Organic matter

Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structure, comprising compounds consisting of hydrocarbons and their derivatives.

Organic-matter degradation

The conversion of organic matter to inorganic forms by biological action.

Orthophosphate

An acid or salt containing phosphorus as PO_4 .

Overflow rate

One of the criteria for the design of settling tanks in treatment plants; expressed in gallons per day per square foot of surface area in the settling tank.

Overland runoff

Water flowing over the land surface before it reaches a definite stream channel or body of water.

Oxidation

The addition of oxygen to a compound. More generally, any reaction which involves the loss of electrons from an atom.

Oxidation pond

A basin used for retention of wastewater before final disposal, in which biological oxidation of organic material is effected by natural or artificially accelerated transfer of oxygen to the water from air.

Oxidation process

Any method of wastewater treatment for oxidizing the putrescible organic matter. The usual methods are biological filtration and the activated-sludge process.

Oxidation rate

The rate at which the organic matter in wastewater is stabilized.

Oxygen demand

The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. See BOD.

Oxygen saturation

The maximum quantity of dissolved oxygen that liquid of given chemical characteristics, in equilibrium with the atmosphere, can contain at a given temperature and pressure.

Ozone

Oxygen in a molecular form in which three atoms of oxygen form each molecule (O_3).

Parshall flume

A calibrated device developed by Parshall for measuring the flow of liquid in an open conduit. It consists essentially of a contracting length, a throat, and an expanding length. At the throat is a sill over which the flow passes at Berlangier's critical depth. The upper and lower heads are each measured at a definite distance from the sill. The lower head need not be measured unless the sill is submerged more than about 67 per cent.

Parts per million

The number of weight or volume units of a minor constituent present with each one million units of the major constituent of a solution or mixture. Formerly used to express the results of most water and wastewater analyses, but more recently replaced by the ratio milligrams per liter.

Pathogens

Pathogenic or disease-producing organisms.

Peak load

The maximum momentary load placed on a water or wastewater plant or pumping station or other system. This is usually the maximum average load in 1 hour or less, but may be specified as instantaneous or within some other short time period.

Percolating filter

A type of trickling filter.

Percolation

a. The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may not fill the pores of the medium. Also called filtration.

b. The movement or flow of water through the interstices or the pores of a soil or other porous medium.

pH

The reciprocal of the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen ions, in grams, per liter of solution. Neutral water, for example, has a pH value of 7 and a hydrogen-ion concentration of 10^{-7} . Acids have pH values less than 7. Bases have pH values greater than 7.

Phosphate

A salt or ester of phosphoric acid.

Pollution

A condition created by the presence of harmful or objectionable material in water.

Polymers

Long-chained, high-molecular-weight, synthetic, water-soluble, organic coagulants. Polymers can be classified as nonionic, cationic, and anionic.

Porous

Having small passages; permeable by fluids.

Postchlorination

The application of chlorine to water or wastewater subsequent to any treatment, including prechlorination.

Potable water

Water that does not contain objectional pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.

Preaeration

A preparatory treatment of wastewater consisting of aeration to remove gases, add oxygen, promote flotation of grease, and aid coagulation.

Prechlorination

The application of chlorine to water or wastewater before any treatment.

Precipitation

- a. The total measurable supply of water received directly from clouds as rain, snow, hail, or sleet; usually expressed as depth in a day, month, or year, and designated as daily, monthly, or annual precipitation.
- b. The process by which atmospheric moisture is discharged onto a land or water surface.

c. The phenomenon that occurs when a substance held in solution in a liquid passes out of solution into solid form.

Preliminary or primary treatment

a. The first major (sometimes the only) treatment in a wastewater treatment works, usually sedimentation.

b. The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter.

Pretreatment

The conditioning of a waste at its source before discharge to remove or to neutralize substances injurious to sewers and treatment processes or to effect a partial reduction in load on the treatment process.

Primary settling tank

The first settling tank for the removal of settleable solids in a treatment works.

Primary sludge

Sludge obtained from a primary settling tank.

Public water supply

A water supply from which water is available to the people at large or to any considerable number of the public indiscriminately.

Pumping station

A station housing relatively large pumps and their accessories. Pump house is the usual term for shelters for small water pumps.

Purification

The removal of objectionable matter from water by natural or artificial methods.

Putrefaction

Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

Radiation

The emission or propagation of energy through space or through a material medium; also, the energy so propagated.

Rakings

The screenings or trash removed from bar screens cleaned manually or by mechanical rakes.

Raw wastewater

Wastewater before it receives any treatment.

Receiving body of water

A natural watercourse, lake, or ocean into which treated or untreated wastewater is discharged.

Recycling

An operation in which a substance is passed through the same series of processes, pipes, or vessels more than once.

Regeneration

a. In ion exchange, the process of restoring an ion-exchange material to the state employed for adsorption.

b. The periodic restoration of exchange capacity of ion-exchange media used in water treatment.

c. Reactivation of activated carbon.

Returning sludge

Settled activated sludge returned to mix with incoming raw or primary settled wastewater.

Runoff

a. That portion of the earth's available water supply that is transmitted through natural surface channels.

b. Total quantity of runoff water during a specified time.

c. In the general sense, that portion of the precipitation which is not absorbed by the deep strata, but finds its way into the streams after meeting the persistent demands of evapotranspiration, including interception and other losses.

d. The discharge of water in surface streams, usually expressed in inches of depth on the drainage area, or as volume in such terms as cubic feet or acre-feet.

e. That part of the precipitation which runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer.

Scale

An accumulation of solid material precipitated out of waters containing certain mineral salts in solution and formed on interior surfaces, such as those of pipelines, tanks, or boilers, under certain physical conditions. May also be formed from interaction of water with metallic pipes.

Screen

A device with openings, generally of uniform size, used to retain or remove suspended or floating solids in flowing water or wastewater and to prevent them from entering an intake or passing a given point in a conduit. The screening element may consist of parallel bars, rods, wires, grating, wire mesh, or perforated plate, and the openings may be of any shape, although they are usually circular or rectangular.

Screenings

Material removed from liquids by screens.

Screw-feed pump

A pump with either horizontal or vertical cylindrical casing, in which a runner with radial blades like those of a ship's propeller operates.

Scum

- a. The layer or film of extraneous or foreign matter that rises to the surface of a liquid and is formed there.
- b. A residue deposited on a container or channel at the water surface.
- c. A mass of solid matter that floats on the surface.

Secondary settling tank

A tank through which effluent from some prior treatment process flows for the purpose of removing settleable solids. See sedimentation tank.

Secondary wastewater treatment

The treatment of wastewater by biological methods after primary treatment by sedimentation.

Sedimentation

The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. Also called settling. See chemical precipitation.

Sedimentation tank

A basin or tank in which water or wastewater containing settleable solids is retained to remove, by gravity, a part of the suspended matter. Also called sedimentation basin, settling basin, settling tank, or clarifier.

Septicity

A condition produced by growth of anaerobic organisms.

Septic sludge

Sludge from a septic tank or partially digested sludge from an Imhoff tank or sludge-digestion tank.

Septic tank

A settling tank in which settled sludge is in immediate contact with the wastewater flowing through the tank and the organic solids are decomposed by anaerobic bacterial action.

Settleable solids

a. That matter in wastewater which will not stay in suspension during a preselected settling period, such as 1 hour, but either settles to the bottom or floats to the top.

b. In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in 1 hour.

Settled wastewater

Wastewater from which most of the settleable solids have been removed by sedimentation. Also called clarified wastewater.

Settling velocity

The velocity at which subsidence and deposition of the settleable suspended solids in water and wastewater will occur.

Sewage

The spent water of a community. Term now being replaced in technical use by preferable term wastewater. See wastewater.

Sewer

A pipe or conduit that carries wastewater or drainage water.

Sewer gas

Gas evolved in sewers that results from the decomposition of the organic matter in the wastewater.

Sharp-crested weir

A weir having a crest, usually consisting of a thin plate (generally of metal), so sharp that the water in passing over it touches only a line.

Short-circuiting

A hydraulic condition occurring in parts of a tank where the time of travel is less than the flowing-through time.

Side water depth

The depth of water measured along a vertical exterior wall.

Skimming

The process of removing floating grease or scum from the surface of wastewater in a tank.

Skimmings

Grease, solids, liquids, and scum skimmed from wastewater settling tanks.

Skimming tank

A tank so designed that floating matter will rise and remain on the surface of the wastewater until removed, while the liquid discharges continuously under curtain walls or scum boards.

Slimes

Substances of viscous organic nature, usually formed from microbiological growth.

Sludge

- a. The accumulated solids separated from liquids, such as water or wastewater, during processing, or deposits on bottoms of streams or other bodies of water.
- b. The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater.

Sludge bed

An area comprising natural or artificial layers of porous material on which digested wastewater sludge is dried by drainage and evaporation. A sludge bed may be open to the atmosphere or covered, usually with a greenhouse-type superstructure. Also called sludge-drying bed.

Sludge blanket

Accumulation of sludge hydrodynamically suspended within an enclosed body of water or wastewater.

Sludge collector

A mechanical device for scraping the sludge on the bottom of a settling tank to a sump from which it can be drawn.

Sludge concentration

Any process of reducing the water content of sludge that leaves the sludge in a fluid condition.

Sludge conditioning

Treatment of liquid sludge before dewatering to facilitate dewatering and enhance drainability, usually by the addition of chemicals.

Sludge density index

The reciprocal of the sludge volume index multiplied by 100.

Sludge dewatering

The process of removing a part of the water in sludge by any method such as draining, evaporation, pressing, vacuum filtration, centrifuging, exhausting, passing between rollers, acid flotation, or dissolved-air flotation with or without heat. It involves reducing from a liquid to a spadable condition rather than merely changing the density of the liquid (concentration) on the one hand or drying (as in a kiln) on the other.

Sludge digestion

The process by which organic or volatile matter in sludge is gasified, liquified, mineralized, or converted into more stable organic matter through the activities of either anaerobic or aerobic organisms.

Sludge-digestion gas

Gas resulting from the decomposition of organic matter in sludge removed from wastewater and placed in a tank to decompose under anaerobic conditions.

Sludge lagoon

A basin used for the storage, digestion, or dewatering of sludge.

Sludge reduction

The reduction in quantity and change in character of sludge as the result of digestion.

Sludge solids

Dissolved and suspended solids in sludge.

Sludge thickener

A tank or other equipment designed to concentrate wastewater sludges.

Sludge thickening

The increase in solids concentration of sludge in a sedimentation or digestion tank. See sludge concentration.

Sludge volume index (SVI)

The ratio of the volume in milliliters of sludge settled from a 1000-milliliter sample in 30 minutes to the concentration of mixed liquor in milligrams per liter multiplied by 1000.

Slurry

A thin watery mud, or any substance resembling it, such as a lime slurry or activated sludge mixed with liquor.

Sodium carbonate

A salt used in water treatment to increase the alkalinity or pH value of water or to neutralize acidity. Chemical symbol is Na_2CO_3 . Also called soda ash.

Solids-retention time

The average residence time of suspended solids in a biological waste treatment system equal to the total weight of suspended solids in the system divided by the total weight of suspended solids leaving the system per unit of time (usually per day).

Specific gravity

The ratio of the mass of body to the mass of an equal volume of water.

Specific resistance

A sludge filterability index, generally expressed as squared sections/gram.

Spray irrigation

A method for disposing of some organic wastewaters by spraying them on land, usually from pipes equipped with spray nozzles. This has proved to be an effective way to dispose of wastes from the canning, meat-packing, and sulfite-pulp industries where suitable land is available.

Stabilization pond

A type of oxidation pond in which biological oxidation of organic matter is effected by natural transfer of oxygen to the water from air.

Sterilization

The destruction of all living microorganisms, such as pathogenic or saprophytic bacteria, vegetative forms, and spores.

Sump

a. A tank or pit that receives drainage and stores it temporarily, and from which the drainage is pumped or ejected.

b. A tank or pit that receives liquids.

Supernatant

The liquid standing above a sediment or precipitate.

Surface evaporation

Evaporation from the surface of a body of water, moist soil, snow, or ice. See evapo-transpiration.

Suspended solids

Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.

Tertiary treatment

A method used to refine the effluents from secondary treatment systems or otherwise increase the removal of pollutants.

Thickened sludge

A sludge concentrated to a higher solids content by gentle mixing, gravimetric settling, centrifugation, or air flotation.

Thickener, sludge

A type of sedimentation tank in which sludge is permitted to settle; usually equipped with scrapers traveling along or around the bottom of the tank to push the settled sludge to a sump.

Thickening tank

A sedimentation tank for concentrated suspensions.

Total Kjeldahl nitrogen (TKN)

The sum of free ammonia and of organic compounds which are converted to $(\text{NH}_4)_2\text{SO}_4$ under the conditions of digestion.

Total organic carbon (TOC)

A measure of the amount of organic material in a water sample expressed in milligrams of carbon per liter of solution.

Toxin

Poisonous compounds produced by the metabolic activity or death and disintegration of microorganisms.

Turbidity

a. A condition in water or wastewater caused by the presence of suspended matter, resulting in the scattering and absorption of light rays.

b. A measure of fine suspended matter in liquids.

c. An analytical quantity usually reported in arbitrary turbidity units determined by measurements of light diffraction.

Ultraviolet radiation

Light waves shorter than visible blue-violet waves of the spectrum, having wave lengths of less than 3900 angstroms.

Ultraviolet rays

Those invisible light rays beyond the violet of the spectrum.

Underdrain

A drain that carries away groundwater or the drainage from prepared beds to which water or wastewater has been applied.

Viscosity

The cohesive force existing between particles of a fluid which causes the fluid to offer resistance to a relative sliding motion between particles.

Volatile

Capable of being evaporated at relatively low temperatures.

Volatile solids

The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 600°C.

Wasted sludge

The portion of settled solids from the final clarifier that was removed from the wastewater treatment processes and transferred to the solids-handling facilities for ultimate disposal.

Wastewater

The spent water of a community. From the standpoint of source, it may be a combination of the liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with any groundwater, surface water, and storm water that may be present. Also referred to as sewage.

Wastewater disposal

The act of disposing of wastewater by any method (not synonymous with wastewater treatment). Common methods of disposal are: dispersion, dilution, broad irrigation, privy, and cesspool.

Wastewater treatment

Any process to which wastewater is subjected in order to remove or alter its objectionable constituents and thus render it less offensive or dangerous. See intermediate treatment, primary treatment.

Water

A transparent, odorless, tasteless liquid; a compound of hydrogen and oxygen, H_2O , freezing at $32^{\circ}F$ or $0^{\circ}C$ and boiling at $212^{\circ}F$ or $100^{\circ}C$, which, in more or less impure state, constitutes rain, oceans, lakes, rivers, and other such bodies; it contains 11.188 percent hydrogen and 88.812 percent oxygen, by weight. It may exist as a solid, liquid, or gas and, as normally found in the lithosphere, hydrosphere, and atmosphere, may have other solid, gaseous, or liquid materials in solution or suspension.

Weir

a. A diversion dam.

b. A device that has a crest and some side containment of known geometric shape, such as a V, trapezoid, or rectangle, and is used to measure flow of liquid. The liquid surface is exposed to the atmosphere. Flow is related to upstream height of water above the crest, to position of crest with respect to downstream water surface, and to geometry of the weir opening.

Weir loading

In a solids-contact or sedimentation unit, the rate in gallons per minute per foot of weir length at which clarified or treated liquid is leaving the unit. See overflow rate.

Wet well

A compartment in which a liquid is collected, and to which the suction pipe of a pump is connected.

Zooglea

A jelly-like matrix developed by bacteria, associated with growths in oxidizing beds.

Zoogleal matrix

The floc formed primarily by slime-producing bacteria in the activated-sludge process or in biological beds.

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