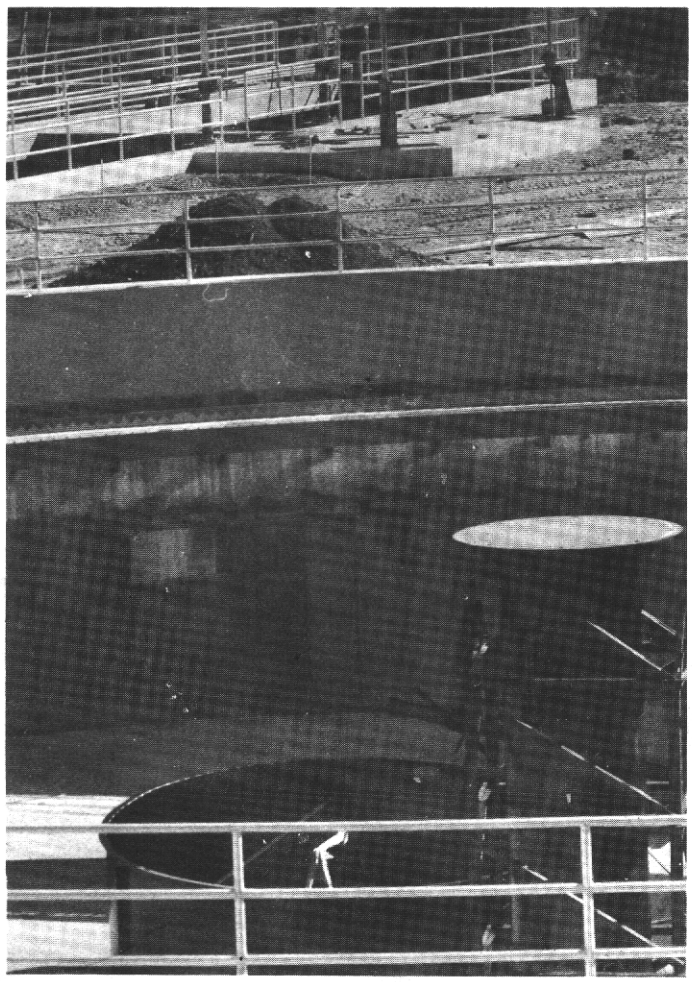
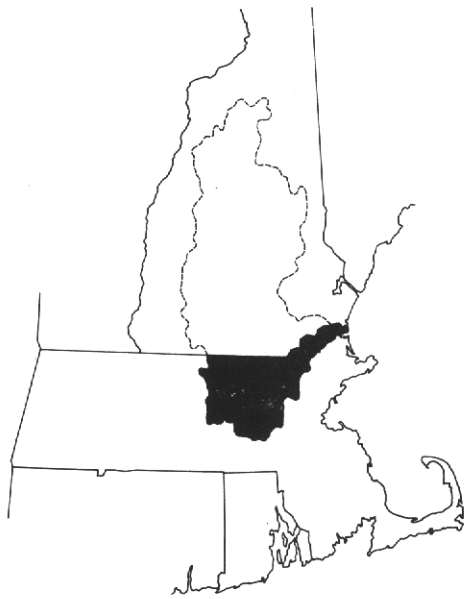
MERRIMACK WASTEWATER MANAGEMENT

key to a clean river



APPENDIX III

DESIGN AND COSTS
Volume 1



NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

NOVEMBER 1974

MERRIMACK WASTEWATER MANAGEMENT
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MERRIMACK WASTEWATER MANAGEMENT

(KEY TO A CLEAN RIVER)

APPENDIX III

DESIGN AND COSTS

(Volume 1)

November 1974

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A. DESIGN GOALS

Wastewater treatment facilities proposed under this study have been designed to comply with the interim 1977 and 1983 treatment re-requirements proposed by the U. S. Environmental Protection Agency (EPA) and the goal of "zero discharge of pollutants" outlined in PL 92-500. As a basis for developing design criteria for the 1985 goal, a sampling program was conducted on feeder streams within the study area to establish data for background water quality. Treatment technology described in other sections of this report have been incorporated in the design of treatment facilities and are discussed in the following sections of this appendix.

All wastewater treatment systems have been selected to achieve, to the maximum extent technically feasible, the degree of effectiveness required to comply with effluent limitations established for the study. In this regard, all wastewater systems have been designed to provide a maximum of process flexibility to insure optimum reliability.

Land use planning has essentially been established by the regional planning agencies within the study area. Development of sewer service areas for projected populations in the various communities within the study area have been derived from the regional planning agency guidelines. However, the proposed wastewater management alternatives have been designed to incorporate not only these considerations but also the further considerations of utility corridors, multiple-use facility siting and planned open space.

Opportunities for reuse of wastewater treatment byproducts and resource goals have been investigated and where considered feasible have been included in the alternative systems for wastewater management.

B. WASTEWATER TREATMENT TECHNOLOGIES

1. POLLUTANTS

The environment we live in is like a house. When the house is tidy, it functions smoothly and the people inside can live easy, unrestricted lives. When the house is poorly managed and becomes disorderly, however, its inhabitants are uncomfortable and their life style is constrained and tense.

In that analogy, the clutter in the environmental house is pollution. For purposes of this report, pollutants are defined as any physical, chemical or biological substance or energy state that acts upon a body of water so that desired uses of that water are restricted or impaired. The origin of pollutants which attack the quality of ground and surface waters fall into three broad classes:

Domestic Wastewater
Industrial Wastes
Stormwater

Domestic sewage is water which has been used for ordinary household purposes, like laundering and bathing and carrying away human wastes. In most urban areas, it flows from home plumbing systems into subsurface collection lines which carry it to treatment plants or , all too often, directly into the nearest natural body of water. Sewage is heavily organic; though the introduction of synthetic detergents has given domestic sewage some of the characteristics of industrial waste.

Waterborne pollutants also emanate from industry as by-products of manufacturing processes. The five major industrial processes found in the Basin are pulp and paper, textiles, tanning, plastics, and metal plating. Some of their process waters contain pollutants which could impair treatment plant operation; others contain process materials too valuable to discard.

Finally, even the water which falls as rain can contain pollutants. It becomes dirty as it cleans the air and runs over or through gutters, streets, parking lots, lawns, raw material stockpiles, and open industrial areas. It carries away pesticides, bacteria, fertilizer, particulate air pollution, litter, oil, road salts, heavy metals and many other pollutants. Moreover, many cities do not have separate collection systems for stormwater runoff, but combine it directly with the sewage flowing

in municipal sewer systems. Because these municipal systems are oftentimes not large enough to handle the sudden high volumes of stormwater, overflows to the rivers have become a serious problem in the Merrimack Basin.

Collectively, such domestic, industrial and stormwater flows are called wastewater. To prevent environmental damage, wastewater should be treated to remove pollutants or, at least, render them harmless before they are discharged into receiving waters. In a river system, it is the nature and quantity of the pollutants which determine the dimensions of a water pollution problem. In the Merrimack Basin, pollutants in wastewaters are categorized according to their method of measurement. These categories include: (1) oxygen-demanding wastes; (2) solids; (3) pathogenic agents; (4) nutrients; and (5) heavy metals.

a. Oxygen-Demanding Wastes

Organic materials are carbon compounds found in domestic sewage and industrial wastes. This category is defined by the resistance of the organic waste to biodegradation.

Biodegradable organics, representing the bulk of organic material, are of plant origin. In the Merrimack Basin, human wastes and manufacturing processes such as food processing, paper production, tanning and textiles are particularly heavy contributors of organics. These wastes are usually measured in terms of biochemical oxygen demand (BOD), or the amount of oxygen necessary for micro-organisms to consume organics in the natural biological process.

A refractory organic is one which resists natural degradation as well as biological degradation. These organics can cause taste and odor problems in drinking water. Refractory organics come from chemical and plastics manufacturing processes, as well as from synthetic detergent compounds. They may include some pesticides, insecticides and herbicides, phenols, and certain oils. Chemical oxygen demand (COD) is another measurement of organic content, both biodegradable and refractory. COD is a measurement again related to oxygen consumption, this time by a laboratory chemical reaction.

Because fish and other aquatic organisms must compete with oxygen-demanding wastes for enough oxygen to sustain life, minimized BOD, and to a lesser extent, COD levels are critically important to a healthy stream community.

b. Solids

A wide variety of materials entering wastewater flowing from manufacturing processes, agricultural practices, and weathering of natural sources are referred to as solids. These solids can be "suspended" or "dissolved," depending on whether or not they pass through a standardized filter mat.

Dissolved solids, or those which pass the filter, consist mostly of inorganic minerals. Excessive dissolved solids concentrations are unacceptable in water supply because of their laxative effect on humans, their residue left in industrial processes, and their toxicity to agricultural products. Common to the basin, dissolved iron, calcium and magnesium contribute to water hardness. Another dissolved solid, sodium chloride, is becoming a serious pollutant in the basin because of its increasing use on highways in the winter.

Dissolved solids in industrial waters can cause foaming in boilers and interference with clearness, color, or taste of many finished products. Water with extremely low dissolved solids is desirable for atomic power reactor cooling system. High contents of dissolved solids also tend to accelerate corrosion.

The total concentration of dissolved solids in irrigation waters generally varies from 150 to 1500 mg/l, and in a few cases is found to be as high as 5,000 mg/l, a concentration tolerated by only the most salt-resistant plants. Some varieties of grain will grow satisfactorily even though irrigated over most of the life cycle with water containing 20,000 mg/l of salt. High salinities may be deleterious to plants directly, or indirectly through the effects on the soil, drainage conditions, types of salts found in the water, climate, etc.

Dissolved solids may influence the toxicity of heavy metals and organic compounds on aquatic life, primarily because of the antagonistic effect of hardness on metals. Chromates, copper, cyanides, detergents, phenolic compounds, zinc and several other substances are generally more toxic in distilled water than in hard water of high dissolved solids.

For high quality domestic water, it has been recommended that color be limited to five units while another source would place the limit at three units. The stream standard promulgated by various state and interstate agencies limits the color in raw water to be used as sources of drinking water to values ranging from none to 100 units.

Water quality standards for the States of Massachusetts and New Hampshire specify that color in raw water shall not be in sufficient amount or of such character as to make the stream objectionable. In domestic water, color is undersirable from aesthetic considerations. Also, it may cause dulling of cloths or stain food or fixtures.

Solids retained on filters are called suspended solids. These solids aesthetically degrade the water quality by coloring the water. In excessive amounts, these solids decrease the amount of sunlight penetration necessary to supply energy to aquatic vegetation. Suspended solids can also be directly toxic to fish in that they may clog their respiratory mechanisms.

c. Pathogenic Agents

In this category are the disease-producing viruses, bacteria, and protozoa which are introduced to surface and groundwaters by domestic sewage and industrial wastes.

Bacteria are the simplest forms of plant life. They are characteristically small, unicellular organisms. In the environment, they may occur as single organisms or as aggregate units. The common size range from bacteria is 0.5 to 3.0 microns. The unique factor of bacteria is that each cell, whether present as a single unit or in a colony, is physiologically independent.

Virus can be defined as an obligate, intracellular parasitic micro-organism which is smaller than bacteria. It is essential that a virus invades a larger, physiologically complete cell so that the biochemical and metabolic functions required for growth and reproduction of the virus can occur.

The basic composition of a virus in its simplest configuration consists of a nucleic acid surrounded by a protein sheath. The nucleic acid governs the genetics and hereditary characteristics of the virus and is unique in that it alters the host's normal metabolic processes to support the life systems of the virus itself.

Viruses are extremely small in size ranging from 10 to 100 millimicrons (1 inch = 25,400,000 millimicrons). For purposes of comparison, bacteria normally fall in the size range between 500 to 3,000 millimicrons. The morphology of the virus can vary widely from rods to spheres to needles to tadpole-life organisms and may even be crystalline in shape.

Another unique characterstic of viruses is that they are highly specific in their reaction with all being parasitic, possess a high degree of host specificity, show a marked affinity to certain tissues, and exhibit an ability to elicit the formation of antibodies in host organisms. These disease-producing agents may find their way to man by the ingestion of polluted drinking water, by eating vegetables irrigated with polluted water, or by swimming in polluted water. Polio and infectious hepatitis are examples of diseases caused by pathogenic bacteria; swimmers' itch and certain types of dysentery are caused by protozoa.

Pollution levels for pathogens are commonly measured by indicator organisms, called coliform bacteria, normally present in the intestines of warm-blooded animals, including humans. However, the reliability of coliforms as an indicator is questionable, because methods of disinfecting pathogens oftentimes kill the coliform bacteria while merely reducing the number of more resistant bacteria and viruses.

An operational difficulty relating to virus is the lack of a suitable method for testing the adequacy of treatment. In the case of bacteria, the testing procedure has been simplified to the point where a plant operator can be trained to perform bacterial analysis. The same cannot be stated for virus because the tests required are complex in nature and not amendable to routine determination. Although it has been shown that the normal coliform index can be used as an approximation for enteric virus concentrations, the correlation is not sufficiently high to warrant this as a criteria. Present research indicates that no suitable indicator organisms exist, and that if virus levels are to be determined, the virus will have to be counted directly.

d. Nutrients

Nitrogen and phosphorus are the two commonly mentioned nutrients. Added to wastewater by domestic sewage, industrial wastes and runoff from fertilized land, they are excellent examples of too much of a good thing in the wrong place. They are essential to plant life but, in excess quantities, they can stimulate excessive growth of algae and aquatic plants. The resulting algal "blooms" are aesthetically unpleasant and can cause severe oxygen deficiencies in the watercourses which may ultimately result in suffocation of fish. In water, nitrogen may be in many forms. The form of nitrogen is as important as the total amount of nitrogen. For instance, ammonia nitrogen which is toxic to fish may inhibit the growth of algae, whereas nitrates stimulate plant growth.

e. Heavy Metals

Heavy metals fall into the broad category of inorganics, being all known elements with the exception of carbon. Heavy metals found in wastewater are largely contributed by industrial processes, and include mercury, lead, zinc, cobalt, boron, arsenic, cadmium and chromium. Air pollution may also contribute heavy metals to wastewater, for example, lead found in exhaust fumes may find its way into the watercourse through stormwater runoff. Laundry detergents may contribute metals such as boron.

Each heavy metal has its own unique characteristics. Many of these metals are needed in small amounts by plants and animals, and in thes instances they are called "micro-nutrients." However, in large quantities these metals can be toxic. Plants differ in their tolerance to heavy metals and also in their uptake of the metals from the soil. The uptake depends mainly on temperature and acidity/alkalinity of the soil and water. In colder climates and in alkaline conditions, the plant uptake is decreased. It is important to note that some heavy metals may exist in plants in large quantities, while a small quantity of that same metal may prove toxic to fish and wildlife. In addition, toxicity of some heavy metals is a function of their synergistic effect, for example, zinc or copper may not singly be toxic but their combined presence in water may be more dangerous than the sum of their solitary presence.

The following list of trace elements occur in treated wastewater and sludge.

Aluminum

Aluminum toxicities to plants may occur in both acid and alkaline soil conditions but are of little importance at near-neutral pH levels. Aluminum may be a problem in mining areas, and certain kinds of fly ash settlings.

Arsenic

Arsenic may be present in fairly high concentrations without causing damage to some plants, whereas 1 mg/l may cause damage to others. Arsenic is used in metallurgy, tanning, dye and ceramic manufacture, and in many pesticides.

Beryllium

This metal is rare in natural waters. It is highly soluble as a chloride or nitrate. Beryllium is highly toxic to both animals and plants, especially on acid soils. It is used in the manufacture of X-ray tubes, electrodes, diffraction tubes and similar products.

Boron

Boron is an essential micro-nutrient for plants, but when there is more than 4 mg/l, it is considered to be unsatisfactory to plants. Crops such as alfalfa, beets, cabbage, carrots, and asparagus are tolerant to boron. Navy beans, apples, pears, American elm, and red pine are sensitive. It is used extensively in industry and is likely to be a constituent in wastewater.

Cadmium

Tolerance limits for this element are set very low because of its highly toxic effects on man and other animals. It is, however, relatively insoluble under alkaline conditions. There is some evidence that cadmium causes hypertensive diseases in man. Metallurgy, ceramics, photography and electroplating processing are the chief sources of cadmium in wastewater.

Chromium

Chromium salts are used in many industris such as plating, tanning, paints, dyes, ceramics and paper. Plants vary in their tolerance to this element.

Cobalt

Cobalt is used in glass and china industries, and alloys in the nuclear industry. There is insufficient information to assess the adverse effect on plants and animals.

Copper

Copper toxicity appears to be associated with pH and organic content with varying effects on plants. Sandy soils are more likely to be affected than silt, clay loam soils. Many industries use copper in their processes.

Lead

Lead is added to wastewater and soil as part of industrial and mining operations. Combustion of leaded gasoline is probably the dominant source of soil contamination. Tolerance levels have not been set for plants, but there is evidence that many vegetables are especially sensitive.

Lithium

Crops sensitive to sodium are sensitive to lithium. Most crops can tolerate concentrations of 5 mg/l. Various states of this element are used in the production of glass, batteries, metallurgy, and pyrotechnics.

Manganese

A great deal of variation exists among plants, but 2 mg/l is set as an upper limit. A shortage of manganese will effect certain nitrogen transformations. There have been very few cases of manganese contaminating soils. Where it is a problem, the addition of lime will alleviate the adverse effects.

Mercury

Mercury occurs mostly in the topsoil, and if the pH is near or slightly above 6.5, it is insoluble. There is concern about methylated mercury. Apparently, inorganic mercury is changed to the methylated form by anaerobic microbes. Since organic wastes may be anaerobic sometime in the processing, the content of mercury in the sludges needs to be carefully monitored.

Molybdenum

Plants may have concentrations of this element that will be toxic to animals. However, it must be present in plants to transform nitrate into amino acids. Toxicity will occur when the pH is neutral or above.

Nickel

Nickel is toxic to many plants, and once toxic concentrations are in the soil, there is no certainty that they can be removed. Toxic concentrations often occur in soils that have a chromium content.

Adding lime to raise the pH to near neutral will reduce adverse effects. This element is used in many industries.

Selenium

Plants containing more than 4 to 5 mg/l are considered to cause toxic effects on animals.

Vanadium

Vanadium is used in the steel industry and manufacturing. Some toxicities have been observed in plants, and become a problem with the use of wastewater.

Zinc

Zinc salts are used in paint, cosmetic, dye, insecticides and similar industries. It is closely bound to soil particles; thus it is difficult to determine toxic levels.

2. PROCESSES

To deal with the ever-increasing number of pollutants, technology has developed a range of individual treatment processes designed to address different compounds of the wastewater pollution problem. No single process can do the whole job. But together, combined into wastewater management systems, they can produce water that meets drinking water quality standards. The following discussion of water renovation techniques is organized into water-oriented and land-oriented approaches.

a. Water-Oriented Processes

1) Primary Treatment

For domestic sewage and many pre-conditioned industrial wastes, basic treatment begins with the primary processes. As wastewater enters the treatment plant, it flows through a screen. The screen removes gross solids and large floating objects like sticks and rags which might foul plant equipment. After screening, the wastewater passes into a grit chamber where sand, gravel, minute pieces of mineral matter and some organic materials are allowed to settle to the bottom. But even when screening and degritting is completed, the wastewater still contains large amounts of suspended solids. This material can be removed by the sedimentation process, the major

component of the primary treatment operation. Here the velocity of the wastewater is reduced and gravity works to settle suspended solids to the bottom of the sedimentation tank. The mass of solids settled out in sedimentation is called primary sludge. In terms of efficiency of pollutant removal, typical primary treatment reduces BOD by approximately 35 per cent and suspended solids by about 65 per cent. Constituents not significantly affected include dissolved organics, heavy metals, nutrients and other dissolved solids. In municipalities with combined systems, those collecting stormwater as well as domestic and industrial wastewaters, these removal rates will be much lower after a storm. This is because the high rate of flow may adversely affect the settling capabilities of the primary tank for particles to settle out.

To complete primary treatment, the effluent, or liquid from the sedimentation tank, undergoes chlorination prior to discharge. Chlorine solution is fed into the water to disinfect pathogenic bacteria, and after a fifteen minute retention period, the effluent is discharged into a receiving stream. By itself, primary treatment is completely inadequate for handling the sophisticated chemical pollutants common in modern wastewater.

2) Secondary Treatment

While primary treatment works on wastewater physically, the secondary part of basic treatment may bring biological processes into play. Biological treatment of wastewater is a complicated procedure. In general, what occurs is that under favorable conditions the microorganisms convert 30-70 per cent of the water-soluble organic compounds into water-insoluble organic compounds. Remaining soluble organics are converted to carbon dioxide, water and energy of metabolism. Three principal types of secondary treatment are trickling filters, activated sludge, and bio-discs. Secondary treatment may also be accomplished by nonbiological means such as coagulation-sedimentation. These are later discussed under Advanced Wastewater Treatment.

a) Trickling Filter

A trickling filter generally consists of broken rock or synethetic media contained in a tank. Sewage can be applied to the filter media by several methods. The more common method consists of a centralized vertical pipe connected to rotating horizontal pipes which continuously spray sewage upon the media below. Bacteria gather and multiply on the media to form a biological slime (zoogleal). These

bacteria consume some of the organic matter in sewage. The cleaner water, with about 40-80 per cent of the BOD removed, trickles out through pipes in the underdrainage system. A major problem with trickling filters is that the bacteria are highly reproductive and some clog the intestices of the filter. In addition, high stormwater flows can detach the bacteria from the filter and flush them into the underdrainage, thus destroying the biological treatment until the slime is able to rebuild.

b) Bio-disc

Rotating-disc is the name of a biological system which is similar in concept to trickling filters. It varies in that the media moves rather than remaining static as in trickling filters.

The rotating-disc system may function as a biological process in secondary treatment to remove organic oxygen-demanding wastes, or as a tertiary process to aid in nitrogen removal. The system consists of large diameter discs mounted closely on a shaft. Wastewater flows parallel to the shaft while the discs rotate through the wastewater. Micro-organisms attach themselves to the discs in a fashion similar to the growth of micro-organisms on the media in trickling filters. While the micro-organisms are submerged and rotate through the wastewater, they convert the soluble organics to insoluble organics. The rotation of the discs keep the solids in suspension and insures that the active biological mass comes into close contact with the organic wastes. As with other biological treatment methods, the rotating-disc system must be followed by a settling tank or clarifier in which the insoluble materials may be settled out of the wastewater. Under favorable conditions and with appropriate rate of flow, the system can achieve about 90 per cent BOD removal as well as a significant degree of nitrification.

c) Activated Sludge

The activated sludge process is more in vogue today than the trickling filters of yesteryear. This process speeds up the work of the bacteria. After the wastewater leaves the sedimentation tanks of primary treatment, it enters an aeration basin where it is mixed with air and sludge heavily laden with beneficial bacteria. During the several hours that the mixture is held in the aeration basin, the bacteria break down many of the organic pollutants. The mixture of wastewater and bacteria-laden sludge then flows to another sedimentation tanks where solids settle out by gravity and are deposited on the bottom of the tank as sludge "activated" with bacteria.

A portion of this sludge is recycled to the aeration tanks for mixing with incoming sewage. A major reason for recycling the micro-organisms is that a proper ratio of incoming waste to the biological mass (food-to-mass) is critical to efficient biological treatment.

Nitrates in water courses may have a high fertilizing effect, and nitrates in drinking water may have a detrimental hygienic effect. It is important to note that bacteria normally found in the activated sludge process tend to convert ammonia in wastewater to nitrates. Under aerobic conditions, the ammonium ion (NH_4) is first oxidized to a nitrite ion (NO_2) and then to a nitrate ion (NO_3). This process is called nitrification. To avoid negative aquatic impacts from the increased availability of this nutrient, the activated sludge process would best be followed by the advanced treatment method of denitrification, where the nitrates are converted to nitrogen gas.

With the activated sludge process, the BOD and suspended solids removals are typically about 90 per cent of the raw wastewater concentrations. That impressive advantage over primary treatment is certainly desirable, but activated sludge does have several limitations.

First, the bacteria are highly sensitive organisms. They are vulnerable to toxic materials from some industrial wastes and stormwater. The bacteria can be killed outright, thus rendering an entire plant biologically inoperative. This difficulty is compounded by the fact that fluctuations in wastewater composition are irregular, and treatment plant operators seldom know what the specific pollutants in incoming flows may be. Additionally, the activated sludge process is sensitive to fluctuations in the temperature and flow rate of incoming wastewater, and the bacteria which break down the organic matter requires an environment with a pH of 6.8-7.2 for reliable BOD removals.

Secondary treatment alone does not remove dissolved solids, heavy metals or nutrients, except where these are associated with settleable solids. The Federal Water Pollution Control Act Amendments of 1972 require construction of State-EPA approved secondary treatment plants by 1977. After this date, municipalities will be required to proceed with best practicable, and industries with best available, technology by 1983.

The goal of the amendments of 1972 is thorough elimination of pollutants by 1985. To deal effectively with the full

range of wastewater pollutants, advanced treatment is required.

3) Advanced Wastewater Treatment

a) Filtration

The purpose of filtration in wastewater treatment is the removal of suspended solids. It may be used after secondary treatment to remove biologically flocculated suspended solids, after coagulation-sedimentation to remove chemically flocculated suspended solids, or after carbon-adsorption as a final polishing step before discharge or demineralization processes.

Filtration may be achieved by several methods with various filtering media. The method selected depends upon the concentration and characteristics of the suspended solids to be removed. The process may be either surface removal by straining, or depth removal by both straining and adsorption.

Microscreening is one example of surface filtration by straining. Microscreens are mechanical filters consisting of a horizontally mounted drum made up of metallic filter fabric (usually stainless steel). The drum rotates slowly in a tank as wastewater flows from the inside of the rotating drum screen. The screens may be cleaned by backwashing; but most commonly, as the drum rotates, the solids are continuously removed at the top by pumping effluent through spray nozzles which extend the length of the drum. The solids are then collected in a trough within the drum for return to the secondary plant. For secondary effluent, microscreens remove 50-80 per cent of the suspended solids.

Other media for filtration include sand, crushed anthracite coal, diatomaceous earth, perlite and activated carbon. These media may be used singly or in combination. A single media filter generally consists of a graded bed of fine to coarse sand. A dual media filter consists of coal over silica sand, whereas a multimedia filter may consist of coal over silica sand, over garnet sand.

Depth removal by filtration depends upon transportation of the particle close to the surface of the filter media, and attachment of the solid to the filter media. The transportation phase may occur by gravity through the media and into an underdrainage system, or by pressure, pumped up through the media. The attachment mechanism may involve adsorption, simple straining, chemical bridging, or interaction

by electrostatic forces. The mechanism which occurs will be affected by the type of treatment already received by the wastewater, as well as by the characteristics of the filter media.

During filtration, the initial layers of filter media tend to hold the solids until, as the voids become smaller and the flow through the voids increases, hydraulic shearing forces tear the solids away and wash them deeper through the media. When the final buildup of materials on the filtration medium begins to clog flow passages, the direction of the flow can be reversed. This backwash dislodges solid materials which are recycled to the coagulation basin for separation. When the resistance to flow has been sufficiently reduced, forward filtration may proceed. In series with coagulation-sedimentation, filtration accounts for up to 15 per cent of the overall phosphorus removal. Seventy per cent of the suspended solids in secondary effluent can be removed by single media filtration units, while up to 100 per cent of the secondary effluent suspended solids can be removed by mixed-media filtration.

b) Coagulation-Sedimentation

Impurities vary in size by about six orders of magnitude. Suspended solids are so small (a few hundred microns) that they do not settle out of solution by gravity. It is necessary to aggregate these tiny particles into larger particles that may be separated from wastewater by settling. The process of aggregation is called coagulation. Coagulation-sedimentation is capable of removing virtually all suspended solids remaining in secondary effluent and up to 90 per cent of the phosphorus compounds.

Suspended solids in their colloidal state have an electric charge; usually it's a negative charge in wastewater. When two similarly charged particles approach each other their electrostatic interaction produces a repulsive force. In order to aggregate the particles, it is necessary to reduce the repulsive forces and activate the attractive forces, termed van der Waal's forces. Coagulation is accomplished by adding a coagulant, a strong cationic (positively charged) electrolyte such as aluminum sulfate, lime, or iron salt. Toward the end of the coagulation stage, a coagulant aid may be added to encourage mechanical bridging of the aggregated particles. These coagulant aids are normally chain molecules called polymers; the larger the chain length, the more effective the bridging. As the particles aggregate and are bridged together, they tend to become insoluble and are easily removed.

Coagulation is also an effective means of removing trace metals. Mercury, for example, can be removed from wastewater by sequential addition of starch xanthate and a cationic polymer.

In addition to removing suspended solids and phosphorus, coagulation has an important ancillary use in the removal of virus. Virus particles are removed in great numbers by precipitation with either lime or aluminum sulfate, although alum treatment is the most effective of the two. Removals increase as the pH rises because of the greater negative charges assumed by the virus and the corresponding greater attraction to the positive calcium or aluminum ion. The process induces permanent inactivation of a large portion of the viruses removed from suspension; in other words, the structure of the virus particle may be permanently altered. There is a nearly linear relation between the amount of phosphate precipitated and the percentage of virus removed. Between 90 - 99 per cent removal of virus may be expected during phosphate precipitation by coagulation-sedimentation.

After coagulation, it is customary to flocculate, a process of bonding together the coagulated particles into a settleable mass called "floc." This is done by increasing the velocity gradients, thereby increasing collisions of coagulated solids so that they agglomerate. Flocculation may induce velocity gradients by mechanical means such as revolving paddles or by air diffusion agitation.

Finally, gravitational sedimentation will separate the "floc" from the partially treated wastewater. Once again, the mass of materials collected on the bottom of the settling basin is called sludge. Sludge from a coagulation-sedimentation system which has employed lime as a coagulant, can be recalcined. Recalcination is the process of recovering lime for reuse. Although, economically, the process of recalcination may not prove less expensive than using fresh lime, it minimizes the large sludge disposal problem.

c) Activated Carbon Adsorption

Adsorption involves the accumulation or concentration of molecules at a surface. Matter is extracted from one phase and concentrated on the surface of another phase because of energy forces active in the surface boundaries. Adsorption is a physical surface phenomenon. Every solid is a potential adsorbent of particles found in solution, however, the surface character of every solid determines the quality of its adsorbency.

Activated carbon is at present the most commonly used adsorbent. Its adsorption characteristics are associated with a system of extremely small uniform pores and a remarkably large surface area per unit weight. The total surface area of activated carbon is about 1000 m^2/gram, mostly due to the presence of internal surface area created by small capillaries. A single handful of activated carbon has the total surface area equal to that of a football field. Although powdered carbon shows increased adsorption rates, granular carbon is normally employed because it is easier to handle and regenerate for reuse.

Carbon columns containing thousands of pounds of activated carbon provide removal of dissolved organics from wastewaters ranging from primary to tertiary effluents. It may be applied as a technique which removes refractory organics remaining even after coagulation-sedimentation. At this point in treatment, it produces an effluent of high quality without any taste and odor problems associated with refractory organics.

Adsorption is at a minimum for charged particles and at a maximum for neutral particles. For instance, carbon adsorption has been shown to remove negatively charged virus particles; however, the carbon has a greater affinity for the more neutrally charged organic molecules. In fact, an adsorbed virus may be desorbed in preference for an organic particle competing for the same site, resulting in low viral removals (less than 35 per cent). The desorbed virus does not, however, lose its infectiousness during the adsorption process since adsorption is a physical process characterized by the capability of recovery of the adsorbed material.

Once the adsorptive capacity of the carbon has been exhausted, it is necessary that the spent carbon be removed and replaced with fresh material.

The most efficient operation of flowing wastewater through carbon columns may be the "pulsed bed" upflow approach. Wastewater is pumped upward through the column and spent carbon is periodically removed from the bottom of the tank while fresh carbon is added at the top. This approach allows almost continuous operation. Meanwhile, the carbon removed is regenerated, usually in a multiple hearth type of furnace at about 1500-1700°F. The adsorbed organics are volatized and oxidized, and 90 - 95 per cent of the original carbon is recovered with most of its adsorption capacity restored. Some carbon is lost by burning and attrition and some by alteration of surface properties. Make-up carbon generally amounts to 5 - 10 per cent by weight.

Carbon columns have an important ancillary wastewater treatment use in addition to the physical surface phenomenon of adsorption; further removals may be accomplished by biological activities of bacteria fixed to the surface of the carbon granules. This is especially important in the use of carbon columns for denitrification, a process which converts nitrate forms of nitrogen (created from ammonia nitrogen in the activated sludge process) into nitrogen gas which can pass off directly into the atmosphere.

The bacteria performing denitrification differ from those that perform nitrification. First, they are anaerobic; for denitrification to occur, there must be an absence of air. Secondly, the organisms are heterotrophic, meaning they require the presence of an organic source of carbon. Methanol, a widely used source of biodegradable organic carbon, is usually added to accelerate denitrification. One mole of nitrate requires at least 5/6 moles of methanol for complete denitrification. As the ratios are so critical, a sophisticated feed-control system is necessary.

If denitrification is going to provide significant overall nitrogen reduction, then all of the nitrogen in the raw wastewater must be converted to the nitrate form prior to the denitrification phase. This requires longer aeration times and lower food to mass ratios than normally found in conventional activated sludge processes. If all considerations are properly managed, greater than 90 per cent nitrogen reductions (to effluent concentrations of 2.0 mg/l) can be achieved.

Slime will form on the carbon. It was indicated that these slimes will not interfere seriously with the adsorption capacity of the carbon; in any case, a continuing sloughing off of the slime will re-expose adsorption sites on the carbon for the removal of organic compounds. However, it is possible that substrates and slime forming organisms will reach the ion exchange beds and reverse osmosis membranes and produce fouling difficulties. Just how important this will be is uncertain. We need additional experience to evaluate this problem and to determine what additional pretreatment processes are required to protect ion exchange materials and membranes. Further, it is not clear that problems of clogging of ion exchange materials and membranes may be eliminated with confidence. Also, it is not certain that we are yet able to produce reverse osmosis membranes that have a satisfactory life under realistic conditions of use.

d) Air Stripping of Ammonia

Raw sewage typically contains about 40 - 50 mg/l of total nitrogen, about 60 per cent of which is in the form of ammonia or urea, from which ammonia is derived. Air stripping is one process by which ammonia nitrogen can be removed from wastewater.

The air stripping process begins by raising the pH of the wastewater to very high levels (10. 5 - 11. 5). Effluent from the high-lime coagulation-sedimentation process would be of the proper pH. The high pH is necessary because at this level, ammonia exists in a dissolved gaseous state that could be easily liberated from the wastewater.

The wastewater is fed into the cooling tower from the top while air is pulled into and upward in the tower by a large top mounted fan. An important feature of the process is that the wastewater be broken down into droplets; and after the water droplet has formed, it must be ruptured and new droplets reformed. This process insures the greatest amount of gas transfer from the water into the air.

During warm ambient temperatures, air-stripping can produce up to 95 per cent nitrogen removal. In addition, the overall costs for nitrogen removal by air-stripping are less than one-third those of nitrogen removal by activated carbon adsorption.

Although these costs and removals look very optimistic, the application of this treatment method is not appropriate for New England. At air temperatures near or below freezing, nitrogen removals drop to well below 40 per cent. The freezing temperatures also result in ice formation on the tower and create local fog conditions. In addition, the air-stripping tower at Lake Tahoe has had problems of scale formation. As the water is cooled in the air-stripping tower, the calcium compounds found in the highly limed wastewater deposit on the media of the tower. These deposits must be periodically removed; a process which is not only expensive and time-consuming, but results in temporary shutdown of the tower.

In this study, we further question the ecological integrity of ammonia stripping by air. Although ammonia gas is removed from the wastewater, it is released to the atmosphere. There it enters into the atmospheric moisture and can re-enter the water course system in the next precipitation event.

e) Breakpoint Chlorination of Nitrogen Removal

Chlorination is a suitable system for nitrogen removal. As a result of its strong oxidizing power, chlorine can be used in a "break-point" technique for the removal of nitrogen. Hypochlorous acid reacts with ammonia to form chloramines and subsequently evolve as chlorine gas. A restriction on this system is that the nitrogen be in the ammonia form. Fortunately, this is the form present in raw wastewater.

Based on the experience of water purification, application of chlorine to large volumes of water should not be an obstacle. Two problems do exist for this method of nutrient removal. First, the cost of chlorine will be significant in that each pound of ammonia requires more than seven pounds of chlorine. The second fact, again relating to quantity of chlorine required, is the dramatic increase in dissolved solids which comes about as a result of the chlorination. The failing becomes acute when recycling is considered.

f) Freezing

Freezing is currently employed in desalination of sea water and is a potential technology for separating inorganic mineral salts from partially treated wastewater. The method capitalizes on the freezing phenomena of water containing salts whereby any initial ice crystals formed are essentially free of dissolved material. By partial freezing of a solution, it is possible to develop salt-free ice crystals in a concentrated salt solution called brine. The ice crystals are then removed from the brine and washed of any brine coating. The washed ice is then sent to a melting tower for transformation to renovated wastewater. The brine is sent to the heat exchanger where it aids the cooling of influent wastewater.

The most obvious technical drawback in the freezing method is the capability to wash the ice crystals free of brine while minimizing the use of product water. Approximately five per cent of the renovated wastewater is returned to the wash column to remove brine coating the crystals.

There are two basic approaches to freezing. In the vacuum flash freezing process, (see Figure 1), the wastewater acts as its own refrigerant. In the heat exchange unit, the influent is reduced to a temperature just above freezing. Then, while in the vacuum flash freezer where pressures are just below wastewater vapor pressures at freezing point, some of the water will vaporize and chill the remaining water. This results in some of the water freezing into

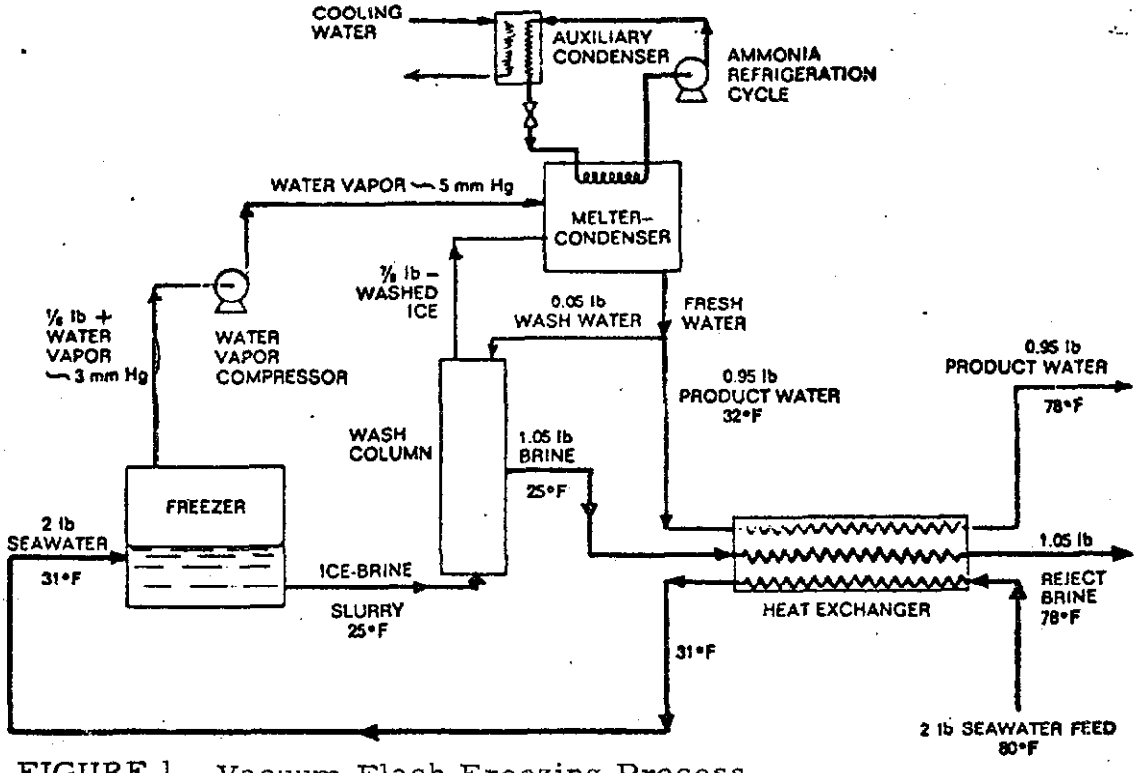

FIGURE 1. Vacuum Flash Freezing Process

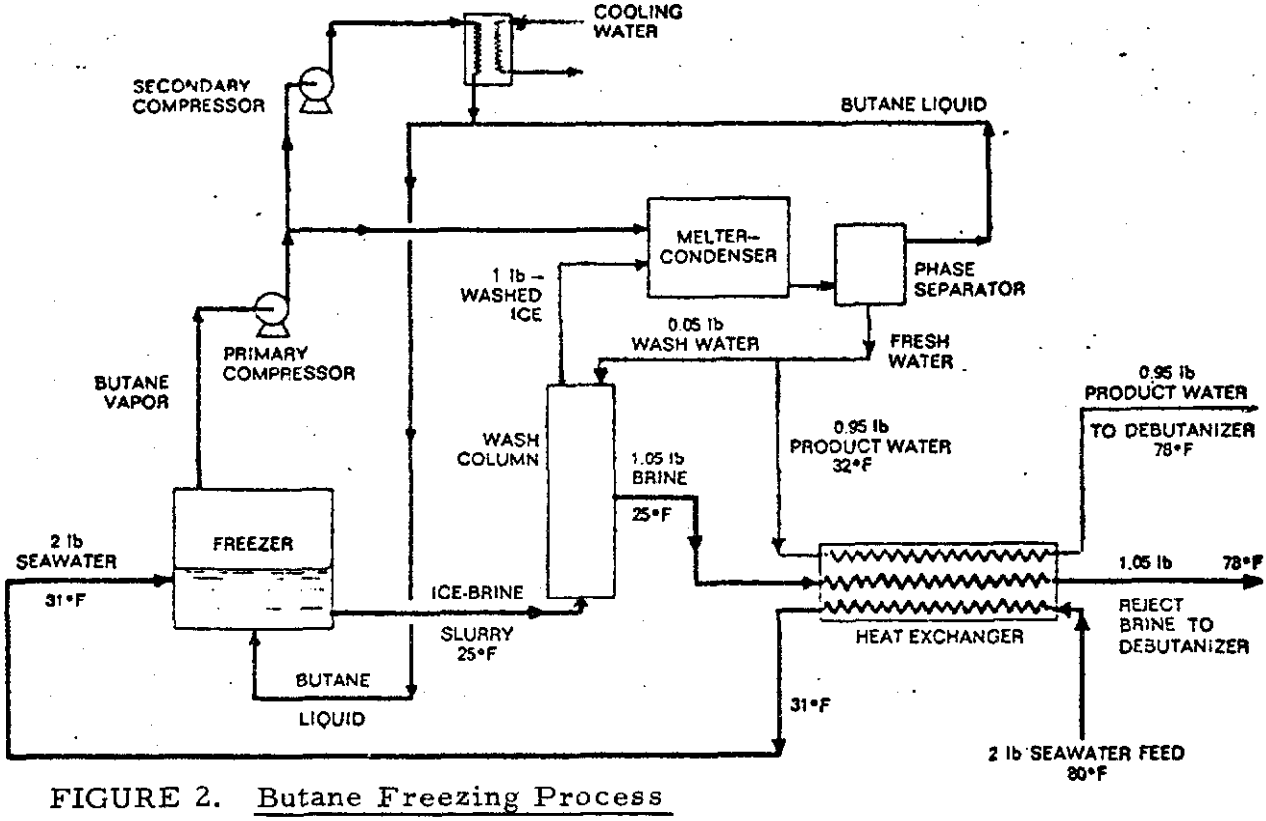

FIGURE 2. Butane Freezing Process

salt-free ice crystals. The slurry of crystals and residual brine is then passed to the wash column as previously described. The process of butane freezing (see Figure 2) incorporates volatile butane liquid as a refrigerant. It operates on the principal that butane and wastewater are mutually insoluble in one another, and that the butane vaporization temperature is slightly higher than the freezing point of water. In the freezer unit, the liquid butane vaporizes as it takes heat from the wastewater. The heat exchange causes some of the wastewater to form salt-free ice crystals. After washing, the ice crystals are melted and passed through a phase separator for recovery of any remaining butane refrigerant.

Although freezing may offer potential as a future wastewater treatment technology, its track record to date is insufficient to warrant our recommendation. The present costs of the system are excessive and further development of the process is necessary before it can be employed at any large scale wastewater renovation facility. Furthermore, economies of scale usually encountered as a system becomes larger do not appear to be applicable to freezing processes.

g) Ion Exchange

The first practical application of the ion exchange principle was in the field of water softening. Water softeners are designed to replace dissolved solids like calcium and magnesium with nonhardness sodium. In wastewater treatment, the process is designed to remove the inorganic mineral salts, including heavy metals, dissolved in wastewater. When a mineral salt is placed in water, it has a tendency to break down into ions, positively and negatively charged species.

These ions in solution can exchange position with similarly charged ions on the surface of a solid immersed in the solution. Because the exchanging ions are transferring from a solution phase to a surface phase, ion exchange is classified as a sorption process (carbon adsorption is also a sorption process).

Ion exchange units consist of resins containing ions which can be replaced by similarly charged ions in the wastewater.

Special acid resins will replace positive ions with hydrogen ions (H+), and base resins will replace negative ions with hydroxyl ions (OH-). These ions will then combine to form water (H_2O). Use of the above resins will reduce the dissolved mineral content instead of simply substituting one ion for another. When no more exchangeable ions are available, the resin becomes exhausted, and the

contaminant appears in the effluent. Before this point, forward flow is reversed as in filtration, and the resins are backwashed to remove strained contaminants. The resins themselves are then regenerated with a solution containing a new supply of the original exchangeable ion and treatment proceeds as before. Ion exchange can be extremely effective but care must be taken to insure that the resins are not attacked by strong oxidants like chlorine.

Brine are concentrated solutions of dissolved solids produced in the regeneration of ion exchange resins. These are the same dissolved solids which were previously present in the influent but which were extracted and concentrated in the ion exchange process. Ion exchange has achieved 90 per cent demineralization of carbon-treated secondary effluent at Ponoma, California. About 87 per cent of the influent water was recovered, which means that the remainder was contained in the brine.

The dissolved solids removed on the resins come from many different sources. Some are present in the water initially; some are added as a result of municipal and industrial use; and some are added by wastewater treatment processes. The ocean may be a compatible recipient for such high salt concentrations and a convenient choice for disposal in this region, situated on the Atlantic seacoast.

h) Reverse Osmosis

Reverse osmosis is a membrane process (see Figure 3). Like filtration, it employs a barrier to retain materials found in solution while allowing the solvent to pass through. Reverse osmosis is dependent on the semi-permeable characteristics of the membrane, characteristics which ideally would prohibit passage of the solute but allow the solvent to flow through.

Reverse osmosis is also dependent on osmotic pressure. When a semi-permeable membrane separates a solution from a pure solvent, the natural tendency is for the concentrations to equalize. The tendency, for the least concentrated liquid (in this case the solvent) to flow to the more concentrated solution, is termed osmosis. The pressure force that drives the flow is the pressure difference between the nature of the solvent and the nature of the solution. This is called osmotic pressure, and it is a function of concentration and temperature.

In reverse osmosis, sufficient pressure is applied on the solution side of the membrane to overcome normal osmotic

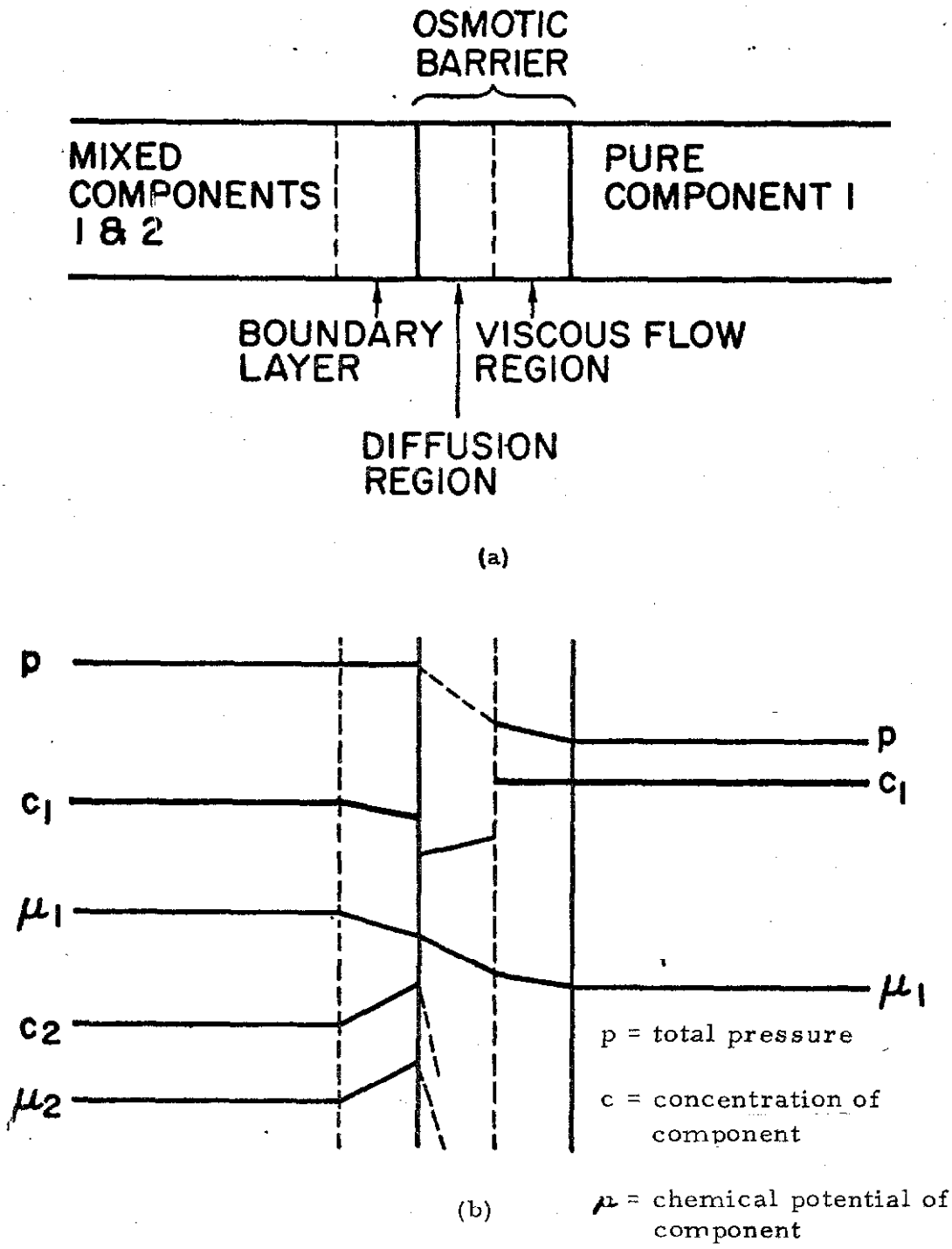

FIGURE 3. Reverse Osmosis Cell

tendencies and insure one way direction of flow from the solution side to the solvent side. During the process, solutes are retained on the membrane. The process is mostly employed for desalination of brackish water. However, reverse osmosis of partially treated wastewater has proven to remove large percentages of nutrients and oxygen demanding wastes, as well as inorganic mineral salts. Removal rates are effected by levels of pH, temperature and dissolved solids content of the influent. Increased dissolved solids in the solution will raise the osmotic pressure, thereby requiring a higher outside driving pressure to be applied.

Reverse osmosis has achieved 95 per cent demineralization, or reduction in total dissolved solids (TDS), at Pomona, California. One of the carbon-treated secondary effluent feed into the reverse osmosis units, approximately 85 per cent became renovated water and less than 15 per cent was brine.

Problems of reverse osmosis are related to fouling of the membrane. (Modified cellulose acetate is currently considered the most effective membrane material). Concentration of solutes on the membrane's boundary surface reduce the through flow and thereby raise the osmotic pressure. Also increased concentration of solutes at the membrane surface may accelerate membrane deterioration. Cleaning of the membrane is essential to optimize removal efficiencies. The most effective cleaning procedure currently employed is flushing with a presoak solution.

An attractive feature of reverse osmosis is that the energy requirements are low compared with electrodialysis and freezing processes. Reverse osmosis does not require the material being removed to undergo a change-of-state or to receive an electrical charge. Although the process is ecologically attractive and removal rates are very high, there is one major drawback. Reverse osmosis is currently very expensive owing to high operational expenses of membrane replacement and cleaning costs. However, the process is in its early stage of development and sharp reduction of costs are expected.

i) Electrodialysis

Although mostly employed for desalination of brackish water, electrodialysis can be used to separate inorganic mineral salts from partially treated wastewater.

Initially, the wastewater solution may be subjected to an electric current which augments the separation of salt compounds into their fundamental ionic units. The solution is then passed through a stack of parallel membranes having either positive or negative charge. Cation selective membranes allow the passage of positively charged ions, while anion selective membranes allow the passage of negatively charged ions. By alternating the cation selective and anion selective membranes, it is possible to concentrate the charged salt ions in alternate cells. The rate of migration can be accelerated by applying a voltage across the cells. Figure 4 depicts a schematic of the electrodialysis cell. Wastewater can be passed through several such cells until the desired salinity reduction is accomplished.

In some cases, charged particles, which are too large to pass through the membrane, may collect on the surface of the membrane and inhibit their efficiency. This problem may be resolved by first reversing the polarity of the terminals and collecting the backwash and then by acid rinse. If the membrane coating is an organic slime, addition of chlorine solution would be employed to cause oxidative degradation of the slime. The degree of membrane coating will depend on the quality of the incoming partially treated wastewater; thus far, electrodialysis can only be used for highly treated wastewater.

A major problem in electrodialysis is membrane selectivity. A good membrane must be able to reliably and continuously discriminate between oppositely charged ions, and it must be a fair electrical conductor. The membrane must also be chemically resistant to oxidation, and have mechanical strength. Most membranes are composed of ion-exchange resins with polymer films or inert binding agents.

Pilot projects in using electrodialysis to renovate wastewater have been studied in Lebanon, Ohio and Pomona, California. In both studies, the influent was a high quality treated wastewater and percentage removals were compatible. Nitrate nitrogen and ammonia nitrogen ions were removed to a greater degree (up to 50 per cent reduction) than phosphate ions. Reduction in total dissolved solids was about 30 to 40 per cent. Pomona report a 34 per cent reduction in TDS of a carbon-treated secondary effluent. Water recovery was about 90 per cent, losing 10 per cent of the water in brine solutions.

j) Disinfection

Disinfection is the process of actual destruction of the infectiousness of a pathogen such as virus. Pathogens are known to be

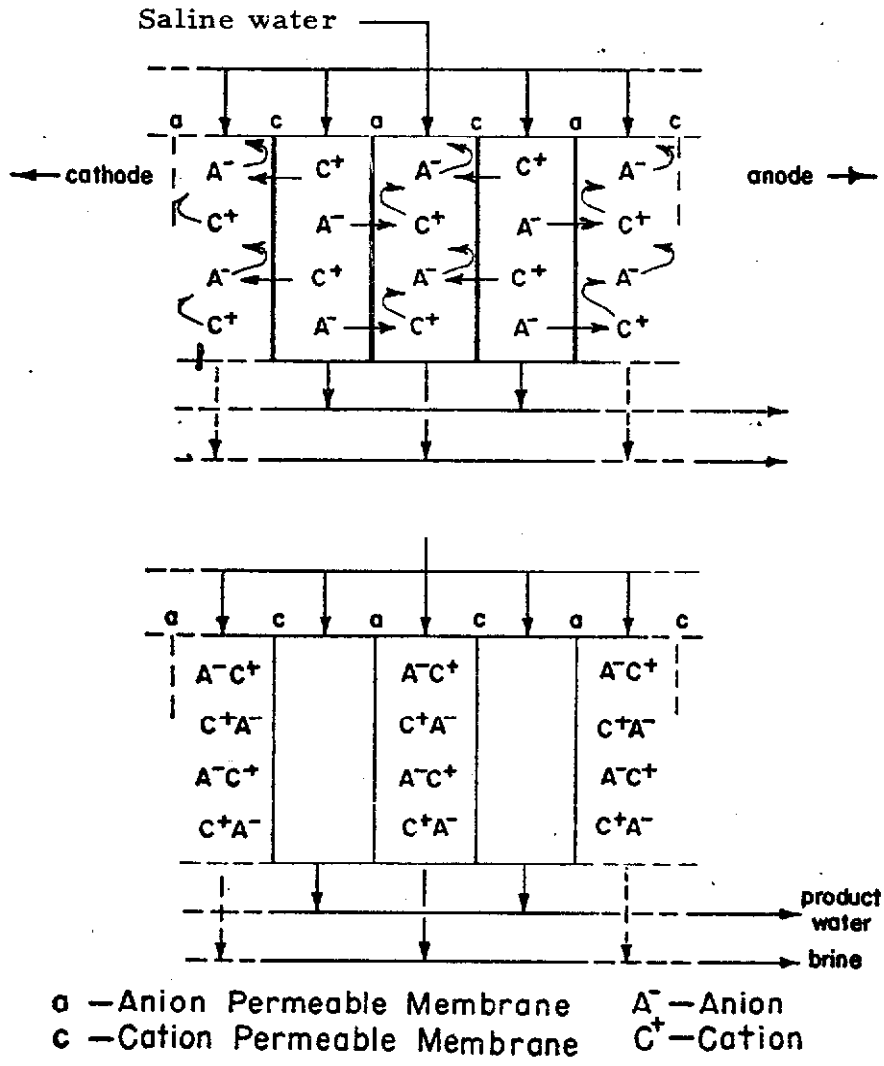

FIGURE 4. Electrodialysis Cell

excreted from humans through the enteric tract. This discussion concerning disinfection will be restricted to virus because of the ever-increasing evidence that bacteria such as coliform are less resistant to wastewater treatment processes and that more rigorous treatment is necessary for virus removals.

We will be most concerned with the de-activation or destruction of viral infectiousness. Treatment processes such as sedimentation, filtration, and adsorption remove virus and may decrease their infectiousness. However, the removals reported by these treatment processes usually indicate transportation of active virus particles from the wastewater environment to the sludge environment. If sludge treatment entails immediate application to the land, then the potential health hazard has not been eliminated.

Disinfection may be accomplished by the direct application of thermal energy, such as in ultra-violet irradiation, or by the addition of chemical agents such as ozone and chlorine. Disinfection methods usually act by destroying cell protein of the pathogens, and by inactivation of enzyme systems essential for microbiological life.

For disinfection to occur, the disinfectant must come in contact with the pathogen; it must penetrate the cell wall; and it must react with enzymes within the cell. Application of thermal energy physically destroys the micro-organisms. Strong oxidizing agents such as ozone literally "burn-up" the organism; they inactivate enzymes and cause oxidative degradation of cell material. Halogens such as chlorine disinfect by oxidation of amino acid groups on bacterial cell walls and viral protein cheaths.

The average virus density in domestic wastewater is about 7,000 infectious units per liter. Ninety to ninety-nine per cent disinfection of virus would leave 70-700 infectious virus per liter. When even one virus infectious unit per liter is present in water supply, individuals may well be infected by normal daily consumption.

1) Chlorination

Chlorination is the most economical form of disinfection of large quantities of wastewater. Chlorine is a halogen that is manufactured by the elctrolysis of NaCl. At ordinary temperatures, it is a greenish gas with a density of 2 1/2 times that of air. Gaseous chlorine, when introduced in water, reacts with water to form hypochlorous acid (HOCl) , an effective disinfectant.

Chlorination has been shown to remove more than 99 per cent of the virus present, when high chlorine residuals are provided. However, current wastewater chlorination practices have little or no effect on infectious virus. Conventional wastewater treatment facilities provide a residual of not less than 0.5 mg/l after a minimum of 15 minutes contact time. This falls far short of the requirement of 9 mg/l residual after 15 minutes needed to obtain 90 per cent viral inactivation.

The rate of chlorine disinfection is a function of the time of contact, concentration of chlorine, amount of ammonia and nitrogenous organic matter present in the wastewater, and the wastewaters' temperature and pH. Concentrations of ammonia reduce the efficiency of chlorination. Ammonia combines with chlorine to form chloramines. These compounds are known to be 100 - 270 times slower in disinfection than free chlorine in the form of HOCl. Chlorination is most effective at high temperatures and at low pH values. About pH 7, hypochlorous acid ionizes to form hypochlorite ion, which is a much slower disinfectant than HOCl.

Unlike ozonation, in chlorination bacterial kill occurs first and more effectively than viral inactivation. Chlorine inactivates bacteria by oxidizing the amino acid groups on the bacterial cell wall. Virus particles are much smaller than bacteria and the virus lack a cell wall; this may relate to their greater resistance to chlorine disinfection.

Although chlorine is the most economical disinfectant and under optimum conditions can effectively inactivate virus as well as bacteria, it has several drawbacks. Chloramines, the compounds formed when chlorine reacts with the ammonia commonly found in wastewater, are shown to be toxic to fish life. Chlorine combines with hydrocarbons and phenols to form undesirable compounds that are difficult to remove and create objectionable tastes. Chlorination increases the dissolved solids content or salt concentration of the water. Transportation and storage of liquid chlorine can be a serious public hazard, however, on-site generation is possible. Wet chlorine is corrosive to all metals and precaution must be exercised to insure chlorine tanks are kept dry. In air, gaseous chlorine is toxic; 1000 ppm of chlorine gas in air rapidly produces fatality. Well ventilated storage areas with sensitive alarm systems are mandatory design criteria.

2) Ozonation

Ozone is a very powerful oxidizing agent that has been used extensively in Europe in water treatment for disinfection and removal of taste, odor and color, and iron and manganese.

Ozone is an unstable gas which is an allotrophic form of oxygen. It can be generated by incorporating the following principles. Dry air is made to flow through a gap between two electrodes. A high voltage AC current is imposed across the gap. Ten per cent of the energy supplied by the current converts gaseous oxygen (O_2) to ozone (O_3). The remaining ninety per cent of the energy is primarily lost as heat. Therefore, an efficient method of heat removal is essential to the process.

Once the ozone is generated, its life is short (about 15 minutes in water). In its unstable O_3 form, one of the oxygen atoms is extremely reactive and thereby a strong oxidant. Every three pounds of ozone can oxidize one pound of COD wastes and yield two pounds of oxygen gas (O_2).

Ozone has a well documented capability to disinfect not only the usual pathogenic indicator organisms, but also stubborn virus and spores. And it can do it 600 - 3000 times more rapidly than free chlorine. 99.99 per cent kill of E. coli. bacteria has been realized in less than 100 seconds using only 100 ppb of ozone. Experiments done on secondary effluent wastewater realized 100 per cent of destruction of virus (f_2 bacteriophage) after a contact time of five minutes and a total ozone dosage of about 15 ppm and a residual of 0.015 ppm. The implication in wastewater treatment is that a shorter contact time results in less storage tank capacity. Ozone is also much less sensitive to the water's pH and temperature than chlorine, and therefore more reliable.

While chlorination may result in the formation of residual chloramine in water, ozone leaves an oxygen residual. Chloramines are toxic to aquatic organisms, while increased dissolved oxygen is beneficial. Another benefit of ozone application is the reduction of taste, odor and color problems. This is in contrast to chlorination, which often results in objectional phenol tastes in water. An interesting occurrence in ozonation is that it consistently produces an effluent near neutrality, regardless of whether the influent was acidic or basic. Because of its unstable nature, ozone cannot be stored. Ozonation requires on-site generation and the equipment is expensive, up to twelve times

that for chlorine. However, ozone can be generated from air, resulting in a much lower chemical cost than chlorine. Operating costs for ozonation chiefly depend on the cost of electricity. Overall ozonation costs are about two to three times that for chlorination, however, keep in mind that the cost of either is very low; less than 1.5¢ per 1000 gallons of water.

As with irradiation, the major drawback of ozonation is its inability to provide residual disinfecting protection. However, the absence of a persistent residual is an advantage in the respect that contaminants are removed without producing secondary pollutants and without increasing the inorganic salt concentration.

3) Irradiation

Ultraviolet light is the short wave length irradiation present in sunlight. Ultraviolet irradiation may also be created by artificial light or photochemical processes.

Ultraviolet irradiation has the ability to alter the structure of organic and inorganic molecules. When wastewater is exposed to ultraviolet light, a change is produced in all of the organisms or materials absorbing the light. We will say that a change is produced in all of the "absorbing species." The degree of change will be affected by the amount of light that reaches the absorbing species and the absorption capacity of the species.

Because ultraviolet irradiation is an expensive process, it should be reserved for absorbing species that are difficult to remove by simpler and less expensive methods. In wastewater treatment irradiation could, therefore, be employed on stubborn virus and refractory organics that remain after treatment by other processes.

The capability of irradiation to destroy virus and refractory organics will be affected by the energy rate, the length of exposure time, and the concentration of absorbing species. Noting that only those species penetrated by the light will alter in structure, a significant increase in destruction results by stirring the wastewater.

The protein material in the cells of pathogenic organisms are highly absorbent of ultraviolet irradiation. The nucleic acids, which include the life-giving chains of DNA and RNA, absorb the energy and are consequently destroyed. Results of destruction of the nucleic acid may be death to the cell or genetic mutation. In ultraviolet irradiation the loss of virus infectivity exceeds 99.9 per cent

after 40 seconds of ultraviolet exposure. Peak destructive action occurs in the wave length region of 2500 - 2650°A.

In irradiation for reduction of refractory organics, the absorbing species is elevated to a higher energy level. At this higher level, the species tends to be unstable and must de-activate by reverting to a lower, less energetic but more stable state. The amount of refractory organics degraded is increased by increasing the energy and the amount of time.

Advantages of the system come from the fact that nothing has been added to the water, therefore, there will be residual tastes and odors or increased salt concentration. In addition, the process is independent of pH and temperature levels.

Gamma irradiation is a product of radioactive decay. It is electromagnetic radiation of very short wave length produced by changes within an atom's structure. Compared to ultraviolet irradiation, gamma irradiation is about one million times as powerful. Working on the same principles as ultraviolet irradiation, a dosage of 100,000 to 150,000 rads is sufficient to destroy over 99 per cent of the bacteria organisms in wastewater. Also, over 99 per cent destruction of refractory organics from synthetic detergents has been achieved by a dose of 100,000 rads. Large dosages of gamma irradiation are capable of complete sterilization of wastewater; sterilization is the destruction of all living organisms regardless of whether or not they are pathogenic.

Because of its prohibitive cost, irradiation is not currently employed as a wastewater treatment process. However, if the reuse of wastewater for water supply becomes a necessity, it may not be able to put a price tag on safeguarding public health.

b. Land-Oriented Processes

Although not a new procedure, ground renovation of wastewater effluent has recently received much attention as an effective advanced treatment method which eliminates the high capital and operating costs of conventional tertiary treatment.

After pretreatment consisting of equivalent secondary treatment and filtration, wastewater would be applied to the land, thereby eliminating direct wastewater discharge to a watercourse. There are three basic techniques for surface application of wastewater effluent to the land: spray irrigation, rapid infiltration and overland runoff.

In spray irrigation, a number of mechanisms are in operation to renovate wastewater and remove impurities. The mechanisms generally occur within the top several feet of soil layer; depending upon low application rates and moderately fine grained soil; and include filtration through the soil, and, to a lesser extent, volatilization and soil fixation removal of oxygen demand, solids, viruses and bacteria, nitrogen removal and phosphorus removal. Properly managed, a system of this type may effect removals greater than 98 per cent of BOD, SS, and viruses and bacteria and, providing crop harvesting (removal) is practiced, nitrogen removals in excess of 80 per cent, and phosphorus removals of greater than 98 per cent.

In rapid infiltration, wastewater loadings of up to 12 inches per day are applied to a deep stratum of highly permeable soil. Wastewater renovation in such treatment may extend many feet below ground, and primary renovation mechanisms are soil filtration and fixation. Nutrient removal (phosphorus and nitrogen) are less efficient than in spray irrigation.

Overland runoff is practiced in soils of extremely low permeability. Applied wastewater runs over the soil surface and is collected at the bottom of the slope. It should be noted that overland runoff does not eliminate direct discharge of effluent, as the wastewater must be collected in this type of treatment. Removal efficiency of this system is considerably lower than either spray irrigation or rapid infiltration.

Of all the land-oriented systems, spray irrigation of wastewater poses the smallest risk to groundwater contamination because of its low loading rate and variety of removal mechanisms. Unfortunately, however, the method requires very large land areas and wastewater storage is normally provided for cold and wet weather periods.

Rapid infiltration is a less dependable treatment system than spray irrigation, and should be used only with extreme caution where groundwater is used as a source of water supply. Even in areas where water supply is not a consideration, the effect of increased groundwater levels of nitrates, phosphates, heavy metals, and dissolved solids might eventually contaminate a surface water body. It is, therefore, essential that rapid infiltration on a large scale basis be very carefully considered during design and monitored while in operation to insure that renovation of wastewater is achieved with minimum harmful effects upon the soils of the application site, and groundwater in the area.

C. CONCEPTUAL DESIGN METHODOLOGY

1. FACILITY SITING

a. Treatment Plant Locations

When this study originated, it was envisioned that no constraints would be imposed on the selection of treatment plant sites especially under centralized alternatives. At one point in the study, the possibility of locating one large treatment plant in the estuary area treating raw wastewater from the entire study area was given consideration.

As the study progressed and the need to determine a workable number of options approached, it was necessary to establish a baseline against which all alternatives could be compared. Since the Commonwealth of Massachusetts and the Environmental Protection Agency have been effectively administering the implementation program since 1967, the schedule for pollution abatement established by that implementation program was a logical choice for use as the baseline. Further analysis of the existing and proposed plants indicated that it would not be feasible to abandon any of the existing or presently proposed plants. Consequently, the existing or "near" existing treatment facilities in Lowell, Billerica, North Andover, Haverhill, Amesbury and Newburyport were considered "givens" and included in every alternate thus eliminating any possibility of a truly regional scheme, which would include both secondary and advanced levels of wastewater treatment.

By accepting the siting of treatment plants as proposed by other consulting engineers and accepted by the Massachusetts Division of Water Pollution Control, the remaining task was to site plants in the remaining areas. Whenever a town had an engineering report done which included consideration of sites for treatment facilities (Pepperell, Westford, Chelmsford, Merrimac and Salisbury), these sites were adopted for this study.

All sites recommended in previous engineering reports were however, examined for suitability for enlargement and it was determined that all sites could be utilized in some manner. Sites not near urban centers (for example Merrimac and Pepperell), were eliminated from consideration as locations for regional facilities.

Upon review of engineering reports, it became obvious that there are towns within the study area that, at the present time, do not require wastewater collection or treatment as evidenced by the lack of a sewerage study and the absence of a water pollution abatement order. It is not the intent of this study to recommend that every town be required to collect and treat its wastewater; what is necessary is that some provisions and recommendations be considered for future years when sewerage may become a necessity. To accomplish this end, it was necessary to establish treatment plant sites in towns such as Boxford, Rowley, Georgetown and West Newbury. For these sparsely developed towns, treatment facilities were located as close as possible to existing population centers and an effluent receiving stream.

b. Main Interceptor Alignments

Wherever possible, gravity pipelines are proposed to carry raw wastewater or treated effluent to the treatment plant, or waterway, respectively. Use of gravity pipe minimizes the total transportation cost as fewer pumping stations are required and gravity pipelines - when placed in a 10' trench, are less expensive than force mains (for those pipe sizes between 18" and 108").

The choice of alignments again is based upon the desire to achieve the lowest cost with the least disruption of private property, traffic or urban areas. In most cases, then, alignments follow along one side of an existing street or highway, as they provide easy construction access, require no easements or acquisition costs, and create only temporary disruption of traffic. No alignments are proposed to lie in the median divider of or travel parallel to an Interstate Highway due to the difficult construction involved and unfavorable attitude often shown by highway officials.

For certain locations, roadway alignments would present undesirably deep cuts or circuitous routes. In these cases it is cheaper to lay pipe in public and private lands.

In a number of municipalities engineering reports have been prepared that propose a collection system leading to a local or regional treatment plant. The location of these collection systems and locationsof pumping stations have not, in most cases, been changed, because it is assumed that the best siting has been selected by that engineer. In certain wastewater management

alternatives, collection facilities are proposed to convey raw wastewater from another municipality. While the affected pipes and pumping stations must be enlarged, the cost to each municipality will be lower than if each constructed their own facilities.

Pipelines carrying treated effluent cannot intercept raw wastewater, but their alignments may travel parallel to, and in some cases in the same trench with raw sewage pipelines.

c. Pumping Stations

Pumping stations are proposed whenever a gravity alignment would require a trench depth greater than 20 feet. Theoretically a force main could be extended a number of miles, but the high power costs associated with such a high pumping head dictate that gravity pipes be used wherever possible in order to reduce the pumping head.

When a sewer line entering a treatment plant is too deep to permit gravity flow through the plant, pumping stations are located ahead of the influent structures of the plant.

2. TREATMENT PROCESSES

a. Introduction

This section outlines optimum wastewater treatment technologies and associated costs which could be utilized to comply with the interim 1977 and 1983 treatment requirements proposed by EPA, and the 1985 discharge limitations outlined by Congress in PL 92-500. Actual Congressional intent is still being interpreted; however, for the purposes of this discussion, several levels of treatment technology will be proposed to effect the degree of removal required under various interpretations of the law. Both land and facilities oriented treatment methods will be discussed for the achievement of effluent goals.

It should be noted that the 1977 and 1983 goals to be outlined in this discussion apply only to wastewater discharges from publicly owned treatment works; effluent limitations for specific industries are presently being developed by EPA and are in Section C8 of this appendix. All capital costs developed in this study are based where possible upon several sources, and have been updated to an Engineering News Record Construction Cost Index (ENR) of 2200. Capital costs presented herein do not include allowances for contingencies, supervision and administration, and engineering. Operation and maintenance costs have been estimated by attempting to assume a correlation between the ENR Index of 2200 and a future time; it is realized that, in view of the behavior of the ENR Index over the past several years, this is an especially hazardous procedure; nonetheless, there seems to be no better technique available. O & M costs have been increased 2.0 percent per year (compounded) between the date for which the estimate was made and the date at which we have assumed the ENR to reach 2200. This is expected to occur sometime in early 1975.

b. 1977 - Secondary Treatment

(1) Introduction

Secondary treatment efficiency is basically defined by the solids and organic carbon removals experienced through the pro-

cess. The level of effluent reduction required by a publicy owned treatment works through the application of secondary treatment has been defined by EPA as follows:

	MAXIMUM EFFLUENT LIMITATIONS	
	30 consec. days	7 consec. days
BOD_5 (mg/l)	30	45
SS (mg/l)	30	45
Fecal coliform (No. /100 ml Bacteria)	200	400
pH	6-9	6-9

(Ref: Federal Register, Volume 38; Number 159 (August 17, 1973), pgs 22298-9)

(2) Biological and Physical-Chemical Treatment

Secondary treatment can be achieved through biological or physical-chemical methods. Biological treatment can be either oriented towards a facilities, as in conventional activated sludge or any of its modifications or towards land, as in aerated lagoons, oxidation ditches, or stabilization ponds. Both facility (water) and land oriented biological secondary treatment facilities operate on similar principles and with similar results; their differences involve the amount of land each requires and the operating control and costs associated with each method; and therefore, the choice of one technique over another requires an examination of each particular treatment situation.

In the past several years, secondary treatment utilizing a total physical-chemical process has been proposed for achievement of secondary treatment removal of solids and organic carbon. The processes as proposed usually involve chemical precipation and settling, filtration, and for higher treatment, activiated carbon adsorption.

Physical-chemical treatment has gained favor recently because such plants are generally less costly to construct, require less skill to operate, and are less subject to upset from shock loading than are biological plants.

This discussion will present costs for both biological and physical-chemical secondary treatment systems. Secondary treatment for removal of solids and organic carbon is, in a sense, a pretreatment required for advanced treatment by facility oriented plants or land application of effluent. It is to be remembered that both biological and physical-chemical secondary treatment are judged in terms of BOD and solids removal, and not on the removal of the full range of pollutants usually associated with municipal wastewater. Experience with biological processes shows that these systems protect the receiving water from a variety of toxic chemicals; three examples are cyanide, hexavalent chromium, and ammonia. Conventional secondary treatment will completely degrade small amounts of cyanide, will remove about 80 percent of any hexavalent chromium and will reduce influent ammonia concentrations approximately 30 to 50 percent. None of the total physical-chemical processes designed solely for solids and organic carbon removal can duplicate this performance. In addition, operating costs of physical-chemical plants are higher than those associated with biological treatment because of large chemical and activated carbon costs in these plants.

Figure 5 is a plot showing costs for biological treatment. The costs presented include handling and dewatering for the primary and secondary sludges generated in the treatment processes.

Figure 6 is similar plot showing capital and operating costs for physical-chemical treatment.

Both cost estimates include disinfection by chlorination. A discussion of disinfection methods will be presented later in this section; chlorination costs are being used for the EPA 1977 and 1983 requirements because of its near universal application in wastewater disinfection.

Cost data for biological treatment is available from many sources. The type of systems represented by Figure 5 includes extended aeration, contact stabilization, and conventional activated sludge. These systems have been widely employed over the past thirty years and a large body of operational data has been accumulated documenting their performance. Much less data has been gathered on physical-chemical treatment processes, since these techniques are relatively new. One of the problems in discussing and generating costs for physical-chemical treatment is that there can be many qualitative and quantitative differences in the process.

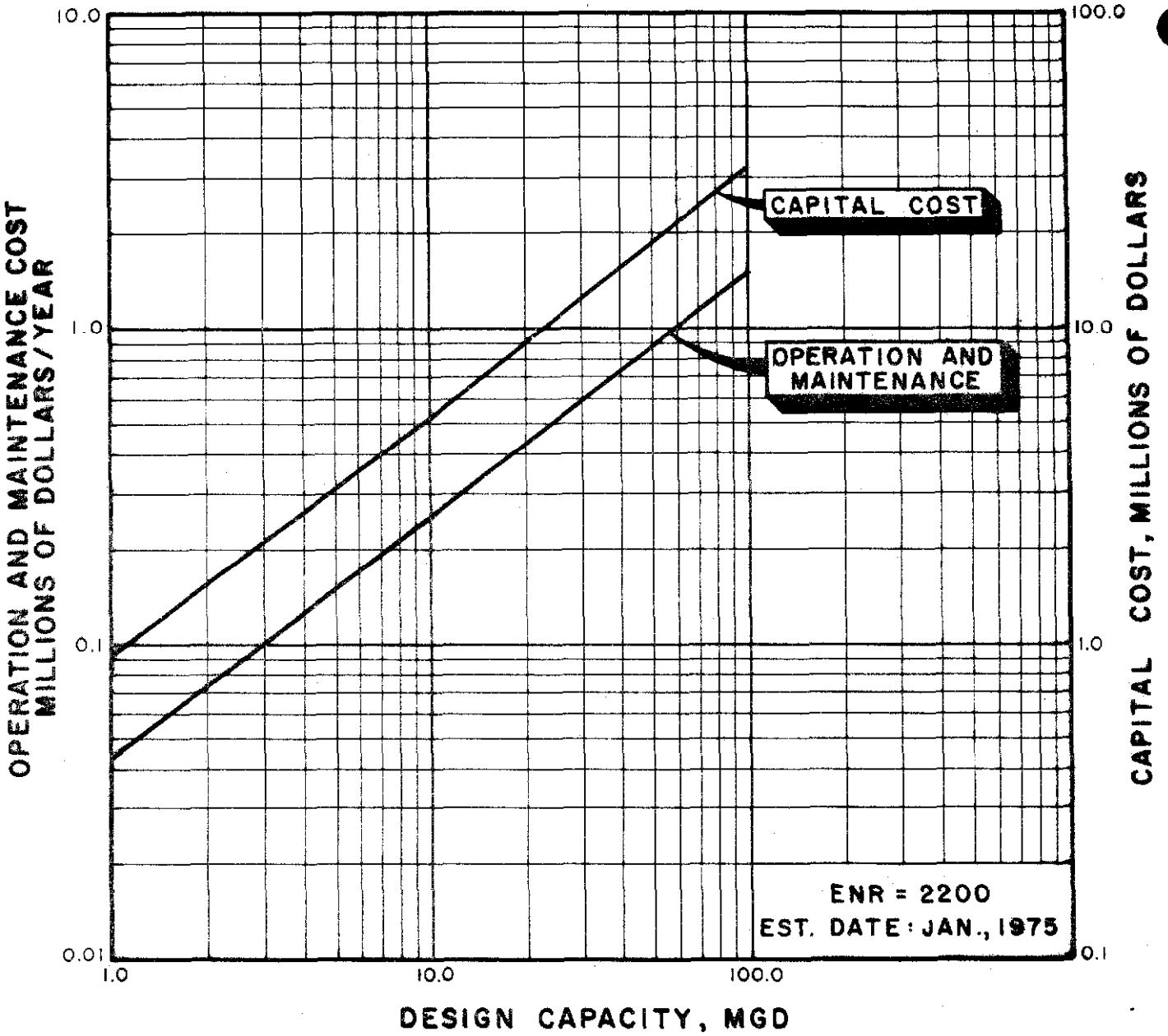

FIGURE 5 1977-Secondary Biological Treatment with Chlorination. Capital Cost, and Operation and Maintenance vs. Design Capacity.

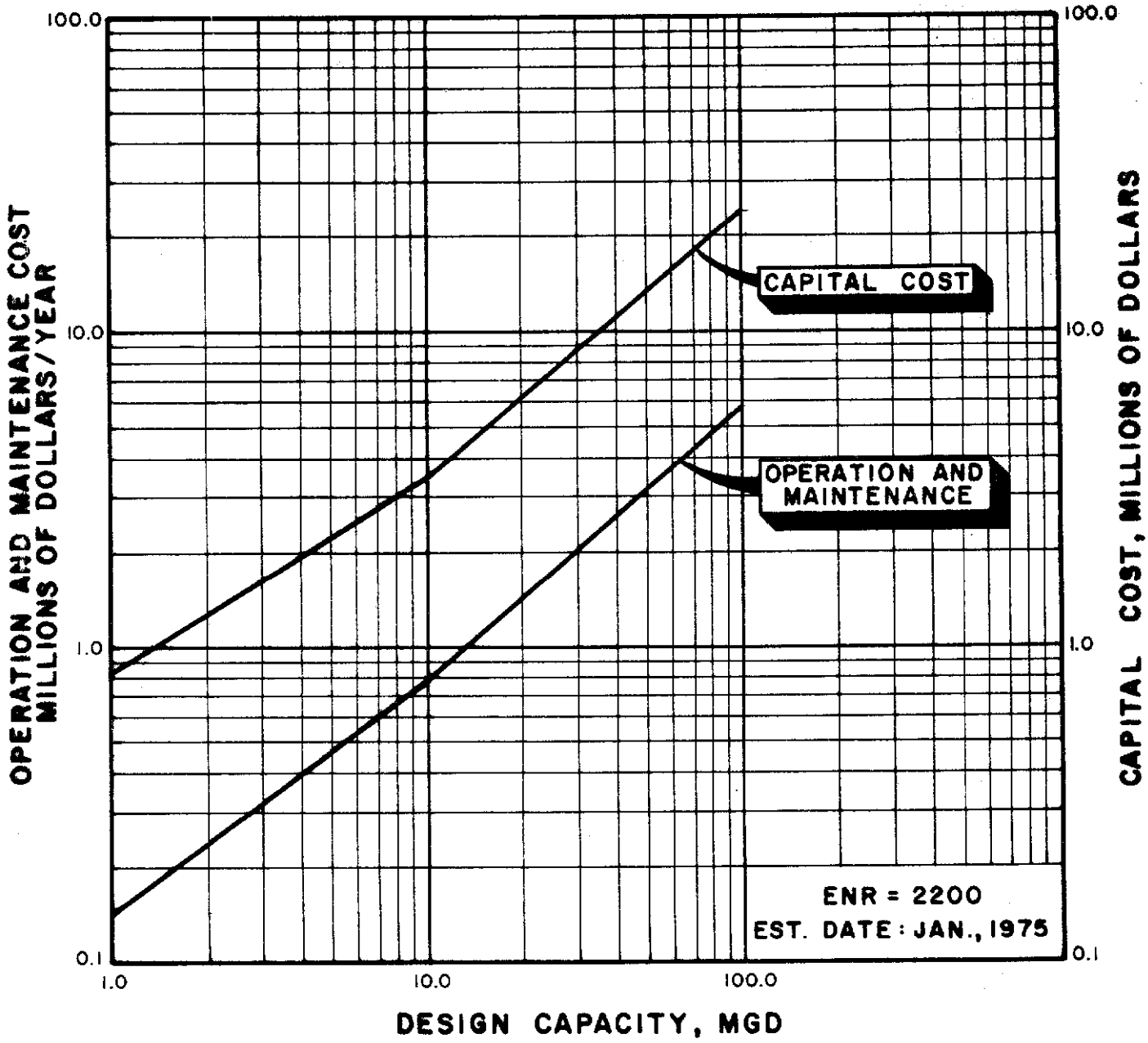

FIGURE 6 1977-Secondary Physical-Chemical Treatment with Chlorination and Sand or Mixed Media Filtration. Capital Cost and Operation and Maintenance vs. Design Capacity.

As generally described, p-c treatment consists of primary settling, with or without chemical addition, secondary coagulation and sedimentation, and finally, various amounts of effluent filtration and carbon adsorption. As a general rule, it might be stated that the chemical additions result in effluent quality approaching (but not quite meeting) the 1977 EPA discharge limitations. The addition of a filtration step effectively meets the 1977, and with the possible exception of ammonia, the 1983 regulations as well. Carbon column adsorption, in place of or more commonly in addition to filtration results in a clear effluent significantly lower in BOD, COD, and turbidity than typical effluent from biological treatment. In addition, the chemical additions required for physical-chemical treatment result in a high degree of phosphate removal.

Costs for p-c treatment consisting of primary settling, secondary coagulation and sedimentation, and effluent filtration, are shown in Figure 6, since those processes most closely correspond with the 1977 EPA secondary regulations. Costs have been calculated assuming coagulation with lime; costs using a metal salt would likely be somewhat higher. It will be noted that capital costs shown in Figure 6 are somewhat less, but that operating costs are greater than the costs of biological treatment shown in Figure 5. A large portion of this high operating expense involves the purchase and handling of large quantities of chemicals required for the process, and the disposal costs of sludges generated by these chemicals. Energy requirements are less, however, than for biological plants, due to the lack of aeration equipment in p-c facilities. Sludges from p-c treatment sometimes pose a greater disposal problem than biological sludges because their chemical contents render them unsuitable for several common methods of disposal; the use of lime will minimize any such disposal problems.

At least ideally, p-c plants should be more reliable and effluent from such plants more uniform than from biological plants, since purely physical and chemical processes are more predictable and controllable than biological ones. It is generally recognized that upsets can occur occasionally in even a well-run biological plant, and a shock loading to a biological plant of some toxic material may seriously disrupt treatment at the facility. Finally, the initial cost of biological plants is high. Weighed against these advantages of p-c plants are their high operating costs and the lack of removal of such wastewater constituents as ammonia and trace quantities as cyanides and chromes. Perhaps even more basic is the

question of resource expenditure and the actual wisdom of dosing wastewater with such large quantities of chemicals when the same treatment levels could be accomplished by allowing the oxygen demand to be satisfied naturally, which is to say biologically.

(3) Land-Oriented Treatment

It was stated earlier that all advanced wastewater treatment processes require secondary treatment, including all types of land application.

Secondary treatment of wastewater by land oriented methods presupposes some sort of land intensive aerated lagoon system. It is difficult to develop generalized costs for aeration lagoons of this type since any lagoon system must be planned with available land as a design restraint. With much land available and at a reasonable cost, the lagoon can be designed for minimum input of resources (concrete construction and power for pumping and aeration). As land becomes less available and more costly, it becomes more economical to substitute resources for land. It might also become more economical to transport the wastes by pipeline to a location where land is more available. A system may therefore vary between total lagooning with minimum aeration, to a mixed system with primary and secondary clarifiers and aeration lagoons designed according to criteria for an extended aeration type of biological treatment. For these reasons, the design and cost of a lagoon system is highly site specific and difficult to generalize. For the purposes of estimating costs of land application, a base cost of secondary treatment by conventional biological treatment (Figure 5) has been used in those areas where available land for treatment is limited. Where land is available, secondary treatment consisting of aerated lagoons with a detention period of 30 days has been assumed. Capital and operating costs of such a lagoon system are lower than equivalent costs for an activated sludge plant.

c. 1983 - Best Practicable Treatment

(1) Introduction

Best practicable treatment, as defined by EPA in the draft of "Information on Alternative Waste Management Techniques and Systems to Achieve Best Practicable Treatment Technology" dated October 3, 1973, prescribes allowable concentrations of

pollutants in the effluent of publicly owned treatment works[1] discharging to navigable waters as follows:

	30 consec. days	7 consec. days
BOD_5 (mg/l)	30	45
SS (mg/l)	30	45
BOD_{ult} (mg/l)*	30	45
Ultimate oxygen demand**	50	75
Fecal Coliform (No. /100 ml)	200	400
pH	6-9	6-9

* defined as 1.5 times BOD_5 minus the dissolved oxygen. This limitation applies to those situations in which influent wastewater temperatures are less than 20°C.

** defined as 1.5 times BOD_5 and 4.6 times NH_3 (as N) minus 1.0 times the dissolved oxygen. This limitation applies to those situations in which wastewater influent temperatures are greater than 20°C for a period of 30 consecutive days prior to the last day of the test period.

In addition to discharges into navigable waters, groundwater chemical quality has also been defined for publicly owned treatment works not discharging into navigable waters such as land application systems (i.e., spray irrigation, overland flow techniques, composting and sludge application) and subsurface discharge. The limits are proposed to lessen the possibility of groundwater contamination from land application and include limitations of such constituents as chromium, cyanide, iron, mercury, and nitrate nitrogen.

(2) Discharge to Navigable Waterways (biological and physical-chemical)

It will be noted that best practicable treatment for water oriented technologies (discharge to navigable waterways) is expressed

[1] includes plants having an average annual flow of one million gallons or more per day or serving a population of 10,000 or more persons.

primarily in terms of the secondary treatment criteria of removal of solids and organic carbon, with the addition of an ammonia requirement which can be relaxed during periods of cold weather.

The 3 October 1973 draft of "Information on Alternative Waste Management Techniques and Systems to Achieve Best Practicable Treatment Technology" is the second such draft we have seen, and it differs somewhat from the first. This latest draft prescribes effluent levels of BOD_5 and suspended solids identical to those of the 1972 EPA Secondary Treatment Criteria. The ammonia requirement during periods of warm weather included in this proposal (computed according to the 4.6 oxygen requirement per part of NH_3 (as N) as defined) is about 4.5 mg/l and 6.5 mg/l for 30 and 7 consecutive days respectively.

However, it is felt necessary to stress that the above regulations are draft proposals subject to change, and are in one respect internally inconsistent, in that the limits for five-day and ultimate BOD are the same, even though ultimate BOD is defined as 1.5 times BOD_5 minus dissolved oxygen. (It should be noted that if the BOD ultimate limitations are divided by 1.5 (which is approximately the BOD_5), the values obtained are close to the BOD_5 effluent limitation stated in the first draft (19, June 1973) of the EPA information. In any case, the level of removals required in this specification entails a relatively small improvement over conventional secondary treatment, and in fact, well run secondary treatment plants could reasonably be expected to approach the effluent BOD_5, SS, and NH_3 levels over a major portion of their operation. Nonetheless, to ensure compliance with the requirements uniformly over the operation of the facility, and because the federal requirements are at this date, not entirely clear, an additional treatment step will be proposed. Where land is available, the least costly additional treatment might be a polishing pond. Such a pond added after secondary treatment could be expected to remove about half of the remaining oxygen demand, solids, and ammonia* from the final effluent. It might also be used to equalize wastewater flow for downstream advanced wastewater treatment processes. Where a suitable land area is not available, intermittent sand filtration would accomplish similar removals on less land but at somewhat higher expense: intermittent sand filters, designed for an organic loading of 2.5 pounds of BOD_5 or SS per thousand square feet per day would produce effluents in excess of the 1983 EPA limitations. Where land is not available rapid sand filtration columns would accomplish removals approach-

* removal of ammonia by biological process in this text refers to oxidation of the Nitrogen to Nitrate.

ing intermittent sand filters, although at a somewhat higher capital and operating cost. The use of some type of microstraining device could also be considered to remove additional suspended solids and their associated BOD from treatment plant effluents. It will be noted that according to the previously mentioned distinctions between land oriented and facilities oriented treatment schemes, polishing lagoons and intermittent sand filters would fall in the former category, rapid sand filter columns and microstraining devices into the latter.

It should be remembered, however, that all of these processes possess both physical and biological elements, since the filtration (a physical process) by both sand columns and microstraining devices is always accompanied by biological growth on the filtration media, and the oxidation (a biological process) proceeding in the polishing lagoons is accompanied by sedimentation of suspended solids in the wastewater. In the cost estimates developed for this study, multi-media filtration has been taken for satisfaction of the 1983 requirement for biological treatment. Figure 7 presents capital and operation costs for this process.

A physical-chemical plant would require ammonia removal during warm weather to comply with the 1983 EPA best practicable limitations. The relaxation of the requirement for cold weather might appear to make ammonia stripping an attractive alternative, since the major problem of efficiency with that treatment involves cold weather operation. On closer inspection, however, air stripping cannot be recommended for ammonia removal because of operating problems which have been experienced with the process, and more importantly, the environmentally questionable practice of releasing gaseous ammonia to the atmosphere when it would be free to enter nearby watercourses. For these reasons, no cost estimates have been developed for air stripping of ammonia.

Another p-c method of ammonia removal is breakpoint chlorination. In this process, large quantities of chlorine are added to the wastewater, react with ammonia, and form chloramines. The process is simple, easily controlled, and has a side advantage of disinfecting the effluent. Unfortunately, enormous quantities of chlorine are needed to convert the ammonia to chloramines; and these substances must then be removed from the wastewater by carbon adsorption, another costly process. Breakpoint chlorination, is, therefore, not suitable for roughing out large quantities of ammonia, but can be used if it is desired to remove the last 0.5 mg/l

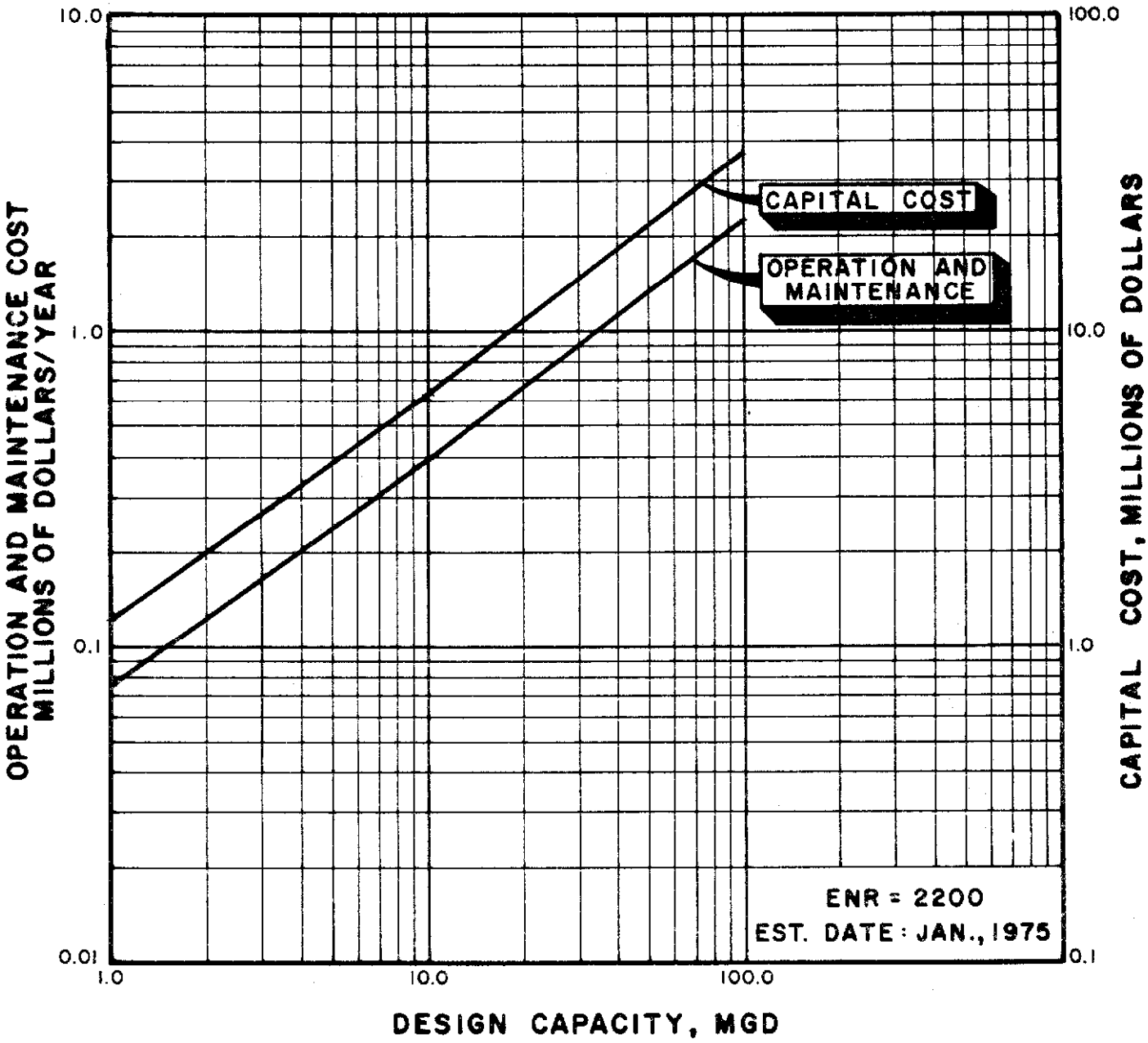

FIGURE 7 1983-Biological Treatment with Chlorination and Sand or Mixed Media Filtration. Capital Cost and Operation and Maintenance vs. Design Capacity.

or so of ammonia from an effluent. This can be normally accomplished with the doses of chlorine typically applied to wastewater for disinfection before discharge of the effluent.

The only other physical-chemical process for ammonia removal on the horizon is treatment on clinoptolite (a zeolite) bed by selective ion exchange. A salt solution is used as a regenerant for the exhausted zeolite; the ammonia in the regenerant is converted to hydrogen and nitrogen gas by electrolysis of the regenerant. Several pilot plant studies have indicated the process is capable of high ammonia removals (to 1.0 mg/l in the effluent), but preliminary scale up of costs to 7 and 10 mg/l facilities has shown extremely high costs for this method and all indications point to the process requiring complex operating control.

A far more economical method of ammonia removal* is single stage nitrification. This biological process converts ammonia to nitrates in an aerobic environment. Being a biological process, the primary input required for the process is power to run the compressors for the diffused air systems. Nitrification is a well-proven technique, with ammonia removals to 0.5 mg/l if desired. Costs for 1983 physical-chemical treatment with chlorination and single stage nitrification are shown in Figure 8.

It should be noted that the costs developed for ammonia removal by both ion exchange and nitrification are associated with ammonia removal somewhat in excess of the draft 1983 EPA regulations. Both of the systems could be run to effect whatever degree of ammonia removal might be desired, and operation of the facility in this manner would result in decreased treatment costs. It is certain, however, that the large disparity between ion exchange and the biological method of treatment would continue to exist.

There exist many other techniques for effluent polishing, including activated carbon treatment, ozone application and multi-stage biological systems, but these techniques are designed for considerably higher efficiencies than are polishing lagoons or sand filters, and their costs are far greater. Such advanced processes will be considered later in this discussion, where higher effluent standards will require advanced levels of treatment.

* actually conversion of NH_3-N to NO_3-N

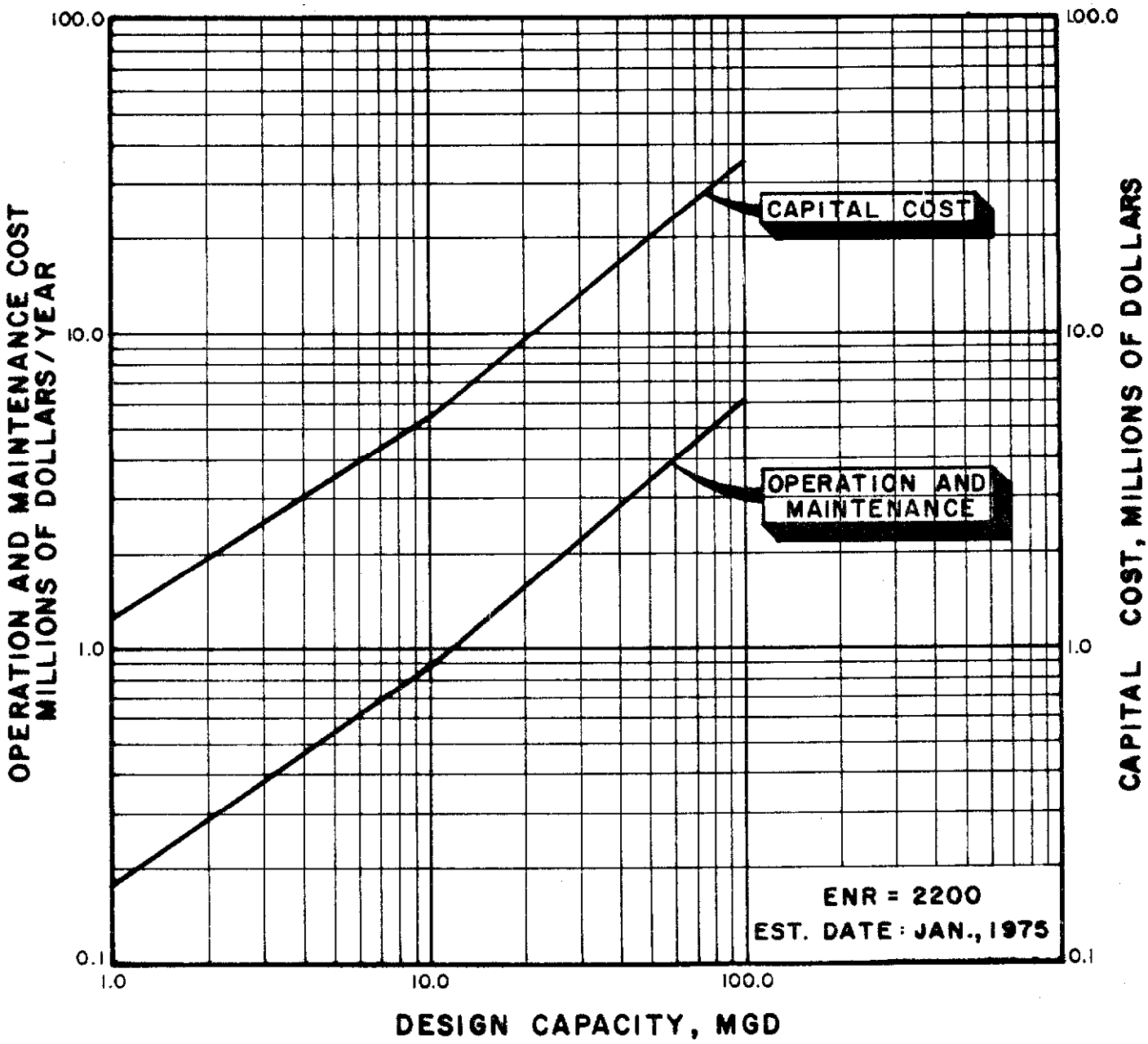

FIGURE 8 1983 - Physical - Chemical Treatment with Chlorination; Single Stage Nitrification and Filtration. Capital Cost and Operation and Maintenance vs. Design Capacity.

(3) Discharge to Non-Navigable Waters (Land Application)

(a) Pretreatment

Regulations for wastewater discharge not into navigable waters is not specified in terms of effluent quality, but rather in terms of the groundwater quality resulting from the discharge. (Permanent groundwater is defined as that water which is not removed from the ground by an underdrain system or other mechanical means in the zone of saturation that results from the application of wastewater.) The central problem at present with the regulations is that it is not known with certainty exactly what they mean. It appears that the regulation, as written, requires that groundwater immediately adjacent to a land application area meet a certain chemical quality. Other interpretations of the regulations that have been encountered, however, have suggested that the regulation is, in fact, allowing a large dilution effect to take place and that the measuring point at which the groundwater is sampled need not be adjacent to the treament area, but might, for example, be the property lines of the application site or even the point at which first used for drinking water supply. We have contacted officials at EPA, and have been told that the 3 October draft is under review and subject to revision, and that there is at this time no official position.

The most troublesome of the constituents in the EPA draft is nitrate, which has a maximum allowable groundwater limit of 10 mg/l.

NO_3-N from secondary treatment has typical values of from 15 to 20 mg/l, and it is our view that a long-term, large scale application of such wastewater in a high rate, i.e., rapid infiltration, (to be discussed later in this section) application process, might well lead to groundwater nitrate concentrations in excess of the EPA draft regulations. The 10mg/l limit would suggest that if rapid infiltration is to be practiced, and groundwater quality is a concern, some sort of denitrification system (that is, conversion of nitrates to nitrogen gas) may have to be included in the treatment process. The most reasonable type of denitrification process for a rapid infiltration system would be a packed column reactor added after conventional secondary treatment and using methanol addition as a source of carbon for the denitrifying organisms. There is to our knowledge no proven physical-chemical treatment process that could be added after secondary treatment that could be used in place of this biological treatment. Recent studies have been performed investigating the feasibility of selected ion exchange of nitrate, utilizing beds of porous polymer beads, but these investigations are very preliminary and

the technology still remote. For the purposes of this study, it has been assumed that no denitrification will be required. We wish to emphasize that depending upon the final determination of groundwater nitrate limitations, such treatment may be required for high rate wastewater application.

(b) Land Application

Although not a new procedure, ground application of wastewater effluent has recently received much attention as an effective advanced treatment method which eliminates the high capital and operating costs of conventional tertiary treatment.

After pretreatment consisting of equivalent secondary treatment and some polishing steps (to be discussed later),wastewater would be applied to the land, thereby eliminating direct wastewater discharge to a waterway. There are three basic techniques for surface application of wastewater effluent to the land: spray irrigation, overland runoff, and rapid infiltration. Each of these will be discussed with particular emphasis toward general design criteria expected performance, and applicability to the New England region. As in the case of aerated lagoons, cost estimates of such systems are site specific because of the interrelationship of such factors as land availability and location: actual construction costs for such facilities are not difficult to estimate, but frequently, land values exceed this construction cost, or there exist tradeoffs between treatment area locations and pipelines costs. For this reason, meaningful system costs for land application cannot be generalized and will be developed only on the basis of specific treatment situations and available land areas. This will occur later in the study.

Spray irrigation has probably received the most attention of any of the land application methods. In spray irrigation, a number of mechanisms are in operation to renovate wastewater and remove impurities. The mechanisms generally occur within the top several feet of the soil layer, depend upon low (2 inches/week) application rates and moderately fine grained soil, and include filtration through the soil, and, to a lesser extent, volatilization and soil fixation (chemical precipitation and absorption/adsorption processes) for removal of oxygen demand, solids, viruses and bacteria, plant uptake and volatilization for nitrogen removal, and plant uptake, soil fixation and; to a lesser degree, ion exchange in the soil for phosphorus removal. Properly managed, a system of this type may have removals greater than 98 percent for BOD, SS, and viruses and bacteria and, providing crop harvesting (removal) is practiced, nitrogen removals in excess of 80 percent, and phosphorus removals of greater than 98 percent.

In rapid infiltration, wastewater loadings of up to 12 inches per day are applied to a deep stratum of highly permeable soil. Wastewater renovation in such treatment may extend many feet below ground, and primary renovation mechanisms are soil filtration and fixation. (Plant uptake in rapid infiltration is insignificant and the soils are too coarse textured for ion exchange; for these reasons, nutrient removal (phosphorus and nitrogen) are less efficient than in spray irrigation.)

Overland runoff is practiced in soils of extremely low permeability. Applied wastewater runs over the soil surface and is collected at the bottom of the slope. Such a system depends to a large extent upon volatilization and to a lesser extent upon filtration and ion exchange. It should be noted that overland runoff does not eliminate direct discharge of effluent, as the wastewater must be collected in this type of treatment. Removal efficiency of this system is considerably below spray irrigation and rapid infiltration; on the other hand, because the water is collected and discharged, there is no significant danger of groundwater contamination, and in fact, this treatment method is more comparable in effect to an advanced water oriented treatment process than a method of ultimate disposal.

Of the land application systems considered in this study, spray irrigation of wastewater poses the smallest risk to groundwater contamination because of its low loading rate and variety of removal mechanisms. Unfortunately, however, the method requires enormous land areas (at 2.0 inches per week, approximately 130 acres per million gallons per day are required) and wastewater storage is normally provided for cold and wet weather periods. Information by the Massachusetts Department of Public Health seems to indicate that a seven month detention must be provided in storage lagoons. The feasibility, then, of spray irrigation is dependent upon the availability of such large treatment areas.

Rapid infiltration is a far less dependable treatment system than spray irrigation, and should be used only with extreme caution where groundwater is used as a source of water supply. While small, on-site treatment systems operating by rapid infiltration pose no problem, a large scale project could have the effect of increasing groundwater levels of nitrates, phosphates, heavy metals, and dissolved solids. Even in areas where water supply is not a consideration, these groundwater contaminants might eventually find their way into a surface water body. (Note, however, that

the problem with nitrate buildup is greatly decreased if some sort of denitrification system is constructed as part of the wastewater pretreatment). It is therefore essential that proposals for rapid infiltration on a large scale basis be very carefully considered during design and monitored while in operation to insure that renovation of wastewater is achieved with minimum harmful effects upon the soils of the application site, and groundwater in the area.

Ground application of effluent by either spray irrigation or rapid infiltration will be preceded by effluent polishing before actual application to the land. For rapid infiltration, the Department of Public Health of the Commonwealth requires secondary effluent polishing consisting of sand or multi-media filtration before land application. The purpose of this filtration is to decrease the solids content of the effluent and thereby minimize clogging of the rapid infiltration beds. While no specific polishing step is required for spray irrigation, the requirement of the DPH for a storage period of 7 months would be a most effective polishing step. Thus, a treatment plant scheduled for spray irrigation or rapid infiltration might construct a secondary treatment plant in 1977, add sand filters (for rapid infiltration) or a polishing storage lagoon (for spray irrigation) in 1983, and not actually implement land application until 1985.

d. 1985 - PL 92-500 (Zero Discharge)

(1) General

It is the stated national goal of PL92-500 "that discharge of pollutants into navigable waters be eliminated by 1985." There is currently considerable discussion revolving about the actual meaning of the law, and the practicality of a strict interpretation of the stated goal. This discussion will proceed without any attempt at clarifying PL92-500; rather, various treatment technologies will be proposed to achieve two possible treatment objectives. These objectives are as follows:

Stage I - Drinking water standards (as modified to be compatible with the well being of indigenous fresh water organisms in the basin).

Stage II - Zero discharge of pollutants.

Several comments should be inserted prior to the discussion of treatment methodologies. The discussion of treatment will focus upon those methods required to upgrade effluent to the actual water quality level associated with the classifications indicated in the above categories. Thus, no assimilation or dilution capacity of the river is being considered. It is realized that in Stage I, this is a perhaps conservative approach (although in Stage II such an approach follows from the water quality objective).

Stage II deals with the achievement of the ultimate goal of zero discharge as it may eventually be defined or interpreted. For lack of an authoritative definition, it is proposed to establish two levels of ultimate water quality desired by PL92-500 and to present treatment concepts to achieve these goals.

Natural background levels are being identified as the highest treatment objective we feel can be justified. Water devoid of all impurities is intollerable in nature because pure water will not support aquatic life. Many dissolved materials are essential for growth, reproduction, and the general well being of aquatic organisms, and therefore distilled water would be as equally polluting as unsatisfactorily treated water.

In Stage I, treatment of wastewater compatible with EPA surface water criteria for public water supplies (modified to be compatible with the well being of fresh water organisms) has been taken as a lower limit of Congressional intent in PL92-500 because such water quality is a well defined goal for which specific criteria exist, and for which technology has been developed and shown to be reliable and effective (although not necessarily cost and resource effective). It should be stressed again that attainment of this water quality objective (surface water supply) could perhaps well be achieved without treatment of all wastewater discharges to 1985 Stage I water quality levels, if dilution and assimilative capacity are taken into account.

It should also be noted that possible reuses of wastewater may require treatment to actual zero contaminants. Such water is called "ultrapure" water, and is used in such specialized applications as semi-conductor manufacture. (The ultrapure water is used for rinsing silicon slices at various stages of fabrication.) Treatment will be proposed to achieve ultrapure water; however, it should be stated that such water would not support aquatic life, would not be suitable to drink, would in fact be far purer than the headwaters of most rivers and streams. It is believed that

consideration for such treatment is not a desirable or even reasonable goal, and that a definition of PL 92-500 to discharge only ultrapure water would effectively eliminate the possibility of any type of water oriented wastewater treatment.

A final statement about wastewater treatment: Wastewater treatment has historically proceeded through several phases. Previous to the 1930's, wastewater treatment was primarily concerned with removal of suspended solids and destruction of pathogenic bacteria, from the thirties to early sixties, satisfaction of dissolved oxygen demand upon the stream was added to these other goals, and for the past few years attention has increasingly centered upon nutrient removal and satisfaction of secondary (nitrogen) oxygen demand. There is now talk of elevating wastewater treatment into the area of demineralization of wastewater. Without getting involved in the controversy as to whether it is a reasonable goal, it should be stated that the increasingly sophisticated historical sequence mentioned above is basically the rational treatment sequence for renovating wastewater to whatever degree of treatment is desired. Thus the 1930 emphasis on BOD removal did not eliminate the need for previous treatment, but simply added to it, and the need for ammonia and nitrate removal requires the addition of one or two additional stages of treatment rather than the substitution of one process for another. Increasingly higher levels of wastewater treatment are required for increasingly sophisticated treatment methods to operate efficiently. While it is possible that intermediate steps or half steps could be eliminated, one should not let such a small modification of wastewater management strategy obscure the fact that we know of no process presently available or foreseeable in the near future to permit the discharge of wastewater to any of the suggested toals of 1985 without employing the existing proven technologies of solids settling (primary treatment), satisfaction of carbonaceous BOD (secondary treatment), and nutrient removal and satisfaction of secondary oxygen demand (advanced treatment).

It will be suggested at this time that perhaps this is not such an unfortunate state of affairs in that it allows a rational choice of levels of possible treatment from a treatment facility to be made based upon the determination of water quality conditions existing at a given time and identification of uses and needs for renovated wastewater of any particular quality.

(2) Stage I - Drinking Water Standards (as modified to be compatible with the well being of indigenous fresh water organisms)

In order to establish permissible levels of effluent constituents, the EPA "Water Quality Criteria" for public water supplies and for fresh water organisms were reviewed and where necessary supplemented. The resulting effluent limitations are tabulated below. It is important to remember that they represent a mix of water uses: for example, nitrates and dissolved oxygen are limited by criteria relevant for the well being of fresh water organisms, and not by surface water criteria for public water supplies. It is important to note that the following table outlines only those constituents which are actually treated in a wastewater treatment plant. This eliminates from consideration a large number of inorganic chemicals routinely encountered in wastewater at concentrations equal to or less than those permissible for water supply or of aquatic biota. It is also being assumed that substances will be allowed into the municipal wastewater collection system only after satisfactory pretreatment of the waste to eliminate any toxicity or otherwise incompatible substances.

(a) Biological Treatment

To effect the high degree of BOD reduction and nutrient removal required to achieve these discharging levels, wastewater treatment consisting of two stage chemical precipitation with lime and ferric salts, and three stage aeration followed by sand filtration, carbon column filtration, disinfection and final effluent aeration is proposed.

Phosphorus: In the proposed treatment scheme, chemical additions for phosphorus removal would be performed before primary clarification and the first stage aeration tank.

In the initial phase of this study, it was suggested that ferric and aluminum salts be employed for phosphorus removal. It now appears that alum precipitation will not be a satisfactory method of phosphorus removal. One of the criteria established in this study by the Corps of Engineers for chemical addition to wastewater is that sludge produced be amenable to ground application. Information indicates that aluminum at concentrations in excess of 1 mg/l has detrimental effects on plant growth, particularly on the growth of roots. Because alum addition to waste-

Drinking Water Standards (Modified)

Constituents	Maximum Concentration
Physical	
Color	50 color units
Temperature	68°F
Turbidity	10 JTU
Microbiological	
Fecal coliforms	200/100 ml
Inorganic Constituents	
Total Kjeldahl Nitrogen (TKN) as N*	0.5 mg/l
Nitrate as N	1.0 mg/l
Phosphates as P	0.05 mg/l
pH Range	6-8.5
Solids:	
Dissolved	400 mg/l
Suspended	1 mg/l
Organic Constituents	
Biochemical Oxygen Demand 5-day, 20°C (BOD_5)	1 mg/l
Total Organic Carbon	5 mg/l
Chemical Oxygen Demand	20 mg/l
Dissolved Oxygen	6 mg/l

* excludes nitrates and nitrites

water results in sludges with high concentrations of aluminum (in the form of $AlPO_4$ and $Al(OH)_3$) alum is no longer considered to be an acceptable precipitant.

In light of this, reconsideration of an earlier recommendation now suggests phosphorus removal consisting of low lime addition immediately before primary clarification and ferric chloride addition to the carbon aeration tank. Sufficient lime would be added to the primary wastewater to raise the pH to 9.5 or 10.0. This pH would not be harmful to the activated sludge process following primary clarification and the pH of primary effluent would be reduced in the aeration tank by the carbon dioxide (CO_2) produced by biological metabolism. Approximately 75 to 80% of the phosphorus would be removed in the primary step with lime addition in the order of 100-150 mg/l (for wastewater with alkalinity in the vicinity of 100-150 mg/l). Phosphorus remaining after the lime clarification would be removed both by synthesis in the biological processes and by addition just before aeration of an additional precipitant ($FeCl_3$) and perhaps a polymeric flocculant.

It is believed that recalcination of lime is not feasible in this treatment situation. A relatively small (150 mg/l) lime dose is applied, whereas most successful lime reuse facilities have been used in situations where high lime dosage is required (because the high alkalinity of the wastewater requires the dosage to raise pH for the process.). Further lime recovery is probably not economically practical when used to coagulate raw wastewater, because of the large amount of inert materials present in raw chemical sludge.

Phosphorus removal studies have shown in general that chemical precipitation is the most effective method of phosphorus removal, although biological treatment and ion exchange continue to be investigated. Biological treatment alone is inefficient (at most 30 percent reduction), although this removal is accomplished as part of the activated sludge process and at no additional treatment cost. Much was written several years ago concerning "luxury uptake" of phosphorus in biological plants, but this phenomenon, if it exists at all, does not appear to be significant in wastewater with low mineral content (as, quite typically, is found in New England). Ion exchange has been shown to be an efficient removal method, but it is very expensive. Experiments have shown that it is possible to effect nearly complete phosphorus removal from aqueous solutions with activated alumina using fixed beds. Alumina, in this process, is washed with distilled water and subsequently regenerated

with nitric acid. A disadvantage of this process (in addition to its high cost) is the disposal of regenerant solution. In addition, organic and inorganic contaminants in wastewater shorten the effective life of such a system, and this is one reason why this technique for phosphorus removal has been pretty much confined to water treatment.

A chemical system of phosphorus removal was selected because such a system achieves high levels of phosphorus reduction at minimum cost, and because the technology is well established and reliable. Phosphorus removal by chemical precipitation utilizes existing equipment in a treatment plant; chemical storage and feeding equipment is required, and a substantial increase in sludge handling capacity at the plant is necessary. Figure 9 is a plot of capital and operating costs for 95 percent phosphorus removal, and a second set of comparison costs for 80 or 85 percent phosphorus removal through a single stage chemical addition. It will be noted that raising the removal efficiency of the process from 85 to 95 percent (decreasing effluent level from 3 mg/l to 1 mg/l) significantly increases the treatment cost for this process. Close investigation should be made to determine if this incremental phosphorus removal is actually significant in the Merrimack River Basin and if the cost required to effect the increment is in reasonable proportion to the water quality improvement which may be anticipated in the basin by the reduction. The main disadvantages of this type of treatment are the large quantities of chemicals required, and waste sludges generated (it will be recalled from the discussion of p-c treatment that disposal of these chemical sludges is frequently a difficult task). A further undesirable by-product of any treatment involving chemical addition to wastewater is the increase in concentration of inorganic solids in the water. (The actual increase in dissolved solids depends on the chemical employed for phosphorus removal, the dosage added, the composition of the wastewater). On the other hand, the low natural salt content of New England waters gives considerable headroom for allowable salt addition, and too, the process of chemical phosphorus removal is simple to operate and control, and can be readily modified to reflect variations in incoming phosphorus levels and hydraulic loadings.

Nitrification and Denitrification: A three-stage activated sludge system is proposed to reduce the oxygen demand, convert ammonia to nitrate (nitrification) and nitrate to nitrogen gas (denitrification). Diffused air is supplied to the nitrification tanks, and methanol (as a source of organic carbon), to the denitrification system.

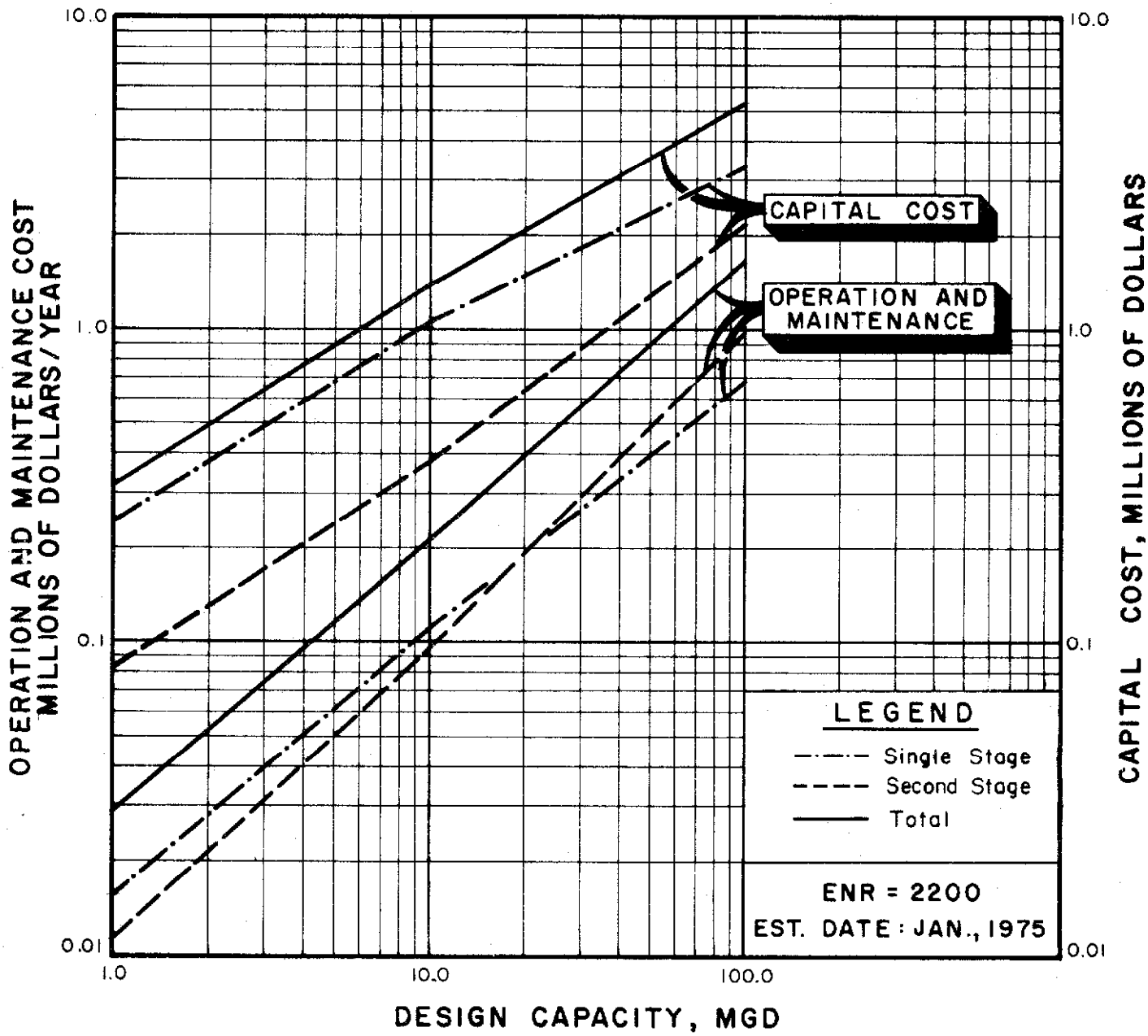

FIGURE 9 Single and 2 Stage Phosphorus Removal. Capital Cost and Operation and Maintenance vs. Design Capacity.

Since, in a biological treatment process, first stage aeration would have been normally provided in an earlier phase of construction, the cost estimates shown in Figure 10 are based upon a two-stage biological nitrification-denitrification system. A useful operating life of 30 years has been used because of the many similarities between this process and conventional treatment.

Justification for the selection of biological conversion of ammonia to nitrates and of nitrates to nitrogen gas was given earlier in this discussion, and will not be repeated. It should, however, be obvious that additional economies are realized by combining the two processes into an integral system (utilizing common walls for the reaction and settling tanks).

There is a considerable body of operating data from pilot plant facilities. If properly operated, the units should produce effluent NH_3-N concentrations of less than 0.3 ± 0.3 mg/l from the nitrification stage and NO_3-N levels of less than 2 mg/l from the denitrification units. There is some decrease in the efficiency of nitrification during very cold weather (although for this very reason, the effect of ammonia concentrations upon a stream is less severe in cold weather than during the summer). In addition, the methanol addition to the denitrification system must be carefully monitored in order to avoid introduction of soluble BOD to the wastewater stream.

Effluent Filtration: Filtration is proposed as the method of achieving the 1983 EPA Best Practicable Treatment. Once facilities for precipitation of phosphorus are added, the system will serve the additional function of removal of filterable phosphorus, and reduction of total phosphate levels from 1-2 mg/l down to the required levels. Capital and operating costs of sand and mixed media filters are shown in Figure 11 (these are the same costs that are included in Figure 7).

Final Treatment: The Stage I treatment standards for biochemical and chemical oxygen demand (BOD and COD), total organic carbon (TOC) and dissolved oxygen (DO) will require an additional polishing stage of organics removal, and effluent aeration.

Of available systems for removing organics from wastewater, carbon adsorption is probably the most common. Carbon adsorption is a physical process capable of removing many refractory organics and of reducing total chemical oxygen demand by 70 per-

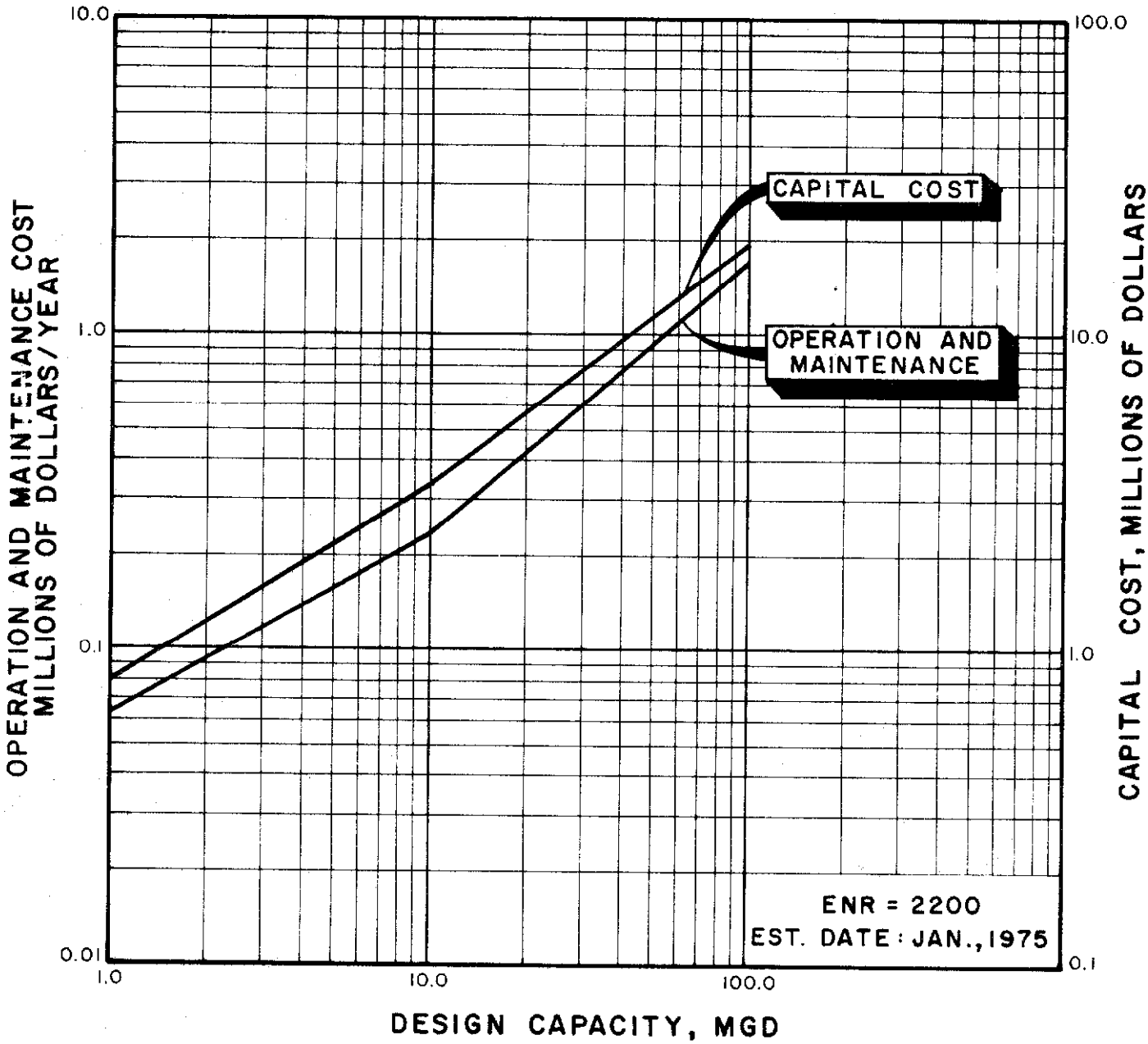

FIGURE 10 Biological Nitrification and Denitrification. Capital Cost and Operation and Maintenance vs. Design Capacity

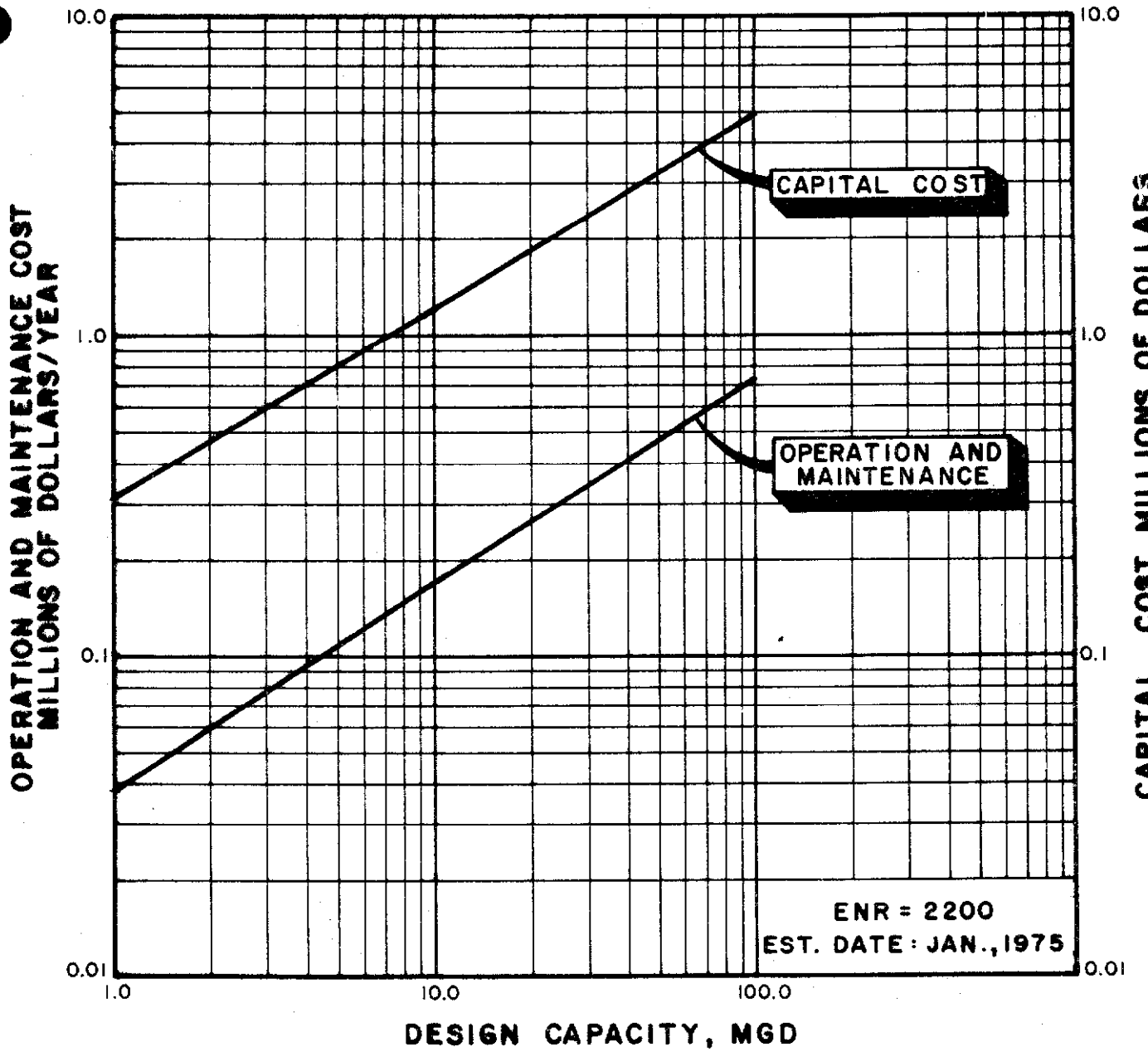

FIGURE 11 Mixed Media or Sand Filtration. Capital Cost and Operation and Maintenance vs. Design Capacity.

cent. While still a new technology, it has been used enough to establish its effectiveness and reliability. Costs for the process are shown in Figure 12. The costs represent 15 minutes contact time. Several available references have developed costs for 30 to 40 minutes contact time. The longer contact times would be required on secondary effluent in order to achieve the BOD, TOC and COD requirements; however, the highly treated effluent resulting from the three-stage biological and phosphorus removal treatment being proposed will probably enable the less costly carbon system shown in Figure 12 to be utilized. A large portion of the costs shown in Figure 15 include the carbon handling and regeneration systems required for the process. The organics adsorbed on the carbon are incinerated and the carbon reused. About 7 percent of the carbon is lost in the regeneration process, and this (apart from labor costs) is the greatest operating cost in the system. The system could probably be expected to last, with proper maintenance, anywhere between 15 and 20 years.

The second treatment process for removal of organics which will be considered is ozonation. Tertiary treatment of wastewater with ozone has four major process steps: generation of oxygen gas from air (or purchase of oxygen gas), generation of ozone gas from oxygen gas, distribution of the ozone gas in the wastewater, and retention of the ozonated wastewater for a period sufficient for oxidation of the organic contaminants to take place.

Most of the significant data regarding organic reduction of wastewater by treatment with ozone has been developed as a result of the pilot plant work done by EPA at the Blue Plains pilot plant in Washington, D.C. We are not aware of any full scale use of ozone for BOD and COD reduction in municipal wastewater treatment, although use of ozone in water treatment for disinfection (which requires ozone applications of a smaller order) is common in much of Europe and Canada, and ozone has been used successfully for the treatment of industrial wastewater. Construction and operating costs for ozone treatment are shown in Figure 13. The costs are derived for an ozone feed rate of 40 mg/l. This rate corresponds to a COD reduction of approximately 10 mg/l.

Pilot plant data from which the information in Figure 13 was obtained contains in addition, cost estimates for higher ozone feed rates (which would correspond to greater COD reductions).

As was the case with carbon adsorption, the effluent would

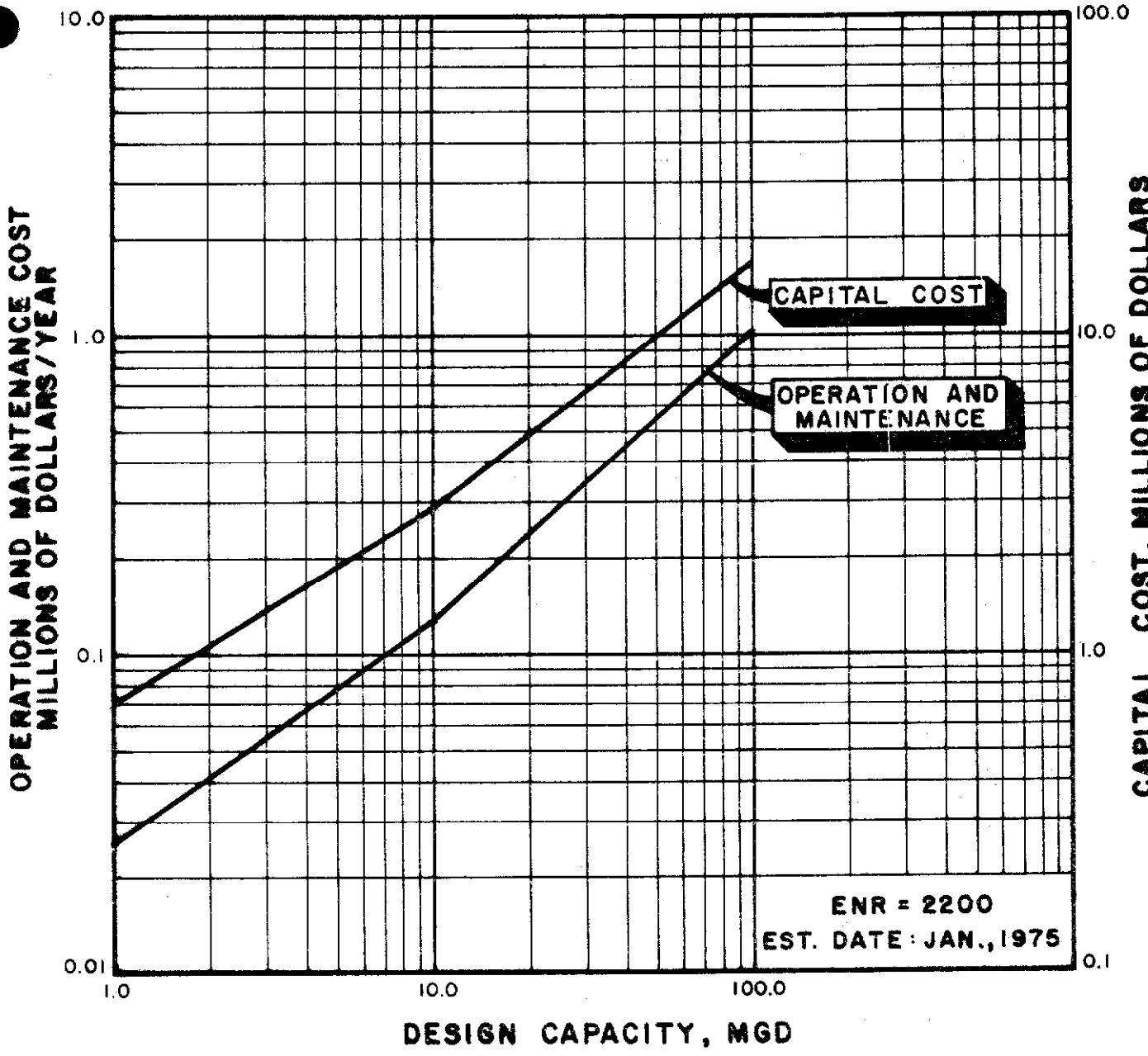

FIGURE 12 Carbon Adsorption. Capital Cost and Operation and Maintenance vs. Design Capacity.

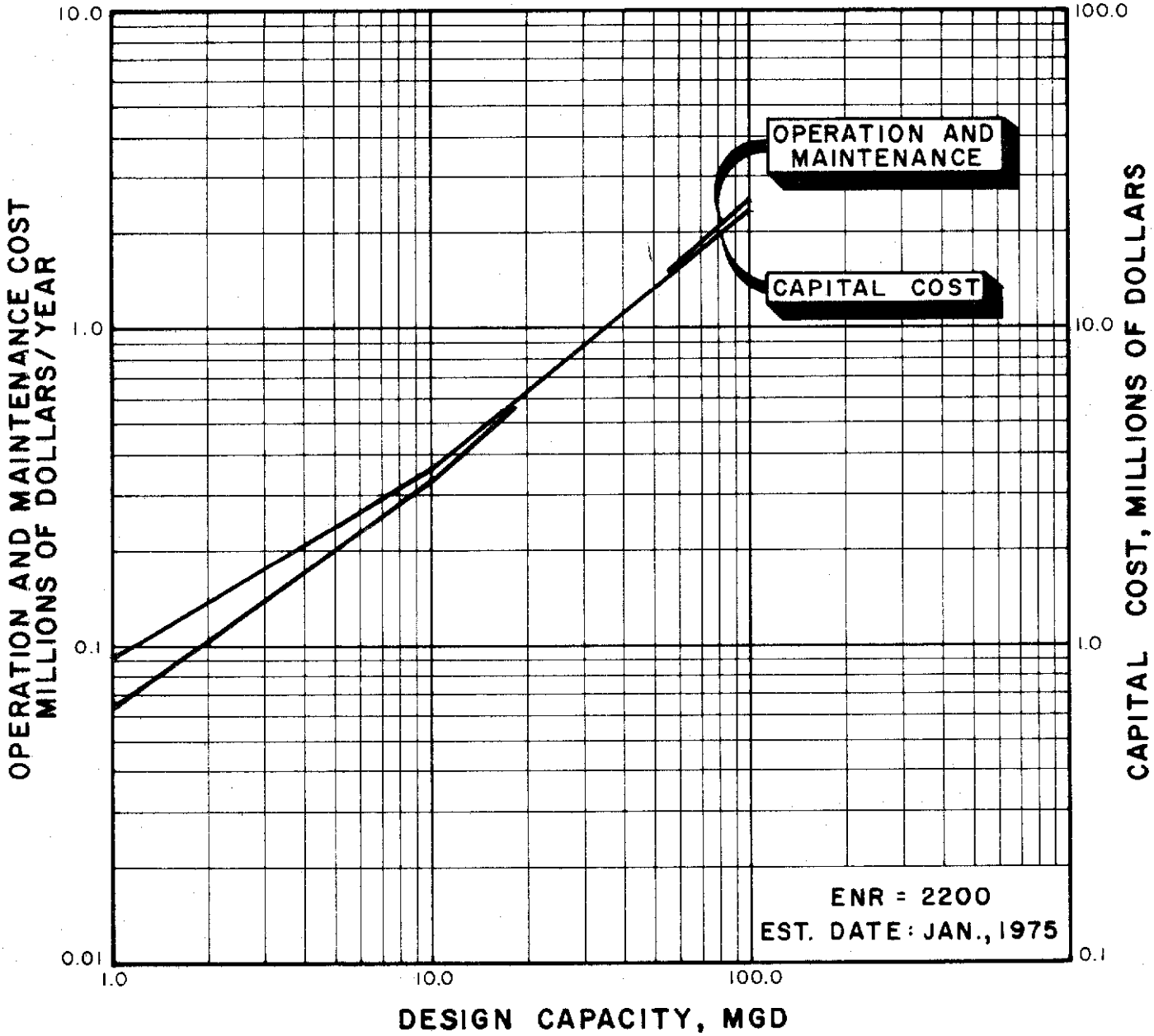

FIGURE 13 Ozonation. Capital Cost and Operation and Maintenance vs. Design Capacity.

already have been highly treated, and the 40 mg/l feed rate will probably be sufficient to reduce COD and TOC to State I levels. It will be seen from a comparison between Figures 12 and 13 that there is a relatively small (about 30 per cent) difference in capital costs between the systems, but a much greater difference (about 160 per cent) in operating costs exist in favor of carbon adsorption for organic reduction. And, in addition, the carbon system will result in greater organic reductions in the waste stream than ozonation. One reason for the high operating cost of ozone treatment is the large amount of electric power consumed in generation of the oxygen (or the chemical cost for oxygen if it is purchased rather than generated) and ozone. Of course, within the last half year, the cost of electrical power has increased dramatically.

There are, however, secondary benefits of ozonation not apparent on inspection of Figure 12 and 13 that must be considered if an accurate comparison is to be made between the treatment systems. One of these is the disinfection of water which occurs when ozone is added to it, the other is the oxygen saturated (actually supersaturated) condition of the water after ozone addition. Since both disinfection and final effluent aeration is mandated by the 1985 Stage I effluent limitations, in order to properly compare the cost difference between carbon adsorption and ozonation, the costs of effluent disinfection and aeration must be added to the costs of carbon adsorption.

In Figure 14, this has been done, and the capital and operating costs of ozonation are compared with carbon adsorption, chlorination and final effluent aeration. (Note that in Figure 14 chlorination costs are identical to those developed for Figures 5 and 6. This is not strictly correct because chlorine doses to highly treated effluent will be less than those to secondary effluents to achieve destruction of pathogens and the desired chlorine residuals). It can be seen from Figure 13 that the capital cost of ozonation is about 10 percent greater than the cost of the three processes, but operation costs, are still approximately 55 to 60 percent higher for ozonation than for the carbon system.

There are several considerations other than cost, however, which should be weighed in the comparison between ozonation and the carbon system. Factors favoring adsorption are the higher removal rate of organics by carbon adsorption and the multiple treatment units employed in the adsorption-disinfection-aeration systems (which would, at least in theory, offer greater operating flexibility

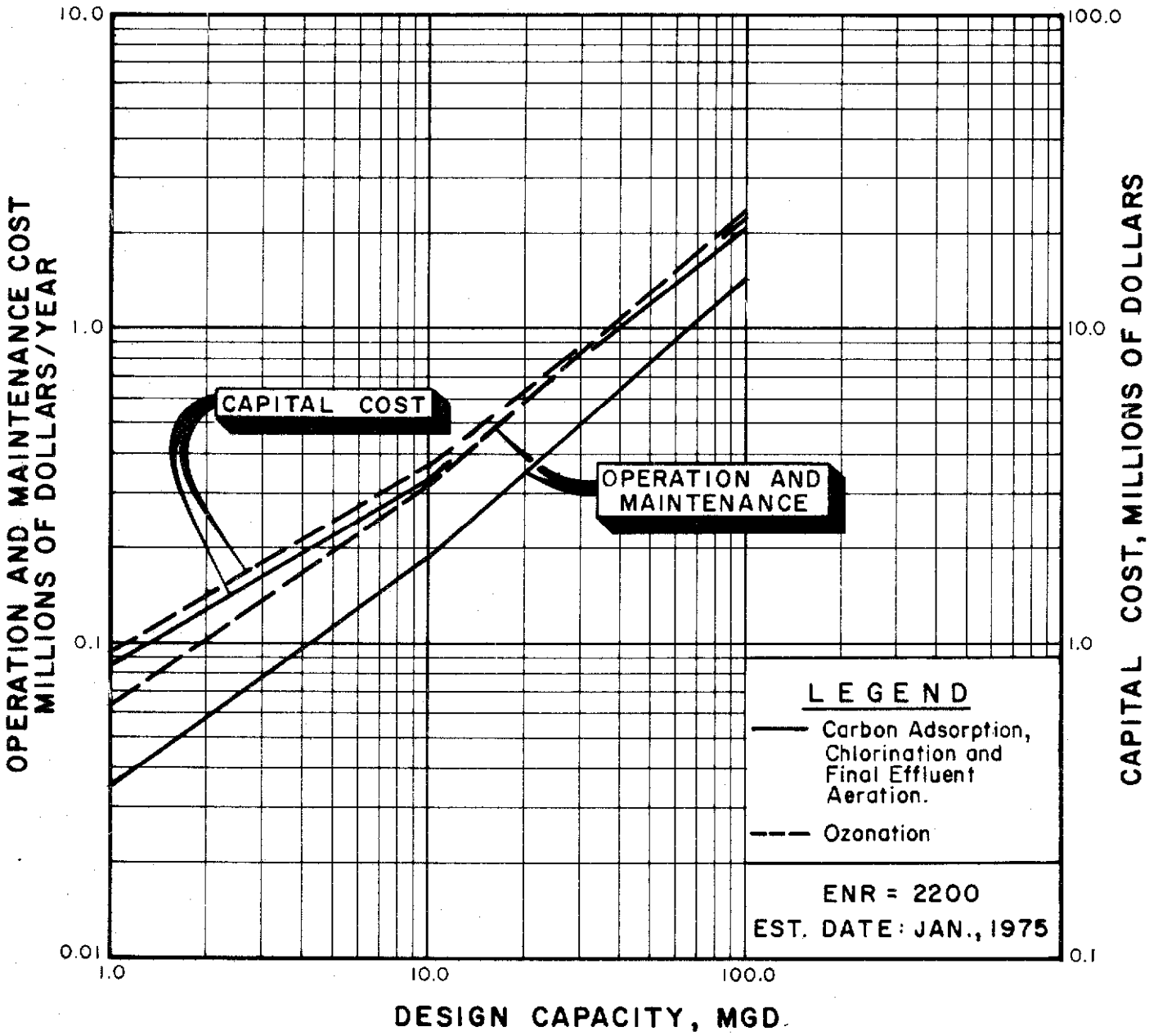

FIGURE 14 Total Cost of Carbon Adsorption, Chlorination and Final Effluent Aeration Compared to Cost of Ozonation. Capital Cost and Operation and Maintenance vs. Design Capacity

and allow the construction of the processes to be phased over a time period); those favoring ozonation include the supersaturation of effluent with oxygen and the disinfection with ozone rather than chlorination. From investigation thus far, it appears that the higher organic removals and ease of construction phasing are perhaps minor advantages since in practical terms the difference in final COD would be rather insignificant, and the major portion of the construction cost is centered in the adsorption system. There do, however, remain the advantages in operating flexibility, and the fact that chlorination systems are already in existence at most treatment plants.

It is felt that the advantages of ozone treatment are more significant than those of the carbon adsorption system. A result of supersaturating wastewater with ozone is that the dissolved oxygen of the effluent will actually be higher than the receiving water; the wastewater would have, in effect, a highly negative BOD. More significant, perhaps, are the advantages of ozone disinfection over chlorination disinfection. When chlorine is added to wastewater, the chlorine reacts with organics to form chlorinated organics and with ammonia to form chloramines. Both of these compounds (and chloramines especially because of their high concentration in chlorinated effluent) can be detrimental to aquatic life. The problem, however, will probably not be significant in the effluent from a plant meeting the 1985 Stage I effluent limitations, because ammonia and organics will have been largely removed from the effluent before disinfection. (As a brief aside, it appears that a significant case can be made for disinfection of effluent from existing secondary or tertiary plants without ammonia removal by ozonation.)

A potentially more significant advantage of ozonation over chlorination is the inability of chlorination to destroy viruses which are quickly destroyed by ozone. Such diseases of polio, hepatitis, and measles are spread by virus, and viruses are now suspect in certain types of cancer. A comprehensive examination of the implications of these viruses for public health and for the environment is beyond the scope of this study even though it can be seen that the basic choice between the ozonation system and the adsorption, aeration and disinfection system revolves basically around the tradeoff between lesser costs of the adsorption/chlorination system, and the viral destruction and oxygen saturation accomplished by ozonation. The advantages of ozonation, at this time, appear impressive. Nonetheless, an analysis of cost and benefits of the two systems is beyond the scope of this study. In any case, for

the purpose of this study, the carbon system has been used to estimate costs. Again, a change to ozone would result in a small increase in capital costs, but a very large increase in operating costs.

Figure 15 is a summary of total costs for secondary treatment, phosphorus precipitation, biological nitrification and denitrification, sand filtration, carbon adsorption, disinfection by chlorination, and final effluent aeration.

(b) Physical-Chemical Treatment

To effect the Stage I effluent levels in physical-chemical treatment, the p-c plant designed for 1983 EPA effluent limitations would be modified to include further chemical additions for more complete phosphorus removal, biological nitrate reduction, and either ozonation or carbon adsorption, disinfection and effluent aeration. On the basis of cost, it is not felt that ammonia removal by selective ion exchange on clinoptilolite can be justified and the use of biological nitrification will also require the construction of denitrification facilities for Stage I effluent levels. (Note, however, that nitrification and denitrification facilities are considerably less costly than clinoptilolite treatment, and also effect additional BOD and solids reduction in the wastewater.) Figure 16 shows capital and operating costs of such a system with adsorption, chlorination and aeration, and with ozonation.

(c) Waste Sludges

A large quantity of waste sludge will be generated in both the biological and physical-chemical treatment models described above, and the carbon adsorption system will require a regeneration system. The possibility exists that sludge disposal, carbon regeneration, and perhaps solid waste disposal could be combined in a joint waste handling system. A detailed investigation of sludge handling and incineration costs is presented elsewhere in this study. The cost estimates presented in this present discussion are based upon gravity sludge thickening, chemical conditioning, and dewatering on vacuum filters.

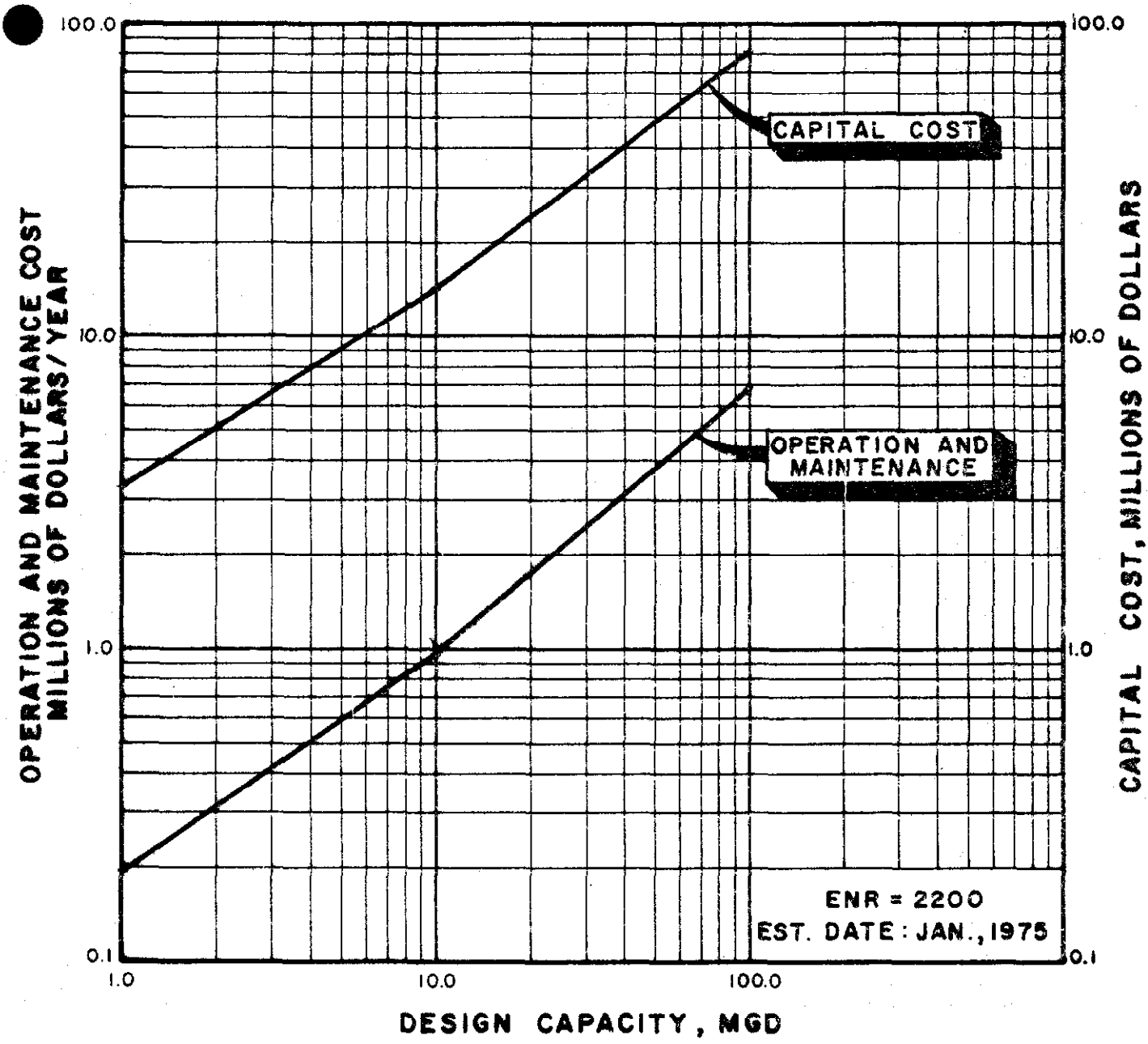

FIGURE 15 1985-Biological Treatment Stage I with Carbon Adsorption, Chlorination and Final Effluent Aeration. Capital Cost, Operation and Maintenance vs. Design Capacity.

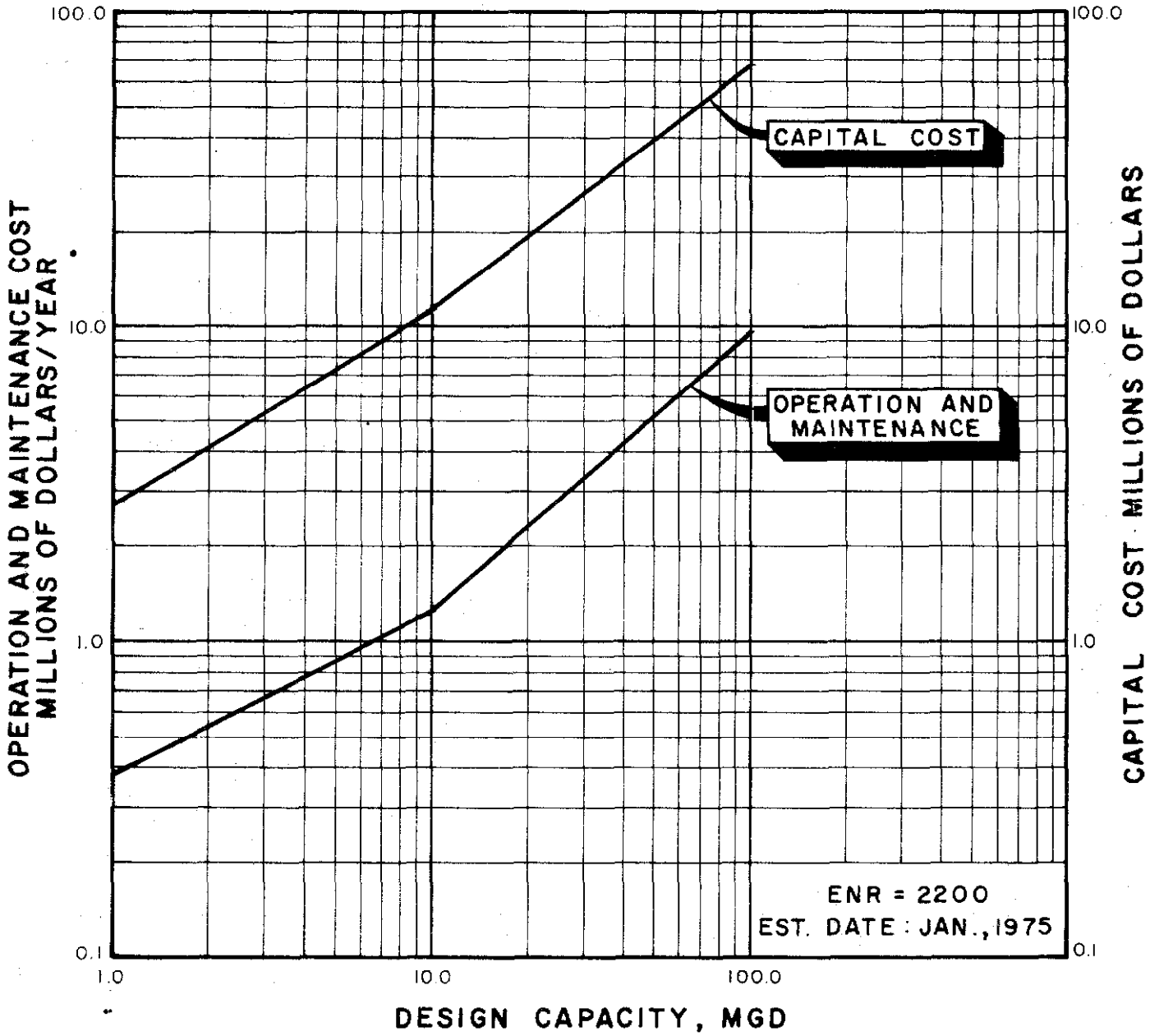

FIGURE 16 1985 - Physical - Chemical Treatment Stage I with Carbon, Chlorine and Effluent Aeration. Capital Cost and Operation and Maintenance vs. Design Capacity.

(d) Land Application

All wastewater treatment processes outlined to this point are facilities oriented treatment techniques designed to comply with the 1985 discharge limitations to navigable waters mandated by Congress in PL92-500. Draft regulations for groundwater quality resulting from ground discharge in 1983 have been proposed by EPA, and it was previously mentioned that wastewater levels of nitrates might be a problem area if only secondary treatment is utilized prior to land application by rapid infiltration.

It will be recalled from our previous discussion that effluent polishing required for both methods of land treatment (sand filtration for rapid infiltration, and storage lagoons for spray irrigation) would satisfy 1983 Best Practicable Treatment requirements, and therefore, actual land application need not be initiated until 1985. It must also be remembered that a differentiation was made between spray irrigation and rapid infiltration as methods of ultimate disposal, and overland runoff, which in fact is more nearly an advanced wastewater treatment process prior to effluent discharge.

Restrictions in available land area within the Merrimack River area limited the application of spray irrigation to small (less than 3 mgd) installations. Because sufficient land areas were not available for large flows, much dependance has to be put on the rapid infiltration method of land application for land oriented treatment systems.

Rapid infiltration areas have been generally selected adjacent to rivers. With this type of configuration, the possibility of contamination of groundwater is greatly reduced, as the tendency of the groundwater is to flow from beneath the rapid infiltration area into the river. It should be pointed out, however, that the utilization of rapid infiltration in this manner is, like overland runoff, more closely analagous to an advanced wastewater treatment polishing process than a method of ultimate disposal. Wastewater discharge will not be eliminated with this type of treatment; further, we do not feel that the process will result in effluent quality equal to that (especially in phosphates and nitrates) which is expected from the wastewater treatment processes recommended for 1985 Stage I Treatment. Even though the quality of wastewater resulting from treatment by rapid infiltration may well be sufficiently high to meet the actual water quality standards which may be established for the river, the cost comparisons between this type of treatment and the more conventional advanced processes proposed should not be made without keeping in mind the differences between the quality of treated effluents emanating from the various treatment processes.

(3) Stage II - Zero Discharge of Pollutants

Preliminary background levels for constituents have been established from raw data generated by a Corps of Engineers sampling program undertaken in nine streams tributary to the Merrimack and Nashua Rivers, water quality criteria as established the Environmental Protection Agency and Appendix B of the publication entitled "Wastewater Management Program Study Procedure", dated 1 May 1972 from the Office of the Chief of Engineers. On the basis of these sources, the following background levels are proposed as one definition of zero discharge:

Satisfaction of suspended solids, BOD, COD, color, kjeldahl nitrogen, fecal coliform, turbidity, dissolved oxygen and pH requirements for natural background levels would be possible in the advanced treatment scheme outlined previously including two stage phosphorus precipitation and 3 stage aeration, sand and carbon column filtration, and final disinfection and oxygenation. However, because the increment of inorganic ions added to wastewater during average use is much higher than background levels of these constituents in the Merrimack River, an additional demineralization process would be required. If the typical increment of dissolved solids added during one use of water is 350-400 mg/l, and 50 mg/l is the background level of dissolved solids, an 85 to 90 percent treatment efficiency in removal of these dissolved minerals would be indicated.

Demineralization of wastewater has been practiced for many years for water supply, and a technique has developed over the past decade for production of highly demineralized product water utilizing a positive and negative ion exchange process. Ion exchange consists essentially of passing water through a bed of ion exchanger where the positive and negative ions of the water will be replaced with hydrogen ions and hydroxyl ions. The process is generally applied to high quality water with medium levels (400 mg/l) of dissolved solids, and must be preceded by pretreatment to substantially eliminate organics. Much operating experience has shown that organic matter in excess of 2 ppm (expressed as oxygen demand) causes excessive fouling of the exchange beds. It should be noted that effluent from the wastewater treatment processes (including ozonation) outlined to achieve modified drinking water standards would be nearly ideal for the capabilities of this system.

Ion exchange processes are from 85 to 95 percent efficient or higher, and therefore ion exchange alone would satisfy the mineral requirements of the background level criteria in the basin.

Background Level Standards

Total Dissolved Solids	50 mg/l
BOD_5	1 mg/l
Heat	Less than plus or minus 1°C of Receiving stream
Color	25 color units
Nitrates and Nitrites (as N)	0.5 mg/l
TKN (as N) (excludes NO_3 and NO_2)	0.5 mg/l
Phosphates	0.05 mg/l
Fecal coliform organisms	200/100 ml
Suspended Solids	1 mg/l
Turbidity	0.5 JTU
Chlorides	10 mg/l
Manganese	ND *
D.O.	near saturation
pH	6-7.5
Phenols	ND
Detergents	ND
Conductivity	30 micromhos/cm.
COD	20 mg/l
Iron	ND

*ND = not discernible

Ion exchange will generate a considerable quantity of waste brines and these wastes will have high mineral contents and will pose a considerable disposal problem: land application is not suitable because of possible contamination of groundwater and deep well disposal has recently come under scrutiny because of environmental concern. Discharge of such wastes to the ocean would be preferable to other means of brine disposal where such methods are deemed appropriate. Transportation of brines could be accomplished by either evaporation and dry transport of the minerals, or a pipeline for ocean discharge. Distillation has always been and is currently a prohibitively expensive operation; however, the possibility exists that heat generated by a sludge and solid waste incineration scheme might, along with technological advances in the evaporation process and the possibility of production of salable salts, make such an alternate possible. It is likely that the quantity of brines generated by regeneration of the ion exchange system would be too small to allow economic disposal by pumping of the brines to the ocean via pipeline.

One severe concern with ion exchange is its relatively high cost. Ion exchange is a mature technology, and it is not likely that any dramatic breakthrough will take place to significantly reduce the cost. We therefore consider the long term prospect of utilizing reverse osmosis (RO) to reduce the mineral content of wastewater to background levels to be potentially more feasible than ion exchange. RO is currently in a rapid stage of development. Ten years ago the technology was in infancy; today in some situations it has supplanted ion exchange or has been combined with the process. At present (and the technology is advancing at a rapid enough rate so that a statement made today may not be true in a month's time) RO can efficiently remove 85 to 90 percent of disolved minerals in wastewater with conversion ratios of 80 percent. (When the system is run for 85 percent removal efficiency approximately 80 percent of the influent water is demineralized, and 20 percent of the volume is generated as brine.) The RO process has the advantage of being able to tolerate higher organic wastewater loadings than ion exchange without experiencing operating problems; it must also be stressed that because RO is in relative infancy, it is almost certain that operation will become more efficient and costs will decrease as time goes on.

Figure 17 is a summary of capital and operating costs for RO treatment of highly treated effluent. Design life for such a system is assumed to be 15 years. A large portion of the operating

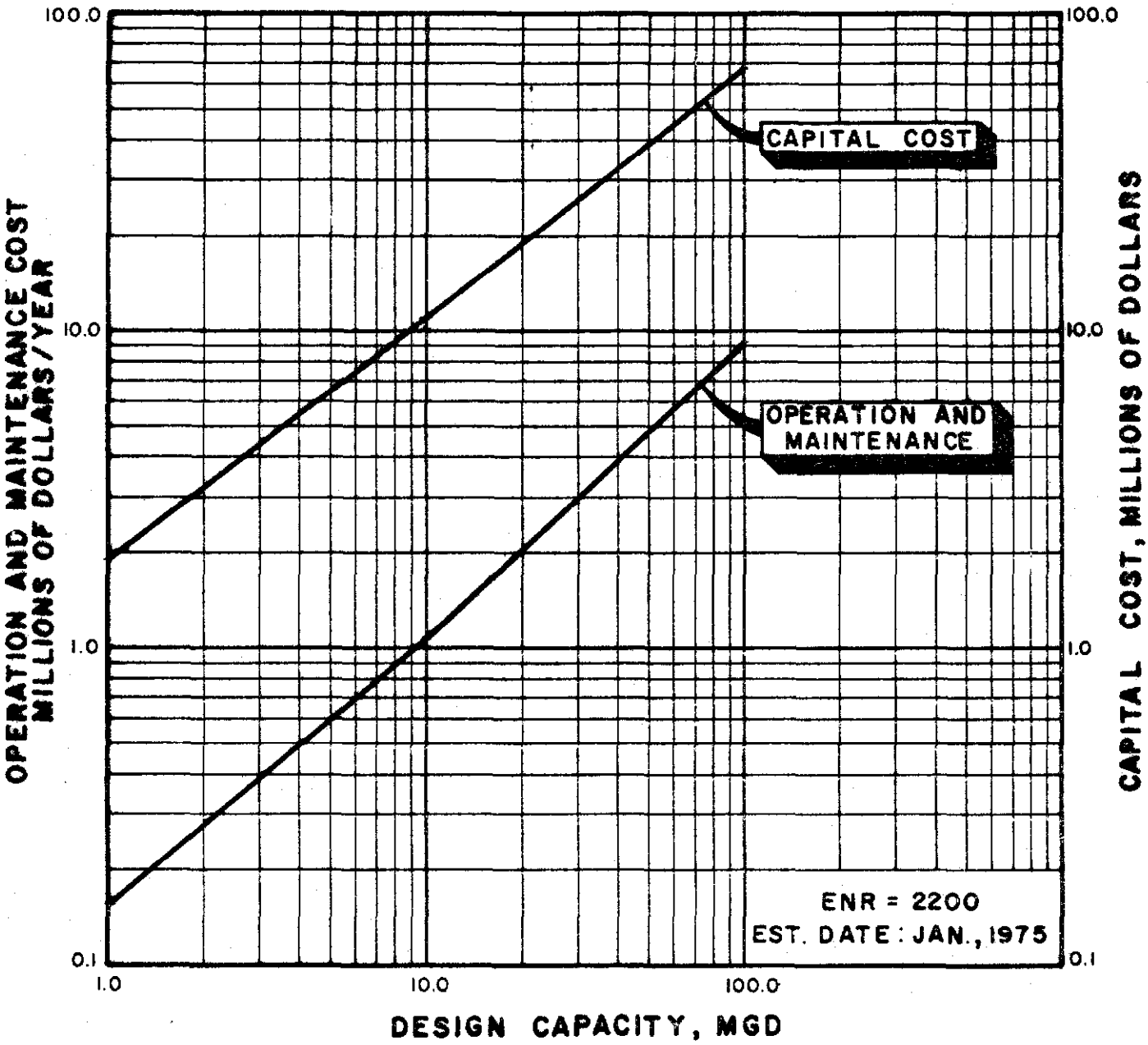

FIGURE 17 Reverse Osmosis. Capital Cost and Operation and Maintenance vs. Design Capacity.

cost is divided between power (pumping) costs and membrane replacement. (Membrane replacement has been taken as an operating cost rather than a capital cost, and membrane life has been assumed to be two years. It should be noted that the possibility exists for substantial improvement in membrane life; several manufacturers are currently developing membranes which may last in excess of three years. On the other hand, the costs shown in Figure 17 do not include disposal of the brine generated in a RO plant, and disposal will add significantly to the cost of treatment.

Figure 18 is a summary of total costs for RO applied to a biological wastewater treatment plant. Except for the addition of RO, the treatment is in all respects identical to the Stage I 1985 treatment described previously and shown in Figure 15.

Figure 19 shows similar RO technology added to physical-chemical treatment. Treatment before the RO process would be identical to that shown in Figure 16.

While it is also likely that improvements will be made in the treatment efficiency with respect to brine generated in the process, it is clear that handling methods for brines will be a significant consideration with RO. The large scale of the demineralization plants would make direct ocean pumping through a pipeline a more feasible alternative than an ion exchange system.

(a) Ultrapure and Beyond

For those situations where ultrapure water approaching distilled water is required, a system involving RO and ion exchange in series would appear to be the most feasible approach. The combination of both processes would result in demineralization efficiency of greater than 98 percent. Combination treatment has become increasingly common in the semi conductor industry and wastewater renovated by these processes could be used in the manufacture of soft drinks, in high pressure boilers, and in other industrial processes where water free from mineral salts is required. Current operating costs for ion exchange on the highly demineralized RO effluent are in the order of 20 to 40 cents per thousand gallons. This cost plus capital costs would be added to the costs of Figures 18 and 19 to determine the total costs of "ultrapure" water.

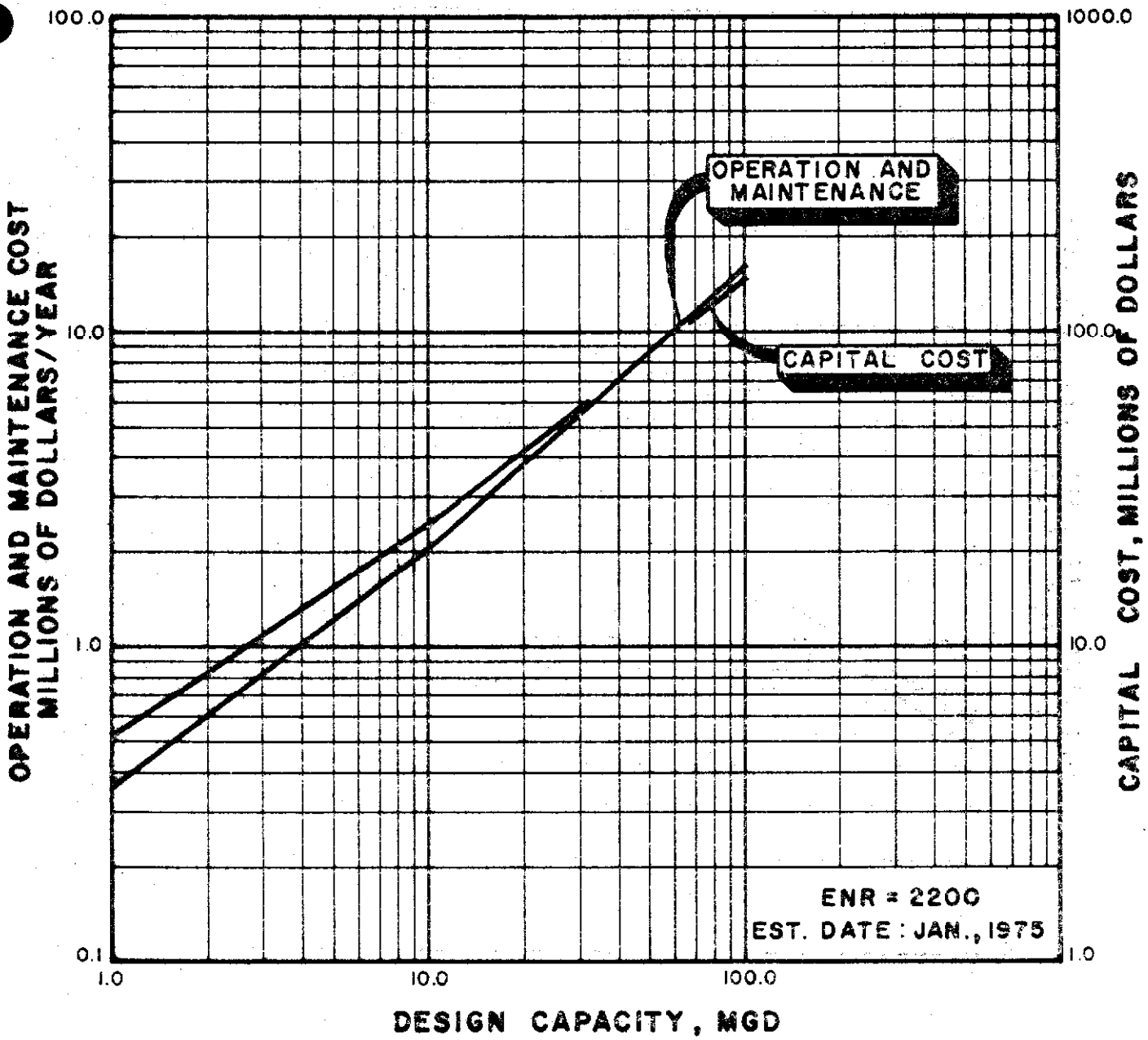

FIGURE 18 1985 - Stage II Biological,* Capital Cost, Operation and Maintenance vs. Design Capacity.

* Includes Reverse Osmosis

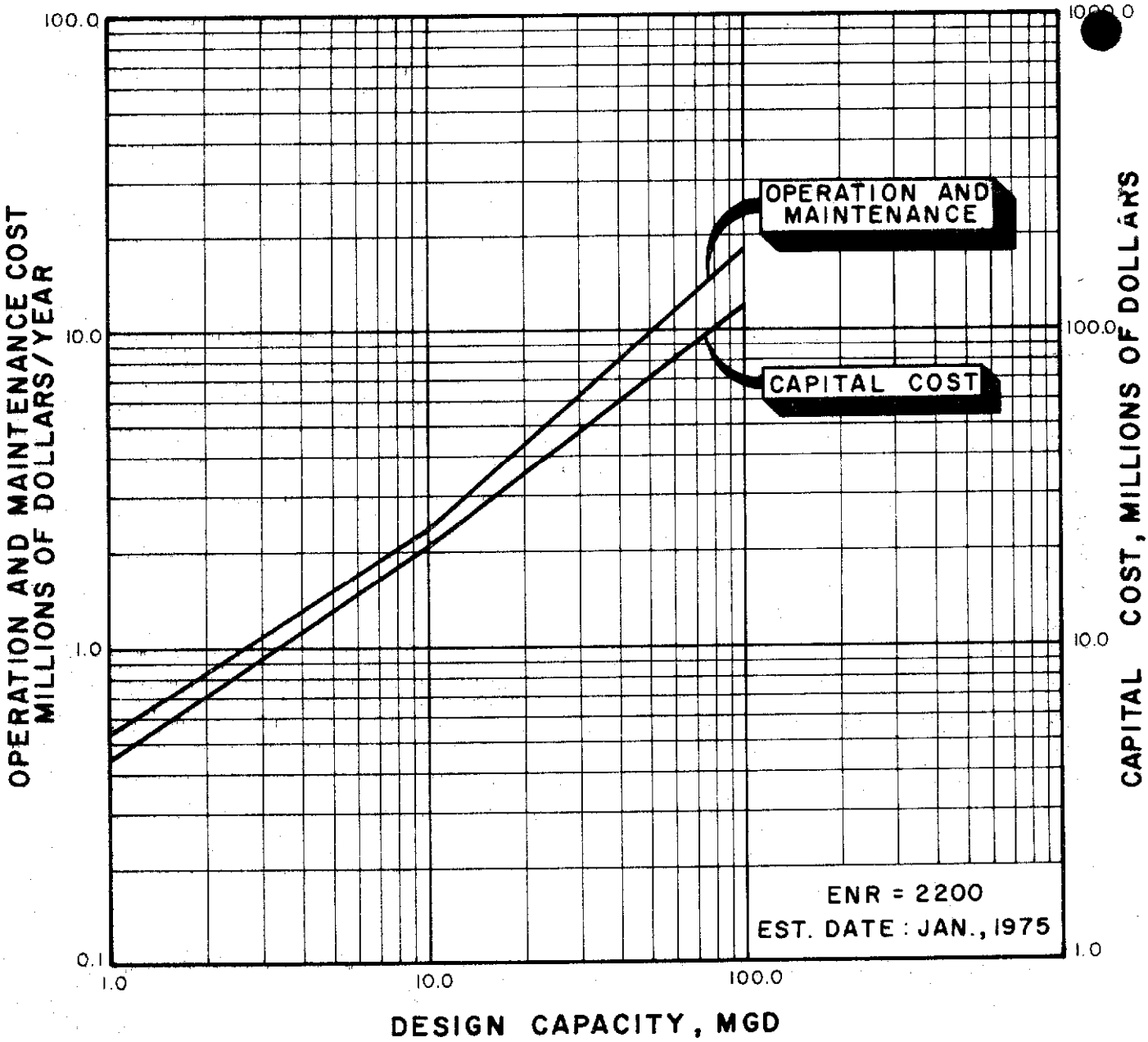

FIGURE 19 1985-Stage II Physical-Chemical* Capital Cost, Operation and Maintenance vs. Design Capacity.

* Includes Reverse Osmosis

e. Summary of Conclusions

In the preceding discussion various wastewater treatment processes were analyzed to determine the optimum combinations of such processes to comply with the discharge limitations for 1977 and 1983 established by EPA, and for 1985 by Congress in PL92-500.

Systems were developed for both biological, physical-chemical and land treatment methods; and it was demonstrated that the increasingly strict discharge limitations can best be met by building upon existing treatment systems developed for less stringent discharge limitations. It was shown that specific wastewater contaminants require physical-chemical treatment even in biological plants, while others can, at present, be effectively treated by biological processes alone. The mechanisms operating in the different types of land treatment were also investigated, and it was seen that here, too, treatment consists of a variety of biological and physical-chemical methods prior to application of the effluent to the land.

Figures 20, 21, and 22 are schematic diagrams of the biological, physical-chemical and land treatment processes which will be employed in arraying the costs and benefits of achieving various levels of water quality. It will be noted that all schematics lend themselves well to phasing, and that in no situation need a treatment unit installed to comply with an earlier discharge limitation be abandoned when a stricter limitation is imposed.

Table 1 is a summary of capital and operating costs for a 10 mgd treatment facility. The data were developed from Figures 5 through 19 for the several levels of treatment required by 1977, 1983, and 1985 discharge limitations.

Table 1 clearly shows the cost advantages of biological over physical-chemical (p-c) treatment: in 1977 the difference exists because of the high chemical additions and filtration step required in the p-c plant (but with attendant phosphate removal); in 1983 the difference represents the chemical additions and the nitrification system required in the p-c plant. (Note, however, that for the 1985 Stage I limitations, where a high degree of phosphorous, ammonia, and nitrate removal are required for both systems, the processes become cost competitive).

WATER ORIENTED BIOLOGICAL TREATMENT

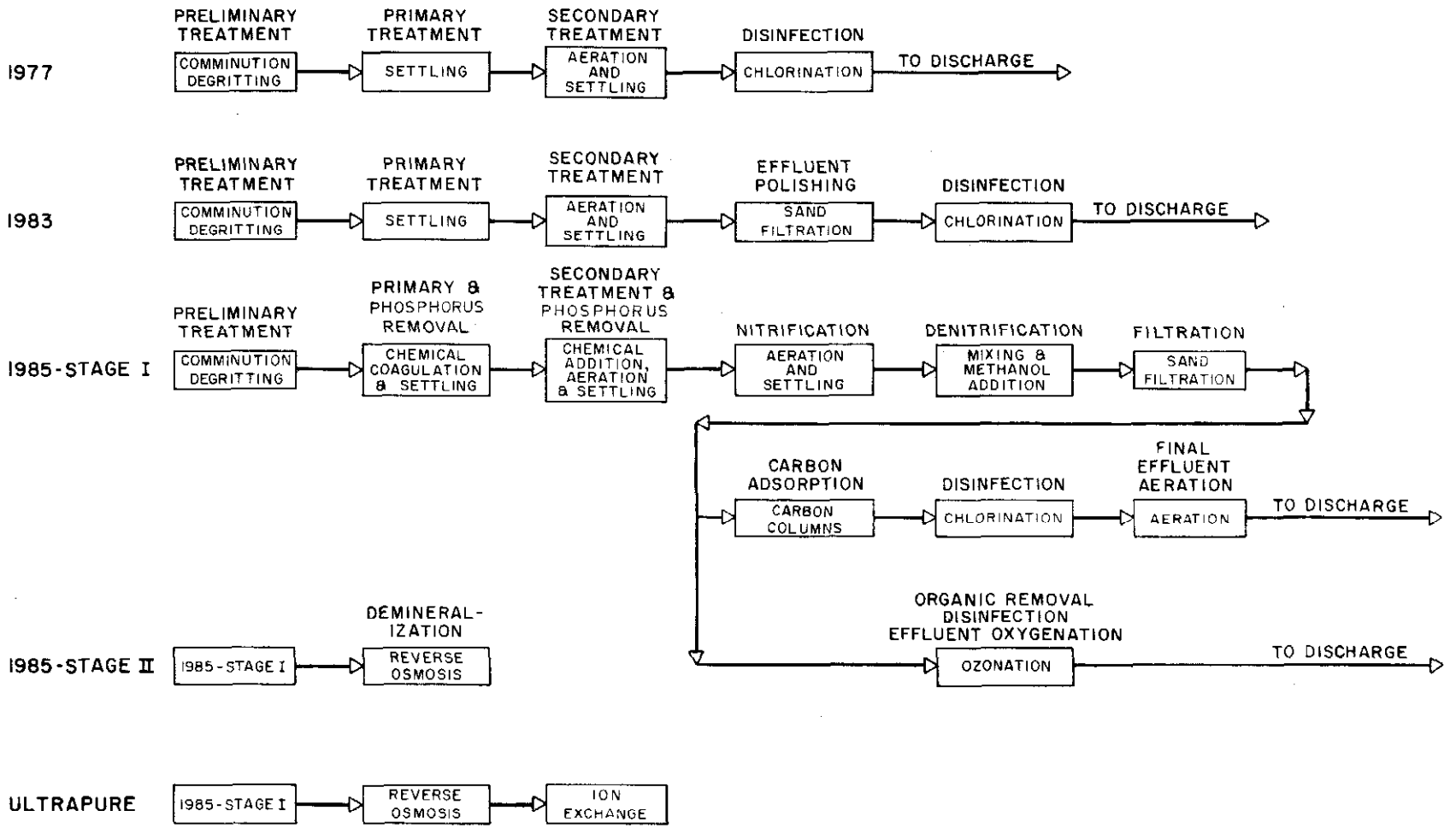

FIGURE 20

WATER ORIENTED PHYSICAL-CHEMICAL TREATMENT

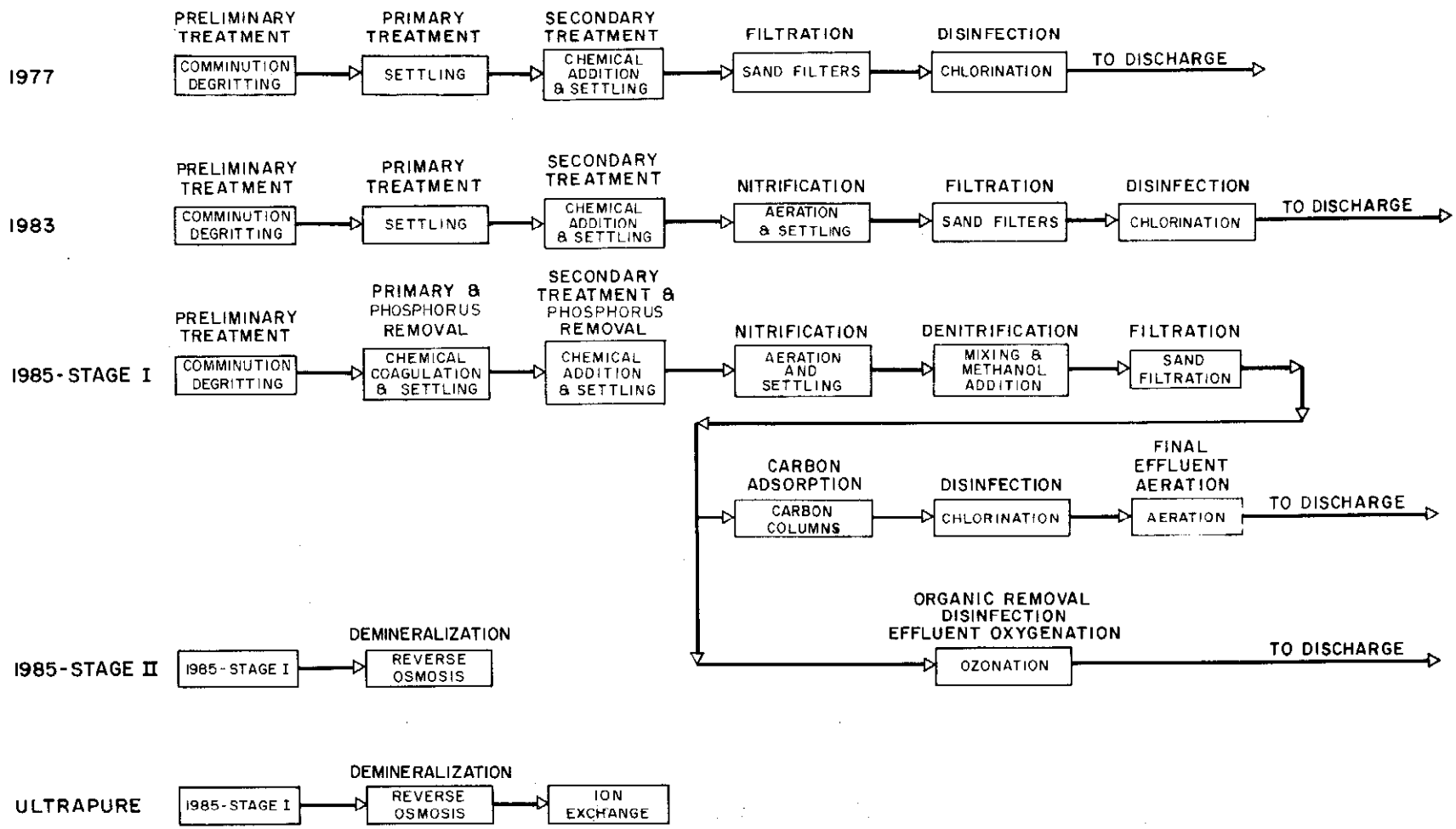

FIGURE 21

LAND ORIENTED

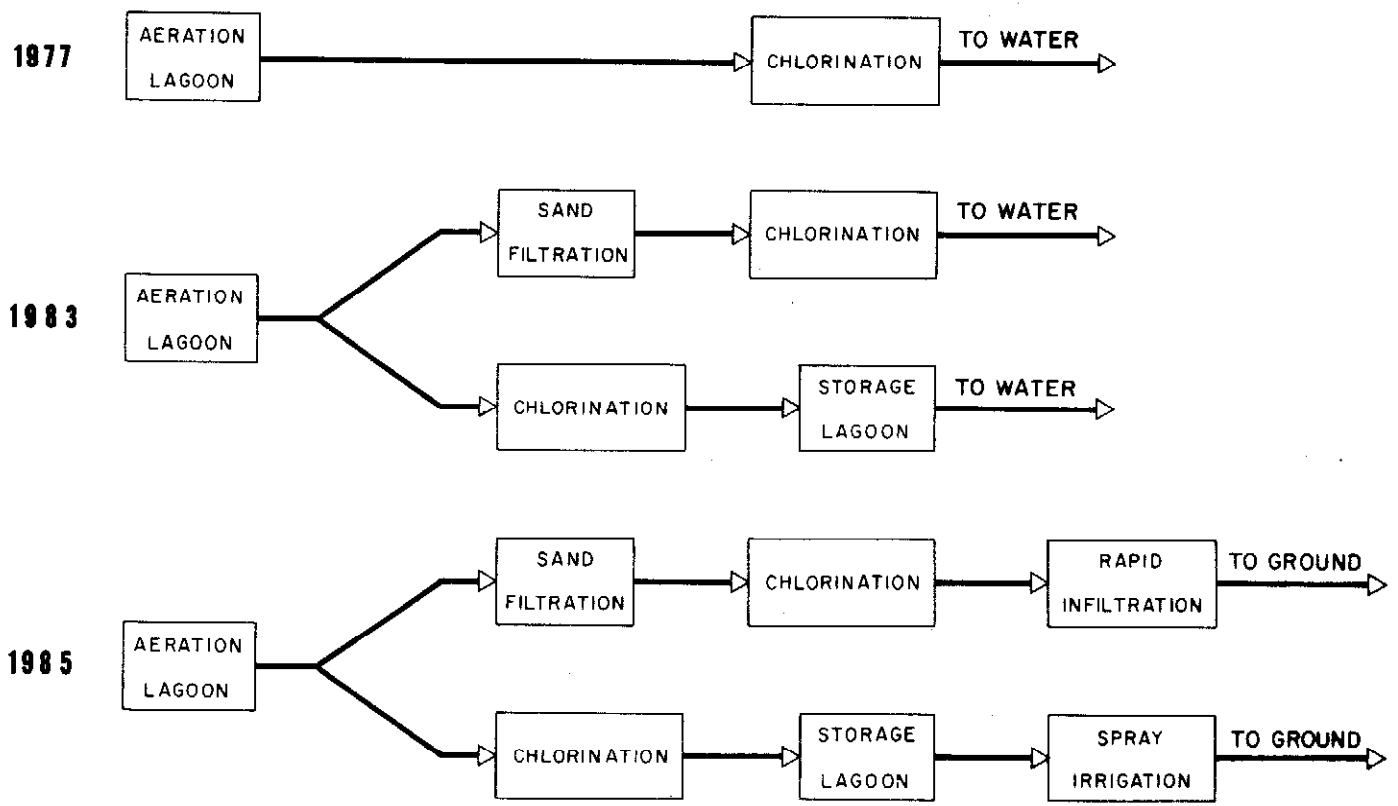

FIGURE 22

TABLE 1

CAPITAL AND OPERATING COSTS FOR 10 MGD DESIGN FLOW

	Capital Cost $	O & M $/year
1977		
Biological	5,074,000	262,800
Physical-Chemical	3,554,000	797,000
1983		
Biological	6,274,000	399,700
Physical-Chemical	5,454,000	874,300
1985, Stage I		
Biological with carbon adsorption	14,274,000	987,400
p-c with carbon adsorption	11,084,000	1,268,600
1985 Stage II		
Biological with carbon adsorption	24,344,000	2,059,000
p-c with carbon adsorption	21,184,000	2,340,600

All capital costs to ENR= 2200, and include no provision for contingencies, engineering, and interest during construction.

O & M costs estimated to January, 1975

It can also be seen from Table 1 that treatment costs for all systems increase slightly between 1977 and 1983 but greatly between 1983 and 1985 Stage I, and Stage II.

It should be stressed at this time that the purpose of developing these costs is not the basinwide implementation of either Stage I or Stage II; rather the cost computations for upper, lower, and intermediate limits will enable the costs associated with various degrees of water quality to be determined. It is only with such knowledge that intelligent decisions regarding the future of the river can be made.

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3. LAND TREATMENT OF WASTEWATER EFFLUENTS

a. Introduction

The national objective to clean up and maintain our environment has made people realize that municipal and industrial wastes can no longer be dumped indiscriminately into our lakes, streams and groundwater aquifers. Dumping raw or inadequately treated wastes to our water resources by individuals or communities results in the tainting and degradation of water supplies. Discharging effluents from adequate secondary treatment facilities which will have sufficient nutrients can lead to the rapid and excessive aquatic plant growth which in turn degrade the quality of surface water.

The soil has long been known as an effective decontaminating system. Dead animals, plant material and animal manures, including human excrement, have long been spread and worked into soils from time immemorial. Thus plant nutrients have been recycled, essential soil micro-organisms fed and soil structure maintained or improved. It has always been essential that these wastes additions were not excessive, in order that the renovation capability of the plant-soil system was not exceeded.

Treatment of municipal and industrial wastes in facilities constructed explicitly for this purpose are utilized by some New England communities. At best, these systems are "secondary" treatment facilites, which remove settleable solids and oxidize organic matter and nitrogenous compounds. Removal of nutrients and very stable organics, as well as soluble cations and ions require additional treatment methodologies in advanced treatment systems.

An alternative to constructing tertiary treatment plants is that of using the vegetative-soil ecosystem with crop production and harvesting, as a means of further treating sewage effluent. By growing crops on the land, wastewater nutrients are immediately recycled into food production while stable organics and cations contained in the wastewater are removed by the soil exchange complex.

Every state allows waste treatment using the land by permitting the use of the universal land treatment system: the domestic septic tank and leach field. Larger land treatment operations for renovating municipal and industrial wastewaters have been practiced many years in California, Texas, Arizona and Pennsylvania (55). The large elaborate spray irrigation systems for treatment of substantial quantities of

municipal and industrial wastewaters are best exemplified by systems at Pennsylvania State University (26), the Muskegon, Michigan project and the Gray Farm in Lubbock, Texas (20). In these projects, wastewater renovation is an integral part of an agricultural operation supplying the necessary nutrients and water for crop growth. The Santee project in California (35) and the Rio-Salata project in Phoenix, Arizona (7) typify multiple use of rapid infiltration treatment facilities and urban use of reclaimed water.

Land treatment methodologies considered in the Merrimack River Basin Wastewater Management Study were spray irrigation and rapid infiltration. Each approach utilizes the soil biological system to further renovate secondary treated wastewater. Since abiotic and biotic processes differ in intensity between various soils, the land treatment method considered and the management procedures used must be carefully selected for the site to insure acceptable wastewater renovation is achieved and adverse impacts are minimized.

b. Methodology for Identifying Potential Land Application Areas

Developing a land oriented treatment alternative for renovation of municipal and industrial wastewater using the soil-vegetative complex requires consideration of many factors, specifically, those pertaining to soil chemical and physical properties, geological characteristics of underlying substrata, current and future land use, and projected wastewater flows for the planning period. An equally important consideration often overlooked is the local expressed desires of a public who must live with and pay for the accepted land treatment systems, once the alternative has been shown technically plausible.

(1) Soil Data

The quantity of secondary effluent which could be applied to agricultural or forested lands for renovation without adversely affecting crop growth is closely aligned with soil properties of the application sites and crops to be grown. To ascertain the extent of each kind of soil in the study area, available soil maps were obtained for the study from the Soil Conservation Service which were developed as part of the ongoing National Cooperative Survey Program. Recent soil maps were available for 38 of the 77 communities in the study area: Andover, North Andover, Boxford, Topsfield, Ipswich, Newbury, Rowley, Groveland, Haverhill, West Newbury, Amesbury, Salisbury, Dracut, Tewksbury, Chelmsford, Billerica, Westford, Littleton, Townsend, Ayer,

Fort Devens, Harvard, Boxboro, Acton, Concord, Lincoln, Sudbury, Stow, Wayland, Natick, Sherborn, Ashland, Westboro, Northboro, Berlin, West Boylston, Holden and Sterling. In addition, the most current surveys for Middlesex, Essex and Worcester Counties were used when more recent community-wide surveys were unavailable. The soils mapped for the study area and the physical characteristics of these soils are given in Table 2.

Once the soil survey maps had been obtained, each soil type in the community was evaluated according to its suitability for land treatment techniques by spray irrigation and rapid infiltration on the basis of: soil depth, flooding frequency, longevity of high water table, permeability, slope, stoniness, and drainage.

(2) Soil Depth

Soils for spray irrigation must be at least five feet deep without a perched or seasonal high water table. Soils with impermeable horizons, "pans," were considered suitable for spray irrigation provided the application rate was adjusted for the presence of the pan horizon.

Primary sites for rapid infiltration were those with water table levels 20-30 feet below the ground surface and which had a saturated thickness of 20-30 feet below the water table. Distance from application area to slope of the application area was +200 feet.

(3) Flooding

Flood plain soils subject to annual or frequent flooding were not considered for either spray irrigation or rapid infiltration.

(4) Groundwater Table

Soils with groundwater tables within five feet of the ground surface for less than four months of the year were considered plausible for spray irrigation if an under-drain system could be installed in order to maintain a 2-3 feet unsaturated root zone throughout the growth season to facilitate crop growth. Soils with water tables within five feet of the surface for more than four months were either not considered or given special management considerations.

Water table beneath rapid infiltration areas should be 20-30 feet below the soil surface. Vertical and horizontal movement of applied water should not be restricted by an impermeable layer nor should

TABLE 2

PHYSICAL CHARACTERISTIC OF MERRIMACK RIVER BASIN SOILS 1/

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity (in.H_2O/in.soil)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Acton	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3+	moderate-well	3E	0.17-0.13	2.0-6.3	1-3
Agawam	fine sandy loam fine sandy loam silty subsoil variant	3-10+	well		0.13-.18	2.0-6.3	3-5+
Au Gres	loamy sand	10+	poor	2D	0.08-0.17	2.0-6.3	0.1.5
Belgrade	very fine sandy loam	10+	moderate-well	3A	0.15-.23	.63-2.0	1.5
Bernardston	silt loam very stony silt loam extremely stony silt loam	3-30+	well		0.10-.28	.63-2.0	3-5+
Biddeford	silt loam	10+	well	1A	0.15-.23	.2-.63	0
Birchwood	loamy sand very stony loamy sand		well		0.07-0.23	2.0-6.3+	1-3
Birdsall	silt loam	10		1A	0.15-.23	0.63-2.0	0-1
Brimfield	fine sandy loam very rocky fine sandy loam extremely rocky fine sandy loam	<2			0.06-.22	0.63-6.3	3-10+
Broadbrook	very fine sandy loam very stony very fine sandy loam extremely stony very fine sandy loam	3-10+	well	1A	.13-.2	0.63-2.0	3-5+

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity (in.H_2O/in.soil)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Brookfield	fine sandy loam very stony fine sandy loam extremely stone fine sandy loam				0.09-.23	.63-2.0	3-10+
Buxton	silt loam rocky silt loam very rocky silt loam extremely rocky silt loam	10+	Moderate-well	3A	0.15-.23	0.2-.63	1-3
Canton	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam extremely bouldery fine sand loam				0.09-.24	2.0-6.3	3-10+
Carver	loamy course sand	20+	Excessive		0.04-0.09	6.3+	5+
Charlton	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3-30+	Well		0.05-0.16	0.63-6.3	3-5+
Deerfield	loamy sand	10	Moderate-well	3C	0.07-.23	2.0-6.3	1-3
Eldridge	loamy sand			3B	0.08-.23	2.0-6.3	1-3
Elmwood	fine sandy loam			3B	0.11-.25	0.63-6.3	1-3
Enfield	very fine sand loam	3-10+			.13-.23	.63-2.0	0-5+

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity ($in.H_2O/in.soil$)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Essex	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3-20	well		0.04-0.21	2.0- 6.3	3-5+
Gloucester	sand loam very stony sandy loam	5-30+			.13-.18	2.0-6.3	3-10+
	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3-20+	Somewhat excessive		0.10-.13	2.0- 6.3	3-5+
Hadley	very fine sandy loam low bottom very fine sand loam, high bottom				0.15-.30	0.63-2.0	3-10+
Hartland	very fine sandy loam				0.12-.30	0.63-2.0	3-10+
Hinckley	loamy sand very stony loamy sand	5+			.03-.23	6.3+	3-10+
Hollis	fine sandy loam very rocky fine sandy loam extremely rocky fine sandy loam	<2	Somewhat excessive		0.10-.24	2.0- 6.3	
Leicester	fine sandy loam very stony and extremely stony fine sandy loams		poor	2A	0.06-.28	0.63-6.3	0-1.5
Limerick	silt loam	10+	poor	2B	0.15-.23	.63-2.0	0-1
Melrose	fine sandy loam				0.11-.25	.63-6.3	3-10+

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity ($in.H_2O/in.soil$)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Merrimac	fine sandy loam sandy loam very stony fine sandy loam	10+	well		0.08-0.25	2.0- 6.3	3-10+
Millis	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam				0.10-.24	2.0-6.3	3-10+
Narragansett	very fine sandy loam very stony very fine sandy loam extremely stony very fine sandy				0.13-.30	0.63-2.0	3-10+
Newport	silt loam very stony silt loam extremely stony silt loam				0.10-.29	0.63-2.0	3-10+
Ninigret	fine sandy loam	10+	Moderate-well	3C	0.10-0.18	2- 6.3	1.5
	fine sandy loam, silty subsoil variant			3B			
Ondawa	fine sandy loam, low bottom very stony loam sand, high bottom	10+	well		0.10-.30	0.63-6.3	3-10+
Paxton	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3+			0.08-.23	0.63-6.3	3-10+
Pittstown	silt loam very stony silt loam extremely stony silt loam	3-30+		3D	0.08-.28	0.63-2.0	1-3

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity ($in.H_2O/in.soil$)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Podunk	fine sandy loam	10+	Moderate-well	2C	0.11-.18	0.63-6.3	1-3
Poquonock	loam sand				0.07-.23	2.0-6.3	3-10+
Quonset	loam sand				0.02-.21	2.0-6.3	3-10+
Raynham	silt loam	10+	poor	2B	0.15-.30	0.63-2.0	0-1.5
Ridgebury	fine sandy loam	3-20+	poor	2A	0.06-.24	0.63-6.3	0-1.5
	very stony and extremely stony fine sandy loam			2A			
Rumney	fine sandy loam	10+	poor	2D	0.10-.30	0.63-6.3	1.5
Saco	silt loam	10+	very poor	1A	0.13-.23	0.63-2.0	0
Scantic	silt loam	10+	poor	2D	0.15-.30	0.63-2.0	0-1.5
Scarboro	fine sandy loam	10+	very poor	1C	0.07-.23	2.0-6.3	0
	fine sandy loam, silty subsoil variant	5+		1D	0.08-.13	0.63-6.3+	0
Scituate	fine sandy loam	3-2.0+	Moderate-well	3D	0.10-2.3	0.63-6.3	1-3
	very stony fine sandy loam						
	extremely stony fine sandy loam						
Shapleigh	fine sandy loam	0-2	Well		0.08-.13	2.0-6.3+	1-1.5
	very rock fine sandy loam						
	extremely rocky fine sandy loam						

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity ($in.H_2O/in.soil$)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Stissing	silt loam very stony and extremely stony silt loam	3-10+	poor	2A	0.10-.28	0.63-2.0	0-1.5
Sudbury	fine sandy loam very stony fine sandy loam	10+	Moderate-well	3C	0.10-.25	2.0- 6.3	1-3
Suffield	silt loam	3-10+	well		0.16-.30	0.63-2.0	3-10+
Suncook	loamy fine sand	10+	Excessive		0.07-.15	6.3+	3-10+
Sutton	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	3-30+	Moderate-well	3E	.10-.23	0.63-6.3	1-3
Swanton	fine sandy loam			2C	0.11-.25	0.63-6.3	1.5
Tisbury	very fine sandy loam	30+		3C	0.13-.30	.63-2.0	1-3
Walpole	fine sandy loam fine sandy loam, silty subsoil variant very stony fine sandy loam	10+	poor	2D 2C 2C	0.10-.23	2.0- 6.3	0-1.5
Wareham	loamy sand	10+	poor	2D	0.03-.17	6.3+	0-1.5

TABLE 2 (Cont'd)

Soil Series	Textural Class	Depth (ft)	Natural Drainage	Drainage Group 2/	Water Holding Capacity ($in.H_2O/in.soil$)	Permeability (in./hr.)	Depth to Seasonal Water Table (ft)
Whately	fine sandy loam		poor	1D	0.12-.25	0.63-6.3	0
Whitman	loam very stony and extremely stony loam	3-10+	very poor	1B	0.08-.28	.63-6.3	0
Windsor	loamy fine sand loamy sand very stony loamy sand very rocky loamy sand extremely rocky loamy sand	10+	excessive		0.08-.15	6.3+	3-10+
Winooski	very fine sandy loam	10+	Moderate-well	3A	0.13-.30	0.63-2.0	1-3
Woodbridge	fine sandy loam very stony fine sandy loam extremely stony fine sandy loam	5+		3D	0.08-.23	0.63-6.3	1-3

1/ U.S. Department of Agriculture. 1970 Estimated Physical and Chemical Properties for Soils in Major Land Resource Area 144: New England and New York Upland. Soil Conservation Service, U.S. Dept. Agric. Preliminary Report.

2/ Drainage Group classification from: USDA, Soil Conservation Service, 1971. Drainage Guide for Massachusetts. Amherst, Massachusetts.

3/ Remarks - Slight, Moderate and Severe pertain to limitation for effluent application by spray irrigation or rapid infiltration. Other remarks pertain to causitive factors limiting soils for land application.

the water table rise to the treatment bed surface during the application cycle.

(5) Permeability

Soils selected for spray irrigation were characterized by moderate and moderately rapid hydraulic permeability (0.63-6.3 inches per hour). Soils with high permeabilities (+6.3 inches per hour) were suitable for spray irrigation but require special management practices to keep optimum levels of nutrients in the root zone and minimize nutrient leakage to the groundwater.

Soils for rapid infiltration sites had moderately rapid to very rapid permeabilities (2.0 to +6.3 inches per hour).

(6) Slope

Spray irrigation sites should have a slope less than 15 per cent. Rapid infiltration sites would require grading to level slope.

(7) Stoniness

Where row crops and soil tillage were not integral to management operations, stones should not be a deterrent because surface stones would be removed during site preparation for spray irrigation. Where under-drains were necessary to maintain the unsaturated root zone, very stony and extremely stony soils could create installation problems and thus should be avoided where possible.

Stones should not present a problem in the sand filtration sites. Even so, stones should not comprise a major portion of the surface horizon. Deep alluvial sandy gravels and gravely sand terraces along streams and rivers would be ideal.

(8) Drainage

Moderately-well to well-drained soils with groundwater tables which can maintain an aerobic root zone to facilitate crop growth were acceptable for spray irrigation sites. Rapid infiltration sites should have water problems.

Suitability of common soil series for spray irrigation or rapid infiltration are summarized in Table 3. Soils suited for rapid infiltration could also be used for spray irrigation by adjusting the wastewater

TABLE 3

Soils Suitable for Wastewater Management

Spray Irrigation	Sand Filtration 1/
Highly Suitable	
Charlton 2/	Carver 2/
**Narragansett	Gloucester 2/
Enfield	Hinckley 2/
Moderately Suitable	Merrimack 2/
Bernardston (P)	Millis
Buxton (D)	Windsor 2/
Canton (W) (S)	
Hartland	
Essex (P) (S) 2/	
Ninigret (W)	
Paxton (P) (S) 2/	
Suffield (D)	
Sutton (P) (S)	
Whately (P)	

W - Manageable seasonal high water table
P - Pan usually 18" - 30" deep
D - Drainage slowly permeable subsoil
S - Stones
** - Complete soil characteristics not determined
1/ - Soil series moderately suited for spray irrigation by adjusting the application
2/ - Major soil series in study area

application to the water holding and permeability characteristics of the soil. Some of the very permeable soils, i.e., Hickley, Merrimack, which are 10-15 feet above surrounding wetland could prove practical for spray irrigation although they would be marginal for rapid infiltration. Some soils were grouped as moderately suitable for spray irrigation because of features (i.e. stoniness and depth to water table) which may require special management consideration. Bernardston, Essex, Paxton, Sutton, and Whately soils have pan layers at depths of 10-30 inches, which may require adjustment in the weekly application rates. Canton and Ninigret soils have seasonal water tables which must be managed by installation of drainage tile. Soils with surface stones require grooming to permit operation of field equipment and installation of application apparatus. Stony soils may be limited to a forage operation, depending upon the degree of stoniness which will affect cultivation practices.

c. Geological Data

Geological data and information on the Merrimack Basin was gathered for land application alternatives. Information concerning the kind and distribution of surficial deposits, bedrock geology and groundwater resources was compiled for the study area (Figure 23). A more complete text and additional maps covering the geological portion of the study area may be found in Annex I-A of the final report (21).

The map shown as Figure 23, extracted from the main geologic report, summarized the type and distribution of the surficial deposits of the entire basin. The unconsolidated sediments have been subdivided into different units based on particle size and genetic classification. Certain areas such as those underlain by peat, muck and silty clays were immediately removed from consideration for land application. Conversely, areas underlain by stratified sands and gravels such as outwash deposits and ice contact deposits were easily recognizable and flagged for further investigation as possible sites of rapid infiltration. The large areas shown as till are suitable for spray irrigation providing other criteria such as slope and land use are also satisfied. Till areas are not, except under very unusual circumstances, suitable for rapid infiltration due to the low vertical permeability.

Surficial geology maps, such as described above, as well as bedrock and groundwater resource maps were prepared. This information is used in conjunction with land use and soils maps to help select land sites for land application. The various maps are compared and commonly superimposed over one another. Areas of land which appear

A SUMMARY OF THE AVAILABLE INFORMATION
SHOWING THE DISTRIBUTION OF UNCONSOLIDATED MATERIALS
IN THE MERRIMACK RIVER BASIN (MASSACHUSETTS PORTION)

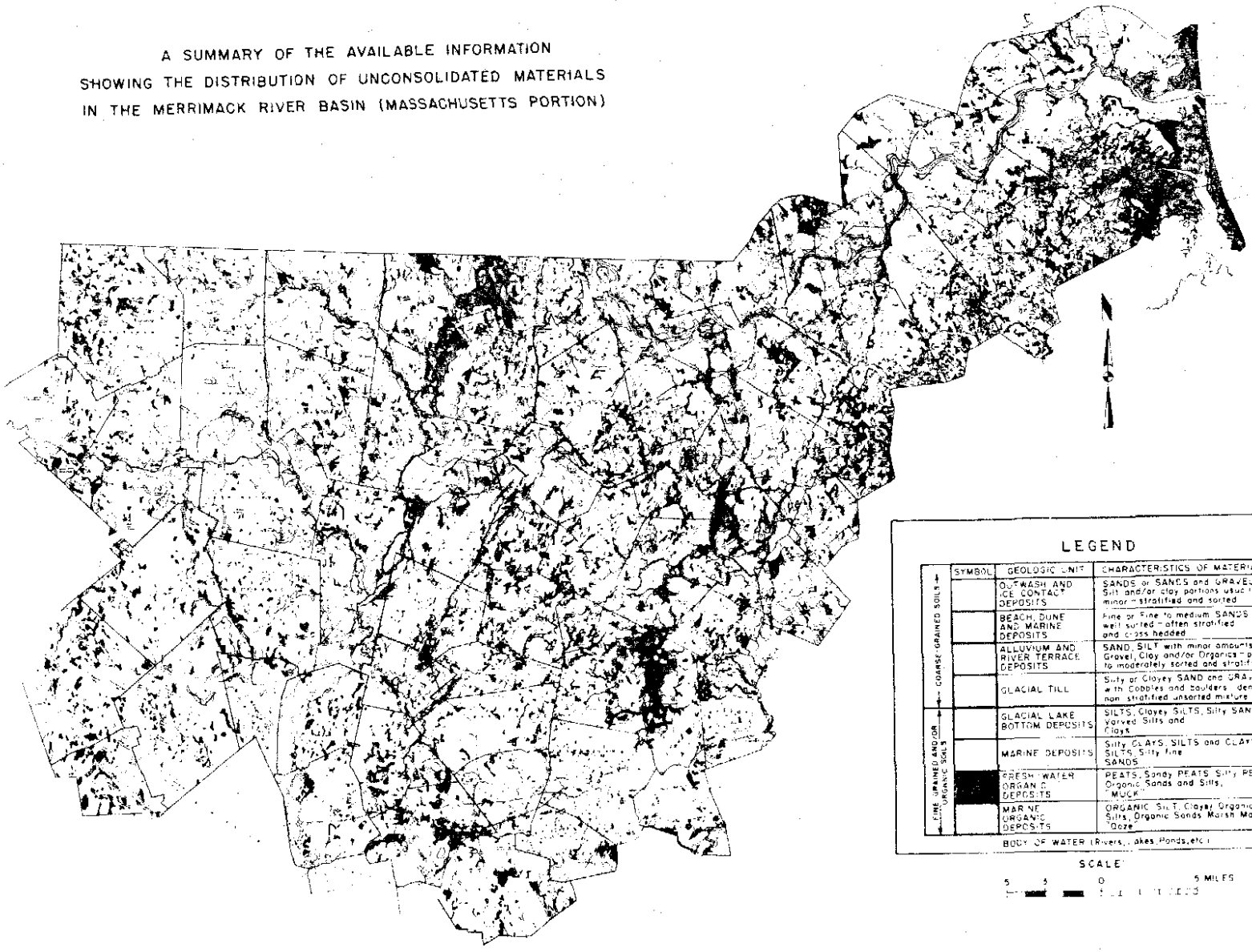

FIGURE 23

PREPARED FOR CORPS OF ENGINEERS BY ANDERSON-NICHOLS & CO. INC. AND GRINBERG-ZONO & ASSOC. INC.

visible through "windows" after the constraints and criteria inherent in the various maps are satisfied, are then selected as possible potential sites. These areas were discussed with local community leaders and in public workshops in order to obtain first hand information concerning future development.

d. Land Use

Recent land use mapping of the study area provided information as to the extent of various land uses within each community (36). Six major land use categories; agricultural and open lands, forested lands, urban land, wetland, mining and waste disposal and outdoor recreational land, were delineated. The acreage of each land use per community is presented in Tables 4, 5, and 6 for Essex, Middlesex and Worcester Counties respectively. The acreages of agricultural, open and forested lands provide some estimate of the upper limit of available lands for possible treatment sites. However, this will be reduced considerably in view of the fact that not all acreages of agricultural, open and forest lands coincided with soil and geological data for lands suitable for spray irrigation or rapid infiltration.

(1) Potential Land Application Areas

The area required to implement a land treatment alternative was calculated for each town or sewer district based on projected wastewater flows for the year 2020. Since any land system implemented should be operable in excess of 50 years, land required for future wastewater flows would by necessity have to be acquired today to ensure its availability. Acreages required to treat the projected 2020 wastewater flows from each community or sewer district in the study area under either spray irrigation or rapid infiltration approach is presented in Table 7. The soil comprising spray irrigation sites was made up of a number of different soil types varying in physical properties which influenced the weekly application rates. It was, therefore, necessary to calculate land requirements for three application rates: 1.25, 2.0 and 2.5 inches per week, in order to get some idea of the actual acreage which might be needed. Nutrient and water inputs under these rates are discussed in later sections.

The length of the application period was assumed to be 26 weeks, with sufficient storage capacity in surface lagoons to hold 30 weeks wastewater flow plus the net annual precipitation falling on the storage lagoon. The depth of the storage lagoon was set at 20 feet in order to minimize the net additions of water added to the lagoon as precipitation.

TABLE 4

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS - ESSEX COUNTY (1970-71)[a]

Community	Total Acreage	Agriculture & Open Land		Forest Land		Urban Land		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lan	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Amesbury*	8838	1764	20	3299	37	2248	25	1164	13	152	2	211	2
Andover *	20475	2232	11	10280	50	6027	29	1265	6	178	1	493	2
Boxford*	15609	1521	10	11494	74	1716	11	711	5	22	.1	145	1
Georgetown*	8384	804	10	5761	69	1374	16	312	4	111	1	22	.3
Groveland *	5997	757	13	3416	57	1133	19	498	8	153	3	40	.7
Haverhill *	22932	4253	19	9092	40	6901	30	1892	8	322	1	472	2
Lawrence *	4635	78	2	319	7	3868	83	270	6	11	.2	89	2
Merrimac *	5779	1076	19	3380	58	885	15	360	6	67	1	11	.1
Methuen *	14752	2612	18	5530	37	5163	35	987	7	147	1	312	2
Newbury*	15578	2612	17	5400	35	1308	8	5945	38	48	.3	265	2
Newburyport *	5702	1039	18	1040	18	1628	29	1734	30	87	2	174	3
North Andover*	17811	2502	14	11247	63	2502	14	1191	7	133	.7	236	1
Rowley*	12166	1478	12	6299	52	1005	8	3161	26	107	.9	116	1
Salisbury *	10323	977	9	4000	39	1285	12	3532	34	124	1	410	4
West Newbury *	9382	2673	28	4582	49	914	10	1183	13	4	-	26	.3

a/ MacConnell, W.P., in Progress, Remote Sensing Twenty Years of Change in the Human Environment in Massachusett 1951-1971. Dept. Forestry and Wildlife Manage. Mass. Agric. Exper. Station. Amherst, Mass.

* Communities in Merrimack Wastewater Management Study area.

TABLE 5

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS
MIDDLESEX COUNTY (1970-71)[a]

Community	Total Acreage	Agriculture & Open Land		Forest Land		Urban Land		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lands	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Acton	12838	1416	11	7317	57	3064	24	698	5	291	2	52	0.4
Ashby	15322	1461	10	12663	82	735	5	392	3	47	.3	24	0.2
Ashland	7942	553	7	5192	65	1480	19	414	5	188	2	115	1
Ayer	5978	648	11	3200	53	1471	25	536	9	47	.8	76	1.3
Bedford	8787	725	8	3844	44	3323	38	674	8	62	.7	159	1.8
Billerica *	16653	1548	9	8870	53	5052	30	860	5	163	1	160	1
Boxborough	6650	1028	15	4746	71	605	9	223	3	37	.5	11	.2
Burlington	7578	427	6	2655	35	4180	55	127	2	101	1	88	1
Carlisle	9837	1134	12	7386	75	967	10	343	3	-	-	7	-
Chelmsford *	14758	1897	13	5978	41	5742	39	844	6	187	1	110	.7
Concord	15974	2956	19	7654	48	3382	21	1610	10	91	.6	281	2
Dracut *	13818	3383	24	6771	49	2776	20	562	4	278	2	48	.3
Dunstable *	10413	1960	19	7672	74	314	3	417	4	21	.2	29	.3
Framingham	16416	1292	8	5980	36	7490	46	1177	7	121	.7	356	2

TABLE 5 (Cont'd)

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS
MIDDLESEX COUNTY (1970-71)[a]

Community	Total Acreage	Agriculture & Open Land		Forest Land		Urban Land		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lands	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Groton	20826	3126	15	14669	70	1575	8	1311	6	43	.2	102	.5
Hopkinton	16896	1361	8	12000	71	2030	12	1223	7	150	.9	132	.8
Hudson	7462	743	10	3941	53	2092	28	493	7	150	2	43	.6
Lexington	10547	759	7	3032	29	5584	53	860	8	58	.6	254	2
Lincoln	9318	1342	14	4844	52	2388	26	703	8	15	.2	26	.3
Littleton	10534	2328	22	5469	52	1777	17	848	8	68	.6	45	.4
Lowell *	9812	586	6	1808	18	6313	64	655	7	141	.1	309	3
Marlborough	13434	1581	12	7051	52	3513	26	862	6	220	2	207	2
Maynard	3354	292	9	1635	49	1120	33	200	6	39	1	68	2
Natick	9523	878	9	3780	40	3814	40	763	8	51	.5	237	2
Pepperell *	14720	3010	20	9651	66	1289	9	697	5	51	.3	22	.1
Sherborn	9702	1625	17	6562	68	948	10	518	5	35	.4	14	.1
Shirley	10259	1390	14	7681	75	831	8	227	2	93	1	37	.4
Stow	11315	1718	15	7254	64	1269	11	698	6	119	1	257	2

TABLE 5 (Cont'd)

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS
MIDDLESEX COUNTY (1970-71) a/

Community	Total Acreage	Agriculture & Open Land		Forest Land		Urban Land		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lands	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Sudbury	15597	2464	16	8133	52	3350	21	1339	9	86	.5	225	1
Tewksbury *	13670	2470	18	5360	39	4782	35	689	5	192	1	177	1
Townsend	21011	1846	9	17391	83	1309	6	354	2	90	.4	21	.1
Tyngsborough*	11520	956	8	7960	69	1153	10	1095	10	163	1	193	2
Wayland	9779	1269	13	4152	42	2620	27	1469	15	43	.4	226	2
Westford *	19974	2424	12	12945	65	2652	13	1449	7	373	2	131	.7
Weston	10752	663	6	5570	52	3630	34	482	4	71	.7	336	3
Wilmington	10931	670	6	5108	47	4166	38	487	4	373	3	127	1

a/ MacConnell, W.P., in Progress, Remote Sensing Twenty Years of Change in the Human Environment in Massachusetts, 1951-1971. Dept. Forestry and Wildlife Manage. Mass. Agric. Exper. Station. Amherst, Mass.

* Communities in Merrimack Wastewater Management Study area.

TABLE 6

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS
WORCESTER COUNTY (1970-71)

Community	Total Area	Agriculture & Open Lands		Forest Lands		Urban Lands		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lands	
	Acres	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Ashburnham	26,170	1,996	7.6	20,570	78.6	1,256	4.8	2,256	8.6	15	<0.1	76	0.3
Berlin	8,435	1,628	19.3	5,736	68.0	542	6.4	332	4.0	172	2.0	25	0.3
Bolton	12,755	2,366	18.6	8,923	70.0	888	7.0	281	2.0	51	0.4	246	2.0
Boylston	12,653	841	6.6	8,403	66.4	787	6.2	2,422	19.1	41	0.3	159	1.3
Clinton	4,614	415	9.0	1,749	37.9	1,342	29.1	1,043	22.6	46	1.0	19	0.4
Fitchburg	18,131	2,188	12.1	10,777	59.4	4,647	25.6	227	1.3	51	0.3	241	1.3
Gardner	14,618												
Grafton	14,925	3,548	24.0	7,656	52.0	2,708	18.0	810	5.0	169	1.0	34	0.2
Harvard	17,267	2,516	14.6	11,206	64.9	2,219	12.9	1,079	6.2	54	0.3	191	1.1
Holden	23,469	1,540	6.6	17,573	74.9	2,931	12.5	1,056	4.5	214	0.9	155	0.7
Hubbardston	26,694												
Lancaster	17,875	3,178	17.8	11,876	66.4	2,022	11.3	631	3.5	138	0.8	30	0.2
Leominster	18,886	1,919	10.2	11,509	60.9	4,406	23.3	695	3.7	144	0.8	213	1.1
Lunenburg	17,594	3,316	18.9	10,458	59.4	1,972	11.2	1,407	8.0	288	1.6	153	0.9

TABLE 6 (Cont'd)

LAND USE FOR COMMUNITIES IN THE MERRIMACK RIVER BASIN IN MASSACHUSETTS
WORCESTER COUNTY (1970-71)[a]

Community	Total Area	Agriculture & Open Lands		Forest Lands		Urban Lands		Wet Lands		Mining, Waste Disposal Lands		Outdoor Recreation Lands	
	Acres	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Northborough	11,981	1,963	16.0	6,999	58.0	2,179	18.0	442	4.0	98	0.8	300	3.0
Paxton	9,856	1,455	15.0	6,637	67.0	1,027	10.0	663	7.0	52	0.5	22	0.2
Princeton	22,850	2,218	9.7	19,399	84.9	665	2.9	486	2.1	25	0.1	43	0.2
Rutland	23,110												
Shrewsbury	13,971	1,788	13.0	7,017	50.0	3,957	28.0	751	5.0	373	3.0	85	0.6
Southborough	8,819	1,146	13.0	4,917	56.0	1,543	17.0	1,048	12.0	6	-	159	2.0
Sterling	20,237	5,007	24.7	12,434	61.6	1,506	7.4	1,128	5.6	140	0.7	22	0.1
Westborough	13,766	2,814	20.0	6,982	51.0	2,731	20.0	1,008	7.0	106	0.8	185	0.9
West Boylston	8,819	1,647	18.7	4,716	53.5	1,442	16.4	765	8.7	83	0.9	166	1.9
Upton	13,823	1,228	8.9	10,841	78.4	1,140	8.2	451	3.3	108	0.8	55	0.4
Westminster	23,844	2,178	9.1	17,778	74.6	1,748	7.3	1,726	7.2	224	0.9	190	0.8
Worcester	24,514	714	2.9	6,954	28.4	15,038	61.3	791	3.2	226	0.9	781	3.2

a/ MacConnell, W.P., in Progress, Remote Sensing Twenty Years of Change in the Human Environment in Massachusetts, 1951-1971. Dept. Forestry and Wildlife Manage. Mass. Agric. Exper. Station. Amherst, Mass.

TABLE 7 - LAND ACREAGES NEEDED FOR LAND TREATMENT

Community Sewer District	Total Land Area (Acres)	Waste-water Flow (2020) (MGD)	Spray Irrigation Application Rate 1/			Sand Filtration Application Rate 2/			
						0.67 ft/day		0.33 ft/day	
						Cycle			
			1.25in/wk 3/	2.0in/wk	2.5in/wk	14 wet-7 dry	7 dry-14wet	14 wet-7 dry	7 wet-14 dry
Amesbury	8,838	2.06	978	629	518	19	29	38	57
Boxford	15,609	0.59	280	180	148	5	8	11	16
Georgetown	8,384	0.92	437	281	231	9	13	17	26
Haverhill/Groveland	28,929	18.58	8,823	5,676	4,670	171	256	342	513
Greater Lawrence Sanitary District	57,673	65.19	30,958	19,915	16,386	600	900	1,200	1,800
Merrimac	5,779	0.58	275	177	146	5	8	11	16
Newburyport-Newbury	21,280	4.45	2,113	1,360	1,119	41	62	82	123
Rowley	12,166	0.43	204	132	108	4	6	8	12
Salisbury	10,323	2.13	1,012	651	536	20	30	40	59
West Newbury	9,382	0.31	147	95	78	3	4	6	9
Billerica	16,653	8.91	4,231	2,722	2,240	82	123	164	246
Greater Lowell (Dracut, Lowell, East Tyngsboro & Tewksbury)	43,060	33.10	15,719	10,112	8,320	305	457	609	914
N. Chelmsford, E. Dunstable & W. Tyngsboro	13,665	5.34	2,536	1,631	1,342	49	74	98	147
South Chelmsford	7,379	3.52	1,672	1,075	835	33	49	65	97
Westford	19,974	1.30	617	397	327	12	18	24	36
Pepperell - W. Dunstable	19,926	9.60	4,559	2,933	2,413	88	133	177	265
TOTALS (ac)	299,020	157.01	74,561	47,966	39,469	1,446	2,170	2,892	4,318

1/ 26-week application period - 30 weeks storage in 20-foot surface lagoon
2/ Continuous application
3/ 14 wks @ 1"/wk plus 12 wks @ 1.5"/wk

Additional information pertaining to the lagoon size and other specific engineering criteria are given in Section D of this Appendix III.

Following the calculation of the land requirement necessary to treat the municipal and industrial wastewater flows, these acreages were compared with the land acreages believed suitable for either spray irrigation or rapid infiltration. Where land was not available within a specific community or sewer district, application areas outside of these communities but primarily inside the hydrologic boundaries of the Massachusetts portion of the Merrimack River Basin were considered.

Land needed for spray irrigation compared with the potentially available lands show that communities or groupings of communities having wastewater flows less than about 3.0 mgd have not yet become too urbanized and still have sufficient land areas suitable for spray irrigation. Communities or community groupings having wastewater flows greater than 3.0 mgd have generally developed most lands conducive to spray irrigation, thus making this land alternative unfeasible.

Geologic information of the Massachusetts portion of the Merrimack River Basin shows extensive deposits of stratified sands and gravels. In many instances, these deposits have been sources of construction material which after excavation are simply abandoned. These abandoned gravel pits plus the large tracts of stratified sand and gravel along the Merrimack and Nashua Rivers are ideal as potential sites for implementing rapid infiltration.

Spray irrigation, because of the low application rates, requires large land acreage. However, spray application offers benefits tied to nutrient and water recovery plus better control over operation. Comparing land requirements for spray irrigation systems at 1.25, 2.0 and 2.5 inches per week application rate shows that about twenty-five per cent, sixteen per cent, and thirteen per cent, respectively, of the total 299,000 acres encompassing the 24 communities of the study area, would be needed. It is evident from land use data given in Tables 4 and 5 and the land area needs for spray irrigation (Table 7) that urbanized communities such as Lowell, Lawrence, and Haverhill, Massachusetts do not have sufficient suitable agricultural, open or forested lands to encourage proposing spray irrigation. Communities such as Billerica, Chelmsford, and Tewksbury have managed to preserve some open lands, primarily wetlands. Remaining available land areas do not have adequate soils for developing a spray irrigation system. This would not preclude proposing future spray irrigation land systems of these communities where viable sites and local responsiveness exist.

Rapid infiltration as an approach to land treatment of wastewater emphasizes treating large volumes of wastewater by application to a relatively small land area. Wastewater renovation and water conservation rather than economic nutrient recycling at least cost to the environment are prime concerns. As applied wastewater infiltrates and percolates through the stratified sand and gravel layers, nutrients, organic matter and pathogenic organisms are removed. Renovative effectiveness of rapid infiltration is discussed in later sections. Most rapid infiltration sites are located along major streams in the study area, and therefore most groundwater flows from rapid infiltration sites are towards adjoining surface streams. Many communities have sites believed suitable for rapid infiltration. The fact that land areas required for rapid infiltration are much less than that needed for spray irrigation, a larger number of communities have the option to utilize land for wastewater treatment using rapid infiltration. The amount of land required is dependent on wastewater flow, rate of application, and the operation cycle (Table 7).

Since 20 of the 24 communities in the study are have the option to implement rapid infiltration systems illustrate the difference between the two land oriented wastewater management systems. The exception is the Greater Lawrence Sewer District where the aggregation of high urbanized communities Lawrence, Methuen, Andover, and North Andover, has resulted in such large volumes of wastewater that sufficient land area is not available within these communities. It should be pointed out that while available surficial geological information shows sufficient suitable land areas in the remaining communities, field studies of these sites must be conducted to ensure each site meets criteria specified for rapid infiltration sites.

e. Proposed Spray Application of Wastewater Effluent

Spray irrigation of treated municipal and industrial wastewater to the land provides many of the less populated communities along the Merrimack River a viable alternative for wastewater management. While agricultural lands within the study area have declined 30-50 per cent between 1959 and 1969, some communities still have suitable agricultural, open and forested lands where land wastewater management could be practiced. The decline in the number of farms and cropland may be arrested in those communities desiring to preserve their rural interests and integrate land treatment with long-range community development. Unfortunately, past community urban development has been, in part, at the expense of agricultural and open areas. Examination of the available surficial geologic information for communities

within the study area revealed substantial acreages of land on which land treatment of municipal wastewater coul be accomplished via spray irrigation. The communities of Merrimac, Amesbury, West Newbury, Boxford, Georgetown, Rowley and Westford all have sufficient suitable lands to accommodate their respective projected 2020 wastewater flows. Soil criteria used for selection of sites suitable for spray irrigation is presented in Table 8.

(1) Application Rates

Several recent discussions have addressed rates at which wastewater may be applied to land (16, 45). The infiltration rate (the rate at which water enters the soil surface) and the permeability or hydraulic conductivity (the rate at which water passes through any subsurface unit of the soil) are the parameters that are measured in the field or laboratory and are used for irrigation design, drainage design and to estimate the runoff characteristics of a soil. However, the arbitrary use of this data directly for the design of wastewater treatment systems should be compatible with the agricultural crop production.

A successful wastewater system should be designed to maintain an aerobic root zone except for short periods. As air enters the soil pores, the hydraulic conductivities drop very rapidly by one or even two orders of magnitude. Thus, systems that are considered conservative because of large safety factors applied to designs using saturated conductivity data could be complete failures in operation.

The recommended rate of application for wastewater application on the various soil groups would be +0.25 inches per hour.

Total weekly effluent application to various soils would be as follows:

Soil Texture	Weekly application rate inches/week
Silt loams, loams very fine sandy loam	1.25
Fine sandy loams loamy sand	2.0
Loamy coarse sand and sands	2.5

TABLE 8

SELECTION CRITERIA FOR SPRAY IRRIGATION SITES

Site Criterion	Limitations		
	Slight	Moderate	Severe
1. Soil Depth	5 feet or more	3 to 5 feet	less than 3 feet
2. Soil Drainage	well drained	moderately to well drained	poor and very poor
3. Soil Texture	silt loam, loam, find sandy loam, loamy fine sand	loamy sand, sand	gravel and cobbles
4. Fragipan	none	well drained with fragipan	all other drainage
5. Slope	0 to 8%	8 to 15%	15%+
6. Stoniness	none	very stony	extremely stony
7. Flood hazard	none	occasional	frequent

Weekly applications could either be a single application or two equal applications, however, drainage considerations would probably favor the latter. Soils with permeabilities less than 0.63 inches per hour were believed ill suited for spray irrigation during very wet years.

Spray irrigation rate to the land was at 0.25 inches per hour during the 26-week application period. Surface storage lagoons would be capable of holding the wastewater flow for a 30-week period plus the precipitation falling on the storage lagoon.

(2) Drainage

It is essential that adequate drainage be provided on all soils receiving secondary municipal effluent. A drainage system will not only enhance the water infiltration rate, but will also assure a well aerated soil that is necessary for renovation of wastewater and crop production.

Although drainage systems may take on many forms, the one most commonly used on poorly drained soils is subsurface tile drainage. Its primary advantage is that it does not hinder machine movement in the field. Using computer techniques, various combinations of depth and spacing of the drainage tile were evaluated for the three soil hydraulic conductivities and three application rates. Design methodology for agricultural drainage systems developed by the Department of Agriculture, Soil Conservation Service (61, 62) was used. Precipitation data was obtained for Haverhill, Massachusetts for 1972, which was a wetter than normal year. It was assumed that an impervious layer was present at a depth of ten feet, that soil hydraulic conductivities were 0.63, 2.0, and 6.3 inches per hour and weekly application rates were 1.25, 2.0 and 2.5 inches over a 26-week application period. No irrigation events would occur on the same day as a precipitation event. Success criteria was to maintain a three-foot unsaturated aeration zone at the mid-point between the drainage tile for no less than two consecutive days.

Although drainage tile systems are not customarily installed in well drained or moderately well drained soils, computer simulation of the irrigation events reveal the water table would be raised sufficiently to warrant installation of a drainage system. It was found that splitting the weekly application volume into equal separate events could attenuate the instantaneous rise in the water table.

Drainage tile for moderately drained soils placed at the seven-foot depth on either 50 or 60 foot centers would maintain the desired

three-foot aeration zone when irrigation was 1.25 inches per week or less. Higher effluent applications to those soils would raise the water within 2.5 feet of the soil surface.

Moderately well drained soils (2.0-6.3 inches/hr) receiving weekly application of two inches or less have a three-foot surface aeration zone when the drainage system was installed either on 60 or 100 foot centers at seven feet deep.

Very well drained soils (6.3 inches/hr) with drainage tile installed at five feet, on 200-foot centers could maintain the desired aerobic zone under 2.0 inches/week effluent applications. Larger applications at 2.5 inches/week, would rise the water table within 2.5 feet of the soil surface over growing season. However, installing the drain tile closer together and at greater depth would permit the higher application rate.

Wherever possible, advantage should be taken of subsurface lateral flow of water. Evidence of such flow is frequently seen as seepage from higher elevations. If sufficiently renovated, this water may be permitted to flow into interceptor tiles, ditches or naturally occurring streams. The monetary savings from such systems in reduced installation and maintenance costs is readily apparent. Tile or trenches may play a special role in seepage systems by keeping the seepage waters from coming to the soil surface and creating an anaerobic excessively wet zone.

(3) Effluent Inputs

Effluent constituent loadings under three application rates (1.25, 2.0 and 2.5 inch/wk) were calculated for an assumed quality of secondary effluent (Table 9).

(a) Nitrogen

Calculations for determining "crop available" nitrogen, 13.3 mg/l were made with allowances for incomplete mineralization of resistant organic nitrogen (16).

Total nitrogen in the secondary effluent was assumed to be 20 mg/l which consisted of organic nitrogen (2 mg/l, NH_4-N (10 mg/l), NO_3-N (8 mg/l). About 1.05 mg/l of the organic-N fraction was considered residual organic-nitrogen and was not readily available for crop utilization. The remaining 18.95 mg/l was essentially crop available

TABLE 9
Annual Nutrient Additions to Spray Irrigation Sites a/

Nutrient	Effluent Quality (mg/l)	Application Rate (inches/week)		
		1.25	2.0	2.5
		. . . . .pounds per acre-year.		. . . .
N	13.3	98	157	196
P	13	96	153	192
SO_4	42	309	495	618.6
Cl	100	737	1130	1473
Ca	40	294	471	589
Mg	17	125	200.3	250.4
K	12	88	141.4	176.7
Na	40	294	471.3	589
Mn	0.2	1.5	2.4	2.9
Phenols	0.3	2.2	3.5	4.4
Cd	0.1	0.7	1.2	1.5
Cr	0.2	1.5	2.4	2.9
Hg	0.005	0.04	0.06	0.07
Pb	0.1	0.7	1.2	1.5
Al	1.0	7.4	11.78	14.7
Ag				
Fe	0.1	0.7	1.2	1.5
Cu	0.1	0.7	1.2	1.5
B	0.7	5.2	8.2	10.3
Zn	0.2	1.5	2.4	2.9

a/ pound per acre over 26 week application period

nitrogen. Under normal agricultural practices, nitrogen loss due to denitrification must be accounted for which in this case was assumed to be 30 per cent. A nitrogen loss of about 30 per cent is a reasonable estimate at this time but the percentage lost may be higher under actual field conditions. Crop available nitrogen is, therefore, about 13.27 mg/l which under the proposed effluent application rates of 1.25, 2.0 and 2.5 inches per week would provide 98, 157 and 196 pounds/acre-year of available nitrogen (Table 9).

To make the best use of the nutrient inputs to the land and avoid possible contamination of underlying groundwater by nitrate, nitrogen inputs must be taken up and utilized by harvestable economic crops. Because of possible health factors stemming from the direct human consumption of vegetable crops which could receive effluent, it is proposed that crops grown in the spray irrigation application area initially be those used for forage or timber.

Quantities of nitrogen removed through various forage crops on the application area are summarized in Table 10. These values are those reported for crops grown under normal agricultural practices. Studies at Penn State in which secondary sewage effluent was applied to alfalfa and corn (silage) observed higher productivities in those plots receiving effluent over those not receiving effluent (26). Corn and alfalfa production varied annually with climatic conditions, but even so, effluent plots had higher crop growth.

Tonnages and N, P and K content of the forages and silage observed in the Penn State studies were comparable to values shown in Table 10 (39). Assuming these values are representative of crop forage, crops grown in the Merrimack River Basin and the quantities of nutrients removed in crop harvesting can be calculated.

Comparison of amount of nitrogen applied in the spray irrigation areas, under the three application rates, with the quantities of nitrogen removed in harvesting crops, is given in Table 11. At the effluent application rates (1.25 and 2.0 in/wk), the amount of nitrogen applied would not be sufficient to compensate for the nitrogen removed in corn silage, alfalfa and most grass forages. Those areas receiving 2.5 inches of effluent per week would receive a projected nitrogen input exceeding the amount removed in the crop.

TABLE 10

ASSUMED NITROGEN REMOVED IN HARVESTED CROPS AS PERCENTAGE OF NUTRIENTS APPLIED IN THE WASTEWATER EFFLUENT

Crop	Inches of Secondary Effluent Applied Weekly		
	1.25	2.0	2.5
	-------per cent	----------	
Corn grain	128	80	63
Corn silage	168	109	86
Alfalfa-brome	225	140	111
Grasses	173	108	85
Sudan grass	143	90	71
Millet (Japanese)	126	78	62
Reed canary grass	160	100	80

TABLE 11

Crop Yields and Removals of Major and Secondary Nutrients

Crop	Production	Nutrient Removed (lb/ac)					
		N	P	K	Ca	Mg	S
Corn grain (15.5% moisture)a/	bu/ac	125	22	28	3	10	10
Corn silage (75% moisture)a/	25T/ac	165	30	150	45	30	15
Alfalfa-Brome (10%)a/	5T/ac	220	30	166	90	37	21
Grasses1/ b/	5T/ac	170	18	165	45		
Sudangrassb/	5T/ac	141	27	188	36		
Millet (Japanese) b/	5T/ac	123	16	210	20		
Reed Canary grass b/	5T/ac	157					

1/ Timothy, bromegrass, orchard grass, bluegrass
a/ Ref 14
b/ Ref 39

Spray irrigation of 2.5 inches of effluent per week would result in more nitrogen being applied than is needed by most forage crops considered here, with the exception of alfalfa-brome grass. The other grasses would use only 60-80 per cent of the applied nitrogen leaving approximately 40-80 lb/acre of available nitrogen in the soil each year. This remaining nitrogen would be available for movement through the soil most probably as nitrate during high precipitation events or during the ensuing non-application period, late October through early April.

In order to determine the nitrogen concentration in the percolate, water inputs to the spray irrigation site as effluent and precipitation plus crop nitrogen-use were approximated. Table 12 shows monthly effluent additions to spray irrigation sites, precipitation and actual evapotranspiration for the study area. From these values, the net change in the water input was determined. Calculation showed a net decrease in water inputs to the application area from June through August due to increased evapotranspiration. This could result in higher concentrate of nitrogen in the percolate. Fortunately, this same period coincides with the period of greatest crop growth when the largest nitrogen demand is exerted by the plants.

TABLE 12

WATER ADDITIONS AND LOSSES TO SPRAY IRRIGATION SITES

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Effluent(in)	0	0	0	7.5	10	10	10	10	7.5	0	0	0
Precip(in)	4.1	3.9	4.2	4.1	3.3	3.2	3.2	4.0	3.6	3.7	3.7	4.2
Actual ET(in)	0	0	0.2	1.4	3.2	4.6	5.4	4.3	3.3	1.9	0.8	0
Net Water Gain (in)	4.1	3.9	4.0	10.2	10.1	8.6	7.8	9.7	7.8	1.8	2.9	4.2
Water Vol Change (%)	-	-	-	+36	N	-14	-22	-3	+4	-	-	-

ET - evapotranspiration
N - negligible change

If crop nitrogen demand was evenly distributed over the growth period, monthly nitrogen inputs would exceed monthly crop needs by 5.7-11.4 lb/acre under the 2.5 inches per week application. Assuming all applied water not lost through crop use and evapotranspiration enters the soil and eventually becomes groundwater, the level of total nitrogen in the percolate can be approximated on a monthly basis (Figure 24). The concentration of total nitrogen in the percolate would vary over the growth season depending in part on crop uptake and nitrogen input. Levels could fluctuate between a low range of 2.4-3.2 mg/l to a high range of 4.9-6.5 mg/l. These values are similar to those observed by Kardos (26) in field investigations involving Reed canary grass which received secondary effluent. Crops removed about 86 per cent of the applied nitrogen. Percolate samples taken at a depth of four feet beneath the study plots contained 4.7 mg/l NO_3-N.

Spray irrigation to forested land has been shown to increase tree growth through nutrient use. Sopper (52, 53) observed 2-4 in/wk application of secondary effluent to mixed hardwood forests significantly increased tree growth. Effluent application to red pine failed to significantly increase tree diameter or height. Application of 2 in/wk appeared to have retarded diameter growth.

Initially, effluent applied to the forest areas received substantial renovation. Nitrogen removal was about 70-80 per cent during the initial two years of the study, however, removal decreased to about 30-50 per cent (10-20 mg/l) after six years. One reason for the reduction in the nitrogen renovation was the total annual nitrogen input to the forest operation was not offset by comparable removals through harvesting or nitrogen loss through natural processes. Effluent addition in association with the annual recycling of foliage, twig, and bark nitrogen without substantial nitrogen removal eventually results in NO_3-N being carried through the soil. It may be possible that with proper management practices to include rapid maturing tree species, with frequent harvesting plus operational practices to enhance denitrification processes on acceptable nitrate level could be maintained (i.e., less than 10 mg/l).

(b) Phosphorus

Phosphorus applied to the land in spray irrigation areas will be effectively removed through crop uptake and harvesting and reactions in the soil complex; ion exchange, chemical reaction and physical adsorption. Plants are known to take up phosphate for use in photosynthetic and metabolic processes thus cropping the plant material and removing it from the application site removes an important amount

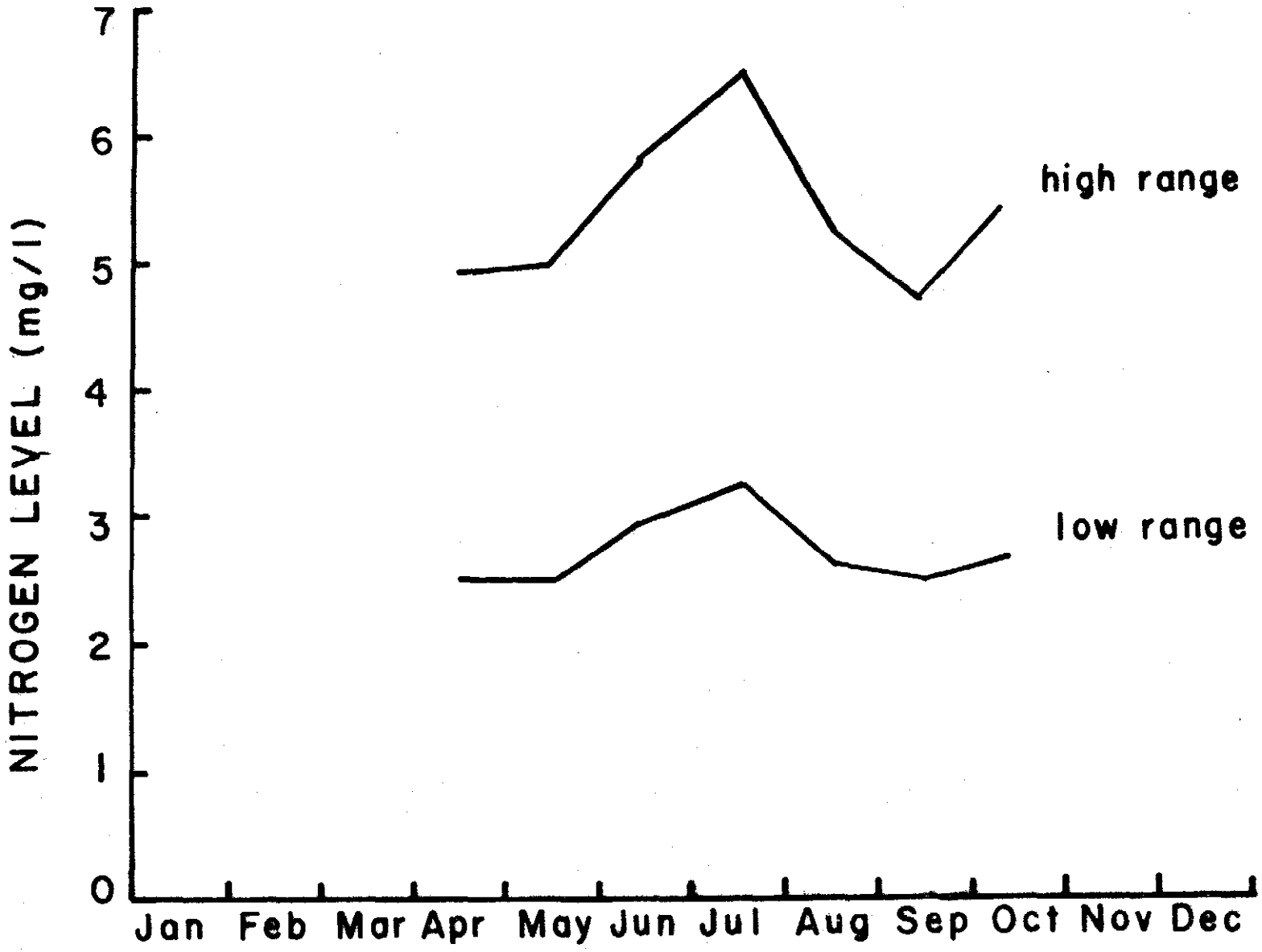

FIGURE 24: PROJECTED NITROGEN LEVELS IN PERCOLATE BENEATH GRASSED SPRAY AREAS (2.5 in/wk)

of phosphorus annually. Although phosphorus uptake can vary among plant species, alfalfa and various grass species generally remove about 20 to 30 pounds of phosphorus per acre during the growing season (39). Thus, under good agricultural management, phosphorus must be periodically applied as fertilizer to compensate for that removal. Under the three application rates proposed for soil in the study area, annual phosphorus addition would be about 96 to 192 lb/ac-yr of which cropping would remove from 26 to 13 per cent of the annual inputs (Table 13).

TABLE 13

PHOSPHORUS ADDITIONS AS A FUNCTION OF APPLICATION RATE AND TIME

Application Rate 1/ (in/wk)	PO_4-P Inputs Total 2/ lb/ac-yr	Net 3/	Net Phosphorus Applied 3/ years 10	20	30	40	50	100
1.23	96	71	710	1420	2130	2840	3550	7100
2.0	153	128	1280	2560	3840	5120	6400	12800
2.5	192	167	1670	3340	5010	6680	8350	16700

1/ Assumes 26-week application period annually

2/ P concentration of 13 mg/l

3/ Assumes a 25 lb/ac-yr P removal by crop harvesting (39)

Phosphorus remaining would be available for various soil chemical reactions. Although the reaction mechanisms are not well defined, it is known that soil adsorption and fixation can immobilize considerable phosphorus. Investigations of long-term fertilizer applications to land has found that very little phosphate is carried in rain water percolating through the soil (26). Other studies in which sewage effluent or industrial wastewater were applied to the land have shown the immobilization mechanisms can remove 90-99 per cent of the applied phosphorus (45).

Data on phosphorus adsorption in the soil points out the fact that adsorption is related to soil texture; sandy soil adsorbing the least and loam, clay loam and clay soils adsorbing increasingly greater amounts. Cole and Olsen (10) reported maximum surface adsorption values clay loam and clay soil respectively. Ellis, et. al. (14, 16) determined this same general relationship for a variety of Michigan soils. While surface adsorptive capacity of the soil is somewhat limited and may be readily satisfied by large additions of phosphorus over a short period of time, the adsorptive capacity is repeatedly renewed upon dry soil over time. Ellis (16) observed phosphorus saturated soils largely recovered their rapid adsorptive capacity by some slow insolubilization mechanism over a period of months. Unfortunately, the rate and the actual mechanism of the immobilization process has not been well defined. From studies of soil receiving large amounts of phosphorus over long periods, some idea of the magnitude of the soil-fixation capacity can be ascertained.

Kardos (27) at Penn State University site determined adsorption capacities of about 2,000 pounds per acre foot; while Murphy (40) found California Aiken clay loam capable of fixing 8,000 pounds of phosphorus per million pounds of soil. In light of these studies, it seems safe to assume the loamy and medium to coarse sand soils in the Merrimack Basin may have the capacity to fix at least 4,000 pounds of phosphorus per acre-foot of soil before losing their ability to effect a 90 per cent reduction in the phosphorus content of percolating wastewater. Assuming that the phosphorus content of the secondary effluent applied to the soil during the 26-week effluent application period is about 13 mg/l as PO_4-P. Approximately 96, 153 and 192 pounds of phosphorus per acre would be applied to under the 1.25, 2.0 and 2.5 inches per week applications, respectively. Substracting the phosphorus removed by forage cropping, the net gain in phosphorus would be about 71, 128, 168 lb/acre-yr. Table 13 shows the net phosphorus addition for each application rate. Assuming soil removal capacity of 4,000 lb/ac-yr as P and the effective depth of five feet to water table or drainage tile, the projected useful life of the site for P removal would be about 280 years under the 1.25 inches per week application ; 150 years at 2.0 inches per week and 120 years at 2.5 inches per week. It should be pointed out that these projected longevities for phosphorus renovation could well change following the necessary field and laboratory investigations necessary to define the phosphorus adsorption and fixation.

(c) Sodium, Calcium, Potassium and Magnesium

Although these elements are all found in natural soil systems, they are usually present in limited available amounts in the New England soils. In certain circumstances particularly near the sea coast and in tidal areas, the soil salt concentration can be sufficient high to limit growth of certain kinds of plants. Salt levels (Table 14) in sewage effluents proposed for application to crop land are not sufficiently high to adversely affect more than the most sensitive plants and should not present any difficulties to agricultural crops (47). Salt sensitive crops such as radishes and green beans could possibly receive effluent application under proper management situations; however, effluent application to vegetable crops is not likely, at this time, for reasons related to public health. Fruit trees also have a low salt tolerance but they, too, should not be adversely affected by the effluent salt levels assumed here. Forage crops, corn, alfalfa and grass species are moderate to highly salt tolerant. Wastewater effluent application of the quality anticipated here should not result in adverse plant responses.

TABLE 14

SALT CONCENTRATIONS IN EFFLUENT, ANNUAL CROP REMOVALS AND NET ANNUAL ACCUMULATIONS

Ion	Concentration effluent (mg/l)	Quantity Applied 1.25 inches/week	2.0	2.5	Crop Removal	Net Annual Accumulation 1.25 inches/week	2.0	2.5
		pounds per acre						
Ca	40	295	469	589	45	250	424	544
Mg	17	125	199	250	30	95	165	220
K	12	88	140	177	150	(62)	(10)	27
Na	40	295	270	589	12	283	258	578
Cl	100	236	1173	1473	15	221	1158	1458
SO_4	42	309	493	619	-	-	-	-

On the other hand, soils themselves may be susceptible to degradation due to excess adsorption of monovalent ions in the applied wastewater. The relationship between the cations in wastewater; cal-

cium, magnesium, sodium and potassium, is important to soil structure. When the ration of Na+ ions to the other cations especially Ca+2 and Mg+2 become too high, sodium tends to replace Ca+2 and Mg+2 ions from the clay particles. Predominance of Na+ ions on clay particles has the effect of dispersing soil particles when freshwater is applied resulting in decreased infiltration and permeability which in effect can "seal" the soil surface horizon.

Identification of potential salinity hazards due to application of wastewater effluents to soil and crop can be ascertained from the electrical conductivities of the irrigation water. The U. S. Department of Agriculture Salinity Laboratory (47) determined that irrigation waters with electrical conductivities in the range of 100-250 umhos/cm at 25°C have a low salinity hazard; those with conductivities of 250-750 have a medium hazard; those of 750-2,250 umhos/cm are highly hazardous; and waters with electrical conductivities above 2,250 umhos/cm are considered very hazardous to crop production. The electrical conductivity of the irrigation water proposed for cropland should occur within the medium salinity hazard category. However, precipitation falling over the year should leach accumulated salts through the soil, thus alleviate some possible salinity hazards to salt intolerant crops.

Coastal communities with sewer lines in the "Saline Plain" (the land area in which sewer collection lines are susceptible to seawater infiltration of direct inflow during the tidal cycle) should carefully consider the potential salinity problems to crop and soils when considering land application as a wastewater treatment method. In cases where seawater comprises even a small portion of wastewater, a substantial increase in conductivity could occur thus making the effluent undesirable for irrigation purposes. For example, if five per cent of a community's wastewater flow was made up of seawater, electrical conductivity of 35,000 umhos/cm and the municipal wastewater has a conductivity of 500 umhos/cm, resulting effluent conductivity would be around 2,225 umhos/cm. Therefore, the effluent would be highly hazardous to crop production and soil structure if applied to agricultural land. Even if saltwater comprised one per cent of the total wastewater, the effluent conductivity would be about 825 umhos/cm which would still be highly hazardous to crop production and soil structure.

In view of the fact that sewer lines degrade over time, the percentage of seawater in the wastewater flow could be anticipated to increase where collection systems lay in the "saline plain." Coastal communities considering land treatment methodlogies would have to install sewer collection systems above the "saline plain" plus implemen-

tation measures which would prohibit direct saltwater inflow to sewer lines.

Calcium, magnesium, potassium and sodium levels assumed for the effluent applied to the land are given in Table 14. The sodium adsorption ratio (SAR) of the effluent is 1.34, thus the effluent should not create problems when applied to crop land. The exchangeable sodium percentage should increase slightly but would not lead to excessive levels of exchangeable sodium.

Annual additions of these cations applied to the land will be greater than quantity removal through crop harvesting, except for potassium at lower application rates. The accumulation of calcium, magnesium and potassium within the soil is not viewed as a problem since most New England soils require some periodic liming to facilitate crop growth. Some supplemental potassium fertilization will be required to overcome the K deficiency under the lower effluent application rates. Most soils considered here should receive effluent in excess of evapotranspiration rate. Since hydraulic conductivities of these soils are moderate to moderately rapid, it can be expected that excess water moving through these soils would remove excess salts particularly during non-application periods.

(d) Chloride

The chloride ion is not adsorbed by soils to any extent, The actual quantity of chloride being applied appears to be substantial, but since it readily leaches, these levels are not viewed as being critical. Since the soil does not adsorb chloride, the total quantity of chloride applied is of lesser importance providing sufficient water is applied to leach the soil (one inch per week or greater). The concentrations of chloride in the drainage effluent is expected to be near that being irrigated. Most of the crops under consideration will tolerate this level of chloride including har and corn.

(e) Sulfate

No values for sulfate were available, thus, it is not possible to calculate the quantities that would accumulate in soil. Sulfate adsorption by soils is discussed by Ellis (14).

(f) Trace Nutrients

The following section explicitly addresses trace nutrients and their plausible impact upon the soil-vegetative system. After

considerable effort to identify and quantify trace nutrients present in municipal and industrial wastewater of the Merrimack River Basin, it became apparent that only an extensive wastewater sampling program could provide this information. Since present EPA guidelines specify the quantity and concentration of pollutatns in industrial waters which may be discharged to receiving streams and municipal sewers, it was assumed pretreatment of industrial wastewaters would be sufficient to meet the "Proposed 1973 Water Quality Criteria" (17) for trace nutrient in irrigation waters under continuous application. Further, it was assumed that industries discharging to municipal sewers would not dilute toxic industrial wastes in the municipal wastewater flow. Rather, the municipalities permitting industrial discharges to municipal sewers would police these discharges to prevent dilution to trace nutrients of industrial origin, in domestic wastewater flows.

For purposes of this discussion, the following trace nutrients (sometimes referred to as heavy metals) were considered: aluminum, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, nickle, and zinc. The discussion relied extensively upon the material of Ellis (14, 16) for summarizing impacts of trace nutrients to the soil-vegetative system.

Levels of trace nutrients in the secondary effluent i.e. proposed "1973 Water Quality Criteria" for irrigation water, the quantities of trace nutrients taken up by plants and the net annual additions to treatment sites under three application rates: 1.25, 2.0, and 2.5 inches per week, are displayed in Table 15.

Data given in Table 15 shows the pounds of each nutrient added to each acre of land under 1.25, 2.0 and 2.5 inches per week effluent application rates. Data are calculated on the basis of 26 weeks of spraying time each year. The amount of nutrient added under a particulr spray regime (Table 15) can be compared with the average total amount of the metal found in an acre furrow slice of soil (Table 16) (acre furrow slice = one acre of mineral soil to a depth of six inches weighing approximately 2,000,000 pounds per acre). Although most trace nutrients may be considered fairly evenly distributed through the soil profile, there can be important changes in composition with depth. As a result, average values discussed will pertain to the acre furrow slice unless otherwise specified. Accumulation of nutrient in the soil with respect to "normal residual" content of metals already present in the soil gives one measure of the impact that trace nutrient addition may have on the soil system. Such information is of limited value, however, because the fixation, leaching and plant uptake potentials are

governed by the form in which metals exist in the soil solution.

Knezek (14) has assessed the probable impact of 13 micronutrients and heavy metals on soils and crops in land treatment systems. It was pointed out that effluent additions would greatly exceed crop removal, a point which is illustrated by data presented in Table 15.

TABLE 15

Trace Nutrient Inputs to Treatment Areas Under Three Application Rates

Trace Nutrient	EPA Proposed Irrigation Water Quality[a] Criteria	Crop Removal[b]	Annual Metal Additions to Soil		
			1.25	2.0	2.5
	(mg/l)		(---pounds/acre-year-----)		
Aluminum	5.0				
Arsenic	0.1	0.006	0.36	0.59	0.74
Boron	0.75	0.18	5.16	8.25	10.31
Cadmium	0.01	0.0036	0.74	1.18	1.47
Chromium	1.0	0.0014	1.47	2.36	2.95
Copper	0.2	0.084	0.74	1.18	1.47
Iron	5.0	1.74	0.74	1.18	1.47
Lead	5.0	0.0162	0.74	1.18	1.47
Manganese	0.2	0.312	1.47	2.36	2.95
Mercury	-	0.00009	0.03	0.06	0.7
Nickel	0.2	0.018	0.74	2.36	2.95
Zinc	-	0.102	0.74	2.36	2.95

a/ Ref 17

b/ 3 ton corn silage per acre - dry weight (16)

TABLE 16

Annual Inputs of Trace Nutrients Under Three Effluent Application Rates Compared to an Average Soil Composition

Micronutrient	Soil Composition[a] (average range) lbs/acre furrow slice	Annual Inputs (lb/a-yr) 1.25	2.0	2.5
Aluminum				
Arsenic	12 (0.2-80)	0.36	0.59	0.74
Boron	20 (4-200)	5.16	8.25	10.31
Cadmium	0.1 (0.02-14)	0.74	1.18	1.47
Chromium	200 (10-6,000)	1.47	2.36	2.95
Copper	40 (4-200)	0.74	1.18	1.47
Iron	38,000	0.74	1.18	1.47
Lead	20 (4-400)	0.74	1.18	1.47
Manganese	1,700 (200-8,000)	1.47	2.36	2.95
Mercury	0.8 (0.03-0.8)	0.03	0.06	0.07
Nickel	80 (20-2,000)	0.74	2.36	2.95
Zinc	100 (20-600)	0.74	2.36	2.95

a/ Knezek (14)

Data clearly show three tons of corn silage (dry weight) per acre would remove one per cent or less of most trace nutrient added on an annual basis. Generally, the rooting zone of a plant already contains one hundred to one hundred thousand times the amount of a trace element likely to be removed by any one crop (Table 16). A real potential danger in spray irrigation, using effluent containing metals, is in surface adherence to leaves of crops and possible foliar adsorption into the plant.

Basically, the proposed land system must be viewed in terms of the capacity of the soil to fix metals so that they will not be toxic to plants or soil microbes nor leach into the drainage water. Each of the lements will be discussed in terms of adding effluent at the rate of two inches per week for 26 weeks per year. Unless otherwise stated, metal will be assumed to remain in the acre furrow slice of the soil.

Arsenic

Arsenates in soils compete for the same fixation sites that are utilized by phosphorus. However, the arsenates are bound in the soil with less strength than phosphates and there is a greater potential of leaching arsenates through the soil profile as the phosphorus adsorbing capacity of the soil becomes saturated. A whole range of total aresenic values from 0.3 to over 100 pounds per acre have been reported on normal and aresenic contaminated soils. Although arsenic concentration may be increased in plant tops, there is little danger of animal toxicity. The effect of arsenic toxicity on plants is such that plant growth is limited before large amounts of arsenic are adsorbed and translocated to the top (1, 35). The concentration of arsenic in corn tops has been increased to about 3 mg/l without plant toxicity (35). There should be little problem with leaching, plant uptake or plant toxicity or arsenic unless the phosphorus adsorbing capacity of the soil is nearing saturation. Several recent articles (12, 70, 71) tend to confirm the soil and plant reactions of arsenic.

Boron

If the relatively high amounts of boron projected for effluents are applied to the soil, there may be serious leaching to the drainage water and possible plant toxicity depending upon the crop being grown. Rhoades, et. al. (48) have stated that manyplants are deleteriously affected by boron concentrations in the range 0.5 to 5 mg/liter. Toxic levels of soluble boron may be removed from soils by leaching. but not as fast as chloride or sulfate. Ellix and Knezek (15) have reviewed the bonding mechanisms for boron in soils. The soil may adsorb sufficient excess boron over a period of time to actually increase the level of soluble boron above the 1.0 mg/liter limit after the first year (49). Corn and most other cereal grains are semitolerant to boron while most sensitive plants, such as navy beans, will tolerate 0.7 mg/liter of boron even for corn. A further assumption must be made that after the first year of spraying wastewater, boron will essentially be moving out in the drainage water at a concentration equal to or greater than that which is applied depending upon evaporation and evapotranspiration rates of water loss.

Cadmium

The chemistry of cadmium is similar to that of zinc and the soil bonding mechanisms of zinc have been recently reveiwed by Ellis and Knezek (15). Recent research by John, et. al. (25) has shown that 90 pounds of cadmium added to a soil surface over several years did not move more than four inches into the soil profile. Their work on cadmium uptake by oats and studies by Traynor and Knezek (58) in Michigan on corn show little increase in plant uptake at the levels of cadmium to be applied. Unless very solubel and mobile complexes are formed with low molecular weight organics, there should be little or no movement into drainage.

Lagerwerff (30) has recently reviewed cadmium in the environment, including soils and plants.

Chromium

The amount of chromium which will be added to the soil (Table 15) is well within the amounts normally found in soils (Table 16). Walter, Traynor, and Knezek (67) have found that certain soils have a large capacity to fix chromium and leaching into the drainage water should not be a problem. The uptake of chromium by plants has been reviewed by Pratt (43). Many times when naturally occurring chromium toxicity to plants was suspected, the concentrations of chromium in plant tops was the same as for normal plants (1, 43). Walter, et. al. (67) found similar results with corn in Michigan, but Turner and Rust (59) found uptake of chromium by soybeans from nutrient solution. They did show apparent toxicity to soybeans in soil culture at ten pounds of chromium per acre, but no uptake data were given for plants grown on soil culture. Apparently, no danger exists from injection into the food chain, but the toxicity potential of chromium in the proposed system is not clear.

Copper

Most of the copper will be bound in organic or clay complexes near the soil surface. The bonding of copper in soils has been reviewed by Ellis and Knezek (15). There should be no toxicity problems (46) and minimal leaching of organic complexes containing copper into the drainage water will occur. Reuther and Labanauskas (46) have reviewed the chemistry and toxicity of copper in soils. The soils proposed should adsorb the copper being added for an indefinite period of time at the rate and quantity being proposed if the soil pH is maintained near 7.0.

Iron

The iron added to the soil is considerable in quantity but will be rapidly fixed by precipitation and surface adsorption (15). Iron is rarely toxic to plants (66). There may be some leaching into the drainage water in the form of organic complexes due to high level of iron addition, but the level should be less than the 0.3 ppm drinking water standard. Addition of such large quantities of iron to the root zone of plants could influence plant nutrition by interaction with the uptake of several nutrients such as manganese and zinc (51, 66).

Lead

Lead addition to the soil will be relatively low. There should be no movement into the drainage water, and plant uptake will probably not be influenced at the levels applied. However, Cox and Rains (11) have reported considerable lead uptake from severely contaminated soils (64 to 196 lbs of lead per acre). The subject has been reviewed by Lagerwerff (30).

Manganese

When manganese is added in excessive quantities, soluble organic complexes can move through the profiles. In the amounts to be added in wastewater effluent, all of the manganese will be fixed in the profile with no significant quantity going to the drainage water. There is no possible plant toxicity danger if the pH is maintained at pH 7 or above and there may be a real possibility of manganese deficiency induced by the high pH and iron application levels (51). The subject of manganese in soil and plant systems has been effectively reviewed (46).

Mercury

The chemistry of mercury in soils is similar to that of copper and lead. The soluble mercury will be rapidly fixed by the organic and clay fractions of the soil and there will be little movement through the profile and probably no significant increase in plant uptake at the levels being applied in the effluent. Extreme potential toxicity of certain forms of mercury, such as methyl mercury, warrant a close investigation of the form being added to the soil and subsequent soil conversions. Lagerwerff (30) has recently reviewed mercury chemistry and toxicity in plants and soils.

Nickel

The chemistry of nickel in the soil is similar to that of cadmium or zinc. The soil should have adequate capacity to adsorb nicket without appreciable leaching to drainage water and without toxicity to plants (58). The higher amount of iron being added in the effluent will probably retard the plant uptake of nickel. Numerous studies of nickel toxicity from serpentine soils have been made. The levels being added in the effluent of the present system should give no serious problems (23). The soil and plant chemistry of nickel has been reviewed by Vanselow (64).

Selenium

The knowledge of selenium chemistry in soils is limited. Where selenium additions to low-selenium soils have been followed by repeated measurements of selenium uptake by plants, over 90 per cent of the added selenium remains in the soil even after two or three years of continuous cropping and plant removal (1). Nearly all of the soils on which high selenium (above 5 ppm) grasses contain free calcium carbonate and calcium sulfate. The difference in selenium availability in acid and alkaline soils has been attributed to the formation of insoluble compounds or complexes of ferric iron and selenite in acid soils and to the formation of relatively soluble selenates in alkaline soils (28).

Underwood (60) has quoted work indicating that soils containing more than 0.5 ppm selenium should be regarded as dangerous. Plants have been divided, from the point of view of toxicity, into three classes according to their capacity to assimilate selenium. These are: (1) those showing a limited tolerance (up to about 5 ppm); (2) those which adsorb moderate amounts (up to about 30 ppm); and (3) those accumulator plants that adsorb more than 20 ppm. Most grasses are in the first class and all cereals are in the second class. There could be some leaching into the drainage water as some forms of selenium are mobile, some potential for plant uptake from soil at toxic levels for animals and humans and a possibility of plant toxicity after a few years of application.

Zinc

Although the zinc additions appear to be high, similar amounts of zinc have been added to comparable soils to prevent deficiency on field beans and corn (65). The soil bonding reactions have been

reviewed by Ellis and Knezek (15). There should be no leaching to the drainage water and no plant toxicity danger unless a sensitive crop such as field beans is grown on the soil. Allaway (1) has indicated that some increase in the zinc content of crops used for feed would be nutritionally beneficial. The soil and plant chemistry of zinc has been reviewed by Chapman (91).

Special Considerations

The foregoing evaluation has been made on the assumption that the metals in the effluent will be inorganic ions, metal precipitate suspensions or weak natural metal organic complexes. Addition or relatively powerful synthetic chelating ligands or metal chelates of substances such as nitrilotriacetic acid (NTA) or ethylenediaminetetraacetic acid (EDTA) or similar compounds will drastically alter the conclusions of this report. The presence of chelating ligands will increase the mobility of metals through the soil profile, increase plant uptake, reduce soil fixation of metals and either increase or decrease plant toxicity depending upon the nature of the system. Substantial quantities of metals could leach into the drainage water if syntehtic chelates are present.

At the organic loads specified in the data provided for this report, it appears that there should not be a significant danger of mobilizing metals through the profile and into the drainage. However, if the organic load is increased and contains 50 per cent fulvic acid compounds as indicated for secondary effluent, significant metals loads could be moved through the soil profile and into the drainage water.

The possibility that boron might be toxic to some crops was pointed out. The five pound/ac of B calculated for 1.25 inch/week effluent in Table 10 would exceed the 3 lb/ac recommendation for correcting deficiencies in responsive crops such as alfalfa. In this quantity was used in a banded fertilizer application for sensitive crops (beans, soybeans, small grains), it would almost certainly produce severe injury. Broadcase applications of three pounds or more on pea beans have produced toxic symptoms, whereas up to eight or ten pounds were broadcast on soybeans before toxic effects were produced.

While there is a potential hazard to sensitive crops from boron, the conditions of application in wastewater will greatly minimize potential hazard. Annual inputs will be distributed by small increments over 26 weeks of the year. The effective concentrations will be attenuated by leaching, redistribution through larger volumes of soil and be

reversion to complexed forms not directly available for uptake by plants.

There remains the possibility that the boron-adsorbing capacity of soils may be saturated over time and that the concentration in soil solution and percolating water will approach that of the applied effluent. Consideration should be given to identifying and reducing sources of the boron which appear in waste effluents.

Another possible nutritional problem stems from the concentration of zinc in the effluent. Deficiencies in beans and corn may be accentuated on certain glacial outwash soils, as well as on acid soils if excessive quantities of lime are used to correct acidity. Such deficiencies are readily identified and can be corrected.

With the possible exception of boron, there is little likelihood that any of the micro-nutrients or heavy metals in the effluent of Table 11 will accumulate to dangerous levels in plants or move into drainage in concentrations to exceed drinking water standards. Most will be immobilized by interacting with mineral and organic colloids, most probably in the soil surface.

As noted by Ellis et. al. (14), toxic activities will be reduced and stabilization of heavy metals promoted by maintaining soil pH near neutrality. Liming acid soils to pH 6.5 is recommended here. It appears inadvisable to correct to a higher pH, since retention of bases from the effluent may lead to further increases in soil pH. The extent to which this may or may not occur will depend on exchange capacity and mineralogy of the soil and on the composition and properties of effluent from a specific source.

f. Proposed Rapid Infiltration of Wastewater Effluent

The daily flood application of large volumes of wastewater effluent to a relatively small confined land area consisting permeable stratified sands and gravels for the purpose of additional renovation of disposal of wastewater effluents has commonly been termed rapid infiltration. This mode of land treatment of wastewater has been used most extensively in arid climates to further renovate municipal and industrial wastewater effluent prior to recharging groundwater aquifers or for agricultural use. While much of our technical understanding of rapid infiltration for wastewater has also been utilized in New England for more than thirty years to provide final treatment/disposal of domestic wastewater effluents. Sewage treatment facilities at Ft. Devens (50) and Otis Air Force Base, Massachusetts, and Lake George, New York (5) have incorporated rapid infiltration as the final step for wastewater treatment.

Until more recently, rapid infiltration was viewed as an "out-of-sight, out-of-mind" disposal mechanisms for partially treated sewage effluent. Following the disposal concept, the design criteria for the rapid infiltration system was founded and operated upon the hydraulic capacity of the site. Organic matter loading while often a consideration was important only as it pertained to hydraulics of the system. Management of the application rate and flooding cycle was only to prevent or correct clogging of the treatment bed surface in order to sustain the infiltration capacity rather than achieving effective effluent renovation. Recent studies of rapid infiltration systems have shown effective renovation of applied sewage effluent is possible and with proper management, acceptable groundwater quality and a sustained infiltration rate can be maintained.

Investigations of the wastewater treatment facility at Ft. Devens, Massachusetts, which includes 22 rapid infiltration basins for final treatment of unchlorinated primary sewage effluent, have shown that a rapid infiltration system can renovate the applied primary effluent to a quality much better than conventional tertiary treatment with less cost. Groundwater quality at the Ft. Devens facility showed BOD_5, COD and total coliform bacteria levels of unchlorinated primary effluent were essentially removed after passing through the sand and gravels layers of the rapid infiltration basins. Organic nitrogen and ammonia-nitrogen were greatly reduced as well as the level of phosphorus (5). Since rapid infiltration systems are operable throughout the year, there is no need for storage lagoons. The elimination of storage lagoons and the greater quantities of wastewater effluent which can be treated per unit of land area reduced the land requirements for rapid infiltration to less than ten per cent of that needed for spray irrigation.

(1) Criteria for Site Selection

Sites suitable for receiving large volumes of partially treated wastewater were based upon a number of criteria. These considerations are presented in Table 17. Employing land use maps (36) and available soil information prepared by the Soil Conservation Service and geological information (21), rapid infiltration areas were delineated. These sites were primarily open or forested lands of stratified sand and gravel deposits. Soil of potential rapid infiltration sites were mapped as Carver, Gloucester, Hinckley, Merrimac, Millis, Winsor soil series. Surface horizons of these soils were generally find sandy loams, loamy fine sands or loamy coarse sand with moderately rapid (2.0-6.3 inch/hr) to very rapid (+6.3 in/hr) permeabilities (61). The underlying materials were sandy gravel and gravelly sands with generally

TABLE 17

CRITERIA FOR RAPID INFILTRATION SITES

CONSIDERATION	LIMITATION		
	Slight	Moderate	Severe
Grain Size	Medium sand and coarser than medium sand	Very fine and fine sand	Clay and silt loam
Permeability	>6.3 in/hr	.63-6.3 in/hr	<0.63 in/hr
Depth to water table	>30 ft	15-30 ft	<15 ft
Confining layer within deposit	None	None	Present
Saturated thickness	>30 ft.	15-30 ft.	<15 ft.
Number of adjacent streams	2	1	None
Distance to edge of low bottom flood plain	>400 ft.	200-400 ft.	<200 ft.
Slope a/	0-8%	8-15%	>15%

a/ Area capable of being groomed to level surface.

less than ten per cent silt and clay. Hydraulic conductivities of these strata were variable depending upon percentage of "fines" but were generally moderately rapid to very rapid.

It is important to note that data available at the time of this study permitted identification of land areas where rapid infiltration of wastewater could be practiced. Field investigation of each proposed site would be necessary, however, before a rapid infiltration system for land treatment of wastewater could be ultimately implemented.

(2) Effluent Quality

The degree of pretreatment given the wastewater applied to the treatment beds will greatly affect the quality of resulting renovated water and management practices followed. It was assumed that wastewater effluent applied to rapid infiltration sites would be municipal

wastewater which had received the equivalent of secondary treatment in either conventional secondary facilities or surface treatment lagoon systems. All industrial wastewater discharging into municipal sewers were assumed to have been pretreated to remove toxic organics and trace nutrients (heavy metals). Oils and greases would be removed during the pretreatment process so none would be applied to the treatment basins. Characteristics of the effluent applied to the treatment beds was assumed to be that given in Table 21.

(3) Operational Cycle

Laboratory and field investigation of the effluent application has shown the importance of management procedures by which treatment beds are inundated for a period of time then allowed to dry before effluent is applied again. In arid climates of Arizona, (7, 8), California (34), and Israel (2, 3), investigation of rapid infiltration systems concluded that continuous or very long inundation periods would result in eventual clogging of the treatment bed surface and negligible infiltration rate. Reduction of the infiltration rate has been directly related to accumulation of organic material and microbial growth on the filter medium which reduced soil porosity. Regeneration of infiltration rate is accomplished by aerobic microbial decomposition of organic matter during the recovery or drying period of the operation cycle. Recovery period is important not only to the infiltration rate but also is an important consideration when manipulating the length of the inundation and recovery periods to provide optimum conditions for non-structural methods of nitrogen removal.

Studies of the application and drying cycle have primarily been carried out in dry climates. Bouwer (7) found a 14-day effluent application period followed by seven days of drying would sustain the infiltration rate over the long term while improving the quality of effluent. Amramy (2, 3) investigated a number of application cycles and determined the ratio of wetting to drying periods should be in the range of 1:2 and 2:1. He observed good renovation of secondary effluent following 7-day wetting period and 14-day recovery cycle. Field studies laboratory tests conducted by Lance (32, 33) and Bouwer (8) found two days of effluent application followed by five to 14 days recovery time was well suited for nitrification of the organic and ammonical forms of nitrogen but was not best for removing nitrogen by denitrification. Satterwhite (50) observed application of primary sewage effluent for two days followed by 14 days recovery, at Fort Devens, has maintained an acceptable infiltration rate while enhancing nitrification of organic and ammonia nitrogen.

Although total nitrogen levels were reduced 40-60 per cent, NO_3-N levels in the groundwater surrounding the infiltration is to remove or reduce nitrogen in reclaimed water, short application periods in association with long recovery periods should be avoided. Since nitrogen removal was an integral consideration in formulating rapid infiltration systems, two operational cycles were proposed which could facilitate non-structural methods for nitrogen removal from secondary sewage effluent yet maintaining adequate renovation of other wastewater constituents. Two application cycles, 14 days inundation followed by seven days recovery and seven days inundation followed by 14 days recovery period were selected.

(4) Application Rate

A number of effluent loading rates have been reported in the literature. The rates used in laboratory and field investigations at the Flushing Meadows Project were founded on application rates of 0.3 to 0.8 ft/day (33, 68). Depending upon the management associated with these rates, considerable differences in effluent renovation were obtained. Lance and Whisler (33) observed 75-80 per cent nitrogen removal when secondary effluent was applied to sand filters at approximately 0.5 ft/day for an annual total of 125-150 ft. Higher application rates, 1.1 ft/day, treated larger volumes of secondary effluent, 280 ft/yr, but nitrogen removed was only 30 per cent of that added. The sustained application rates selected for this study were 0.33 ft/day and 0.67 ft/day based on guidance from the Massachusetts Department of Public Health (4). Using these loading rates and operational cycles previoulsy discussed, acreages required to treat a wastewater flow of one million gallons per day (1 MGD) were calculated (Table 18).

TABLE 18

LAND ACREAGE REQUIRED TO TREAT ONE MILLION GALLONS PER DAY FLOW UNDER TWO WASTEWATER APPLICATION RATES AND CYCLES

(RAPID INFILTRATION)

	Application Cycle	
Application Rate	7 days wet - 14 days dry	14 days wet - 7 days dry
0.33 ft/day	27.6 ac	18.4 ac
0.67 ft/day	13.8 ac	9.2 ac

Quantities of wastewater treated annually under two application rates and operation cycles are given in Table 19. Compared to experiences at the Flushing Meadows project, loading rates and volumes of effluent treated appear quite conservative. However, this may be warranted in view of the scarcity of available operational criteria for rapid infiltration treatment facilities, as opposed to effluent disposal systems in New England.

TABLE 19

ANNUAL EFFLUENT LOADING TO RAPID INFILTRATION BEDS

Cycle	Application Rate	
	0.33 ft/day	0.66 ft/day
14 days wet - 7 days dry	82.5 ft	164 ft
7 days wet - 14 days dry	41.3 ft	82 ft

Compared with proposed spray irrigation system, rapid infiltration approach for land treatment of wastewater could treat an equivalent amount of effluent on two to ten per cent of the land area.

(5) Constituent Imputs

Water Budget

The amount of effluent applied to rapid infiltration beds varies with the application rate and inundation recovery cycle followed; 41 to 164 ft per annum (Table 19). Using precipitation and actual evapotranspiration data for Fitchburg, Massachusetts, a water budget for rapid infiltration sites was determined (Table 20).

During November through April, monthly precipitation would exceed monthly actual evapotranspiration, while during June through August, monthly evapotranspiration could offset the monthly precipitation. Following a management scheme in which the application rate is 0.33 ft/day and operation cycle is 7 days inundation - 14 days recovery, about ten per cent of the monthly water additions to treatment sites from late fall through early spring would stem from precipitation. During the summer months, net water loss of about five per cent could be expected due to increased evapotranspiration.

TABLE 20

MONTHLY WATER ADDITIONS AND LOSSES TO RAPID INFILTRATION SITES

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Effluent (in) a/	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3
Precip (in)	4.1	3.9	4.2	4.1	3.3	3.2	3.2	4.0	3.6	3.7	3.7	4.2
Actual ET (in)	0	0	0.2	1.4	3.2	4.6	5.4	4.3	3.3	1.9	0.8	0
Net Water Gain (in)	45.4	45.7	45.3	44.0	41.4	39.9	39.1	41.0	41.6	43.1	44.2	45.5
Effluent Volume Change (%)	+10	+11	+10	+7	N	-3	-5	-1	+1	+4	+7	+10

a/ - Effluent application rate 0.33 ft/day (41.3 ft/yr) following a 7-day inundation and 14 days recovery cycle.
N - negligible change
ET - evapotranspiration

In those rapid infiltration systems in which larger effluent applications are followed, the per cent monthly water gains and losses stemming from precipiation and evapotranspiration would be less than exemplified here.

(6) Organic Material

Additons of organic material as expressed in terms of five-day bio-chemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are dependent as are other wastewater constituents upon concnetration in the effluent, application rate and operation cycle followed (Table 21). BOD_5 and COD levels assumed here were 30 mg/l and 70 mg/l, respectively. Annual BOD_5 loading under the two proposed application rates and application cycles would vary between 3,300-13,300 lb/ac while COD loadings would be 7,800-31,000 lb/ac. Although these levels may appear high, studies of the rapid infiltration systems which treat primary or secondary wastewater effluent have shown that organic material can be essentially removed without impairing renovation effectiveness of treatment basins. Investigations of the Fort Devens, Massachusetts sewage treatment facility have found annual BOD_5 and COD loading of 28,500 lb/ac and 47,600 lb/ac, respectively, id not reduce infiltration. After some 30 years operation, BOD_5 and COD levels in the groundwater were 2.5 and 19 mg/l, which represent about wo per cent and five per cent, respectively, of the BOD_5 and COD levels of applied primary effluent. Organic matter inputs to the treatment beds at Ft. Devens plus the annual increment of plant material, growing naturally on the surface of the infiltration beds, has not clogged the filter surface so as to reduce infiltration or continued removal of organic constituents (50). Studies of the capacity of rapid infiltration basins to renovate secondary effluents have shown similar results. Bouwer (7) found BOD_5 of secondary effluent applied to rapid infiltration basins was reduced to zero in groundwater. COD levels were reduced 50 mg/l to 17 mg/l after percolating through sand and gravel to the groundwater.

Investigations of the rapid infiltration bed which have been operated for more than thirty years at Lake George, New York, found similar reductions in BOD_5 levels after secondary effluents passed through ten feet of permeable sand and gravel (5).

From these investigations, it seems reasonable that under proper management, BOD_5 and COD levels assumed here can be adequately removed from wastewater effluent as it moves through permeable sand and gravel strata of the treatment basin. It is important to note

TABLE 21

Annual Input of Wastewater Constituents Under Two Application Rates and Two Operational Cycles

Constituent	Effluent Quality	Constituent Additional Treatment Basin			
		Application Rate			
		0.33 ft/day		0.67 ft/day	
		Application Cycle			
Constituent	mg/l	A	B	A	B
		pound/acre - year			
pH	6.5 - 8.0	-	-	-	-
BOD_5	30	3,327	6,654	6,654	13,304
COD	70	7,763	15,522	15,522	31,048
Total Nitrogen	20	2,214	4,436	4,436	8,872
Organic-N	2	223	443	443	886
NH_4-N	10	1,109	2,214	2,214	4,432
NO_3-N	8	886	1,775	1,775	3,547
NO_2-N	neg.	-	-	-	-
PO_4-P	13	1,438	2,884	2,884	5,765
SO_4	42	4,652	9,315	9,315	18,629
Cl	100	11,090	22,176	22,176	44,352
K	12	1,332	2,661	2,661	5,322
Ca	40	4,436	8,872	8,872	17,740
Mg	17	1,885	3,770	3,770	7,540
Mn	0.2	22	44	44	88
Na	40	4,436	8,872	8,872	17,740

A - 7 days inundation followed by 14 days recovery

B - 14 days inundation followed by 7 days recovery

that industrial effluent with high levels of organic matter of effluents containing grease and oils should receive prior treatment to meet the assumed effluent quality in order to avoid clogging the treatment beds.

(7) Nitrogen

Level of total nitrogen in the secondary quality effluent applied to the rapid infiltration basin was assumed to be about 20 mg/l; approximately 10 mg/l NH_4-N, 8 mg/l NO_3-N, 2 mg/l organic nitrogen, and negligible NO_2-N. Under the proposed application rates and operating cycles, total quantities of nitrogen applied to the treatment area would vary between 2,210-8,870 lb/ac-yr (Table 16). Lance (31) reviewed various soil mechanisms for removing nitrogen and determined land oriented wastewater treatment systems which treated large volumes of wastewater could not continuously remove large nitrogen additions without substantial denitrification. Removal mechanisms including crop uptake, soil fixation, and adsorption, ammonia volitalization and chemical denitrification all have limited capacity or were short-lived removal mechanisms which eventually would return nitrogen to the infiltration system.

Biological fixation and accumulation of organic nitrogen compounds in the horizon of the treatment basin could account for about ten per cent of the nitrogen applied annually, but unless assimilated nitrogen is routinely removed through crop harvesting, biologically-fixed nitrogen would be released following microbial decay of organic matter.

Ammonia adsorption on clay and colloids of the soil could also account for substantial nitrogen removal. However, during drying period, adsorbed NH_4-N would be oxidized to NO_3-N and would be available for movement through treatment basins in the percolate during the next application period. Control of nitrogen available for transport to groundwater can be accomplished under adequate and proper management practices which facilitate both nitrification and denitrification in the treatment beds.

Several management practices have been shown to be effective in reducing the nitrogen levels:

a. Carbon-nitrogen ratio in applied effluent
b. Management of the application cycle
c. Management of the application rate

Maintaining proper C:N ratio is probably the key to nitrogen removal be denitrification, as nitrified water moves through the reduced zone in the treatment beds. During application period, NH_4-N and organic nitrogen applied to the treatment beds are adsorbed in the soil or oxidized to NO_3-N in aerobic zones of the treatment basin or water column above the soil surface. Because the soil adsorption capacity of the treatment bed is limited, the application rate must be adjusted so that ammonia and organic nitrogen additions do not exceed adsorbtive capacity which would result in any excess being carried to the groundwater. During the recovery period, ammonia nitrogen and organic nitrogen adsorbed in aerobic horizons of the treatment basin would be oxidized to NO_3-N, which in turn must undergo denitrification before being carried into underlying groundwater. At this point, C:N ratio becomes very critical. The C:N ratio for secondary wastewater effluent varies from 0.5-1.0. The stoichiometric equation for denitrification indicates a minimum requirement of 0.7 mg of carbon per 1.0 mg NO_3-N. However, in actual practice, this ratio has shown to be somewhat greater due to the fact that some carbon is assimilated by other than just denitrifying bacteria and variation in carbon source. St. Amant and McCarthy (1969) reported denitrification of agricultural wastewater required about 1.3 mg methanol-carbon per 1.0 mg NO_3-N. Lance found increasing the C:N ratio by adding glucose to a carbon concentration of 80 ppm resulted in 60 per cent reduction in nitrogen, while increasing glucose-carbon level to 150 ppm resulted in a 90 per cent nitrogen removal. Because organic carbon is necessary in the denitrification process, other readily available sources of carbon could be used. One source is the primary effluent which generally contains about 54-108 mg/l TOC. By bleeding primary sewage effluent into secondary treated sewage effluent, the C:N ratio could be effectively increased to facilitate biological denitrification, once mixing ratios for optimizing nitrogen removal have been determined. Economical benefits gained by this procedure would be those associated with expenditures for a carbon source such as methanol or glucose. Once suitable C:N ratios have been achieved, the proper application rate and operation cycles can be employed in order to simultaneously create aerobic conditions for nitrification while at the same time creating anaerobic conditions at the soil-water interface of the treatment beds to achieve denitrification.

Field investigations have shown that using an effluent application rate of 3.2-8.6 gal/ft/day, 75-80 per cent of the applied nitrogen could be removed (32, 33, 68).

Studies of rapid infiltration at Ft. Devens, Massachusetts showed total nitrogen was reduced 40-60 per cent under a two-day application - 14 days recovery cycle; however, the majority of the remaining nitrogen was NO_3-N in concentrations of 10-20 mg/l (50).

In order to optimize nitrification-denitrification pathways for nitrogen removal, specific management and operation practices will require field experience in the New England environment.

(8) Phosphorus

Phosphorus level in secondary effluent treated by rapid infiltration was assumed here to be about 13 mg/l PO_4-P, which would result in annual phosphorus additions to the treatment area under proposed operation procedures of 1,440 to 5,760 lb/ac/yr. Under these application rates, the capacity of sand and gravel medium to adsorb and fix phosphorus could be a short-term feature. Adsorptive capacity of sandy soils has been reported as being quite low. Ellis (16) reported values for sandy soils in the range of 25-400 lb/ac/ft. Using these values to approximate adsorptive life of a treatment site with groundwater at 30 feet, the phosphorus adsorption capacity would be satisfied in one to eight years.

Recent studies have shown phosphorus adsorption in a soil as as approximated by the Langmuir Adsorption tends to underestimate adsorption capacity of the soil (14, 57). Soils tend to rejuvenate phosphorus adsorption capabilities upon drying which woul extend the life of a soil to remove phosphorus. Studies of the rapid infiltration basin at Ft. Devens, Massachus tts tend to bear this out (50). Analysis of the soil samples taken from the treatment basins which have received primary effluent for over 30 years show phosphorus levels in the range 1,500-1,900 lb/ac-ft. Analysis of groundwater samples from observation wells located around the application area showed total phosphorus levels were generally less than 2 mg/l PO_4-P with ortho PO_4-P levels less than 0.2 mg/l, although phosphorus levels in the applied effluent averaged 11 mg/l.

(9) Chlorides

Chloride levels in effluent are not expected to be reduced substantially due to stability of chlorides compounds and mobility of the ion. This should result in minimal chloride retention within the sand and gravel medium of the treatment beds. Studies of rapid infiltration sites operated over extended periods of time show chloride levels in

percolate from these sites were approximately equivalent to that of the applied effluent.

(10) Sulfate

Sulfate levels are not expected to increase significantly in the treatment beds due to chemical fixation. Field studies have shown increases are not large. Satterwhite (50) observed sulfate levels in percolate samples were approximate to those found in the effluent. There is the possibility some sulfate can combine chemically with iron to form a ferrous sulfide precipitate where anaerobic conditions exist in the treatment beds. This could result in decreased infiltration oxidize ferrous sulfide precipitate.

(11) Pathogenic Organisms

Wastewater effluent receiving additional renovation by rapid infiltration was assumed at this time to have been disinfected prior to application to the land either by chlorination or ozonation. Health and economic impacts stemming from either process are discussed in other sections of this report. Studies of rapid infiltration systems which have renovated unchlorinated wastewater effluents have shown that total coliform bacteria and fecal coliform bacteria are effectively treated to acceptable levels for potable water supplies by physical, chemical and biological processes of land treatment sites. Satterwhite (50) found total coliform and fecal coliform bacteria levels in unchlorinated primary sewage effluent were essentially removed by the rapid infiltration system. Counts of total coliform bacteria in the primary effluent applied to rapid infiltration treatment area varied between $18 \times 10^6 \times 52 \times 10^6$ per 100 ml. Groundwater samples taken directly beneath the treatment site contained total coliform counts in a arange of 200-4,000 per 100 ml of sample while coliform counts in samples collected from observation wells 300 feet from the application area ranged from zero to 300 per 100 ml of sample.

Bouwer (7) found the number of fecal coliform bacteria in unchlorinated secondary effluent applied to rapid infiltration systems ranged between 1×10^5 to 1×10^6, but after percolating through 30 feet of stratified sand and gravel, fecal coliform counts beneath the application area were less than 10 per 100 ml and were absent in wells located 100-200 feet distance from the application area. Most coliform bacteria were believed removed in the upper three feet of the treatment basins. When long inundation periods were used, two-three weeks, total coliform bacteria MPN values were 200 per 100 ml; however, bacteria observed under

short flooding period of two to three days were 5 per 100 ml (7, 50).

Evaluation of the rapid infiltration system at Lake George, New York has shown total coliform bacteria were effectively treated by rapid infiltration of unchlorinated secondary sewage effluent (5). Total counts of coliform bacteria in the effluent numbered 600-2,400 per 100 ml of sample. Samples taken at a five-foot depth showed coliform bacteria counts were reduced to 0-350 per 100 ml and after percolating through ten feet of sand and gravel bacteria ranged 15-50/100 ml.

Disinfection of effluent applied to the land in spray irrigation systems may be a necessity because of unresolved concerns centered around hygienic effects of aerosols. However, disinfection of effluent applied to rapid infiltration sites may not be necessary due to the application method and renovation obtainable as effluent percolates to the water table.

Concerns of viruses applied to very permeable sand and gravels will require additional investigation as to their fate in rapid infiltration treatment systems. Present data is inconclusive as to capacity of soils to remove viruses, thus, additional laboratory and field investigations are needed.

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4. EFFLUENT DISCHARGE

a. Outfall Systems

The discharge systems for treated wastewater may fall under two main categories, (1) river outfalls and (2) estuary or ocean outfalls. Generally, river outfalls are constructed with the outfall pipe terminating at a concrete headwall above the receiving waters or with a cascade for more pleasing aesthetics. In cases where high-velocity flood flows may be encountered, special provisions in the design of the outfall facilities to prevent undermining or flood damage must be included.

Estuary or ocean outfall systems require special studies to explore tidal currents, upstream flow of salt water at the bottom and available dilution in order to determine optimum discharge locations. For proper design of such facilities, it is essential to obtain detailed data on the following: (a) shore use and conditions to be maintained, (b) profiles of possible routes, (c) nature of the bottom, (d) density stratification or thermoclines, by seasons, and (e) patterns of water movement at point of discharge and travel time to shore.

A critical consideration in the discharge of treated wastewater into a seawater environment is the development of complete mixing of the wastewater plume. Due to the greater density of seawater, the wastewater effluent rises rapidly at the discharge normally producing a "boil" at the surface. As the plume mixes with the seawater, dilution increases rapidly. In locations where the outfall is deep and there is good density stratification, the wastewater plume can pick up enough cold water at the discharge so that the resulting mixture is heavier than the surface water. The plume will stop below the surface or reach the surface and then resubmerge. Maximum benefit of density stratification can be obtained by diffusing the wastewater effluent so that the flow is widely dispersed and large flows of diluted water can approach at low velocity.

Ocean outfalls are generally constructed at water depths sufficient to protect them from wave action and tidal movement. Stone protection over the outfall pipe is generally used to prevent undermining of the structure in softer bottom materials.

b. Deep-Well Disposal

Deep-well disposal involves the injection of liquid wastes into a porous subsurface stratum which contains non-commercial

brines. The wastewaters are stored in sealed subsurface strata isolated from groundwater or mineral resources. Wastes disposed of in wells are usually highly concentrated toxic, acidic, or radioactive or wastes high in organic content which are difficult or economically unfeasible to treat by some other process.

Disposal of wastewater through injection wells to the subsurface is currently receiving careful consideration. Simply stated, this method consists of drilling a well into the earth and disposing of the waste by injecting it into the rock material at the bottom. It was first practiced in this country in the oil fields during the 1920's as a means of disposing of brine accumulated during the drilling process.

Wastewater injected through wells is disposed of in the sense that it is removed from the surface and stored in the subsurface. The effluent does not disappear, it is not recycled, it is not used in any fashion; it is simply stored within the ground.

There are some certain and many possible impacts resulting from injection disposal of wastewater. Major impacts are listed below.

1. Some modification of the groundwater regimen.

2. The introduction into the subsurface of exotic fluids not natural to the subsurface environment. The above are certain impacts, those that follow are possible impacts.

3. Contamination of groundwater.

4. Contamination of other subsurface material such as coal, oil or gas resources.

5. Chemical reaction between wastewater and natural groundwater and/or rock material in injection zone.

6. Earthquake stimulation.

In order to ensure that wastewater disposed of by well injection will not significantly impact upon the subsurface environment, several constraints must be observed. Chief among these are:

1. The availability of an injection zone with sufficient permeability, porosity, thickness and areal extent to act as a storage area at safe injection pressures.

2. An injection zone that is located below the zone of fresh water circulation and confined vertically by rock or unconsolidated sediment that is impermeable to the liquid effluent.

3. The groundwater in the injection zone be saline or brackish. It would not be practical or reasonable to contaminate high quality fresh water with the stored wastewater and so all zones which are used for storage should be salty groundwater rather than fresh.

Pretreatment equipment is generally required for well disposal of wastewater and usually includes a basin for flow equalization; treatment facilities for the removal of oils and floating material, suspended solids, biological growths, dissolved gases, precipitable ions, acidity or alkalinity; and high-pressure pumps for injection of the waste into the subsurface stratum. Inasmuch as the municipal and industrial wastewaters found in the study area are amenable to treatment in municipal or regional treatment facilities, deep-well disposal has not been employed in any of the alternative wastewater management considerations.

5. ENVIRONMENTAL INTERACTIONS

a. Wastewater Reuse

A number of opportunities exist for the reuse of treated wastewater which, even in areas where water resources may appear abundant, may be encouraged in view of enhancing economics and aesthetics, and minimizing wastage.

Uses of renovated water include:

Industrial Process Water

Cooling Water

Boiler Feed Water

Irrigation

Groundwater Recharge

Municipal Water Supply

Prevention of Salt Water Intrusion

Recreation

River Flow Augmentation

The supply of natural fresh water in any geographical area is relatively fixed over a long period of time. In any specific location, to be sure, there are wet years, wet cycles and dry cycles, but over a long span of time, the fresh-water supply from rainfall is relatively constant.

The concept of wastewater reutilization is certainly not a novel approach and has, to varying degrees, gained public recognition and acceptance. Such reutilization has been occurring for years along the major rivers of the United States, where many cities and large industries take water from the river and return their wastewater to the river for subsequent use by downstream entities.

Purification of water, prior to municipal use, has long been standard practice. In recent years, treatment of the returned wastewater has also become mandatory inasmuch as natural stream self-purification has become increasingly inadequate to protect multiple beneficial uses deemed suitable for the water. An indirect reuse of domestic wastewater also occurs in areas replete with septic tanks and leaching drain fields. With such systems, liquid wastewaters percolate through the soil and eventually replenish the ground water supply.

Undiluted but highly treated municipal wastewater has also been used for recreational lakes, for irrigation of crops, and for many industrial purposes, as described later in this section.

Despite its potential value, no one cherishes the thought of using treated wastewater for any purpose. However, when pristine or previously unused water ceases to be available and plentiful, or when it must be imported great distances at high cost, the rationale for wastewater renovation and reutilization becomes more acceptable, especially in relation to beneficial uses where water quality requirements are not too stringent. It is evident, therefore, that the feasibility of wastewater reuse in any region must be evaluated on the basis of all local conditions and factors.

Although there are some communities facing water supply problems at present, the supply of fresh water for the study area, taken as a whole, appears to be adequate for municipal and industrial demands with continued maintenance of existing systems, extended distribution, and planned waterworks expansion; the natural supply of fresh water should be adequate to meet anticipated population growth and industrial expansion at least through the year 2020. Thereafter, a need for supplemental water may arise.

The reutilization of treated wastewater may be "indirect or direct". Implementation of either category requires the thorough prior consideration of water hygiene in order that reuse does not lead to the spread of disease. Indirect reutilization is considered to occur where treated wastewater loses its identity by dilution, blending, and/or natural treatment. It takes place when return flows to rivers are diluted and later reused by downstream entities. Indirect reutilization also occurs as a result of groundwater recharge from such sources as septic tank drainage

which is commonly discharged to land for infiltration into pervious soil and percolation to groundwater basins. Here the effluent is subjected to a very high degree of natural treatment, and quickly loses its identity by blending with natural groundwater.

Direct reuse of treated wastewater (municipal and industrial) may be practiced in the following ways: (a) irrigation of crops, grazing land and cemeteries; (b) recreational lakes for boating, fishing, and even bathing; (c) industrial process water; and (d) industrial cooling water.

In a few rare instances, treated sewage has been used in a quasi-direct manner for municipal water supply, however, there appears to be no need to consider direct reuse for municipal water supply in this study area. Other direct uses, as well as indirect methods of reuse are discussed below:

(1) Industrial Process Water

The reutilization of wastewater by industry may be divided into two categories, (a) the in-plant recycling and reuse of industrial waters, and (b) the purchase and use of adequately treated municipal wastewater. Process water is considered to include all waters required in production operations except cooling waters.

The first category, in-plant recirculation, is very common in many of the industries located in the study area (i.e. textile manufacturing, manufacture of paper, etc.). A paper manufacturing firm may, through recirculation and recycling, reduce its average water requirement in the order of 50% - 75%. Such recirculation diminishes total water demand and promotes conservation of valuable fresh-water supplies.

The second category, use of municipal wastewater for industrial processes (other than cooling water and boiler feed water) is largely dependent on the water quality requirements for direct process water. The need by industry for high quality process water from municipal treatment plants must be sufficiently great to offset the high costs of additional treatment and conveyance. This is not likely to occur soon within the study area.

Industries requiring a high quality water might, after use of the water, discharge it to other industries with less critical requirements. In doing this, a network of reuse could be established which would both minimize the quantity of pristine water required by industry and the cost of treating this water after use.

(2) Cooling Water

Many industrial operations involve the dissipation of excess heat. This thermal adjustment is generally accomplished by transfer of the heat through cooling coils to circulating water. Where water is abundant, it is circulated only once through the cooling coils then discharged to a waterway. When natural water is scarce, it is recirculated, frequently through a circuit of heat-transfer coils and cooling tower which release the heat to the atmosphere.

Industrial cooling water requirements which need not be of potable water quality may be satisfied by recycle of process or reuse of treated wastewater. The closed cycle practice of water reuse is simply the use of water more than once, with careful attention given to the quality of the water after each successive use. The volume of water can be considerably less than that consumed in a once through process, with smaller equipment investments and lower operating costs inherent in this type of operation.

(3) Agricultural Irrigation

Irrigation with treated sewage has been practiced in the United States primarily for the water content, as a substitute for scarce natural waters or sparse rainfall in arid areas. In many other more humid parts of the world municipal effluents have been used for irrigation largely as a source of nitrogen, phosphorus, and other nutrient substances.

The following paragraph is taken from the EPA publication "Wastewater Treatment and Reuse by Land Application":

> "The use of wastewater for irrigation is attractive for several reasons, including the following: (1) it is a positive alternative to advanced wastewater treatment and surface water discharge; (2) it can result in

economic return on the sale of crops; (3) it can be part of a water conservation and reuse program; (4) it can provide fire protection by forested hillside spraying; and (5) it can foster the preservation and enlargement of greenbelts and open space."

(4) Groundwater Recharge

Wastewater that has received sufficient pretreatment may be added to the natural groundwater supplies:

a. By intermittent spreading on natural soil or artificial sand beds (rapid infiltration).

b. By sprinkler irrigation of crops or woodland (spray irrigation).

c. By direct injection into recharge wells. This latter method is applicable where the presence of an aquaclude prevents percolation from the surface into a suitable groundwater basin or aquifer.

Intermittent percolation from a spreading basin (rapid infiltration) normally is to be preferred to pressurized injection into a confined aquifer. Intermittent percolation provides a high degree of aeration that promotes oxidation of carbonaceous organic matter and ammonia nitrogen. In contrast, the only oxygen available to injected water is that which is already dissolved in such water prior to injection. Furthermore, intermittent percolation will generally work quite effectively even when the water being spread contains pinpoint activated sludge floc or moderate concentrations of algae. These substances will rapidly clog an injection well and hence they must be removed by controlled filtration before injection. The rate at which a good activated sludge effluent can be spread on a natural soil bed, day after day and month after month for many years without extensive resting or repairs, is a function of the soil characteristics (median grain size and geometric deviation), soil chemistry, depth to groundwater, the organic content of the effluent, and the frequency, duration, and depth of application.

Spray irrigation has been used successfully for growing of crops. In most instances, secondary effluent is sprayed over cultivated or forested land with the expectation that part of the water

will evaporate, part will be transpired by the vegetation or crop, and the remainder will percolate into the soil or perhaps be purified by slow overland surface run off.

Direct injection of treated sewage through pressurized recharge wells into deep pervious strata has been practiced by the Los Angeles County Flood Control District and other agencies in California, to establish fresh-water barriers against salt water intrusion in coastal areas.

Direct injection has several inherent advantages over rapid infiltration and spray irrigation; but also some serious drawbacks. Among the favorable factors are the minimal surface area requirements, the freedom from extensive grading and earth moving, the absence of possible odors, and the unobtrusive appearance of injection structures above ground in contrast with spreading basins. Disadvantages include the necessity for sand or diatomaceous earth filtration, chlorination, and other possible pretreatment before injections, the absence of any mechanism for maintenance of aerobiosis after soil-water contact and the necessity for cleaning and redeveloping the recharge wells periodically as means of waste disposal and not as a mechanism for wastewater recovery and reuse.

(5) Recreational Lakes

In arid areas remote from natural surface waters, the use of highly treated sewage for recreational lakes has proved to be popular, especially from the viewpoint of public relations. The most publicized example has been Santee, California, where disinfected polished effluent is used in lakes for boating, fishing, and even bathing, with a high degree of public acceptance.

In areas where numerous natural impoundments suitable for recreational uses exist, it may be desirable (such as during severe droughts) to pump some highly treated municipal effluent into certain impoundments to maintain water levels.

(6) Low-Flow Augmentation

River flow augmentation holds possibilities for reuse in some areas. After use for virtually any purpose, and subsequent treatment, the effluent would be discharged to a stream which would

benefit from additional volume, either year round or on a seasonal basis. This type of scheme is not applicable to every situation, such as where existing channel capacities are marginal.

Summary

The reclamation and reuse of municipal wastewater in the study area represents a potential means for increasing the total water resources of the area. Although supplies of fresh water are generally adequate for present municipal uses and for the foreseeable future, a need for additional water may be evidenced earlier and it is prudent, therefore, to explore and develop ways by which existing water resources can be conserved by reclamation and reuse of wastewater.

The rationale for reuse is enhanced by the fact that new water-quality standards (1972 Amendments to the Federal Water Pollution Control Act) will necessitate a high degree of treatment of municipal and industrial wastewater plants. The effluents from these facilities should be suitable for several forms of direct and indirect reutilization with little or no additional treatment.

Among the classical forms of renovation and reuse, groundwater recharge by spreading, spraying, or direct injection, as well as agricultural irrigation present potential areas for wastewater reuse. Existing and future recreational lakes in the study area can be replenished adequately with natural fresh water, except during drought periods when the use of supplemental water sources would be required. The use of renovated wastewater by industries for process or cooling water presents great potential within the study area and should be given further consideration.

b. Power Plant Sitings

It is anticipated that increasing demand for electrical power will require substantial expansion of generating facilities in the study area over the next twenty-five years. Whether such facilities derive heat from fossil fuels or from nuclear power, they will require cooling water in large quantities. They will also require disposal areas into which to discharge their thermal wastes, since the discharge of wastes with elevated temperatures is detrimental to aquatic life. With the increasing difficulty in obtaining new sources of cooling water and adequate locations for thermal

discharges, it may be to the mutual benefit of both the power industry and the sanitary district for new electric generating plants to be located adjacent to wastewater treatment plants. Power plants might take make-up water from the treatment facility and discharge blow-down water to the treatment plant where its elevated temperature would be beneficial to biological treatment processes.

Specific advantages which might be derived are as follows:

1. The power plant would consistently have large quantities of cooling water available. The need for increased cooling water would be matched by increasing flows from the treatment plant. The treatment plant would similarly have electric power available in large quantities.

2. Cooling water obtained from treated wastewater would eliminate a large demand for unused or higher quality water.

3. Power and wastewater treatment plants are usually located near population centers; locating the two together would eliminate the costs of transporting the treated water to the power plant.

4. Steam generated in the power facility might be used for heating the plant or dewatering sludge.

5. Sanitary district would have a market for its treated wastewater; its biological waste treatment would benefit from thermal discharges.

6. Both the power company and the sanitary district could utilize the same transmission easements and rights-of-way for pipelines and power lines.

Possible disadvantages of joint siting:

1. Treatment facilities and power plants are of such large scale that the siting of both at a single location could create a considerable ecological disruption.

2. While unused water supplies are plentiful and inexpensive, it may be difficult to convince power companies that a water reuse plan is in their best interest.

3. Joint siting of such facilities would require considerable and enlightened cooperation between the sanitary district and the power company.

c. Solid Waste Management

There exist many possible areas in which solid waste management and wastewater management schemes might be structured to mutually complement each other. Both solid waste and wastewater management have developed into public responsibilities, and are generally operated by municipal or regional governments. Because of this, many opportunities for operating efficiencies might exist if the facilities were integrated. Two possible areas of integration of solid waste and wastewater facilities which will be discussed are incineration and pyrolysis. In incineration, the intent is primarily to decrease sludge volume and organic content for ease of disposal, while in pyrolysis, the purpose is to alter organics into recoverable products.

(1) Incineration

In an urban area where landfill areas are not readily available, economical disposal of wastewater sludges depends upon the use of an efficient method to remove water from the sludge. Typical sludges from wastewater treatment are from 95 (primary) to 99 (secondary and some chemical sludges) percent water. Removal of water results in decreased sludge volume and therefore decreased handling costs. (For example, sludge with a solids content of 1.0 percent is five times more voluminous than that with a solids content of 5 percent.)

Mechanical methods of sludge dewatering, such as flotation thickening, vacuum filtration and sludge centrifuging, can be expected to decrease water content to about 80 percent (in a mixed primary-secondary sludge) and overall sludge volume by about 80 percent. Higher reductions require the application of heat to drive off water from the sludge, and the need of an inexpensive source of heat from this process can be well satisfied by excess heat generated in a solid waste disposal facility.

An incineration system capable of handling a combination of sewage sludge and municipal solid waste could serve as the nucleus of a municipal or regional solution to the total waste disposal

problem. Such systems may vary in their details, but nearly all such installations consist of a sludge drying unit separate from a solid waste incinerating furnace. In operation, wet sludge is fed to the dryer, frequently a cyclone, where it is dried and sterilized at high temperatures. Initial heating of the sludge and the hot air supply to the cyclone are furnished by the municipal solid waste incinerator. In addition, stack gasses generated in the drying process require cleaning and deodorization. This is accomplished by feeding these gasses back to the incineration system.

The most attractive aspect of such a system is its flexibility of operation. After drying, sludge can be hauled to a landfill site, or bagged and sold as a low grade soil conditioner, or incinerated in the presence of municipal refuse. In addition, the plant could serve as a regional salvage and separation area where cardboard, paper, rags, glass and metals could be removed for salvage and recycle.

There does not exist a large amount of useful operating and cost data on such installations because such facilities are still relatively rare, and because actual operating costs are based on such variables as character and quantity of wastewater sludge and dry waste and possible market utilization potential of recycled material and process by-products. The Sanitary District of Chicago is currently utilizing a sludge drying operation on a portion of its waste sludge. Production cost per ton of soil conditioner is about $60. and the material is sold for $15. per ton. During some months of the year, there is repeatedly some difficulty in selling the product.

A successful application of fertilizer production involving composting of refuse and sewage sludge has been underway in Houston, Texas, for the past several years. Such operations are fairly common in Europe where labor costs are lower and refuse has a higher percentage of organic material. In Houston, 400 tons of municipal refuse and 120,000 gallons of waste activated sludge (5 tons of dry solids) are processed into 240 tons of organic compost per day.

Refuse, including garbage, is mechanically conveyed to a salvage and separation area where the cardboard, paper, rags, glass and metals are manually removed for salvage and reprocessing. Non-compostables, such as ceramics, are also separated for clean landfill. The paper and rags are baled and sold.

The remaining material is then ground and mixed with the thickened activated sludge, and composted for 6 days. The final result is a tobacco colored textured humus-like compost that contains 3 percent nitrogen-potash phosphate. The compost is non-burning and odorless. Before being sold, the material is ground once more, screened and dried at high temperatures for complete pathogenic kill. It is sold in bags or in bulk to municipal and private firms for soil conditioning and mulching of golf courses, citrus groves, greenhouses, and similar areas. The plant reportedly operates at a profit.

A similar type of solution for sewage sludge disposal problems within the Merrimack Study Area would require a municipal and probably regional waste management plan in order to generate the large quantities of refuse required for efficient operation of the process. It should be remembered that, in most successful operations of this type, the primary source of material for the compost is solid refuse and garbage rather than sewage sludge and, therefore, only if a total waste management plant for the area is desirable, will this type of solution be feasible.

(2) Pyrolysis

While incineration is a rapid means to convert the organic portion of waste into an inert ash, pyrolysis is a controlled process to distill such compounds as tar, oil, gas and char from the organic portion of such waste. The process takes place in the presence of high temperature and pressure, but without oxygen. Several processes for pyrolysis of waste materials are being developed; however, it is important to remember that none of them have been tested on a full scale basis for a period sufficient to generate reliable operating data.

Many of the same factors allowing efficiencies to be realized in a combined solid waste and wastewater sludge incineration plan would be in operation in a correspondingly comprehensive pyrolysis plan. Very preliminary data we have seen have indicated that the costs of solid waste disposal by both incineration and pyrolysis are that the system does not use air so there is no air pollution -- air pollution is a serious problem in solid waste incinerators (although not generally in sludge incinerators), and the recoverable constituents from the organic wastes are valuable resources. The recovery and sale of these constituents could

well reduce operating costs of pyrolysis below those of incineration. In addition, the predicted shortages of precisely the types of substances distilled in the pyrolysis process indicates that the cost advantages of pyrolysis will probably become more significant in the future.

We have been requested to investigate the feasibility of a regional resource recovery center as a portion of this study. The center would be composed of advanced wastewater treatment facilities, a pyrolysis solid waste recovery plant, and compatible industries that could utilize the renovated wastewater and pyrolysis products. Solid waste collection and shredding facilities would be located adjacent to local secondary treatment facilities. Solid waste would be shredded and mixed with wastewater sludge to form a slurry for piping to the regional recovery center. In this way, the water content of the sludge could be a useful characteristic enabling economic transport of the solid waste to the regional facility. Pipelines for secondary treatment effluent, slurries of solid waste and lines conveying stormwater overflow storage could be constructed by deep tunneling or along rights-of-way corridors. Utilities in the area, especially power plants located near the regional center, could utilize these tunnels or rights-of-way for power distribution corridors.

d. Land Right-of-Way Utilization

The proposed use of many miles of transport corridors for transmission of wastewater, and large land areas devoted to ground disposal of wastewater effluent presents several unique opportunities for regulation of development and land use in the Basin which might not otherwise be available. The use of these land areas for recreational purposes will be discussed in a later section; at this point, we are concerned with the use of these corridors and land areas as planning tools which can be used by a municipality or a regional agency to direct development in the Basin in order to optimize the impact such future development may have in the area.

The location of transport corridors for wastewater transmission along the banks of the Merrimack River could be a significant planning tool for redirecting development along the river and restructuring the manner in which the general population has come to regard or to utilize the river. Many developing

communities along river banks have restricted private development within 300 or 500 feet of the riverfront; while similarly large land buffers are probably not immediately possible in a densely developed urban area, such restrictions might be possible in the more rural areas between population centers, and the necessity of a 30 to 50 foot wide corridor along the entire river front for transmission of wastewater would supply a continuous connection between these undeveloped areas. Even within a city, zoning restrictions upon existing development within a 300 to 500 foot distance from the river would encourage eventual transfer of existing private development along the river front to public use, either by outright removal of existing facilities or by conversion of the facilities from private to public uses when they are no longer needed by the owner. Such a process would be enormously costly and would of necessity be a continuing project over an extended period; nonetheless, the rapidity with which an area can be cleared of existing private development for such public exigencies as highways indicates that a program of conversion from private to public river access can be successful if there is the public will that it be done. Transport corridors for the transmission of wastewater between treatment facilities could be the first step in such a program.

In more rural areas, there is currently much concern that future development may eliminate the watershed areas so necessary for hydrologic stability of a river basin. Most of the suggested areas for spray irrigation in the Merrimack River Basin are in the watershed of the Basin upstream of Lowell. The possible use of these areas for ground disposal of wastewater effluent could serve the secondary purpose of eliminating the potential of future development of the land, and thereby preserving its use as a watershed area. In addition, the land areas given over to ground disposal and transport corridors might serve as massive physical boundaries delineating various types of development.

Similar limitations in the past have been haphazardly supplied by large private development and by railroad, and more recently highway rights-of-way. An intelligently planned wastewater management system could be the basis of a more rational development plan for an area.

e. Recreational Use of Treatment Facilities

The following discussion will suggest possible recreational uses that might be made of treatment plant sites, transmission corridors developed to convey wastewater to regional treatment areas, and spray irrigation areas.

Opportunities for recreational use of treatment plant sites within urban areas is limited because of the land intensive nature of wastewater treatment in an urban environment. Any recreational use, therefore, of such a facility would involve a correspondingly land intensive type of recreation.

Treatment plant sites are typically a series of concrete structures at or below grade. In a situation where a treatment facility has been located on a desirable piece of urban land, wether through bad planning, or because no other site existed for the facility, the possibility exists that air rights over the facility could be used for such types of construction as sports arenas or shopping centers. Construction of such facilities will entail greater expense than similar construction on an undeveloped site; yet the scarcity of undeveloped urban land and the desirability of maintaining undeveloped areas in their virgin state might dictate such multiple use of the land.

Recreational use of treatment sites in rural areas would be primarily centered upon multi-use of land oriented treatment facilities such as storage lagoons and spray irrigation areas. Storage lagoons for treated wastewater could be utilized as recreational waterbodies. The areas adjacent to these lagoons could be reserved for use as wildlife areas, and for walking, hiking, and camping. Spray irrigation areas would not normally be used in the winter months; during these periods, the areas could be used for hiking, cross-country skiing and skimobiling.

Perhaps the greatest potential for recreational opportunity exists in utilization of transmission corridors which would be used to convey untreated or partially treated wastewater to a regional treatment facility. Such transmission lines would in many instances be located upon the river bank of the Merrimack, and the installation of these lines provides an opportunity for opening up the visual and physical access to the river. Recreational opportunities presented by these transmission corridors

have been discussed in "Designs for a Clean River". Among the possibilities suggested in that report are a network of linear paths connecting playgrounds, mini-parks, schools and neighborhoods with the transmission rights-of-way. The recreational corridors themselves could be used for horseback riding, bicycling, hiking and as a means of non-mechanized access into rural areas.

6. SLUDGE HANDLING AND DISPOSAL

a. Introduction

The purpose of wastewater treatment is to purify influent wastewater to produce an effluent of acceptable quality for return to the natural hydrologic cycle or to be further reused. The operation of the treatment facility in accomplishing its goal should not, in as much as possible, have any adverse effects upon the quality of the surrounding air, land and water resources in the region. Acceptable treatment involves two basic aspects:

(1) The impurities contained in the wastewater must be removed before the water may be discharged to the surrounding surface or ground water source.

(2) The solid impurities removed, or sludge, must be handled, treated and ultimately disposed of by efficient and economical methods which will not endanger the public health, result in nuisance conditions, cause undue degradation of the land resource or create non-point sources of pollution which may contaminate ground or surface water supplies.

The two most common objectives of sludge handling are the decrease of sludge volume by reduction of its water content, and decomposition of organic matter. The following sections discuss means of achieving these objectives in order to render the sludge suitable for some method of ultimate disposal. It will hopefully be demonstrated in the course of the discussion that selection of the optimum processing method depends in large part upon the type of ultimate disposal selected.

b. Sludge Characteristics

Sludge is defined as a semi-liquid waste having a total solids concentration of at least 2500 mg/l. Sewage sludge is an amorphous, heterogeneous, non-newtonian liquid containing dissolved, colloidal, and suspended solids. Three broad categories of sludges commonly encountered in wastewater treatment are primary, biological and chemical sludges. In many plants, these sludges are combined, as for example, in extended aeration (where primary and secondary sludges are removed in a single clarification step) or physical chemical treatment of wastewater for BOD and solids removal.

Primary sludges obtained from wastewater through gravity settling have characteristically an objectionable odor, are greyish in color, and have moisture contents of between 95 and 97 percent. Biological sludges in contrast are flocculent in character and have much higher moisture contents than primary sludges. They are brownish in color, and in a fresh state have an innocuous odor. Chemically precipitated sludges have color, appearance, and water content which vary according to the chemicals used; they are nonetheless more similar in appearance to primary than secondary sludge, although their odor is less objectionable.

c. Sludge Generation

Quantities of sludge which are generated during the treatment processes proposed for wastewater management along the Merrimack River and characteristics of this sludge will be estimated in the following section. The treatment processes as outlined previously consist of primary settling and three stage biological treatment. Consideration will also be given to sludges which may be generated in the treatment processes used to remove phosphorus. For the purposes of the discussion, the following typical wastewater characteristics will be assumed:

5-day Biochemical Oxygen Demand (BOD_5)	250 mg/l
Suspended solids (SS)	200 mg/l
Total Kjeldahl nitrogen (TKN)	35 mg/l
Ammonia Nitrogen (NH_3-N)	15 mg/l
Total Phosphorus (P)	15 mg/l

Primary Sludge

Typically, about 65 percent of influent (SS) are removed by primary clarification. Sludge produced per million gallons is therefore:

$$0.65 \times 200 \times 8.34 \times 1.0 = 1084 \text{ lbs of sludge solids}$$

assuming a solids content of 4%, and specific gravity of 1.02 sludge volume in gallons would be:

$$\frac{1084 \text{ lbs}}{1.02 \times 8.34 \times 0.04} = 3186 \text{ gals.}$$

Biological Sludges

Conventional Activated Sludge

Assuming 35 per cent BOD reduction in primary treatment: BOD per million gallons applied to secondary treatment is therefore:

$$0.65 \times 250 \times 8.34 \times 1 = 1355 \text{ lbs}$$

Assuming an 85 percent reduction of BOD_5 through process:

$$0.85 \times 1355\# = 1152 \text{ lbs per million gallons removed in BOD aeration}$$

if 0.5 lb V.S.S.* generated per pound of BOD removed:

576 lbs VSS produced per million gallons applied

The solids are approximately 80 percent volatile:

*V.S.S. = Volatile Suspended Solids

$$\frac{576}{0.80} = 720 \text{ lbs per million gallons of waste activated sludge produced}$$

And if solids content of secondary sludge is 0.75 percent, the volume of sludge in gallons would be:

$$\frac{720 \text{ lbs}}{1.02 \times .0075 \times 8.34} = 11,285 \text{ gals.}$$

Table 22 is a summary of major and minor elements found in primary and activated sludges. Both primary and waste activated sludges are normally between 70 and 85 percent volatile (on a dry basis).

Nitrification Sludge

Pilot plant data has indicated that wasting is not often required in the nitrification process.

Denitrification Sludge

Preliminary estimates indicate that waste sludge generation from the denitrification process will be about 0.7 pounds of sludge per pound of nitrate reduced. Denitryifying sludges are reported to have settling characteristics comparable to good activated sludges, and volatile matter of about 65 percent. If 25 mg/l of nitrate are produced by the nitrification process, the dry weight of denitrification sludge produced per million gallons would be:

$$0.7 \times 25 \times 8.34 = 146 \text{ lbs.}$$

and if solids content is 0.75 per cent, the volume would be:

$$\frac{146}{1.02 \times .0075 \times 8.34} = 2288 \text{ gallons per million gallons}$$

TABLE 22

SUMMARY OF MAJOR AND MINOR ELEMENTS IN SLUDGE
(mg/g dried sludge)

Element	Primary Sludge	Activated Sludge
Aluminum	5.1	10.0
Antimony	n.a.*	n.a.
Arsenic	< 1.2	1.2
Barium	2.2	1.2
Beryllium	0.0025	0.0035
Boron	0.10	0.070
Cadmium	< 0.19	0.35
Calcium	n.a.	13.0
Chromium	2.0	4.3
Cobalt	0.22	0.002
Copper	2.0	1.1
Gallium	0.06	0.05
Iron	16.1	40.5
Lead	1.0	1.5
Magnesium	10.6	7.0
Manganese	0.78	0.31
Mercury	0.005	0.02
Molybdenum	0.36	0.20
Nickel	0.52	0.38
Phosphorus	3.8	19.9
Potassium	n.a.	4.2
Silicon	n.a.	40.0
Silver	0.24	0.15
Sodium	4.0	4.4
Strontium	0.13	0.16
Sulfur	n.a.	10.1
Tin	0.95	0.50
Titanium	14.8	11.8
Vanadium	2.1	0.7
Zinc	6.9	3.3
Zirconium	1.7	10.0

*n.a. - not available

A portion of Table VI, Sewage Sludge Incineration, EPA publication EPA-R2-72.040. August, 1972.

Chemical Sludges

It now appears that alum precipitation will not be a satisfactory method of phosphorus removal. One of the criteria established in this study by the Corps of Engineers for chemical addition to wastewater is that sludge produced be amenable to ground application. Information indicates that aluminum at concentrations in excess of 1 mg/l has detrimental effects on plant growth, particularly on the growth of roots. Because alum addition to wastewater results in sludges with high concentrations of aluminum (in the form of $AlPO_4$ and $Al(OH)_3$) alum is no longer considered to be an acceptable precipitant.

In light of this, reconsideration of an earlier recommendation, now suggests phosphorus removal consisting of low lime addition immediately before primary clarification and ferric chloride addition to the carbon aeration tank. Sufficient lime would be added to the primary wastewater to raise the pH to 9.5 or 10.0. This pH would not be harmful to the activated sludge process following primary clarification and the pH of primary effluent would be reduced in the aeration tank by the carbon dioxide (CO_2) produced by biological metabolism. Approximately 75 to 80 % of the phosphorus would be removed in the primary step with a lime addition in the order of 100-150 mg/l (for wastewater with alkalinity in the vicinity of 100-150 mg/l). Phosphorus remaining after the lime clarification would be removed both by synthesis in the biological processes and by addition during aeration of an additional precipitant ($FeCl_3$) and perhaps a polymeric flocculant.

The additional weight of sludge to be expected from the lime addition would be significant, but lime is an effective sludge conditioner and stabilizer, and the total volume of such sludge might not be much greater than that to be expected in primary settling alone. A portion of the additional sludge results from the augmented efficiency of solids removal in primary sedimentation which, of course, would reduce somewhat the quantity of biological sludge produced in the activated sludge process.

Assuming a dosing level of 150 mg/l of lime in the primary, approximately 85% of suspended solids could be expected to be removed, and quantities of calcium carbonate ($CaCO_3$), calcium hydroxyapatite $Ca_5(OH)(PO_4)_3$ and calcium hydroxide $Ca(OH)_2$. Total mass of sludge would probably be about 3 times greater than that produced by primary treatment alone, or roughly, about 3,500 pounds. The sludge would have a solids content of between 6 and 8 percent, or, (assuming 7 percent):

$$\frac{3500}{1.02 \times 8.34 \times .07} = 5878 \text{ gals per million gallons treated}$$

The increase in suspended solids removal from 65 to 85 percent will result in a decrease of BOD loading to the activated sludge process from the 65 percent of influent BOD assumed for only primary to perhaps 55 percent or (.55 x 250 x 8.34 x 1) 1147 lbs. per day, and assuming 85 percent BOD reduction through the process, 0.5 lbs. V.S.S. per lb. of BOD removed, and 80 percent volatile solids, the weight of secondary sludge would be:

$$\frac{0.85 \times 1147 \times 0.5}{0.80} = 609 \text{ lbs. of solids produced per million gallons applied}$$

In addition to this secondary sludge, there would be added ferric chloride ($FeCl_3$) (and perhaps a polymer) for further phosphorus removal, and this would generate ferric phosphate ($FePO_4$) along with the biological sludge. Because phosphorus levels will be less that 4 mg/l after the primary lime clarification, $FeCl_3$ doses of between 5 and 10 mg/l (as Fe^{+3}) will probably be sufficient for phosphorus removal. This addition will result in about a 20 percent increase in solids mass over the 609 pounds estimated in the activated sludge process alone, or 120 pounds additional solids per million gallons. Assuming a solids content of .75 percent for this sludge, volume generated would be as follows:

$$\frac{609 + 120}{1.02 \times 8.34 \times .0075} = 11,426 \text{ gals per million gallons}$$

Table 23 is a summary of sludge mass and volume which may be expected in the treatment processes proposed.

TABLE 23

WASTE SLUDGE GENERATION

PROCESS	MASS (lbs per million gallons)	VOLUME (gals per million gallons)	ASSUMED SOLIDS CONTENT (per cent)
Primary w/o chemicals	1,084	3,186	4.0
Secondary Biological w/o chemicals	720	11,285	0.75
Primary w/lime	3,500	5,878	7.0
Secondary Biological w/$FeCl_3$	729	11,426	0.75
Nitrification Aeration	0	0	0
Denitrification Reactor	146	2,288	0.75

d. Sludge Thickening

In wastewater treatment it is desirable to have a sludge with as high a solids content as possible. A sludge with solids content of 1 percent is 5 times as voluminous as a 5 percent sludge (for the same amount of solids). With a thicker sludge, there is less water to pump and store in the sludge treatment facilities, and less volume for ultimate disposal. The process of reducing water content in sludge generally proceeds in two stages: sludge thickening and sludge dewatering. The distinction between thickening and dewatering is that in the latter, the sludge is processed into a non fluid form.

The three types of sludge thickening devices that will be discussed are gravity thickening, dissolved air flotation, and centrifugation. Centrifugation is actually a combination thickening and dewatering process and will be investigated in more detail when sludge dewatering is discussed. Sludge elutriation is a combined thickening and conditioning process, but since its application is confined almost exclusively to sludge treatment after anaerobic digestion and before dewatering, it will be discussed later in this report when anaerobic digestion is considered.

(1) Gravity Thickening

A gravity sludge thickener usually consists of a tank equipped with revolving raking arms. These stir the sludge slowly, releasing entrapped gases and water. The unit operates like a clarifier: the supernatant is returned to the primary treatment units and the thickened sludge that collects on the bottom of the tank is pumped either to disposal or to additional treatment. Typical loading rates for primary and waste activated sludges are in the order of 8 to 12 lbs. of sludge solids per square foot per day. Gravity thickening has been successfully practiced for many years. When combined primary and secondary sludges are processed by gravity thickening, total sludge volume can be expected to result in sludges of approximately 4 percent (or even higher) solids representing (using the quantities of sludge determined for primary and secondary treatment developed in Table 2) a volume of 5,300 gals of sludge from the influent 14,470 gallons. This is a significant volume reduction, and the savings achieved in sludge handling can more than pay for the capital and operating costs of the sludge thickener.

(2) Air Flotation

Air flotation thickeners are used primarily with waste activated sludge and are capable of producing a sludge with 4 percent solids content. Concentrations of 6 percent are possible with mixtures of primary and waste activated sludges. In contrast to gravity thickening where sludge solids fall to the bottom of the thickening tank, the objective of flotation thickening is to attach a minute air bubble to suspended solids and thereby cause the solids to float to the water surface. The most common type of flotation for sludge thickening is dissolved air pressure flotation. Air is dissolved into a sludge dilution feed or combined dilution liquid and sludge feed under a pressure of from 40 to 60 psi. Upon release of the liquid to the thickening tank at atmospheric pressure, air comes out of solution to form the small diameter bubbles which attach themselves to the sludge solids. The use of a cationic polyelectrolyte or other flocculant can significantly increase the efficiency of flotation thickening.

(3) Centrifugation

The centrifugation process has been used for many years to thicken and dewater industrial sludges. Centrifuges used in modern day treatment plants are of the solid bowl type with electric motor drive. Sludge is fed into a rotating bowl where it is separated into a mass containing solids and a dilute centrate. The centrate is returned to the influent of the treatment plant. A centrifuge is capable of dewatering activated sludges from less than 1 percent to 6 or 7 percent solids, a mixture of primary and secondary sludges can be thickened to greater than 10 percent solids. Even higher solids concentrations are possible, but solids capture (the amount of fine suspended solids contained in the centrate) decreases markedly and can result in a significant loading upon the plant when centrate is returned to the headworks. The practical limit of solids concentration in dilute activated sludge is therefore about 7 percent. Normally, chemical flocculating agents are employed with centrifuges.

Summary

The selection of sludge thickening methods depends very much upon the type of sludge to be dewatered, and the subsequent sludge disposal processes which are to be utilized.

Gravity thickening has been proven to be an effective way of thickening mixed sludges at low operating costs. Dilute sludges, as for example biological and many chemical sludges (including iron and aluminum sludges) are not effectively thickened in a gravity thickener. Because of the low loading rates and the stirring equipment required, gravity thickening has a higher capital cost than most other sludge thickening methods. When properly operated, the overflow from a gravity thickener has concentrations of BOD and SPS equivalent to raw sewage and when this overflow is returned to the influent of the treatment plant, it should not represent an operational problem.

Air flotation thickening will not operate effectively unless raw sludge concentrations are low enough to allow the flotation process to operate. In a typical mixture of primary and secondary sludges, the raw sludge will probably require dilution before air flotation. The process has shown its value for thickening dilute sludges to concentrations higher than is possible in gravity thickening tanks. On the other hand, using mixed primary and secondary sludges, the performance of air flotation thickeners is reportedly not significantly better than gravity thickeners. For primary and activated sludges, loadings in the order of 20-30 lbs per square foot per day are possible for flotation thickeners. This results in lower capital costs than gravity thickeners, although higher operation costs and total costs.

Flotation thickening has the added disadvantage of being more dependent upon sludge characteristics and more sensitive to changes in these characteristics than gravity thickening. While chemical flocculants can on occassion be successfully employed in gravity thickening, they are much more commonly required for flotation thickening, and can represent a large additional cost of sludge processing. In comparison, then, with gravity thickening, flotation is not as simple, dependable, or economical. Its use is best confined to thickening very dilute activated or chemical waste sludges.

The operation of centrifuges is straightforward and clean. The units are flexible and self-contained, and the capital cost is low in comparison to other thickening methods. The major problem in the operation of centrifuges is their poor solids-capture ratio in dilute sludges. The resulting centrate, which is high in suspended, non-settling solids can impose a large burden upon the treatment works when recycled. Chemicals can be used to coagulate the sludge ($FeCl_3$ and lime or organic polymers) and thereby increase the solids-capture ratio but such chemical additions add to the cost of sludge treatment. Generally speaking the thickening of waste activated sludge can still be done best by air flotation, and of mixed primary and waste activated sludge by gravity thickening. The application of centrifuges to dewatering (as opposed to thickening) has a very promising future. Dewatering techniques will be discussed in later in this section.

e. Waste Sludge Stabilization

Methods of sludge disposal include land spreading, ocean dumping, incineration and pyrolysis. It will be noted that in the first two of the above methods, it is generally essential that organic material in the sludge be reduced in order that the disposal process not create nuisance conditions; the latter two disposal methods utilize the organics in the sludge and therefore their removal should not be a part of sludge pretreatment. The reduction of organic material in sludge is termed sludge stabilization and it should be used wherever the mode of ultimate disposal might result in odor or other nuisance conditions if stabilization were not performed. The types of stabilization that will be considered are anaerobic digestion, aerobic digestion, chemical stabilization and thermal conditioning.

(1) Anaerobic Digestion

Anaerobic digestion is a process of decomposition in a closed usually air-tight tank. The process is accompanied by liquefaction, production of gas and stabilization of organic matter. Digestion is usually carried on at temperatures of about 95° F. In the tank the digested solids settle to the bottom, a layer of scum floats to the top of the liquid and a relatively clear but strong liquid termed supernatant occupies the middle portion of the tank.

Gas, primarily methane and carbon dioxide, and small amounts of ammonia and hydrogen and hydrogen sulfide produced in the fermentation process accumulate at the top of the tank. There are two main categories of digestion processes, conventional and high rate.

While some small conventional facilities utilize a single stage process (in which mixing, digestion, stratification and storage are accomplished in a single tank), the majority of conventional and all high rate processes utilize a two stage process consisting of two tanks in series. The first tank is used for digestion and is equipped with mixing facilities; the second is used for storage and concentration of digested sludge and for formation of supernatant.

In the majority of primary treatment plants constructed in the past, anaerobic digestion was included as a primary part of sludge handling and disposal. The major reason for digester installations has been to remove organics from the sludge and thereby render it amenable to ultimate disposal. Digestion stabilizes from 50 to 75 percent of the organics, and decreases the quantity of pathogens in the sludge. Well digested sludge has a characteristic and not objectionable tarry odor, and can be disposed of by inexpensive land or ocean disposal. Other advantages of anaerobic sludge treatment include a decrease in sludge volume and the production of methane as a byproduct of sludge fermentation.

Digesters are not presently as widely used in wastewater treatment as they once were. There are three reasons for this: (1) different types of wastewater treatment are used, and (2) different methods of ultimate sludge disposal are feasible at present then when the use of digesters became widespread, and (3) many operational problems are encountered in the operation of digesters.

When most digesters were constructed, the predominant type of wastewater treatment was primary clarification; at present, secondary treatment is in most areas the minimum level of treatment allowed. The character and quantity of sludges generated in primary and secondary treatment are tremendously different. The use of sludge digestion in a secondary plant means that digesters must be at least twice as large as those

needed for a primary plant. The digestion process, in addition, has undesirable effects upon the dewatering characteristics of activated sludges. Digestion has been shown to increase the quantity of fines and colloidal material and the bicarbonate concentration of free water in the sludge. The effect of the increased fine material is to cause the digester supernatant (which is recycled to the treatment plant) to impose an additional load upon the facility; the increase in bicarbonate alkalinity results in a much higher flocculant demand (the quantity of chemicals required) for the sludge to be dewatered efficiently.

Dewatering characteristics of digested sludge can be improved significantly by elutriation, which is a sludge washing operation intended to remove sludge constituents which interfere with dewatering processes. Elutriation is especially important for vacuum filtration of digested activated sludge. Elutriation dilutes the bicarbonate concentration of the sludge and washes out gas bubbles and fines formed during digestion. But apart from the additional cost of elutriation, the process has the additional disadvantage of separating these fine materials from the sludge and causing them to be recycled to the treatment plant where they can impose a significant load to the plant or can flow through the plant and to the plant effluent. Nitrogen and phosphorous in wastewater sludge is released to the treatment plant in the digester supernatant and ultimately into the receiving stream. And because digested sludge gives up these nutrients, the final sludge has significantly less value as a fertilizer than it would otherwise.

Digestion is primarily a means of reducing the organics in sludge which can cause problems in land or ocean disposal, and it is apparent that if the sludge is to be incinerated or pyrolyzed, the organics are valuable, and it makes no sense to destroy them. The types of disposal for which digestion was important are becoming less common. Ocean dumping of sludge is becoming less acceptable from an environmental point of view, and there are indications that the practice may be eliminated in the future; similarly dumping of sludge to land fill is being seriously questioned. In addition available land areas suitable for land fill are becoming more difficult to find and more costly to acquire for sludge disposal purposes. Methods of sludge disposal will be discussed in a later section. At this point, it will only be stated that incineration of sludge has become an increasingly common

disposal method in the last few years, and if land disposal of sludge in agricultural applications is practiced, the decrease in nitrogen and phosphorous levels in the sludge as a result of digestion is undesirable, especially since stabilization of the organics in the sludge could be accomplished using lime which would have additional benefits as a soil conditioner.

Perhaps the most serious objection to anaerobic sludge digestion lies in the operating difficulties which are commonly encountered in the units. The operation problems are caused by the slow growth rate of the microorganisms responsible for anaerobic decomposition which renders the process susceptible to all manner of upsets. To quote one reference:

> In regard to operational problems, digestion (and digesters) are usually the operators' biggest headache, they require a lot of attention... For example: digesters get 'sick', they foam, they require liming; grit removal is a major operation; gas production falls off, odor problems arise because the sludge is incompletely digested; scum blankets form; mechanical mixers corrode; and sludge does not thicken. (1)

When a serious upset occurs, digestion capacity can be lost for several months while foul smelling sludge is removed from the digestion tanks. There is probably no other plant operation which is more involved and miserable.

(2) Aerobic Digestion

Aerobic digestion is a relatively new method for treating waste activated sludge. It is based on the principle that biological cells will use their own cell material and dead cells present as food if there is no external source of food in their environment. This growth phase is termed endogenous respiration. Note

(1) A Study of Sludge Handling and Disposal: R.S. Burd; FWPCA publication WP-20-4, May, 1968.

that the process is primarily intended to treat activated sludges and not highly organic primary sludges where large quantities of oxygen are required to oxidize materials.

Specific advantages of aerobic digestion include the following:

1. Volatile solids reduction approximately equal to that obtained anaerobically.

2. Relatively simple to operate.

3. Supernatant is relatively clear, has low BOD, ammonia and phosphorus levels (although high nitrate levels), which should impose no burden upon the treatment plant.

4. Sludge produced is odorless, humus-like with excellent dewatering characteristics. Less of the phosphorus and nitrogen are lost from the sludge (higher value as a fertilizer) and pathogens are reduced to a low level.

5. Capital costs are much less than anaerobic digestion. because the shorter digestion period results in smaller facilities.

The major disadvantage of the process includes the high power cost associated with supplying the required oxygen and the unclear design parameters at present, and the highly nitrified sludge resulting from the process.

Note that the comments made previously in the discussion of anaerobic digestion questioning the necessity for sludge digestion if certain types of ultimate disposal are contemplated apply equally for aerobic digestion. Note too that the combination of low capital and high operating costs will tend to favor the application of aerobic digestion to relatively small treatment facilities. (In this regard, it will also be appreciated that small treatment plants are most likely to have the type of activated sludge process resulting in the maximum quantities of activated sludges most amenable to aerobic treatment). Finally, since anaerobic digestion works best with primary sludges and aerobic with activated sludges, the most economical sludge disposal system might be one in which primary and secondary sludges are handled separately. This is especially true in a plant with existing anaerobic digesters.

(3) Chemical Stabilization

Chemicals are commonly added to sludge in order to condition it for sludge thickening and dewatering. Chemicals, however, are also used to stabilze sludge by either oxidizing the objectionable organic material or rendering it unobjectionable. The most common chemical used for the first objective is chlorine; for the latter, lime.

Chlorine Oxidation

There are a number of plants in operation treating combined primary and secondary, excess activated, or septic tank sludge by chlorine oxidation. Chlorine is capable of rapidly converting highly organic sludge into inert material. The process stabilizes, coagulates and deodorizes in one operation; no sludge pretreatment is required, and once treated, the sludge will not reputresce. Treated sludge is bleached by the chlorine to a light buff color, inert and odor free. pH after treatment is between 2.5 and 4.5; for this reason lime is usually added to the sludge before land disposal. The sludge is reportedly easy to dewater on sand beds although, without chemical or polymer conditioning, difficult to dewater on vacuum filters. Chlorine requirements for chemical oxidation are high, about 2,000 mg/l for primary, 2,500 for mixed primary and secondary sludges and 600 to 1,000 mg/l for waste activated sludge (depending upon whether primary clarification is used.) Time required for complete treatment varies between one and one half to two minutes.

One of the most severe limitations of the chlorine oxidation process is the supernatant from the treated sludge. Not long ago the chemical composition of the supernatant in comparison with anaerobic digester supernatant was considered an asset to the treatment operation. The supernatant from chlorinated sludge has pH typically between 3 and 5, and large quantities of chloramines and choro-organic components. These substances do not interfere with biological treatment but they are conservative through it. They are also highly toxic to many aquatic organisms and not acceptable for discharge from a treatment plant. Removal of chloro-organic com compounds from wastewater can be accomplished using carbon adsorption; most treatment plants however, are not equipped with these units.

If a satisfactory method of treating the process supernatant is available, the method has definite advantages over anaerobic digestion. The technique is especially suitable where ultimate disposal of the sludge will be accomplished by landfill after sand drying, as highly chlorinated sludge would probably have no agricultural use. These restrictions, together with the high operating cost of the process (consisting primarily of the cost of chlorine, which has been in short supply and increasing in price over the past year) pretty much limit optimum applications of the process to small installations.

Lime Stabilization

The increase of pH in sludge to 11 or 11.5 stabilizes organics as long as the pH remains elevated. In addition, elevation of pH to 11 for 24 hours is a highly effective method of killing pathogens. Lime addition to the sludge is the most common method of raising pH, and has the added advantage of conditioning the sludge for dewatering. Vacuum filtration and centrifugation are both especially effective on limed sludge; in addition, limed sludge dewaters without odors on sand beds, although the lime does decrease the speed of the drying process.

Lime addition to undigested sludge and subsequent disposal in landfill is especially attractive if there is adequate land available or if there is available some agricultural use of the sludge. The need of costly digestion facilities is eliminated and the lime allows the sludge to be dewatered mechanically or on sand beds.

Caution should be used in application of sludge stabilized by pH increase to avoid disposal in thick layers. Should pH drop because lime is leached from the sludge because of the rinsing action of direct rainfall and runoff,the biological activity that could occur would result in byproducts similar to those obtained in anaerobic digestion, including such odorous gases as hydrogen sulfide and a highly organic subnatant which might be carried into and pollute the adjacent ground water. Nonetheless, we feel that carefully controlled chemical stabilization of sludge with subsequent disposal to landfill or application to agricultural lands is the best approach where land disposal is desired.

(4) Thermal Processing

The following discussion will deal with thermal processing of sludge at very high temperature and pressure to stabilize sludge by near complete destruction (80-90 percent) of putrescrible matter. As such it perhaps should be thought of in the same kind of terms as are the various incineration processes. We have not done so in this discussion because the "ash" obtained from wet air oxidation is a slurry and therefore either requires additional dewatering or disposal of large sludge volumes.

The wet oxidation process is based on the discovery that any substance capable of burning can be oxidized in the presence of liquid water at temperatures between 250°F and 700°F. The process is uniquely suited to the treatment of difficult-to-dewater waste liquors and sludges where the solids are but a few percent of the water streams. In general, given the proper temperature, pressure, reaction time, and sufficient compressed air or oxygen, any degree of oxidation can be accomplished.

This process has been commercialized and patented as the Zimmerman or Zimpro process. This process has also been known as wet incineration, wet combustion and wet air oxidation. Wet air oxidation does not require preliminary dewatering or drying when compared to the conventional flash combustion. Water can be present up to 99% in this process whereas in conventional combustion it must be reduced to about 75%, or auxiliary fuel must be added.

Another significant difference is the flameless oxidation of the organics at low temperatures of 250°F to 700°F when compared to 1500° to 2700°F in the conventional combustion processes. Air pollution is controlled because the oxidation takes place in water at low temperatures and no fly ash, dust, sulfur dioxide or nitrogen oxides are formed.

In a continuous wet air oxidation process, the sludge is passed through a grinder which reduces particles to about 1/4 in. size. Sludge and air are then pumped into the system and the mixture is passed through heat exchangers and brought to the initiating reaction temperature.

As oxidation takes place in the reactor, the temperature increases. The oxidized products leaving the reactor are cooled in the heat exchanges against the entering cold sludge and air. The gases are separated from the liquid carrying the residual oxidized solids and released through a pressure control valve to a catalytic oxidation unit for complete odor control. Where economic conditions make it attractive, the gases may be expanded in power recovery equipment before being discharged. The oxidized liquid and remaining suspended solids are released through a level control valve and the solids may be separated by settling and drainage in lagoons or beds, or by mechanical dewatering and disposal by landfill.

For startup, heat is obtained from an outside source, usually a small steam generator. With high degree oxidations and high fuel value sludges, no external heat is needed once the process is started. Whenever the process is not thermally self-sustaining, steam may be injected continuously to sustain the reaction temperature.

The advantages of wet oxidation have been reported to be: sterile end products low in volume and of special value as a soil amendment are produced; fly ash or dust are not produced as the oxidation take place in the presence of water. Wet air oxidation renders sewage sludge easily dewaterable by filtration or settling without chemical conditioning; the system permits a clean, sanitary plant without exposure of operating personnel to obnoxious unsterilized sludge solids; wet air oxidation has the flexibility of handling any type of sludge using a wide range of oxidation conditions, producing a variety of end products; land and building area requirements are minimal; and the oxidation units can be integrated into existing facilities with digesters, vacuum filters or incinerators to increase the sludge-handling capacity.

The major disadvantage associated with wet oxidation is the cost of construction and operation. This system is generally the most expensive of the sludge handling processes considered in the design of sewage treatment plants. Other disadvantages include the need for high quality and constant supervision and maintenance because of the complex equipment and controls. Scaling in heat exchangers and piping has been

a problem with wet air oxidation, although it is reported that this can be controlled by preconditioning sludge with ammonia or soda ash. Then too, the process effluent, containing very high BOD must be recycled to the treatment plant where it places an additional burden upon the treatment facility and can degrade the plant effluent. Finally, the final ash resulting from the process requires further treatment before final disposal and the process does not approach the degree of destruction of organic matter achieved in dry combustion.

f. Sludge Dewatering

Sludge dewatering in contrast to thickening is defined as water reduction which changes the physical form of the sludge from primarily a liquid (capable of being pumped) to a solid. The purpose of dewatering is to decrease sludge volume if the sludge is to be disposed of in landfill or to reduce water content to allow autogenous combustion to take place.

Additives are frequently used to improve the flocculant characteristics of sludges and thereby improve the efficiency of the dewatering process. Such inorganic chemicals as lime, ferric chloride and alum have been used with some although by no means universal effectiveness. Recently, the use of organic polymers has increased both as supplements to and substitutes for inorganic chemicals. One of the big advantages of polymers over say, lime, is the relatively small quantity of polymer required compared with the large amount of lime necessary for sludge conditioning. Conditioning chemicals have been known to account for up to 40 percent of the total dry solids weight of the sludge. Other materials, such as fly ash or tree bark have been used as dewatering aids, however these are pretty much limited to specific situations where such a material is readily available.

No specific recommendations can be made for conditioning chemicals, as selection should be based on laboratory and pilot plant studies. Lime is perhaps the most commonly used chemical, because it is fairly dependable, relatively inexpensive and, although it increases the mass of sludge solids for disposal more than most other chemicals, the sludge stabilization effected by the lime addition (because of pH elevation) and the beneficial effect of limed sludge for agricultural use increases the attractiveness of lime as a conditioning chemcial.

(1) Sludge Drying on Sand Beds

Sand beds are the most common and least costly method of dewatering sludge in the United States and many other parts of the world. It is a common misconception that the use of sand beds is confined to small treatment facilities; in fact they are used in many large treatment plants. Sand beds are the least costly dewatering method and they will continue to be used where feasible.

Sand bed dewatering of sludge takes place both by filtration of water down through the sand and evaporation from the surface of the beds. Filtration is thought to be the dominant mechanism for the first several days and the mechanism responsible for the greatest water loss; evaporation continues for the remainder of the drying period resulting in additional small decreases in water content.

Dewatering characteristics for sand drying of sludge can be improved by the addition of sludge conditioners; alum is widely reported to be the most effective chemical; ferric chloride and polymers have also been used with some success. It will be remembered from previous discussions that, on the advice of the Corps of Engineers, the use of aluminum compounds such as alum were eliminated from consideration because of plant toxicity to aluminum. It is interesting to note that lime, which has been mentioned previously as an effective sludge conditioner for mechanical dewatering, soil stabilizer, and, which has been recommended for phosphorus precipitation, is generally not effective for sand drying because the lime has a tendency to decrease drainage (filtration) through the sludge.

Digestion is generally required before drying on sand beds in order to stabilize the organic material. Both anaerobic and aerobic digestion conditions sludge to dewater well on sand beds; anaerobic sludge has the additional advantage of allowing the sludge to be stored for several months during periods when weather is not suitable for process. Air dried sludge has solids of between 25 and 30 percent; the sludge after drying can be hauled to landfill or incinerated or heat dried and sold as soil conditioner.

(2) Vacuum Filtration

In the past decade, vacuum filtration of sludge has become the most common method of mechanical dewatering Filters are effective with all types of sewage sludge. In most instances, the chemical conditioning requirements for sludge dewatering are such that the sludge is stabilized and the need for expensive digestion is eliminated. In fact, the capital costs of vacuum filtration is generally less than that of digestion and dewatering on sand beds (although operating costs are higher). Other reported advantages of vacuum filtration include the small space required by this dewatering method, the relatively (compared with digestion) trouble-free operation of the filters, the consistent quality of the dry filter cake and the good solids capture in the units. Sludge dewatered on vacuum filters will have about 25 percent solids content.

There are disadvantages of vacuum filters which require that their application be carefully considered before selection of the units. High operation costs, resulting primarily from chemical conditioning costs, have been reported as well as operational problems with certain types of filters, clogging of filter media the requirement by most regulatory agencies that duplicate dewatering facilities be provided, odor problems when dewatering raw sludge, and lack of efficiency when dewatering anaerobically digested sludge. It is important to note that some of the problems result from improper or inappropriate use of the filters. For example, vacuum filters are known not to operate well on digested waste activated sludge, and odors from raw sludge will be a problem is an alkaline environment at high pH is not maintained in the sludge.

(3) Centrifugation

While centrifugation as a means of solid liquid separation is by no means a new process, its application in wastewater treatment is not as widespread as vacuum filtration. Nonetheless, because of recent improvements in centrifuge technology, centrifugation can be expected to be increasingly competitive with vacuum filtration in the future. Specific advantages claimed for centrifuges include their lower capital cost compared with vacuum filters or sludge digestion and drying beds. In addition the units are flexible and require less operating supervision than

digesters or vacuum filters. Disadvantages of centrifuges which continue to restrict their use are the poor solids capture without chemical conditioning and high maintenance costs for the units. Chemical conditioning of the sludge can increase the performance of the units with respect to solids capture and sludge solids content to almost any degree desired; however, this results in large chemical additions and attendant high chemical costs. Centrifuges are especially useful for fibrous and lime sludges for which their performance is excellent; they will likely remain restricted to these applications until design improvements are made to increase their efficiency on dilute sludges.

Summary

There are a number of sludge dewatering or conditioning and dewatering processes which have been investigated in an attempt to find a more efficient method of separating the solid and liquid portions of a sludge. A not comprehensive list of these techniques would include sludge pressing, freezing, heat treatment, electrical treatment and screening.

Sludge pressing, while common in Europe has not been successful in this country, reportedly for two major reasons: (1) the sludge is not sufficiently dried and (2) the solids capture of the units are poor. Some of the other methods have been tried and found unsuccessful; others, on the basis of preliminary tests, appear promising. None at this time however, can be considered competitive with the more conventional methods described earlier because there is not the body of operating data on the processes which is necessary for a valid comparison to be made.

Of the three conventional methods of sludge dewatering, it is considered that vacuum filtration has the greatest applicability to the types of wastewater sludges expected in wastewater treatment in the Merrimack Valley. The method offers the optimum combination of low operating costs and trouble free operation, predictable dewatering performance, high solids capture and operating flexibility. It is felt that these advantages outweigh the higher initial expenditure required for the units.

g. Sludge Disposal

In previous sections of this report, we have indicated that in the operation of a municipal wastewater treatment plant large quantitites of waste sludges are generated. The handling and disposal of these sludges consumes a sizable percentage of the effort expended in the treatment operation. The amounts and characteristics of the waste sludges which are expected as a result of the proposed wastewater management systems along the Merrimack River have been estimated, and various sludge handling techniques were discussed with a view to finding optimum methods for decreasing water content, stabilizing organics, and destroying pathogens in the sludge. Even after this is done, however, some method must be found to dispose of, or better, to utilize this stabilized material. Several methods of disposal will be investigated in this section. Ideally the method should have some element of reuse or resource recovery within it; but at the very least, it should not endanger public health, should be aesthetically acceptable, and should not have a dileterious effect upon the plant, animal and aquatic life forms in the area. Disposal of waste sludge on land should not infringe excessively upon future land use and development for commercial, residential, industrial and recreational purposes. Sludge disposal mechanisms should also ensure that there will be no degradation of surface or ground water quality in the area. And sludge disposal practices must not abate the land and water pollution problem by unduly increasing air pollution in the area.

Three broad categories of ultimate disposal will be included in this discussion including land and ocean disposal, multiple hearth incineration and pyrolysis. It should be perhaps indicated that neither inceneration nor pyrolysis are in a strict sense ultimate disposal methods since a quantity of inert ash or char remains for disposal. Nonetheless, the volume of residue (estimated at between 5 and 20 percent of the solids fed to the reactor) is so reduced and the material so innocuous that disposal of this ash can be accomplished by dumping with little environmental impact.

Under each category of land or atmospheric disposal there are two or more possible approaches. As we have indicated at several points during the course of the previous discussion, the methods of thickening, conditioning and dewatering will depend in large part upon which method of disposal is selected.

(1) Land Disposal

(a) Dumping

Unrestricted land dumping is a satisfactory method of dumping only for sludges which have been stabilized. This includes both aerobically and anaerobically digested sludges and chemically stabilized sludges, although chemically stabilized sludges must be dumped in such a way that the chemical stabilizer will not be washed from the sludge. Note too that the free water contained in digested sludge is high in nutrients and BOD and can be a source of ground water pollution in an area if not carefully controlled. One of the means available to reduce the possible pollutional effects from land disposal of the sludge is to create an impermeable membrane between the sludge deposited and the surrounding soil. Incinerator residue or the char resulting from pyrolysis can generally be disposed of safely by land dumping. It should be mentioned that the Environmental Protection Agency is planning to establish guidelines regulating land disposal of sludges based on the maintenance of certain ground water requirements. Some of these criteria, in particular nitrate limitations, may be incompatible with land dumping of sludges.

(b) Land Fill

A sanitary landfill may be used for disposal of either stabilized or non stabilized sludges. The difference between a sanitary landfill and a dumping operation is that the former is more carefully controlled: the sludge is compacted and covered with a layer of soil after placement. The effect of the soil cover is to eliminate nuisance conditions such as odors and flies.

Although the pollution potential from a land filling operation is less than that possible with dumping the same general cautions are applicable (as are possible requirements for artificial liners for the disposal area.) Basically, the problem with any method of intense application of sludge to land disposal is that the high organic and nutrient loadings of the leachate from a sludge will almost certainly exceed the fixing capacity of the soil and result in increasing ground water concentration of such constituents as nitrates, phosphates and soluble BOD. Whether the increase in levels stays within acceptable limits depends very much upon the acceptable limits finally determined (these have at this

date, not been finally determined), the actual interpretation of the limits (near the disposal site or same distance from it), and the characteristics of the disposal site.

(c) Soil Spreading for Agricultural Use

Disposal of wastes by returning them to the soil is an ancient practice which over the years has experienced periods of popularity followed by periods of disfavor. The increasing popularity among ecologists, environmentalists and others for the utilization of natural or organic materials makes this a period of increasing interest in such methods of disposal.

The concept of using the soil as a receptacle for wastes is based on the soil being a natural body at the earth's surface that supports or is capable of supporting plant growth. The soil environment consists of mineral matter, organic matter, biological populations, water solutions and air in a dynamic system undergoing continual change. Soils have properties that enable it to serve as an assimilator of wastes by filtering, buffering, absorbing, adsorbing and transforming both chemically and biologically waste materials. Soil also supports plant life that can re-use nutrients contained in wastes.

While, in a sense, the soil system is capable of "treating" sludge, the sludge itself can be beneficial, in turn, to the soil by supplying nutrients, organic material, and conditioners which can upgrade a poor soil and render it more effective for plant growth or increase existing yields of harvestable crops. The most important point concerning beneficial sludge application is that a budget must be established whereby the requirements of the soil system for supplying nutrients to plant growth is matched to the application of nutrients contained in the sludge.

Due to the presence of pathogens and other disease-causing organisms in the sewage sludge, the sludge is stabilized and sometimes disinfected before spreading it on land. Several references on anaerobically digested stabilized sludge state that the pathogen populations are reduced. Indications are that most pathogens die quickly in the soil, but some may live for several weeks. Chemical stabilization using lime to raise

the pH to 11.0 for 24 hours has been effective in stabilizing sludge and killing pathogens in the laboratory. In connection with this, lime sludge has promoted the growth of grass in short-term greenhouse studies and is expected to have long-term results beneficial to soils particularly where acid soil conditions exist.

Loading rates for soil conditioner and fertilizer applications range from 0.5 to 300 tons of solids per acre per year with 10 to 25 tons per acre per year typical for average conditions. These loading rates require a substantial amount of crop land and a suitable system for distribution and spreading of the sludge to the land. A recent large scale application of this method is the plan of the Metropolitan Sanitary District of Chicago to pump digested sludge from two existing treatment facilities to 50,000 acres of cropland. District studies indicate that total disposal costs will be $22 per ton of dry solids to dispose of sludge in this way. It is clear that unless suitable farmland is located immediately adjacent to the treatment facility, a large scale agricultural operation would be required to justify the pipeline or shipment costs involved. There is serious question whether the agricultural need for this type of large scale operation exists in the New England area.

(2) Ocean Disposal

Disposal of digested sludge at sea is used by many large coastal cities. The sludge may be transported in barges and dumped, or it may be pumped to deep water through a submarine outfall. Successful disposal of sludge in the ocean requires careful design of the outfall line if pumping is used and in all cases, the impact of dumping upon public health and the marine biota must be determined. There is some evidence to indicate that dumping of sludge by large cities along the Northeastern Atlantic coast is having a detrimental effect upon the receiving water, there are some indications that ocean dumping may not be allowed in the future.

(3) Incineration

(a) General

The purpose of incineration for the disposal of waste sludge is to achieve destruction of the volatile organic matter,

a reduction in the volume of waste materials and production of an end product which can be easily and readily disposed of without creating a nuisance, endangering the public health or creating any adverse effects on the quality of the environment. The incineration process may be divided into the two phases of drying and combustion. The drying step should not be confused with preliminary dewatering which proceeds the incineration process.

The drying phase consists of the following: raising the temperature of the feed sludge to 212°F, evaporating the water from the sludge and increasing the water vapor and air temperature of the gas. In the combustion phase, the temperature of the dried sludge volatile matter is raised to the ignition point and burned. The drying and combustion may be performed successively in the same unit or separately in different equipment units. Manufacturers have developed widely varying types of sludge drying and combustion equipment for incinerator processes, including traveling grate furnaces, rotary kiln type furnaces, atomized spray units, flash drying units, multiple hearth furnaces and fluidized bed units. Of these, the last two have been the most widely used for waste sludge incineration.

(b) Multiple Hearth Incineration

The multiple hearth incinerator is the most popular sewage sludge incinerator in use today, having been employed in more than 100 installations.

The unit consists of a circular steel shell surrounding a number of solid refractory hearths and a central rotating shaft to which rabble arms are attached. Since the operating capacity of these units is related to the total area of the enclosed hearths, they are designed with various diameters and a varying number of hearths, usually between four and twelve. Each hearth has openings that allow the sludge to be dropped to the next lower hearth.

The central shaft and rabble arms are cooled by air supplied in regulated quantity and pressure from a blower discharging air into a housing at the bottom of the shaft. An annular space between the inner "cold air tube" and the outer

wall of the shaft exposed to incinerator heat serves as a conduit for hot air. Rabbling is very important to combustion because it breaks up the large sludge particles, thereby exposing more surface area to the hot incinerator gases that induce rapid and complete combustion.

Partially dewatered sludge is continuously fed to the upper hearths which form a drying and cooling zone. Here, vaporization of some free moisture occurs as well as cooling of exhaust gases, all by transfer of heat from the hot gases to the sludge.

Intermediate hearths form a high temperature burning zone, or combustion chamber zone, where all volatile gases and solids are burned. Combustion of most of the total fixed carbon takes place on the lowest hearth of the combustion zone.

The bottom hearth of the incinerator functions as a cooling and air-preheating zone where ash is cooled by giving up heat to the shaft cooling air which is returned to the unit in this zone. Incinerator temperatures range from 1,000°F on the top hearths to 1,600 - 1,800°F on the middle hearths to 600°F at the bottom. In many incinerators the waste gases from combustion are heated to 1,250°F or higher to guard against odor nuisance. Exhaust gases leaving the incinerator at the top are scrubbed in a wet scrubber to remove fly ash.

The ash discharged from multiple hearth incinerators is essentially free of all organic solids; therefore, nuisance problems are not expected.

Multiple hearth incinerators may also be operated as sludge dryers. When operated for drying, the flow of sludge and the rabbling action are identical to incineration procedures. Modifications to the basic unit design include fuel burners at the top and bottom hearths plus down-drafting of the gases. As the solids move downward through the unit, the gases become cooler and the solids become drier. At the point of exit from the furnace, the gas temperature is about 325°F and the solids temperature about 100°F.

The multiple hearth unit has become the most popular incinerator for sewage sludge incinerator because of its many advantages: its established reliability, simplicity of operation

ruggedness, adaptability to automation, ability to accept sludge of any reasonable moisture content, and its ability to accomplish nearly complete organic destruction in one operation. Disadvantages of the system include its generally high capital cost (especially for small operations), start up and shut down time requirements and its requirement of large quantities of excess air for combustion (which must be cleaned). With regard to air pollution, however, we should point out that all testing that we have seen indicates that multiple hearth furnaces equipped with suitable dust collectors or scrubber devices are capable of complying with all present or proposed air quality codes, provided they are properly operated.

(c) Fluidized Bed Incineration

Fluidized bed incineration of sewage sludge is a fairly recent development. It employs a fluid bed technique in which sludge and sand particles are suspended in an upward stream of gases causing the mixture to behave much like a liquid. The solids in the mixture are said to be fluidized, and their circulating action is similar to that of boiling water. The operation of the incinerator is frequently described as follows: Solids are extruded into the incinerator operating at a pressure of about 2 psi and a temperature of 1,400 - 1,500°F. They are retained in the bed until the rapid combustion reduces them to an inert ash. Sludge is not fed to the reactor until the fluidized sand bed is heated to a temperature of 1,250°F or higher. At this temperature, the sludge quickly dries and burns, thereby maintaining the bed temperature. The ash is removed from the fluidized bed by the upward flowing combustion gases.

Gases released from thermal oxidation of the solids are scrubbed and cooled in wet gas scrubbing equipment using general treatment plant effluent as the scrubbing medium. The method of disposal of inert solids contained in the scrubber water depends on local conditions. Ash solids can be separated from the liquid in a hydrocyclone, if necessary, and the liquid can be returned to the raw waste stream or recycled to the scrubber.

The economy of the fluidized bed system is a function of the percentage of excess air; therefore, automatic controls are used to keep the excess air at about 20 percent. This

minimizes the loss of input heat and reduces the fuel demand. An air preheater is an optional piece of equipment which can reduce the auxiliary fuel cost. The air preheater could represent 15 percent of a fluidized-bed plant's investment, so its cost must be compared with the economics of using additional auxiliary fuel.

Temperatures from 1,250°F to 1,400°F have eliminated stack gas odor. The use of automatic devices to control combustion after start-up maintains optimum combustion conditions with a minimum of attention. An oxygen analyzer in the stack controls the air rate into the reactor and the auxiliary fuel feed rate is controlled by a temperature recorder. Shut down controls for emergency situations further decrease the need for operator attention.

Specific advantages of fluidized bed incineration include the following: heat retention of the sand bed minimizes start up time for intermittent operation, there are no moving parts in the incinerator, much less excess air is required than with multiple hearth incineration so air emissions are very low and lower capital cost than multiple hearth furnaces. The disadvantages center primarily about the necessity of dewatering sludges to greater than 30 percent solids prior to incineration. If this is not done, operating costs are very high.

(d) Flash Drying with Incineration

A flash drying process involves two independent steps. First, the dewatered sludge feed is mixed with dry sludge to reduce its moisture content. Then, the mixture is fed into the drying system where it moves at a velocity of several thousand feet per minute in a stream of gas having a temperature of about 1,100°F. The sludge passes through this high temperature-turbulent zone in a few seconds during which time the moisture is reduced to about 10 percent. Heat dried sludge is separated from the gases and vapors in a cyclone separater.

The fluffy, dried sludge produced by the flash dryer is blown into an incinerator in a manner similar to that of powdered fuel. Temperatures near 1,400°F are usually maintained for deodorization. The heat of combustion is used in the drying operation.

Advantages of flash drying include the flexibility of being able to either utilize the dried sludge as a soil conditioner or to incinerate it. Disadvantages include the necessity of deodorizing the drying gas, the explosion and fire danger present in the flash drying device, the large quantities of excess air required, the need for scrubbing units on both the dryer and incinerator, and the greater complexity required in a two stage operation. The biggest disadvantage of the process is the lack of any established fertilizer market for the dried sewage sludge. Without a market for the sludge, the flexibility of the process has no use.

There is a situation, however, where drying and incineration of sludge would appear to be an economically attractive proposition and this would occur where an inexpensive source of heat is available to dry the sludge and deodorize the stack gases resulting from the processes.

An incineration system capable of handling a combination of sewage sludge and municipal refuse could supply this heat and in addition, serve as the nucleus of a municipal or even regional solution to the total waste disposal problem. The incineration plant, in addition to drying sludge and incinerating unused sludge and solid waste can be utilized as a regional salvage and separation area where cardboard, paper, rags, glass and metals can be removed from the solid waste for salvage and recycle.

There does not exist a large amount of useful cost data on such installations because they are still relatively rare, and because actual operating costs are based on not only the type of waste sludge (which are predictable) but also upon the character and quantity of dry waste, details of dry waste collection in the areas served by the facility, and market utilization potential of recycled material and process by products. Such variables are difficult to generalize into typical installations, and therefore, to determine costs for this type of disposal method, each situation must be analyzed for its particular process variables. From preliminary investigations, it does appear that costs for the drying and wastewater sludge portion of the incineration process can be somewhat lower in a well run sludge and solid waste incinerator than those of multiple hearth incineration. Operating costs for fuel for the drying /incinerating process are lower than with any other type of sludge incineration system, and in addition, the large incinerator required for solid waste disposal should allow significant saving in operating labor to be realized.

In the final analysis, combined wastewater sludge and solid waste handling is economically justified only if a municipality or region is considering incineration of its solid waste. Just as sludge disposal is most economically accomplished by hauling to a local landfill/dump, so too is solid waste disposal, and incineration is considered in both cases only when continued landfill is no longer feasible or desirable. It is not known if this is the situation within the study area. It is reasonable clear however, that a regional approach or even a municipal approach to combined solid and sewage waste would require an amount of co-ordination among governmental agencies and planning effort far greater than that required for simply a solution to the excess wastewater sludge disposal problem.

(4) Pyrolysis

Pyrolysis is not specifically a method of disposing of sewage sludge but rather a method of stabilizing and decreasing the volume of solid municipal wastes. The idea is basically that wastewater sludges could be added to solid wastes and would contribute to the pyrolysis process.

Pyrolysis differs from incineration in that it involves heating without oxygen. In pyrolysis, the organic portion of solid waste is distilled into lower molecular weight compounds such as gas, tar, oil, organic compounds and char by controlling temperature and oxygen levels in the heating units. It has the advantages over incineration of eliminating air pollution (because reaction takes place in a closed system) and allowing the recovery from waste of useful byproducts.

Research on pyrolysis has been underway for some time and results to this time have been promising. An in depth appraisal of the application of pyrolysis to wastewater sludge must of necessity await the availability of more data regarding the efficiency of the process to solid waste. At this point little more can be done than to indicate that the process should be investigated, perhaps in a demonstration facility within the study area. Preliminary information on several pyrolysis systems and the quantities of wastewater sludges and solid waste from one study area are included in another section of this report in the hope that this information will assist in the determination of feasibility of such a demonstration facility. It should be pointed out that the pyrolysing of solid and sewage wastes is similar in concept to the regional sludge drying and incineration proposal in that there are many variables affecting the economy.

and feasibility of the process which are unknown to us, and in any case, such a plan would entail far more governmental/planning effort than would a more self-contained solution.

Summary

It is proposed to estimate costs for ultimate sludge disposal on the basis of multiple hearth incineration. We are doing this because of the two proven incineration methods available, we believe the multiple hearth process has the optimum combination of advantages particularly in the mixed primary and biological sludges expected from treatment. We expect the major portion of the ash from multiple hearth incineration will be disposed of in land fill, possibilities for utilization of the ash exist, for example for conditioning of thickened sludge, and these should be investigated.

h. Conclusions

Quantities and characteristics of waste sludges have been estimated for the wastewater treatment processes consisting of primary clarification, secondary aeration and settling, nitrification, denitrification and chemical coagulation and precipitation for phosphorus removal.

A generalized sludge handling program has been proposed. The proposed treatment consists of gravity thickening, chemical conditioning and subsequent vacuum filtration, and multiple hearth incineration with disposal of ash to land fill.

Gravity thickening was shown to be the most satisfactory method of dewatering mixed primary and secondary sludge; flotation thickening is a useful tool for dewatering dilute sludges and centrifugation for dense raw sludges.

Anaerobic digestion has fallen into disfavor because the increasing prevalence of secondary treatment, and incineration. Supernatant from anaerobic digesters exerts a large loading upon the treatment plant, anaerobically digested biological sludge

does not dewater well without costly conditioning (elutriation), and the closed digesters are difficult to operate and subject to all manner of upsets. Aerobic digestion is easier to operate and substantially eliminates the other disadvantages of anaerobic digestion; the process is, however, expensive to operate and therefore probably limited to small plants. Chemical stabilization with lime is an inexpensive process which enables the sludge to be dewatered more easily, and substantially eliminates pathogenic organisms and odor and other nuisance problems.

Vacuum filtration was selected as the optimum method of sludge dewatering. Sludge drying beds are less costly to operate than mechanical dewatering systems, but the land areas required for the beds will increasingly make this disposal method less practiced. Centrifuges have lower capital costs and are simple to operate; they do, however, have poor solids capture with mixed biological and primary sludges if high solids content in the sludges is desired. Vacuum filters work especially well with lime stabilized mixed primary and waste activated sludge, have good solids capture, and reasonable operating costs. From the above treatment operation, sludge after thickening should be about 4 to 5 percent solids; after thickening solids contents are in the order of 25 percent.

Multiple hearth incineration is recommended for ultimate disposal of the sludge. Land filling or lagooning of raw wastes is the least costly method of disposal; however land areas for such use are becoming scarce and nuisance and environmental problems of such dumping are coming under ever closer scrutiny. Land availability and environmental concern are also factors mitigating against the disposal of stabilized sludge by dumping or landfill. And there are indications that ocean dumping may in the near future be prohibited. Spreading of sludge on agricultural land such that the nutrients in the sludge are utilized for soil conditioning has a beneficial effect on land and can be economically feasible if suitable farm land exists near a treatment facility or if the operation is large enough to justify transport of the sludge to suitable areas. There is considerable doubt whether either of these situations exist to any large degree within the study area.

Of the several types of incineration systems studied, multiple hearth was selected because of its established performance and reliability. The concept of a combined

municipal solid waste and wastewater sludge incineration or pyrolysis facility was briefly examined. The idea has much merit but its feasibility depends upon factors outside the realm of wastewater treatment, factors which because of their uncertainty are beyond the scope of this study.

Costs associated with sludge thickening, chemical conditioning and dewatering have been estimated and included in the costs of treatment processes outlined in previous sections of this appendix. Costs for incineration of the waste sludges is presented in Figures 25 and 26 for both best available and best practicable treatment and for advanced treatment consisting of primary treatment with lime addition, secondary aeration, nitrification and denitrification. Figure 25 shows capital costs for multiple hearth incineration, and Figure 26 yearly operation and maintenance charges. The latter plot includes a nominal per ton cost of disposing of incinerator ash in a landfill.

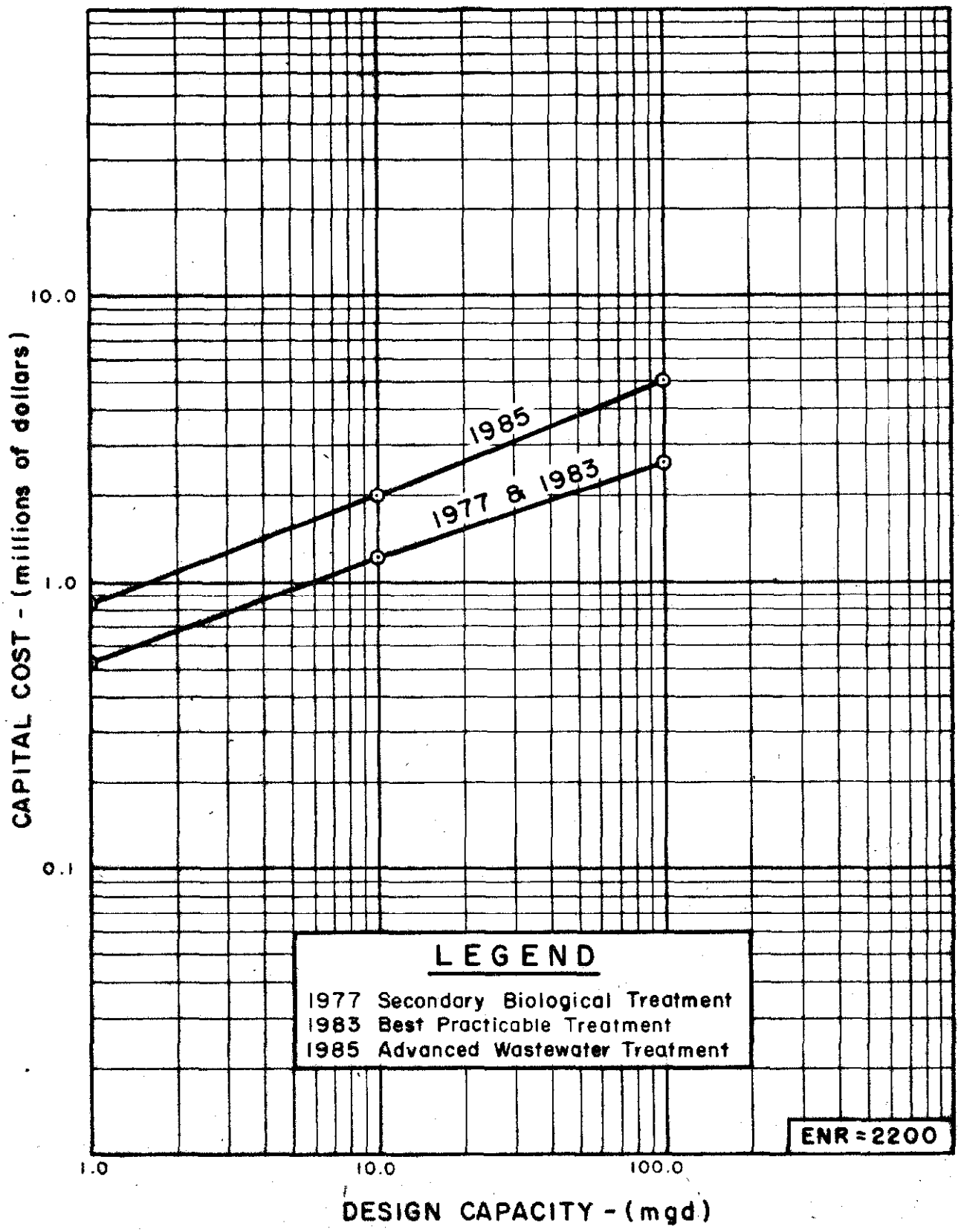


FIGURE 25 Construction Costs - Multiple Hearth Incineration

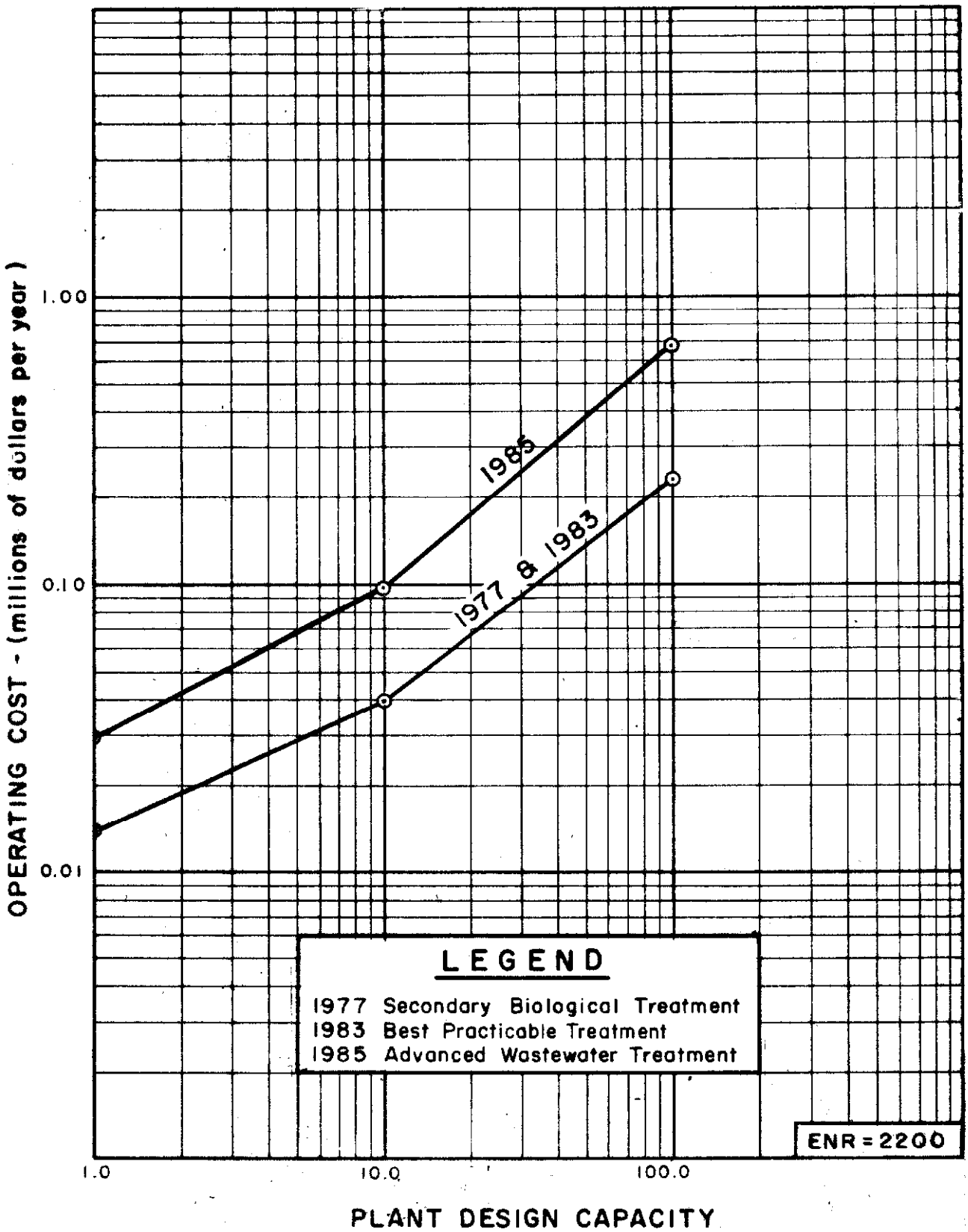


FIGURE 26 Yearly Operating Costs - Multiple Hearth Incineration

7. SEPTIC WASTE TREATMENT

Appendix I discussed the current and future use in portions of the Northern Middlesex Area and Merrimack Valley Planning Commissions of private subsurface wastewater disposal systems consisting of septic tanks and leaching fields or of cesspools. In that discussion, it was recommended that septic tank systems be inspected every year, but that with adequately sized tanks, pumping would only be necessary every three to five years.

The disposal of the septic sludge pumped from septic tanks is a major potential source of pollution which to this time, has received little attention in water quality planning. A rural community of 1,000 homes, for example, might generate approximately one 1,000 gallon truckload of septage each day. Formerly, and to a large degree, even at present, handling of septage has been a haphazard operation. In some areas (not specifically within the study area), the tank trucks (generally called honey wagons) are illegally emptied by simply discharging into the most convenient water course; in other areas the waste is spread onto land or buried at some municipally designated area frequently located near a solid waste disposal site.

The undesirable effects of disposing of septage into streams or brooks should be obvious enough not to require comment. Disposal of septage by land spreading or burying results in less immediate environmental degradation; however, on a long term basis, such disposal poses odor and insect problems, and contamination of first ground water and eventually surface water near the disposal area.

In those areas where a wastewater treatment facility is available, it is becoming increasingly common for septage to be brought to the facility and treated, and for this reason, it is important that the handling and treatment of septic wastes be given consideration in the design of future wastewater treatment facilities. Without adequate provision for the acceptance of septic wastes, the introduction of even a relatively small quantity into the headworks of a wastewater treatment facility can cause serious disruption in the operation of the treatment works. This is because the organic loading from a typical 1,000 gallon load of septic tank sludge is the loading equivalent of several hundred people, and this load can be introduced into the treatment plant

over a period of several minutes. Table 24 is a summary showing typical values of BOD, COD, solids, and nitrogen for septage and septic waste supernatant. The plant overloading resulting from a large quantity of such a strong waste can have a devastating effect upon wastewater treatment.

There exist two generally acceptable approaches for treatment of septic wastes: the most commonly used technique involves the holding of septic waste and the continuous, regulated feeding of these wastes into the headworks of a treatment plant; the other technique bypasses the conventional treatment processes, and directs the septage either with or without some sort of pretreatment to the sludge disposal facilities of a treatment plant. Typical pretreatment processes in the latter technique include degritting, comminution and reduction of oxygen demand and water content of the sludge. Supernatant from the septic waste is recycled to the headworks of the treatment facility where it undergoes conventional secondary treatment.

Provided that a reasonably uniform schedule of septic waste delivery can be assured, the most straightforward treatment method for septic waste involves simply holding the wastes and allowing them to be bled slowly into the treatment plant flow. Such a system is desirable because of its simplicity: little more than a waste holding tank and pump, as well as provisions for chlorination, are required; the septic waste can then be added into the waste stream of the plant and degritted, comminuted, settled and aerated utilizing existing facilities into which increased solids and BOD capacity should be designed. We have been advised by the Division of Water Pollution Control of the Commonwealth that this method of handling septic wastes in Massachusetts appears to be the best at this time. However, there is not a large number of plants with this type of system and consequently operational records are short-term.

BOD of the septic wastes can be reduced by both biological or chemical means. When the septage is continuously fed to the treatment facility, it undergoes biological (or chemical in a P-C plant) degradation along with the wastewater in the treatment facility. Because 1,000 gallons of septic waste are approximately equal in solids and organic loading to 10,000 to 50,000 gallons of typical domestic wastewater, those treatment units designed on the basis of solids loading or oxygen demand (for example aeration tanks and sludge handling facilities) must be modified to accept this additional loading. Treatment units designed on the basis of hydraulic loadings: for example comminution facilities, clarifiers and conduits need not generally be modified to accomodate septage

TABLE 24
SEPTIC WASTE EFFLUENT

	Median	Mean	75% Less Than	Ultimate Value
Percent solids	2.24	1.45	3.5	14
BOD-septage	4,794	2,912	6,300	14,000
BOD-supernatant	1,948	1,528	2,600	5,000
Total Suspended Solids	2,350	2,302	3,100	6,800
COD septage	26,162	16,803	34,000	55,000
COD supernatant	6,343	5,280	9,500	17,000
Free Ammonia	72	62	95	140
Organic Nitrogen	26	12	40	130

Note: All values in mg/l.

John J. Kolega, "Design Curves for Septage," Water and Sewage Works, May 1971.

since the additional hydraulic loading of septage is minimal. In biological treatment, increased BOD can be handled by either increasing the size of aeration tanks, or by inserting a BOD roughing process ahead of conventional aeration. For example, if septic wastes constituted 25 to 50 percent of the organic loading into a plant, the addition of a packed plastic media roughing (trickling) filter would reduce BOD concentrations in the wastewater to those typically encountered in domestic wastewater. In physical-chemical plants, this reduction would probably be best accomplished by increasing the dosage of chemicals applied to the wastewater flow.

It will be noted from Table 24 that a large proportion of the BOD and COD of septic wastes is associated with the solids present in the septage, and it follows that the clarification and removal of these solids from the waste stream would significantly decrease BOD loading upon the plant. It is, therefore, highly advantageous that the treatment step proposed for septic wastes include the preliminary treatment step of primary clarification. Whether this is desirable depends upon subsequent handling of the sludge: if it is to be chemically stabilized or incinerated, then it is inefficient to do more than settle these suspended solids in the plant. If a sophisticated sludge handling system is not to be used (as for example in a small plant, where sludge is air dried on sand beds) then aeration and biological degradation of the suspended solids is needed to avoid nuisance problems in disposal of the sludge.

It appears from the limited amount of data available from Table 24 that except for COD, septic waste will have its greatest impact upon design of the treatment plant in the treatment processes generally associated with secondary treatment. Table 24 shows that mean Kjeldahl nitrogen (ammonia and organic nitrogen) in septage is about three times higher than in domestic wastewater, as compared to the ten or more times difference between solids and BOD of wastewater and septic wastes. When the comparatively small volumetric flow of septic wastes is introduced into the treatment plant, relatively modest additional facilities for nitrification will have to be added to accommodate the septic waste, and while little data are available showing phosphorus levels in septic wastes, we feel that they would similarly not introduce a significant loading into the plant unless septic wastes became a significant portion of treatment plant flow.

The ratio of COD to BOD is much higher in septic wastes than

in domestic wastewater. The actual composition of the constituents in the septic waste COD is not known, and without this knowledge, it is impossible to estimate the efficiency of biological treatment upon the waste. It is considered that only a small portion of the high COD shown in Table 24 is standard 5-day BOD and nitrogenous oxygen demand from the ammonia and organic nitrogen. If the COD is caused by a significant amount of refractory material which has accumulated in the septic waste, and if such septic wastes constitute a significant amount of the total loading into a facility, then biological treatment alone will not be sufficient to reduce COD concentrations to those normally encountered in secondary effluent from a biological plant and some type of physical-chemical treatment (chemical coagulation, carbon filtration, etc) will be required.

The second method of handling septage utilizes the treatment facility for only the supernatant or filtrate of the septic waste. The septage is stored in a blending/holding tank and then thickened and/or chemically treated; because of the highly anaerobic nature of the wastes, biological stabilization of concentrated septage is generally not economically feasible. The principal type of stabilization employed is chlorine oxidation: large doses (in excess of 500-800 mg/l) are added to the septic wastes and the chlorine oxidizes the organics in the waste. The sludge thus stabilized has no objectionable odor and can be dewatered without nuisance, and disposed of by landfill or incineration. The supernatant or filtrate from the sludge has a low pH (3.0), a BOD of 200 mg/l, and suspended solids content of 300 mg/l. After neutralization, the filtrate can be discharged to the treatment plant where it will exert no extraordinary organic loading or detrimental effect upon the treatment facility.

There does exist, however, the possibility that the production of chloramines and other compounds (caused by the reaction between ammonia and organics in the septage and chlorine) may render the effluent unacceptable for discharge to a water course. While such compounds have been shown not to affect biological treatment processes nor to be affected by them, they are toxic to certain types of aquatic life, and depending upon the quantity of septic wastes introduced into the plant, the level of chloramines in the effluent might be unacceptably high. If this is the case, it would be necessary to remove these compounds; this would be accomplished by carbon filtration at the conclusion of the conventional treatment processes.

CONCLUSIONS

On the basis of investigations, it has been concluded that in those situations where septic wastes represent a small (20 percent or less) portion of the total wastewater loading into a plant, treatment of these wastes can be effectively accomplished by carefully regulated bleeding of the wastes into the treatment plant flow. However, whenever septic wastes constitute a significant portion of the loading upon a wastewater treatment plant, there is some indication that acceptable reductions of chemical oxygen demand might not be achieved in a biological plant. In these situations, consideration should be given to some type of refractory organic removal system in the biological plant (if it desired to treat the septage along with the wastewater), or installation of a separate system employing chemical oxidation for stabilization of the sludge. It would further appear that in those situations where ultimate disposal of the waste sludge will be accomplished by complete destruction (for example, incineration, wet oxidation, or pyrolysis), it is wise to attempt to clarify the septic wastes before they are subjected to biological treatment. When sludge is to be dried and disposed of by landfill and no chemical treatment is to be given, it is probably best to subject the septage to the complete biological process and allow maximum oxidation of the sludge to take place.

8. INDUSTRIAL WASTEWATER TREATMENT

a. Pretreatment for Publicly-Owned Treatment Works

The 1977 and 1983 discharge limitations apply only to wastewater from publicly owned treatment works. Following this discussion can be found an investigation of the composition and separate treatment of industrial wastes. But for those situations in which joint[1] treatment is to be performed, the constituents in industrial wastewater must be compatible with those for which the treatment plant has been designed. Compatible is defined in the EPA Federal Guidelines entitled "Pretreatment of Pollutants Introduced into Publicly Owned Treatment Works" as follows:

> Compatible Pollutant. Biochemical oxygen demand, suspended solids, pH, and fecal coliform bacteria, plus additional pollutants identified in the NPDES permit if the publicly owned treatment works was designed to treat such pollutants, and in fact does remove such pollutants to a substantial degree. The term substantial degree is not subject to precise definition, but generally contemplates removals in the order of 80 percent or greater. Minor incidental removals in the order of 10 to 30 percent are not considered substantial. Examples of additional pollutants which may be considered compatible include:
>
> - Chemical oxygen demand
> - Total organic carbon
> - Phosphorus and Phosphorus compounds
> - Nitrogen and nitrogen compounds
> - Fats, oils, and greases of animal or vegetable origin (except as prohibited where these materials would interfere with the operation of the publicly owned treatment works).

Incompatible can mean pollutants which, either by quality or quantity would interfere with the operation of the publicly owned treatment works, or which would not be adequately treated in a plant and result in unacceptable discharge from the treatment works. It will probably be to the advantage of a particular industry, if it has a wastestream with a compatible pollutant, to

[1]joint treatment is defined as including treatment works for both non-industrial and industrial wastewater.

send the flow to the joint facility without pretreatment, and make any private arrangement with the sewer district that may be required for the additional cost of treating the waste. For this study, however, it was assumed that industrial wastewater flow with higher than average[1] compatible contaminants would receive pretreatment to decrease levels to acceptable amounts. This was done because it is not possible to determine the effect upon these constituents which would result from (1) in-house process modifications, which will become increasingly common once an industry is required to assume the responsibility and costs of treating its wastewater and (2) the effect upon compatible pollutants when pretreatment is performed to remove incompatible pollutants.

Joint treatment is of course not possible for wastewater containing incompatible pollutants. Incompatible implies that the constituent would be harmful to either the treatment process or to the receiving stream. The EPA (in the publication cited previously) has tabulated characteristic pollutants from the major types of industries (paper, textiles, metal finishing, leather and tanning industries, etc.) as follows:

Characteristics

Flow	Turbidity
BOD	Explosives
TSS	Dissolved Gases
TDS	Detergents
COD	Foaming
Grit	Heavy Metals
Cyanide	Colloidal Solids
Chlorine Demand	Volatile Organics
pH	Pesticides
Color	Phosphorus
Nitrogen	Oil and Grease
Temperature	Coliform (Fecal)
Phenol	Coliform (Total)
Sulfides	

Some of the above pollutants are compatible with certain types of joint treatment; as a basic rule it might be said that any which are not compatible with municipal wastewater treatment or

[1] BOD_5, 250 mg/l; SS, 200 mg/l; TKN 35 mg/l; NH_3-N, 15 mg/l; PO_4-P, 15 mg/l.

which are determined to be environmentally harmful in the wastewater effluent would require pretreatment. The determination of what is environmentally harmful is being discussed in Appendix IV of this study. For purposes of the conceptual design of wastewater treatment systems, it was assumed that treatment of the inorganic chemicals typically found in wastewater at concentrations equal to or less than those permissible for the 1985 Stage I (drinking water-modified) effluent limitations would not be required, and that industrial flow will be allowed into the municipal wastewater system only after satisfactory pretreatment of these constituents down to the levels encountered in domestic wastewater. Acceptable limits of incompatible contaminants is probably well approximated by Table 1, "Surface Water Criteria for Public Water Supplies" from the Report of the Committee on Water Quality Criteria,[1] which is reproduced here as Table 25.

[1]Federal Water Pollution Control, April 1, 1968.

TABLE 25

Surface Water Criteria for Public Water Supplies

Constituent or characteristic	Permissible criteria	Desirable criteria	Paragraph
Physical:			
Color (color units)	75	<10	1
Odor	Narrative	Virtually absent	2
Temperature *	do	Narrative	3
Turbidity	do	Virtually absent	4
Microbiological:			
Coliform organisms	10,000/100 ml [1]	<100/100 ml [1]	5
Fecal coliforms	2,000/100 ml [1]	<20/100 ml [1]	5
Inorganic chemicals:	(mg/l)	(mg/l)	
Alkalinity	Narrative	Narrative	6
Ammonia	0.5 (as N)	<0.01	7
Arsenic *	0.05	Absent	8
Barium *	1.0	do	8
Boron *	1.0	do	9
Cadmium *	0.01	do	8
Chloride *	250	<25	8
Chromium,* hexavalent	0.05	Absent	8
Copper *	1.0	Virtually absent	8
Dissolved oxygen	≥4 (monthly mean) ≥3 (individual sample)	Near saturation	10
Fluoride *	Narrative	Narrative	11
Hardness *	do	do	12
Iron (filterable)	0.3	Virtually absent	8
Lead *	0.05	Absent	8
Manganese * (filterable)	0.05	do	8
Nitrates plus nitrites *	10 (as N)	Virtually absent	13
pH (range)	6.0–8.5	Narrative	14
Phosphorus *	Narrative	do	15
Selenium *	0.01	Absent	8
Silver *	0.05	do	8
Sulfate *	250	<50	8
Total dissolved solids * (filterable residue).	500	<200	16
Uranyl ion *	5	Absent	17
Zinc *	5	Virtually absent	8
Organic chemicals:			
Carbon chloroform extract * (CCE)	0.15	<0.04	18
Cyanide *	0.20	Absent	8
Methylene blue active substances *	0.5	Virtually absent	19
Oil and grease *	Virtually absent	Absent	20
Pesticides:			
Aldrin *	0.017	do	21
Chlordane *	0.003	do	21
DDT *	0.042	do	21
Dieldrin *	0.017	do	21
Endrin *	0.001	do	21
Heptachlor *	0.018	do	21
Heptachlor epoxide *	0.018	do	21
Lindane *	0.056	do	21
Methoxychlor *	0.035	do	21
Organic phosphates plus carbamates.*	0.1 [2]	do	21
Toxaphene *	0.005	do	8
Herbicides:			
2,4-D plus 2,4,5-T, plus 2,4,5-TP *	0.1	do	21
Phenols *	0.001	do	8
Radioactivity:	(pc/l)	(pc/l)	
Gross beta *	1,000	<100	8
Radium-226 *	3	<1	8
Strontium-90 *	10	<2	8

* The defined treatment process has little effect on this constituent.

[1] Microbiological limits are monthly arithmetic averages based upon an adequate number of samples. Total coliform limit may be relaxed if fecal coliform concentration does not exceed the specified limit.

[2] As parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures. See par. 21.

b. Industrial Waste Treatment Designs

PAPER MANUFACTURING

I. INTRODUCTION

There are at present ten mills, producing diverse paper products which discharge their effluent, directly or indirectly, into the Merrimack River Basin within Massachusetts. Four mills manufacture various combinations of printing, business, reproduction, and hanging paper; two produce paper board; and one each for kraft, filter and saturating, coating, and stereotype dry mats. There are no pulp mills within the boundaries, and therefore treatment of wastes from these sources will not be discussed here. We attempt instead to summarize the sources of pollution from the paper making process itself; the principal problems they lead to; the methods used to cope with them; and the probable directions that improvements must come from in the future.

Reduced to its elements, paper making consists first of preparing a thin suspension of fibers in water, a highly developed art, and then dewatering them under closely controlled conditions, usually on extremely sophisticated machinery. A variety of additives is employed to impart particular properties to the product. Masselli, et al. (1) describe paper making in a summary from which we quote in the following section.

II. PAPER MAKING

Process Description

In paper making a dilute slurry of fibers (2000 to 5000 mg/l; 17 to 42 lbs/1000 gallons) is placed over a filtering device to allow passage of the water and formation of a thin mat of fibers. Before this, however, considerable work must be done on the fiber to insure proper conditions for the kind of paper desired.

Stock preparation includes operations on the pulp to separate it into loose fibers of desired length, strength, density, opacity and freeness and to put it into slurry form so that it may be readily transported through various operations and finally to the machine. Additives may be used to make the paper water-and-ink resistant, opaque, smooth, dense, colored, and to increase its wet strength. Furnish

is a term applied to the water slurry of fibers and chemicals which finally is transported to the paper machine.

Pulp or waste paper used for furnish-making is first broken up into fiber bundles in breaker beaters or hydropulpers. Generally a 5 to 8% water slurry (100-165°F) is prepared. Preliminary screening or refining removes large fiber bundles, dirt or other extraneous materials. In many instances the slurry may be diluted before such screening to approximately 1% pulp and then be reconcentrated to 5 to 12% by thickeners and to 30% by pressing. The slurry is then processed in secondary beaters or refiners to produce desired fiber characteristics.

Beating and refining are essentially the same and are done to increase the fiber surface and its flexibility and to decrease its length. The water of hydration is increased, causing swelling and a less "free" fiber, along with increased bursting, tensile and folding properties. On the other hand, the tear, stretch, opacity, brightness and porosity are decreased. Prolonged beating (24 to 48 hours) will produce a completely transparent paper (glassine) when it is calendared. Additives -- particularly rosin, alum, starch, clay and other pigments -- may be added during beating to prepare the furnish which is then dumped into stock chests, usually at 3% solids concentration. Before delivery to the paper machine, this slurry is diluted to 0.2-0.5% total solids, pumped through finishing jordans and given a final screening for dirt removal.

Paper forming may be carried out in either of two ways -- on a fourdrinier machine or on a cylinder machine. In the fourdrinier the dilute slurry is pumped to a headbox from which it flows in a thin stream through a narrow opening called a "slice" onto a revolving wire screen. Part of the pulp remains on the screen as a mat and part passes through with the water. A vigorous sidewise shaking aids in formation of the mat and once formed, care is taken not to disturb it while removing the water from it. This is done by means of several table rolls which support the wire near the headbox and by suction boxes with flat perforated tops for water removal. From the suction boxes the sheet and wire move to the couch (pronounced cooch) where the wire returns downward to the headbox and the sheet, now unsupported, jumps a short gap to the press section. Fourdrinier machines may be very wide (up to 345 inches) and move at very high speeds (up to 2500 feet per minute).

The cylinder machine consists of one or more cylinder vats. In each vat a wire cylinder rotates in a dilute stock slurry. The natural head of pressure forces the slurry through the wire, forming a wet web that is picked up by an endless woolen felt which is pressed against the top of the cylinder by means of a rubber roll. In machines with more than one cylinder the same felt picks up succeeding wet webs and laminates them together by pressing. In this manner very heavy sheets or boards can be formed in machines having up to ten vats. White or colored furnish can be supplied to the end vats to form any color board, and the middle or filler vats may use cheap filler furnishes. Cylinder machines are limited in width (up to 200 inches) and speed (up to 800 feet per minute).

From the wet end of either machine the wet sheet is carried by woolen felts through a series of press rolls where more water is removed. The sheet is then threaded through the drier section which consists of a series of highly-polished, steam-heated cylinder rolls which reduce the moisture to 4 to 8%. Coatings may be put on the paper at this stage.

After drying the sheet surface is smoothed in a calendar stack consisting of a vertical row of highly polished cast iron rolls. The paper is wound on large rolls at the reel and then re-wound and slit into final rolls or cut into sheets and trimmed to desired size.

Essentially the same pulping, refining and machinery is used for the production of heavy boards. The machines move more slowly (5-45 feet per minute) and coarser wire is used. The wet-felted sheets may be dried in tunnel kilns, steam-platen driers or continuous roller-dryers.

The process is shown diagrammatically in Figure 27.

Process Chemicals

The kind of paper or board made will depend on the pulp used, the extent of beating and refining, and on the sizes, fillers, pigments, and coatings employed.

Sizing of paper is done to increase resistance to penetration by liquids, particularly water. Unsized paper (facial tissue, blotting paper, etc.) will freely absorb water. Rosin is practically always used when sizing is required but natural waxes, starches, sodium silicate, glues, casein, synthetic resins, rubber latex,

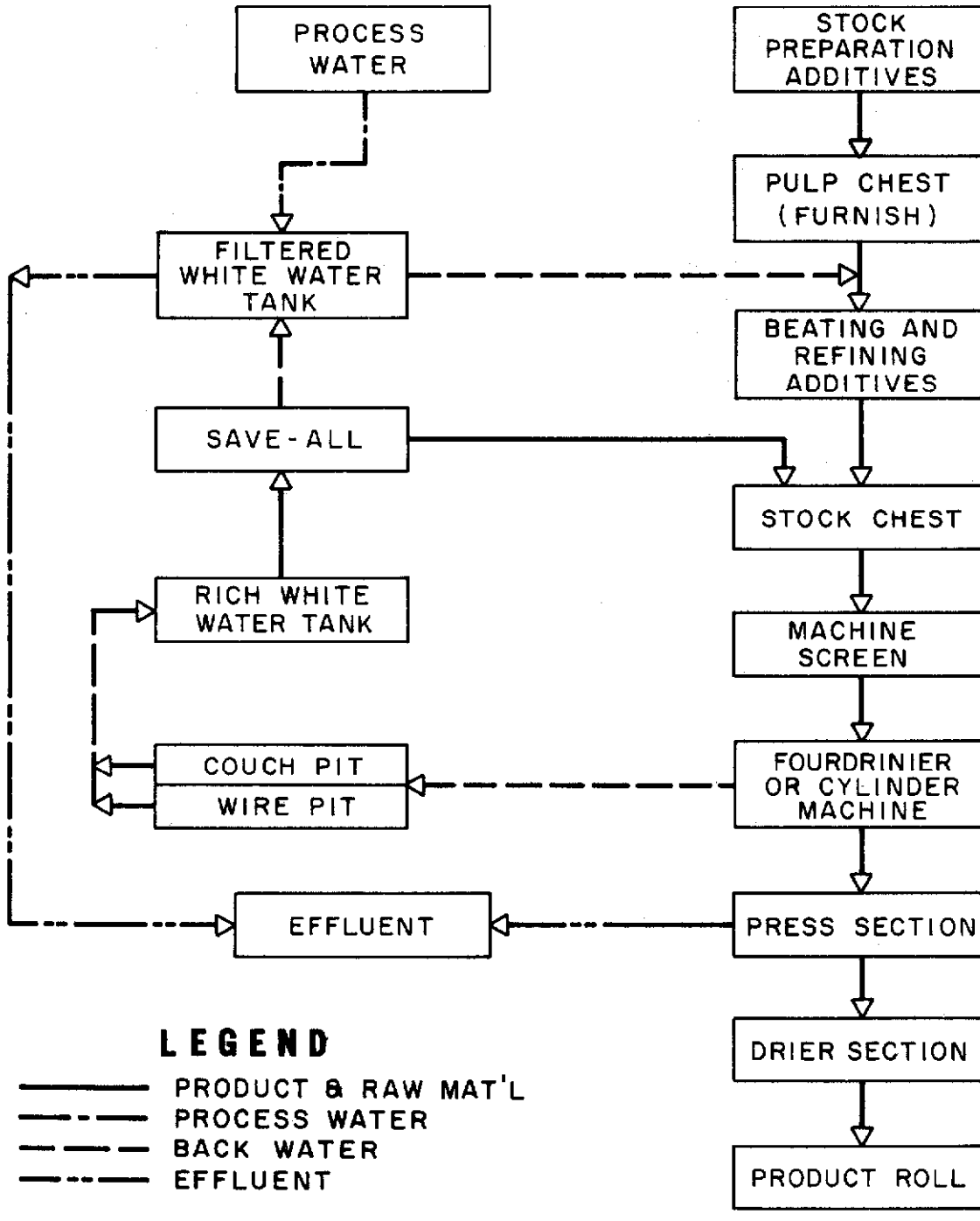


FIGURE 27 Paper Making Process Diagram.

and various hydrocarbons are also used. They may be added to the beater (stock, engine, or internal sizing) or the sheet may be run through a size solution (tub sizing) or on a roll coated with size (surface or external sizing).

Rosin is usually used internally at loadings of 0.5-3.5% based on the weight of the fiber. Alum is practically always used to precipitate ("set") the rosin as small particles or fibers which are readily absorbed or held on the pulp fibers. Alum loadings are always higher than the rosin loading and range from 0.5 to 4.5%, based on the fiber. The pH is critical and should be maintained at 4.5 to 5.5. In addition to its use as a rosin precipitant, alum is also imployed to increase filler retention, and to control foam, pitch, and sticking.

Starch may be used internally at loadings from 0.5 to 5% on weight of fiber. Its retention is difficult since it forms colloidal solutions and readily passes off with the filtered water. Because of this it should be added near the wire.

Fillers or paper loading materials are added to paper to increase opacity, brightness, flexibility, bulk, weight, softness, smoothness, ink receptivity, and printability. A filled sheet burns more slowly, is more limp, and has less tendency to curl. The sheet, however, has lower strength and a "two-sided" effect because the filler is concentrated on the top-side of the paper. Both natural and artificial fillers are used in paper making. Some of the natural substances are clay (aluminum silicate), talc (magnesium silicate), ground or burnt gypsum (calcium sulfate), barytes (barium sulfate), and chalk (calcium carbonate). Some of the artificial substances are precipitated chalk, raffold (calcium carbonate-magnesium hydroxide), basic magnesium carbonate, calcium sulfate, magnesium carbonate, blanc fixe (barium sulfate), titanium dioxide, titanium calcium pigment (titanium dioxide-calcium sulfate), zinc sulfide, lithopone (30% zinc sulfide-70% barium sulfate), and titanated lithopone (82% lithopone-18% titanium dioxide).

Fillers are often added dry to the beater but they also may be added to the stock chests, at the fan pump or at the wire. The problem of retention is a difficult one and is closely watched in all mills, particularly when expensive fillers are being used.

Calcium silicate-fibrous filler, made by impregnating well-fibrillated cellulose fibers with calcium chloride and then adding sodium silicate to precipitate calcium silicate within the pores of the fiber, may be used as a pigment filler at 2 to 4% loadings. It causes improvement in brightness, opacity, bulk, permeability, absorbency, softness, and tear-strength. The dried product is 20% cellulose -- 80% calcium silicate.

Barium sulfate use in paper making is very limited and is used in special printing papers that are required to lie very flat. It has a high specific gravity resulting in poor retention and tends to make the paper two-sided.

Calcium carbonate use is second only to clay in the paper industry. It is used to impart whiteness, brightness, opacity, and ink receptivity and to lower the furnish cost. It may contain some magnesium hydroxide and basic carbonate. It is practically insoluble in water but imparts an alkaline reaction because of hydrolysis. It is attacked by acids, alum, and acidic sizes, liberating carbon dioxide gas and thus causing foam, pitch, and sizing problems in early applications. With proper precautions however it is now being widely used at loadings as high as 28% in magazine paper, 12% in book paper, 20% in cigarette paper, and 4 to 6% in newsprint. Retention in the web is fairly good and is better than clay in this respect.

Calcium silicate is used at 2 to 6% loadings in bond and offset paper, mimeograph and duplicator papers, uncoated book and magazine papers, newsprint, tissues and absorbent papers, and in top liners for cylinder board. It imparts opacity, brightness, softness, absorbency, and smoothness.

Calcium sulfate has been used to impart color, brightness, and feel but its solubility in water (1200-1550 mg/l) causes losses and also tends to plug machine felts.

Calcium sulfite has been used in printing, envelope, poster, label, and offset papers at loadings of 10 to 20%, mainly for brightness. It reacts with alum and other acidic compounds to liberate sulfur dioxide, however, causing corrosion and felt degradation.

Clay is the most widely used filler in paper making primarily because of its relative cheapness. It does not excel in any particular attribute but is effective in imparting opacity and printability. Clay

may be used at loadings as high as 30 to 35% in some book papers. It has a tendency to form colloidal solutions in water and imparts turbidity to the white water. Its colloidal chemistry is complex and is important when clarification of the white water is desired. Colloidal glue, cationic starch, and various gums have been used as additives to increase retention.

Diatomaceous earth usage has been increasing because it is easily retained, controls pitch, increases bulk and machine speeds, and reduces fiber and titanium dioxide needs. It can also be used as a filter aid in the filtration of white water for shower usage, the filter cake then being re-used as a filler in the furnish. Loadings of 0.5 to 5% are generally used.

Talc is used as a filler in many grades of paper and paper board because of its good retention, chemical inertness, whiteness, and brightness. Loadings of 1 to 10% are used.

Titanium pigments are finding increasing favor in paper making because of their excellent opacity, brightness, high retention, chemical inertness, non-toxicity, printability, and ready dispersibility. Loadings of 1 to 2% are used for groundwood catalog papers, 1 to 4% for magazine papers (with balance, as high as 35%, made up of clay, calcium carbonate, or both), 4 to 5% for book papers, and as much as 15% for other printing papers.

Zinc sulfide and lithopone pigments are added when color, brightness, and opacity are of prime importance. When luminescence with short after-glow (30-120 minutes) is desired specially prepared zinc sulfide with or without cadmium sulfide may be used. Longer after-glow (6-12 hours) may be obtained with specially prepared calcium and strontium sulfides.

It should be noted that all of the fillers discussed here are inorganic and have little or no biological oxygen demand. The sulfite in calcium sulfite and the sulfide in the zinc, calcium, cadmium, and strontium sulfide have a chemical oxygen demand. It is expected that the BOD contribution of the fillers in the white water wastes will be negligible.

Coating of paper has been a rapidly expanding part of the paper industry aimed at solving two of paper's short-comings in performance -- easy printability and impermeability to water, oils, vapors, and fluids. Clay coatings were first developed in the

1930's after successful application of the roll coater and the air doctor coater. Synthetic coatings started growing rapidly in the late 1940's and considerable research has been going on in this field ever since. Coatings for a high grade paper can represent 10 to 50% of the total weight and the operation may consume more chemicals than any other part of the paper making process. The best solution to the permeability and printability problem has been combination with plastics. Paper-polyethylene combinations are now being widely used for milk cartons, multi-wall bags, motor oil, frozen food packaging, etc. Other chemicals which may be used as binders or coatings are polyvinylidene chloride, polypropylene, "saran" lacquer, rubber, acrylic latex, styrene-butadiene latex, polyvinyl acetate, polyvinyl alcohol, vinylidene chloride polymers and carboxymethyl cellulose. Two newer developments are silicones and a chromium complex of a fluocarbon polymer. Some of these chemicals will prevent re-use of the paper and can complicate the pollution picture but some may reduce pollution.

It must be recalled that considerable waste paper is used in making new paper and especially boards. Consequently in reprocessing the waste paper, a considerable amount of the sizes and fillers are re-dispersed in soluble or colloidal form and become an important part of the pollution in the white water. Any or all of the materials discussed above may be present, the concentration depending on the amount in the waste stock used, the soluble or colloidal characteristics of the actual compound, and the dispersing or complexing strength of associated chemicals.

Product Description

The kinds of pulp and paper produced by the paper industry are listed in Table 26.(2) It should be noted that the industry in many instances re-uses its end-product as starting material for new production. The variety of products made by the industry is almost endless, varying from the sheerest tissue to the heaviest boards. Only broad classifications are indicated in the table and these may in turn be subdivided to indicate the varieties involved, for example wrapping paper (butcher's, bag, wax, grease-proof, glassine); tissue (facial, toilet, cigarette, tea-bag, condenser, towel, napkin, etc.).

TABLE 26

GROWTH TRENDS IN PAPER, PAPERBOARD AND WOOD PULP CAPACITY

Paper and Paperboard	Additions 1956-1971		Capacity Forecast End 1971	Additions 1972-1974 Committed		Additions 1972-1974 Committed and Tentative	
	16 Year Increase	Average Annual Growth		3 Year Increase	Average Annual Growth	3 Year Increase	Average Annual Growth
Total All Grades	27,231	3.8%	60,400	3,814	2.1%	4,187	2.3%
Total Paper	12,381	4.8	26,138	1,260	1.6	1,413	1.8
Newsprint	1,941	5.2	3,472	249	2.3	319	3.0
Printing, Writing & Related	6,319	4.5	12,519	745	1.9	774	2.0
Packaging & Ind. Conv.	1,698	2.1	5,886	30	.2	30	.2
Tissue	2,422	5.4	4,260	237	1.8	291	2.2
Total Paperboard	12,856	3.8	28,468	2,231	2.5	2,451	2.8
Unbleached Kraft	8,156	6.6	12,770	1,028	2.6	1,028	2.6
Solid Bleached	2,232	6.4	3,555	439	4.0	439	4.0
Semi-Chemical	2,595	6.6	4,058	558	4.4	778	6.0
Combination	(126)	(0.7)	8,086	205	.8	205	.8
Total Construction Paper & Board & Wet Machine Board	1,994	2.7	5,794	323	1.8	323	1.8

III. WATER REQUIREMENTS

Uses

Masselli *et al.* also describe the uses of water in the paper making process as follows:

The primary function of water in the paper mill is pulp preparation and transportation. A secondary usage is wire, felt, and cylinder cleaning, vacuum sealing, journey box lubrication and general clean-up.

In preparation-transportation, water is used with pulp slurries of 0.1 to 6%. Highest pulp concentrations are in the breaker-beater or hydropulper, usually at 4-6%, while lowest are at the machine. The gallons of water required for each ton of pulp may be calculated from the following formula:

$$\text{gallons per ton} = \frac{100 - \%\ \text{pulp}}{\%\ \text{pulp}} \times 240$$

It may thus be calculated that 239,760 gallons will be needed to transport one ton at 0.1% pulp concentrations and 3760 gallons will be needed at 6%. In most mills 5% pulp is used at the breaker beater (4560 gallons per ton) and 0.3% is used on the wire or cylinder (79,752 gallons per ton). A machine producing 120 tons per day (5 tons per hour) would need 22,800 gph at the breaker beater and 398,760 gph at the wire or approximately 9.6 million gallons per day. It is obvious that once-through usage would be costly and possible with only the largest supply sources and consequently re-usage through recycling is necessary. In practically all mills the water from the wire or cylinder is recycled to the breaker-beater and to some point before the wire for dilution purposes. Water discharged to waste in paper mills vary from 3000-20,000 gallons per ton in board mills to as high as 250,000 gallons per ton in high-grade specialty papers. If 0.3% pulp is being delivered to the machine (79,752 gallons per ton) and 3000 gallons per ton is discharged to waste, it may be seen that the water going to the wire must be re-used approximately 26 times; at 10,000 gallons per ton it will be re-used approximately 8 times. The pulp storage chests are usually rated to hold enough stock to run the machine for 30-60 minutes. Consequently if beating and refining times are short, the time of stay of the water in the mill is usually approximately an

hour. In that time, however, it is being cycled and recycled rapidly from the wire.

In addition to the pulp preparation-transportation cycle, a considerable amount of water is used for showers on the felts, cylinders, and wires. This must be relatively free of suspended solids in order to minimize clogging of the shower heads. Consequently the white water from the wire or cylinder is filtered through a save-all or filter and then used in the showers. The shower water is returned with the white water and is re-used time and again. Shower usage may amount to 25-50% of the total going to the machine (20,000 to 40,000 gallons for each ton) and usage of the white water is necessary to reduce total water consumption. Some mills use clean water, particularly as the final felt shower.

Another important use of water is for the vacuum pumps which remove the water squeezed onto the top surface of the wet web at the couch roll. Water is used to seal the ends of these squirrel-cage pumps and also to lubricate the journey box. In some mills the water used for this purpose is 20-40% of the total used. The white water vacuumed from the wet web may be kept separate from the vacuum seal and journey box water by use of a vacuum chamber for separation.

In many mills, water spray is used for foam control, particularly at the cylinder vats.

In addition to these major uses, water may be employed for general clean-up for washing down dirty floors, tanks, and spills during regular production hours.

Considerable amounts of steam are necessary at the drier section alone, since a 100 ton mill will evaporate 50,000 gallons of water or approximately 200 tons per day. In addition to this, considerable amounts of steam are needed for heating the process water. Reports indicate that higher and higher temperatures are being used in processing, and plant effluents of 110-130°F are not uncommon. Temperatures of 150-170°F are often used in the breaker-beater to facilitate fiber separation.

In practically all large mills a mill-owned plant is used for generation of electric and steam power. The water required for this phase is generally kept separate from the pulp processing water and will not be discussed in this report.

Quality

Mussey's discussion (3) of water supplies for paper making shows the problems which may arise in the product, if water quality requirements are not met. Excess turbidity, for example, usually caused by clay, silt, sand, or organic particles, can result in loss of brightness. Another instance of this occurs when color, often the result of organic iron complexes or organics in wastewater (industrial and domestic), is adsorbed or absorbed by the paper fibers. The presence of organic compounds may also contribute to the formation of slime.

Hard water tends to scale on the paper making equipment, while the calcium and magnesium may precipitate the resin size. Excessive alkalinity will require the addition of extra alum to neutralize it before the alum can react with the size.

Iron and manganese will be adsorbed by the cellulose, causing white paper to become yellow and colored paper to become dull. Oxides of both metals, by various processes, may become deposited in pipes, and bacteria associated with iron may contribute to slime formation.

Free carbon dioxide, aside from the corrosive action associated with its low pH, may have a detrimental effect on sheet formation on the paper machine. Any corrosion producing characteristics, such as low pH or excessive amounts of chloride, must necessarily be detrimental to the equipment, unless corrected, especially if significant amounts of iron are brought into the process water.

The standards in Table 27 are also quoted from Mussey.

IV. WASTEWATER

The principal materials used in papermaking, which determine the components of the waste discharge, have been described in Section II. In this section the data are arranged somewhat differently; sources of waste within the typical paper mill are listed, and data on the quantities of waste to be expected are presented.

TABLE 27

SPECIFICATIONS FOR CHEMICAL COMPOSITION OF PROCESS WATER FOR MANUFACTURE OF VARIOUS PULPS AND PAPERS

(From tentative standards established by the Technical Association of the Pulp and Paper Industry. These specifications should be considered only as a guide in determining the quality of water needed for manufacturing the pulps and papers indicated. Maximum allowable amounts in parts per million)

Constituent or property	Soda and sulfate pulps[a]	Groundwood paper[a]	Kraft (sulfate) paper		Fine paper
			Bleached	Unbleached	
Turbidity	25[b]	50[b]	40	100	10
Color	5	30	25	100	5
Total hardness as $CaCO_3$	100	200	100	200	100
Calcium hardness as $CaCO_3$	50	--	--	--	50
Magnesium hardness as $CaCO_3$	50	--	--	--	--
Alkalinity as $CaCO_3$	75	150	75	150	75
Iron (Fe)	0.1	0.3	0.2	1.0	0.1
Manganese (Mn)	0.05	0.1	0.1	0.5	0.05
Silica (SiO_2)	20	50	50	100	20
Dissolved solids	250	500	300	500	200
Free carbon dioxide as CO_2	10	10	10	10	10
Chloride (Cl)[c]	75	75	200	200	--
Residual chlorine as Cl_2	--	--	---	--	2.0

(a) Not applicable to groundwood paper made from southern pine.

(b) Materials causing turbidity must not be gritty.

(c) Limits for chloride are for the purpose of decreasing corrosion in the metal parts of the manufacturing system. For fine paper the chloride is limited by the maximum for dissolved solids.

Sources of Waste

Typically, the principal sources of liquid waste from a paper mill include these, listed (again, typically but not necessarily) in order of decreasing flows:

1. Paper machine wet end, i.e., the white water removed from the sheet in the initial formation and dewatering.

2. Paper machine press section, where additional white water is squeezed out.

3. Water filter backwash.

4. Wastes resulting from changes of grade (highly variable, both within and among mills).

5. Vacuum pumps.

6. Excess water from liquid pump glands.

7. Floor drains -- spills, hoses, and general wash-ups.

8. Piping leaks.

9. Boiler blowdown.

In the aggregate, the volumes will vary from as much as 100,000 gallons down to a few thousand gallons per ton of product for the mills in the study area. The high figure would be that of a manufacturer of special industrial paper who may not have started responding to the pressures for waste reduction. The lowest volumes would generally represent wastes from a board mill that has started a program of water conservation and/or increased recycle. Both types are represented among the mills in the Basin, at least up to the time of the most recently published data. A majority of the plants are in the 10,000 to 20,000 gal/ton range.

The variety of specific compounds used in paper making is nearly endless and is alluded to in practically every standard waste treatment report or book which touches on the industry. The following list of compounds, arranged by type of product and compiled from an EPA "State-of-the-Art Review," (42) provides a convenient general reference:

Coarse Paper:	Alum, starch
Fine and Book Paper:	Sizing materials; alum, resins, sodium aluminate, wax emulsions.
	Specialities such as acrylics, isocyanates, flurocarbons, and so on.
	Fillers; calcium carbonate and sulfate, talc, barium sulfate, alumina, titanium oxide.
	Coatings; pigments, fillers and adhesives (starches, dextrins, natural and synthetic resins).
Tissue:	Resins for wet strength.
Specialty:	Many hundreds of papers make it impossible to generalize.

Deinking of paper for reuse is carried out in large specialized plants, but may be practiced on a limited basis by many mills. The process is one in which the solubilizing of the adhesives (with, for example, alkalis, sodium silicate, dispersing agents) allows the ink, coatings and filler to be washed out. Thus the waste load, besides the excess process chemicals, will contain all of the components of the waste paper. Total losses to the sewer can run as high as 50 percent of the bale weight.

Waste Loadings

As indicated above, tremendous variations in wastewater quantity and characteristics can be expected. These depend not only upon the type of product and raw material, but also upon the degree of effort a given plant has put into reducing material losses and minimizing waste discharges.

"The Cost of Clean Water" (5) presents data for paper making effluent ranges, based on two levels of technology which that publication distinguishes as:

1. Practice of fiber recovery and wastewater reuse;

2. Practice of fiber recovery, segregation of wastewater by quality, and extensive wastewater reuse.

These data are presented in Table 28 as Processes 1 and 2. The data included under Process 3 are from another source (4). The tremendous variation between mills, as much as an order of magnitude in some categories, is striking.

V. WASTEWATER REDUCTION

Recycling and Water Control

The industry practice has always included recycling of many of the streams which emanate from the paper process. For a mill not to do so would reduce its competitive effectiveness, simply because of heat and materials losses. However, in order to reduce the costs of making a paper mill's wastes acceptable to the community, the mill must recycle to a far greater extent than can be justified on the basis of energy and material costs. In addition to the direct costs of these activities, the mill must face increasingly difficult technical hurdles in the manufacturing process as it attempts to achieve complete closure of its water-waste-water cycle.

1. Current Practice

That there is no quantitative way to define current practice is evident from a cursory examination of the data of Table 28 which show tremendous variance. However, it is possible to select a typical paper mill abatement effort on the basis of experience in the industry. The particular measures discussed below have, of necessity, been chosen somewhat arbitrarily for this study. The measures do combine a degree of process modification and end-of-the-pipe treatment, and represent either current or soon to be achieved practice for a number of mills.

As with the other industries under discussion, the first steps to be taken in a serious effort to control the waste problem in a paper mill are to measure and control fresh water usage, and then to modify equipment, flows and processes accordingly. The water pollution control agency's order for abatement, and pressure from the local community, force the mill's attempt to achieve an economic balance: between the increasing costs of the modification effort, and the consequent decreasing costs of any required treatment facility.

Let us assume for this illustration that the mill is a well-run manufacturer of fine paper. A water usage of, say, 15,000 gallons per ton of product indicates an awareness of water waste, but invites the

TABLE 28

PAPER MAKING WASTES

Processes	No. Mills in Survey	Wasteload, in lbs/ton of Product: Suspended Solids Range[b]	Suspended Solids Mean[c]	Dissolved Solids Range[b]	Dissolved Solids Mean[c]	Total Solids Range[b]	Total Solids Mean[c]	BOD Range[b]	BOD Mean[c]	pH Range[b]	pH Mean[c]	Wastewater Quantities in gallons/ton: Range[b]	Wastewater Quantities in gallons/ton: Mean[c]
1. General[d](5)		10-166	46	21-425	73	31-591	119	3- 80	16	4.3-6.9	5	5,700- 40,000	13,000
Newsprint		20- 60	40	--	--	--	--	10- 20	15	--	--	37,000	--
Uncoated Groundwood		--	--	--	--	--	--	--	--	--	--	--	--
Coated Printing Paper		--	--	--	--	--	--	--	--	--	--	--	--
Uncoated Book Paper		--	30	--	66	--	116	--	16	--	--	8,000- 28,000	14,000
Fine Paper		47-100	73	--	80	--	153	15- 40	20	--	--	9,000- 40,000	18,000
Coarse Paper		10- 30	20	--	--	--	--	10- 25	15			2,000- 29,000	10,000
Special Industrial Paper		200-400	300	--	--	--	--	140-170	155	--	--	20,000-100,000	--
Sanitary and Tissue Paper		50-100	50	--	150	--	200	15- 30	22	--	--	8,000- 37,000	14,000
2. General[d](5)		2- 38	30	24- 66	40	26-104	70	2- 16	10	(4.5)		4,500- 11,000	7,500
3.[e]													
Fine Paper	13	18-440	110	--	--	--	--	7- 50	33	--	--	7,000- 70,000	32,000
Coarse Paper	13	10- 42	17	--	--	--	--	4- 26	16	--	--	2,000- 15,000	7,700
Tissue	20	40-156	58	--	--	--	--	10- 96	37	--	--	10,000- 62,000	28,000
Waste Paperboard	42	8-123	42	--	--	--	--	12- 75	25	--	--	2,000- 24,000	11,000

(a) Wastewaters from paper making include those from stock preparation, paper machine, and finishing and converting operations. (older technology)
(b) Single pieces of data are entered under the "Range" column with parenthesis.
(c) The mean values shown are not truly statistical average; they are considered to be probable average values based on the available data.
(d) Wastewaters from paper making include those from stock preparation, paper machine, and finishing and converting operations. (newer technology)
(e) These data from Gehm. (4)

closest engineering scrutiny before the design of any treatment plant that might be required is attempted. Our hypothetical mill will undertake the following steps in the course of a program to achieve what waste reduction it can by "current" good practice. No particularly "advanced" procedures are included.

Segregation of many of the waste streams is essential. Those which are relatively unpolluted can be used where their purity is required; the more concentrated can be used in less critical functions. Uncontaminated condensate and cooling water would be collected and reused in, for example, the pump glands. The leaner whitewater can be segregated from the richer and used as a fresh water substitute for such things as housekeeping. Most obviously of all, storm water must be taken out of the process water sewers.

Control of every sizeable water user must be achieved. This does not necessarily mean that sophisticated instrumentation and modulating controls are called for. For example, controlled knockoff showers, by both high pressure-low volume units and intermittent on-off controls, can save several thousand gallons per ton over the uncontrolled showers. Orifice plates in water lines, such as those supplying showers, can be installed. Hoses can be partially brought under control with spring loaded shut-offs. Flows to individual pump glands can be controlled manually if small rotameters are installed in the supply lines. The measurement of water losses during changes of grade and washup, as well as the total sewered flow from each paper machine, are important means for helping achieve control.

Because of the increasing requirements for building and operating treatment plants, measurement and control are coming to be recognized as an integral part of the paper making-waste treatment whole. With these technically simply (though by no means inexpensive) improvements in effect, our hypothetical plant will have reduced its water use, and hence the treatment plant size, perhaps by as much as 40 to 50 percent.

Equipment changes at this level may well include alleviation of any overloading or installation of more efficient savealls. Savealls will certainly be in use already, but depending on conditions, may be subject to surging and bypassing at times. Or, it may be advantageous to supplement a flotation unit with a filter. Obviously, no universally appropriate recommendation is possible. Equipment to settle white water to some degree may be worthwhile as a means of making it more usable. White water settling, for example, has

been used to provide a rich return to the pulpers and an intermediate concentration to be used for dilution water, with only the leanest top water being wasted to the sewers.

Recycling of fiber (i.e., product recovery), of water, and of other materials in the furnish to the maximum degree practicable is the foundation of waste management in the paper industry, probably more so than in any of the other industries discussed in this report. With recycling to the extent outlined above, few operating problems would be expected. As progress towards meeting ever stricter effluent standards is made by increasingly intensive recycling, however, new problems will be introduced. These will be discussed in the next section.

2. Advanced Practice

No attempt is made here to define the term advanced practice; we use it simply to refer to a more intensive practice of the same types of procedures discussed in the preceding pages for wastewater reduction. The application of these more intensive measures (6) is usually accomplished over a period of years, is frequently accompanied by severe (but not necessarily insurmountable) problems, and can be expected to effect a reduction in wastewater volume of from 50 percent to over 90 percent. The figure will depend upon the interval, during the extended period of improvement, one chooses to designate as the beginning of the "intensive" effort.

Any reduction in the rate of bleeding off impurities will necessarily be accompanied by a severalfold increase in the concentration of dissolved solids in the process streams, as well as a marked increase in temperatures (of up to 40°F). The effects of these changes on operations can be considerable. For example, they may include reduction in the life of paper-machine wire, excessive condensation and drips, deterioration of working conditions because of heat and humidity, and increased corrosion. Slime control will need more attention. There will be increased scale problems because of increased concentrations of scale formers -- a result of recycling. In a high recycle operation there is less time to correct errors than in an open end system, so that increased monitoring and control must be provided (for example, dissolved solids monitoring and alarms). Tankage to take care of surges must be provided.

Additives react with some of the recycled solids, and gumming impurities tend to accumulate in the wire as their concentrations build up. In spite of these and other problems, "... the costs are relatively low when compared to those incurred by treating the wastes at the end of the pipe." (6)

Basically, then, advanced procedures consist in carrying recycle just as far as it can be carried in a given situation. The only important qualitative differences in methods from those discussed under Current Practice are two, and even they do not form the basis for a sharp line of distinction:

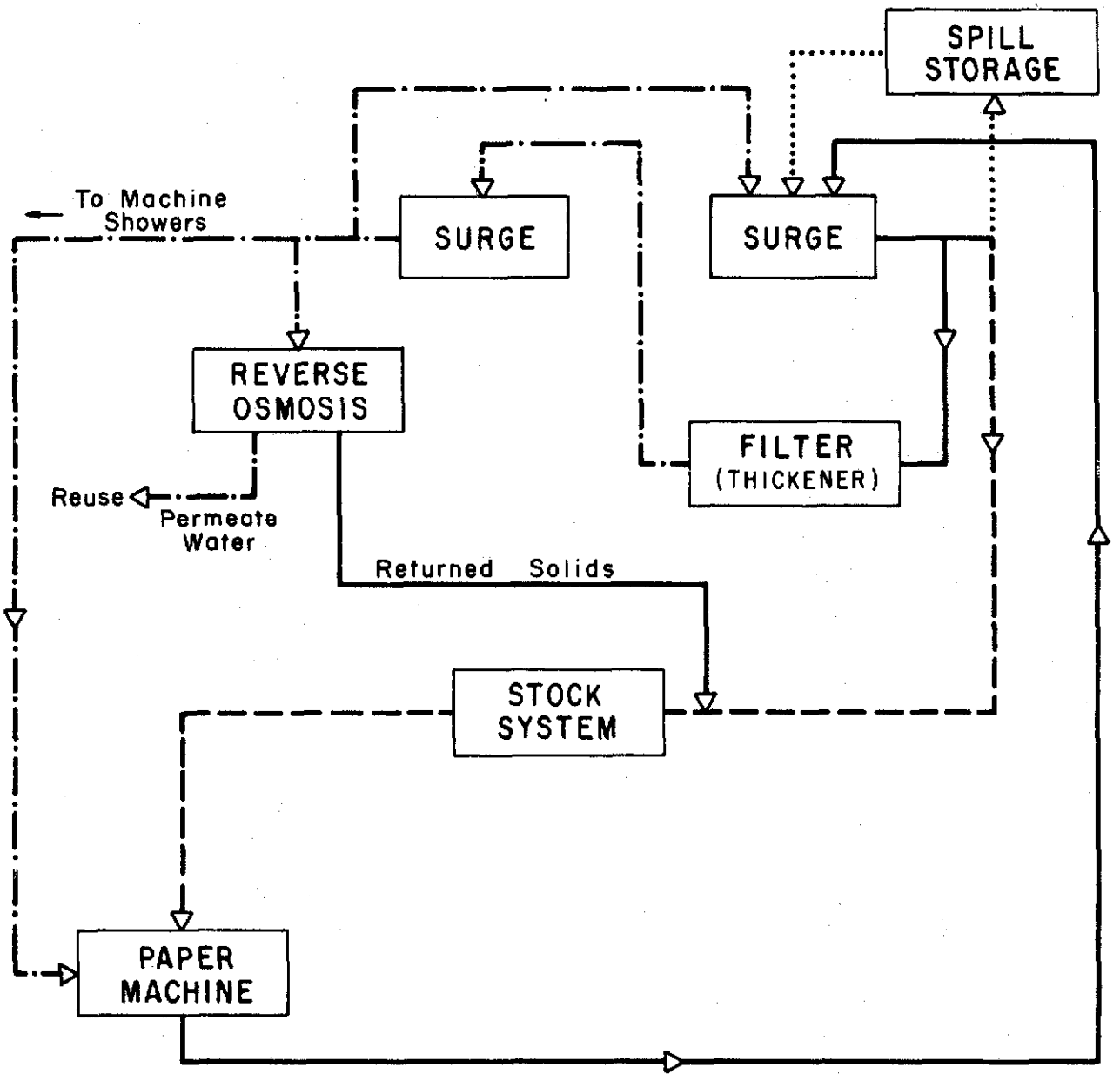
(1) Use of whitewater in the wet end showers. This is already being practiced in many mills, to some extent. In the limit of course, no fresh water would be used at all in the paper process except to replace losses by evaporation, and all accumulating impurities would reach an equilibrium at which they would be carried out totally by the product.

(2) Treatment of recycled water to reduce the buildup of dissolved solids.

The most substantially researched (at least on a plant scale) treatment has been that of reverse osmosis at Green Bay Packaging, where a program of evaluation and use, in conjunction with extensive modifications of the mill water flows, has been carried on for several years. The most recent report on these activities(7) presents the schematic shown in Figure 28.

Aside from the use of reverse osmosis on a production basis for balancing excess whitewater, the proposed system is most notable for its concern with prevention of spills and overflows. The following excerpt from the referenced report describes its objectives at the present stage of this example of advanced practice:

"A joint effort under the Research, Development, and Demonstration program was defined, and an R, D, and D grant was made in July 1972, in support of further work on the reuse concept. The resultant project (S-800520) includes modification of the mill process for stabilization of the reuse scheme, entrapment and collection of spills and surges, and return of the entrapped excess waters to the white water system. The objective of this project is to demonstrate stable operation of this type of in-plant control with consistent low losses of pollutants from the process.



LEGEND

- Unclarified Water from Machine
- Unclarified Water Reuse
- Unclarified Water Spill Storage Loop
- Clarified Water

FIGURE 28 Planned Water Reuse Schematic

"The principal areas of activity under this project are:

"1. Prevention of spills by process control modifications.

"2. Revision of overflow pipes, trenches, etc., to direct potential spills into the contaminated water system for reuse.

"3. Local surge reduction by improvement of equipment capacities.

"4. Provision of a large available surge capacity, at a single point, for accumulation, temporary storage, and return of collected excess spills and upsets.

"5. Redundancy for a few key pumps in the reuse scheme to prevent major losses during failures and routine maintenance.

"6. Monitor system for use by production personnel for detection and early warning of abnormal or potential loss conditions.

"7. Utilization of a production reverse osmosis plant for processing excess white water to maintain total system volumetric balance. The operation will separate the excess into a clarified stream suitable for fresh water replacement or direct discharge from the mill and a more concentrated stream for return to the reuse system."

In conclusion: Advanced recycle practice leads to problems resulting from the accumulation of impurities and energy. Prior to advanced recycling, the unwanted surpluses had been bled off, at whatever stages they became obtrusive, to avoid the accumulation.

With an increase in the degree of close-up, the problems increase in severity. Their solutions will require increased amounts of money, ingenuity, and operating skill. It is conceivable that they will eventually force acceptance of changed product standards; up to now, however, this has not occurred. On the other hand, up to now <u>total</u> recycle has not been practiced either, except for short periods of time, and in the laboratory. (8)

VI. WASTEWATER TREATMENT

Paper making effluents need to be treated for the removal of their two gross constitutents -- suspended solids and dissolved organic matter -- if they are to be discharged to a stream. The suspended solids will be principally fine fiber, fillers, coating materials and pigments, which were not retained in the sheet or the machine wire. Dissolved organics may be any of those listed on page 242 but will be principally starch. Even though starch may not be part of a particular mill's raw material, it is likely to be present if any reclaimed paper is in use. In any case, there will always be some biochemical oxygen demand, as indicated in Table 28. Masselli summarizes the soluble loading in whitewater waste as follows:

"... it may be concluded that starch alone among the organic chemicals used for paper making is likely to be found in appreciable concentrations since the rosin, glue, paraffin, synthetic resins and others are insoluble or rendered insoluble during the processing.

"Sulfate and sulfuric acid from alum and calcium from calcium carbonate fillers are the most likely inorganic ions and these may reach appreciable levels.

"The organic and inorganic solids extracted from waste paper stocks will be of the same nature and these will be superimposed on the chemicals used by the mill." (1)

Current Practice

There are numerous New England mills that do not yet practice any form of waste treatment. We shall, however, assume "current practice" to be the type of treatment commonly being planned to satisfy the EPA effluent guidelines of 12 June 1972, for "Best Practicable Control Technology Currently Available." The Schedule A values for BOD and suspended solids are those values expected to be achieved by new plants, or by plants starting abatement programs in 1972. They are listed in Table 29.

TABLE 29

RECOMMENDED EFFLUENT LIMITATIONS, LB/TON FOR BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

	BOD_5	SS
Paperboard (No De-inking)	3	3
Paper from Purchased Pulp		
Coarse	2	3
Fine (8% filled)	6	7
Book (8% filled)	3	4
Tissue	8	6

EPA mentioned additional limitations as follows:

"Toxic Materials, Oil and Grease. These parameters should be considered to determine their significance on an individual basis. If they are determined to be significant, then the appropriate 'Special Conditions' should be applied.

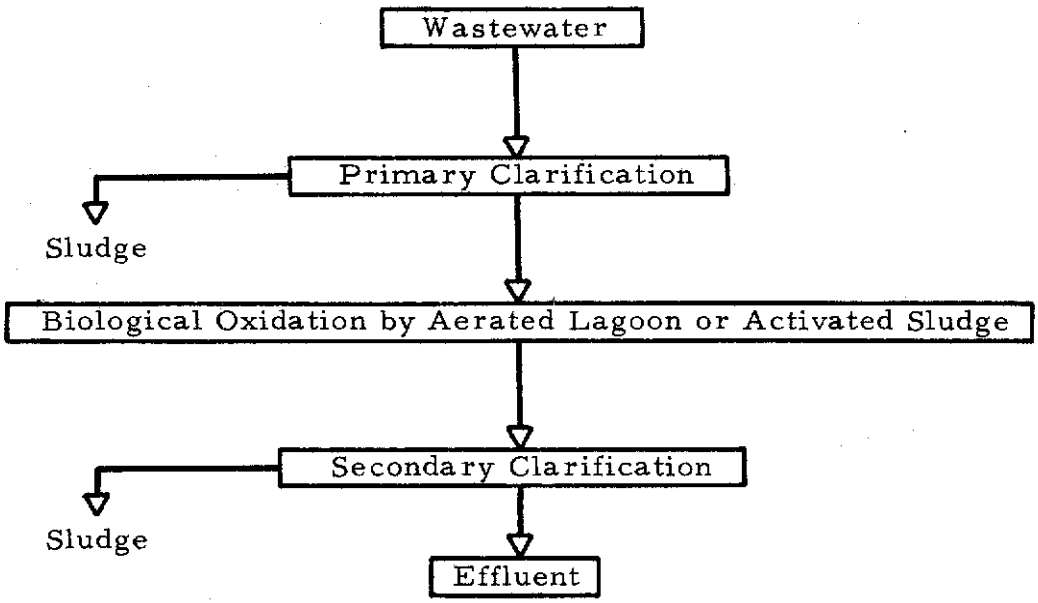
"pH. The pH shall be maintained between 6.0 and 8.5 unless unusual receiving water conditions necessitate a variance (e.g., the natural pH is outside this range.)

"Other Limits. The following may be significant parameters depending on production and receiving water characteristics:

Color
Turbidity
Foam
Phenol
Ammonia
Sulfite Waste Liquor

"When deemed necessary, effluent limits applied to these parameters shall consider receiving water quality and available technology."(9)

The values were selected primarily on the basis that they could be achieved by the following traditional processes, carried out in the classic sequence:



Little comment on the above seems necessary; we discuss the sludge problem briefly in the pages following. Usually, paper mill effluents are deficient in nutrients, so that small amounts of phosphate and ammonia are added at some stage before the biological step. It will be ordinarily necessary to install some sort of pH control. Depending on the characteristics of the individual mill, it may or may not be advisable to add a coagulant to assist in the primary clarification.

The exception to the above discussion is the BOD_5 guideline for tissue manufacture. This is based on the assumption that tissue mill effluent need only be coagulated and/or settled, since "the application of biological oxidation to this wastewater would not significantly lower the effluent BOD." (9) (The BOD of tissue mill effluent is principally associated with the waste fiber.)

Future Practice

1. Joint Treatment

Paper mill wastes, as opposed to those from pulp or integrated

mills, present relatively few technical obstacles to possible joint treatment. To generalize, it is a "compatible waste," being mainly characterized by BOD and suspended solids. The strength, typically, is low in BOD compared with domestic sewage, and high in suspended solids. Consider, for example, the values for fine paper in Table 3. If we take the average waste in lb/ton and compute the strength based on the average water usage, the result is 400 mg/l SS and 120 mg/l BOD_5. It is probably not profitable to pursue these widely-ranged data too far in this context, but the calculation at least gives an indication of the suitability of the wastes for joint treatment.

The wastes are nutrient deficient for biological treatment and obviously will in many cases (as in the example) have a heavy concentration of fibers. Neither of these is a bar to successful joint treatment, provided that it is anticipated.

Furthermore, not only is joint treatment always at least considered whenever it is at all possible, the usual choice for a mill treating its own wastes, as described in the last section, is apt to be a variety of municipal practice.

It seems likely that the anticipation of 1983 standards will lead to greater pressure than ever in favor of joint treatment, provided there is a regional or municipal plant close enough to allow transportation of the mill wastes to it. If a zero discharge requirement is anticipated by the industry (and there are not many indications to that effect at present), there may well be a tremendous urge to place the (economic) onus of meeting the requirement on a publicly owned and operated treatment facility, if the industry's wastes are compatible with it.

2. Treatment Technology

The EPA draft report (10) on effluent guidelines for the industry provides values for expected effluents only for integrated mills and waste paperboard. In the absence of specific guidelines for that segment of the industry under review here, beyond Best Practicable Control Technology Currently Available, (BPCTCA), discussed above, we shall try to give some idea of possible trends, without trying to distinguish very much between "Best Available Technology Economically Achievable" (BATEA) and "zero discharge."

BATEA technology is identified in the draft report as being the best now employed by a specific source. Not surprisingly, therefore, this turns out to be a more intensive application of the same internal controls needed for BPCTCA, with the suggested addition externally of a second stage of biological treatment, and possibly the unit operations of filtration, reverse osmosis, and carbon adsorption (or chlorination), the last for removal of trace organics:

"The additional external processes applicable to this advanced technology are as follows:

"a. suspended solids removal through either coagulation and flocculation followed by settling, filtration, or reverse osmosis;
"b. BOD_5 reduction through the application of two-stage biological treatment;
"c. trace organics removal through either carbon adsorption or chlorination;
"d. color reduction by application of either lime precipitation or carbon adsorption;
"e. possible nitrogen reduction by use of either ion exchange, nitrification-denitrification in the biological process, or ammonia stripping." (10)

It is impossible to disagree with any forecast of increasing emphasis on internal mill improvements. How much new external treatment will be desirable is a more controversial area. Our own view leans generally toward the integration of the newer and more expensive operations into the mill itself, rather than to their use as add-on. Sizes and costs of these are usually heavily dependent on both hydraulic loading and the degree to which the impurities must be concentrated. As much as possible, therefore, it is desirable, indeed economically essential, to segregate streams for treating in such a way that none is overtreated merely because it had been unnecessarily combined with another of substantially different character. Our understanding of "external treatment" in this context is that almost by definition it is applied to the entire plant effluent. This is appropriate for catchall processes such as sedimentation and biological oxidation, but may not be for, say, a carbon adsorption or reverse osmosis unit, which might be necessary for removing individual (or a limited class of) contaminants.

We must make at least one exception to this last generalization immediately: a full-scale treatment plant already designed,

using activated carbon (11). The plant, which embodies chemical coagulation, flocculation, sedimentation, followed by the adsorbers, was estimated to cost 6 percent more than a comparable activated sludge plant, but the additional flexibility it provides was deemed worth the extra capital cost.

A further example of advanced physical-chemical treatment, in this case embodying filtration as the final step and a 13 percent average bleed to groundwater, is provided by the facility at a new tissue mill. (12) The description and flow sheet that follow are from the referenced paper (Figure 29).

"The effluent from the tissue process is normally low in fiber solids because of the saveall. Color changes cause about the only exception to the low solid condition. The screened effluent is pumped to a primary clarifier-surge tank to remove settleable solids. The surge capacity built into this clarifier is designed to hold surges because the water contains an investment in terms of heat, magnesium, and calcium over and above that found in the makeup water. The overflow from the primary clarifier is blended with makeup water. This total flow is then split. Part of the water is diverted to a 10-stage dissolver where magnesium oxide, the process flocculant, is placed into solution by reaction with the bicarbonates of magnesium and calcium and supplementary carbon dioxide. This magnesium-enriched stream is recombined with the untreated portion and treated with excess lime to a pH of 10.8 in the presence of recirculated sludges, and then one to two tenths mg/l anionic polyelectrolyte. The flow is flocculated, then clarified. This portion of the process precipitates the magnesium as hydroxide flocculant by the use of excess lime using conventional equipment, i.e., quick-mix basins, a slow-mix flocculation basin, and a conventional clarifier, plus sludge recirculation.

"The overflow from the preceding excess lime clarifier passes on to a reaction-type clarifier where the water is mixed with recirculated, precipitated, calcium carbonate, scrubbed and compressed flue gas containing carbon dioxide, and another polyelectrolyte. This unit converts a controlled amount of caustic alkalinity to carbonate and stabilizes the carbonate alkalinity at a controlled concentration. The pH of the operation is approximately 10.3.

"Next, the overflow from the preceding clarifier is filtered through single-media sand filters and than passes to the 300,000 gal. capacity clearwell. The water is recarbonated as it leaves the

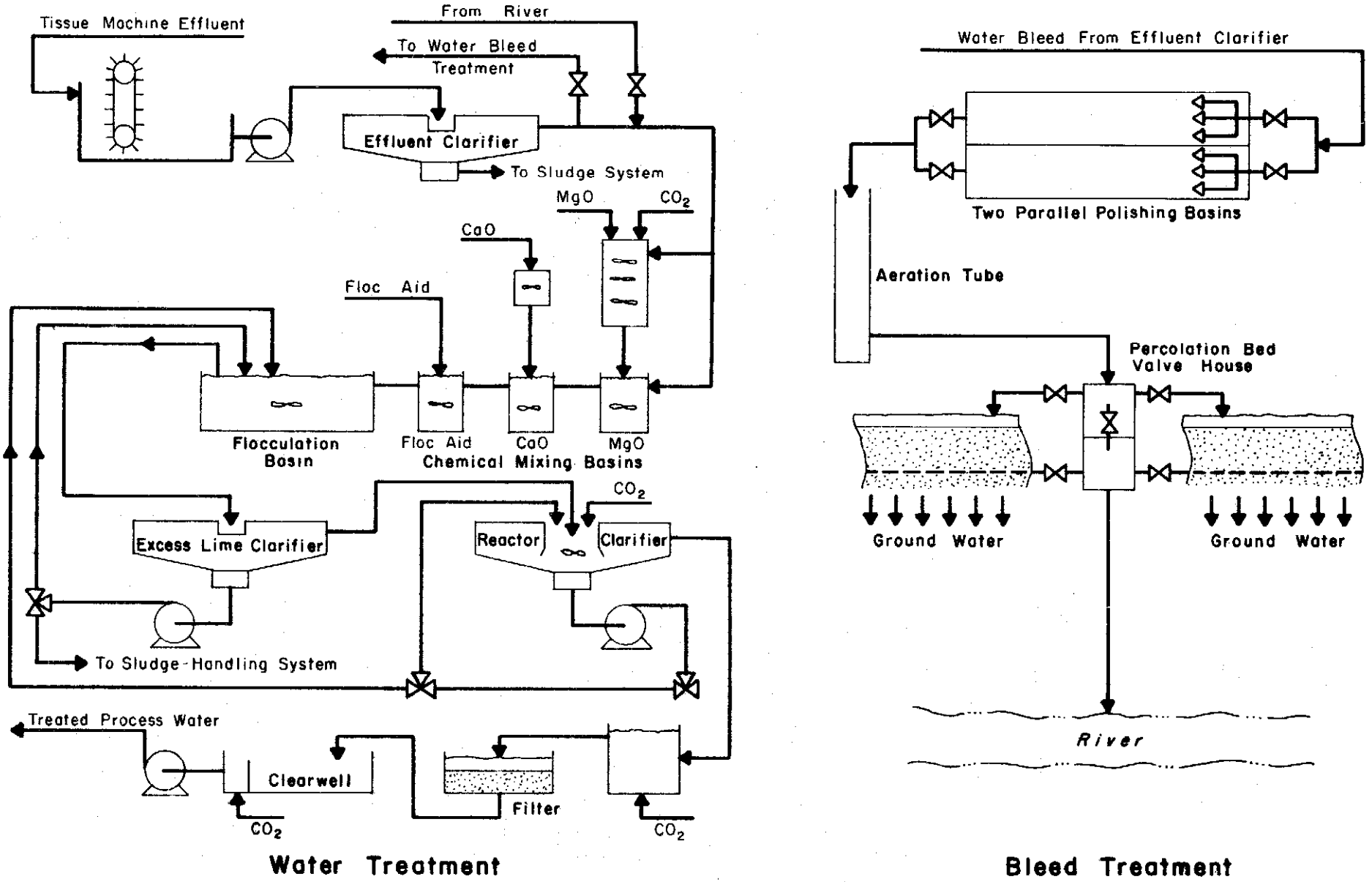


FIGURE 29 Tissue Plant Recycle

clearwell prior to use in tissue manufacture. The final pH in use is between 7 and 8. Initially, the water was recarbonated to the preceding pH prior to filtration. This practice was discontinued because bacteria would plug the filters. The water is essentially sterile through the excess lime and carbonate stabilization stages, but the water contains readily biodegradable substrates. When the pH is reduced by recarbonation to a level tolerable to the bacteria, they proliferate, especially on the sand filters, much as they do on a trickling filter. Control of bacteria has been relatively easy at the Huntsville plant, especially since recarbonation was moved to a point after the filters.

"Effluent Treatment"

"Normally, the effluent from the system is a controlled portion of the overflow from the primary clarifier although it can be a portion of the full-treated water controlled at the operator's discretion. This system effluent flows to a polishing basin. The only negative aspect of this basin is an algal growth in the warm months which is a problem in the percolation beds downstream.

"An aeration tube follows the polishing basin and is the conduit to the percolation beds. There are two percolation beds of one acre each. The effluent is flooded to one bed for 24 hr and then flooded over the other bed for 26 hr. The aerated overflow from the polishing basin carries enough oxygen for the aerobes which occupy the full 5-ft depth of sand in the beds. Because the base sand and silt has some permeability, 30% of the underflow flows through the strata to the river. The percolate is crystal clear, uncolored, of negligible BOD_5 content, and contains negligible nonfiltrable residue. There have been problems, however. One bed contains silt which required removing 2 ft of fill. The silt remaining appears to form low-permeability lenses which require deep plowing to remix in the sand. Normal maintenance requires plowing or harrowing the beds approximately quarter-annually to turn the algae in along with other organic debris carried from the preceding polishing into the bed where the bacteria can metabolize these relatively gross materials. These beds, made feasible by the low volume of effluent from the reclamation system, have made it possible to produce an extremely high-quality effluent."

Pressures and filters have been used successfully in full-scale trials to improve sufficiently the quality of primary clarifier topwater to allow its recycle in a fine paper mill. (13) The filters

failed to remove color bodies to the extent desired, but the problem was solved by floc forming in a special way, described more fully by Schwonke and Davis in a companion article; (14) and summarized in the following paragraph.

Part of the color and suspended solids problem was the result of their dispersion by starch in solution. If the starch could be degraded, it would lose its ability as a dispersing agent. This was accomplished on a plant scale by the introduction of starch-destroying enzymes. The result of this work was that the operation of the primary clarifier was so improved, filtration was hardly necessary. What little material did not settle in the clarifier agglomerated into flocs that were easily filtered.

Even a cursory examination of the literature indicates a substantial effort to close in paper's waste streams. A great deal of this appears to be directed toward the recycle of both material and water. The emphasis on the latter is what is relatively new, and it is, we repeat, probably the principal route, if not the only one, by which the 1983 standards and beyond may be reached.

Sludges

Sludges from secondary biological treatment of whitewater resemble those of any municipal plant, and will not be discussed here.

Sludges specific to the paper making process are, of course, those which comprise the collected solids not retained in the sheet. If one thinks of the actual production of paper as a process of concentrating solids, then the formation of sludge in a clarifier is simply an extension of this process by a secondary concentrating of materials which are almost identical chemically with those in the furnish. It is necessary to say "almost," since some chemical or biochemical degradation occurs, slimes form, and so on. Further, the actual process of concentrating this waste may have involved the addition of coagulants and aids, particularly lime or alum.

Physically, the components of sludge are distinguished chiefly by their fineness. They are particles so small, either inherently, or as the result of mechanical degradation, they could not be retained on the sheet. Environmentally, they are surrounded by 20 to 100 times their weight of water, often partly bound to them and sometimes difficult to remove.

After adjustment of the effluent whitewater (pH, coagulants, enzymes -- vide supra), it is usually settled in a conventional clarifier. The resulting primary sludge is then ordinarily dewatered on a vacuum filter. At present, there is a strong market for the resultant filter cake. A paper maker may be able to add some extra-long fiber with the reclaimed fines and use them up completely in a special run himself. Alternatively, he can sell it to a board mill, where it is used routinely. Thus, with a properly operated clarification operation, the solids leaving the plant under present practice should be minimal. They will go along to the biological treatment step and, depending upon the system's design, will either become biologically digested eventually, or will accumulate. In the latter case, the solids, along with the biological sludge, become finally a disposal problem, identical with that of municipal treatment plants.

In order to provide pure water for the recycle, a mill, very rarely, may resort to sand filtration of the clarifier effluent as a polishing measure. This obviously does not make the solids disappear, but in effect, concentrates them still further, this time in the pores of the filter. Filter backwash is customarily either discharged to surface water or sent back through the waste treatment cycle. Obviously the latter practice will be the only one allowed, eventually.

VII SUMMARY AND COSTS

Despite its position as the heaviest water user (on a total volume, not a gallons-per-unit product basis) in the Basin, the paper-making industry appears to have as good a chance as any to reduce its effect on the aquatic environment to zero. It is the only industry, for one thing, among the five which uses process water only as a medium for transportation. Unlike the others, all of which must deliberately wash greater or lesser amounts of impurities out of the product, the paper-making process is inherently clean. Everything added to the water in the mill is put there with the hope that it will be retained in the sheet to be carried out as part of the product, not washed away. The fiber, the clays, the size, the brighteners and so on are there as product, not like the salt of tanning or the soaps of the textile industry, for example, which serve their purposes and then must be discarded. As a consequence of this unique characteristic, the paper mill operator is under the strongest economic pressure to reduce his waste, simply because every bit of it represents a loss of product, as well as an environmental liability.

The problems in closing up then, are principally the changes that occur as a result of circulating the huge volume of water and raw materials so that they undergo degradation - physical, chemical and biological. Under present practice, a fraction of this degraded material must be bled off to a waste treatment plant. Successful efforts to reduce this bleed would obviously, in the limit, result not only in zero discharge, but in a 100 percent yield from the raw materials.

Whether or not this ideal is achievable is a question, but reduced to its simplest form, this is the direction in which the industry must go if it is to attain the goals set forth by the Congress.

Development of better retention aids, better slimicides, better sizes and the reductions of water usage discussed in Section V are all steps along the way. Because these steps are less than perfect at present, there is now a tremendous bleed (varying from mill to mill) of water and impurities, which for now, anyway, must be treated biologically. This simple conversion of one form of contamination to another (secondary biological sludge) is the most economical we have to offer. This report hopes to convey the impression that this may not always be so.

It seems idle to speculate on the costs of such future possibilities. We can, however, report in a general way on the costs of present methods.

A. D. Little, Inc. (15) in a report prepared for the Council on Environmental Quality, estimated costs of removing 95 percent of the suspended solids and 90 percent of the BOD for various types of paper manufacture (see Table 30). They believe their estimates to be accurate to within $\pm$ 20 percent.

This report also estimates the effects of pollution abatement on prices in the industry. These costs are presented in Table 31.

We close with a quotation from the same source, commenting on the probable impact of pollution abatement costs. The outlook for marginal companies appears rather grim.

"In most cases marginal single-mill companies in these sectors will be unable to obtain capital for pollution control equipment because their return on investment is destined to remain very low.

TABLE 30

SUMMARY OF ANTICIPATED POLLUTION ABATEMENT COSTS [a]

Product Sector	Operating Costs ($/Ton)	Capital Costs ($/Daily Capacity Ton)
	Water [b]	Water [b]
Printing and Writing [c]	10.50	16
Tissue [c]	12.20	18
Combination Board [c]	6.20	10
Construction Paper [c]	5.90	9
Insulation Board [c]	7.10	9
Hardboard [c]	8.70	8

(a) Based on minimum economic size mills in 1971 dollars. Costs for economically marginal mills are higher. Example: operating costs/ton - Tissue $19; Printing and Writing $19; Combination Board $9. Capital costs/daily ton ($000): Tissue $46; Printing and Writing $43; Combination Board $17.
(b) Based on extended aeration.
(c) Not integrated to pulping.

TABLE 31

ANTICIPATED POLLUTION ABATEMENT COST IMPACT ON PRICES

1972-1976

Key Grades	Approximate Current Average Price ($/ton)	Estimated Abatement Cost for Efficient Mills ($/ton)	% Increase Over Current Price
Unbleached Kraft Liner	120	8.50	7
Bleached Paperboard	210	12.00	6
Semi-chemical Medium	104	5.50	5.5
Combination Paperboard	110	5.50	5
Unbleached Bag and Wrapping	160	8.50	5.5
Bleached Packaging Paper	200	11.00	5.5
Newsprint	160	12.50	8.5
Uncoated Groundwood	180	12.50	7
Coated Publication	220	8.50	4
Uncoated Book	220	8.50	4
Tissue Paper (Converted)	400	8.50	2
Special Industrial Paper	600	9.50	1.5
Construction Paper (shingles)	65	1.00	1.5
Insulation Board	135	6.00	4.5
Hardboard	80	7.50	10
Bleached Kraft Pulp			
Hardwood	120	10.00	8.5
Softwood	140	10.00	7
Dissolving Pulp	220	7.05	3.5

Most such mills are not integrated to woodpulp and will face a cost/price squeeze since prices for the market pulp or waste paper upon which they are dependent are expected to increase at a more rapid rate than the price of the end products which they produce. The life of many of these mills will be prolonged if they are able to minimize their capital costs by joining in a municipal water treatment system. For other mills, particularly tissue paper and special industrial paper companies, it is still questionable whether they can absorb the increased operating costs for pollution abatement since these costs are significantly higher for them than for large-scale producers.

"Many marginal mills are parts of larger companies which will have difficulty justifying the expenditure of the necessary capital in an obsolete facility. A number of tissue, printing and writing, and combination paperboard mills fit this category. In many cases the parent companies will elect to centralize their production in a larger mill rather than revamp a marginal mill. Again the life of these mills will be extended if they are able to share a municipal treatment system and thus minimize the required capital investment."

Bear in mind that these comments apply to an industry-wide survey, so that caution must be exercised in trying to relate them to any specific region, such as the Merrimack River Basin.

VIII. REFERENCES

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TEXTILE MANUFACTURING

I. INTRODUCTION

Overall, the textile industry contributes about 1 - 2% of the total wastewater discharged annually by United States manufacturing. The majority of mills are located in New England, along the Mid-Atlantic coast, and in the Southeast. Because of the textile industry's great diversification of manufacturing processes, pollution control has been more of an individual company's effort than it has been an industry-wide cooperative program.

A national profile (1) of water use characteristics in the textile industry indicates that out of approximately 7,000 establishments in SIC category 22, only some 600 - 700 mills use 20 million gallons or more water per year - totalling about 450 mgd and representing approximately 85 - 90% of the total industry water intake. Among major water users, the average discharge is 0.6 mgd per establishment and, based on all 7,000 textile operations, approximately 0.078 mgd per establishment. Process wastewater represents 90% of the discharge.

In Massachusetts, there are approximately 45 textile mills, representing 44% of the textile industry in New England, with a water intake of 20 million or more gallons per year. The total water intake is about 36 mgd.

Within the Merrimack basin are approximately 28 textile establishments, having a total water intake of 5 mgd. Ten mills (35% of the total) appear to fall in the 20 million gallons or more per year category, with an average of 0.48 mgd per mill accounting for 95% of the total water use. Overall, the water intake averages out to 0.18 mgd for each of the 28 establishments. The significant water users in the study area represent 22% of the major water using establishments in Massachusetts, 10% of the establishments in New England, and 1.5% of the textile industry's significant water users in the nation.

Textile establishments within the study area process predominately wool products, but cotton and synthetics - particularly nylon and dacron - are included as well. It will be the purpose of this

section to describe in brief the wool, cotton and synthetics processing operations, discuss water quality and quantity requirements, identify the major sources of water borne pollution, and, on the basis of average textile industry characteristics, provide information on: the types and strength of pollutants discharged, in-plant water and waste reduction potential, and terminal wastewater treatment methods available, including associated costs, which have been successfully employed to achieve various levels of pollutant removal.

II. TEXTILE PROCESSING

Process Description

Raw materials, dry and wet processing operations, and intermediate and final products used in the textile industry have been well defined (2,3,4,5,6,7) and are summarized below.

1. Wool

Wool is a natural fiber of animal origin and is classified as a protein, keratin. The wool fiber consists of five basic elements: carbon (50%), hydrogen (7%), oxygen (22-24%), nitrogen (16-17%), sulfur (3-4%). Wool is insoluble in water under most normal operating conditions. In the raw state wool contains natural, acquired and applied impurities. Each pound of scoured wool fiber produced yields approximately 1-1/2 pounds of impurities removed from it, much of which is discharged as wastes.

Natural impurities include suint (water soluble) and wool grease (insoluble in water), glandular secretions of animal origin adhering to the fleece. Acquired impurities include dust, dirt, straw, vegetable matter and earth. Applied impurities may include substances used for treatment against disease and insect pests, and tar or paint, used for identification.

In producting the final product, wool must undergo both weaving and finishing operations: the weaving operation cleans, separates and treats the pieces of raw fiber in order to develop a continuous cloth, and the finishing operation imparts the desired characteristics to the cloth or finished product (Figure 30).

Weaving operations include sorting and blending of raw fibers, scouring to remove natural grease and foreign matter, drying, carding

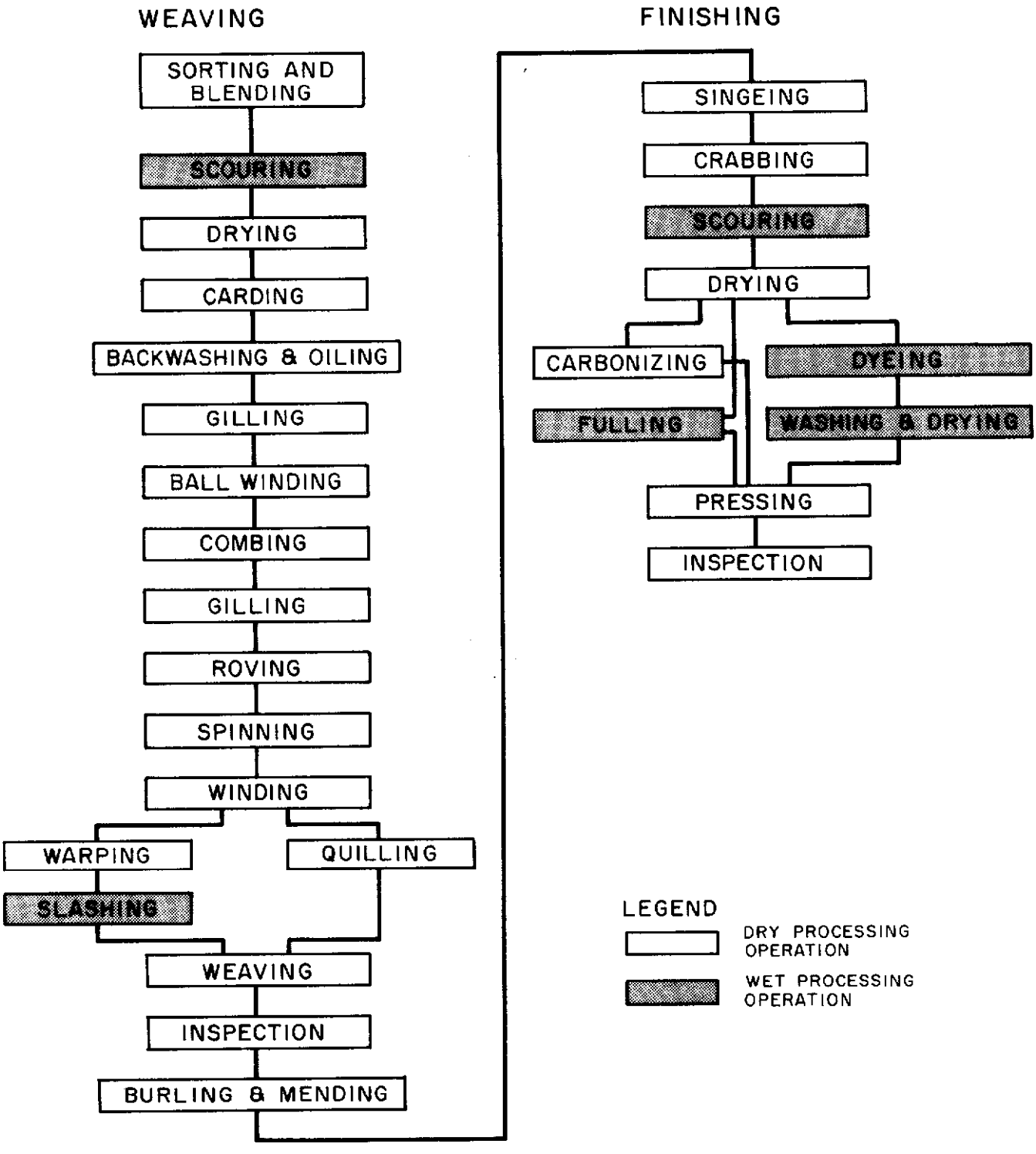

FIGURE 30 Wool Processing Flow Diagram

to open and parallel fibers, rewashing, oiling to reduce static electricity, gilling (paralleling of fibers), combing to remove trash, roving or drawing of fibers into rope form, spinning for further drawing of fibers into threads, slashing - starch sizing of wool thread to protect fiber against abrasion and friction generated in the weaving operation - weaving the threads into cloth, and mending.

All of these operations are mechanical or manual dry processing steps; only two, scouring and slashing, are wet operations, discharging significant quantities of wastewater. The scouring process, performed by detergents or solvents, generates the greatest source of pollution in the wool textile industry. Oils from the oiling operation are removed by subsequent wet process operations, and the slashers containing the sizing compound are periodically washed down and discharged to waste.

Wool finishing operations include singeing, or burning off loose fibers, drying, carbonizing and pressing. These are essentially dry operations, with the exception of carbonizing, which produces a rinse water used to neutralize the "acid" cloth. The major wet operations are scouring, dyeing, fulling, washing and bleaching. Pollution potential in stock dyeing is a function of the type of dye used. Fulling, accomplished by a soap solution which usually remains in the cloth, imparts a felt quality to the wool. All residual process chemicals are removed in the washing operations, using soap solutions, squeezing between rollers, and rinsing. Bleaching may be performed to whiten the natural yellow tint of the wool.

Chemicals used in wool manufacturing include the following, listed according to process:

Scouring: Soap, synthetic detergents, sodium carbonate, sodium sulphate, sodium chloride or solvents such as benzene, carbon tetrachloride, ethyl alcohol, methol alcohol, isopropyl alcohol, trichloroethylene and petroleum naphtha.

Oiling: Olive oil or mixtures of mineral oil with substances such as lard oil, peanut oil, sulfonated red oil, coconut oil, and hydrogenated sulfonated soybean oil.

Slashing: Sizing compound, usually of starch or polyvinyl alcohol.

Fulling: Soap, soda ash, sequestering agents, sulfuric acid, hydrogen peroxide, and metal catalysts such as chromium, cobalt or copper.

Carbonizing: Sulfuric acid, aluminum chloride, magnesium chloride, sodium carbonate.

Dyeing: Acid dyes, sulfuric acid, acetic acid, metalized dyes, ammonium sulfate.

Bleaching: Sulfur dioxide, hydrogen peroxide, sodium silicate, ammonia.

2. Cotton

Cotton processing may also be subdivided into two basic steps, weaving and finishing, as shown in Figure 31. Cotton is a vegetable fiber of natural origin and is usually received at the mill in bales.

Opening, cleaning, picking, cording and combining manually and mechanically remove trash and foreign matter from the new fibers. Drawing, roving, spinning and winding and a sequence of operations which join and straighten the fibers, draw them into thread and wind them on spools. Slashing applies a sizing to the thread by passing it through a starch solution; it is then dried to impart the strength and stiffness required to withstand the abrasion and friction generated in the weaving operations. The strengthened thread is then woven into cloth (greige or grey goods). The only wastewater of consequence is produced from the spills and washout of the slashing boxes, and the preparation of the size solution.

The finishing mill receives the greige goods for further processing into a variety of textile products. This processing is almost entirely wet. Natural (wax, pectins, alcohols) and acquired (unremoved size agent, dirt, oil, grease) impurities must be removed to make the cloth suitable for further chemical processing, which gives the desired properties and appearance to the cloth.

Finishing operations include singeing, desizing to remove the applied starch, kiering or cooking the greige goods to remove cotton wax, dirt, grease, etc., bleaching to whiten the cloth,

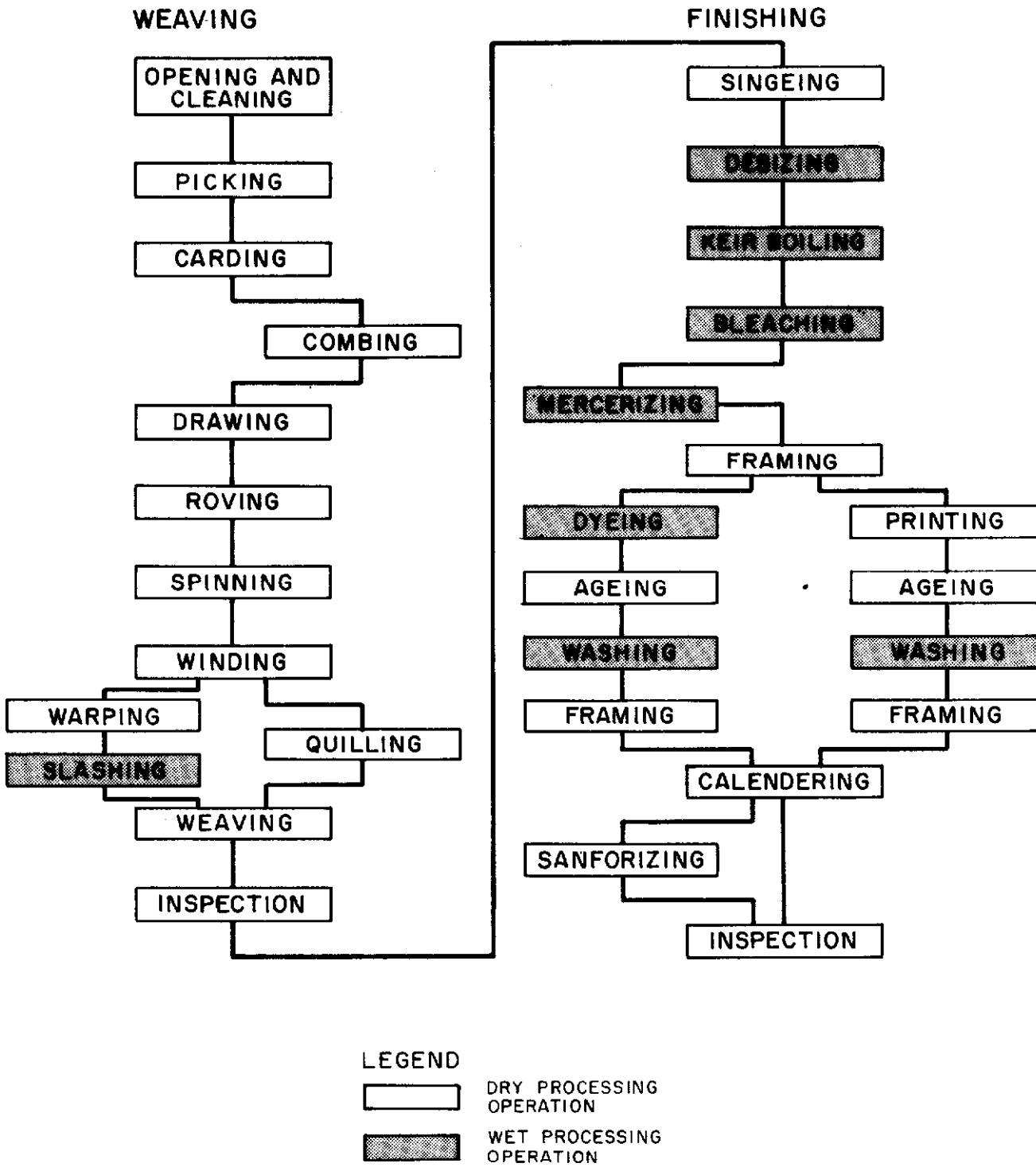

FIGURE 31 Cotton Processing Flow Diagram

mercerizing - or treatment to swell the cotton fiber, add luster and increase dye affinity -, dyeing to color the cloth, printing a pattern or colored design on the cloth, and final finishing (the application of a final size or resin to give a smooth appearance and the desired stiffness to the fabric). This operation is followed by the final operations of calendering and rolling. Specialty treatment may be provided to yield a cloth which is preshrunk, water-proofed, fire-proofed, etc. These specialty finishes are of liquid waste generation significance.

The Chemicals used in cotton wet processing operations include the following, arranged by process:

Desizing: The starch is solubilized using enzyme, sodium chloride, and penetrant or sulfuric acid solution. Caustic soda is used for neutralization. The starch is hydrolized to glucose or intermediate dextrine, which produce a high BOD waste.

Kiering (scouring): sodium hydroxide (caustic soda), sodium carbonate, soap, sodium silicate to remove wax, dirt grease. Other chemicals used include fatty alcohol sulfate, phosphates, wetting agents, and pine oil soap.

Bleaching: Chlorine, hypochlorite, hydrogen peroxide, chlorine dioxide, sodium perborate, peracetic acid, sodium bisulfite and sulfuric or hydrochloric acid.

Mercerizing: Caustic soda followed by acid neutralization.

Dyeing: This process is performed in a variety of ways. The various types of dyes used and classified according to their method of application. The more prominent dyes are: vat (applied in reduced state and then oxidized), developed (applied and diazotized and the color developed by use of a secondary chemical), naphthol (applied to fabric and then coupled with developer), sulfur (applied in reduced state and then oxidized), aniline block (applied and then air or steam oxidized), or direct (applied directly to cloth). Table 32 presents a listing of chemicals used in the application of dyes (2)(4). All dye types use a small amount of surfactant, and subsequent washing and rinsing uses detergent, sodium carbonate and phosphate.

TABLE 32

CHEMICALS PRESENT IN COTTON DYEBATHS

Dye Type	Auxiliary Chemicals Necessary
Aniline Black	Aniline hydrochloride, sodium ferrocyanide, sodium chlorite, pigment, soap.
Developed	Dye, penetrant, sodium chloride, sodium nitrate, hydrochlori acid or sulfuric acid, developer (beta naphthol), soap or sulfated soap or fatty alcohol, sodium nitrite, sodium carbonate
Direct	Dye, sodium carbonate, sodium chloride, and wetting agent or soluble oil or sodium sulfate.
Naphthol	Dye, caustic coda, soluble oil, alcohol, soap, soda ash, sodium chloride, base, sodium nitrate, sodium nitrite, sodium acetate.
Sulfur	Dye, sodium sulfide, sodium carbonate, sodium chloride, sodium dichronate, acetic acid alternatives, hydrogen peroxide, acetic acid
Vat	Dye, caustic soda, sodium hydrosulfite, soluble oil, gelatine, perborate or hydrogen peroxide, sodium hydrosulfite, dispersing agent, acetic acid, sodium perborate alternative, sodium dichromate chemicals
Disperse	Orthophenyl phenol, butyl benzoate alternative, bisphenyl carriers, chlorobenzene, acetic acid alternative, monosodium phosphate, dispersing agent
Acid	Acetic acid, ammonium sulfate , ammonium acetate, sodium chloride
Cationic	Acetic acid or formic acid, sodium sulfate
Reactive	Sodium chloride, urea, sodium carbonate, sodium hydroxide

[In addition to the chemicals listed, all of the dye types will usually use a small amount of surfactant. After the dyeing has been completed, the dyed goods are washed and then rinsed. Washing will involve use of a detergent as well as soda ash and a phosphate.]

Printing: Dyes, starch-base thickener, glycerol, vegetable gums, albumin, casein and detergents.

Final Finishing: Starch, dextrine, waxes, tallow, oils, clay talc, resins, cellulose esters, ether solutions, cellulose solutions, lacquers, quaternary ammonium salts, sulfonated compounds, glue, gelatin, vegetable gums, albumin and casein.

3. Synthetics

Synthetic textiles are manmade chemical based fiber compounds. The most prominent synthetics are acetate, acrylic, nylon, polyester and rayon. Other fibers used in lesser quantity include glass, metallic, rubber, Saran, Spandex, triacetate, and Vinyon. Only finishing operations will be considered here, beginning with the raw wound fiber.

When received at the finishing plant, the synthetic fibers require no processing for the removal of natural impurities; if in fabric form, however, they do require treatment for removal of sizing, antistats, and lubricating oils used in the weaving operation. Figure 32 presents a typical flow diagram for processing of 100% synthetic fibers.

There is considerable difference between the slashing (sizing) requirements of spun and continuous filament yarn. Spun yarn is handled like natural fibers and requires a quantity of size to impart strength and a protective coating on the yarn for weaving. Continuous filament yarn requires considerably less size, and of different types. Because of the low moisture content of synthetic fibers, static electricity problems are encountered in yarn preparation and weaving. Antistatic oils and lubricants are applied to the fiber before weaving. Compounds commonly used are: polyvinyl alcohol, styrene-base resins, polyalkylene glycols, gelatin, polyacrylic acid and polyvinyl acetate.

The finishing processes are similar for most synthetic fibers and include light scouring, revising, dyeing or bleaching, second rinsing and final finishing. The operations, sequence and chemical employed will vary with the type of fiber and will be considred separately under the categories: Rayon, acetate, nylon and polyester.

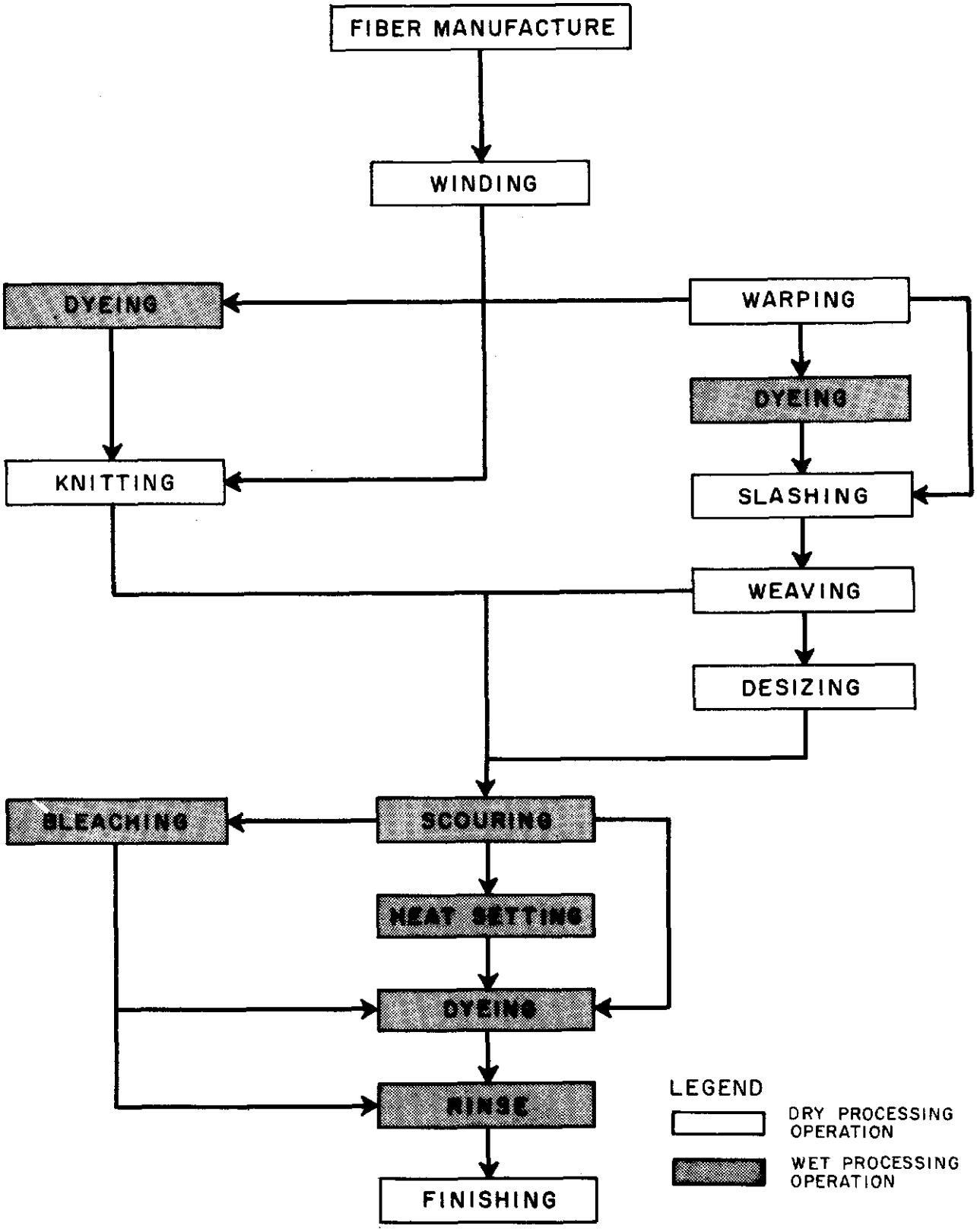

FIGURE 32 Typical Processing of 100 Percent Synthetic Fabric

A. Rayon - Scouring and dyeing are usually done concurrently in a single bath in finishing rayon. A solution of soluble oil and detergent is used for the scouring action. The same dyes as are used for cotton can be applied to rayon; however, lower temperatures, retarding agents and lower concentrations of electrolytes are used to effect exhaustion of color. The main reason for scouring and dyeing rayon in the same bath is that very little rayon is bleached, because of degradation of the fiber by the oxidizing bleaching agents. After scouring and dyeing, the rayon is subjected to a salt bath to remove residual scouring material and to assure fastness of the dyestuff. This bath contains detergent and salt solution which is subsequently rinsed from the fabric.

B. Acetate - The usual sequence for processing acetate fabrics is a preliminary desizing action; if necessary, a scour-and-dye-bath or a scour-and bleach-bath, followed by two rinses. The anti-static coumpounds are solubilized by diastatic or proteolytic enzymes prior to scouring. Soap or a synthetic detergent is used for scouring, and dyeing is done by dispersed dyes, dispersed developed dyes, acid and naphthol dyes. Sulfonated oil, aliphatic esters and softeners are applied to each class of dye to facilitate dyeing. They are subsequently removed by rinses. If bleaching is required, mild oxidizing agents such as peroxide bleaches and chlorine can be used.

C. Nylon - Finishing usually involves scouring, two rinses, dyeing and another rinse. A little nylon (approximately 1%) dissolves when scoured. Nylon fibers can also be colored by every class of dye. When nylon is used in blended fabrics, however, the choice of dye usually depends on the other fiber component of the blend. Soap and sodium carbonate are used in the scouring process, and sulfonated oils are used as dye dispersants.

D. Polyester - Finishing is usually carried out in the following order: scour, rinse, dye and second scour. If blended fabrics are processed, there is usually a second dyeing before the final scour. A non-ionic synthetic detergent is used for scouring. Polyester may be dyed in several ways. Conventional dyeing temperatures may

be used, but carriers are required to take the dye into the fiber. Alternately, high temperatures and pressures can be used to set the dyes. Carriers used in polyester dyeing are: ortho-phenylphenol, biphenyl, benzyl alcohol, methyl naphthalene and chlorobenzenes.

Table 33 presents a listing of the significant pollutants produced in the various synthetic fiber wet processing operations.

III. WATER REQUIREMENTS

Sources

Approximately three-quarters of the textile establishments in the United States draw their water from a utility - municipal or private (8). The great majority of these mills, however, are dry or semi-dry operations, so domestic services represent the largest demand for water.

By comparison, the operations using 20 million gallons of water per year or more, the significant water users, draw most of their water from surface supplies or from ground water. The following table (1) presents the water source and water discharge characterization for significant users in Massachusetts in comparison with New England, and the national average for the textile industry:

TABLE 34
WATER SOURCES AND DISCHARGES
TEXTILE INDUSTRY

	Water Source(%)			Water Discharge(%)	
	Utility	Surface	Ground	Sewer	Environment
United States	32	58	10	33	68
New England	19	77	4	11	89
Massachusetts	27	64	9	9	91

Gross water used by the industry nationally among significant water users is 950 mgd, compared with a water intake of 450 mgd. This indicates a recirculation ratio as high as 1.1(9) with a probable range of 0.3-1.1. Recirculation ratio is defined as:

TABLE 33

SIGNIFICANT POLLUTANTS IN SYNTHETIC FIBER WET PROCESSING

Fiber	Process	Liquid Waste Pollutant
Rayon	Scour & Dye	Oil, dye, synthetic detergent, and anti-static lubricants
	Scour & Bleach	Synthetic detergent, and hydrogen peroxide
	Salt bath	Synthetic detergent, chloride or sulfate
Acetate	Scour & Dye	Anti-static lubricants, dye sulfonated oils, synthetic detergents, esters and softeners
	Scour & Bleach	Synthetic detergent, hydrogen peroxide or chlorine
Nylon	Scour	Anti-static lubricants, soap, tetrasodium pyrophosphate, soda, and fatty esters
	Developed Dispersed Dye	Dye, N_aNO_2, Hydrochloric acid, developer, and sulfonated oils
	Bleach	Peracetic Acid
Acrylic/ Modacrylic	Dye	Dye, formic acid, wetting agent, aromatic amines, retarding agent, and sulphates
	Thermosol Dyeing	Acid
	Bleach	Chlorite
	Scour	Synthetic detergent and pine oil
	Thermosol Dyeing	Acid
	Dyeing with carriers	Chlorobenzenes, hot water, any dye; or phenylmethyl carbinol, dye, and hot water; or ortho-phenylphenol and dye
	Scour	Anti-static lubricants, chlorite or hypochlorite and non-ionic synthetic detergents
	High temperature & pressure dyeing	Dye and hot water
	Bleach	Chlorite, N_aNO_2, acetic acid, oxalic acid, nitric acid, bisulfite, proprietary bleaches

$$\frac{\text{(gross water used) - (water intake)}}{\text{(water intake)}}$$

This represents the degree to which daily water intake is reused in plant processing prior to discharge. In Massachusetts the recirculation ratio is only 0.09.

Uses

Water actually used for processing of textiles represents 70 - 75% of the total water intake; water consumption (or loss) is 6 - 9%, with the remainder ultimately discharged to sewer systems or the environment. Sixty percent of total daily water intake is treated prior to use, aside from process water (72%); the remainder is utilized for power generation (7%), cooking and condensing(10%), and boiler feed, sanitary services and other uses (11%).

Among significant users in Massachusetts 40% of intake water receives treatment prior to use and water distribution is subdivided as follows: Process (67%); power generation (8%); cooling and condensing (16%); and boiler feed, sanitary services and other uses (9%). Water discharged represents about 92% of water intake. Table 35 presents a summary of water use characteristics by the textile industry (4).

Quality

Water used for processing in the textile industry must be of high quality. Non-staining water is mandatory in most textile mill operations. Hence, the water should be as free of turbidity, color, iron and manganese as possible. Hardness can adversely affect the soaps and detergents used in the various operations and may also increase breakage during reeling and throwing operations, as well as cause the deposits of curds on the textiles. Nitrites and nitrates may create problems in wool and silk dyeing. Excessive calcium, magnesium, suspended solids and soluble organic matter are also objectionable in some operations. Table 36 presents representative water quality tolerances for process water usage in the textile industry (8) (10).

TABLE 35

WATER USE BY THE TEXTILE INDUSTRY

SIC Code	No. of Plants	Process Water Used 10^6 cu m/yr (BG/yr)	Average Water use/plant cu m/d (MGD)	Water Sewer 10^6 cu m/yr (BG/yr)	Discharged Surface 10^6 cu m/yr (BG/yr)	Treated Before Discharge Total 10^6 cu m/yr (BG/yr)	Treated Before Discharge Ponds 10^6 cu m/yr (BG/yr)
22	684	413. (109.0)	2100. (0.56)	192. (50.6)	306. (80.9)	203. (53.7)	117. (30.8)
2297	9	2.6 (0.7)	1100. (0.28)	0.38 (0.1)	3.4 (0.9)	2.3 (0.6)	- (-)
2231 +2283	67	47.3 (12.5)	2600. (0.68)	15. (3.9)	42.4 (11.2)	26. (6.9)	15. (3.9)
2211 +2221 +2241 + 226	348	269. (71.1)	2800. (0.73)	99.5 (26.3)	213. (56.4)	137. (36.3)	74.9 (19.8)
225	100	32. (8.4)	1100. (0.30)	28. (7.4)	11. (2.9)	8.7 (2.3)	2.3 (0.6)
227	50	30. (7.8)	2100. (0.56)	23. (6.1)	11. (2.8)	11. (2.8)	6.4 (1.7)
228 (-2283)	60	21. (5.6)	1200. (0.33)	16. (4.2)	16. (4.3)	15. (3.9)	14. (3.8)

TABLE 36

TEXTILE INDUSTRY WATER QUALITY TOLERANCES

	Process Requirement (p.p.m.)				
Constituent	General	Sizing	Scouring	Dyeing	Bleaching
Hardness	20	25	25	20	25
Total Dissolved Solids	--	100	100	100	100
Total Suspended Solids	--	5	5	5	5
Turbidity	5	--	--	5	--
Color	20	5	70	5-20	5
Copper	--	0.05	0.01	0.01	0.01
Iron	0.25	0.30	1.00	0.25	0.10
Manganese	0.25	0.05	1.00	0.25	0.01
Iron & Manganese	--	--	1.00	0.25	--
Chloride	100	--	--	--	--

Compared with national data for significant water users, the textile industry in Massachusetts relies more on direct intake from and discharge to the local environment, and less on utility and/or municipal services for water sources and disposal. It uses more water per establishment, requires less pretreatment and recirculates less water prior to discharge. The percentage of wastewater receiving final treatment prior to discharge to municipal sewer systems or to the local environment is also below the national average.

IV. WASTEWATER

Characteristics

The pollutional characteristics of textile waste differ widely among various segments of the industry, and each type of waste presents a special treatment problem. It is obvious that the water-borne pollutants from a textile mill will be dependent on the size and functions of the mill and, more significantly, the chemicals used in its various processes.

Mills processing synthetics, for example, will have a lower pollutional level in their effluent since certain processes are omitted when there are no natural impurities to remove. Woolen mills practicing weaving and finishing operations generally produce greater pollutional loads than similar mills processing cotton. Finishing operations can vary greatly, producing almost no process wastewater (semi-dry operations) for small specialty mills, or considerable process wastes, depending on the state of the starting raw material, and the characteristics of the final product.

Cotton

In general, liquid wastes from cotton processes will have the following characteristics:

Operation	
Desizing	High BOD, neutral pH, high total solids
Scouring	High BOD, high alkalinity, high total solids, high temperature
Bleaching	High BOD, alkaline pH, high solids
Mercerizing	Low BOD, alkaline pH, low solids
Dyeing and Printing	High BOD, high solids, neutral to alkaline pH

In treating 1000 pounds of cotton fabric, a composite waste stream has the following characteristics: pH of 8 to 11; the color either a gray or that of the predominant dye used; the BOD, total solids and suspended solids with concentrations of 200 to 600 mg/l, 1000 to 1600 mg/l, and 30 to 50 mg/l, respectively. These wastes will be contained in a volume of 30,000 to 93,000 gallons of water (2).

Another source (6) reports the following average cotton mill waste characteristics, based on survey data after equalization: 300 mg/l BOD; 1300 mg/l total solids; 600 mg/l total alkalinity (predominantly hydroxide); pH of 10.0 to 11.5; 2 mg/l total chromium and 40 mg/l suspended solids. The waste will have a grey colloidal turbidity tinged with dye color.

The major BOD sources will be glucose from slashing starch and waxes, and pectins and alcohols from the cotton. Soap and sodium acetate (from acetic acid) will be important BOD sources, if they are used in great volume. Because of the soluble nature of these compounds, little or no BOD will be removed by settling. Sodium hydroxide, sodium carbonate, sodium sulfate, sodium silicate and sodium chloride will be the most important inorganic compounds affecting alkalinity and dissolved solids content. Approximately 70,000 gallons of water will be used to process each 1,000 pounds of cloth.

One hundred pounds of natural impurities and 900 pounds of process chemicals will be discharged to waste for each 1000 pounds of cloth finished. The two major wastes are those from the desizing and caustic kiering operations, which contributed 67 to 100% of the total BOD. A total BOD load of 10 - 20% of fiber weight is expected from the average mill. Table 37presents the average ranges of the pollutional effect of cotton processing wastes for the various typical operations (2).

Wool

In the processing of woolen fibers, the major pollutional loads are caused by scouring, dyeing, washing after fulling, neutralizing after carbonizing, and bleaching with optical brightners. In general, wool processing wastes will have the following characteristics:

TABLE 37

POLLUTION EFFECT OF COTTON PROCESSING WASTES

Process	pH	Wastes (p.p.m.) B.O.D.	Wastes (p.p.m.) Total Solids	Gallons Waste per 1,000 lbs. goods	Pounds B.O.D. per 1,000 lbs. goods	Pounds Total Solids per 1,000 lbs. goods
Slashing, sizing yarn	7.0-9.5	620-2,500	8,500-22,600	60-940	0.5-5.0	47-67
Desizing	-------	1,700-5,200	16,000-32,000	300-1,100	14.8-16.1	66-70
Kiering	10-13	680-2,900	7,600-17,400	310-1,700	1.5-17.5	19-47
Scouring	-------	50-110	----------	2,300-5,100	1.36-3.02	------
Bleaching (range)	8.5-9.6	90-1,7000	2,300-14,400	300-14,900	5.0-14.8	38-290
Mercerizing	5.5-9.5	45-65	600-1,900	27,900-36,950	10.5-13.5	185-450
Dyeing:						
Aniline Black	-------	40-55	600-1,200	15,000-23,000	5-10	100-200
Basic	6.0-7.5	100-200	500-800	18,000-36,000	15-50	150-250
Developed Colors	5-10	75-200	2,900-8,200	8,900-25,000	15-20	325-650
Direct	6.5-7.6	220-600	2,200-14,000	1,700-6,400	1.3-11.7	25-250
Naphthol	5-10	15-675	4,500-10,700	2,300-16,800	2-5	200-650
Sulfur	8-10	11-1,800	4,200-14,100	2,900-25,600	2-250	300-1,200
Vats	5-10	125-1,500	1,700-7,400	1,000-20,000	12-30	150-250

Process	Significant Pollutants
Scouring	High BOD, high grease content, high alkalinity, turbid brown color and a temperature of 115° to 125°F.
Dyeing	Acid pH, highly colored, relatively high in BOD and possibly toxic.
Washing	High BOD, high oil content and temperatures of 110° to 150°F.

In treating 1000 pounds of scoured wool, the total waste load will contain 1,500 pounds of grease, suint and dirt, plus up to 500 pounds of process chemicals (detergents, alkali, softeners, etc.). This waste load is broken down into 250 pounds of BOD, 188 pounds of alkalinity and 40 pounds of acidity. The volume of water used will range from 55,000 to 134,000 gallons. A composite waste stream produced by the finishing of wool fibers would have the following pollutional loadings: pH of 9.0 to 10.5; BOD and total solids concentrations of 430 to 1200 mg/l and 6,500 mg/l, respectively (2).

Other survey data (6) indicated that wool scouring and finishing mills will produce an equalized effluent containing approximately 900 mg/l BOD; 3000 mg/l total solids; 600 mg/l total alkalinity (predominately carbonate); pH of 9 to 10.5; 4 mg/l total chromium and 100 mg/l suspended solids (predominantly sand and dirt in scouring effluents). It will have a brown colloidal color. The major BOD (88 - 96%) source will be the wool grease and suint removed in scouring, and the soap used in fulling and washing. Approximately 70,000 gallons of water will be used to process each 1,000 pounds of wool. A total BOD load of 40 - 50% of the weight of fiber processed is expected from the average mill.

Wool finishing mills that do not scour their own wool will eliminate the discharge of natural impurities, and so the pollutional load will be less. The equalized effluent will contain approximately 400 mg/l BOD, 800 mg/l total solids, 300 mg/l total alkalinity, pH of 9 to 10, 5 mg/l total chromium and 30 mg/l suspended solids. It will have a grey colloidal color tinged usually with the predominant dye color. The major source of BOD (at least 60% of the total) will be soap. Acetic acid, if used in substantial volume, will produce up to 25% of the total BOD. Both of these are soluble and

little BOD reduction will be obtained by settling alone. The wash water after fulling and the stock dye waste will produce almost 100% of the typical mill BOD.

A total BOD load of 15 - 25% of the weight of fiber processed is expected. Approximately 500 pounds of process chemicals will be discharged for each 1,000 pounds of wool processed. The water use will still be about 70,000 gallons per 1,000 pounds of cloth, since very little water is used for grease scouring. Table 38 presents the range of pollutional loads from wool wet processing operations (2).

Synthetics

Since the manufacture of synthetic fibers can be well controlled, chemical impurities are relatively few; often only light scouring and little or no bleaching are required prior to dyeing. While waste loads and volumes are generally less than those for processing natural fibers, the concentrations can be quite high and the variety of products produced very great, however. This is evident when one considers the kind of fibers available and the complex product mix that can occur when various synthetic and/or natural fibers are blended. Table 39 presents a summary of waste characteristics from synthetic fiber finishing operations for the various fibers and operations (6). Except for dacron processing, the BOD produced represents a relatively small percentage of the weight of fiber processed.

Synthetic fibers are pure, insoluble chemical compounds and there are no natural impurities. Caustic and soda ash consumption in these operations are less than those for natural fibers, and the average pH will be much lower. For example, a mill which finished a mixture of the five fibers considered produced a waste-water composition as follows: salt: 400 mg/l; soda ash, sodium tetra-phosphate, emulsified mineral oil, alum-wax emulsion: 70 - 80 mg/l each; ammonia, acetic acid, sulfonated castor oil, polyethylene oxide detergent, fatty ester of polyhydric alcohol, soap, hydroxyammonium sulphate, phenol, sodium sulphate: 30 - 50 mg/l each; ammonium sulphate, caustic soda, copper sulphate, formic acid, amine condensate, sulfonated vegetable oil, oxalic acid, peroxide, polyamino carboxylic acid, bleach, sulphuric acid: 10 - 30 mg/l each. The major BOD sources were soap, phenol, emulsifiable mineral oil, acetic acid, sulfonated castor oil, in descending order of importance. All are in true solution or colloidal, and settling produces little or no BOD reduction. Water use in the finishing of these fibers is comparatively low at 5,000 - 25,000 gallons per 1,000 pounds of cloth. Because of this

TABLE 38

POLLUTION LOADS OF WOOL WET PROCESSES

Process	pH	B. O. D. p. p. m.	B. O. D. lbs/1,000 lbs. cloth	Total Solids p. p. m.	Volume (gallons)
Scouring	9.0-10.4	30,000-40,000	104.5-221.4	1,129-64,448	5,500-12,000
Dyeing	4.8-8.0	380-2,200	9.0-34.3	3,855-8,315	1,900-2,680
Washing	7.3-10.3	4,000-11,455	31-94	4,830-19,267	40,000-100,000
Neutral-ization	1.9-9.0	28	1.7-2.1	1,241-4,830	12,500-15,700
Bleaching	6.0	390	1.4	908	300-2,680

TABLE 39

ANALYSES OF WASTES FROM SYNTHETIC FIBER FINISH MILL

	ph range	Total Solids range, ppm	BOD avg. ppm	BOD %OWF avg*
Rayon processing:				
Scour and dye	8.2-9.0	1,042-5,572	2,832	5.7
Salt take-off	6.8-6.9	3,388-7,256	58	0.1
Waterproof	-------	----------	960	1.9
Acetate processing:				
Scour and dye	8.3-8.5	1,534-2,022	2,000	5.0
Scour and bleach	8.9-9.6	766-946	750	1.8
			(Estimated)	(Estimated)
First rinse	7.0-9.1	108-188	Peroxide	
Second rinse	6.8-7.3	80-88	Contained Peroxide	0.0
Nylon processing:				
Scour	9.3-12.6	1,492-2,278	1,360	3.4
First rinse	8.2-10.7	150-954	90	0.2
Second rinse	6.5-8.2	106-932	25	0.1
Dye	7.8-9.0	318-1,016	368	0.9
Last Rinse	7.3-7.6	106-134	11	0.0
Waterproof	-------	----------	450	1.1
Orlon Processing:				
First scour	9.5-10.0	1,350-2,470	2,190	6.6
First rinse	6.4-8.7	102-294	109	0.4
First dye	2.2-6.5	170-1,950	175	0.5
Second rinse	4.1-6.5	116-300	42	0.1
Second dye	1.3-1.7	130-3,002	995	3.0
Second scour	5.9-7.7	612-1,824	688	2.0
Third rinse	6.3-7.4	82-152	50	0.2
Waterproof	3.7-4.3	896-2,318	2,110	6.3
Dacron Processing:				
	(Estimated from OWF concentrations as listed)			
Scour	---------	---------	650	
Dyes:				
o-Phenylphenol (10%OWF)	---------	---------	6,000	18.0
Benzoic acid (40%OWF	--------	---------	27,000	81.0
Salicylic acid (40%OWF)	--------	---------	24,000	72.0
Phenylmethylcarbinol (30% OWF)	--------	---------	19,000	57.0
Monochlorobenzene (40% OWF)	--------	---------	480	1.4

*% on weight of fiber, a weight percentage based on dried cloth weight.

the average BOD of the equalized effluent can be high if appreciable BOD loads are discharged (6). See Table 40.

The BOD contribution of the various chemicals used in the processing of synthetic fibers is presented in Table 41, and the expected pollutional loads from scouring and dyeing of various textile fibers are presented in Table 42 (11).

Most of the chemicals used in processing synthetic fibers have been widely used for cotton. However, some of the newer compounds unfortunately have very high BOD's (phenol 200%, orthophenylphenol 138%, benzoic acid 165%, salicylic acid 141%, phenylmethylcarbinal 150%), and are expected to cause considerable increases in pollution loads when used. Table 43 presents a comprehensive listing of the BOD's of the various process chemicals used in the textile industry. (6).

Unlike wool and cotton, synthetic fibers of the same type can have different physical and chemical properties. The manufacturers of manmade fibers are continually producing variations of existing fibers and totally new fibers to meet existing or anticipated needs. As a result, the techniques used in finishing synthetic textile fibers are largely dictated by the manufacturer. For these reasons, the processing of these fibers can produce a variable waste load, depending on the particular fiber type used, the manufacturer's suggested method of processing, and the particular process chemicals used. A summary of the average pollutional loads generated from current practice in processing synthetics is presented in Table 44 (2).

Considerable basic pollutional volume-loading information has been provided in this section on wastewater characteristics to stress the variety of materials, processes and methods of operation used within the textile industry. Wastewater from each will have its own peculiar character. This is mainly because processing, although easily described in general, is actually quite complicated, since each process may be performed in several steps. Further, any one operation may be performed:

1. Batchwise or continuous
2. In kiers, jigs, or other machines
3. To variable end points of client demands.

TABLE 40

EXPECTED B.O.D. LOADS AND CONCENTRATIONS FROM PROCESSING OF VARIOUS FIBERS*

	Gallons per 1,000 lbs.	B.O.D. % OWF	Average B.O.D. p.p.m.
Rayon	5,000	5.0-8.0	1200-1800
Acetate	9,000	4.0-6.0	500-800
Nylon	15,000	3.5-5.5	300-500
Orlon	25,000	10.0-15.0	500-700
Dacron:			
o-phenylphenol	12,000	15.0-25.0	1500-2500
Monochlorobenzene	12,000	3.0-5.0	300-500
Benzoic acid	12,000	60.0-80.0	6000-8000
Salicylic acid	12,000	50.0-70.0	5000-7000
Phenylmethylcarbinol	12,000	40.0-60.0	4000-6000
Cotton	70,000	12.5-25.0	200-600
Wool	70,000	40.0-60.0	700-1200

* Based on actual plant surveys, excepting dacron.

TABLE 41

B.O.D. CONTRIBUTIONS * OF PROCESS CHEMICALS USED

	B.O.D.		
	%	lbs. p.t.p.c.	% of Total
ACETATE PROCESSING			
1. Scour and Dye			
(Antistat-lubricant)	--	15.0	44
2% Sulfonated oil	52	10.4	31
1% Syndet	5	0.5	2
2% Aliphatic ester	41	8.2	24
2% Softener	0	0	0
Total		34.1	
RAYON PROCESSING			
1. Scour and Dye			
(Antistat-lubricant)	--	15.0	50
3% Syndet	14	4.2	14
2% Soluble oil	53	10.6	36
10-30% Common Salt	0	0	0
Total		29.8	
ORLON PROCESSING			
1. Scour			
(Antistat-lubricant)	--	15.0	12
2% Soaps	150	30.0	24
4. First dye			
0.5% Syndet	0	0	0
3% Formic acid	20	6.0	5
7. Second dye			
1% Wetting agent	14	1.4	1
3% Phenolic compounds	200	60.0	48
3% Copper sulfate	--	--	--
2% Hydroxy ammonium sulfate	4	0.8	1
8. Scour			
2% Syndet	0	0	0
1% Pine oil	108	10.8	8
Total	--	124.0	--

TABLE 41 (Cont.)

B.O.D. CONTRIBUTIONS* OF PROCESS CHEMICALS USED

	B.O.D.		
	%	lbs. p.t.p.c.	% of Total
NYLON PROCESSING			
1. Scour			
(Antistat-lubricant)	--	15.0	29
1% soaps	150	15.0	29
1% Fatty esters	55	5.5	11
4. Dye			
2-4% Sulfonated oils	56	16.8	32
Total	--	52.3	--
DACRON PROCESSING			
1. Scour			
(Antistat -lubricant)	--	15.0	9
1% Nonionic syndet	5	0.5	0
2. Dye			
4% Acetic Acid (84%)	58	23.0	13
10% Ortho-phenylphenol	138	138.0	78
Other Possible Carriers			
6% Para-phenylphenol	--	--	--
40% Benzoic acid	165	(660.0)	(94)
40% Salicylic acid	141	(564.0)	(94)
30% Phenylmethylcarbinol	150	(450.0)	(92)
Total		176.5	

* The B.O.D. contribution is calculated from the OWF concentration and the % B.O.D. of the chemical used.

Under B.O.D., % indicates the % B.O.D. of the process chemical. For example, 52% B.O.D. for sulfonated oil indicates that when 1 lb. of the oil is used, 0.52 lbs. of B.O.D. would be contributed.

lbs. p.t.p.c. indicates the pounds of B.O.D. contributed by the process chemical for each 1000 lbs. of cloth.

% of total indicates the % contribution of the chemical in the total B.O.D. of the waste.

TABLE 42

EXPECTED POLLUTION LOADS FROM SCOURING AND DYEING OF VARIOUS TEXTILE FIBERS

	Gallons p. t. p. c.	lbs. B. O. D. p. t. p. c.	Average B. O. D. p. p. m.
Rayon	5,000	50-80	1200-1800
Acetate	9,000	40-60	500-800
Nylon	15,000	35-55	300-500
Orlon	25,000	100-150	500-700
Dacron:			
O-phenylphenol	12,000	150-250	1500-2500
Monochlorobenzene	12,000	30-50	300-500
Benzoic acid	12,000	600-800	6000-8000
Salicylic acid	12,000	500-700	5000-7000
Phenylmethylcarbinol	12,000	400-600	4000-6000
Cotton	70,000	125-250	200-600
Wool (grease)	70,000	400-600	700-1200

* These results are estimates from actual plant surveys, except for Dacron.
Average B. O. D. is for the equalized waste.
p. t. p. c. means per thousand pounds of cloth.
If the cloth is to be water-proofed, B. O. D. loads will be increased by 20 to 40 lbs. p. t. p. c. and the volume will be increased by 2000 to 4000 gallons p. t. p. c.

TABLE 43

B.O.D.'S OF VARIOUS PROCESS CHEMICALS

Chemical Name	Chemical Composition	B.O.D. (%)[1]
	(a) SOAPS	
Non-pareil (92%)	Sodium salt of fatty acid	140
Rome soap flakes	Sodium salt of fatty acid	122
Special textile flakes	Sodium salt of fatty acid	112
Soap	Sodium salt of fatty acid	150
Ivory Snow	Sodium salt of fatty acid	141
Lux	Sodium salt of fatty acid	147
Super Suds	Sodium salt of fatty acid	97
	(b) SYNTHETIC DETERGENTS	
Ethofat C/15	Polyethoxyethanol fatty acid ester	100
Ethofat C/60	Polyethoxyethanol fatty acid ester	22
Ethomid HT/15	Polyethoxyethanol fatty acid amide	100
Ethomid HT/60	Polyethoxyethanol fatty acid amide	9
Exol XP Special	—	70
Iherscour	—	53
Igepal	Ethylene oxide alkyl phenol condensate	4
Igepal CA-630	Ethylene oxide alkyl phenol condensate	13
Igepal CA-conc.	Ethylene oxide alkyl phenol condensate	7
Igepon T-77	Sulfonated amide	166
Igepon AP-78	Oleic ester of sodium isothionate	121
Kreelon 8D	Sodium alkylarylsulfonate	15
Kreelon 8G	Sodium alkylarylsulfonate	23
Rinsol	—	72
Sandopan TLF	Sulfonated fatty amide	5
Santomerse 3	Sodium alkylarylsulfonate	9
Solpinol Special	Pine oil compound	70
Solvent A	—	25
Solvent GTS	Pine oil preparation	41
Solvent T	—	25
Solvex	—	1
Strodex	Sulfated amide condensation	12
Supertex E	Fatty acid soaps, solvent, and cresylic acid	25
Kyro AC	Amine condensate	12
Kyro EO	Polyethylene oxide condensate	0
Syntholite 100	Sulfated secondary alcohol	10
Triton 770	Alkylaryl polyether sulfate	9
Triton 771 conc.	Polyether sulfate	1
Ultrawet DS	Arylalkyl ether sulfate	50
Ultrawet 35K	Sodium alkylarylsulfonate	0
Duponol C	Lauryl sulfate	125
Duponol D paste	Long-chain alcohol sulfate	45
Duponol RA	Long-chain alcohol sulfate	33
Duraline	Solvent-type detergent	16
Monatone A	Built soap gel	20
Naccosol A	Sodium alkylnaphthalene sulfonate	0
Nacconol NR	Sodium alkylarylsulfonate	2
Nacconol NRSE	Sodium alkylarylsulfonate	0
Nekal NF	Alkylarylsulfonate with organic solvent	12
600 Neutronyx	Aromatic polyglycol ether	0
Orvus AB	Alkylarylsulfonate	8
Orvus Neutral granules	Alkylarylsulfonate	3
Orvus Extra granules		9
Parval	Fatty amine condensate plus amine soap	5
Peregal O.K.	Cationic ethylene oxide condensation	2
Pluronic F68	Polyglycol ethers	12
All	—	4
Dreft	—	49
Unico Scour M	Alkylnaphthalene sulfonate	10
Saponite	—	83
Zipsuds	Soap "break"	56
Dri-sudz	—	43
Tergitol NPX	—	2
Tween 80	Sorbitan monooleate polyoxyalkylene	35
Sodium alginate	—	36
	(c) SIZES, SPINNING, AND CARDING OILS	
KD gum	Starch	57
RTC gum	Starch-Urea	12
Starch No. 450	Starch	46
Tragtex R	Gum tragacanth	2
Wheat starch	Starch	55
Ambertex M	Starch paste	2
Amioca	Waxy-maize starch	7
B-2 gum	Starch dextrins	61
Brytex gum 745	Starch	61
Crystal gum	Converted starch	9
Dextrin	Converted starch	50
Pearl cornstarch	Starch	50
Nicol starch	Starch	57
Morningstar starch	Starch	47
Carboxymethylcellulose	Carboxymethylcellulose	3
Hydroxyethylcellulose	Hydroxyethylcellulose	3
Nopco 1656	Soluble fatty ester	12
Proxol T	Mineral oil plus nonionic emulsifier	20
Ahco Nylon warp size	—	34
Peter Cooper size	Glue	118
Gelatin	Gelatin	100
Ucon H-6	Polyalkalene glycols	4
Ucon H-15	Polyalkalene glycols	4
Picking oil	—	13
Glue	Glue	66
Elvacet	—	1
Avcosol 20	Waxy sorbitol ester	42
Orthocryl 25	Polyacrylic acid	1
Stymer R	Styrene maleic anhydride salt	1
Stymer S	Styrene maleic anhydride salt	1
Elvanol	Polyvinyl alcohol	1
	(d) SPECIAL FINISHING AGENTS	
Finish T.S.	Soya bean oil	39
Urea	NH_2CONH_2	9
Wool finish B	High carbohydrates and enzymes	57
Zelan AP Paste	High molecular nitrogen compounds	15
Zeset S	Resin solution	7
Aerotex M-3 resin	Melamine-formaldehyde	23
Aerotex softener H	Mixed cationic-anionic long-chain derivatives	3
Aerotex syrup 250 conc.	Urea-formaldehyde condensate	5
Ahcovel G	Fatty carbamide	2

[1] Per cent B.O.D. is based on weight of chemical; for example, 140 per cent B.O.D. indicates that each pound of chemical will exert 1.4 lb. of B.O.D.

TABLE 43 (continued)

Chemical Name	Chemical Composition	B.O.D. (%)[1]
Avitex SF	Long-chain alcohol sulfate	35
Avitex R	High alkylamine	5
Avitone A	Sodium hydrocarbon sulfate	2
Casein	Casein	25
Catalyst AC	Nonammonium stable organic salt	2
Cetosol SF	Resin	24
Concental H60	Highly sulfonated organic material	100
Dimethylolurea	Dimethylolurea	10
Lustramine	—	33
Lustrasol	—	20
Meleine RS	Aliphatic amino compound	30
Methacrol FNH	Resin emulsion	4
Resloom HP special	Melamine-formaldehyde condensate	13
Resloom M 75 G	Melamine-formaldehyde condensate	14
Rhonite 313	Urea-formaldehyde resin	11
Rhonite 610	Urea-formaldehyde resin	5
Rhonite R-1	Urea-formaldehyde resin, modified	7
Norane W-1	Wax emulsion	70
Norane W-2	Metal-organic dispersion	1
Alum-wax	Alum-wax dispersion	30
Softener cream	Sulfonated tallow oil	39
(e) EMULSIFYING AGENTS		
Kierpine Extra	Sulfonated tall and pine oils	61
Sandozol KB	Sulfonated vegetable oil	15
Triethanolamine	$(HOCH_2CH_2)_3N$	1
B.P. solvent	Pine oil mixture	94
Merpol B	Alcohol sulfate	44
Sulfonated castor oil	Castor oil, sulfonated	52
Sulfonated vegetable oil	Vegetable oil, sulfonated	59
Nopco 1111	Sulfonated coconut oil	96
Rexan O	Ethylene ether condensation	2
Pentex 46	—	35
Capracyl	—	5
(f) DYEING		
Formaldehyde 37%	HCHO	37
Formic acid 85%	HCOOH	20
Glucose corn syrup	Glucose $C_6H_{12}O_6$	53
Glycerine	$CH_2CH\ CHOH\ CH_2OH$	64
Sodium acetate	$CH_3\ COONa$	32
Sodium hydrosulfite	$Na_2S_2O_4$	22
Sodium sulfide	Na_2S	40
Sulfoxite	$NaHSO_2 \cdot HCHO \cdot 2H_2O$	27
Acetic acid, 56%	CH_3COOH	35
Acetic acid, 80%	CH_3COOH	52
Acetic acid, 84%	CH_3COOH	62
Ammonium sulfate	$(NH_4)_2SO_4$	0
Sulfuric acid	H_2SO_4	0
Aniline oil	$C_6H_5NH_2$	150
Anthomine	High molecular weight fatty esters and nitrogen compounds	9
Carbogen	—	2
Lanazine tip	Albumen derivative	9
Metachloron	—	0
Monochlorobenzene	C_6H_5Cl	3
Dowicide A	o-phenyl phenol	138
Salicylic acid	$C_6H_4(OH)COOH$	141

Composition Name	Composition Chemical	B.O.D. (%)[1]
Benzoic acid	C_6H_5COOH	165
Phenylmethylcarbinol	—	150
Phenol	C_6H_5OH	200
(g) MISCELLANEOUS		
Ethanol	C_2H_5OH	125
Ethylacetate	$C_2H_5COOCH_3$	85
Isopropyl acetate	$(CH_3)_2CH\ COOCH_3$	26
Acetone	CH_3COCH_3	122
Methanol	CH_3OH	80
Allyl alcohol	$CH_2{:}CHCH_2OH$	20
Butyl acetate	$C_4H_9COOCH_3$	52
Butyraldehyde	C_3H_7CHO	106
Methyl isobutyl ketone	$CH_3COCH_2(CH_3)_2$	12
Morpholine	$O : (CH_2CH_2)_2 : NH$	2
Dypenol SED	Polyhydric alcohols and cresylates	39
Ethylene glycol	$HOCH_2CH_2OH$	16
Extender No. 31	Mineral spirits	8
Formopon	$NaHSO_2 \cdot HCHO \cdot 2H_2O$	27
Glucone delta lactone	Delta lactone of gluconic acid	52
Inhibitor M	Ethylene diamine tetra acetic acid	26
Iversol	Soap, solvent, and penetrant blend	60
Rhozyme LA	Diastatic enzyme	2
Serizyme	Proteolytic enzyme	2
Rapidase M	Diastatic enzyme	2
Soluol	—	64
Syton W-20	Colloidal silica	0
Tallow	Tallow	162
Vel	Sulfated monoglyceride of coconut fatty acids	27
Diastofor L	Amylolytic, proteolytic enzyme mixture	2
Diethylene glycol	$O(CH_2CH_2OH)_2$	4
Leucophor	—	33
Oxalic acid	$H_2C_2O_4 \cdot 2H_2O$	14
Pine oil	Pine oil	108
Kalex	Sodium salt of ethylene diamine tetra acetic acid	2
Hydroxyammonium sulfate	$(NH_2OH)_2SO_4$	4
Facid CE	—	20
Stantex FG	—	20
Immersol Supra	Alkylarylpolyether	2
Hycar L	—	2
Fabrisec AA	—	44
Unipen	—	40
Zelex DX	—	2
Zelex DP	—	9
Propionic acid	C_2H_5COOH	78
Sodium propionate	C_2H_5COONa	50
Butyric acid	C_3H_7COOH	84
Valeric acid	C_4H_9COOH	106
Nonylic acid	$CH_3(CH_2)_7COOH$	59
Palmitic acid	$C_{15}H_{31}COOH$	107
Stearic acid	$C_{17}H_{35}COONa$	144
Sodium oxalate	$Na_2C_2O_4$	11

[1] Per cent B.O.D. is based on weight of chemical; for example, 140 per cent B.O.D. indicates that each pound of chemical will exert 1.4 lb. of B.O.D.

TABLE 43 (continued)

Chemical Name	Chemical Composition	B.O.D. (%)[1]
Lactic acid	$CH_3CHOH\ COOH$	72
Succinic acid	$HOOC(CH_2)_2COOH$	48
Fumaric acid	$HOOC(CH)_2COOH$	61
Maleic acid	$HOOC(CH)_2COOH$	38
Maleic acid	$(CH)_2\ C_2O_3$	50
Tartaric acid	$HOOCCHOHCHOHCOOH$	30
Citric acid	$CH_2COOH\ C(OH)COOH\ CH_2COOH$	40
Sodium citrate	Sodium salt of above	37
Undecylenic acid	—	54
Sodium oleate	$C_{17}H_{33}COONa$	136
Sodium benzoate	C_6H_5COONa	125
Phthalic acid	$COOH \cdot C_6H_4\ COOH$	106
Phthalic anhydride	$C_6H_4\ CO(O)CO$	106
Sulfanilic acid	$C_6H_4(NH_2)SO_3H$	111
Toluene sulfonic acid	$C_6H_4(CH_3)SO_3H$	0
Anthraquinone sulfonic acid	$C_{14}H_7O_2 \cdot SO_3H \cdot {}_3H_2O$	0
Tannic acid	—	38
Isopropyl alcohol	$(CH_3)_2CHOH$	133
n-butyl alcohol	$C_2H_5CH_2CH_2OH$	157
n-amyl alcohol	$CH_3(CH_2)_3CH_2OH$	155
Iso-amyl alcohol	$(CH_3)_2CH\ CHOH\ CH_3$	156
Cyclohexanol	$(CH_2)_5CHOH$	8
Octyl alcohol	$CH_3(CH_2)_6CH_2OH$	109
Ethylene glycol	$HOCH_2 \cdot CH_2OH$	70
Diethylene glycol	$(HOCH_2CH_2)_2O$	2
Triethylene glycol	$(CH_2CH_2OH)_2\ OCH_2CH_2O$	50
Tetraethylene glycol	—	50
Polyethylene glycol	$(HOCH_2 \cdot CH_2OH)_x$	19
Benzyl alcohol	$C_6H_5\ CH_2OH$	155
Acetaldehyde	CH_3CHO	127
Belzaldehyde	C_6H_5CHO	150
Methylethylketone	$CH_3COC_2H_5$	214
Diethylketone	$C_2H_5COC_2H_5$	100
Ethanolamine	$NH_2\ CH_2\ CH_2\ OH$	78
p-toluidine	$CH_3C_6H_4NH_2$	154
o-toluidine	$CH_3C_6H_4NH_2$	143
Acrylonitrile	CH_2CHCN	70
Polyacrylonitrile	$(CH_2CHCN)_x$	4
Sucrose	$C_{12}H_{22}O_{11}$	69
Lactose	$C_{12}H_{22}O_{11} \cdot H_2O$	57
Dextrin	$(C_6H_{10}O_5)_x$	45
Cellulose	$(C_6H_{10}O_5)_x$	15
Alpha-cellulose	$C_6H_{10}O_5$	78
Methylcellulose	—	1
Ethyl ether	$C_2H_5\ O\ C_2H_5$	3
Diethyl ether	$C_2H_5\ O\ C_2H_5$	0
Methylcellosolve	Ethylene glycol monomethyl ether	110
Dioxane	$O\ (CH_2)_4\ O$	0
Gasoline	—	8
Kerosene	—	53
Benzene	C_6H_6	120
Toluene	$C_6H_5CH_3$	0
Xylene	$C_6H_4(CH_3)_2$	0
Naphthalene	$C_{10}H_8$	0
Chloroform	$CHCl_3$	0
Carbon tetrachloride	CCl_4	0
Nitrobenzene	$C_6H_5NO_2$	0
Ortho-cresol	$C_6H_4(CH_3)OH$	164
Meta-cresol	$C_6H_4(CH_3)OH$	170
Para-cresol	$C_6H_4(CH_3)OH$	144
Beta-naphthol	$C_{10}H_7OH$	179
Glycine	$NH_2\ CH_2\ COOH$	54
Glutamic acid	$HOOC\ CHNH_2\ CH_2CH_2\ COOH$	50
Glucose	$C_6H_{12}O_6$	71

[1] Per cent B.O.D. is based on weight of chemical; for example, 140 per cent B.O.D. indicates that each pound of chemical will exert 1.4 lb. of B.O.D.

TABLE 44

POLLUTIONAL LOAD OF SYNTHETIC WET FIBER PROCESSES

Process	Fiber	pH	B.O.D. p.p.m.	B.O.D. lbs/1000 lbs of cloth	Total Solids p.p.m.	Total Solids lbs/1000 lbs of cloth	Suspended Solids lbs/1000 lbs of cloth	Volume in gal. per 1000 lbs of cloth
Scour	Nylon	10.4	1360	30-40	1882	30-50	20-40	6,000-8,000
	Acrylic/ Modacrylic	9.7	2190	45-90	1874	12-20	25-50	6,000-8000
	Polyester	----	500-800	15-25	----	25-35	5-15	3,000-5,000
Scour & Dye	Rayon	8.5	2832	50-70	3334	25-39	0-3	2,000-4,000
	Acetate	9.3	2000	40-60	1778	-----	1-20	4,000-6,000
Dye	Nylon	8.4	368	5-20	641	20-34	2-42	2,000-4,000
	Acrylic/ Modacrylic	1.5-3.7	175-2000	2-40	833-1968	6-9	5-20	2,000-4,000
	Polyester	---	480-27,000	15-800	----	30-200	-----	2,000-4,000
Salt Bath	Rayon	6.8	58	0-3	4890	20-200	2-6	500-1,500
Final Scour	Acrylic/ Modacrylic	7.1	668	10-25	1191	4-12	3-7	8,000-10,000
	Polyester	----	650	15-25	----	10-50	3-50	2,000-4,000
Special Finishing	Rayon	----	-----	20	----	3-100	3-50	500-1,500
	Acetate	----	-----	40	----	3-100	3-50	3,000-5,000
	Nylon	----	-----	10	----	3-100	3-50	4,000-6,000
	Acrylic/ Modacrylic	----	-----	60	----	3-100	3-50	5,000-7000
	Polyester	----	-----	2-80	----	3-100	3-50	1,000-3,000

At best, only broad generalizations can be made regarding the character of a plant's waste, and considerable rudimentary data is provided here to assist in evaluating each mill in the study area, so that a rational basis for determining wastewater loadings discharged from each installation within a particular category may be derived. Table 45 presents additional information on unit wastewater loadings, to aid in determining loading parameters (5) for cotton, wool and synthetic processing.

Data for cotton textile mills appears to be the most predictable. An overall summary of BOD contribution for the various cotton processes (Table 46) can be reduced to a usable formula for approximation, as follows:

Total BOD from mill (lb) = [0.067 x lb (dry) of cloth desized] + (0.045 lb of cloth scoured) + (0.005 x lb of cloth bleached) + (0.006 x lb of cloth mercerized) + (0.025 x lb of cloth dyed and printed).

The BOD loads from the various operations were computed as a percent OWF (that is, a weight percentage based on dried cloth weight) in order to develop a general relationship among pollution potentials of these operations (6).

More interesting, however, is the fact that when ratios are taken of the percent OWF BOD potential of all operations, it can be seen that desizing, which must always be performed on grey goods received at the finishing mill from the weaving mill, contribute a minimum of 45 percent of the BOD load from a textile finishing mill. Also, in the event that all operations listed in Table 46 are not performed, the BOD contribution from desizing to the overall plant waste will increase. This fact has stimulated intensive research in the area of finding substitutes for starch which will produce less pollution, but with no loss in cloth product quality. The possibilities for in-plant wastewater reduction in volume and loading are considered in more detail in the next section.

TABLE 45

ANALYSIS AND POLLUTION POTENTIAL OF VARIOUS TEXTILE MILL SOLUTIONS

Item	pH range	Total solids range, ppm	BOD range, ppm
Experimental desize solutions, first rinse water following detention time for enzyme action	5.0-9.5	4,968-9,474	2,600-5,450
Caustic kier:			
First boil	11.0-13.1	33,804-58,126	6,100-14,100
Second boil	11.5-12.9	5,790-48,458	1,525-2,300
Continuous scour:			
Drippings from J box	11.6-12.8	66,428-97,468	13,800-15,700
First rinse following caustic	11.0-12.3	1,858-2,370	425-630
Second rinse following caustic	9.9-11.0	174-264	24-46
Bleaching:			
First rinse following hypochlorite bleaching	7.3-8.1	140-548	6-100
First rinse following peroxide bleaching	7.5-9.5	214-368	26-78
Rinse following mercerizing (after 4th box)	12.1-12.5	2,032-4,952	7-54

TABLE 45 (continued)

POLLUTION EFFECT OF COTTON PROCESSING WASTES

Process	Wastes, * ppm pH	Wastes, * ppm BOD	Gal. wastes per 1,000 lb. goods
Slashing, sizing yarn **	7.0-9.5	620-2,500	60-940
Desizing	---	1,700-5,200	300-1,100
Kiering	10-13	680-2,900	310-1,700
Scouring	---	50-110	2,300-5,100
Bleaching (range)	8.5-9.6	90-1,700	300-14,900
Mercerizing	5.5-9.5	45-65	27,900-36,950
Dyeing:			
Aniline black	---	40-55	15,000-23,000
Basic	6-7.5	100-200	18,000-36,000
Developed colors	5-10	75-200	8,900-25,000
Direct	6.5-7.6	220-600	1,700-6,400
Indigo	5-10	90-1,700	600-6,000
Naphthol	5-10	15-675	2,300-16,800
Sulfur	8-10	11-1,800	2,900-25,600
Vats	5-10	125-1,500	1,000-20,000

* Composite of all wastes connected with each process.

** Cloth weaving mill waste.

TABLE 45 (continued)

COTTON DESIZE WASTE CHARACTERISTICS

Waste	Flow, gal *	BOD, ppm	Pop. equiv. **
Desizing bath	140	8,000	54
Wash water	200-1,800	840	42
Total	1,100	1,750	96

QUANTITY AND SANITARY CHARACTERS OF ENZYME DESIZE AND STARCH RINSE WASTES

Item	Enzyme desize	Starch rinse
Volume (gal/1000 lb. goods)	25	7200
pH	7.35	7.1
5-day BOD, ppm	4,375-5,063	997
Total solids, ppm	8,946-10,548	1,482-1,830
Suspended solids, ppm	197-272	244-268
Total dissolved solids, ppm	8,682-10,276	1,238-1,562
Color, x ppm	400	80
Turbidity, Jackson, ppm	---	250

KIER LIQUOR WASTE COMPOSITION

Component	Volume, xx gal
Caustic soda waste	25.0
Bleach waste	16.3
Wash water waste	4.4
Total	45.7

Notes to Table 45:

* Per 1,000 lb goods.

** Per 1,000 lb goods per day.

x Standard color wheel.

xx As found in typical North Carolina mill, in gallons per 100 lb of cloth processed.

TABLE 46

BOD CONTRIBUTION OF COTTON PROCESSES

Process		BOD potential % OWF*	BOD contribution,** %	BOD sources
Desizing	Avg	6.7	45	Glucose from starch hydrolysis
Scouring:				
Pressure kier, first boil		5.3		Natural waxes, pectins, alcohols, etc. (80%), penetrants and assistants (20%)
Pressure kier, second boil		(0.8)		
Open kiering		(0.4)		
Continuous scour		4.2		
	Avg	4.7	31	
Bleaching:				
Continuous, hypochlorite		0.8		Penetrants
Continuous, hydrogen peroxide		0.3		
Open kier, hydrogen peroxide		0.4		
	Avg	0.5	3	
Mercerizing	Avg	0.6	4	Penetrants
Coloring:				
Dyeing		0.5-3.2		Sodium sulfide, sulfite, acetic acid, etc.
Printing (including color shop wastes and wash after printing)		1.9-4.2		Starch mainly, plus glycerol, reducing agents, detergents, soap
	Avg	2.5	17	
Grand total (based on avg)		15.0	100	

* % on weight of fiber or lb BOD/100 lb fiber or cloth.
** Based on grand total of averages (15.0 percent OWF).

V. WASTEWATER REDUCTION

One of the first and most obvious possibilities that should be investigated in textile mill waste disposal is in-plant reduction of wastewater volume and load discharged. Many opportunities exist to reduce process water usage: segregation; reduction of water volume to the minimum needed to maintain product quality; changes in plant operating techniques to conserve water; and recycling and reuse. Also, there are many opportunities to recover raw materials and process chemicals used in textile mill operations, either for reuse in the mill itself, or for possible sale of by-product recovered chemicals elsewhere. In some cases, substitution of process chemicals by use of compounds with lower pollution potential will minimize the requirements for ultimate pollution abatement facilities, and will aid in attaining the ultimate goal of zero discharge of pollutants, or complete plant close-up.

The techniques that can be employed to reduce wastewater within a mill are many. They include the use of improved operating and housekeeping procedures, process modification or closer process control, reduction of process chemical usage, substitution of newer, less polluting chemicals, water conservation, water segregation, water use minimization, water recycle, recovery and reuse of chemicals, and by-product utilization.

Better Housekeeping

One method of reducing the pollutional load from a mill, concurrently reducing production costs, is the implementation of good housekeeping procedures. Analysis of a mill's operations should be made to improve its operating efficiency and reduce material losses.

Accidental spillage and wasting to drain must be avoided. Since large batches of process solutions may spoil or not be of proper quality, they must be thrown away at the end of the production run. Preparing smaller batches would eliminate this waste. It is also a good housekeeping practice to dilute accidental spillages of toxic chemicals, if they should occur, to prevent shock loadings from reaching the wastewater treatment facility. Maintaining a clean facility will also reduce pollutional load. If the possibilities of picking up dirt, grease, rust, etc., from the floor and the machinery are eliminated, less washing and less re-processing of the fabrics are required.

A plant can be engineered for minimum losses through spillage, breakage, etc., by the incorporation of retaining walls, splash boards, and sills, but effective housekeeping depends on the efforts, cooperation, and support of the operating personnel to implement the procedures to the fullest extent possible. It has been estimated that conscientious good housekeeping practices eliminate from 5 to 10% of the total pollutional load of a textile mill. (2)

Process Control

Closer process control could be a greater help in pollution reduction. It is believed that textile mill processing is often based on handling the worst condition that may prevail. This condition may prevail only 1 to 5% of the time, but the more rigorous processing for worst conditions is used 100% of the time, to eliminate chances of re-processing. For example, cotton kiering at 5% of fiber weight produces a very white cloth, and should be used only when white cloth is desired. When the cloth is to be dyed a dark shade, less rigorous kiering with 1 to 2% caustic could be used. This will reduce the caustic used, and experiments indicate that only half as many natural impurities will be extracted. Lower BOD and alkalinity could thus be discharged, if the operator paid close attention and used the lower caustic add-ons when possible.

In sizing thread for weaving cloth, furthermore, 2 to 15% size concentrations may be used. The 15% is necessary particularly with tightly woven goods and highly twisted threads; but for loosely woven goods and low-twist threads, lower size concentrations can be used. It is the general practice, however, to utilize the 15% solution even on such fabric as light gauze.

Many times one-fifth to one-half the amount of chemicals ordinarily used may be employed successfully in washing, dyeing, acidifying, oxidizing, and reducing, without effect on product quality. An intelligent and discriminating operator would be able to discern when such processing may be used and can reduce the pollution loads considerably. As indicated, however, unless it involves the important wastes, maximum reduction will be below 30%. (6)

Process Modification

The changing of processes and materials flow procedures is another way of eliminating unnecessary wastes. Continuous opera-

tions generally require a smaller space, use less water and process chemicals, and therefore will reduce waste loads. Whenever possible, separate operations should be combined, such as scouring and dyeing in the finishing of synthetic fibers, and desizing and scouring of cotton fibers. Another method of process change is to substitute standing baths and rinses for running ones, thus conserving water and concentrating the waste load in the bottom of the process unit.

One drastic process modification is not to discharge the effluent at all, but to pump the process liquor to a storage tank, where it may be stored and saved for use in the make-up of the next similar bath. Another modification is the use of more heat exchangers to transfer the high temperature of some effluents to incoming process water, thereby conserving water and costs, and reducing the possibility of thermal pollution.

Solvent processing is still another method of conservation. Solvents in certain applications would eliminate use of water altogether, thereby reducing or eliminating the wastewater discharge from a mill, and concentrating pollutants within the plant for disposal, by haulage to a landfill site, or for recovery for reuse or resale. This processing technique will be discussed in greater detail in the next section, under advanced treatment methods that may ultimately be employed to achieve zero discharge.

Water usage can be reduced substantially if design engineers take water economy into more active consideration. For example, so-called "double-laced" box washers have recently been introduced, with claimed savings of up to 40% in the number of machines. Significant water savings are claimed, but detailed quantitative data are not available. More complex open-width washing machines, designed to induce greater turbulence, have been offered without great success. Since the physical aim to be accomplished is the breaking down of an effective thick diffusion film in the fabric interstices, it is likely that more efficient open-width machines can be developed. The problem is to provide suitable incentives for the development, testing and use of such machines, which will also coincidentally reduce water usage.

Rope washers are generally more effective than open-width washers, but further improvement may be necessary if the back-mixing is to be controlled in a practical manner.

In addition to better washer design, there are opportunities for water economy in the use of more counter-current flow operations. A finishing plant operator prefers to use fresh water at every machine, for ease of control and adjustment, and for freedom from danger of cross-contamination of the product. However, some opportunities for counter-flow are neither unduly difficult nor injurious to product quality. For example, it is almost always acceptable (but not always practiced) to counter-flow water from machine to machine when several machines are used in series at the same point in the process. It is common to use 5, 6 or more open-width box washers in series after scouring or mercerizing operations, or two Tensitrol-type rope washers after scouring. It is best for water economy to counter-flow the water through the series. This is frequently but not universally practiced today.

Furthermore, it is almost certainly practical to counter-flow water from later stages (such as final rinses) to earlier stages, where the water is more heavily contaminated. For example, white wash effluent can almost always be used as feed water for caustic washes. Additional opportunities for back-flow of water also exist; however, there are limitations. Wash water from dyeing operations, for example, always contains color, and is generally unsuitable for reuse without cleanup. Caustic scour and desizing washwaters are heavily laden with dissolved and suspended solids, and unsuitable for reuse except after treatment to remove the impurities.

Water Conservation

In addition to the use of counter-current flow, the recycle or reuse of water, or changes in machine design and operational sequence, other possibilities exist for reducing water usage. Significant reductions can be made by equipping all hoses with automatic spring clamps or shut-offs, using solenoid valves on continuous units to stop rinsewater when cloth is stopped; using dry vacuum cleaning for plant and machine cleanup, instead of water wash-down; using liquor/cloth ratios of 8.34 (1000 gal/1000 lb) or less in each standing bath; using counter-current rinsing with 5 to 10 separate compartments, and squeeze rolls at each compartment; and reusing all cooling, air conditioning, and condensate waters which are unpolluted for processing. (12)

In counter-flow processing, the water flows through the process in the direction opposite to the movement of the fabric. The scheme can be employed in operations that work on the continuous flow principle: for example, the rinses following bleaching of

cotton and the scouring train in wool processing. By the time the fabric reaches the last unit, it should contain the least amount of natural impurities and/or process chemicals. Fresh water is used to remove this small amount of waste material and then, retaining the waste, it advances to the preceding unit and is used to rinse fabric containing a larger quantity of waste matter. This counter-flow process is continued until the water is finally used in the first unit of the process. At this point, the water may be discharged, or used to make up the process bath or possibly the solution of some other process.

Another way of reducing the volume of wastewater is to use the same water several times before discharging it, a technique commonly known as water downgrading. The water quality requirements for each wet process operation are determined and aligned in a sequence or series, with the highest water quality requirement first and the lowest, last. The water quality produced by each operation is then determined; these waters are then routed to other operations, to the limit of acceptable water quality for each process. This scheme can be used for batch processes, where the contents of one bath cannot be forwarded to a preceding bath. Process water can be reused in the same process or in other processes. For example, waters used to rinse fabrics after dyeing can be used to make up a new dye solution; or mercerizing wash-waters can be used to prepare scour, chlorine bleach, and "wetting-out" baths. Process water can, of course, also be upgraded through the use of filtering or other water treating devices, to remove impurities and increase water reuse and recycle potential. (2)

Substitution of Chemicals

One method of reducing the BOD load of the mill is to substitute low BOD process chemicals for ones that have high BOD values. By consulting the BOD list of textile chemicals (Table 12), the analyst can determine which low BOD chemicals can be exchanged for those of higher BOD value.

Three classic examples of process chemical substitution exist in the textile industry: the substitution of synthetic warp sizes (1 to 3% BOD) for starch (50% BOD) and gelating (100% BOD) in cotton slashing operations; the substitution of ammonium sulfate, chloride, or mineral acids (0% BOD) for acetic acid (33-62% BOD); and low BOD synthetic detergents (0-22% BOD) for soaps (140% BOD). In wool processing, the traditional carding oil, olive oil, which has a 100% BOD

value, has been replaced in some mills by mineral oils with non-ionic emulsifiers that have a 20% BOD value. Of course, the mill must be assured that the low BOD chemicals are not more harmful (toxic or degrading to product quality) than the high BOD chemicals originally used.

Other possible chemical substitutions have been proposed. The use of sulfuric acid in place of soap in wool fulling operations has been suggested by one group of researchers. Not only does the sulfuric acid have no BOD, but when used in conjunction with synthetic detergent washing, the combined waste is highly acidic instead of highly alkaline. (6) The substitution of steam ranges for the oxidation of dyes in place of dichromate-acetic acid baths, and the use in dyeing of low BOD dispersing, emulsifying and leveling agents in place of their high BOD counterparts will decrease BOD loading. (13)

The substitution of low BOD process chemicals for high BOD ones has two drawbacks, however. One is the increased cost usually associated with these products; the other is that, while these chemicals have low 5-day BOD values, little is known about their long-term effects upon aquatic life, and waste treatment costs downstream. Careful study of the ultimate decomposition of these chemicals should be undertaken before they are indiscriminately substituted for high BOD compounds.

The substitution of synthetic detergents for soap presented treatment problems for textile wastes in the early 1960's. The typical synthetic detergent used prior to 1965 was the alkyl benzene sulfonate surfactant type, commonly referred to as ABS. This synthetic detergent exerted no BOD on the receiving stream, but was non-biodegradable, and therefore passed into the receiving stream unaltered, causing severe foaming problems. Soap, on the other hand, is thoroughly decomposed by biological treatment. Since June 30, 1965, the detergent industry has switched to the production of biodegradable synthetic detergents of the linear alkylate sulfonate type, known as LAS. These compounds are converted to new biological cell tissue by aerobic oxidation, and removed in conventional treatment processes. The additional BOD exerted by using biodegradable detergents is only 5% over loads exerted by wastes containing non-biodegradable synthetic detergents. For the most part, textile surface active agents are of the "soft" or biodegradable type, thereby eliminating the foam problem, but increasing the BOD, although much less than that for natural soap.

Probably the greatest activity in the area of chemical substitution has been research in finding substitutes for the starch used in the slashing or sizing operations. Table 47 shows a 50% reduction in the BOD of a textile finishing mill's waste when carboxymethylcellulose (CMC) was used as a substitute for cornstarch in sizing and when soap was replaced by detergent in the yarn dyeing process. These substitutions had no effect on product quality. Data from two other large finishing operations, one finishing mostly purchased goods with starch sizing, and the other with a controlled source of greige goods using CMC, produced an average 5-day BOD approximately 60% lower for the CMC operation. (5)

Other chemicals used as substitutes for starch in addition to CMC include hydroxyethylcellulose, polyacrylic acid, and polyvinyl alcohol. Table 48 indicates that process chemical substitutions can indeed make substantial reductions in the pollution loads from wool scouring and finishing mills, and particularly in wool finishing mills when variations in process chemical formulations are used. All of the substitutions listed have been used on a production basis and can be accomplished with little or no difficulty. As such, no treatment plant should be planned unless serious consideration has been given to pollution reduction through the substitution method. (6)

Recovery and Reuse

Little or no attention has been paid to the recovery of cotton's natural impurities - waxes, pectins, alcohol, etc. - and whether or not there is any value to these substances is not known. Certainly the textile industry should attempt to generate interest among chemical manufacturers dealing in similar compounds, and point out to them that approximately 200,000 tons of these cotton impurities are being dumped into sewers and streams annually.

An indication of the amounts and the value of process chemicals in cotton wastes may be obtained by scanning the results obtained from a survey of one large cotton mill (Table 49). It will be noted that caustic soda and slashing starch are used in great amounts, and may be valuable if they can be recovered.

About half of the caustic soda is used in kiering, and will be associated with the natural impurities extracted from the cotton. Both kiering caustic and the impurities are soluble, and separation

TABLE 47

POLLUTION REDUCTION DUE TO PROCESS CHEMICAL CHANGES

Item	Before Changes	After Changes*	Reduction
5-day BOD, ppm	400	210	190
pH	11.5-12.0	10.0-10.5	2.0
Total alkalinity, ppm	1,600	560	1,040
Hydroxyl alkalinity, ppm	...	180	
Carbonate alkalinity, ppm	...	380	

*Changes were: (1) starch replaced by CMC (carboxymethyl cellulose) and (2) soaps replaced by detergents.

TABLE 48

POLLUTION POTENTIAL OF WOOLEN PROCESSES

	Scour and Finish Mill BOD			Finish Mill BOD		
	% OWF[a]	% of Total[b]	% Red'n[c]	% OWF[a]	% of Total[b]	% Red'n[d]
Method I						
Scour with soap	25.0	55.4	--	--	--	--
Stock dye with acetic acid	4.9	10.9	--	4.9	24.4	
Card with 100% BOD oil)						
Full with soap)	15.0	33.3	--	15.0	74.6	
Wash with soap)						
Neutralize after carbonizing	0.2	0.4	--	0.2	1.0	
Total	45.1	--	--	20.1		
Method II						
Scour with 12% BOD detergent	22.1	74.6				
Stock dye with Ammonium sulfate	0.9	3.0		0.9	12.0	
Card with 20% BOD oil)						
Full with 12% BOD detergent)	6.4	21.6		6.4	85.3	
Wash with 12% BOD detergent)						
Neutralize after carbonizing	0.2	0.7		0.2	2.7	
Total	29.6		34	7.5	--	63
Method III						
Solvent scour, recover grease only	0	0				
Wash out suint salts and dirt with 12% BOD detergent	10.0	58.9				
Stock dye with ammonium sulfate	0.9	5.3		0.9	12.9	
Card with 3% BOD oil)						
Full with 12% BOD detergent)	5.9	34.7		5.9	84.3	
Wash with 12% BOD detergent)						

TABLE 48 (continued)

POLLUTION POTENTIAL OF WOOLEN PROCESSES

	Scour and Finish Mill BOD			Finish Mill BOD		
	% OWF[a]	% of Total[b]	% Red'n[c]	% OWF[a]	% of Total[b]	% Red'n[d]
Neutralize after carbonizing	0.2	1.2		0.2	2.9	
Total	17.0	--	62	7.0	--	65
Method IV						
Scour with methyl and isopropyl alcohols, recover grease and suint	0	0				
Wash out dirt with detergent	1.0	19.6				
Stock dye with ammonium sulfate	0.9	17.6		0.9	22.0	
Card with 3% BOD oil) Full with 12% BOD detergent) Wash with 12% BOD detergent)	3.0	58.8		3.0	73.2	
Neutralize after carbonizing	0.2	3.9		0.2	4.9	
Total	5.1	--	89	4.1	--	80

a - Based on oven-dry wool

b - Based on the total of that particular method.

c - Based on the total of Method I (45.1% OWF).

d - Based on the total of Method I (20.1% OWF).

TABLE 49

COTTON MILL WASTE SURVEY *

Chemical	Pounds Used	% OWC	Pounds	% of Total	Effluent Concentration ppm	Effluent Concentration BOD
	DeSize Contribution					
Slashing Starch (glucose)	733134	59	432549	69.5	176.0	103.8
Sub-total	733134	--	432549	69.5	176.0	103.8
	Scour (Kier) Contribution					
Natural Impurities	337800	--	128364	20.6	81.1	30.8
Sub-total	337800	--	128364	20.6	81.1	30.8
	Process Chemical BOD Contribution					
Soap	13715	140	19125	3.7	3.3	4.6
Acetic Acid 56%	54350	35	19023	3.6	13.1	4.2
Sodium hydrosulfite	113250	11	12458	2.0	27.2	1.5
Urea	85600	9	7704	1.2	20.5	1.8
Rhozyme LA	45600	2	912	0.1	10.9	0.2
Tergitol NPX	63000	2	1260	0.2	15.1	0.3
Detergent MPX	11700	8	936	0.1	2.8	<0.1
Sub-total	387215		61418	9.9	91.9	12.6
	Process Chemicals with Negligible BOD Contributions					
Caustic Soda (100%)	2148000				513.8	
Sodium bicarbonate	260300				62.5	
Sodium hypochlorite	236100				56.6	
Sodium chloride	144800				34.7	
Sulfuric acid	137600				32.2	
Sodium silicate	67500				16.0	
Sodium carbonate	56000				13.8	
Phosphoric acid	44100				10.6	
Hydrogen peroxide (30%)	27500				6.6	
Sodium chlorite	23000				5.5	
Sub-total	3144900				752.3	
Grand Total	4603049		622331		1102.2	147.2

Notes to Table 49:

* This plant received 6,431,000 pounds of goods during the inventory period (1 year) and used 2,000,000 gallons of water per day. It desized all of the cloth but caustic boiled only 3,378,000 pounds of it. The remaining "fancy" cloth, with colored pattern already woven in, (3,053,000 pounds) was peroxide kiered. The plant dyed 2,360,000 pounds and left 1,018,000 pounds white.

** % OWC is BOD inherent in the chemical based on its own weight. Pounds equals the pounds of BOD exerted by the chemical. % of the total is the % contributed by the chemical to the total plant BOD.

of the two is probably not economically feasible if only caustic recovery is planned. Some thought should be given to the use of concentrated kier liquor as is. It may be readily recovered from the kier as it is being pumped by the circulating pump. Its use in paint strippers and for drain cleaners are two obvious applications for which the caustic may be satisfactory. There may be some alkalizing process widely used in another industry where the caustic kier waste may also be used profitably.

The other half of the caustic soda is used for mercerizing. In many plants, the first three or four rinses are used in the mercerizer. The dilute wastes following these rinses are often concentrated in an evaporator, and reused for mercerizing or for kiering. Considerable savings in caustic consumption are effected, and this practice should be used in all mills.

Slashing starch consumption is very high in contton weaving, but the application of the size is the function of a fabricating mill, while size is removed in a finishing mill. Many cotton mills are commission houses that receive cloth from different sources, and have nothing to do with putting the starch on the cloth. Their primary interest is getting the starch out of the cloth. They do this by converting it to the more soluble glucose by means of enzymes or acid, and then washing it out in the desize waste. Glucose is a high-energy sugar and finds usage in animal feeds, candy manufacture, bacterial fermentations, alcoholic fermentation, and sorbitol production.

The desize waste may be readily recovered and concentrated in evaporators by methods used by the sugar industry. Since glucose is very soluble, a production of a syrup containing 50% glucose should be relatively easy. The syrup will be sterilized during evaporation and should be ready for use in any of the industries mentioned above. However, each batch would have to be checked for toxic constituents, since zinc chloride or phenol may be used as bacteriostatic agents in the slashing starch, and thus may be present in the waste. These agents are not necessary for the starch, however, and the industry may be educated to omit them if a market for glucose is developed. No appreciable concentration of zinc or phenol was found in two checks made of desize waste solutions.

Other valuable materials that may be recovered and reused are dye baths, chromate, and hydrogen peroxide. Recovery and reuse of dye baths are only possible in large mills which find ready use for the recovered bath. By proper addition of just enough dyes,

dispersants, emulsifying agents, etc., to bring their concentration up to the desired values, considerable savings can be made. Since dye wastes only produce a maximum of 25% of the total BOD, however, only slight reduction in pollutional loading may be realized. The same considerations apply to chromate and hydrogen peroxide.

The lanolin present in wool grease has often been recovered through solvent extraction when the market for lanolin is high. Usually, aviation gasoline, naphtha, trichlorethylene, benzene, and carbon tetrachloride are used. A potential supply of 50,000 to 100,000 tons of wool grease may be recovered annually if a strong enough market is developed. Its recovery can produce BOD reductions of 20 to 30% on scouring and finishing mills. Suint, which contributes about half of the natural impurities and BOD, is not removed by the solvents and would remain in the wool.

Suint recovery is not often practiced, but it may be recovered by the new alcohol extractions previously discussed. It could be used for detergent manufacture, or for recovery of its potassium salts. If both wool grease and suint are recovered, BOD reductions of 45 to 55% may be obtained in wool scouring and finishing plants.

The only other chemical in woolen mills that may be of value is soap. It may be recovered for reuse as such, or as a fatty acid after acidification and separation. Little or no recovery has been practiced in modern times, but it should be investigated, since carding oil and soap recovery in wash after fulling waste alone, for example, can produce 30% BOD reductions in scouring and finishing mills, and 70% BOD reduction in finishing mills. Its recovery will be doubly profitable on this basis. The recovered fat may be used for rendering or as a fuel source. (6)

VI. WASTEWATER TREATMENT

In considering wastewater treatment requirements for the textile industry to meet the EPA effluent guidelines currently under development for pollution abatement, the following list of chemical, physical, and biological pollutants was developed as being of primary importance to this industry: BOD_5, COD, suspended solids, phenols, oils and grease, ammonia and nitrate nitrogen, phosphates, dissolved solids, toxic organic chemicals, pH, color, alkalinity, temperature, sulfides, chromium, other heavy metals, and coliform bacteria.

Each of these pollutant parameters has been identified in the industry's wastewater; however, no single textile mill will have all of them present in its wastewaters. (4)

For the purpose of establishing effluent guidelines, textile industry wastewaters have been subdivided into seven broad categories:

1. Wool scouring
2. Wool finishing
3. Greige or grey goods
4. Woven fabric finishing
5. Knit fabric finishing
6. Carpets
7. Stock and yarn dyeing

Table 50 (4) presents a tentative summary of the quality of effluent from the textile industry that should be attainable by the application of Best Practicable Control Technology, to meet the 1977 goals of pollution abatement. Allowable BOD, COD, suspended solids and pH, based on lb/1000 lb of production, are presented. In addition, maximum limits for coliform organisms, total chromium, phenols, and color are stipulated. Reference is made to other industrial effluent guidelines for limits which have been (or will be) established for specific physical, chemical, or biological pollutants not covered here, particularly allowable concentration levels for heavy metals and other toxic chemicals.

In general, major pollutants from the textile industry are not unlike those from conventional domestic waste treated in municipal sewage treatment plants. Most of the wastewater treatment operations used in sewage treatment are also applicable to the treatment of textile wastes, except that, of course, different design parameters and equipment unit sizes are required to achieve equivalent removals of the pollutants. Chemical treatment for pH adjustment and for coagulation, however, is used to a far greater extent in treating textile mill wastes today as a part of the total treatment process than in treating municipal wastes.

Current Treatment Practice

Present-day practice for the treatment of textile wastes uses, in general, the conventional sequence of physical, chemical and biological processes for the removal of impurities from the wastewater, and the subsequent disposal of these impurities as sludge. Certain precautions not usually required in the treatment

TABLE 50

SUMMARY OF TENTATIVE LEVEL I POLLUTANT GUIDELINES[a]

Category	Maximum 20 Working Day Averages, kg/1000 kg (lb/1000 lb)			
	BOD	COD	Suspended Solids	pH[b]
1. Wool Scouring	2.85	28	2.0	6-8.5
2. Wool Finishing	5.1	51	7.6	6-8.5
3. Greige Goods	0.15	1.17	0.22	6-8.5
4. Woven Fabric Finishing	3.3	45	5.0	6-8.5
5. Knit Fabric Finishing	3.6	45	6.1	6-8.5
6. Carpets	2.1	21	2.4	6-8.5
7. Stock and Yarn Dyeing	4.0	52	6.1	6-8.5

[a] In addition to the guidelines shown, the following apply to all categories.
Coliform organisms 200/ml MPN
Total chromium - not to exceed 0.25 mg/l
Phenols - not to exceed 0.25 mg/l
Color - not to exceed 200 ADMI units

[b] Values are the maximum permitted range.

Note: Daily maximum may not exceed twice the maximum 20 working day average.

of domestic sewage must be taken in treating textile wastes, however, although the precautions are common in many industrial fields. These pre-treatment or control measures are necessary to minimize the volume of wastewater requiring treatment, to reduce shock loads and other variations, and to create an environment which will maximize treatment wherever biological treatment processes are employed.

Segregation

When the results of a waste sampling program are compared with the effluent water quality standards, it may be found that some wastes will require substantially less treatment, or no treatment at all. Whenever possible, unpolluted cooling and condensate waters, etc., should be segregated from process waters for direct discharge without treatment; or toxic substances, for example, may require segregation from wastes that will be treated biologically. Wastewater treatment costs will be reduced by minimizing the volume of process water requiring treatment.

Equalization

Operations such as kiering, desizing, and most other textile mill batch operations yield intermittent slug discharges of waste. These variations must be reduced, if maximum treatment performance is to be obtained from all operations. Equalization by holding ponds or storage tanks with controlled discharge is most frequently employed.

pH Adjustment

pH must normally be controlled early in the treatment process in order to optimize chemical coagulation processing (if used), to protect the biological process, and ultimately to meet effluent standards.

Shock Loads

Because of the great variation in waste volume, strength, and character over the day, equalization and/or intimate mixing and dilution are frequently necessary treatment procedures. Toxicity from substances such as heavy metals, bacteriocidal agents, slimeicides, mildew depressants and other agents must be controlled, by eliminating the use of the substances, by removal of the toxicity, or by dilution to a level at which the substances are harmful neither to subsequent treatment processes, nor to the environ-

ment.

Synthetic Detergents

These compounds are a special consideration. Excessively high uncontrolled discharges of them can affect the settling of suspended solids, reduce biological activity, or cause undesirable foaming problems in the treatment operation, thus requiring the use of additional control measures, particularly when aeration is employed.

Nutrients Deficiency

The normal BOD:Nitrogen:Phosphorus ratio for optimum efficiency of aerobic biological treatment processes is approximately 100:5:2. However, considerable latitude from this ratio has been tolerated in a number of sizeable operations. When required, nutrients may be added by seeding or dilution (with domestic sewage), or by the use of chemical additives.

When all of these precautions have been taken, the pretreated wastewaters from the textile industry generally can either be discharged to a municipal sewer system for treatment, or be processed by the industry's own facilities.

1. Cotton Waste Treatment -- Figure 33 presents the recommended waste treatment flow chart for the cotton textile finishing industry. The wastes from the individual processes should be discharged to an equalization basin or its equivalent. From equalization and holding, the effluent may be discharged, after screening to remove gross suspended solids, to a municipal system or to the industry's own facility, using the traditional physical, chemical, biological treatment sequence.

Sedimentation is the most frequently employed operation for fine suspended solids reduction. Chemical treatment is used for pH adjustment and for chemical coagulation, particularly for removal of turbidity and color from dyes. The soluble organic biochemical oxygen demand (BOD) is removed by the use of one or more common treatment methods such as oxidation ponds, aerated lagoons, extended aeration or conventional activated sludge processes, and rock or plastic media trickling filters. Disposal of sludges is usually accomplished by concentration and dewatering, with ultimate disposal to a land fill site.

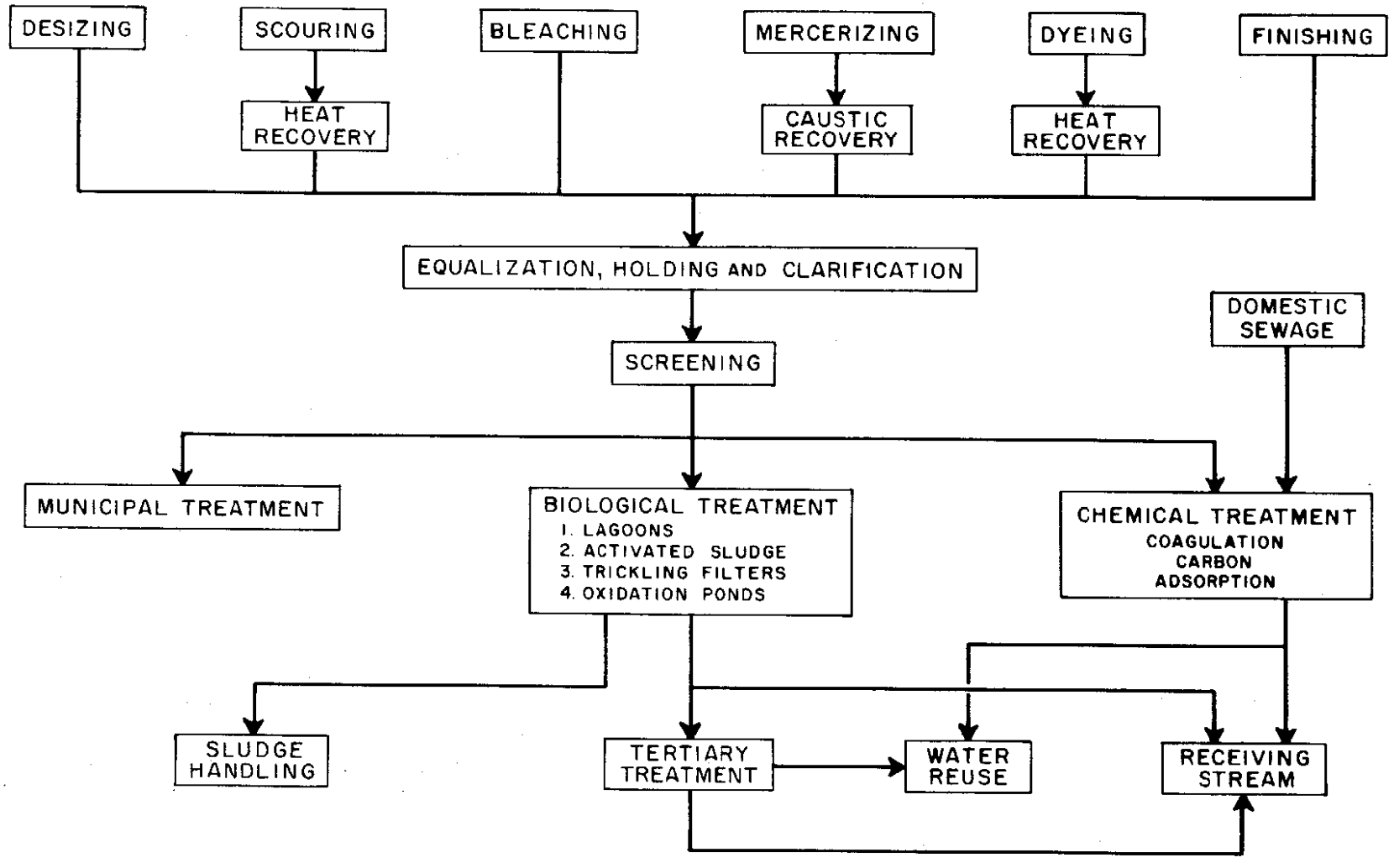

FIGURE 33 Cotton Waste Processing Flow Chart.

One special consideration in the treatment of textile mill wastes in current practice is the use of chemical treatment for the removal of color or dyes from the wastewater. Chemicals that have been employed successfully for the precipitation of textile wastes are aluminum sulfate, ferrous sulfate, chlorinated copperas, ferric alum, ferric chloride, ferric sulfate, lime and sulfuric acid. Lime and sulfuric acid are for pH adjustment, while the others are normally coagulants.

Table 51 (2) presents treatment removal efficiencies expected, in general, in the treatment of cotton mill wastes for various treatment methods employed. The values in the table reflect the use of any auxiliary units normally associated with the process; for example, the trickling filter and activated sludge efficiencies required primary sedimentation and effluent recirculation.

The activated sludge process consistently produced BOD reductions of 90% or better, when aeration times were extended and a higher concentration of mixed liquor suspended solids than normally used in the conventional method were employed. A single-stage trickling filter process cannot reach the removal efficiencies of conventional activated sludge, and is therefore expected to be used less in the future.

Polishing ponds have been used to treat cotton wastes. The most economical method is simply to store the treated effluent in an oxidation pond after it has been subjected to secondary treatment. Polishing ponds may reduce the effluent's pollutional load an extra 50% for example, from a 90 to 95% total BOD removal.

2. Wool Waste Treatment -- Figure 34 is a representation of a waste treatment flow chart for wool processing wastes. The only effluent in wool processing that would require segregation is the wool scour liquors, which produce 30% of the mill's total BOD load. Two reasons for segregating wool scouring liquors are to reduce the high organic load on secondary biological treatment facilities, or to recover wool grease, which is a major source of high quality lanolin, as previously discussed. The wool scour liquor can be discharged to equalization basins, along with the three other wool waste-producing processes.

There are three methods of treating wool scour liquors: centrifuging, acid or salt cracking, and solvent extraction. Centrifuging may be used by itself to recover 25-40% of the grease from the scour liquor, or may be used on high grease content liquors as a pretreatment step for salt or acid cracking. In the acid cracking process, sulfuric acid is added to settle scour

TABLE 51

TREATMENT REMOVAL EFFICIENCIES
REMOVAL EFFICIENCY (PERCENT)

Removal Method	BOD	Suspended Solids	Total Dissolved Solids
Screening	0-15	5-20	0
Sedimentation	5-15	15-60	0
Chemical Coagulation	25-60	30-90	0-50
Trickling Filter	40-85	80-90	0-30
Activated Sludge	70-95	85-90	0-40
Lagoon	30-80	30-80	0-40
Aerated Lagoon	50-95	50-95	0-40

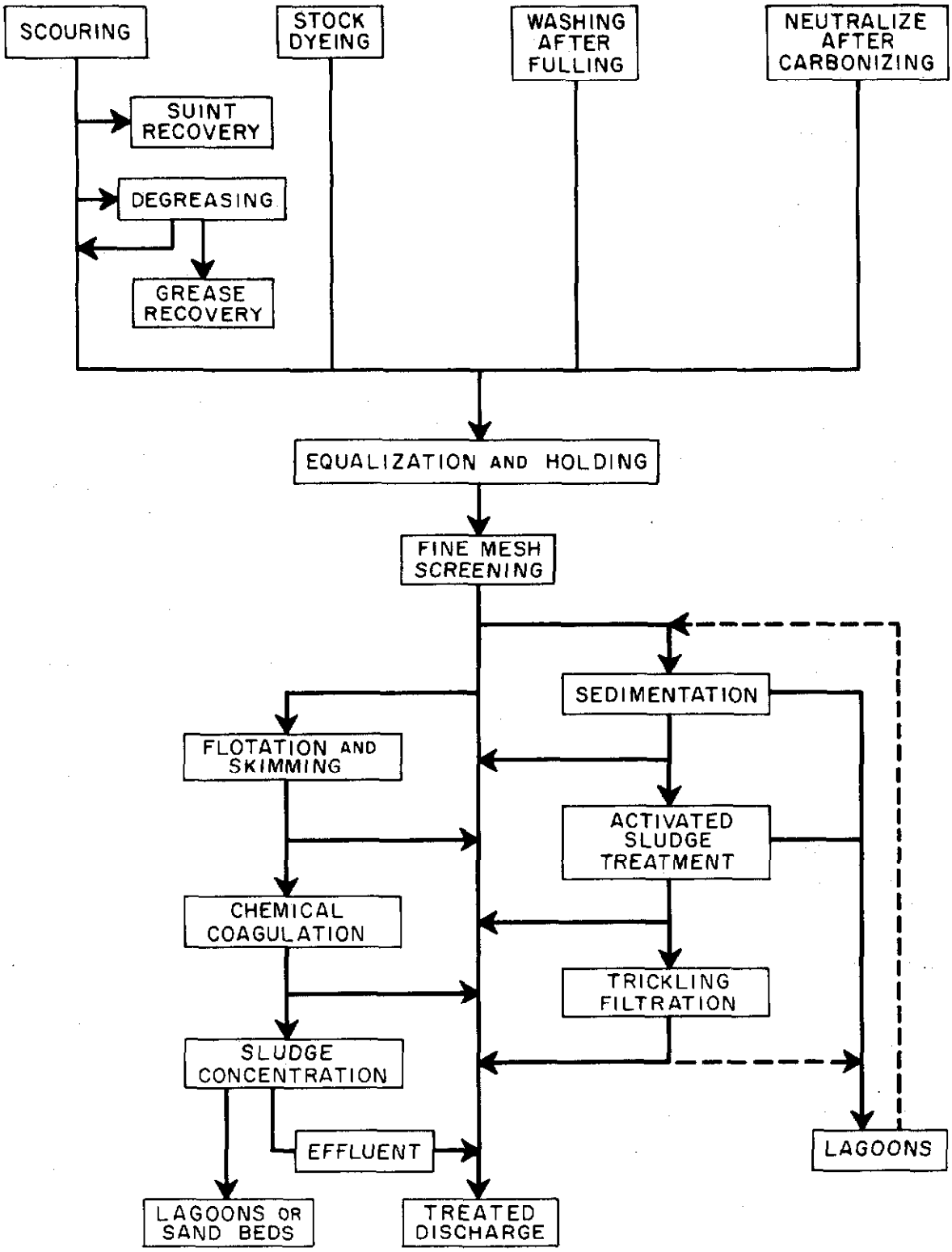

FIGURE 34 Wool Waste Processing Flow Chart.

liquor, and the mixture is aerated and allowed to stand overnight. The resultant "magna" is either scooped off the surface or passed through the sludge disposal drain. Acid cracking is used on scour liquors containing synthetic detergents; it removes about 65% of the grease from the effluent.

The salt cracking process makes use of calcium chloride addition to soap and alkali scour liquors. At present the wool grease, soap, and alkali are precipitated as an emulsion from the liquor, thus making recovery of wool grease by this method uneconomical. Solvent degreasing uses two separate alcohol extraction procedures. Methanol is used to remove suint salts from the fibers and ethanol or a mixture or isopropanol and methanol is used for removal of grease. The grease is then recovered by evaporation. However, this process does not remove the inert vegetable matter contained in raw wool fiber. Suint recovery is not often practiced, although total plant BOD reductions of 45-50% are possible if both suint and grease are removed from the scour liquors.

Because most wool processing mills are located adjacent to or within population centers, particularly in New England, it has been traditional to discharge their wastes to municipal sewers. It is estimated that 60% of the effluents from wool manufacturing were discharged to municipal sewers in 1967.

Equalization of wool processing effluents, with discharge to municipal or plant-owned facilities, is a necessity, as most of the processes are batch operations. Wool also has a high settleable solids content, composed mostly of grease, inert dirt, and small fibers. The solids should be removed as efficiently as possible in order to assure proper functioning of the chemical and biological oxidation processes which would follow.

In the past, wool wastes were treated at plant-owned facilities by chemical precipitation with grease recovery. Today, the activated sludge process using extended aeration and pH adjustment will reduce BOD load about 90%.

Table 52 lists pollution reduction percentages of the various treatment techniques used for wool wastes. The figures cited for activated sludge, trickling filtration, and lagoons, are for systems that make use of degreasing, either by recovery or chemical coagulation prior to treatment. (2)

TABLE 52

REMOVAL EFFICIENCIES OF TECHNIQUES USED IN WOOL WASTE TREATMENT

Treatment Method	Removal Efficiency BOD	Grease	Suspended Solids (%)
Grease Recovery:			
Acid Cracking	20-30	40-50	0-50
Centrifuge	20-30	25-45	40-50
Evaporation	95	95	
Screening	0-10	0	20
Sedimentation	30-50	80-90	50-65
Flotation	30-50	95-98	50-65
Chemical Coagulation:			
$CaCl_2$	40-70		80-95
Lime and $CaCl_2$	60	97	80-95
CO_2-$CaCl_2$	15-25		80-95
Alum	20-56		
Copperas	20		
H_2SO_4 and Alum	21-83		
Urea and Alum	32-65		
H_2SO_4 and $FeCl_2$	59-84		
$FeSO_4$	50-80		
Activated Sludge	85-90	0-15	90-95
Trickling Filter	80-85	0-10	90-95
Lagoons	0-85	0-10	30-70

Synthetic Wastes -- Figure 35 is a waste treatment flow chart for synthetic fiber finishing wastes. Synthetic wastes are free from fiber impurities, except for the small amount of nylon which is decomposed during the scouring of that fiber; therefore, any waste reduction program must deal with reducing the BOD load of the process chemicals. In many plants, screening and physical sedimentation for suspended solids removal are not utilized.

In general, the wastes produced by synthetic fiber wet processing have a lower pollution potential than those of natural fiber effluents. The greatest pollutional load in synthetic fiber processing is generated by the dyeing of polyester and acrylic fibers. The problem is associated with the special dyeing assistants, or "carriers", used with these two fibers. The carriers give rise to three sources of pollution: odor, toxicity, and high BOD.

Table 53 (2) presents removal efficiencies of treatment methods used for synthetic fiber wet processing wastes. Either biological oxidation or chemical precipitation can be the principle BOD reduction treatment for synthetic fiber processing mill wastes; however, the latter is generally employed now as a pretreatment, to reduce concentrations prior to discharge to a municipal system for further treatment.

Segregation or chemical pretreatment may be required to treat the toxic chemicals used in polyester and acrylic dyeing before biological treatment. It is common procedure in treating synthetic fiber wastes to adjust the pH of the waste stream prior to chemical coagulation, in order to reduce the requirement of the costly coagulation chemicals.

Dyeing Wastes -- Wastes from the dyeing of textile fibers present a particular problem to the industry. As mentioned previously, some dyestuffs, for example, sulphur dyes, are toxic in themselves, or, as in the case of polyester dyestuffs, require the use of toxic assistants, emulsifiers, and leveling agents. These chemicals, however, can be effectively treated by segregation or chemical coagulation. The real difficulty lies in the color imparted to receiving streams by dyestuff residues. Although most dyes have low BOD values they add organic carbon and color to the water which is objectionable to the public for esthetic reasons.

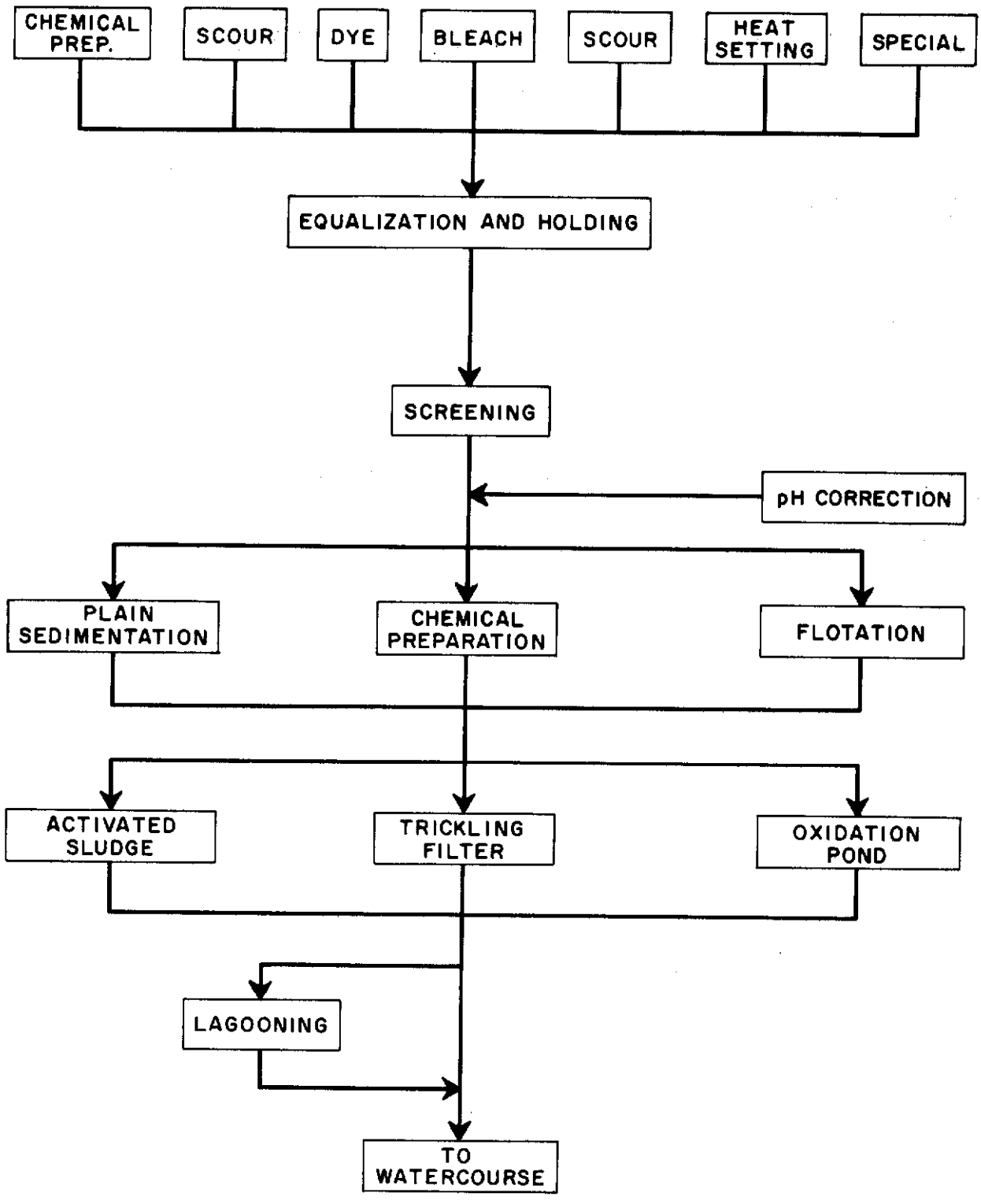

FIGURE 35 Synthetic Textile Finishing Waste Treatment Flow Chart.

TABLE 53

REMOVAL EFFICIENCIES OF TREATMENT METHODS USED FOR SYNTHETIC FIBER WET PROCESSING WASTES

Treatment Method	Removal Efficiency (Percent)		
	BOD	S.S.	T.D.S.
Screening	0-5	5-20	0
Sedimentation	5-15	15-60	0
Chemical Precipitation	25-60	30-90	0-50
Trickling Filter	40-85	80-90	0-30
Activated Sludge	70-95	85-95	0-40
Lagoon	30-80	30-80	0-40
Aerated Lagoon	50-95	50-95	0-40

Color removal from textile effluent streams showed that the trickling filter and activated sludge processes could remove effectively 84 and 93 percent of the color in textile effluents, and chemical coagulation of cotton dye wastes averaged 80 to 91 percent removal of color. The color of today's new, improved and virtually non-destructible dyes can only be reduced by 50 to 85 percent. Chemical coagulation now and probably carbon adsorption in the future offer the most promise for maximum color removal and dye reduction used in conjunction with biological processes.

Many of the coagulants are particularly effective in treating specific dye and other wastes. Some examples are as follows:

Lime alone: For dye wastes: aniline black and indigo

Sulfuric acid alone: For naphthol dye wastes

Copperas alone: For sulfur dye wastes

Copperas with lime: For cotton finishing wastes and for developed, direct, indigo and vat dye wastes of the cotton, nylon, and rayon finishing industries.

Ferric chloride with lime: For deterging wastes and dye wastes in wool and cotton finishing industries.

Ferric sulfate: For direct dyes

Alum: For Kier wastes and indigo wastes

Ferric alum with lime: For rayon wastes.

Ferric iron salts are particularly effective in treating deterging, finishing, and dyeing wastes, and combinations of these wastes. Excellent coagulating properties of ferric iron account for this. The objection to their use from the standpoint of expense and corrosiveness, is overcome by using chlorinated copper.

Flexibility in sequence of chemical feed may spell the difference between poor or good coagulation. Applying lime ahead of coagulant may improve the slow formation of floc; applying the coagulant ahead of the lime may improve BOD and color removal. (14)

In summary, there are many wastewater treatment facilities in operation today in the textile industry. For specific information, with respect to the flow sheets employed, removal efficiencies attained, costs, and problems and practices, please refer to the following references for additional information: (15, 16, 17, 18)

Future Treatment Practices

No guidelines for achieving effluent quality beyond 1977 goals have as yet been developed. Considerable study of advanced waste treatment technology has been made, however, to determine the operations which may achieve increasingly higher levels of effluent quality and beyond to the ultimate goal of "zero discharge". Figure 36 presents a schematic diagram indicating tertiary or advanced waste treatment techniques that can be added to conventional present-day primary-secondary treatment systems in the textile industry. Techniques are currently available to increase substantially suspended solids and BOD removal. It appears that major problems of the future will be the attainment of significant reductions in COD, color, specific organic compounds, and dissolved salts.

Water treatment type processes can be added, such as further chemical coagulation and sand filtration, to increase removals of suspended solids, turbidity, color and BOD. Beyond that, more sophisticated unit operations must be considered, including phase change operations, membrane separations, sorption of various types, special chemical precipitation, and combustion.

The most promising approaches at this time appear to be the application of membrane technology, sorption (particularly activated carbon adsorption), combustion and, ultimately, solvent processing which would replace water in some of the wet processing operations employed in the textile industry.

Membrane Processing

Within the last ten years, considerable research effort has been directed toward the application of membranes for the removal of both suspended and dissolved solids. Both reverse osmosis and ultrafiltration have been employed. The major difference between these two methods is the porosity of the membrane and the pressure utilized. Reverse osmosis uses high pressures with "tight" membranes; the transfer mechanism is largely by diffusion, and will achieve dissolved salts rejection. Ultrafiltration, on the other hand,

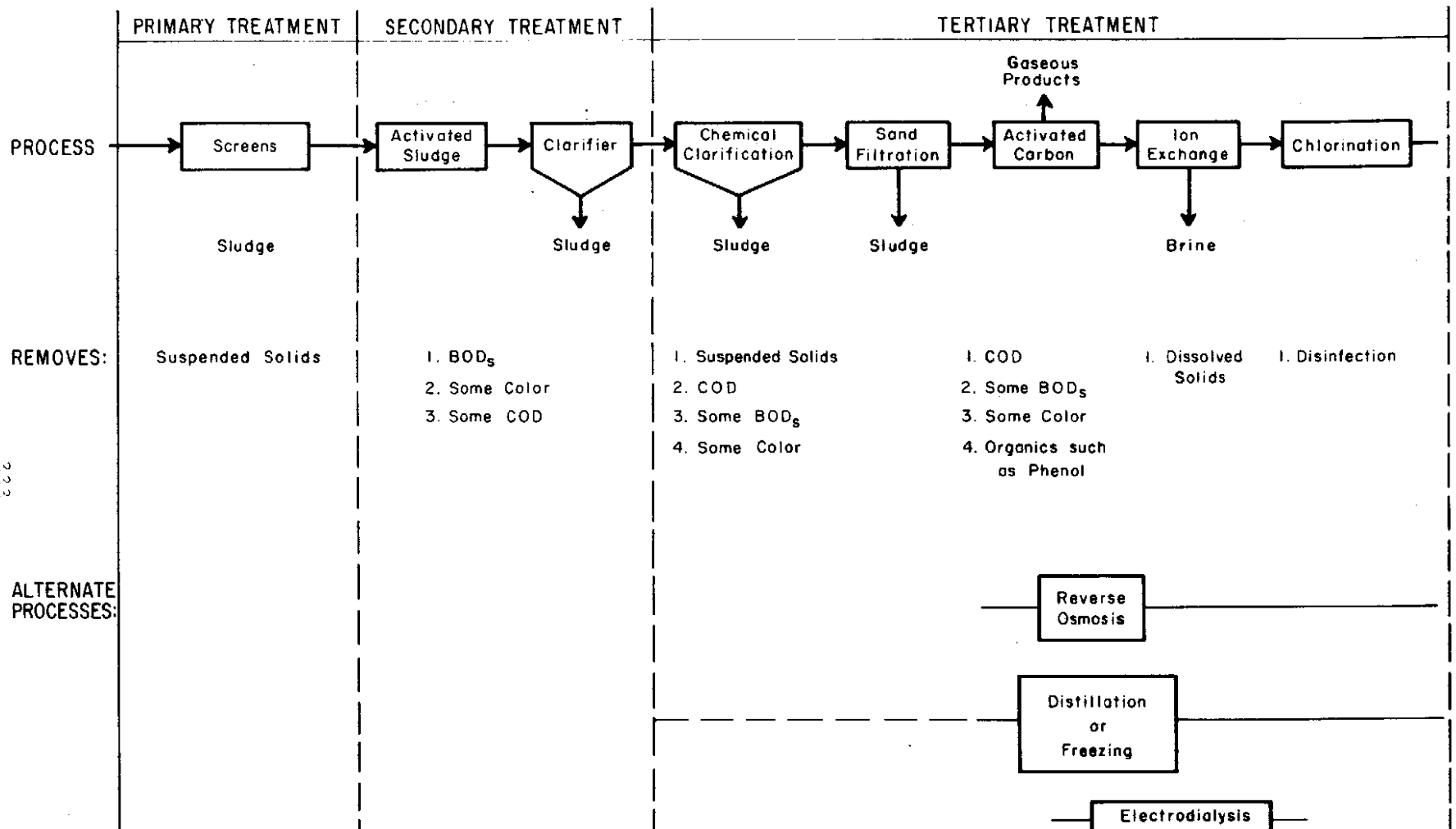

FIGURE 36 Textile Waste Treatment Stressing Advanced Waste Treatment Techniques.

uses lower pressure and more porous membranes which act more like a filter media, but can reject suspended matter in the sub-micron size range.

The major application of reverse osmosis in textile wastes would appear to be in the removal of salts from tertiary treated textile effluents. The technology appears adequate to reduce the effluent salt content to potable water levels (less than 200 mg/l), while also providing for additional color removal, and substantial reduction in residual BOD and COD. The major limitation at this time appears to be the cost, which for large plants (5 mgd or higher) is presently estimated to be 50-75¢/1000 gallons. The major technical limitation of the process is the high degree of suspended solids removal required prior to the use of reverse osmosis, making the initial use of primary, secondary and tertiary treatment methods mandatory.

Ultrafiltration, although less costly and requiring less pretreatment than membrane processing, will not remove salts and low molecular weight organic compounds such as dissolved dyes. Its utility in textile waste treatment would appear to be limited, except where product water must be of extremely high quality, completely sterile and colloid-free; where the wastes contain a pollutant of value which may be recovered; or where the waste water quality will increase water reuse potential. Concentration and recovery of dispersed dyes by ultrafiltration may be feasible, but will be practical only when a single color is in a waste stream, so that the dye may be reused. Concentration of polymeric cotton sizing materials (PVA and CMC) is technically feasible, since the ultrafiltration membranes will retain the polymers and pass the polymer-free water at reasonable fluxes (rates). However, costs for these operations, at this time, are high, estimated to be in the range of $.50-$1.00/1000 gallons.

Electrodialysis is another technique that can be used to separate dissolved and ionized solutions by specially synthesized semi-permeable membranes having ion exchange characteristics. As yet, electrodialysis has not been used to treat textile plant wastes. Some efforts have been made to investigate its use in dye removal. Unfortunately, because of their large molecular size, dye materials do not traverse the membrane readily. There may be some possibility of using electrodialysis to remove dissolved salts from dye solutions, but it has not yet been demonstrated.

Sorption Systems

This group of processes removes compounds from wastewater by passing the water over a material which "adsorbs" a compound on its surface and retains it, thereby removing the compound from the water. Activated carbon adsorption is the most commonly used and versatile adsorbant today. Activated carbon has been employed to reduce phenol, color, and other organic substances to a very high degree. Rinse waters and dilute dye solutions have been treated by activated carbon to a sufficiently high degree that the water could be reduced. High concentration dye solutions, however, have not been treated economically, to date. A novel approach to treating a highly colored textile dyeing waste effluent has been developed recently. (19) It comprises the removal by activated carbon of color bodies and other organic matter. The spent carbon granules are then subjected to a virule aerobic biological culture which desorbs and bio-oxidizes the desorbed matter, thereby regenerating the carbon for subsequent reuse. This process has been demonstrated in a 50,000 gpd plant installed at a yarn spinning mill. Color removal was virtually complete and COD removal was greater than 85%. The estimated operating cost of the decolorizing for a 1 mgd plant is 8.3¢/1000 gallons, not including amortization.

Special Chemical Precipitation

As mentioned earlier, special chemical precipitations are already applied in the industry for the select removal of the various types of dyes employed in the textile industry. Other chemicals may be employed to selectively remove heavy metals for possible reuse in textile mill operations. One such process (20) describes zinc precipitation and recovery from viscous rayon wastewater. In the production of viscous rayon, zinc sulfate is used as a component of the acid-spinning bath. Zinc is lost in a dilute form when the acid-spun yarns are washed with water and at various points in the spinning bath system. The recovery system involves the initial neutralization of the waste stream to pH 6.0, sedimentation of insolubles, the crystallization of zinc hydroxide in a high pH environment, and sedimentation of zinc hydroxide, and finally the resolubilization of the zinc with sulfuric acid.

A reuse of 2,000 pounds of zinc daily assures recovery of 12.5-14¢/lb of zinc operating and maintenance costs. The cost of zinc oxide purchased amounts to 15.6¢/lb of equivalent zinc.

Other chemical precipitation processes may be used to remove some of the dissolved salts present in these wastewaters. However, use of this method will produce large quantities of sludge unless there is an incentive to recover and reuse the product, or produce it in a form readily marketable by resale.

Combustion

Various combustion processes have been proposed for incinerating by-product sludges, particularly the organic sludges, produced in the various treatment processes. Wool grease, of course, could be incinerated, but it should be considered too valuable a material for this purpose, unless its fuel value outweighs its conversion and resale in the market place.

Zero Discharge -- Ultimately,. three approaches may be available to the industry to assist them in approaching the goal of zero discharge. Byproduct recovery can be maximized for reuse and/or resale and water volumes reduced to minimum via treatment to upgrade the water quality to the point where the only make-up water required would be that to replace the losses (or consumption) in textile mill operations, which are estimated to be 6-9% of total water used.

A second approach would be the concentration of impurities in the wastewater by the use of multi-stage flash evaporation or reverse osmosis, followed by incineration of the solid residues. Evaporation represents proven technology and reverse osmosis, unproven technology, in this industry at this time.

Finally, a substitution of solvents for use in certain processing operations, or possibly in all processing operations, is a possibility to replace water now used in the various wet operations. (21) Solvent processing of textiles is not, in itself, a new technical approach. After many years of dry-cleaning garments with petroleum distillates, such as naphtha, it was apparent that improved solvents would be required, and that the ideal solvent should have the following properties:

1. Low cost and ready availability

2. Low toxicity

3. Low water and air pollution propensity

4. Non-flammability

5. Stability to repeated distillations

6. Inert behaviour toward textiles

7. Non-corrosive

Today, solvents are available which meet these requirements. Chlorinated hydrocarbons such as perchloroethylene and trichloroethylene are used in greatest volume.

The solvent used most frequently in continuous processing of woven fabrics is trichloroethylene. With a boiling point of 187° F, it is easy to remove by vaporization from a fabric, since exposure to steam or boiling water causes it to distill out of the fabric structure very quickly. As trichloroethylene is also about five times heavier than air, the control of any escaped vapors is relatively easy, since they fall rapidly to the floor level to be vented away.

The advantages claimed for solvent processing include the following:

> Solvent-soluble waxes, oils, and dirt are collected as an oily semi-solid at the solvent purification stills, rather than being discharged into the waste water treatment plant; traditional highly alkaline and soap-laden effluent from cotton preparation is eliminated; the fresh water requirement, as well as the volume to waste disposal, is greatly reduced in both cotton and wool processing; the aesthetics of the fabric are improved. The solvent, when flashed off by exposure to temperatures above its boiling point, boils quite violently in the yarn structure, giving the fabric a softer hand. Some fabric types are finished with a cleaner surface appearance after solvent proces sing; because water-repellant residues are more completely removed by a solvent preparation, the penetration of dye during dyeing is increased; solvent processing eliminates or reduces the need to use difficult-to-remove surfaceactive agents, subsequent water-repellant finishes produce better performance; lower energy input is required because a few gallons of solvent are being heated to 187° F., instead of many gallons of water to 212° F.; in addition, the latent heat of vaporization of trichloroethylene is only 1/10th that of water; more consistent lot-production is realized, in terms of

shade - both white and dyed work - as well as in finish.

Use of solvents in this industry has started and it has already realized major successes while development work is continuing. In the future we can expect: Totally solvent-soluble warp sizing systems, or yarn-in-the-loom lubrication systems which will enable complete recovery of all fabric pollutants, perhaps even to be reused; collection of the oils and waxes in preparation processes and feeding this residue to the plant oil burners for use as a fuel; the development of new lines of dye stuff and chemical finishes which can be combined and applied in one operation; the development of a range of solvents with specific properties to enable any existing and yet-to-be-developed, textile wet finishing operations to be done in a solvent medium; increased application of point-of-use electrical heating because of low-energy requirement of solvent processing, thus lowering smokestack contamination and allowing more equipment arrangement flexibility; highly automated, closed-loop solvent processing units assembled in a plant much smaller than those of today.

VII. SUMMARY AND COSTS

The estimated 9.8 billion pounds of textile fibers consumed in the United States in 1970 produced about 1150 million pounds of pollutants (just suspended solids and BOD). These pollutants must be removed and disposed of without polluting already-overloaded water supplies. (22)

The textile industry is fortunate in that many of its major pollutants, such as suspended solids and BOD are compatible in municipal sewage treatment plant processing and can be handled by those plants or can be treated by existing present-day pollution-abatement technology, utilizing more or less the conventional primary-secondary-tertiary techniques now employed. The major pollutional problems in the textile industry appear to be the complete removal of dyes with their attendant color, and the future reduction of dissolved salts and COD in wastewaters. Also, because of the extensive number of chemical compounds employed in the industry, care must be exercised in their selection and application to insure that they do not introduce undue toxicity into effluent waters.

Costs of treatment in the textile industry (3) are a small fraction of the costs of production. The percentage of waste treatment cost in total production cost is estimated at 2.0% for wool, 1.7% for cotton, and 2.2% for synthetic textiles. These percentages are for the entire industry related to 1967 data.

Tables 54, 55 and 56 present summaries of production and waste treatment cost for the wool textile weaving and finishing, cotton textile finishing, and synthetic textile finishing industries, respectively.

TABLE 54

SUMMARY OF PRODUCTION AND WASTE TREATMENT COSTS

Wool Textile Weaving and Finishing

Item	Quantity
Total Production	412 Million lb
Total value added in manufacture	392 Million $
Average unit value added in manufacture[2]	0.95 $/lb
Estimated replacement value of waste reduction facilities[3]	19 Million $
Annual amortized cost of facilities at 7% and 10 yr life [3]	2.7 Million $
Estimated annual waste reduction operating and maintenance cost[3]	5.0 Million $
Average industry cost[1] of waste treatment per unit of production	.0194 $/lb
Total waste reduction costs as percent of total production cost	2 Percent

The above table is a comparison of the total capital, operating, and maintenance cost per year of end of the line waste treatment to the total cost of production per year. These are industry-wide estimates and individual plants may deviate considerably.

[1] Not including grease recovery costs, which may increase total waste reduction costs by 50 percent or more, depending upon the prevailing market for wool grease.

[2] From the Business and Defense Services Administration, U. S. Department of Commerce, 1967.

[3] Estimated replacement value, estimated amortization, and estimated annual operating costs include an estimate of the cost of municipal treatment facilities attributable to this industry's waste.

TABLE 55

SUMMARY OF PRODUCTION AND WASTE TREATMENT COSTS

Cotton Textile Finishing

Item	Quantity
Total Production	2015 Million lb
Total value added in manufacture[1]	328 Million $
Average unit value added in manufacture	0.16 $/lb
Estimated replacement value of waste reduction facilities[2]	24.5 Million $
Annual amortized cost of facilities at 7% and 10 yr life[2]	3.5 Million $
Estimated annual waste reduction operating and maintenance cost[2]	2.2 Million $
Average industry cost of waste treatment per unit of production	.003 $/lb
Total waste reduction costs as percent of total production cost	1.7 Percent

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[1] From the Business and Defense Services Administration, U. S. Department of Commerce, 1967.

[2] Estimated replacement value, estimated amortization, and estimated annual operating costs include an estimate of the cost of municipal facilities attributable to this industry's wastes.

TABLE 56

SUMMARY OF PRODUCTION AND WASTE TREATMENT COSTS

Synthetic Textile Finishing

Item	Quantity
Total Production	975 Million lb
Total value added in manufacture[1]	179 Million $
Average unit value added in manufacture	.18 $/lb
Estimated replacement value of waste reduction facilities[2]	16 Million $
Annual amortized cost of facilities at 7% and 10 yr life[2]	2.3 Million $
Estimated annual waste reduction operating and maintenance cost[2]	1.5 Million $
Average industry cost of waste treatment per unit of production	.004 $/lb
Total waste reduction costs as percent of total production cost	2.2 Percent

The above table is a comparison of the total capital, operating, and maintenance cost per year of end of the line waste treatment to the total cost of production per year. These are industry-wide estimates and individual plants may deviate considerably.

[1] From the Business and Defense Services Administration, U. S. Department of Commerce, 1967.

[2] Estimated replacement value, estimated amortization, and estimated annual operating costs include an estimate of the cost of municipal facilities attributable to this industry's wastes.

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PLASTIC AND SYNTHETIC MATERIALS MANUFACTURING

I. INTRODUCTION

The plastics and synthetic resins industry is one in which products and processes vary widely. Consequently, waste loads and characteristics also vary from plant to plant and from process to process, making generalization difficult. Studies are therefore required for each plant's wastes before efficient waste treatment facilities can be installed. It is the purpose of this report to describe the processes of the plastics and synthetics industry located in the Merrimack River Basin, and to present alternatives for treatment of the liquid wastes resulting from these processes. Included in the treatment of plastics wastes will be the current practices, "Best Practicable Technology Currently Available", and "Best Available Technology Economically Achievable" for reducing wastes.

The plastics producers in the Basin are Borden, Foster Grant, Great American Plastics and Paragon Plastics. These companies produce Nylon 6, low and high density polyethylene, polyvinyl chloride, polyvinyl acetate, polyvinly alcohol, polystyrene, and Butadiene-styrene resins. The processes for manufacturing these plastics differ greatly in design and waste production, but are generally bulk, solution, emulsion or suspension. Typically, an initiator for polymerization and some modifying agents are added to the monomer to produce the desired product. Waste water production is generally low, compared with that of other chemical manufacturing, because there is minimal water contact with the product. A description of the individual product manufacture will outline some basic manufacturing processes: polyvinyl, polystyrene, polyethylene, and Nylon 6.

II. PLASTICS AND SYNTHETICS MANUFACTURE

Process Description

1. Polyvinyl chloride (PVC)

The growth of polyvinyl chloride over the past twenty years has been steady, but manufacturing processes have generally gone unchanged. The process most used in PVC is suspension, accounting for 85-90 percent of the PVC produced.

In the suspension process, the monomer is dispersed as tiny droplets in a stabilized water medium containing 0.01-0.5 percent (by monomer weight) suspending agents. The suspending agents are commonly polyvinyl alcohol, gelatin or cellulose ethers. After dispersion, the suspension is heated with catalysts to initiate polymerization. Unreacted monomer is recovered, after polymerization has been completed, in a blow down tank or a stripper. Recovery of the polymer is completed by dewatering and washing in a centrifuge (Figure 37).

The remaining 10-15 percent of PVC production is by the emulsion process. Here the monomer is solubilized and dispersed in the medium, which is generally water, although cyclohexane and tetrahydrofuran may also be used. The polymerization results in a milky latex of dispersed polymer particles from which the product is recovered by spray drying or, less frequently, by coagulation followed by centrifugation.

2. Polyvinyl alcohol

Vinyl alcohol does not exist in a free state, so polyvinyl alcohol cannot be made by polymerizing vinyl alcohol. Instead, polyvinyl alcohol is manufactured by alcoholysis of polyvinyl ester, or polyernyl acetate. Methanol or ethanol can be used to effect alcoholysis, but methanol is generally preferred because it is miscible with polyvinyl acetate at room temperatures, and it yields a product of more acceptable color. When methanol is employed, methyl acetate may also be used as a second solvent. Methyl acetate is also a product of the polyvinyl alcohol process reaction.

Acid or base catalysts may be used with the basic ones, such as caustic soda or sodium methoxide, effecting more rapid alcoholysis. Increasing catalyst concentration decreases residual acetate content after completion of the reaction; and this is used to control the degree of alcoholysis. (1)

3. Polyvinyl acetate

Polyvinyl acetate is commonly made by the emulsion process. Approximately equal quantities of water and vinyl chloride are stirred together in the presence of a suitable colloid emulsifier system, such as polyvinyl alcohol and sodium lauryl sulfate, and a water soluble initiator such as potassium persulfate. The batch is reacted for about four hours at approximately 70° C. The reaction is exothermic and must be cooled when batch sizes are greater than a few liters.

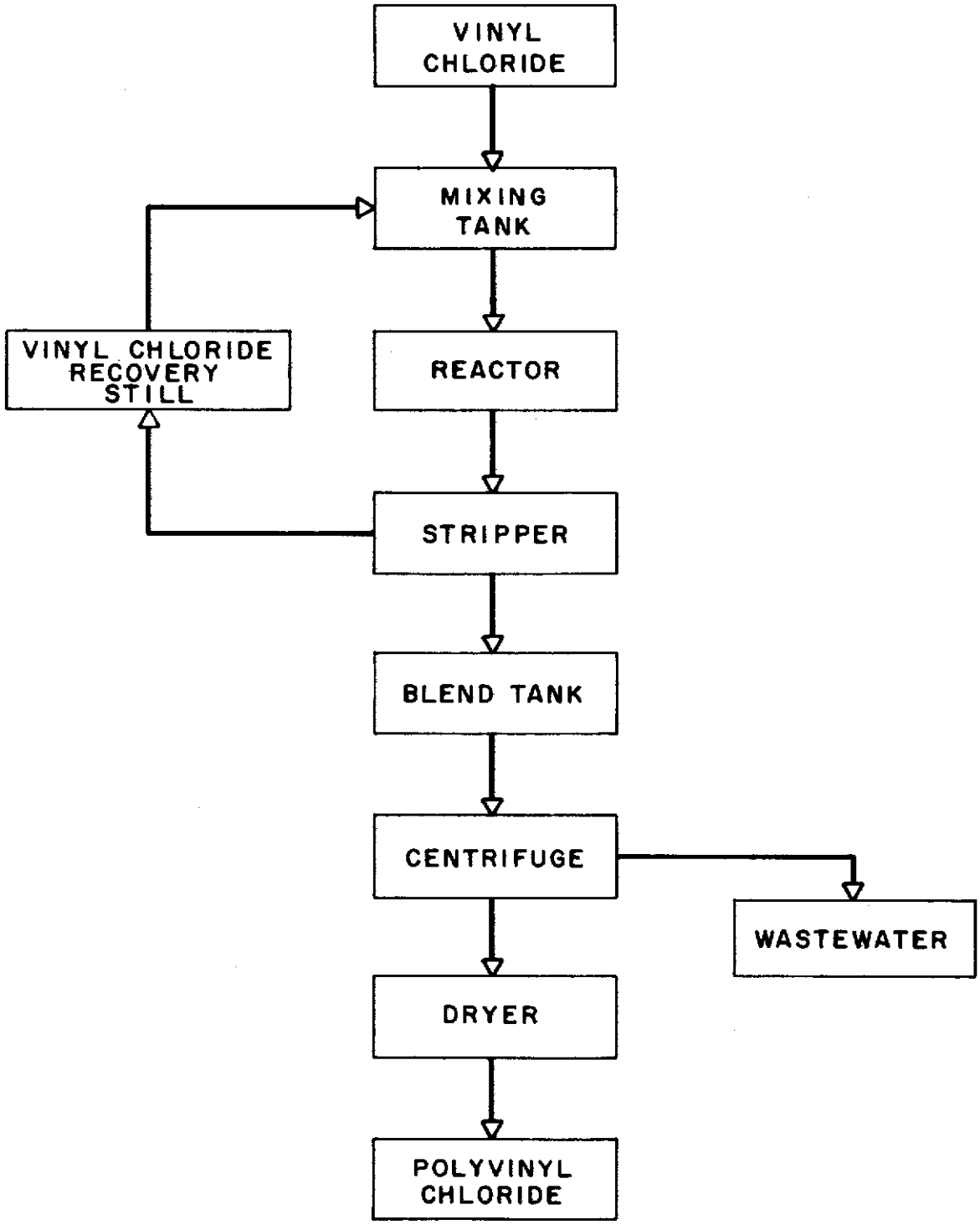

FIGURE 37 Flow Chart for Polyvinyl Chloride Production by Suspension

To maintain control over the reaction, and to obtain small size polymer particles, only part of the monomer is initially polymerized; the rest is added slowly over a three- to four-hour period. pH must also be controlled within a certain range to minimize hydrolysis of vinyl acetate during the polymerization. Sodium acetate is commonly used as a buffer in this case. (1) Conversion to polymer is near 99 percent, so that monomer stripping need not be employed. (2)

4. Polystyrene

Polystyrene is made by one of two batch methods, either by a bulk stage followed by a suspension stage, or by a suspension stage alone. In the first technique, monomer is purified by distillation or by a caustic wash in order to remove inhibitors. Monomer and initiators are then charged to a reactor, and polymerization to about 30 percent completion takes place at approximately 90° C. Water is used here only for cooling purposes and does not enter the reaction mixture. The partially reacted mixture is transferred to a suspension system, where suspending agents, such as talc or inorganic phosphates, are added. The reaction mixture is then stripped of unreacted monomer in a blow down tank, and the remaining liquid is centrifuged to extract the product. Finally, the polymer is filtered, washed and dried.

The second process, that with a suspension stage alone, is essentially the same as the combination bulk and suspension process, except that the bulk stage is eliminated and reactants are charged directly to the suspension system. (See Figure 38).

5. Polyethylene

Polyethylene falls into two categories, low density and high density. Low density polyethylene is made by compressing gaseous ethylene and passing it through a reactor with initiators. The stream is divided into a monomer rich stream and a polymer rich stream; the latter is usually concentrated further, then extruded into ribbons or strands for pelletizing in a chiller-chopper process. The monomer stream can be cleaned and reused for polymer production, or other process requiring ethylene.

High density polyethylene (HDPE) is manufactured by a low pressure method, either the Phillips or the Zeigler process, the Phillips being the more common. In the low pressure process, solvents are used which must be recovered, and are reused. Few water wastes are generated in low density polyethylene (LDPE) production, except for thermal

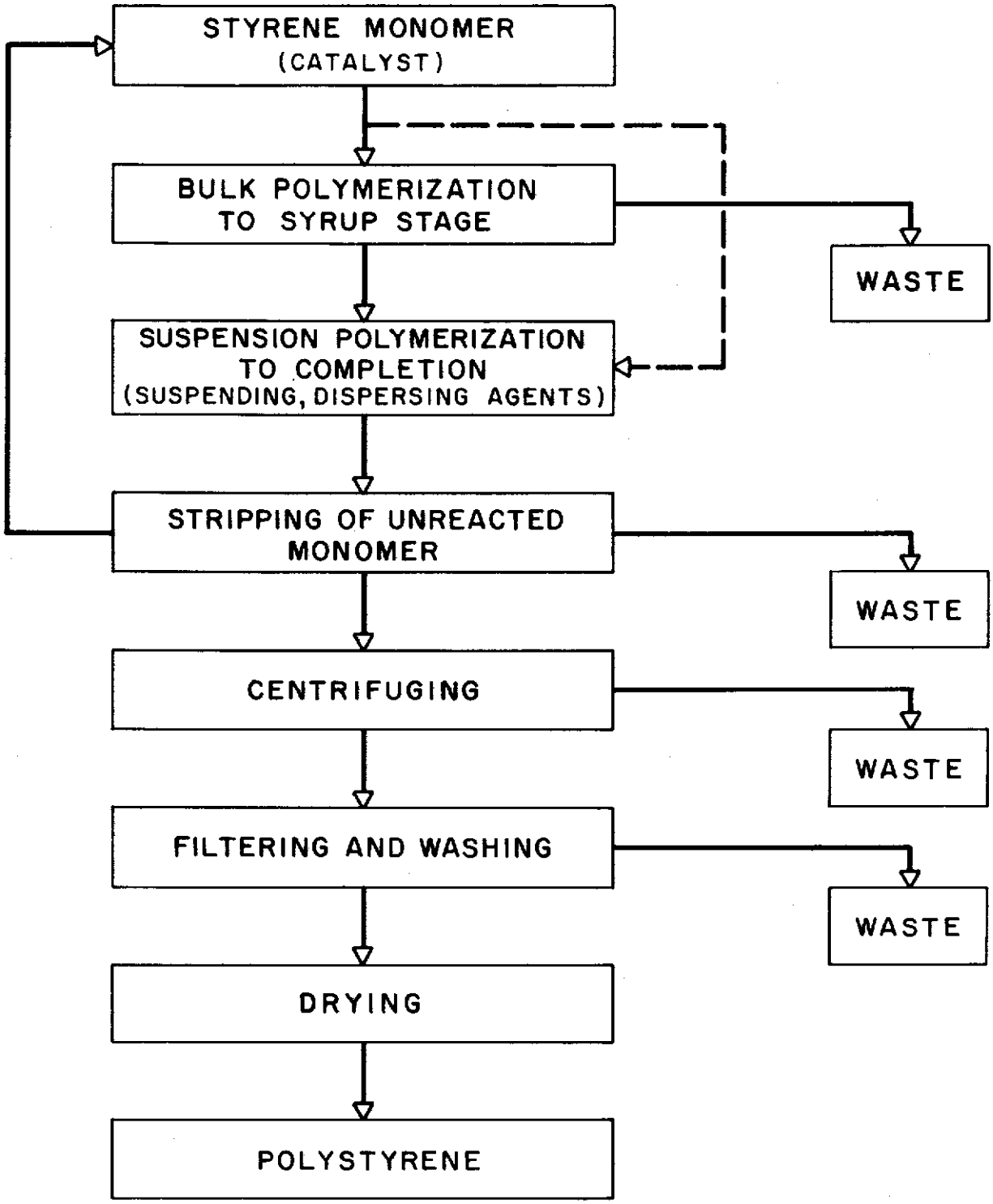

FIGURE 38 Flow Chart for Polystyrene Production by Bulk and Suspension Polymerization

pollution from cooling operations.

6. Nylon 6

Nylon 6 is manufactured by either batch or continuous methods. In the batch process, caprolactum, water and a molecular weight regulator are charged to a vessel and reacted for about twelve hours under a nitrogen atmosphere. The water serves as a carrier and a catalyst, and acetic acid as a molecular weight regulator. Product is about 90 percent high polymer and 10 percent low polymer and monomer. The low molecular weight compounds can be removed by leaching or vacuum distillation.

In the continuous process, reactants are mixed and stored in reservoirs which continually feed reactor columns operating at approximately 250° C. (1)

III. WATER REQUIREMENTS

In all of the plastics and resins manufacturing processes, it can be seen that water is essential, either as a suspending medium, a solvent, a reaction controller, or a coolant. Water used in the chemistry of the process must be free from impurities so it does not inhibit or alter the desired reactions. Hence, little water is reused for chemical processes, because it becomes contaminated during its use in a reaction.

Conversely, cooling water does not need to be as free of contaminants and is therefore more easily reused. Corrosion inhibitors and other chemicals may have to be added to protect equipment. Unreused cooling water could therefore pose both a chemical pollution problem from the additives, and a thermal pollution problem. However, in this industry, recycling of cooling water is a relatively easy procedure, compared to recycling of manufacturing waters, and this would prevent cooling water pollution.

IV. WASTEWATER

Sources

1. Polyvinyl chloride

The production of polyvinyl chloride by the suspension process

results in one continuous wastewater stream which contains the bulk of the waste from the manufacturing process. This stream issues from the centrifuge (See Figure 37), carrying with it suspending agents surface active agents, small quantities of unreacted monomer, much finely divided unrecovered polymer, and additives such as acrylates and acrilonitrile, which are used in the PVC latex. Small amounts of phenol, sodium phenolate, and caustic soda may be found in this waste stream, resulting possibly from monomer purification. In addition, compounds used for polymerization arrestors, such as carbon tetrachloride and choloform, may appear in the wastewater.

Other sources of wastewaters are the washing and rinsing of reactor vessels, which contribute solvents and process chemicals to wastewater streams, and spills of highly contaminated water, made during transfers and reactor sampling.

The emulsion process represents no continuous wastewater source, since the process water is evaporated to the atmoshphere during the drying stage. Wastewaters here are mostly from spills and cleaning.

Wastes from both processes contain solids, soluble carbonaceous matter and, to a lesser degree, foam and odors. Solids are both settleable, characteristic of the suspension process, and non-settleable and colloidal, characteristic of the emulsion process.

2. Polyvinyl alcohol

Wastes from polyvinyl alcohol production result from neutralization, recovery and drying, and from methanol recovery. Contained in the wastes are unreacted polyvinylester (or polyvinyl acetate), unrecovered polymer, methyl acetate, unrecovered methanol, catalysts, plus other reactor additives, such as initiators.

3. Polyvinyl acetate

Wastes from polyvinyl acetate production contain unreacted vinyl acetate, reaction buffer, emulsifiers, and initiators.

4. Polystyrene

Wastes of the polystyrene manufacturing process consist typically of suspension waters, flowing from the centrifuge, and of wash waters Spills and leaks will contribute slugs of waste to the plant's waste stream. The wastewater contains unreacted monomer, suspending agents, initiators, catalysts and other additives. Cooling water will also appear in

the waste streams if it is not reused. Table 57 is an example of wastewater characteristics for one specific polystyrene plant, that of Foster Grant, Inc. (3) The sample used for analysis was a randomly collected composite.

TABLE 57

WASTEWATER CHARACTERISTICS
(3)

Characteristic		Composite Analysis (mg/l except pH)
pH		5.4
Total solids		21,100
Suspended solids		19,200
Total volatile solids		20,100
Fixed solids		1,000
Alkalinity:	Total bicarbonate	18
	Bicarbonate	8
Hardness:	Calcium	22
Magnesium		6
BOD, 5-day, 20° C		330
COD		14,500
Total phosphate		84
Orthophosphate		81

Wastewater Characteristics

Table 58 shows raw wastewater characteristics for the various plastics and resins plants herein discussed. (4)

V. WASTEWATER REDUCTION

For this, and for the following sections on wastewater treatment, we shall draw on relevant experience of the organic chemical industry. The two are closely related: both use many of the same unit operations, and some of the products of the one are the raw materials for the other, thus leading to similarities in some of their waste treatment problems and in outlook. Although the volumes and strengths of

TABLE 58

RAW WASTE LOADS
(4)

PRODUCT	BOD_5 Reported Range[a] (Units/1000 Units of Product)	BOD_5 Observed Value[b] (Units/1000 Units of Product)	COD Reported Range[a] (Units/1000 Units of Product)	COD Observed Value[b] (Units/1000 Units of Product)	SUSPENDED SOLIDS Reported Range[a] (Units/1000 Units of Product)	SUSPENDED SOLIDS Observed Value[b] (Units/1000 Units of Product)
Polyvinyl chloride	0.1-48	5.7	0.2-100	25	-	30
Polyvinyl acetate	0-2	1.4	-	-	0	-
Polystyrene	0-2.2	-	0-6.0	-	0-8.4	-
ABS/SAN	2-15	6.4	5-30	-	0-30	8
High density polyethylene	0-1	-	0-2.4	-	0-3.4	-
Low density polyethylene	0.2-3.2	4.4	0.2-54	12	0-4.1	0.4
Nylon resins	1-135	66 {9, 4}	1-300	16 {14, 8}	0-8	{0.2}
Nylon fibers	0.1-60	6 {21, 10}	0.2-90		0.1-6	
Polypropylene fibers	0-10	-	0-20	-	-	-

(a) Barson, Norman, and Gilpin, James, Industrial Waste Study of the Plastics Materials and Synthetics Industry. Draft Report prepared by Celanese Research Company For the Water Quality Office, Environmental Protection Agency.

(b) Plant visits by Arthur D. Little, Inc.

wastes per unit of product, and the specific compounds which comprise them, differ considerably among the industries, we shall not attempt to treat each one individually in this discussion.

Recycle

If one were to judge solely by the issuance of a 173-page EPA report on how to conduct a mill survey (5), as late as 1971, the outlook would be bleak. Fortunately, there has been, in the case of individual plants, progress considerably beyond what this might indicate. Nevertheless, recycling of process water has not been carried out extensively by the industry. In the first place, many polymerization reactions are quite sensitive to small amounts of initiators or chain terminators (as well as unintended impurities). Therefore, it is important for some of the processes that the water be thoroughly purified, or at least that it have a constant and known composition. If there are no other considerations, it is then easier to use fresh water than recycled. Secondly, several of the processes use little water in any case, so that the incentive for saving it has been negligible.

The opportunities for recycling must be presumed to exist, as in other industries, whether the recycle is direct, or occurs only after treatment of some kind. We present two examples, one of a very specific application, the other a generalized approach.

B. F. Goodrich (6), whose treatment process will be discussed in Section VI, operates a number of large PVC plants. Upon completion of their wastewater treatment facility at the newest plant, * they undertook to study the feasibility of reusing secondary treatment plant effluent by returning it to the inlet of one of their well water treating stations. The water is evidently perfectly satisfactory for cooling, and service and fire water. There is no mention in the report (written in 1971) of recycling to process.

There are plants, of course, where the amount of water evaporated in cooling tower or blown down from the boilers may be equal to or greater than the volume of process waste. Such a plant is reported by Gloyna, Ford and Eller (7). This is a rather specialized chemical plant in the business of recovering byproducts from refinery wastes. However, the principles are of such general application to any chemical processing plant, it seems worthwhile to summarize the procedures. The company, before deciding on intensive recycle, investigated biological, physical and chemical schemes of waste treatment. Except for

* Salem County, New Jersey

boiler blowdown, they conduct a closed up operation, all the rest of the water going out with the product or by evaporation from the cooling towers. (The plant carries out considerable distillation and evaporation.)

Rainwater runoff is segregated not only as stormwater, but by degree of contamination, so that water of low organic content is fed to the boiler room and cooling towers, while the richer water is collected and reused in process operations. Sumps and dikes can handle up to 2 inches of rain in 15 minutes, or 8.5 inches in a day. Overflow after this storage is exhausted is relatively clean.

A "drip system" includes a pan under every pump for stuffing box leaks, a funnel under each sample cock and overflow pipes on all vessels, so that all "waste" may be pumped back to process. Cation exchanger and careful control of these additives to the boilers eliminates a former COD problem in the boiler blowdown.

The most interesting feature of the entire scheme is the use of the cooling towers as waste treating facilities. Both active biological and heavy metal sludges accumulate in the tower. A combination (presumably) of stripping and biological oxidation reduces the COD in the circulating stream. Bleed from the tower consists of windage losses and intermittent sludge drawoff. The sludge at the bottom of the tower being relatively concentrated in heavy metals, presents an unsolved problem of disposal, now being handled in the usual manner of such problems.

Process Changes

Organizations engaged in manufacturing polymers are almost constantly looking for "better" processes. The processes in use generally will represent something which, unlike those in some of the more traditional industries, have been chosen quite deliberately after a series of logical engineering, economic and scientifically based decisions.

Consequently, few outside (or for that matter, within) the industry, would have the temerity to suggest a substantial change in process as a means of curing a waste problem. The EPA draft report (4), page 114, writes of replacing present technology and gives examples from the recent past. These replacements, however, did not come about because of waste treatment problems. The report continues:

"The possibilities for applying this approach will require assessment of the availability of new technology and the capital investment required for retiring present plants and erecting new plants. It will also require determining if the quality range of products produced can meet the requirements of the market. In those product categories, ... where less water use and lower pollutant-generating processes exist, the replacement approach is dependent upon a socio-economic decision, i.e., is the early retirement of more polluting processes and their replacement with less polluting processes going to result in effectively reducing the emission of environmental pollutants in a manner in which the greatest benefits/cost ratios result for the environment and society. At the present time, significant reductions in pollutant loads can be achieved in the ... products by replacing one production method with another. In general, however, the plastics and synthetics industry considered in this survey is a mature industry, and there appears little potential for dramatic breakthroughs in the production technology. The most probable results will be replacement of some products with newer products. "

Less drastic changes are those incremental ones exemplified by better process control (temperatures, pressures, raw material uniformity, and so on). Of course, any minimizing of side reactions or decrease in the amount of unreacted monomer left in the final mix will make recycling and/or waste treatment easier. Replacing barometric with surface condensers, improving operator education, and vigilant maintenance to prevent drips apply to all of the industries considered in this study.

VI. WASTEWATER TREATMENT

Current Practices

Some of the waste treatment being carried on by segments of the industry at present will suffice as Best Practicable Control Technology Currently Available (BPCTCA) or, in other words, it should be adequate until 1983. The EPA draft report (4) states that exemplary treatment plants are in operation, thus current practice and BPCTCA (1977) can most conveniently be lumped together for our purposes. The guidelines developed for those plastics of interest here have been proposed by EPA (8) and are excerpted in Table 59.

TABLE 59

GUIDELINES FOR BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

Maximum averages not to be exceeded during any consecutive thirty day period

Values are expressed as lb/1000 lb product produced or Kg/1000 Kg product produced

Product	BOD	COD	SS	Total Chromium
PVC				
a. Suspension	0.31	3.1	0.62	
b. Emulsion	0.11	1.1	0.22	
c. Bulk Polymerization	0.053	0.53	0.11	
Polyvinyl Acetate	0.18	1.8	0.36	
(ABS)/SAN	0.63	6.3	0.73	.0088
Polystyrene				
a. Suspension	0.20	2.0	0.39	.0023
b. Bulk	0.035	0.35	0.07	
Polyethylene				
a. Low Density	0.18	1.8	0.36	
b. High Density (solvent process)	0.27	2.7	0.53	.0031
c. High Density (polyform process)	0.045	0.45	0.09	
Nylon 6				
a. Resin	3.71	37.1	1.58	
b. Fiber	1.90	19.0	0.80	
c. Resin and Fiber	5.61	56.1	2.38	

To achieve these levels, EPA suggests that application of in-plant changes and technology such as those discussed in Section V "may be helpful". However, "BPCTCA for existing point sources is based on the application of end-of-pipe technology such as biological treatment for BOD reduction as typified by activated sludge, aerated lagoons, trickling filters, aerobic-anaerobic lagoons, etc. with appropriate preliminary treatment typified by equalization to dampen shock loadings, settling clarification, and chemical treatment, for removal of suspended solids, oils, other elements, and pH control and subsequent treatment typified by clarification and polishing processes for additional BOD and suspended solids removal and dephenolizing units for the removal of phenolic compounds where applicable."

This standard technology was plainly selected on the basis of the performance of the exemplary plants mentioned above. The waste treatment plant at Goodrich's PVC production on the Delaware (6) is one of the most modern of which we are aware, and we include a brief description and flow sheet (Figure 39) as an example of the end-of-the-pipe treatment proposed for the industry as a whole.

The producing plant uses emulsion, suspension and bulk polymerization processes, and the wastes contain unreacted monomer, polymer, various salts (both organic and inorganic), organic acids, resin and rubber fin solids, dispersants, wetting agents and catalysts. The raw waste enters an equalization tank supplied with strong agitation and pumped discharge so that both flow and concentration are leveled out, thus protecting the primary clarifier against surging and the biological treatment system against shock. A coagulant ($FeCl_3$) and coagulant aid are added in successive short hold-up mix tanks. It had been determined by pilot plant work that a high degree of inert solids removal was desirable, partly to minimize turbidity and suspended solids in the final effluent, and partly to improve operation of the aeration tank. Next flocculation and clarification occur in a standard combination unit, and pH is adjusted as necessary with caustic.

Resin-plastic plant wastes are usually deficient in either the phosphorous or nitrogen or both required for biological treatment. The topwater from the primary clarifier, then, receives additions of phosphoric acid and ammonia before being split between two aeration tanks. The aeration tanks, which form part of a conventional activated sludge process, are equipped with 75 HP mechanical aerators. Foaming (which can frequently be a problem with these types of waste) is controlled by spray nozzles using effluent water. The sludge return system

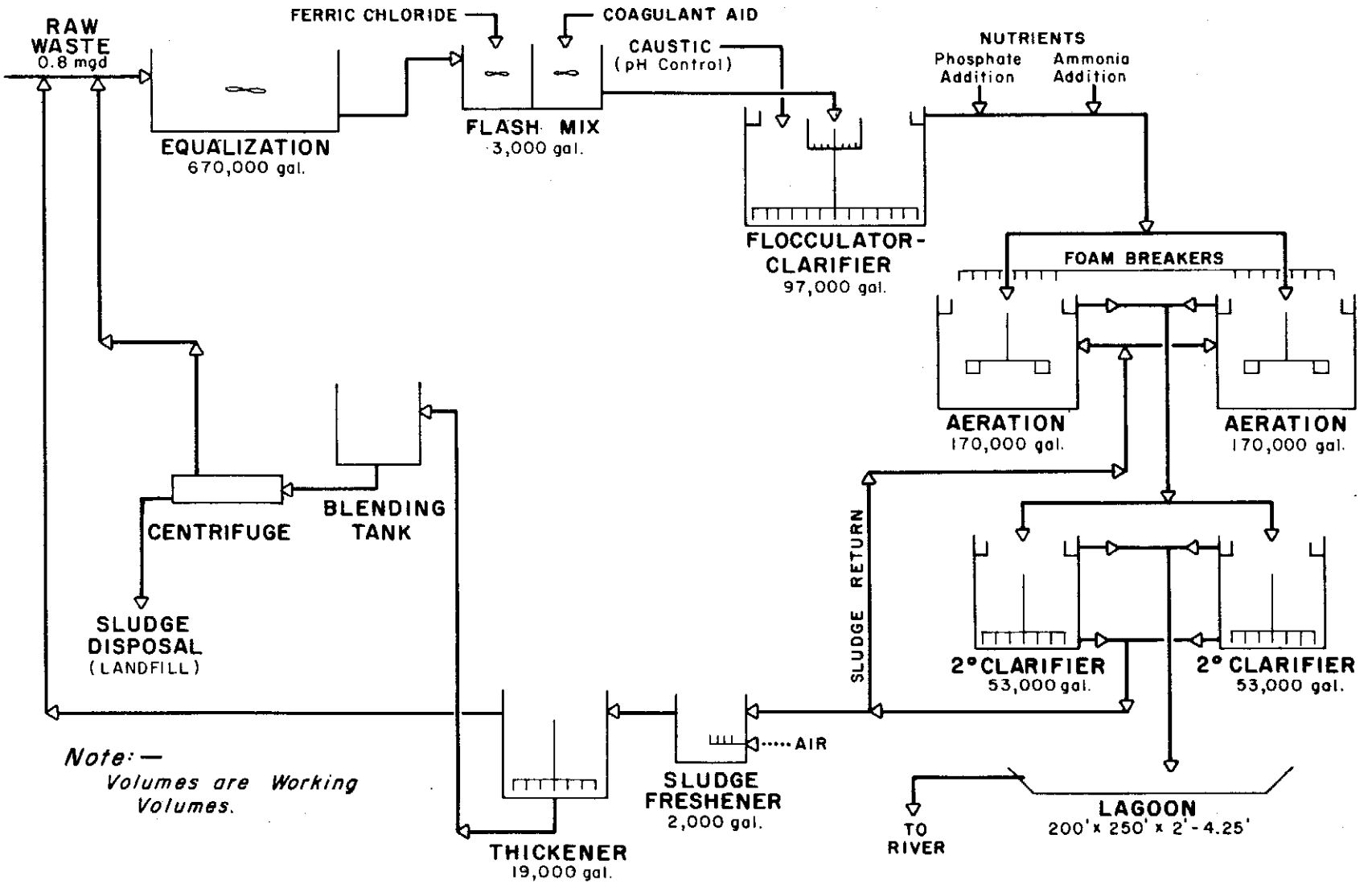

FIGURE 39 Waste Treatment Flow Sheet (PVC Production)

embodies variable speed pumps which allow recycle over a range of 0-230 percent of flow. Wasted sludge goes via a small "freshening" (aerating) tank to a thickener and thence to a centrifuge. The secondary sludge may be blended with that from the primary clarifier before centrifuging. In any case, both types of sludge are sent to landfill while the filtrate is returned to the equalization chamber at the head of the plant. The plant effluent flows through a polishing lagoon, where it is hoped some further BOD and suspended solids removal may occur, and where spills could be held up should one overpower the treatment plant.

Although the discussion so far emphasizes conventional biological treatment, usually carried out as described or with aerated lagoons instead of activated sludge, there have been successful applications of physical-chemical treatment by themselves in this industry. Tucker and Mason (3) report such a one for treating effluent from a polystyrene manufacturer.

A typical analysis for the effluent from the plant was previously presented in Table 57. What do not show up in that table are the color, turbidity, taste and intense odor caused by residual styrene monomer and other organics. Reduced to its elements, the interesting two-stage treatment process consists of pH adjustments, flocculation and sedimentation. Raw effluent is limed to pH 11.5-11.8 to precipitate phosphate as the hydroxyapotite, bicarbonate as the carbonate and magnesium as the hydroxide, the latter two present from the water supply. The $Mg(OH)_2$ acts as a flocculant, further improving phosphate removal. After primary sedimentation the topwater is carbonated to reduce pH, bringing down calcium carbonate with the help of alum to coagulate and settle the remaining phosphate. The troublesome dissolved organics are precipitated with the calcium hydroxyapotite in the primary stage. A full scale treatment plant followed the pilot work and Table 60 gives typical operating results. Note particularly the reduction in COD and phosphate compared with the values of Table 57. The last column of Table 4 gives results of applying carbon adsorption to the effluent in order to provide a water suitable for recycling to process.

EPA (8) and the draft report (4) gloss over the question of COD removal, despite a statement in the former that BOD, COD and suspended solids are <u>the critical constituents</u> requiring guidelines and standards (emphasis added). They present standards for this measure of chemical pollutants, but to simplify (possibly oversimplify)

TABLE 60

OPERATING RESULTS - PHYSICAL-CHEMICAL TREATMENT

Characteristic	Primary Clarifier Effluent*	Secondary Clarifier Effluent*	Carbon Filter Effluent*
Turbidity	81	45	13
pH	11.7	7.6	7.4
Total solids	874	388	280
Suspended solids	68	9	7
Total volatile solids	412	0	0
Volatile suspended solids	60	0	0
Alkalinity: Total	500	74	47
Bicarbonate	440	74	47
BOD, 5-day, 20° C	--	160	5
COD	--	304	56
Total phosphate	0.86	0.44	0.36
Orthophosphate	0.30	0.016	0.004

* Units of measurement are mg/l, except turbidity and pH.

their presentation on pp. 140, 141, 149, and 150 of the Draft report, the COD limits are those values which were observed at plants which were doing an adequate job of BOD removal. The picture is somewhat further muddied on pp. 123 and 127, where the report opts for carbon adsorption to remove refractory organics, but recognizes the specificity of carbon and (for advanced treatment) assumes only a 60% removal of COD.

Except for chromium, zinc and phenolics, standards for metals and organics are left in limbo, with the receiving water quality standards determining if limitations are necessary. Parenthetically, if the receiving water is a municipal sewer with a publicly owned treatment plant at the other end, limitations are most certainly necessary for the various "incompatible" pollutants (9).

Future Practices

Table61 comprises a partial listing of the guidelines proposed by EPA (8) for the pollutant levels to be achieved by applying Best Available Technology Economically Achievable (BATEA). The increase in severity of these guidelines compared with those for BPCTCA is striking, particularly for COD. Methods for reducing substantially the refractory portion of the COD are not known with any certainty for the effluents of many of these industries. We assume, in light of the above, that the main thrust toward achieving low levels of COD must come from extraordinary efforts to curtail waste volumes by in-plant measures, and to reduce the amount and number of refractories entering the waste to an absolute minimum. Presumably, if this minimum is sufficiently small and concentrated, or if it can be made so by one of the standard or advanced concentrating techniques, it can be oxidized by one means or another.

Whether any of the 15-20 concentration or the dozen or so oxidation methods that first come to mind can be applied economically to any of the specific situations which will need attention is hard to say without a case-by-case evaluation. What we seem to be saying, though, is that almost complete hydraulic close-up may be required. EPA offers a grab-bag of unit operations and processes,* one of which, they

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* "Potentially applicable control and treatment technology includes adsorption (activated carbon, adsorbent floc), multi-media filtration, chemical precipitation, chemical treatments, anaerobic processes, air or steam stripping, foam separation, algal systems, wet air oxidation,

TABLE 61

GUIDELINES FOR BEST AVAILABLE CONTROL TECHNOLOGY ECONOMICALLY ACHIEVABLE

Maximum averages not to be exceeded during any consecutive thirty day period

Values are expressed as lb/1000 lb product produced or Kg/1000 Kg product produced

Product	BOD	COD	SS	Total Chromium
PVC				
a. Suspension	0.11	0.75	0.075	
b. Emulsion	0.04	0.27	0.027	
c. Bulk Polymerization	0.038	0.25	0.025	
Polyvinyl Acetate	0.065	0.42	0.042	
(ABS)/SAN	0.13	0.88	0.088	0.0022
Polystyrene				
a. Suspension	0.070	0.46	0.046	0.0012
b. Bulk	0.025	0.17	0.17	
Polyethylene				
a. Low Density	0.065	0.42	0.042	
b. High Density (solvent process)	0.095	0.63	0.063	0.0016
c. High Density (polyform process)	0.032	0.22	0.022	
Nylon 6				
a. Resin	0.28	1.9	0.19	
b. Fiber	0.15	1.0	0.10	
c. Resin and Fiber	0.43 /kkg fiber	2.9 /kkg fiber	0.29 /kkg fiber	

seem to feel, will be capable of adaptation to any specific problem remaining after mill close-up and biological treatment have reached their limits.

The feeling is that the Draft Development Report relies pretty heavily on activated carbon, which would seem to be more a hope than an actuality for achieving the 1983 standards.

Once again, it seems more than a remote possibility that meeting all of the 1983 effluent limitations may mean changes in the products of some of these industries, perhaps in some cases forcing moves from highly polluting products to others with the disappearance from the market of the former. At least with nine years to prepare, there should be ample time for making possible process changes, though whether these possibilities will have much economic appeal for those forced to make them is another matter.

Future practices in sludge disposal apparently will bear a strong resemblance to present priorities, judging from the Draft Development Report's conclusions...

> Prior treatment to dewater the biological sludges by chemical or mechanical means will probably be increasingly employed. However, the problem of landfill disposal remains. Consequently, one of the long-term aspects of wastewater treatment is ascertaining that appropriate landfill sites have been obtained. The cost of sludge disposal from plastics and synthetics plants will be essentially equivalent to the cost of sludge disposal from municipal sewage treatment plants. The same type of disposal methods are applicable, but there will be significant variations in the amounts of sludge generated.

A range of disposal costs is shown in Table 62.

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incineration, liquid extraction, ion exchange, reverse osmosis, freeze thaw, evaporative and electrodialysis. Most of these technologies are for the removal of specific pollutant parameters, and can be applied in cases where the pollutant parameter is a problem."

TABLE 62

COST OF SLUDGE DISPOSAL

Type of Plant	Cents/Ton of Product Landfill	Incineration
Polystyrene, PVC, ABS/SAN, Polyethylene	0.5-5	5-10

VII. SUMMARY AND COSTS

Basically, there are two major conclusions to be drawn from the survey of the literature reported on here. The first is that since the guidelines for 1977 (BPCTCA) have been developed on the basis of performance by exemplary wastewater treatment plants now in operation (4), they describe goals which can be attained by known technology and within the economic capabilities of the industry as a whole. We have given a brief description of this technology in Sections V and VI.

The methods by which the stated 1983 (BATEA) goals are to be attained are not well understood. They depend first upon a change of attitude toward water, from that which regards it as an inexpensive conveyor of unwanted product contaminants to that which sees it as an expensive raw material of the process and a valuable resource. Carried to an extreme, this leads to the concept of zero discharge, and based on what we know of present technology for removing trace amounts of some organic coumpounds from water, that approach will almost surely have to be considered. In the words of the EPA draft report, "the methods for removal of refractory carbonaceous materials ... present the major challenge to specifying reliable end-of-pipe systems."

In light of this great unknown, it seems unrealistic to try to project the costs for achieving the higher standards. However, based presumably on assumptions made in the draft report, about the possible efficacy of activated carbon, EPA estimates the cost of applying BATEA to existing plants as being between 2.1 and 8.1 percent of sales price, on the average.

Estimates of the costs of applying technology needed to achieve the 1977 goals are on somewhat firmer ground. A. D. Little (4) developed curves for both capital costs (Figure 40) and operating costs (Figure 41) for the treatment required.

We conclude by quoting from EPA once more (8) in order to give the most up to date available assessment of the probable impact of these changes on the industry:

"There are no indications that any significant economic impact would result from imposition of the recommended guidelines for 1977. Some smaller, older plants, whose profitability may be severely impaired by these costs, however, may decide to close prior to 1977. These plants comprise on the order of 1 percent of the industry's capacity, and in most cases, have become uneconomic due to their size or age. Overall, profitability may decline if market conditions prevent those costs from being passed on as price increases.

"The effect of the recommended effluent levels for 1983 BAT [BATEA] and NSPS [New Source Performance Standards] are more difficult to project. For some products, the added costs for BAT appear to be significant (PVC, PVA, HDPE, epoxies, phenolics), if evaluated under current market conditions. However, due to the complexity of projecting market trends a decade into the future, such variables as new products development and high costs of feedstocks may overshadow any pollution abatement costs."

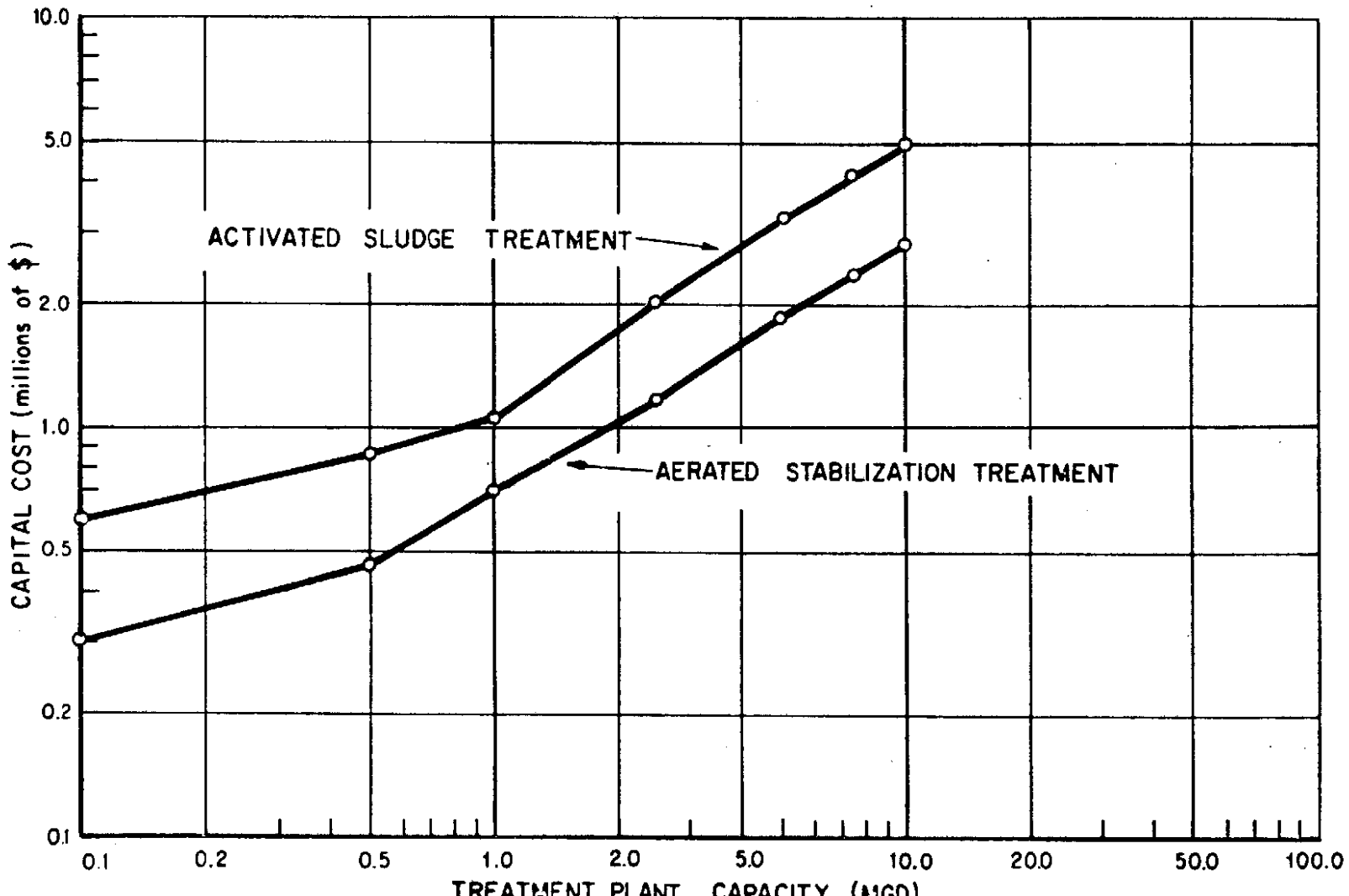

FIGURE 40 Secondary Treatment in the Plastics and Synthetics Industry · Capital Cost.

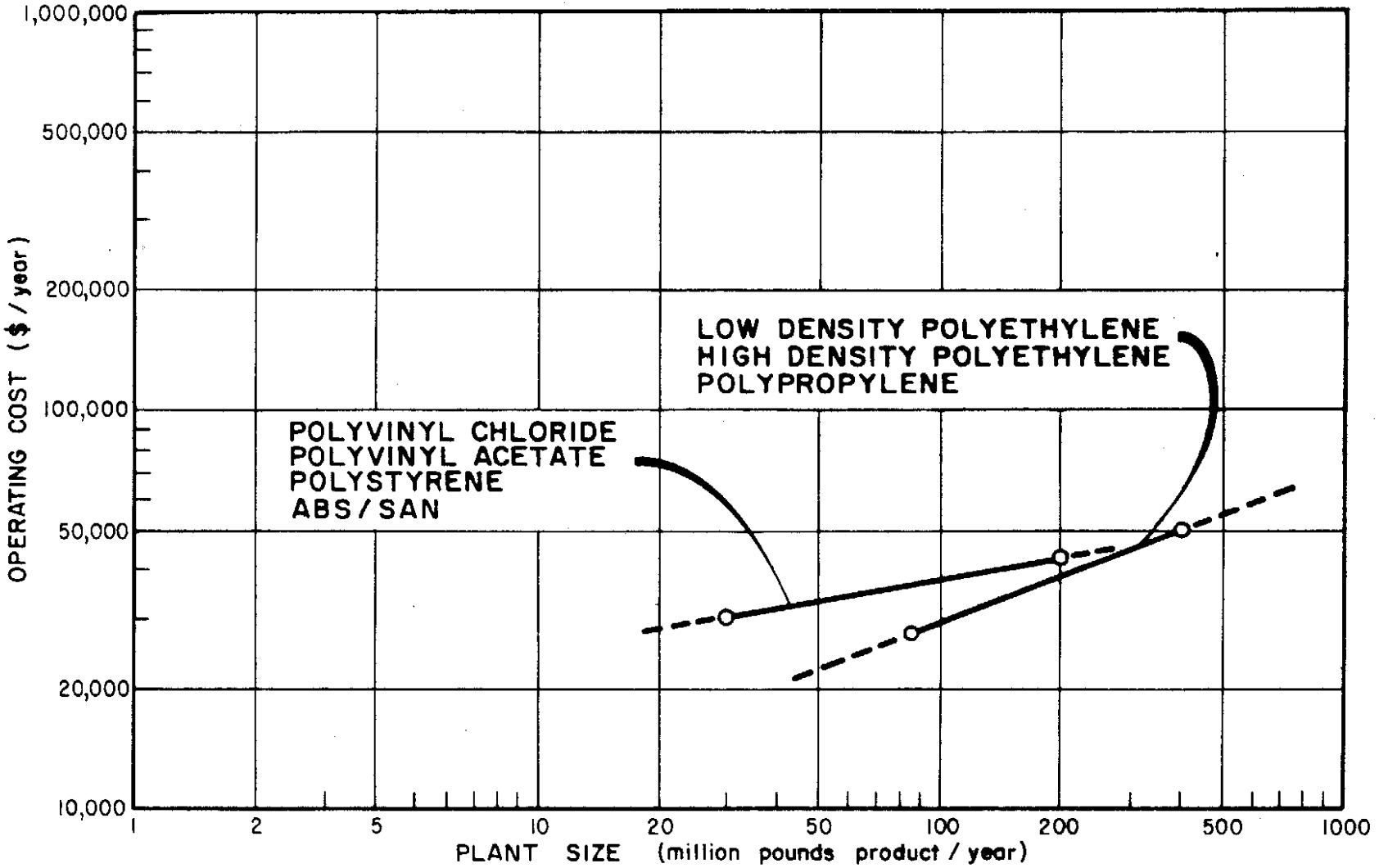

FIGURE 41 Secondary Treatment in the Plastics and Synthetics Industry·Operating Cost

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METAL PLATING

I. INTRODUCTION

The industries generally thought of as "metal finishing" or "plating" are those in SIC categories 3471 and 3479: "Establishments formally engaged in all types of electroplating, plating, anodizing, coloring, and finishing of metals and formed products for the trade. Most of the work done in this industry is done on materials owned by others."

SIC 3479 includes coating, engraving, and allied services not elsewhere classified. The following is an additional description (from Standard Industrial Classification Manual - 1967):

"Establishments primarily engaged in performing the following types of services on metals:

"1. Enameling, lacquering, and varnishing metal products for the trade.

"2. Hot dip galvanizing of mill sheets, plates, and bars, castings and formed products fabricated of iron and steel; in retinning cans and utensils;

"3. Engraving, chasing and etching jewelry, silverware, notarial and other seals and other metal products for the trade and for job contracting for purposes other than printing; and

"4. Other metal services, not elsewhere classified."

There were some 15,000-20,000 metal finishing plants in the United States in 1968, of which the largest number were captive shops, followed in number by several thousand small-job shops and some larger independents. Captive operations are common in the electrical and electronic industries, automotive, appliance, and many others.

II. METAL FINISHING AND PLATING

Process Description

EPA's proposed rules (1) for effluent limitations are, to date, restricted to a somewhat narrower segment of the industry, namely, ". . . for the electroplating of copper, nickel, chromium, and zinc on ferrous, non-ferrous, and plastic materials subcategory of the electroplating category of point sources . . ." (emphasis added). The standards encompass the bulk of all electroplating, though numerous other metals are plated in smaller amounts. It should be added that tremendous quantities of metals are applied to surfaces by methods other than electroplating.

Essentially, plating embodies only 2 steps: preparation of the surface to be plated, and electrodeposition of a metal, with optional post-treatment of the surface, such as lacquering or coloring. We shall not attempt to describe the hundreds of varieties of the dozens of processes employed in the industry. (If the basic material is a non-conductor, such as plastic, ceramic, or the like, it is first coated with a lacquer or varnish containing a suspended conductive pigment, such as graphite, copper, or silver, after which it can be electroplated in a standard bath.)

1. Surface Preparation

a. Mechanical Preparation

Surface preparation often includes various types of mechanical finishing. Polishing and buffing can be carried out by abrading the work with brushes, wheels, or belts. Abrasive compounds may be used with them, as well.

Abrasive blasting, is the forcing of abrasives such as steel shot, or various grits of all sizes and compositions and shapes, against the work. Compressed air is a common carrier. So is water, in wet blasting where an abrasive slurry is made up. Mechanical means, such as centrifugal force, are common methods of propulsion.

In mass finishing, or tumbling, a vibratory or rotating motion (as in barrel milk) is imparted to the work. Media (abrasives) suspended in a dilute water solution of "compounds" (salts, etc.) rub against the work. Some of the materials in use will be discussed later in this section.

b. Chemical and Physical Preparation

Chemical and physical surface preparation may range from, for example, a single degreasing operation to a series of closely controlled chemical and electrochemical reactions and rinses. The summary presented here is after Homrok & Innes (2), Jeffrey (3), and Hall (4).

Precleaning and final cleaning may both be required, or sometimes only the latter. Precleaning is used to remove as much soil as possible, or to condition the metal for removal in final cleaning.

Straight solvent cleaning may be carried out in liquid or vapor, using petroleum fractions or chlorinated solvents. The latter are usually preferred in vapor degreasing, which consists of allowing the vapor to condense on the work and run off, carrying the soil, and providing pure solvent continuously. Solvents may also be used in a variety of emulsions, the emulsion may be formed in the cleaner, or on the work. Application is by soaking or spraying.

Acids, together with water rinsible solvents, and wetting and emulsifying agents, are used to remove oil and light metal oxides. Heavy duty alkaline cleaners are mixtures of caustic, silicates, soda ash, and the like, together with sequestrants and dispersing and other surface active agents. Used hot, acids are the commonest of all cleaners; detergents are also in heavy use.

Final cleaning, which uses basically the heavy duty alkaline cleaners, is distinguished from precleaning since it always employs electric current. The objectives are to remove all soil and activate the surface to be plated.

Anodic electrocleaning is desirable for final cleaning where possible; metal is dissolved slightly as well as cleaned. Gas scrubbing by the oxygen generated helps in the cleaning.

In cathodic cleaning, the hydrogen (twice the volume of oxygen, of course, for a given current density) scrubs the work. The work, as cathode, is actually being plated and for this reason may develop objectionable films. Cathodic cleaning is used for metals that are dissolved or etched too easily as anodic, or where positivation by formation of an oxide film would occur. The current may be periodically reversed (PR) for some cleaning so that the work becomes alternately cathodic and anodic.

Acid dipping is what its name implies. The purpose may be either to pickle the surface of the work, or to activate it. Pickling is to remove scale and oxide, activation to neutralize an alkaline film and dissolve light oxide films. Acids may be used with or without DC current, depending on the particular application.

Ultrasonic cleaning is used for specialized cleaning operations, such as removing soil from small complex electronic components.

Molten salt baths form a separate step in the preparation of the surface of some metals. They are used to remove scale from high alloy stainless steels, titanium alloys and the like after hot treating. The baths, operated at temperatures from 400°F to 1000°F may be either oxidizing or reducing, depending on the composition of the alloy. The salt bath is usually followed by an acid pickle (typically, nitric-hydrofluoric) and rinse.

2. Electroplating

The Metal Finishing Guidebook and Directory's formulae and basic instructions for plating 21 metals and alloys lists as many as a dozen procedures for a single metal. We shall try simply to give a basic idea of what two of the most common processes, plating and anodizing, accomplish.

In electroplating a conductor (or a nonconductor coated with a conductive coating) is placed in a solution of the metal to be deposited. A voltage is impressed across the cell, the work is made the cathode, and either a sacrifical anode (e.g., in nickel or copper plating) or an inert anode such as platinum is used. Metal(s) from the solution deposit(s) on the work. Having said this, we mention only the two principal mechanisms for accomplishing the result, rack plating and barrel plating. In the former, the work hangs from racks in a still plating bath. In the latter, a bulk processing procedure, the work is tumbled continuously in a "barrel." Figure 42 after Olson(5) shows a schematic diagram of a zinc plating line with a chromate conversion coating, as a single example of one common operation.

There are many degrees of mechanization, from hand loading of racks and hand carrying from tank to tank, to elaborate automatic machinery for conveying racks or barrels along a production line of operations.

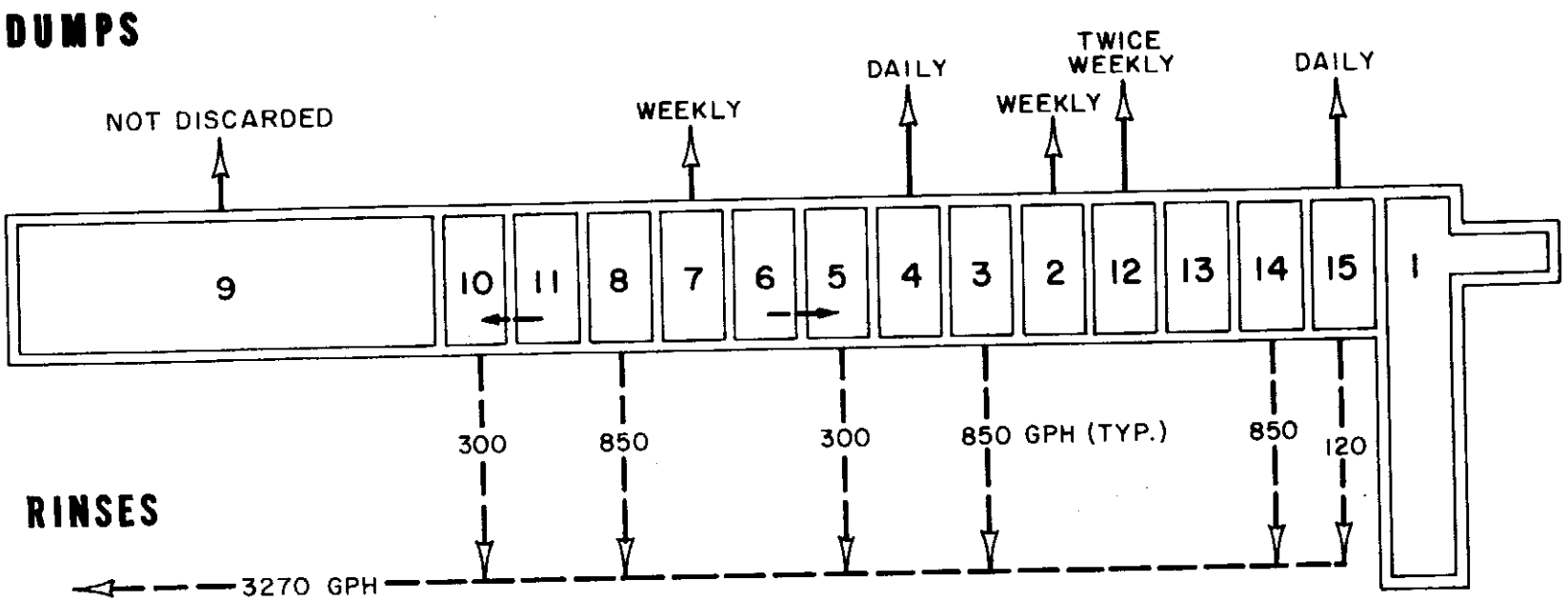
Anodizing of aluminum is one of the most common electrochemical operations, though it is not plating; the work is made anodic in either a chromic acid or sulfuric acid bath. Under the proper operating conditions, a film of aluminum oxide is built up. The color of the work can be changed rather simply by dyeing with a water soluble dye immediately after anodizing. The somewhat porous coat of aluminum oxide is sealed by immersion in hot water, which converts it to the monohydrate, hydrous aluminum oxide ($Al_2O_3 \cdot H_2O$). The resulting increase in volume closes the microscopic pores.

III. WATER REQUIREMENTS

Uses

The plating industry uses water primarily for two purposes, rinsing and cobling. The rinsing water is commonly thought of as being that used to remove plating solutions and perhaps pickling acids from the work pieces. It is, of course, also used with detergents and other cleaners for general cleaning of work, and for carrying away the solids after mechanical surface preparation.

Water is required for condensing vapor at degreasers and for removing heat from some plating baths.



PROCESS

1. LOAD & UNLOAD
2. SOAK CLEAN
3. C.W. RINSE
4. ACID PICKLE
5. C.W. RINSE COUNTERFLOW
6. C.W. RINSE
7. P.R. ELECTRO CLEAN
8. C.W. RINSE

PROCESS

9. ZINC PLATE
10. C.W. RINSE COUNTERFLOW
11. C.W. RINSE
12. CHROMATE I
13. CHROMATE II
14. C.W. RINSE
15. W.W. RINSE

LEGEND

C.W. - Cold Water
W.W. - Warm Water
P.R. - Periodic Reversal

FIGURE 42 Barrel Zinc Plater - Schematic

After OLSON (5)

Quality

Tapwater of "good" quality is adequate for many purposes in the typical plating plant. It is usually used for washing and for the less critical rinses. Homrok and Innes (2) point out the necessity for quality in the washing function:

"An all too often overlooked fact in metal cleaning is the condition of the available water. Water with hardness exceeding 25 grains definitely is a problem and must be treated for the satisfactory operation of most cleaners. Many of the wetters or surface active agents are deactivated by the formation of insoluble calcium and magnesium products. For this reason proper treatment with deionizers, for example, should be considered along with the proper choice of cleaners."

Deionization, using ion exchange resins, and distillation are used to a considerable extent to supply pure water in the industry for making up plating baths and for the more critical process rinses.

IV. WASTEWATER

Sources

Wastewater from the metal finishing industry is popularly thought of as that stemming from the rinsing of objects during and after an electroplating operation. The rinses, which are essential for removing the chemical reagents and reaction products of one operation before its successor, do make up most of the volume of water discharged, unless, as is occassionally true, there is an unusually high discharge of cooling water from a vapor degreaser. Then, rinses are usually more or less continuous and are always dilute.

Such wastes are far from being the only ones, however. The industry generates others from many cleaning and other surface preparation operations, including chemical, mechanical, electro-chemical and physico-chemical. For example, there are intermittent discharges of concentrated baths, which have become contaminated beyond use, and of the plating bath filters and adsorbers. There are spills and drips, and probably discards resulting from mistakes. If solvent drying is used, there may be a discard of wet solvent, if its volume is too small for economical recovery by distillation. Laboratory wastes may be significant and toxic; and regenerants from ion

exchange columns, and/or bottoms from water stills, are a part of many plating room discards.

Character

For convenience in summarizing the types of waste material to be expected, the sources of pollutants in the plating industry have been divided into the categories listed in Figure 43. Only those operations which produce significant amounts (or types) of liquid wastes are included. The listing makes no pretense at completeness in detail, but is meant to include the classes of material that result from the dozens of processes and hundreds of combinations of chemicals, proprietary and otherwise. Solutions to the problems caused by the members of this list will show the way to pollution abatement from any but the most specialized of processes.

V. WASTEWATER REDUCTION

There are a number of accepted methods for reducing the volumes of wastewater from plating operations. In spite of their having been recognized for years, and written up in texts and handbooks, there are still many plating shops where wastewater reduction steps have yet to be applied. It is commonly possible to effect a 50 to 90 percent reduction in water use, and hence in wastewater volume, where conservation measures have not been put into effect. Olson (6) has summarized the measures which may be taken as follows:

Processing Changes

1. Kushner (6) twenty years ago developed rules which are still valid for minimizing dragout:

a. Keep the concentrations of all dissolved materials at the minimum value requisite to the proper operation of the bath.

b. Do not add anything to a plating bath that does not perform a necessary function in the same.

c. Operate the plating bath as hot as possible.

d. If there is a choice of conducting salts that can be used in a plating bath, use the salts that give the greatest density and the smallest viscosity per unit concentration.

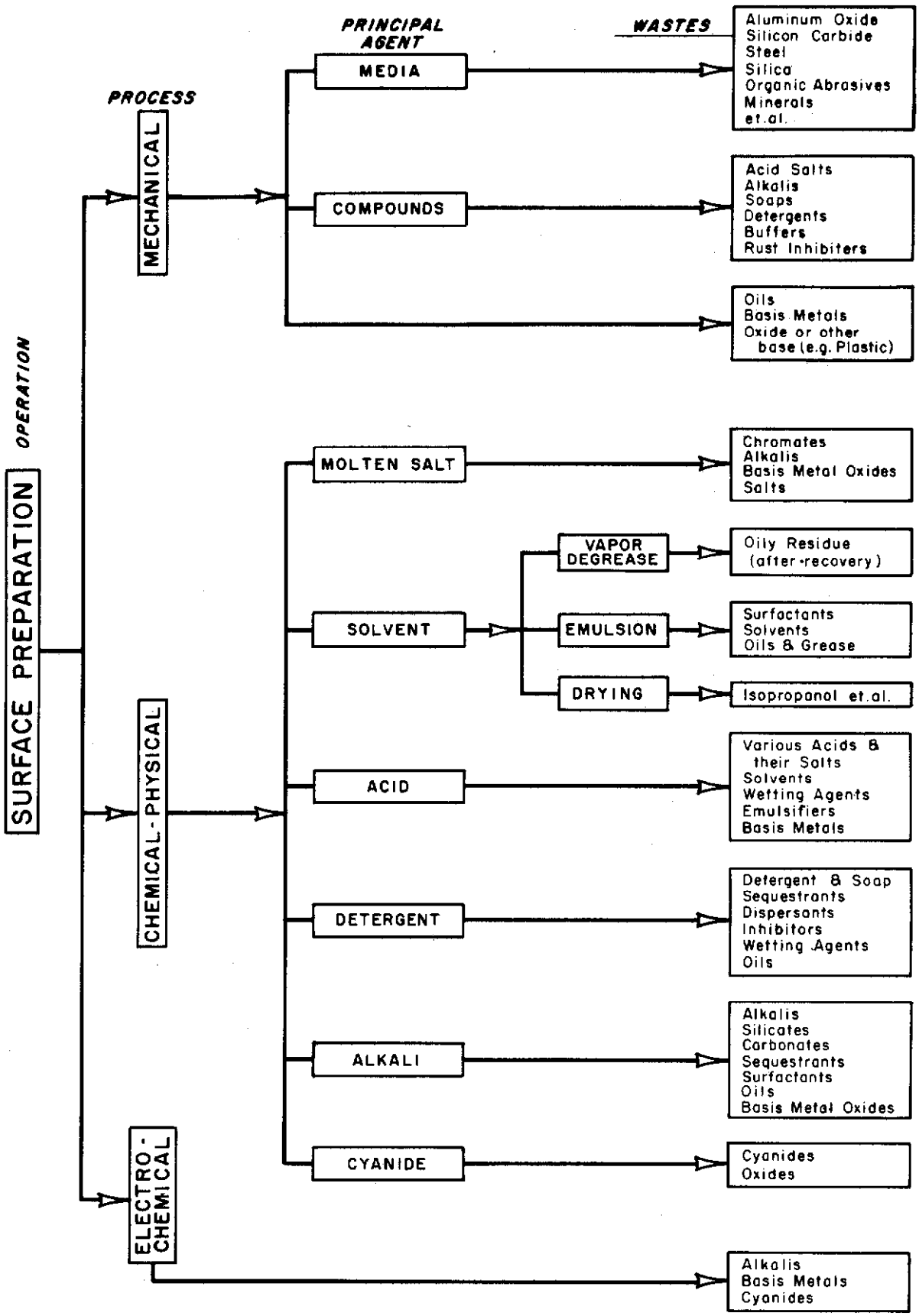


FIGURE 43 Typical Wastes

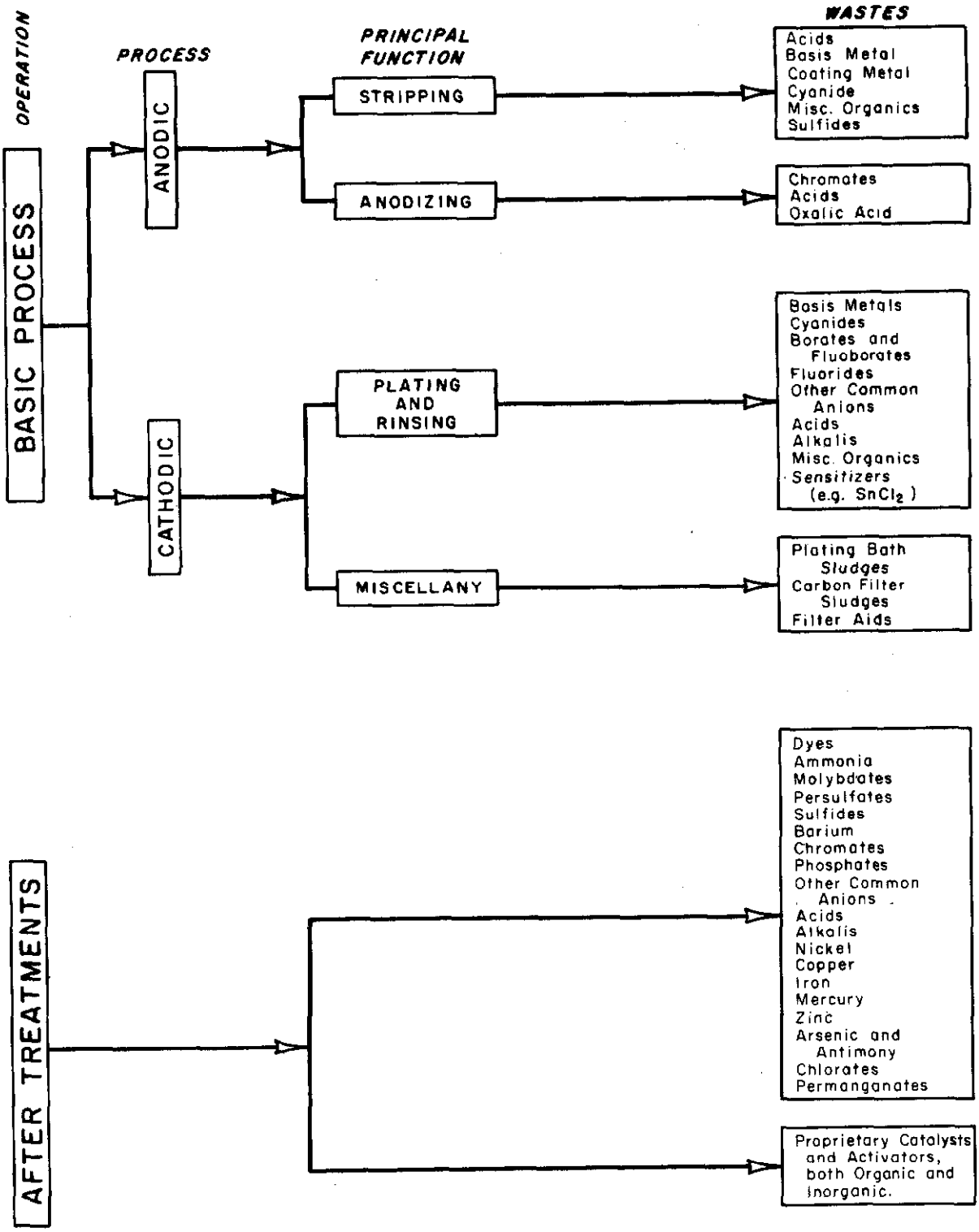


FIGURE 43 (Cont.).- Typical Wastes

e. Make use of an effective wetting agent in the plating bath.

f. With a given, fixed time period allowed for withdrawal and drainage, use the largest part of the period for withdrawal.

g. For minimum dragout, rack solid objects so that they are extended in area rather than in depth.

h. Do not rack objects directly above each other so as to lengthen the drainage path.

i. Tilt all solid objects with plane or singly curved surfaces so that drainage flow is consolidated.

j. Every solid object, outside of a sphere, has at least one position in which dragout will be at a minimum.

2. After the attainment of the minimum practicable dragout, attention can be directed to measures for minimizing the amount of water needed to remove this irreducible residue.

a. The least costly procedures start with the establishment of some sort of control (frequently lacking) over the flow of rinse water. More often than not, the rinse water will be found to depend solely on the water main pressure and the supply piping, the inlet water valves being left wide open. Thus the most obvious measures, such as reducing flows until they are just above those needed to prevent poor work, eliminating short circuiting in the rinse tanks (sometimes no more than a ten-minute plumbing job) and shutting off rinses (manually or automatically) when not needed, will often be highly productive.

b. Proceeding beyond the simplest steps, logic and experiment applied on a case by case basis will lead to further reduction in rinse volume. Some or all of the following procedures may be worthwhile, and are often introduced during a waste reduction program:

(1) Increasing the agitation in rinse baths

(2) Using a still rinse before the running rinses

(3) Using spray rinses or fog rinses

(4) Using countercurrent rinsing

c. The volume of rinsewater may sometimes be reduced substantially by the use of a chemical rinse prior to the final rinse, if the original chemical dragout can be converted into compounds which are easier to remove, or less harmful to the next operation. This principle is used for waste treatment also, and will be discussed in Section VI.

3. Reductions in the concentrations of process solutions and substitution of chemicals have been another means for reducing wastes.

Plating baths are traditionally at a concentration in the middle of a range that produces acceptable work. Operating at the more dilute end of the acceptable range obviously can reduce wastes, both in the sense of metal losses and effluent treatment requirements. At the same time, more precise control is necessary to insure against concentrations falling below the minimum for acceptable work.

There is space here only to suggest a few examples of possibilities for substituting chemicals.

a. Substitution of the sulfuric acid process for the chromic acid process, to eliminate hexavalent chromium from anodizing solutions.

b. Use of methods other than strong cyanide baths for stripping, where possible.

c. Gold and copper plating by processes not requiring cyanide.

d. Low cyanide or non cyanide zinc plating baths.

e. Substitution of nickel strike (non cyanide) for copper strike from copper cyanide solutions.

f. Elimination of high phosphate cleaners.

g. Replacement of chromic acid bright dips with hydrogen peroxide type pickling solutions.

It should go without saying that common sense and experience must accompany the substitutions. It contributes little to the cause of pollution reduction, for example, to eliminate a zinc cyanide bath and at the same time substitute a heavy concentration of chelates, which may make the removal of heavy metals from the waste next to impossible. Equally obvious is that attention must be paid to the effects of substitutions on the work. The original highly polluting baths were presumably chosen for their efficacy, and substitution of other chemicals and processes may well introduce new problems in control, in quality of product, and in cost.

Recycling

Recycling of chemicals, except for the recovery of precious metals, is not widely practiced at present by the plating establishments in the Merrimack Basin. Generally speaking, rinsewaters are allowed to go their way to the drain or sewer, after whatever treatment is coming to be required by the State Division of Water Pollution Control. (Of course, plating baths, which are rarely dumped in any case, are customarily reclaimed for their metal.)

The plating industry, more than most, should be particularly amenable to the recycling of its wastewater for the following reasons:

Most of the plating baths and rinses require water which is relatively free of dissolved solids, and many need water which is virtually ion free. This means that many plants, particularly those plating critical electronic components or jewelry, purify a fraction of their water routinely. The water supplied to the purification process may often require the removal of more material than would a supply of dilute rinsewater(s). When a plant approaches these conditions, it is obviously to its advantage to get pure water via this route. One purification step replaces two, purification of process water and purification of wastewater.

The author knows of one captive plating shop, which, having only just completed a treatment plant for its waste, is planning to take care of all future expansions and stricter effluent standards by increasing its ion exchange capacity to allow recirculation of rinses.

Obviously, cooling water should be, and often is, segregated and used where possible in lieu of fresh water makeup. Its most frequent use is probably as rinsewater. Certainly it must never be mixed with contaminated water going to the waste treatment plant. The requirement for separation of this sort customarily forms part of a state pollution abatement order, in any case.

VI. WASTEWATER TREATMENT

Current Practice

Current practice in the treatment of metal finishing wastewater most commonly consists of the destruction of cyanides by oxidation and of chromates by reduction, and the precipitation and separation of heavy metals from the effluent as hydroxides. These functions may be carried out as batch operations, as continuous processes or in integrated systems. Metal recovery from the sludges may or may not be practiced depending on the value of the metals.

Less commonly, ion exchange, evaporation and reverse osmosis may be employed, alone or in combination with each other, or with the oxidation, reduction or neutralization processes, as circumstances dictate.

1. Control by Destructive Processes

The standard methods for controlling plating wastes are described in varying detail in the literature of numerous instrument and equipment manufacturers, as well as in reference (7) and texts (8), (9), (10), (11), to cite a few (secondary) sources of information. Consequently, we present here only the following generalized block diagrams, as a convenient reminder (see Figure 44).

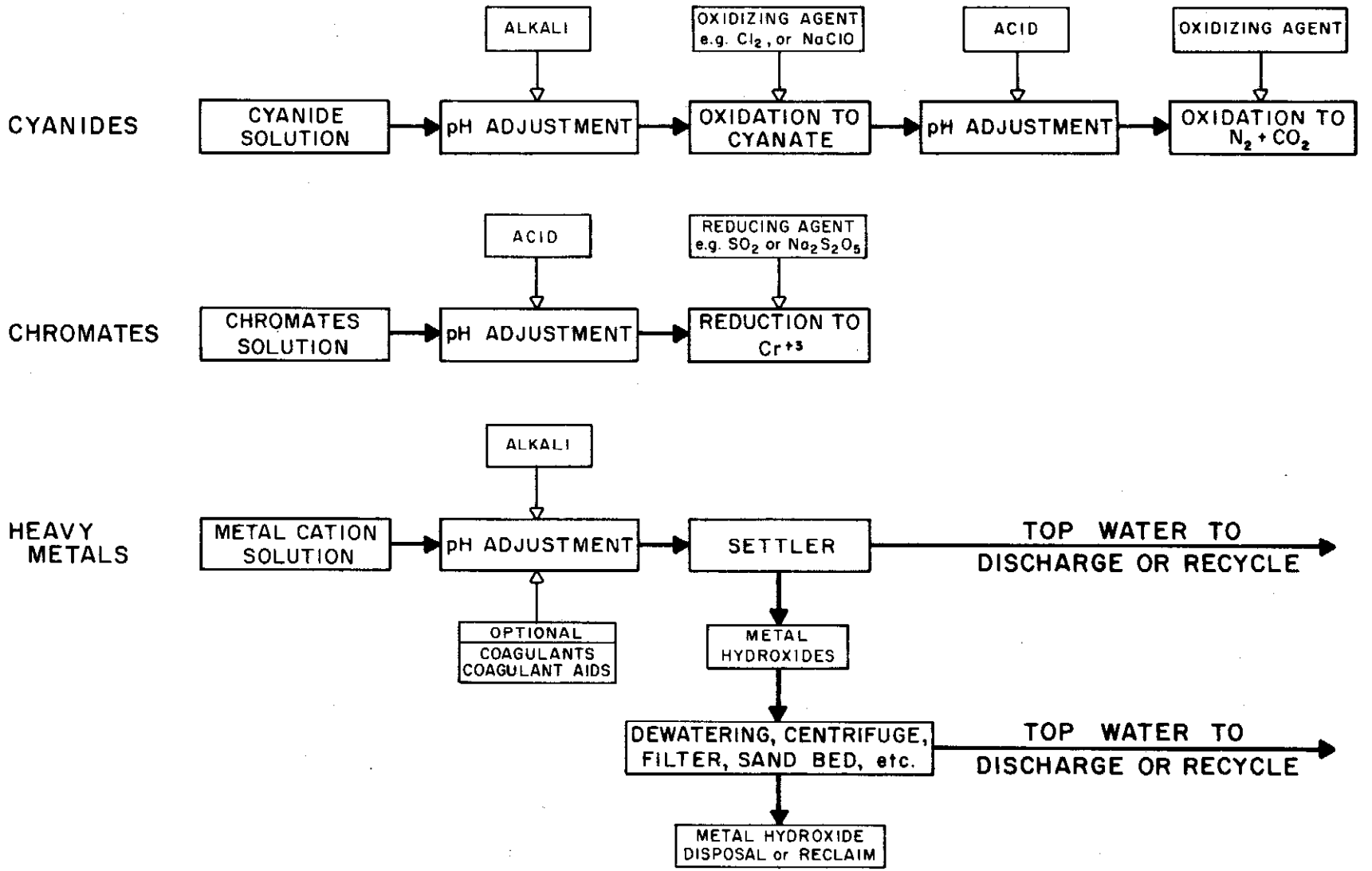


FIGURE 44 Conventional Plating Waste Treatment Schematics

The three processes shown on the schematic, with some variations in detail, have been the foundation of waste treatment for the industry. They are simple, well understood, from a practical standpoint, and the instrumentation and equipment are pretty much available off the shelf. They are not foolproof, however. Even if such elementary pitfalls as the mixing of nickel and cyanide streams before cyanide oxidation, or the presence of excessive amounts of heavy metal chelating agents, are avoided, there is still a requirement for careful operation of the hydroxide separating step. Depending on concentrations, proportions, agent of neutralization, degree of agitation, and so on, the hydroxides may or may not settle out cleanly in a clarifier of reasonable overflow rate. High rate settlers, coagulants, coagulant aids, or all of these may be required to effect a separation between the fluffy precipitates and the water, before the water is discharged.

The integrated system of treatment is an ingenious adaptation of chemical rinsing, mentioned in Section V, to treating waste. Reduced to essentials, the process consists of maintaining a relatively large volume of treating chemicals as a sink. The solution is circulated through what would otherwise be the first rinse tank. Thus, dragout from the plating is treated and rinsed off in the same operation; the work then proceeds to a water rinse which has only to remove, say, trivalent chromium, or to a non cyanide film instead of Cr^{+6} or cyanide solution, as the case may be. The principle is illustrated in the schematic in Figure 45.

The inventor of the integrated system of treatment lists its advantages and disadvantages in the EPA Technology Transfer Bulletin (7):

a. Advantages:

- Low equipment costs
- Simplified supervision and control
- Improved rinsing, reduced volume of rinsewater
- Reduced chemical costs
- Denser sludge, and segregation of metals for easier recovery
- Easier to meet effluent standards

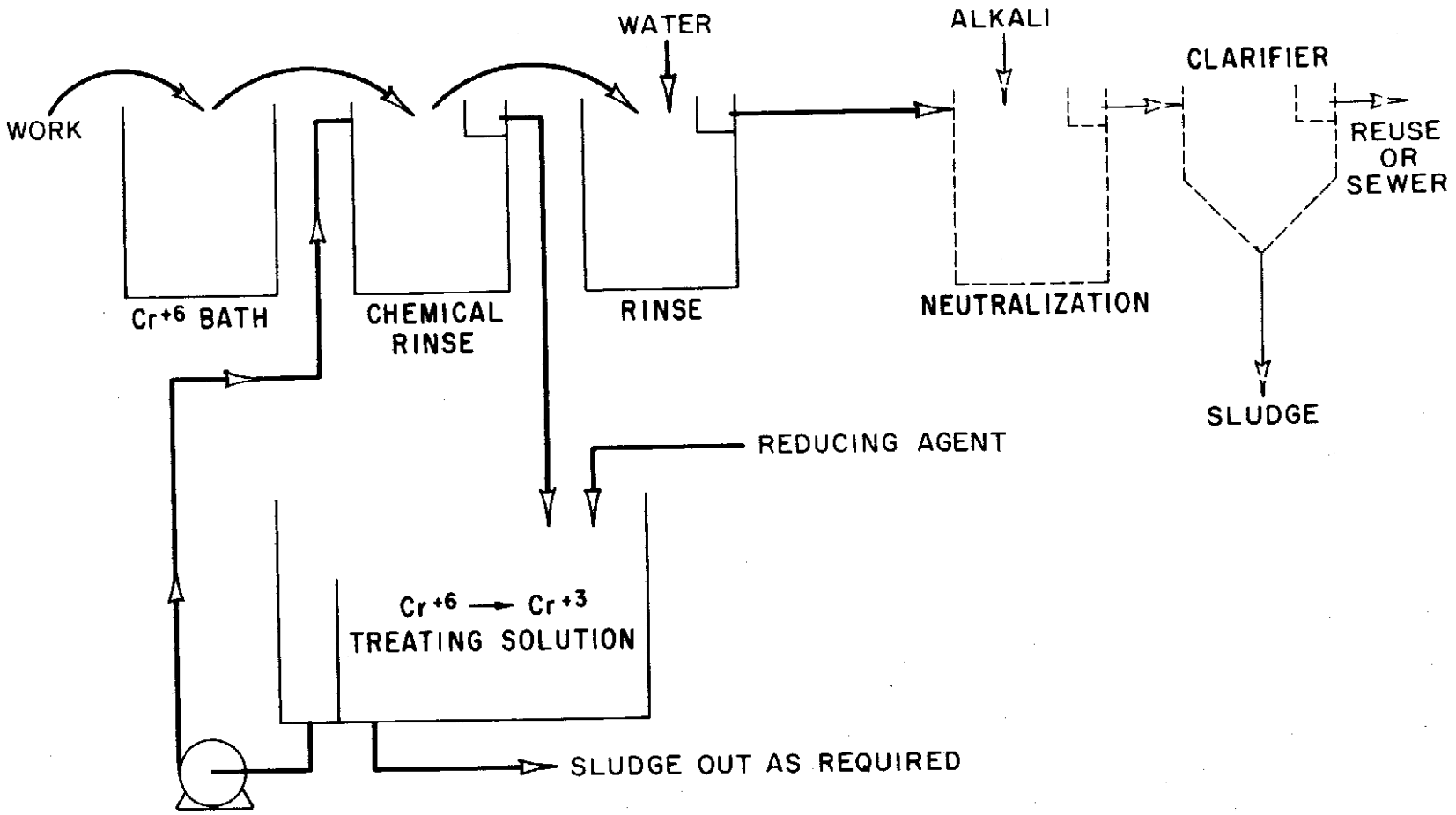


FIGURE 45 Schematic - Integrated Chromate Treatment

b. Disadvantages:

- Additional rinse tanks required
- Improper operation may affect quality of work
- Finisher must operate treatment instead of having separate treatment plant operator.

2. Control by Concentrative Processes

The principal non destructive control technologies now in use are two, evaporation and ion exchange. Reverse osmosis is just beginning to come in for commercial applications also. The three technologies have in common their concentrating of waste materials, without the chemical alterations which characterize the methods described in 1, above. They may be used simply to reduce the volume of a waste stream prior to destruction or separation in order to reduce the costs of disposal. Or, they may produce pure water and a concentrated chemical solution for recycle to the plating process. An example of the former [Industrial Wastes (12)] is the use of an ion exchange unit to concentrate a chromate rinse, producing water for recycle at the same time. The concentrate is then acidified, reduced with sodium meta bisulfite; precipitated with caustic and clarified in the conventional way. The point is that the size of equipment is much smaller than would have been necessary for treating the rinsewater directly by reduction and precipitation; and water is reclaimed.

Depending on the nature of the effluent being treated by ion exchange, some pretreatment may be necessary to prolong the life of the resin bed. If the pH of the waste is such as to form precipitates, it may be desirable to insert filters of some kind before the waste stream reaches the ion exchanger. If organic material (from cleaning operations), brighteners, or wetting agents are a significant part of the general waste, carbon adsorption may be indicated to prevent fouling. All that this conveys is the truism that every mixed plating waste is a problem unto itself; and the most economical and socially acceptable arrangement of techniques for alleviation of wastes requires study before a method is selected.

As implied above, ion exchange may also be appropriate for metal recovery or process solution regeneration (7). For example, chrome plate rinsewaters may be susceptible to purification by a cationic exchange medium which removes metallic impurities, allowing the chromate anion to be returned to the plating process.

The exchange medium is regenerated by dissolving the retained cations in acid. This solution, of course, must be treated for the removal of the metals, which are now much more concentrated than they were in the rinsewaters. It may be economical in some circumstances to reclaim the dissolved metals, depending on their identity and relative concentrations.

In shops where a sufficient number of countercurrent rinses and other precautions are used to keep rinse volumes small and fairly concentrated, it is sometimes economical to reclaim solutions from the rinses by evaporation. Both closed and open systems are operated, (i.e., total recovery or some bleed-off). The EPA draft report (13) mentions a plant in which three closed loops are operated with evaporation as the tool, one each for the copper, nickel and chromate lines.

Reverse osmosis has seen more use as a pretreatment process in water purification before final deionization, than as a waste treatment tool in the plating industry. The EPA report does cite a low flow (2 gpm) unit handling the rinses from nickel plating, with the concentrate returned to the plating bath and the permeate returned to the rinses. The installation operates as a closed system, except for a small back wash every two weeks.

Evaporation and ion exchange are standard industrial tools, and have been for a long time. Reverse osmosis is on its way to entering the same category, chiefly as the result of research and development of methods for desalinization. Its use in waste treatment up to now, however, has been limited, principally because of problems with plugging of the membranes, and with membrane service life. These difficulties have been overcome sufficiently to make the unit operation attractive for a number of waste treatment applications. There can be little doubt as to its eventual widespread utility.

Obviously, all three of the operations discussed in this section share in common the characteristic that some use or disposition of the concentrate is necessary.

3. Miscellaneous Control Processes

Carbon adsorption, although it has seen but limited use in plating waste treatment, is used routinely as a means for purifying

concentrated plating baths. These are often circulated through a combination of wound filter and carbon cartridge. It is also used to some extent in the recovery of gold from waste solutions. The Calgon Corporation offers a proprietary process in which an activated carbon tower is used in conjunction with a dissolved copper catalyst to destroy cyanides by direct oxidation with air or oxygen.

Electrolytic methods for recovery of metals are not uncommon. The metal or metals are plated out on a cathode, either continuously or in batch operation. A process has been developed (14) (and put into practice) by which the primary pickling solution in a copper wire mill is regenerated and the copper recovered by continuous electrolysis. The process is being applied successfully to both copper and brass pickling. Cyanides can be oxidized to cyanates electrolytically also, but the further oxidation of the cyanates to nitrogen and carbon dioxide is required by water pollution control authorities prior to discharge. This requirement effectively eliminates another process (proprietary-duPont) in which hydrogen peroxide is the oxidizing agent, in conjunction with formaldehyde.

Cementation - the displacement of a metal from solution by one higher in the electromotive series - is employed on a commercial scale at one brass mill (15). Iron is used to reclaim copper from waste pickling liquor. The process, generally speaking, is for recovery and recycle from reasonably concentrated solutions (by waste discharge standards) not for making an effluent pure enough to discharge.

4. Miscellaneous Dumps, Cleaning Solutions and Spills

The preceding three sections have dealt essentially with process rinses. These make up by far the largest volume of wastes to be treated, and usually, therefore, set the size of treatment facilities. Thus a plating waste treatment plant is usually designed for (relatively) high volume-low concentration work. It is important to recognize that when a concentrated cyanide stripping bath, for example, or a chromic acid-carrying plating solution has outlived its usefulness, it cannot simply be dumped into the plating room drain. In the first place, the chemical feed and instrumentation mechanisms of the treatment plant would be overwhelmed. In the second place, dumping might result in the evolution of toxic gases, or unacceptable temperature changes.

In the small plating plant, such a problem is approached by arranging to have concentrated dumps bled gradually into the treating system over an extended period of time; or, what amounts to the same thing, adding the concentrate to a suitably large tank of water before destroying it. Of course, the other alternatives are to reclaim process materials (e.g. chrome, or precious metals which are reclaimed routinely), or to send the concentrates to centralized facilities equipped to process them.

Spills, leaks and drips are usually provided for in new plating rooms by proper attention to the segregation of floor drains as required-possibly with the addition of holding sumps, depending on the particular problems involved. In existing plants, where little attention may have been paid to the problem beyond draining the floor to the nearest sewer or watercourse, considerable and frequently expensive, rearrangement may be required.

We have concerned ourselves to this point only with the more toxic wastes from metal finishing. There is another entire class of waste which must be considered in any abatement program, but which we shall only touch upon. This is the effluent from non-chemical cleaning, i.e., mechanical and detergent wastes. The abrasives and polishing materials are usually settled out in the course of treating general process wastes, and will turn up as part of the sludge. Oils, if present in large amounts, will be removed in gravity separators or skimmers. In the more likely event that oil or grease is present in small amounts, either in emulsion or in solution, it may be necessary to segregate the waste and break the emulsion, or salt out the dissolved oil. Membrane processes have been applied to the problem, though so far as we are aware, only to such relatively concentrated solutions as machining coolants and cutting oils.

Future Practices

It is apparent that the future practices in waste treatment envisioned by the EPA for this industry are all a part of current practice. EPA Proposed Rules (1) outline the technology believed to be needed to achieve the goals of Best Practicable Control Technology Currently Available (BPCTCA), Best Available Technology Economically Achieveable (BATEA), and best available demonstrated control technology, the last to apply to new sources.

The guidelines for BPCTCA are listed in Table 63. The values for new sources are exactly half of those of BPCTCA; the values for BATEA are "no discharge of process wastewater pollutants." The door is left ajar for a possible escape to new source standards for plants producing less than 120 sq. m./hr.

Comments from the public were invited by EPA and it is safe to assume that the invitation has been accepted by the industry. Whatever the eventual standards, the means for achieving them (as assessed by the draft guideline development report (13) and proposed by EPA) are those discussed previously in Section V, Wastewater Reduction, and in Current Practices of this Section.

Theoretically, achievement of the standards in the guideline is possible. Actually, there is a need for further development, particularly of such concentrating processes as reverse osmosis and activated carbon; or equipment such as that used for phase separations (settlers, centrifuges, oil skimmers and the like); and physical-chemical operation, such as coagulation or improved precipitation techniques. In other words, these standards, while they may be achieveable by the use of present technologies, will certainly not be achieved without steady and considerable improvement in present practices.

There do not appear to be any technological breakthroughs on the horizon; but it would be foolish to predict that there will be none by 1983. The research literature contains references to ion flotation, solvent extraction and adsorption on activated alumina as well as on carbon (16).

Avila et al.(17) investigated the recovery of metals from plating and etching baths by freeze drying. They found it technically feasible to recover the salts this way, but they presented no economic evaluation of the process.

Golomb (18) reported on a plant trial in which reverse osmosis was used to recover nickel salts and deionized water. He predicts an important role for reverse osmosis in plating plants, particularly if the operable pH range can be extended. His analysis of the nickel recovery process predicts capital payout in 2-1/2 to 19-1/2 months, depending on the size of the plating operation. (Golomb considered three sizes.)

TABLE 63

EFFLUENT LIMITATIONS BASED ON BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

Effluent characteristic	Effluent limitation	
	Maximum for any one day	
	mg. /sq. m.	lb. /10^6 sq. ft.
Copper (Cu)	80	16.4
Nickel (Ni)	80	16.4
Chromium, hexavalent (Cr+6)	8	1.6
Chromium, total (CrT)	80	16.4
Zinc (Zn)	80	16.4
Cyanide, oxidizable (CN)	8	1.6
Cyanide, total (CN)	80	16.4
Suspended solids (SS)	2,400	492
pH	Within the range of 6.0 to 9.5	

	Effluent limitation	
	Maximum average of daily values for any period of 30 consecutive days	
	mg. /sq. m.	lb. /10^6 sq. ft.
Copper (Cu)	40	8.2
Nickel (Ni)	40	8.2
Chromium, hexavalent (Cr+6)	4	0.8
Chromium, total (CrT)	40	8.2
Zinc, (Zn)	40	8.2
Cyanide, oxidiable (CN)	4	0.8
Cyanide, total (CN)	40	8.2
Suspended Solids (SS)	1,200	246
pH	Within the range of 6.0 to 9.5	

A possible chromate treating method was reported by Onstott (19) who devised it for treatment of cooling tower blowdown. Continuous electrochemical generation of ferrous hydroxide in a flow cell resulted in the simultaneous quantitative reduction of hexavalent chromium and its precipitation, without pH adjustment. A large fraction of the phosphate and other anions were precipitated as well.

Sludges

Except for the cyanide ion, oil and grease, any possible detergents, and small amounts of other organics, the plating industries' wastes nearly all wind up as sludge after any treatment which does not recycle the material. The sludges are capable of being redissolved under proper conditions, and consequently require further attention to insure their harmlessness. EPA's Proposed Rules (1) beyond advocating metal recovery, are somewhat restrained in the number of suggestions for coping with this aspect of plating waste treatment, for all levels:

"Solid constituents from the waste water should be disposed of in an acceptable landfill, which means a landfill at which complete long term protection is provided for the quality of surface and subsurface waters, from hazardous substances contained in electroplating wastes deposited therein, and against hazard to public health and the environment. Such sites should be located and engineered to avoid direct hydraulic continuity with surface and subsurface waters, and any leachate or subsurface flow into the disposal area should be contained within the site unless treatment is provided. Where appropriate, the location of the solid hazardous materials disposal site should be permanently recorded in the application office of legal jurisdiction."

It seems plain that the ultimate solution to the problems, if by that we mean no discharge of pollutants, whether solid or liquid, can only lie in complete recycle. While this is not now practical from an economic point of view, the technology for achieving the goal is much more available in the plating industry than it is in any of the other industries in this series of reports, with the possible exception of paper. All of the metals used in the industry were won from ores originally, and all were originally in much less concentrated form than they are in sludge. Granted that economics dictate very large scale operations for recovering metals from their oxides, it seems possible that environmental pressures could eventually force recovery of all the metals, if not at individual plants, then at central facilities.

VII SUMMARY AND COSTS

The fact that the techniques exist for reducing the most objectionable plating wastes to very low concentrations indeed is encouraging. The present state of their application, their cost, and the skill and attention required to keep them operating at their best are enough to prevent any euphoria on the part of those acquainted with the industry.

As with the other industries considered in this series, cost data of a sort are available, but any on which to base generalizations are exceedingly scarce. Part of the difficulty is illustrated if one compares the capital cost for treating the water of say a manufacturer or radar components and that of a plating job shop operator. One plates a few dozen or a few hundred minute parts a day; the other, let us say, a few hundred square feet per hour. They may think they require comparable volumes of water, and hence comparable waste treatment facilities. Generalizations on the basis of cost per square foot plated, or percentage of sales, or of value added are meaningless. Of course, the electronic supplier should recycle water, purifying it and concentrating the wastes, but again, our cost comparison will be worthless because we will be using an entirely different method (e.g., evaporation or ion exchange instead of precipitation and settling) for much of this treatment.

It is in this context that the cost data presented by EPA (1) should be viewed.

"It is estimated that the total annual cost of chemical treatment would amount to approximately 15 percent of sales for medium to large facilities (24 square meters plated per hour or more) and approximately 37 percent of sales for very small facilities (24 square meters plated per hour or less). These estimates represent maximum increases and assume that no controls are currently in place. The incremental cost to eliminate the discharge of pollutants by combining chemical treatment with other control and treatment technologies is estimated to be approximately 8 percent of sales for facilities plating more than 54 square meters per hour and from 6 percent to 15 percent for facilities plating less than 24 square meters per hour. The cost of lagooning or landfilling sludges after chemical or other treatment has not been considered in arriving at the above cost estimates. . . . Firm data on the relative costs of landfilling on recovery of metals is not yet available. However,

current expenditures by industrial waste generators for treatment and disposal of hazardous waste sludges are believed to be low relative to the cost required for adequate treatment and disposal."

EPA admits that ". . . some electroplaters may experience financial difficulty in attaining effluent limitations based on the best practicable control technology currently available because of individual peculiarities such as size, geographical location or age of the facility. Where these peculiarities become critical, the choices for the plater may become relocation, judicious space utilization, cooperative waste treatment, or specialization." (1)

These reflections on and emphasis on costs of treating are probably less relevant in the long term than is the development of an attitude of total conservation of the resource, water. As long as water must leave the plant, other than by evaporation, there will be either a pollutional problem or a cost problem, or both. Once the true value of this water is recognized, a plant will have at least started toward the goal of best control technology economically achievable, along the route most likely to yield achievable results.

In closing, it should be mentioned at least that the product of a given plating shop may not always be what it is today. It may require a change in marketing or in the public's idea of what constitutes a desirable product, but who is to say that something which is particularly bright only because of a particularly polluting process must be made? Perhaps a downgrading in appearance will someday be traded off for an environmental improvement.

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LEATHER TANNING AND FINISHING

I. INTRODUCTION

This section relies upon a previous report, Thorstensen's "The Nature and Treatment of Tannery Effluent" (1) for a description of the tanning processes, which will be presented in a condensed version below for reference. The discussion of waste treatment practices will also draw on this source, but results primarily from a review of recent literature (up to September 1973), from the EPA guidelines development report (2), and from direct experience in the industry.

The types of manufacture which concern us here are three: side upper leather, sheepskin, and split processing. The flow sheet for side upper leather (Figure 46) (1) shows closely enough the principal sources of waste from all three types, the last two differing qualitatively only in starting material and number of steps required. It should be understood that this diagram is necessarily generalized, and that there is a wide variety of individual operations and materials within a tannery, not merely within the industry.

In order to take advantage of the data on wastewater assembled in the EPA report, it is useful to adopt their industry categories. Their numbers 2, 4 and 5 cover the industry in the Merrimack River Basin:

Category	Beamhouse	Tanning	Finishing
2	Save Hair	Chrome	Yes
4	Hair Previously Removed	Previously Tanned	Yes
5	Hair Previously Removed	Chrome	Yes

These describe processes begun at various stages in the flow sheet, (Figure 46) rather than specific products or raw materials. Thus Category 2 encompasses the entire side upper leather flow sheet, Category 4 from flow sheet Step 5 on, and Category 5 includes Steps 3 or 4 *et seq.*

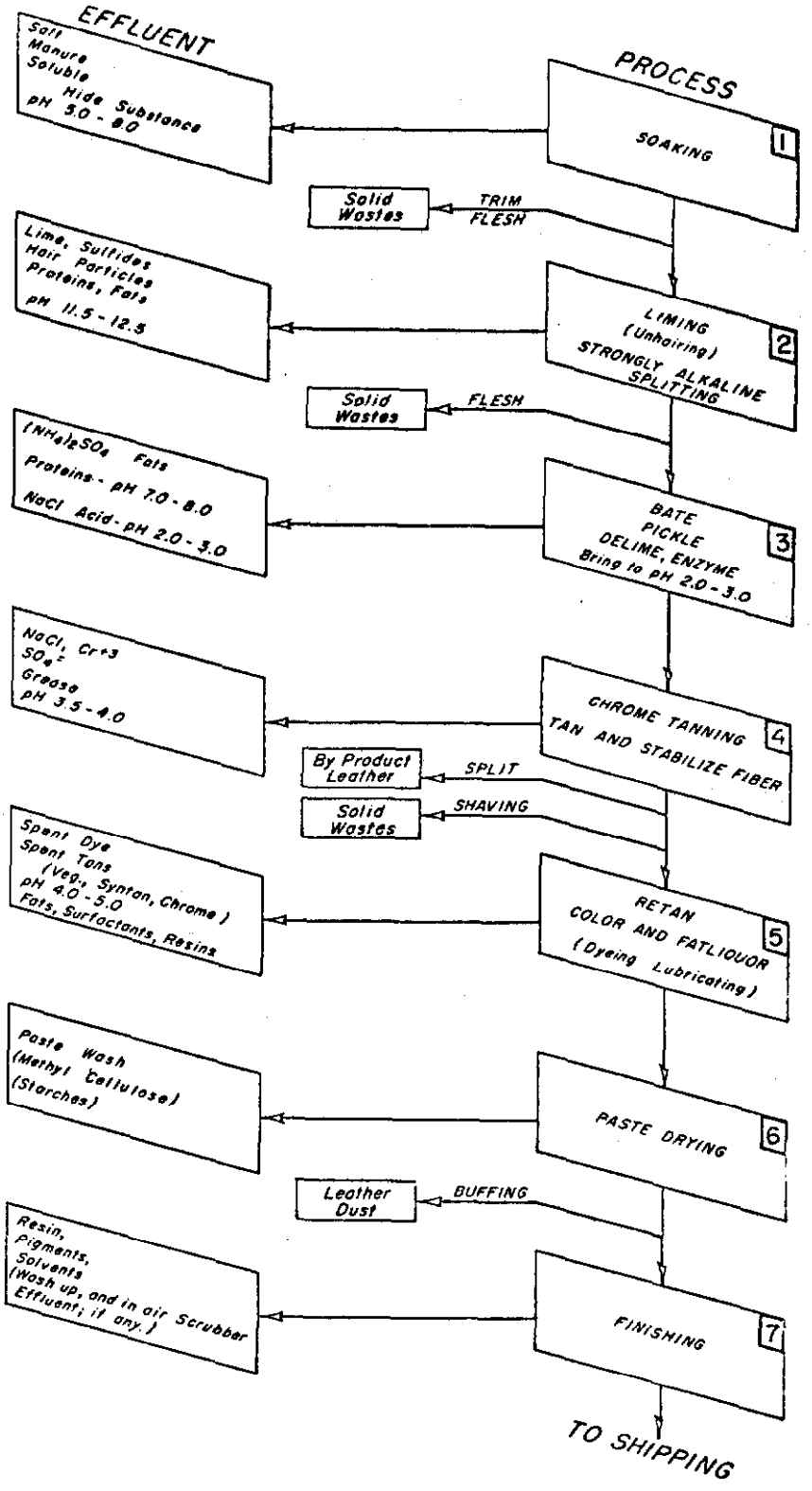

FIGURE 46 Flow Sheet Side Upper Leather

The process described here is that for side upper leather; the reader is referred to the two previously referenced texts for a detailed explanation of split and sheepskin leather.

II. LEATHER TANNING

Process Description

The production of tanned leather can be described in the following steps:

1. Storing, Soaking and Fleshing.

Hides received at the tannery have been salt-cured at the packing company for preservation in shipping, and as such contain about 40% moisture and 15% salt. Therefore, they must be soaked and washed to remove the curing salt and other materials on the hides, such as dirt, blood, manure, and soluble proteins. The soaked hides are then trimmed and fleshed to discard any adhering skin, fibers or excess matter. (Fleshing may precede or follow the soaking process; its purpose, in addition to discard waste, is to facilitate the penetration of the chemicals to be used in later processes.)

2. Liming (Unhairing) and Lime Splitting.

Hides are unhaired by one of two methods, depending on whether or not the hair is to be saved and sold for re-use. Hair may be loosened and pulled mechanically, in which case it is recovered; or it may be destroyed chemically by soaking in a solution of lime and reducing agents, such as sodium sulfhydrate and dimethylamine sulfate. The liming process loosens and breaks down the hair, while also changing the protein structure of the hide for preparation for tanning later on.

The hide that has been unhaired is mechanically slit through the middle of its thickness, producing a side "grain" layer and a flesh "split" layer. The side upper tannery seldom finishes the split, however, primarily because the product uses of split differ significantly from those of side upper leather, and as such would require different finishing treatment.

3. Bating, Pickling, and Degreasing.

Bating serves the function of treating the swollen and highly alkaline hides with a deliming material, such as ammonium sulfate, acids, and enzymes, to break down any remaining unwanted proteins, to clean the skin surface, and to soften the leather. The pH and swelling are subsequently reduced.

Pickling then is performed to render the hides acidic enough to resist precipitation of chromium salts on the skin fibers during tanning, and sometimes to preserve the hides during storage prior to tanning. The hides are washed with a solution to which brine and sulfuric acid have been added.

Degreasing, when done, eliminates any undesirable fatty substances and greasy areas on the hides, to allow for an even tanning process.

4. Tanning.

This is the actual process of converting the hide fibers into leather. Most commonly, tanning is accomplished by vegetable or chrome tans, although chrome tanning is far more prevalent a method in the United States.

Chromium salts, sodium chloride, some acid, and masking materials help change the hide into leather; at the same time, protein materials become stabilized against bacterial degeneration. The tanned leather is then leveled in thickness by a belt knife, and shaved for the desired size.

5. Retanning, Coloring, and Fatliquoring.

The once-tanned hides are treated to vegetable tanning materials extracted from plants, in the retanning phase of finishing. Acid dyes add color, and oils in an emulsion lubricate, or fatliquor, the leather. Fatliquoring prevents cracking, and renders the leather pliable, strong, and resistant to tearing. The oils used in fatliquoring are usually sulfated or sulfonated.

6. Paste Drying.

The leather is dried after fatliquoring by a process known as paste drying. A paste of methyl cellulose or starch is applied to the leather for adherence to glass sheets, which are moved through a tunnel dryer. When dry, the leather is buffed or sandpapered lightly to remove any surface blemishes which may have been created.

7. Finishing.

Finishes - acrylic, lacquer, resin or solvent emulsions - are applied to the tanned and dried leather. The final steps in the production at the tannery are measuring, grading, and shipping the leather.

Process Chemicals

From the beginning to the end of the leather tanning operation, significant pollutants are discharged from the tanneries because of the chemicals used in the process. Constituents of the waste stream include free lime and sulfide, and potentially toxic chromium. The wastewater is also hard; high in pH, BOD, mineralization, and suspended solids (especially hair, grease, and proteinaceous fibers); and colored - milky from liming, green-brown to blue from tanning, and varied from dyeing.

Each process has a specific pollutant to contribute to the tannery's general outflow. Soaking the hides, for example, is one of the major sources of the industry's pollution, since so much salt, dirt and undesirable hide substances are removed.

The washing and liming effluent from the unhairing process contains, as expected, hair particles, and lime, sulfides, protein degradation products, fatty soaps, and a pH of 12. Furthermore, fleshings that are not rendered for grease or converted for glue become solid waste, and must either be dumped at a landfill, or be sent to the waste stream as a partially digested protein.

Pickling produces wastes from degradation products in the hides, fats, much salt, and low pH (2-3), while tanning effluent includes sodium chloride and chromium salts.

The final processes leave residues of spent dyes and tanning materials, a small amount of oil, starch or methyl cellulose (from washing the glass sheets of the paste drying process), and leather buffing dust.

The following table (Table64) breaks down more specifically the process chemicals and their effluent discharges.

Product Description

The finished leather from the side upper process is durable, and is used primarily in the manufacture of shoes. Splits are used for some suedes and for products requiring a less durable leather; sheepskin is used for most suedes.

III. WATER REQUIREMENTS

The quality of the water for the leather making industry is dependent on the specific process for which the water is used. Tanning, for example, is a step making few stringent demands on water quality, while finishing and coloring require water of extremely good quality. In general, it can be said that the water utilized should not contain high amounts of elements which will be detrimental to the hides, or which will hinder or otherwise affect the tanning process. Excessive manganese, iron, turbidity, and color, for example, would stain the hides, and therefore inhibit the uniform processing of the leather. A high bicarbonate content could be detrimental, since the formation of calcium carbonate near the surface could inhibit dyeing. Bicarbonate may also cause swelling, and inhibit the processes of leaching tanning extracts, and fatliquoring.

Table 65 depicts the industry's water requirements. (3)

IV. WASTEWATER

The sources of leather tanning and finishing waste streams have been indicated on the flow diagram (Figure 1) in Section I. Presented here are the constituents which appear in the untreated tannery wastes.

TABLE 64

PROCESS CHEMICALS AND THEIR WASTES

Process	Chemicals Utilized	Effluent Characteristics
1. Soaking	Hides (40% moisture 15% Salt NaCl))	Salt, manure, dirt, soluble hide substances pH 5-8
Fleshing	--	Solid waste (flesh)
2. Unhairing	Lime sulfides Wash Water	Lime sulfides, hair particles, proteins, Fats pH 11.5-12.5
3. Bating, Pickling,	$(NH_4)_2 SO_4$ Enzyme acid Sodium Chloride H_2SO_4	Ammonium sulfate, Fats pH 7-8 NaCl, Acid pH 2-3
4. Tanning	$CrOH SO_4$ NaCl Sodium Formate $NaHCO_3$	NaCl, Cr^{+3} SO_4= grease pH 3.5-4.0
5. Retaining, coloring, fat-liquoring	Vegetable tannin AZO Dyes (acid) Oil Emulsions	Spent dyes and tannin pH 4-5
6. Paste Drying	Methyl Cellulose Starch	Paste wash
Buffing	--	Leather dust
7. Finishing	Leather emulsions Lacquer emulsions Pigments Solvents Wax	Resins Pigments Solvents

TABLE 65

WATER QUALITY REQUIREMENTS

LEATHER INDUSTRY

Material	Process		
	Tanning	Finishing (in mg/l)	Coloring
Fe	60	0.3	0.1
Mn		0.2	0.01
Ca	60	Lime Soft	0
Cl	250	250	
SO_4	250	250	
Hardness	150	Lime Soft	0
Alk.	*	*	*
Color	5	5	5
Coliform	U.S. Drinking Water Standards		
pH	6-8	6-8	6-8

* Accepted as received

Thorstensen's report has provided quantitative information on the contribution of the tannery processes to waste loadings and volume. The information has been summarized as percentages in Table 66, and reproduced from Thorstensen as Table 67.

It is important to recognize that these data are somewhat limiting; although they provide a useful guide, they cannot be relied on for predicting the effluent from any given tannery. The problem is evident from the more recent data, presented in the EPA draft report, and given here as Table 68.

Although it is reasonable to expect considerable variation from tannery to tannery, ranges of ten- and twenty-fold (even 200 in one case) cast some doubt on the validity of the data. The EPA report attributes this in part to differences in processes and to analytical inaccuracies, but mainly to "the variations in waste quality associated with the multiplicity of waste discharge patterns which can exist and the sampling methods ... This waste variance, along with the shortcomings of the normal time-spaced proportional flow waste increment method of composite sample preparation, are the principal contributors to variance." (2) In other words, sampling a multiplicity of different batch processes is inherently difficult and, as frequently carried out, is unreliable. These limitations notwithstanding, the data provide the least unsatisfactory generalizations available for the industry.

A further characteristic of tanning and finishing wastes is their variation with time, not only because of the customary batch mode of operation, but because the industry traditionally carries out the same operations during the same time of day, every day. This is probably universally true of small facilities, and to a considerable extent of all. Thus a series of washes may be started at the beginning of the day. Next, all of the retanning may be completed, then all of the dyeing and fatliquoring. With some overlap, there are three distinct types of waste, segregated by time. This obviously is a help if wastes are to be segregated before treatment, but a considerable handicap to equalization within periods shorter than an operating day (usually one or two shifts).

TABLE 66

APPROXIMATE PERCENTAGES OF WASTES BY PROCESS

Process	Effluent Volume	Total	Suspended	Volatile	BOD_5	Salt	Sulfide	Ammonia Nitrogen
Soak	20	24	26	13	15	45	--	--
Unhair	31	25	26	21	39	15	100	--
Bate & Pickle	7	4	12	9	12	--	--	100
Pickle Liquor	--	8	5	3	3	17	--	--
Chrome Tanning	2	21	18	11	4	23	--	--
Color & Fat Liquor	28	17	8	40	11	--	--	--
Paste	--	negl.	negl.	negl.	1	--	--	--
Finish	12	1	5	3	15	--	--	--

TABLE 67

COMPOSITION OF CONCENTRATES AND WASHES

CATTLEHIDE UPPER LEATHER PRODUCTION

Process: Soaking

	mg/l	lbs/1,000 lbs hides
Alkalinity (CO_3)	500 - 650	4.5
Total Solids	25,000 - 33,000	204
Suspended Solids	4,000 - 10,000	40
Volatile Solids	3,000 - 9,000	30
BOD	2,300 - 2,600	15
pH, units	6.5	--
NaCl	19,000 - 23,000	136
Volume Solution	Concentrated	800 gal /1,000 lbs
	Wash	2,000 gal/1,000 lbs

The soak water concentrate contains mostly salt (NaCl) from the salt curing. The organic matter includes soluble proteins and manure. Since this is a washing operation, the total water used may be 2 or 3 times the concentrated solution volume. The effluent is dark brown, very dirty, but has little odor.

TABLE 67(cont.)

Process: Unhairing

	mg/l	lbs/1,000 lbs hides
Alkalinity (CO_3)	13,000 - 26,000	54
Total Solids	70,000 - 85,000	210
Suspended Solids	13,000 - 18,000	40
Volatile Solids	12,000 - 25,000	48
BOD	10,000 - 20,000	40
pH, units	11.0 - 12.0	--
NaCl	15,000 - 22,000	45
$S^{=}$	3,000 - 4,000	10
Volume Solution	Concentrated	300-400 gal/1,000 lbs
	Wash	3,000-5,000 gal/1,000 lbs

The concentrated unhairing wastes are the largest problem of the side leather tanning effluent. The BOD represents approximately 50% of the total BOD produced. The large volume of wash water used is to remove the sulfides and surface dirt. The sodium chloride is from the carry over from the soaking. The effluent is blue-white, very dirty, and has a bad odor.

TABLE 67(cont.)

Process: Bate and Pickle

	mg/l	lbs/1,000 lbs hide
Alkalinity (CO_3)	2,500 - 3,000	7
Total Solids	11,000 - 17,000	37
Suspended Solids	5,000 - 8,000	21
Volatile Solids	6,000 - 10,000	21
BOD	4,000 - 9,000	13
pH, units	7.5 - 9.0	--
Ammonium Nitrogen	2,000 - 2,500	10
Volume Solution	Concentrated	300-400 gal/1,000 lbs
	Wash	500-600 gal/1,000 lbs

Bate wastes are high in ammonia nitrogen from the ammonium chloride in the process. The effluent is slightly milky, and may have an odor of ammonia or sulfide.

TABLE 67(cont.)

Process: Pickle Liquors

	mg/l	lbs/1,000 lbs hide
Acidity	2,000 - 3,000	3
Total Solids	65,000 - 80,000	70
Suspended Solids	5,000 - 8,000	7
Volatile Solids	6,000 - 8,500	7
BOD	2,500 - 3,000	3
pH, units	2.5 - 3.0	--
NaCl	45,000 - 50,000	50
Volume Solution	Concentrated	130 gal/1,000 lbs
	Wash	0

There is no wash from a pickle solution. The pickle may be one step in a bate-pickle and tan operation. Some tanneries start with pickled hides and skins. Others may dump part of the pickle solution to adjust liquid levels. The effluent may be slightly milky but clear in color. The odor is mild.

TABLE 67(cont.)

Process: Chrome Tanning

	mg/l	lbs/1,000 lbs hide
Acidity	3,500 - 5,000	8
Total Solids	85,000 - 100,000	180
Suspended Solids	12,000 - 18,000	28
Volatile Solids	10,000 - 14,000	24
BOD	1,800 - 2,400	4
pH, units	3.5 - 4.0	--
NaCl	30,000 - 40,000	70
Cr^{+3}	6,000 - 8,000	15
Volume Solution		200-300 gal/1,000 lbs

The chromium salts used in the tanning may be fixed to the extent of 50 to 75%. In the latest equipment, more concentrated solutions are used and efficiencies of up to 90% fixation may be obtained.

The data on sheepskin tannage are essentially the same. The effluent is dark blue-green in color, contains suspended fats, and has a distinctive odor.

TABLE 67(cont.)

Process: Spent Color and Fatliquor

	mg/l	lbs/1,000 lbs of hide
Alkalinity (CO_3)	0	0
Total Solids	9,450	150
Suspended Solids	745	12
Volatile Solids	5,500	90
BOD	500 - 1,000	12
pH, units	3.6	--
Volume Solution	Concentrated	2,000 gal/1,000 lbs
	Wash	2,000 gal/1,000 lbs

Color and fatliquor formulae vary greatly from tannery to tannery. The above data are estimated averages from a variety of processes. The effluent is usually cloudy and colored. The odor is not offensive.

TABLE 67 (Cont.)

Process: Pasting

	mg/l	lbs/1,000 lbs hide
Alkalinity (CO_3)	41.8	--
Total Solids	428	0.5
Dissolved Solids	228	0.2
Volatile Solids	390	0.4
BOD	1,000	1
pH, units	8.8	--
Volume Solution		120 gal/1,000 lbs

The effluent from the pasting unit is small relative to the rest of the tannery. The effluent is milky but odorless.

TABLE 67(cont.)

Process: Finishing Room

	mg/l	lbs/1,000 lbs hide
Alkalinity (CO_3)	49.2	--
Total Solids	768	10
Suspended Solids	284	4
Volatile Solids	520	7
BOD	1,000	15
pH, units	6.8	--
Grease	92.7	1.3
Volume Solution		1,700 gal/1,000 lbs

The finishing room data given above are from a single tannery. There will be large variations from tannery to tannery depending upon the finishing processes used. In most tannery effluent studies, the finishing room effluent is ignored as being too small to consider. The effluent is highly colored, cloudy, but without objectionable odor.

TABLE 68

RAW WASTEWATER CHARACTERISTICS BY CATEGORY*

Raw Wastewater Characteristics (lb/1,000 lb of Hide)**

	Category No. 2				Category No. 4				Category No. 5			
Characteristics	No. of Data Points	Range	Average	Strength mg/l	No. of Data Points	Range	Average	Strength mg/l	No. of Data Points	Range	Average	Strength mg/l
Flow: (gal/lb)	14	(0.1-22.6)	(7.6)		10	(0.3-3.9)	(2.4)		20	(0.7-24.4)	(7.6)	
BOD_5	9	22-140	69	1100	3	6.7-67	37	1900	8	10-140	67	1000
COD	7	88-215	140	2200	3	5.7-68	28	1400	5	11-265	170	2700
Total Solids	7	140-900	480	7600	2	47-285	140	7000	7	52-980	490	7700
Suspended Solids	9	30-350	145	2300	3	7.0-125	47	2400	8	3.1-865	88	1400
Total Chromium	7	0.3-12	4.9	78	3	0.4-4.8	2.6	130	7	0.1-2.1	1.2	19
Sulfides	4	0.1-2.8	0.8	13	1	2.1	2.1	110	1	4.5	4.5	71
Grease	5	0.7-105	43	680	3	2.2-19	7.9	390	7	0.6-46	24	380
Total Alkalinity (as $CaCO_3$)	1	62-85	72	1100	1	39	39	2000	3	6.6-180	69	1100
Total Nitrogen (as N)	6	3.6-22	13	210	2	0.8-6.5	3.7	190	5	0.6-29	6.0	90
pH	8	4.0-12.4	--		3	3.4-11.2	--		9	1.5-12.5	--	

*Refer to Section I, p. for a description of the categories.
**Except pH; flow in gal/lb; strength based on average, in mg/l.

V. WASTEWATER REDUCTION

Process Changes

1. Operating Procedure.

Practice in reducing wastewater in the tanning industry at the start of conservation efforts usually follows methods conventional in other industries, such as plating and textiles.

Specifically, conservation efforts include the following:

a. Educate employees in the need for conservation, with the hoped-for consequence of eliminating water losses, such as those caused by hoses which are allowed to run continuously.

b. Introduce or improve control of flow, temperature and volume parameters. The use of flow meters, timers and the like, let alone sophisticated automatic control, is by no means universal. (Up to quite recently there has been a surprising number of tanneries in which the only methods of controlling these parameters were subjective ones - an operator's touch to determine heat, e.g. - with the result that control fluctuates widely.)

c. Substitute batch for running rinses where possible. Van Vlimmeren (4) points out that 80-90 percent of the effluent volume comes from rinsing, and that therefore this is where reductions must be achieved. He reports work in which he and his co-workers followed rinsing procedure by measuring conductivity. They were able to set up a batch procedure for soaking wet, salted pre-fleshed hides, which used only one-fifth the amount of water used formerly, while removing the same degree of salt in less time. They report similar results at all stages of manufacture where hides or leather had to be washed.

It should be noted that achievement of such a degree of change represents quite advanced practice, and no implication that the industry is generally this advanced is intended.

d. Develop procedures for shorter floats and more concentrated solutions than those which are now standard.

2. Raw Materials.

The raw material of the tanner is, of course, fixed. However, tanners in the area, principally because of environmental pressures, have been closing their beamhouses. This single, though admittedly drastic, change can reduce the BOD_5, suspended solids and salt discharges, as well as the effluent volume, by 60-70 percent (cf. Table 3, Approximate Percentage of Wastes by Process, up to chrome tanning). In addition, sulfides and ammonia will be virtually eliminated. The tannery with a closed beamhouse probably will buy its raw material in the pickle stage (or contract to have the hides pickled by a processor elsewhere). Alternatively, the tanner may elect to purchase hides already chrome tanned (in the blue) and perform only the retanning, finishing and marketing functions.

Economics often favor an abridged operation of this sort for several reasons:

(a) the salt curing step may be eliminated;
(b) freight costs for shipping hides in the pickle are lower than those for green-salted hides;
(c) the specialized pickling plant can effect economies of scale and process efficiencies that a small tanner could never achieve in his beamhouse; and
(d) the specialist can be located at a site where economical waste treatment processes may be used (a contrast to the urban locations of most of the tanners in the Merrimack Basin).

One modern plant, having a capacity of 2 million hides a year, (total tanning capacity of the United States is about 35 million) claims to have reduced its water use to 1000-1500 gal/1000 lb. hide, and is using "best available" pollution control technology in its waste treatment plant. (5)

3. Equipment.

The one major equipment change in recent years having a bearing on wastewater reduction has been the introduction (and gradual spread) of the hide processor, or cement mixer. Although conversion from paddle vats to hide processors represents a considerable investment, there is growing evidence for its economic justification. Larsen (6) describes the experimentation which led to the adoption of hide processors for the entire beamhouse of a major tannery. What is pertinent to his discussion is that water consumption in the beamhouse was reduced by 85 percent. It is interesting, also, that among several benefits achieved, the tannery increased production from 18,000 sides on a 6-day week to 19,000 sides on a 5-day week. The remarkable water consumption of the plant mentioned in item 2, above, would not be possible without the use of hide processors.

Recycling

Recycling of waste solution has not been widely practiced by tanners. The literature refers mostly to partial re-use of solution in vegetable tanning establishments, with which we are not concerned here; there are in addition numerous suggestions as to what might be done, together with reports of some experimental work.(1) (2) (7) (8) For example, lime unhairing washes could be used in place of fresh water for soaking and unhairing solutions. Spent chrome liquor, after settling, can be fortified and re-used for considerable periods of time without ill effect. Spent chrome can also be used in pickling to give a slack preliminary tannage or as float in chrome tanning. The solution may be limed or treated with caustic to precipitate the chrome, settled, and the top water re-used. The chromic hydroxide in the sludge may be taken up with sulfuric acid to reform basic chrome sulfate for tanning.

Considerable development in mitigating the effects of accumulated impurities, as well as the exertion of economic pressures (generated by the costs of makeup water and effluent disposal), will be required before much recycling is accepted widely.

VI. WASTEWATER TREATMENT

An inspection of Table 5 in Section IV shows at once that tannery wastes contain incompatible pollutants, according to the EPA's definition.* The chromium, sulfides, and grease must be reduced before admission to a publicly owned treatment plant. In addition, despite the uncertainties inherent in the data, it seems plain that if an average tannery is to avoid insupportably high surcharges, it must pre-treat to reduce the BOD_5 and suspended solids drastically. The alternatives appear to be (a) to provide for removal of incompatible pollutants and enough BOD, SS, pH and coliform reduction to allow discharge to a stream or land disposal; (b) to employ total recycle of fluids, and therefore complete elimination of discharges; or (c) to cease operation.

The following sections on waste treatment are of necessity somewhat general, like those on wastewater characteristics above. Without a detailed study of each of the plants in the area, it is difficult to determine the relevance of a discussion of waste treatment to the few small tanneries which remain. In any case, their numbers are diminishing rapidly, as evidenced by the author's direct knowledge of three in the Basin which, within the past year, or so have either closed completely, or ceased all wet processing.**

Current Practices

In the words of the EPA draft report, "[c]ompared with other industries, waste treatment facilities for those plants in the leather tanning and finishing industry discharging directly to rivers or streams are severely lacking. There are no exemplary waste treatment plants handling only tannery waste." (2) One tannery has been reported (10), however, which may require some modification of this statement. It will be discussed later under Future Practices.

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*Proposed rules. Fed. Reg. 7/19/73, p. 19237, para. 128.121: (9)
"Compatible pollutant.
"For purposes of establishing Federal requirements for pretreatment pursuant to 128.133, the term 'compatible pollutant' means biochemical oxygen demand, suspended solids, pH and fecal coliform bacteria."
Para. 128.122. "The term 'incompatible pollutant' means any pollutant which is not a compatible pollutant as defined in 128.121."

**L.H. Hamel Leather Co., Merrimack Leather Co., Louis Verza Tanning Co.

At present waste treatment generally varies from the traditional none, through screening, primary settling, either in a pond or open tank, to pH adjustment in combination with the above. Some segregation of waste streams may be practiced, particularly if a city ordinance requires the removal of chrome before accepting the waste into the sewer. Where wastes are segregated, the chrome stream, after pH adjustment, is normally settled, and the topwater decanted and sent to the sewer. The chromic hydroxide is dewatered on sludge beds before disposal as landfill. Such a scheme, typical of the sheepskin tanneries in the region, is represented schematically in Figure 47. Typical also is the fact that beamhouses have been abandoned, in favor of receiving skins in the pickle. This is in response partly to environmental pressures and partly to other economic conditions.

Figure47 would apply equally to a side upper leather tannery, except that continuous precipitation and settling would be used for large flows, instead of the alternating tanks.

The minimum treatment of wastes from a tannery which still operates its beamhouse has usually consisted of screening the beamhouse and tan waste streams, and combining them with wastes from fatliquoring, dyeing, and finishing. The combined waste is then sent to lagoons from which the topwater is discharged to a river. Solids are periodically taken from the lagoons (usually operated in pairs, to allow drawdown and settled sludge removal without loss of production) and disposed in landfill.

That this rudimentary approach is no longer adequate is obvious from an inspection of Table 69. The column showing effluent concentrations after primary settling indicates the degree of treatment that may be expected from the screening and lagooning. BOD_5, suspended solids, and chromium concentrations are reduced substantially, but the discharge to a stream of wastes of this nature is not allowed. Neither could it be sent to a municipal sewer without further reduction of chrome and sulfides, and partial neutralization, at least to a pH of 9-9.5.

Future Practices

This discussion will revolve principally around the two levels proposed by EPA for 1977 and 1983 -- "Best Practicable Control Technology Currently Available" and "Best Available Technology Economically Achievable," respectively -- and will touch also on a third level, zero discharge. The EPA guidelines require

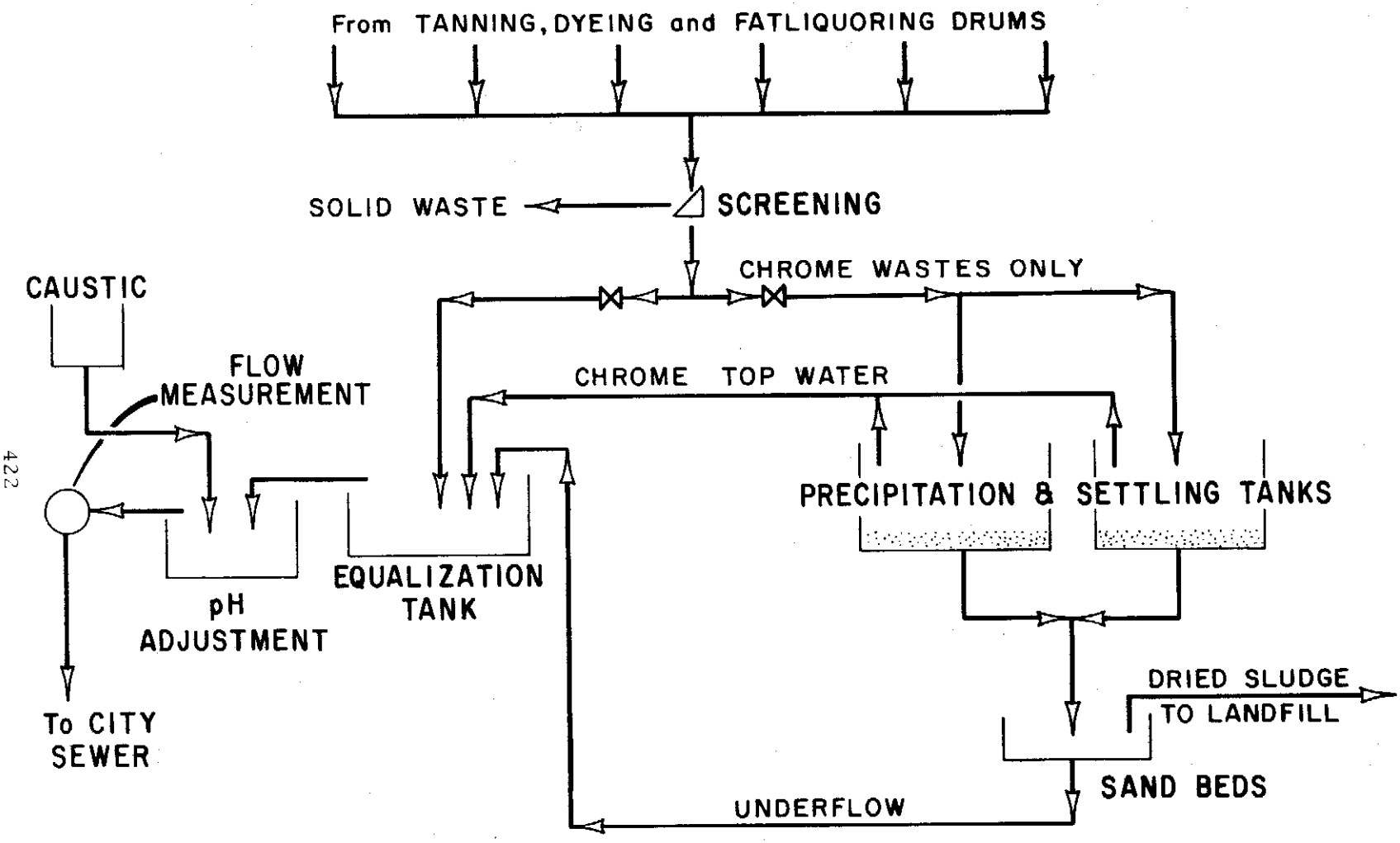

FIGURE 47 Typical Waste Flow Segregation Schematic

TABLE 69

EFFECTS OF CONVENTIONAL TREATMENTS ON TANNERY WASTES

	Plant Influent	Primary Influent Settling	Carbonation	Activated* Sludge & Sec. Settling
Alkalinity	1.2	1.2	8.7	--
Total Solids	5100 mg/l	5100 mg/l	5700 mg/l	4200 mg/l
Suspended Solids	900 mg/l	540 mg/l	440 mg/l	370 mg/l
Volatile Solids	1000 mg/l	1000 mg/l	480 mg/l	170 mg/l
BOD	1500 mg/l	800 mg/l	600 mg/l	50 mg/l
$S^{=}$	93 mg/l	80 mg/l	60 mg/l	1.5 mg/l
Cr^{+3}	70 mg/l	35 mg/l	5 mg/l	4 mg/l

*Sanitary Wastes Added. Dilution to 150% by Sanitary.

Data taken from WPCR-ORD-5. (11)

pre-treatment to the first level (1977) for municipal acceptance, with the exception of BOD_5, SS, and coliforms removal. It is to be understood, in what follows, that Level I technology is meant to apply to pretreatment, omitting biological treatment and chlorination.

It should be stated that there has been strong criticism of the proposed guidelines from within the leather industry. There is no guarantee that the guidelines will be adopted permanently, but they make as sound a basis for prediction of requirements as exists at this time.

1. 1977 -- Best Practicable Control Technology Currently Achievable (Level I)

   The guidelines proposed for Level I appear in Table 70.(2)

TABLE 70

LEVEL I EFFLUENT LIMITATIONS GUIDELINES --

JULY 1, 1977

Parameter(1)	Category (lb/1,000 lb hide)(2)		
	2	4	5
BOD_5	2.0	0.7	2.5
COD	49	9.8	60
Total Chromium	0.05	0.02	0.02
Oil and Grease	0.5	0.20	0.06
Sulfide	00.005	0.002	0.006
Suspended Solids	1.0	0.33	1.3
pH, units	6.5-8.5	6.5-8.5	6.5-8.5
Fecal Coliforms/100 ml	200	200	200

(1)Basic values average over a 90-day period are shown; up to 2 times these values allowed in 5 percent of the samples; values may never exceed 4 times these limitations. Maximum limit for chromium is 2 times basic values. pH must be within basic limits shown at all times.

(2)Except pH and fecal coliform.

The EPA draft report, based on an extensive literature survey, site visits, and other sources of information, calls for the following end-of-the-pipe treatment to achieve Level I effluent quality:

1. Screening
2. Equalization
3. Primary settling
4. Aeration (biological oxidation)
5. Secondary settling
6. Filtration
7. Chlorination

In other words, the proposal is for standard secondary treatment, followed by polishing, to offset less than perfect sedimentation of the biological floc.

Although no tannery carries out all stages of this proposed scheme at present, the experience of one small tannery, the Caldwell Lace Leather Company (10), in employing the first five steps seems to confirm the technical feasibility of the process.

As reported by Thackston, Caldwell Lace Leather Company's principal operation is alum tanning, with only about 15% in chrome and vegetable tanning. Their data are of general interest, however, because they operate their own beamhouse. Over a six month period, BOD_5 in the plant's effluent averaged 24 mg/l; and suspended solids, 52 mg/l. From the data in the report, the values can be reshaped to give an approximate comparison with the guidelines:

	Level I Guidelines (Category 2)	Caldwell Effluent
BOD_5	2.0 lb/1000 hides	0.7 lb/1000 hides
SS	1.0 lb/1000 hides	1.4 lb/1000 hides

Thus, a satisfactory reduction in BOD_5 is being achieved, while suspended solids are approaching the required level. It is conceivable that the latter could be reduced further by process modifications, but sludge from secondary treatment tanning wastes is notorious for its poor settling; hence the addition of the final filtration step. No report on the concentration of sulfide in the effluent, other than that it was "low," was given, because most of the sulfide normally used in unhairing had been replaced by dimethyl amine. Spent chrome liquors were precipitated by liming and added to the main waste stream before primary settling.

The results mentioned above are somewhat deceptive in their apparent simplicity. The following should be kept in mind:

a. No two tanneries are close enough alike in their raw materials, their use of chemicals, their processes, and their product to insure that their wastes will be susceptible to treatment in exactly the same way. Adjustments, some of them major, will always have to be made in the treating process.

b. The successful operations of the waste treatment plant are highly dependent on the skill of the operator.

c. It may not always be practicable to substitute dimethyl amine for sulfides in sufficiently high proportion to hold effluent sulfide to the guideline value. The remedy which appears most likely to be applied is the catalytic oxidation of sulfide to sulfate in the aeration basin, using manganese salts for the catalyst and the air for the oxidizing agent.

Costs associated with the attainment of the pollutional loads of Level I could, theoretically, be estimated from the known costs of building and operating the standard sewage treatment processes needed, provided only that we could arrive at some basis for sizing the equipment. The obvious starting point might be to base unit costs on quantity of hide processed and the average values of the parameters listed in Table 68. However, as discussed previously, data on parameters whose ranges extend over one or two orders of magnitude are not such as to encourage reliance on their averages. The data presented in Table 71 will serve to give an idea of relative costs for different degrees of treatment.

Data do exist which purport to estimate costs of waste treatment as a function of total sales of the industry. Though these also vary over wide ranges, they are presented in Section VII, below.

2. 1983 -- Best Available Technology Economically Achievable (Level II)

The guidelines proposed for Level II appear in Table 72 (2). These differ from those of Level I by requiring nitrogen removal, further BOD_5 reduction by 50 percent, and an 85 percent reduction in color of the effluent. The steps proposed to accomplish Level II treatment are as follows:

TABLE 71

ESTIMATED WASTE TREATMENT COSTS FOR TYPICAL SIZE PLANTS[a]

(August, 1971 price levels)

Category	Flow cu m/day (mgd)	Alternatives[b] A	B	C	D	E
No. 2	598 (0.158)					
Investment Cost		$0	1,336,000	2,165,000	2,720,000	5,075,000
Annual Cost		0	365,000	662,000	812,000	1,557,000
No. 4	257 (0.068)					
Investment Cost		0	405,000	703,000	950,000	1,470,000
Annual Cost		0	120,000	205,000	282,000	435,000
No. 5	420 (0.111)					
Investment Cost		0	473,000	782,000	1,013,000	1,752,000
Annual Cost		0	137,000	226,000	297,000	523,000

(a) Investment costs include equipment, construction, engineering, overhead, and contingencies. Annual costs include depreciation, interest, operation and maintenance. [Ref. EPA Draft Report (2)]

(b) Alternative A = No treatment.
Alternative B = Pretreatment.
Alternative C = Activated Sludge
Alternative D = Activated Sludge and Nitrification-Denitrification.
Alternative E = Activated Sludge and Nitrification-Denitrification and Reverse Osmosis-Evaporation.

TABLE 72

LEVEL II EFFLUENT LIMITATIONS

GUIDELINES -- JULY 1, 1983
(Complete Treatment)

Parameters[a]	Category (lb/1,000 lb hide)[b] 2	4	5
BOD_5	1.0	0.33	1.3
COD	49	9.8	60
Total Chromium	0.05	0.02	0.06
Oil and Grease	0.5	0.2	0.62
Sulfide	0.005	0.002	0.006
Suspended Solids	1.0	0.33	1.3
Total Kjeldahl Nitrogen[c]	0.25	0.08	0.31
Ammonia Nitrogen[c]	0.15	0.05	0.19
Nitrate Nitrogen[c]	0.25	0.07	0.12
pH, units	6.5-8.0	6.5-8.0	6.5-8.0
Color, % Removal[d]	85	85	85
Fecal coliform/100 ml	200	200	200

(a) Basic values average over a 90-day period are shown; up to 2 times these values allowed in 5 percent of the samples; values may never exceed 4 times these limitations. Maximum limit for chromium is 2 times basic values. pH must be within basic limits shown at all times.

(b) Except pH, color, and fecal coliform.

(c) Limitations for nitrogen forms do not apply when the water temperature is below 10° C (50° F).

(d) No reasonable data are currently available upon which absolute limits may be established. Treatment can provide this percent removal, however.

1. Water conservation to reduce the size of treatment units.

2. Recycle of chrome and vegetable tanning solutions (where applicable).

3. Collection of beamhouse wastes containing sulfide; oxidation of sulfide using a catalyst such as manganous sulfate (where applicable).

4. Fine screening.

5. Equalization to dampen variations in quality and quantity which will impair subsequent processes, particularly biological units.

6. Aeration and clarification of solids to remove carbonaceous BOD, COD, and suspended solids.

7. Aeration to nitrify organic and ammonia nitrogen, followed by settling.

8. Mixing with a carbon source to cause denitrification; nitrogen stripping to assist nitrogen gas removal; and a final settling tank.

9. Filtration of the final effluent using deep-bed, mixed-media filters or similar devices for final suspended solids removal.

10. Chlorination to disinfect the final effluent.

11. Sludge handling and disposal using thickening, chemical conditioning, dewatering, and landfill for final disposal.

The addition of steps 7 and 8 to those required for Level I treatment is logical in the present state of technology, if nitrogen is to be reduced to the desired levels. Reeves, in a 1972 review (12), concluded that "[t]he most practical method available is biological nitrification-denitrification. A three-stage system will be needed in most locations, including a carbonaceous BOD removal unit, ... nitrification (aerobic) unit, and a denitrification (anaerobic) unit. Also a small air stripping unit would be helpful to remove the nitrogen gas. There are three available denitrification units which could be used: anaerobic activated sludge, anaerobic filter system, and an anaerobic lagoon." It should be noted that these processes, although tested extensively in pilot plants, are not in large-scale use.

The substitution of a percentage of removal for effluent limitations, in the case of color, begs the question, since the color of untreated effluent can vary enormously and since methods of removal will necessarily vary with the compounds causing it. It seems highly likely that any requirement for substantial reduction of color will be most economically met by process changes such as recycling of chrome top water, fortifying dye batter, and so extending their life or possibly developing biodegradable dyes. (Solvent dyeing is another possibility.) Pigments, if any, would be expected to drop out in the course of the several sedimentation steps, thereby transferring, though not eliminating, the problem. It should be apparent that each case must be approached on an individual basis. Carbon adsorption might be employed on segregated streams as a last (and by no means guaranteed effective) resort.

3. Zero Discharge

There is no generally accepted definition of zero discharge, just as there are no universal drinking water standards, or, for that matter, universal standards for support of aquatic life (which aquatic organisms? in what abundance?). It seems appropriate, however, to attempt a few generalizations on possible trends. There will be, inevitably, some overlap with the previous discussion on treatment under Levels I and II.

One of the favorite truisms of the pollution control industry is that the techniques exist for almost any conceivable degree of effluent treatment. It is equally common knowledge that the injudicious application of some of them would lead to economic disaster. Pollution abatement, then, at the level implied by the phrase "zero discharge", becomes more than ever the art of balancing the expense of eliminating a pollutant, by seeing that it never leaves the plant, against removing it from the waste stream. The greater the degree of removal required, the more the emphasis must shift to in-plant modifications and contaminant-by-contaminant consideration. The

application of more and more sophisticated catch-all treatments to remove traces from the gross plant effluent will generally become less and less attractive as the degree of reduction required approaches one hundred percent for each constituent.

a. Chemical and Engineering Changes.

These modifications will necessarily involve substitutions of process chemicals, use of solutions more concentrated than present practice, changes in dyeing procedures, improved machinery, and probably a high degree of segregation of spent solutions and washes, all aimed at maximizing recycle of materials and water. There may also be substantial modifications of the product.

Perhaps the biggest unresolved problems for the tanner of the zero discharge era will be the high volume of high concentration salt waste, thoroughly contaminated with organics, both in solution and in suspension. Reverse osmosis must always be considered, at least for concentrating solutions of dissolved inorganics. With membrane clogging problems on wastewater and substantial capital in-investment requirements, there will certainly be a considerable effort to adopt alternatives.

Williams-Wynn (13) mentions alternative methods of marketing hides, including short-term preservation with antiseptic and no salt, as well as immediate use in a tannery adjacent to the slaughterhouse (no curing stall). These drastic changes would eliminate the salt used in curing, but not the lesser amount used in pickling.

The amount of salt used in pickling and chrome tanning can be reduced by using shorter floats, but elimination of the waste will probably depend on the development of successful procedures for re-cycling, with some bleed and concentration of impurities by evaporation or reverse osmosis.

Considerable recycling of chrome tanning solutions was practiced during World War II. Possibilities for closing

up the chrome cycle, in addition to direct recycle, include the use of "dry" tanning procedures. Here, the tanning material is taken up in liquid in the drained hides, with no excess.

Young (14) discusses chrome recovery via precipitation, filtration (in a filter especially designed to handle flocs at reasonable throughput), and re-solution in a process whose automation is the subject of patent applications. Regeneration of process material having the value of chrome tanning salts can be a profitable operation, quite aside from its beneficial effect on wastewater problems. Mohan (7) describes a liming-flocculating-settling procedure by which chromium was reduced to 0.4 mg/l in the top water, which was reused in pickling and tanning. Cortese (15) has reported pilot plant work on re-use of chrome liquors.

For some purposes, alum or zircanium salts may be substituted in whole or in part for the usual basic chromium sulfate; even though aluminum generally makes a less undesirable salt than chromium when discharged in the environment, however, the problem would not be solved by such substitutions.

Solvent tanning, which has been under investigation off and on for years, could come in to more common use, the implication being that all tanning agents would be taken up by the hide (or recycled) while the solvent is recovered by evaporation or distillation. In this connection, the fact that conventional tanning is also solvent tanning, the solvent being water, is obvious; under conditions of zero discharge, solvent recovery must be practiced, whether the solvent be water or an organic.

The elimination of any excess fat liquor will be much easier than no-effluent tanning. In fact, virtually 100% take up of fat is practiced frequently, even now.

Dyeing without excess discharge of exhausted solutions will prevent considerable problems. A certain amount of fortifying and reuse can be carried on, but at present there are limits to this. Work on dyeing processes without float may lead to no effluent. Spray

dyeing with no liquid waste is applicable in some circumstances. A somewhat farfetched possibility would be the development of dyes which are relatively biodegradable, so that they could be removed in a conventional treatment plant.

Fungicides, such as p-nitro-phenol, which are sometimes now added in an immersion process (and result in wasting to the sewer), will be applied without loss through spraying, roller coating, or swabbing. This is not new, but is mentioned as one of the things which must be considered. Trace elements from pigments, as well, could show up in a wet discharge, and must be eliminated by substitutions or changes in methods of application.

b. Waste Treatment Changes

It is a basic thesis of this report that zero discharge for the leather industry will be approached only because of gradual changes in processing, not because of any spectacular changes in wastewater treatment methods. End-of-the-pipe treatments, however incomplete they may be in a zero discharge context, will probably always serve either or both of two principal functions:

(1) To pretreat tannery effluent to the extent necessary to eliminate "incompatible pollutants" before discharge to a publicly owned treatment facility.

(2) To serve as one bleed-off of impurities (by concentration and segregation, or destruction) to the extent necessary for recycling solutions. The ideal bleed, one seldom achieved, is that in which all pollutants are carried out of the process as part of the product.

Development of waste treatment processes has centered around chrome removal and recycling (mentioned in (a) above), sulfide removal, and more or less conventional sedimentation and biological treatments, none of which is capable, by itself or in combination, to allow total recycle or complete removal

of pollutants.

It is generally assumed that sulfides will be removed satisfactorily by the use of a manganese catalyst in the (assumed) biological aeration basin. This, however, produces sulfates which are not easily removed in the course of achieving zero discharge. A possibly more attractive alternative has been explored at the Blueside tannery. (5) The alternative involves acidification, air stripping of the H_2S and absorption in caustic to regenerate Na_2S for reuse in the tannery.

Simoncini and Del Pezzo (16) have reported pilot studies in which a considerable (but not total) recycle of beamhouse effluent was achieved by alum flocculation and settling. Total recycle was prevented by the accumulation of salt. If salt cannot be held down by process changes, then present technology leaves almost no option but concentration by reverse osmosis. One then has to assume further treatment complexities to purify the concentrated salt before reuse.

Coretese (15), in semi-works tests on segregated beamhouse effluent, used neutralization, clarification, biological treatment, disinfection, and ion exchange in series, yet managed to recover 60% of the water as pure. Part of the less fully treated effluent, containing salt, could also be used.

Solid Wastes and Sludges

Disposal on land has been the classic method of removing sludges and other solids in the tanning industry, as in so many industries (and municipalities). There has been almost no development in the field of solid waste management pointed specifically at tannery problems. Wastes may include the following:

1. Solids
   a. Fleshings and raw hide trimmings. These may be sent to a rendering plant or converted into glue, but the market for animal glue is hardly what it was before the advent of synthetic adhesives.
   b. Hair. Hair from the save hair process is a marketable product.

c. Tanned fleshings and trimmings. Depending on size, amount and quality, these may be sold for low quality leather or as raw material for leather board. The small bits that are screened out of various effluent streams must join other general wastes as part of the whole plant problem.

d. Buffing dust. Attempts have been made to use dust as a boiler fuel. This is not a satisfactory substitute for incineration under carefully designed conditions. The dust is hard to handle in a boiler not meant for it; and the recoverable heat is not worth the effort. If the dust is from chrome tanned leather, there will be an air pollution problem.

2. Sludges

a. Lime sludges and other primary sludges, possibly with flocculants such as aluminum or iron hydroxides, may be part of the waste.

b. Chrome sludge has been discussed under recycling in an earlier section.

c. Biological sludge presents the same problems as any other similar sludge with the additional difficulty that if chromium has not been adequately removed from the waste, it will have been concentrated to some extent in the sludge.

d. Office and general plant waste. Since, with the exceptions noted, the possibilities of by-product recovery are virtually nil, the only acceptable solutions appear to lie in dewatering, to the extent possible by thickening, filtering, or centrifuging on a case by case basis, followed by incineration.

The alternative of putting raw or thickened wet sludges in the land or in landfills will probably have outlived its usefulness in land-scarce areas before long.

VII. SUMMARY

Needs

From a scrutiny of two of the principal sources of quantitative information, Thorstensen's study and the EPA draft report, it seems plain that one of the great needs of the industry in any general attack

on its waste problems is for more accurate data. As indicated in Section IV, the ranges of values given for most parameters, necessary for any intelligent evaluation of the problems, not just of the solutions, are such as to discourage planning efforts. Better flow measurements, better sampling, and careful interpretation of the data so obtained are glaring needs.

Agreement on the next point will be less universal, but we agree with Shuttleworth (17) in his argument for a much increased research effort by the U.S. leather industry. Shuttleworth is not referring to research aimed alone at solving waste problems, but that is a large part of what he is talking about. He lists the expenditures on collaborative leather research in 1972 as a percentage of sales for five countries as follows:

USA	0.1%
UK	0.3%
France	0.6%
Germany	0.3%
South Africa	2.1%

These expenditures do not include private research within tanneries (believed to be minimal), but are striking in their contrasts nonetheless.

It would be hard to argue, in light of the efforts of other nations, that the U.S. could not afford to increase its leather research effort. It would be equally hard not to expect substantial results in waste reduction if a significant portion of any research were to be directed that way.

Conclusions

Any conclusions drawn from such a general study as this must necessarily reflect the leanings of the authors. The EPA report, itself the result of a much more detailed investigation than this, has provoked strong disagreement with its conclusions from the industry.

We conclude that:

1. It is technically feasible to achieve the effluent guidelines proposed for 1977 and 1983.

2. It may be technically feasible to achieve zero discharge. Whether or not this is true depends on one's definition of zero discharge; whether it ever becomes practicable depends, as well, on one's definition of practicable.

3. The achievement of the lowest quantities of pollutants will in part result from specialization of production functions. A tannery such as Blueside (5), which is large and concentrates on a segment of the leather industry process, is better able than a small general tannery to minimize its wastes (of limited variety), and eventually perhaps to eliminate them.

4. The achievement of levels set by stringent effluent standards will occur in a practicable way only after the most persistent and skillful attention is given to the tanning processes themselves. Or, to quote Shuttleworth on effluent improvement: "Although each tannery presents a different problem, because of the differing types of leather made, and the variations in local conditions, the optimum solutions to these problems require leather chemists and not general effluent consultants. I believe that it is a matter of survival for this problem alone to be given adequate support on a co-operative national basis." (17)

Costs

It is as difficult to find agreement on costs of treating tannery effluent as on its quantity and strength.

The EPA report suggests that total costs to achieve the 1977 levels (essentially conventional secondary treatment) range from 1.8 to 12.4 percent of the finished product costs, based on August, 1971 prices. They suggest 1.8 to 16.0 percent for the 1983 levels, essentially the same processes with nitrification-denitrification added.

On the other hand, a report for the Council on Environmental Quality (18) posits 1 to 3 percent of annual sales for the cost of secondary treatment of tanning and finishing plant wastes, with the strong intimation that the lower figure is more nearly correct. Granted that this may be somewhat weighted on the optimistic side because of the way the data were gathered, it is still difficult to reconcile it with the predictions of the other report, and no attempt to do so will be made here.

Regardless of which data are more accurate, the CEQ report gives an excellent overview of the structure of the industry in the course of trying to assess the impact of waste treatment costs. It is probably as authoritative as any publicly available paper, and for that reason we close by quoting its summary below.

"This report summarizes a review made in October and November, 1971, of the impact of pollution control costs on the leather tanning and finishing industry (SIC 3111) in the United States.

"Recent trends in production, employment, and product acceptability have been reviewed along with current and planned pollution control expenditures. Executives of eighteen of the firms were interviewed for an impressionistic description of trends in the industry and their expectations as to the impact of pollution control costs.

"The Executive Summary presents an overview of the total study highlighting the industry trends and the relative importance of pollution control costs to the future of the industry.

"The essential conclusions of this study are first that the cost of controlling the industry's water pollution at least to the level of secondary treatment will represent an additional cost of production equal to one percent or less of annual sales for most of the firms in the industry. A small number of firms could face costs of 3 percent though no such firms were found.

"The second conclusion follows from the industry's frequent experiences with large increases and decreases in the cost of its basic raw material -- hides -- by as much as 50 percent to 100 percent in an one to two year period. The selling price of leather correspondingly has changed from ten percent to 25 percent in the same period with no apparent effect on production. In the aggregate the industry would not have any difficulty passing on a one percent or even three percent price increase deriving from pollution control costs.

"The third major conclusion is that the future of the industry will be determined by the health of the American shoe industry, not by pollution control costs even though the industry is a major pollutor. In the last three years, domestic shoe production has begun to decline due to competition from imports and thus leather production has also begun to decline. There is also strong pressure toward

the substitution of synthetics for leather which has ended most leather sole usages and made large inroads in lower priced shoes. The future trends are very hard to predict.

"The fourth and final conclusion regards the ability of individual firms to raise the necessary capital to pay for control equipment and to pay financing and operating costs. Financial information is very difficult to obtain for leather firms because they are almost exclusively privately owned. Reviewing the financial data which was obtained one would have to conclude that the average firm could absorb a one percent yearly charge for pollution control. Most companies interviewed did not seem very concerned -- probably because of their confidence in their ability to increase prices to cover the costs. The ability of the firms to raise large amounts of capital is not evident from their financial statement. They have very little convertible plant and equipment and there is little convertibility in the pollution control equipment which may need to be purchased. However the industries' current ratios average around two. There is also strong evidence that the owners of the firms hold assets related to the tannery which are not shown on the tanneries accounts. The owners interviewed were completely confident that they could either raise the capital required from banks or they were willing to put up the capital themselves. Thus marginal firms have been closing and will continue to close. But this phenomenon results from a contracting market for leather not from the inability of firms to live with pollution control costs.

"In the worst case where a firm is facing severe control costs, tanneries now have the option of closing what is called their "beam house" and subcontracting the preliminary tanning operations and thus eliminating 90 percent of the BOD waste. Companies now provide this service at a cost equal to what it costs the average firm to perform the work in house. The employment reduction is about 20 percent. This option has been taken by a number of firms. Thus only in very unusual circumstances might a tannery actually have to close because of pollution control costs."

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9. CONCEPTUAL STORMWATER DESIGNS

a. Introduction

The status of stormwater collection, treatment and discharge varies greatly within the Merrimack River Basin, depending on a community's state of development, wealth, desires and objectives. The rural community of Boxford, for example, maintains a stormwater control system containing only a few catch basins, with no formal collection, treatment or discharge network at all. Urban Lowell, on the other hand, has an intricate conglomeration of combined sewers and separate sanitary sewers and storm drains at present; by 1976, the city proposes to have in operation a wastewater treatment plant and associated interceptors.

It should be recognized, however, that none of those communities has a system that comes close to satisfying the goal of zero discharge of pollutants as stated in the 1972 Amendments to the Federal Water Pollution Control Act. Therefore, because of the varied states of community development, no one methodology will satisfy the stormwater demands within the Merrimack River Basin. The significance of stormwater runoff on the increased pollution loading of our rivers has become apparent only recently. As a result, much research, numerous studies and implementation of pilot treatment plants have been undertaken to deal with stormwater quality and quantity, and with methods of collection, treatment and discharge. One of the objectives of this study, therefore, is to analyze existing conditions and available data, in order that a basin-wide stormwater abatement system may be developed. Since much of the research and study of the past was theoretical, and not conducted with the problems and characteristics of the Basin in mind, it has been necessary to extrapolate data and project methodologies to a basin- or area-wide scale; and to attempt to identify the difficulties that might develop when the methodology is extended to such large proportions. To determine which methodologies are applicable in treating stormwater run-off so that it will not have a detrimental effect on the quality of the receiving water, it is necessary to ascertain the following:

- the anticipated quantity of stormwater (hydrologic data to be furnished by the Corps of Engineers)

- the constituents of combined sewage

- the advantages and disadvantages of the treatment methodologies available

- the discharge objectives of the Environmental Protection Agency

The discharge objectives will coincide with the interim 1977 and 1983 treatment requirements proposed by the Environmental Protection Agency (EPA), and with the 1985 goals outlined by Congress in PL 92-500 (see discussion on Conceptual Designs of Treatment Processes presented earlier in this section).

A clear definition of the current state-of-the-art of stormwater treatment will serve as a basis for developing a series of design alternatives for stormwater treatment, which will be analyzed for their effectiveness in the problem areas throughout the Massachusetts portion of the Basin. Stormwater treatment is a unique problem, because of the special quality of stormwater, and the unpredictability of its volume. The study will describe the characteristics of stormwater, and then examine the various methods by which the stormwater problem may be eliminated, reduced, or controlled, to satisfy the effluent requirements of the Environmental Protection Agency.

b. Quality and Quantity of Stormwater

Major sources of water pollution are municipal and industrial wastes, but these are not the only significant sources. As these concentrated sources of pollution are brought under control through construction of wastewater collection and treatment facilities, the remaining more diffuse and difficult to control sources may determine the water quality and the types of water use that can reasonably be maintained. The quality of stormwater is greatly influenced by many factors: the quality of the rainfall; the physical characteristics of the community (type and degree of development, economy, etc.); the interval since the last rainfall; collection techniques and procedures; land use; and the method of transporting the stormwater (storm sewers, combined systems, natural drainage channels, or overland flow). Its classification, then, cannot be as routine as that of sanitary and industrial wastewater,

on which much analysis has been performed, and of which the constituents are generally known.

Dust and dirt from streets, material eroded from land and pavement, fecal material from domestic and other animals, and oily residues from vehicles significently degrade the quality of runoff from urban areas. To date, no definitive studies have been made of the quality of urban runoff in the study area, but a number of investigators have studied the quality of urban runoff in other areas. Some of the important constituents of stormwater that have been identified in studies conducted are listed in Table 73. Tables 74 and 75 respectively summarize the Cincinnati data on the bacteriological quality of runoff and compare the pollution load from the urban runoff with that from sanitary sewage.

The data on these tables indicate that there appear to be no major problems expected in the treatment of stormwater, although it is evident that surface runoff from urban areas, may constitute a significant source of pollution. It is important to note that there is at present no fully accurate description of "typical" stormwater runoff characteristics, because of the variable nature of the rainfall-runoff patterns. However, the development of pollutographs for various types of storms, considering their frequency, duration, and antecedent conditions, should reduce the uncertainty about typical stormwater runoff characteristics.

Since stormwater quality is not uniform throughout the storm cycle, it is also not uniform as it enters the treatment system--a fact that complicates its treatment. The initial runoff entering the system is usually of the worst quality, because of the "first flush" effect, although major scouring of the system may continue for several hours after the start of a storm. "First flush" results when the entering runoff washes the drainage area clean, carrying with it all the debris that has accumulated since the previous rainfall. In combined sewers, "first flush" consists also of the solids that have settled within the system during dry weather flow periods when the sanitary sewage travels very slowly through the massive complex. The deposits of sludge thus formed are transported to the treatment plant with the initial influx of stormwater into the system.

Stormwater runoff quality can be altered by many conditions within the drainage area: animal waste discharge, human waste,

TABLE 73

CONSTITUENT CONCENTRATIONS IN URBAN STORMWATER RUNOFF(1)

	Ranges of Discrete Samples	Storm Average
Turbidity (J.T.U.)	30-1,000	176
Color (C.U.)	10-460	87
pH	5.3-8.7	7.5
Alkalinity (mg/l)	10-210	59
Total hardness (as $CaCO_3$) (mg/l)	19-364	81
Chloride (mg/l)	3-428	12
SS (mg/l)	5-1,200	227
VSS (mg/l)	1-290	57
COD (mg/l)	20-610	111
BOD (mg/l)	1-173	17
N (mg/l) (2)	0.3-7.5	3.1
Inorganic N (mg/l)	0.1-3.4	1.0
Hydrolyzable PO_4 (mg/l)	0.02-7.3	1.1
Organic chlorine (mg/l) (3)	0.38-4.72	1.70

(1) From 27-acre residential, light-commercial area, Cincinnati, Ohio, July, 1962, through July, 1964. January and February, 1963, not included.
(2) Arithmetic sum of the four forms of nitrogen.
(3) From 11 storms, August, 1963, to February, 1964.

TABLE 74

BACTERIAL COUNTS IN URBAN STORMWATER RUNOFF SAMPLES (1)

Bacterial Count	Counts Exceeded in Designated Per Cent of Samples, Per 100 ml		
	90%	50%	10%
Coliforms	2,900	58,000	460,000
Fecal coliforms	500	10,900	76,000
Fecal streptococci	4,900	20,500	110,000

Note:

(1) From a 27-acre residential, light-commercial area, Cincinnati, Ohio, 1962 and 1963

TABLE 75

COMPARISON OF URBAN STORMWATER RUNOFF LOADS WITH SANITARY SEWAGE LOADS(1)

	Sanitary Sewage Production		Urban Stormwater Runoff Loads as Per Cent of Sewage Load	
Constituent	lb/day/acre	lb/yr/acre	During Runoff	Annually
SS	1.5	540	2,400	160
COD	2.6	960	520	33
BOD	1.5	540	110	7
Total hydrolyzable phosphate (PO_4)	0.19	68	70	5
Total nitrogen (N)	0.23	82	200	14

Note:

(1) At Cincinnati, Ohio.

street cleaning operations, land use (commercial, industrial, residential), fertilizing operations, road salting and sanding, the amount of new construction within the community, and the quality of the air throughout. Control of these conditions would be most beneficial in reducing the pollution loading of stormwater prior to its entering the drainage treatment network.

Even though the quality of stormwater is unique in comparison to domestic and industrial wastes, it is, however, the tremendous volume of stormwater entering the system sporadically that poses the major treatment problem. If stormwater runoff occurred uniformly at a normal rate of flow, its treatment would not be difficult; but the huge amounts occurring without predictable regularity make it unfeasible to design a wastewater treatment plant with the capacity to accommodate all the runoff.

A great deal of thought must be given to the selection of the "design storm," to be used as a basis for designing the ultimate stormwater system. The quantity of its water, and its effect on the quality of the water at the receiving body are important considerations. The Corps of Engineers' pollutographs represent graphically the pollution loading of stormwater runoff during the duration of a storm, within the basin. The data thus obtained will give further insight into the quality of the stormwater throughout the basin, and in the frequency and duration of the design storm. Furthermore, the pollutograph information will make it possible to utilize various design storms, to attempt to analyze how frequently the proposed stormwater network would be overtaxed and what would be the quality of its overflow.

The quality constituents that will make the treatment of such large quantities of stormwater a problem are its BOD and solids content (total, suspended, and volatile suspended). The time required to reduce these ingredients to meet the effluent requirements will necessitate either the construction of extremely large treatment plants or the development of other means to control the quantity of water to be treated at one time (i.e. diversion and storage).

A discussion of stormwater runoff and its effects in the Merrimack River Basin is presented in Appendix I of this report.

c. Abatement of Pollution Caused by Stormwater Runoff

Once the quality and quantity of stormwater to be expected throughout the basin has been identified, emphasis may then be transferred to the collection, transportation, treatment and discharge of stormwater of acceptable effluent quality. In this section will be discussed the methods by which the ultimate effect of stormwater on the quality of the Merrimack River can be diminished. Not all methods will be applicable to the study area, however, so a review of the methods to evaluate their usefulness within the basin will follow.

Methods of Reducing the Quantity of Stormwater

Some type of storage for stormwater in need of treatment is required during peak flow periods; otherwise, the capacities of treatment plants must be increased significantly. Therefore, the following methods involve reducing the quantity of the stormwater during peak flows by storage, until the treatment processes can handle the water during non-peak flow periods.

A. Storage System: Preserving stormwater for discharge into the treatment plant during non-peak periods.

1. Man-made underground storage (with or without treatment).
2. Storage in pipes not affected by a particular storm.
3. Storage in natural underground caverns and subsequent pumping into system during non-peak periods.
4. Storage in abandoned treatment plants located within the basin.
5. Storage in surface lagoons, ponds, etc.
6. Any combination of the above. (These approaches generally can be designed to include some type of primary treatment, if desired.)

B. Storage Prior to Entering System: Delaying the entrance of portions of stormwater into the system until non-peak periods. This, in fact, is leveling off the stormwater hydrograph.

1. Reduce size and/or number of catch basins, inducing local surface storage (must not result in any major water damage).
2. Roof Top Storage -- Utilize commercial and industrial rooftops for storage. All new buildings would be designed to carry 1 foot of water, with downspouts so sized as to delay the entrance of the water into the system by at least 48 hours.

C. Other Methods of Reducing Quantity

1. Eliminate infiltration and illegal connections into sewer system.
2. Use porous-type asphalt for roads and parking lots, thus reducing runoff.
3. Impose a mandate that all dwellings have roof drains emptying into dry wells.
4. Control land use within drainage area to reduce the runoff characteristics of the area.

Methods of Improving Water Quality of Stormwater Prior to Formal Treatment

The following operations will result in improved quality of the stormwater influent into the treatment plant (either wastewater or overflow), thereby reducing the work load of the plants. A prime reason for implementing any of these operations is to improve the quality of stormwater that, during extreme occurrences, will by-pass all formal treatment, including the overflow treatment plant. It is not feasible to design a stormwater treatment facility capable of handling the ultimate storm (Standard Project Storm, or greater); therefore, there is the likelihood that, on occasion, untreated stormwater will bypass treatment plants.

A. Control Prior to Entering System

1. Improve air quality.
2. Develop street cleaning procedure that coincides with EPA effluent criteria.
3. Develop maintenance procedure for catch basins.
4. Enforce anti-litter laws.
5. Control salt and sand use for winter.
6. Enforce Federal and State guidelines on the use of fertilizers, pesticides, etc.

B. Control Upon Entering System

1. Flush out combination systems during periods of dry weather, to diminish the impact of the "first flush".
2. Utilize storage devices to reduce suspended solids and BOD content of stormwater (primary treatment) prior to full treatment.

Stormwater Collection and Transportation

The purpose of this section is to enumerate the methods by which stormwater can be collected and transported within the Merrimack River Basin. The status of stormwater systems within the study area vary widely, in some areas new transmission facilities must be constructed, while in others only additions and modifications are needed. The terms collection and transportation of stormwater refer to those operations beginning at the catch basins, including trunk lines, diversion regulators, interceptors, overflows, and sewer mains, and ending at the wastewater and overflow treatment facilities.

A. Combined Sewers: The process of stormwater collection and transportation is critical in Haverhill, Lowell, Lawrence, Methuen, and Newburyport, because combined sewers are currently in use there. The combination of sanitary sewage and stormwater assures that an overflow of the untreated waste would be extremely detrimental to the quality of the receiving body of water. The following options are available to those areas in which combined sewers are partially or totally in use, for the advancement toward the goal of "zero discharge":

1. The use of combined sewers is antiquated and theoretically should be phased out in favor of separate systems to increase the efficiency of both stormwater and sanitary sewage collection and treatment.

    a. Modify all combined systems utilizing the existing combined systems for stormwater collection, and transport sanitary sewage in a newly constructed parallel system.
    b. Utilize existing combined systems for stormwater collection, and transport sanitary sewage in newly installed pressurized pipe located inside the existing combined sewers.
    c. Utilize existing combined sewers, changing to separate system only as major portions of the existing system become unusable or obsolete; and develop transporting devices, including regulated diversion, to include existing combined sewers in the ultimate system (wastewater/stormwater), to insure that EPA effluent criteria are met. Existing combined sewers usually have a series

of overflow areas that must be collected by interceptors, thus eliminating this potential source of pollution.

B. Separate Stormwater Systems: The methods described on the subsequent pages are to be used in the collection and transportation of stormwater in areas for which the following are applicable: no stormwater system exists; separate storm and sanitary sewers exist, either for the entire area or a portion thereof; combined sewers exist now and will continue in the future, and must be integrated into a proposed wastewater/stormwater system.

1. Regulated Diversions -- Because of the tremendous variations in quantity of stormwater in a sewer system it is necessary to include "regulated diversion". This process diverts excess water as required to various areas within the system. The diversions can be operated manually, by computer, hydraulically, or in combination. Regulators and their appurtenant facilities are devices which have the responsibility of monitoring both quantity and quality of stormwater overflows (including combined sewage) to receiving waters, for more effective pollution control.

   Within a complete wastewater/stormwater system regulated diversions are used:

   a. To insure the design capacity of the wastewater treatment plant by diverting flow to storage areas or to stormwater overflow treatment plants.
   b. To insure the design capacity of the stormwater overflow treatment plant by diverting flow as untreated overflow sewage into the receiving water body or into a land disposal area. The overflow will be stormwater entirely, or combined sewage, and will be diluted to insure minimal environmental impact.
   c. To maintain control of the quality of stormwater, in systems receiving stormwater from both storm sewers and combined sewers. For systems with storm sewers, storage areas will contain some type of device to act as a regulated diversion, controlling the effluent or outflow of the stormwater. The storage effluent will then be transported either to a wastewater treatment plant or a stormwater overflow treatment plant, depending on the capacity of the former, and the volume of stormwater collected. For systems

with combined sewers, regulated diversions in the form of "interceptors" will collect and transport the combined sewer overflows either to a storage area, or to the wastewater treatment facilities.

The term"regulated diversion" actually encompasses many forms of collection, control and diversion schemes that range from quite simple devices to major facilities. Regulators were developed originally to divert combined sewer flow to overflow locations so that pumping stations and wastewater treatment plants would be protected from overloading of mechanical facilities and treatment processes. Now, however, regulating devices are more sophisticated, controlling and diverting water as required throughout various complex systems. As such, all regulated diversions will function automatically or semi-automatically, adjusting to the change in flow conditions. Their mechanical devices consist of tipping gates, cylinder-operated gates, cylindrical float-operated gates, motor operated gates and some types of siphons. By design, they have a range of settings to accommodate the varying volumes of overflow/stormwater to be intercepted and diverted, and respond to flow conditions upstream, downstream, or both, according to their design. Since the control of flow from a proposed wastewater/stormwater system that ultimately requires zero discharge is of a critical nature, regulated diversions lend themselves ideally to automated methods of operation.

2. Trunk Lines, Interceptors, Sewer Mains, Etc. -- Regulated diversions are unique because of the tremendous quantities of stormwater handled. The remaining portions of the stormwater collection and transportation network, however--trunk lines, interceptors, storm drains, etc. --do not require modifications in their system, because they are designed to accommodate the large volumes of water.

   The possibility of storing stormwater within these drain lines should be considered. In a large regional complex, for example, rainfall may occur in certain portions of the system, taxing only small segments. The remainder could be utilized as storage areas for excess water, if the entire system contains: (1) a computer monitoring system to utilize hydrologic data, weather forecasts, flow data (discharge and quality), and wastewater/stormwater treatment facilities data, to control flow throughout the system; and (2) a series of control devices, such as inflatable dams, control valves, sluice gates and diversion regulators, that are capable of being operated by the computer monitoring device.

Stormwater Storage

The periodic fluctuations in the quantity of stormwater necessitate the development either of enormous treatment plants or large storage areas to accommodate excess overflow that might occur under extreme conditions. Unless new techniques that can treat large stormwater flows are developed, most conceptual designs of facilities will include storage as a basic part of the wastewater/stormwater scheme.

Stormwater storage can be subsurface, surface or system storage (in-line). Presented below are the different types of storage available, and the possibilities for their inclusion into a wastewater/stormwater system. The storage areas would be used as required, when the capacities of the treatment facilities become inadequate for the large volume of stormwater which may be predicted.

The principle of storage is that stormwater be stored during peak flow periods, and returned to the system during low-flow periods. Regulated diversions are a key element in the proper regulation of stormwater storage; the efficiency of the storage facility is greatly enhanced by the quality of stormwater and/or combined sewage selected for storage. The following points should be observed in the storage of stormwater, whatever method is utilized:

(1) Whenever possible, the "first flush" stormwater or combined sewage should be transported directly into the wastewater treatment facility.
(2) When the capacity of the storage facility is exceeded, the quality of the stored water should be analyzed against the quality of the incoming water, to determine which source of water will be diverted to the stormwater treatment plant.
(3) The storage capacity requirement will be governed by the design storm selection, selection capacity, and an analysis on the frequency of rainfall within the basin. The capacity of the storage facility must insure that it will be operational in all storms except perhaps the very rare event.
(4) The facility must be controlled automatically so that its discharge can be directly related to flow rate at the wastewater treatment plant.
(5) The storage facility by nature could afford a degree of primary treatment: the settling action of the stored stormwater would reduce its BOD and solids constituents. However, it is anticipated that by providing these operations,

the cost of such a facility would become too high. Consequently the stored wastewater will be kept in suspension by mixing, and aeration.

(6) It is anticipated that the storage will be reduced during non-peak flow periods. A further reduction is expected during periods when sanitary sewage is not utilizing the full capacity of the wastewater treatment plant, such as: nighttime hours, off-peak hours, holidays, and weekends.
(7) The storage facilities must be constructed to allow for periodic maintenance and cleaning, so that the quality of the stored water does not deteriorate.

Considerations to be made when determining the type of storage to be utilized are the following:

(1) Cost comparison with alternative measures of storage.
(2) Availability of land for use as surface storage.
(3) Location of storage site from main system.
(4) Environmental impact of proposed facilities.
(5) Useful life of storage facilities.
(6) Potential problems in operating the chosen form of storage facility.
(7) Reliability of storage system.
(8) Support facilities required.
(9) Other uses of facility.
(10) Legal problems.

Surface Storage

There are various forms of surface storage available for use in a complete wastewater/stormwater system: surface ponds or lakes; lagoons; channels; metal, rubber, and plastic storage tanks; and abandoned primary treatment plants.

The advantages of surface storage facilities over other alternatives are several:

(1) The construction costs are lower than those for man-made subsurface structures.
(2) Maintenance is simpler.
(3) Potential operating problems are fewer in a straightforward system than in an elaborate underground one.
(4) The legal problems of subsurface ownership are avoided because of established ownership of surface land.

There are, however, disadvantages to the facilities utilizing surface storage, among them:

(1) The lack of available land to construct surface facilities.
(2) The possibility that construction of such facilities may prove environmentally unsound.
(3) The unesthetic aspect of a surface storage facility.
(4) The problem that size requirements may force the construction underground, where an abundance of available undeveloped area exists.

Subsurface Storage

Subsurface facilities for the retention of stormwater appear feasible because of the large potential for space, a necessary commodity when anticipating the demands of nature. Subsurface storage can be natural, such as caverns and caves, or man-made structures such as deep tunnels, underground retention tanks, and underwater inflatable tanks. Natural cavern storage, however, can be dangerous because of the possibility of groundwater contamination. Therefore, essential in developing natural areas for underground storage is a sound geologic-hydrogeologic investigation, in order to determine the groundwater status and to develop methods to eliminate any potential dangers.

Natural storage areas require support structures, and so the facilities are not entirely provided by nature. Some pumping is required to insure that the area detaining water until the wastewater treatment plant can accommodate the flow, can be emptied on schedule. It is unlikely that there exists a natural area capable of storing untreated stormwater and discharging it naturally, with no adverse environmental effects.

The utilization of man-made underground storage structures is attractive because of the availability of space, but geologic conditions may refute the wisdom of construction. The construction of deep tunnels such as in the Chicago plan, however, is one approach to creating enormous underground storage chambers.

Advantages of using underground stormwater storage facilities include the following:

(1) The natural storage facilities may be less expensive than even surface storage facilities.
(2) The space to construct facilities of adequate size appear readily available, whereas surface land in close proximity to the urban areas appears minimal.
(3) The cost of transporting stormwater would be less because of the potential proximity of the underground storage facilities to urban areas.

(4) The environmental impact of constructing underground storage facilities may be less controversial than the construction of surface facilities.

There are also disadvantages in utilizing underground storage facilities:

(1) The costs associated with constructing man-made underground stormwater storage facilities are greater than those for surface storage facilities.
(2) Problems of maintenance and operation are more difficult in subsurface facilities than in surface systems.
(3) Legal disputes concerning the ownership of the subsurface area may develop.

System Storage

The many miles of tunnels, trunk lines, and storm drains that exist within a stormwater system could, under certain conditions, be used to store stormwater temporarily. Large metropolitan areas such as Chicago and Detroit utilize this kind of storage; this approach might be feasible also for the large regional systems that may be developed within the Merrimack River Basin. The utilization of system storage is dependent on an accurate assessment of existing conditions, usually obtained from a computer network, and based on the following data: size and location of storm; weather forecast; flow in various portions of the drainage network; flow at the wastewater treatment plant; and the location of the flow diversion devices.

Utilizing only a segment of the stormwater system as a storage facility is limited, since its usefullness diminishes as the storm size increases, thereby eliminating the availability of storage areas within the system. However, the segment approach, as part of a total system that includes surface or subsurface storage facilities, may be used as an overflow device if a storm of great magnitude should occur.

In-system storage areas are created by a series of inflatable dams, valves and regulated diversions. A major advantage of system storage is that the apparatus can be used to reduce or delay the storm hydrograph at the treatment facilities, which may prove beneficial in reducing off-system storage requirements.

Other advantages of system storage include minimal costs for development; and little if any impact on the environment.

The disadvantages of this method are that capacity and nature of the available storage dictate that other forms of storage be utilized to insure the satisfaction of the effluent criteria established by EPA; the storage is available only during local storms, and not when the entire stormwater system is being utilized; the system approach may not be adaptable for existing storm drainage systems; and the technical expertise necessary to properly operate the system may not be justifiable for such a small area.

Summary

It is apparent that some form or combination of forms, of storage will be required to insure that the treatment plants are not unnecessarily bypassed or overflowed because of the tremendous quantities of stormwater expected from rainfall. Factors such as economics, current and future land use, reliability, and environmental policies will weigh heavily in the selection and design of a storage system for a particular region.

Stormwater Treatment

Stormwater may need to be treated prior to its discharge into a receiving body of water, in order to comply with EPA stream quality criteria. As a result, there is a need for the development of wastewater/stormwater systems capable of treating the tremendous quantities of stormwater emanating from a particular area. The following discussion considers the methods of stormwater treatment.

Stormwater will ultimately enter the Merrimack River in one of the following manners:

(1) As effluent from the wastewater treatment plant. The treatment plant will utilize either physical-chemical, biological or land treatment techniques, or any combination thereof, depending on the characteristics of the sanitary sewage and stormwater.
(2) As effluent from the stormwater treatment plant. This plant will be designed to handle the stormwater and, in some cases, combined sewage that exceeds the design capacity of the wastewater treatment plant.
(3) As excess untreated overflow from the stormwater treatment plant. The quality of the overflow discharge will be regulated, by the utilization of the other elements of the total wastewater/stormwater system, either from the stormwater storage facilities in which some form of primary treatment is applied;

or directly from the stormwater drainage network, having bypassed the storage facilities.

(4) As direct overland runoff in rural areas, where no formal drainage systems exist or are contemplated.

Wastewater Treatment Plant

The entire concept of treating stormwater is based on the knowledge that, in all probability, the wastewater treatment plant will not be able to accommodate the stormwater input without major modifications in its operation. The quantity of wastewater influent to conventional wastewater treatment plants that do not handle stormwater, is fairly predictable. The greatest quantity of sanitary sewage occurs with the early morning and early evening hours, while low flow periods usually occur at night and on weekends; this schedule has established routine operating procedures.

The wastewater treatment plant will be used whenever possible to treat stormwater, since its effluent will be of the highest quality. There may be a few modifications necessary for the plant to handle the fluctuating flows of stormwater, but no major process changes are anticipated. The design capacity of the plant will be increased to treat the anticipated stormwater flow only when this is more feasible, economically or practical, than the two other options available: construction of stormwater treatment facility or increase the system storage capacity.

Including stormwater in the system will result in drastic changes, because the design capacity of the plant will be utilized more frequently. Furthermore, the stormwater released from the storage areas will be passed through the treatment plant during periods of nonpeak flow, resulting in modifications of the usual maintenance procedures, which have been based on the expected periods of low flow.

The biological wastewater treatment method will be capable of handling stormwater flow after storage and in conjunction with stormwater treatment facilities to avoid shock loadings that could upset the biological process.

Stormwater Treatment Plant

The design capacities of wastewater treatment plants and storage facilities are limited by economic constraints, therefore, these capacities will be exceeded periodically. A "stormwater treatment plant" will be included in the system to treat overflow from the principal system and to increase further the design capacity of the total system. This treatment plant will probably utilize physical-chemical processes, because of the expected fluctuations in stormwater volume,

since physical-chemical processes are less susceptible to shock loadings than are biological ones.

The degree of sophistication of the stormwater treatment facility will be determined by the anticipated constituents of stormwater inflow and by desired effluent quality. More elaborate treatment processes will be utilized when combined sewers become part of the system, thus incorporating combined sewage into the stormwater treatment plant. Less sophisticated treatment will be possible only when stormwater alone will be treated. The basic purpose remains to treat all the flow at the wastewater treatment plant, whenever possible, utilizing the stormwater treatment facility only when the principal system is overtaxed. The effluent quality of this plant should go far towards satisfying the discharge criteria of EPA.

Stormwater Overflow

It is recognized that the design capacity of the entire wastewater/stormwater system will, on occasion, be incapable of handling the entire stormwater flow. When this occurs, a stormwater overflow facility will by-pass excess flow around the stormwater treatment plant, discharging untreated stormwater into the receiving water or onto a land disposal area. The total system will be operated by an automated regulated diversion, to insure the discharge of all excess flow at the overflow facility, located in the vicinity of the stormwater treatment plant.

Although field studies are now being undertaken in the Nashua River Basin to investigate the quality of combined sewer overflows, it is anticipated that the quality of the untreated stormwater overflow will not meet the criteria as established by EPA; its occurrence, however, will be infrequent. Since the discharge of excess stormwater will usually be associated with high river flows, its impact will be diminished.

As more economical treatment methodologies are developed in the future that are capable of absorbing the overwhelming quantities of stormwater runoff, the need for the overflow system may be eliminated.

Direct Overland Runoff (Rural Areas)

Until recently, little attention has been directed to the contribution of rural surface runoff to water quality problems, except for the suspended solids resulting from soil erosion. In the last few years, however, the importance of fertilizers, pesticides and animal wastes

as water pollutants has become generally recognized.

Handling and treatment of stormwater will occur in those urban areas that will be included in proposed regional schemes, however, there are rural areas within the Basin that will not be a part of a regionalized plan because their present and projected needs do not justify inclusion. These rural areas, therefore, become a potential source of pollution that may eventually enter the Merrimack River. In order to diminish the impact of the pollution source, there are several procedures that can be utilized:

(1) Identify and achieve proper management and control of non-point sources of pollution within the area, such as sanitary landfills, dumps, septic dumping areas, industrial storage areas, recently cleared but undeveloped land, areas under construction, and farm areas practicing fertilization. Steps should be taken to insure that those responsible for these sources operate and maintain them according to procedures that will minimize their pollution potential.
(2) Encourage land use management throughout the area to reduce pollution impact.
(3) Encourage the utilization of separate drainage systems by those located within the rural areas, to reduce pollution loading.
(4) Construct interceptors to collect any overland flow that appears destined for the Merrimack or one of its tributaries.

Summary

The treatment process is extremely critical, because it is the last process before the stormwater reaches the surface stream. Apparently, no restraints other than quantity will hinder the satisfactory treatment of stormwater, according to existing data on stormwater quality. The final decision on the actual treatment processes for stormwater will be made after careful analysis of the pollutograph data furnished by the Corps of Engineers. The design of the wastewater treatment plant will be influenced by the sanitary-industrial loadings, with minor qualitative modifications resulting from the treatment of stormwater. The design capacity of the wastewater treatment facility will be greatly influenced by the amount of stormwater anticipated at the plant.

Stormwater Discharge

There are several alternatives available for the ultimate discharge of stormwater effluent from the wastewater/stormwater system. Three potential sources of effluent discharge from the system are the wastewater treatment plant, the stormwater treatment plant, and stormwater

overflow facility; and the two receptacles of this discharge are water bodies such as rivers, lakes, ponds; and land disposal areas. The possibility of reuse of this effluent should also be considered.

The effluent from the combined wastewater/stormwater treatment facilities will be of a high quality and, therefore, can be discharged into either water or land. However, the potential overflow of untreated stormwater is a serious problem which must receive consideration. The effluent from all three sources could potentially be reused in some manner, depending on its particular quality.

(1) Discharge into River

The discharge of effluent into the waterways of the Merrimack River Basin is to be controlled to meet the quality standards established by EPA. The effluent from the combined wastewater/stormwater treatment plants will satisfy these requirements; but, the quality of the discharge from the stormwater treatment facilities may not consistently meet these standards. The impact of this is lessened, however, because of the infrequency of occurrence and the resultant high river flow, which dilutes the effluent discharge.

(2) Land Disposal

The use of land disposal instead of effluent discharge to a waterway is being investigated throughout the nation for two major reasons: (1) to determine whether a viable alternative to effluent discharge into rivers exists, thus possibly improving the quality of our rivers; and (2) recharging groundwater and irrigating crops with treatment plant effluent.

The groundwater supplies can be refurbished by the technique of rapid infiltration. However, maintenance of the existing quality of the groundwater aquifer must be insured. Utilizing wastewater/stormwater effluent to recharge groundwater supplies could be a tremendous boon to the water supply dilemma that exists in the U.S. Northeast. This matter is more fully discussed in the wastewater section of this study.

(3) Reuse of Effluent

In order to conserve one of our most critical natural resources, water, the concept of reusing, appears not only feasible, but essential. Reuse can take the form of augmenting the current

potable supply, or developing a separate non-potable supply system for certain functions. A primitive form of reuse already exists, in that the downstream users of river water are, in fact, using the effluent of upstream communities. However, a more sophisticated system could be developed to create a "closed" system, from which minimal amounts of water would be lost in the process. The irrigation and groundwater recharge schemes mentioned in the previous section are, in fact, forms of reuse.

d. Summary and Findings

Although of major concern facing the study area today is the discharge of acceptable effluent to the Merrimack River Basin, various alternatives to this approach are presently being developed. It appears that any implementation of these alternatives will not greatly affect the quality requirements of the effluent. If major reuse of water occurs in the near future, this could change the nature of the entire wastewater/stormwater treatment concept.

Findings

Stormwater runoff has a tremendous influence on the total design of a complete wastewater/stormwater scheme that is capable of discharging acceptable effluent into the waterways. However, the inclusion of stormwater into a system with sanitary sewerage eliminates some of the alternative treatment schemes because of stormwater characteristics such as quantity, periodic occurrence, and fluctuating flow.

The basic elements in wastewater/stormwater systems are their collection systems (combined or separate), regulated diversions, storage areas, treatment plants (wastewater and/or stormwater) and discharge facilities. Variations in the basic elements are a possibility, but without a rigorous investigation of a particular situation these are the ingredients essential to any complete system utilizing current technology.

Conclusions

Careful examination of existing stormwater runoff data and data generated by the Corps of Engineers for this project indicates that treatment of separate stormwater runoff will not be necessary as pollutional loadings are predicted to be too low to warrant treatment.

Consequently, all towns with separate systems will not require stormwater treatment. Cities with combined systems (Lowell, Lawrence and Haverhill) will receive detailed consideration.

Due to the unpredictability of storms, it will not be possible to treat the entire discharge, including storm and sanitary flow without employing some type of storage facility to equalize the flow. Additional criteria indicates that the optimum storage period is 15 days during which the stored overflow would be bled back into the system. At that rate, domestic wastewater treatment facilities would have adequate capacity to treat the added flow, thus eliminating the need for stormwater treatment facilities. In addition to the low hydraulic loading rates, there is little available land in the above cities to permit construction of stormwater treatment plants separate from the proposed wastewater treatment facilities.

10. RESOURCE REQUIREMENTS

Water Oriented Treatment

An estimate has been made of man hour, power and chemical requirements for the various processes associated with treatment of wastewater to what has been termed 1985 Stage I levels. These resource requirements are presented in Table 1.

Cost estimates for operating labor for most treatment processes have been computed using a wage rate of $5.50 per hour in order to take into account the rapidly rising pay scale of treatment plant operators; similiarly, the costs of power (electricity and fuel) have risen sharply in recent months and it has been attempted to take this into account by adjusting whenever possible the power costs given in the sources from which cost estimates have been taken. Chlorine has been estimated at $0.15 per pound, methanol at $0.35 per gallon, lime at $25 to$30 per ton, ferric chloride at $90 to $110 per ton (depending upon quantity purchased) and polymer at $1.30 per pound.

In addition to the uncertainty resulting from rapidly changing costs of labor, power and supplies, it should be noted that many of the estimates of operating costs and component parts of the cost of operation have been based upon pilot plant work and required major adjustments to develop cost estimates for full scale facilities. A number of the estimates which have been published are not complete in proportioning costs of operation between labor, power, chemicals, and other costs, and it has therefore been necessary in some cases to perform the apportionment based upon best judgment. Finally, it should be noted that since the costs are derived from several sources, unit costs, wage rates, and scaling factors were not the same in each, it has been necessary to adjust (inasmuch as possible) the costs in order that they be comparable. It should be re-emphasized that advanced wastewater treatment processes are simply too recent a development to have abundant and totally dependable operating data available for their operation, and any detailed cost breakdown for operation must be examined and utilized on this basis.

Table 76 clearly depicts the large savings in labor and power costs realized in large facilities. It can be seen that a tenfold increase in treated flow requires but a four to sixfold increase of labor or power input. Note, however, that chemical savings are relatively minor with increasing size: this is true because the costs of chlorine at a constant $0.15 per pound have been estimated for all sizes of treatment plants, (this was done because

TABLE 76
RESOURCE REQUIREMENTS FOR
1985 STAGE I TREATMENT

MAN HOURS (per year per mgd)	Plant Size (mgd)* 1	10	100
Secondary & chlorination (1977)	6250	3000	1560
Equalization & filtration(1983)	3880	1750	860
Phosphorous removal	2700	1750	1380
Nitrogen removal	4830	1160	530
Carbon filtration	3800	1630	1200
Final effluent aeration	400	130	60
Incineration			
1977	1770	510	340
1985	2500	900	750
Total for 1985 Stage I (excludes 1977 incineration)	24,360	10,320	6340
POWER COSTS (dollars per year per mgd)			
Secondary & chlorination(1977)	10,000	4,500	2,250
Equalization & filtration(1983)	3,100	1,370	730
Phosphorus removal	1,800	1,200	950
Nitrogen removal	9,000	4,100	1,820
Carbon filtration	1,900	1,300	1,220
Final effluent aeration	1,600	580	290
Incineration			
1977	3,200	650	240
1985	12,000	3,000	1,350
Total for 1985 Stage I (excludes 1977 incineration)	$39,400	$16,050	$8,610
CHEMICALS (dollars per year per mgd)			
Chlorine	3650	3,650	3,650
Lime, Ferric chloride, Polymer	11,000	9,130	7,300
Methanol	11,200	11,200	11,200
Total for 1985 Stage I	$25,850	$23,980	$22,150

* mgd - million gallons per day

of the current scarcity of chlorine and uncertainty about its future price), and of methanol at a constant $0.35 per gallon, inasmuch as the pilot plant scale up from which costs for the process were derived indicated that no scale economies in the bulk purchase of methanol would be likely.

Table 76 allows the resource requirement for each increment of treatment to be computed in the same way that the costs developed earlier (in the conceptual design of treatment systems) allowed total treatment costs for each step of treatment to be calculated. In Table 76, secondary treatment and chlorination refers to the 1977, equalization and filtration to the 1983 EPA requirements and the remaining processes to the 1985 Stage I limitations. Labor and power costs for incineration are shown both for 1977 and 1983 treatment (which will consist of primary and secondary sludge)and 1985 treatment (in which chemical sludge will be generated by the addition of lime and ferric chloride for the purpose of phosphorus removal.) The labor and power costs are much higher in the latter situation because the volume of sludge is considerably increased with chemical precipitation and the greater content of inorganic chemicals in the sludge has the effect of increasing the power required to incinerate a unit quantity of it.

Land Application

Table 77 presents resource requirements for land application of effluent by rapid infiltration. Secondary treatment and filtration requirements are identical to those developed for water oriented treatment and presented in Table 76. To these have been added resource requirements associated with rapid infiltration. Note that the incineration requirements shown on Table 77 is the lower of the two costs presented in Table 76, since phosphorus removal and advanced biological processes (and the waste sludges that these processes generate) will not be a part of rapid infiltration treatment. An inspection of Tables 76 and 77 clearly shows the smaller resource demand of the ground treatment system: operating labor and power requirements for rapid infiltration are roughly half, and chemicals costs between 15 and 20% of those associated with complete 1985 Stage I treatment.

We wish to repeat again the statement made in the wastewater treatment section: that rapid infiltration as it is being used in the wastewater management alternates developed for this study, will not result in treatment equivalent to the 1985 Stage I limitations. We are thus making mixed comparison when the resource requirements of both systems are contrasted. Having

TABLE 77
RESOURCE REQUIREMENTS FOR
LAND APPLICATION OF EFFLUENT
(Rapid Infiltration)

MAN HOURS (per year per mgd)	Plant Size (mgd)*		
	1	10	100
Secondary treatment and chlorination	6,250	3,000	1,560
Equalization and filtration	3,880	1,750	860
Sludge incineration	1,770	510	340
Rapid infiltration application (includes pumping to site)	1,180	440	340
	13,080	5,700	3,100

POWER COSTS (dollars per year per mgd)			
Secondary treatment and chlorination	10,000	4,500	2,250
Equalization and filtration	3,100	1,370	730
Sludge incineration	3,200	650	240
Rapid infiltration	1,845	1,230	1,110
	$18,145	$7,750	$4,330

CHEMICALS (dollars per year per mgd)			
Chlorine	$3,650	$3,650	$3,650

* mgd - million gallons per day

pointed this out, it must also be stated that for equivalent treatment, (or in other words, water oriented treatment resulting in wastewater discharge similar to that which will emerge into a waterway from bank storage after rapid infiltration) resource requirements and costs would still be significantly greater for the water oriented than the rapid infiltration system. The method of land application which is capable of achieving wastewater treatment equivalent to 1985 Stage I discharge limits is spray irrigation; however, this type of wastewater treatment was not widely feasible within the study area because of the land requirements necessary for this method. For this reason, no large scale treatment operations using spray irrigation were calculated as part of the study.

Spray irrigation is, however, feasible in several small treatment situations, and spray irrigation operations consisting of aerated lagoons and chlorination, storage lagoons and land application areas were estimated. The facilities were in the size range of 0.3 to 1.0 mgd, and Table 78 displays a comparison of resource requirements for a 1.0 mgd spray irrigation installation with a similiarly sized water oriented facility utilizing 1985 Stage I treatment. (To make the comparison more correct, the incineration unit costs for a 10.0 mgd installation have been used since one of the design decisions in the study was that small facilities would transport their sludge to a nearby large installation for incineration. Note too that there is no sludge handling required for the aerated lagoon design proposed since complete aerobic digestion of the sludge is presumed to take place in the aerated lagoon.)

Table 78 shows that staffing requirements are about a third, power costs about the same, and chemical costs much less for spray irrigation compared with the water oriented technology. The lower man hour and chemical requirements of spray irrigation are not a surprise since the treatment is so much simpler; however, the (roughly) equal power costs are. This is due to the type of lagoon system selected (allowing complete sludge digestion and therefore no sludge handling costs), the 7 month storage period required for spray irrigation (and the necessity of aerating the storage lagoon to maintain its aerobic character), and the power usage associated with high pressure spraying for irrigation. Considerable savings in power costs could be realized by using less or perhaps no aeration in the secondary or storage lagoons; this would however, lead to a dramatic increase in land area required (for example treatment lagoons would be decreased in depth from 12 to perhaps 3 or 4 feet, and the storage lagoon from 20 to perhaps 5 feet).

TABLE 78
RESOURCE REQUIREMENTS
WATER ORIENTED VS. SPRAY IRRIGATION
(based on 1 mgd plant)*

WATER ORIENTED	Man Hours per year	Power ($/year)	Chemicals ($/Year)
Secondary & Chlorination	6,250	10,000	3,650
Equalization & Filtration	3,880	3,100	-
Phosphorous removal	2,700	1,800	11,000
Nitrogen Removal	4,830	9,000	11,200
Carbon Filtration	3,800	1,900	-
Final Effluent Aeration	400	1,600	-
Incineration**	900	3,000	-
Total	22,760	$30,400	$25,850
SPRAY IRRIGATION			
Secondary Aeration Lagoons & Chlorination	2,420	9,360	3,650
Storage Lagoons	1,670	9,950	-
Spray Irrigation	3,230	9,850	-
	7,320	$29,660	$3,650

* mgd - million gallons per day
** Incineration based on 10 mgd facility, see text.

This would result in greater staffing requirements than wastewater treatment by spray irrigation (this, because of rainfall being a partial function of the surface area of the lagoons).

Ozone and Carbon Filtration

In the conceptual design of water oriented treatment processes a comparison of the use of ozone for organic reduction, disinfection and effluent aeration with a more conventional (if any of the advanced treatment processes can be considered conventional) treatment sequence consisting of carbon filtration, chlorination and final effluent aeration was addressed. It will be recalled from that discussion that operating costs of the carbon filtration system were significantly lower than those for ozonation, but that there were other considerations beyond cost which might favor the ozone system, and these were beyond the scope of this study. In order to assist the study team to evaluate the two systems, a breakdown of resource requirements for ozonation is presented in Table 79. Similar requirements for the carbon filtration and chlorination systems are also shown in Table 79 to facilitate the comparison.

TABLE 79

RESOURCE REQUIREMENTS
OZONATION VS. CARBON FILTRATION
CHLORINATION AND EFFLUENT AERATION

	Plant Size (mgd)*		
Ozone	1	10	50
Manhours per year/mgd	1,900	380	380
Power Costs, dollars/mgd	33,900	23,390	20,000
Oxygen Cost, dollars/mgd	13,900	5,550	4,050
Carbon Filtration System (including chlorination and aeration)			
Man Hours per year/mgd**	4,200	1,760	1,260
Power, dollars/mgd**	3,500	1,880	1,510
Chlorine, dollars/mgd	3,650	3,650	3,650

* mgd - million gallons per day

** Man Hour and Power requirements for chlorination not included in this total. These costs represent a very small fraction of the secondary costs shown in Table 76.