PHYSICAL-CHEMICAL WASTEWATER TREATMENT TECHNOLOGY:
An Analysis of Impacts to Wastewater Service

by

James G. Osborn, Jr.

Submitted in Partial Fufillment
of the Requirements for the
Degree of Bachelor of Science
at the
MASSACHUSETTS INSTITUTE OF TECHNOLGY
June, 1973

....
Department of Urban Studies and Planning
May 11, 1973

Certified by..
Thesis Supervisor

Accepted by..
Chairman, Departmental Committee on Theses

ABSTRACT

Physical-Chemical Wastewater Treatment Technology: An Analysis of Impacts to Wastewater Service

by

James G. Osborn, Jr.

Submitted to the Department of Urban Studies and Planning on May 11, 1972 in partial fulfillment of the requirements for the degree of Bachelor of Science.

Spiralling demand and constant supply of water resources indicate that more efficient waste water treatment practices are necessary. Traditional practices have used biological processes to treat wastes. through generally large regional sewerage systems.

Emerging physical-chemical technology promises the feasibility of environmentally sound smaller treatment networks. These smaller networks offer a number of advantages over larger ones in achieving more efficient management of a community's water and financial resources. Physical-chemical plants also promise the feasibility of alternate forms of urban development. These arguments suggest that planners may wish to take a greater part in the process through which wastewater networks are designed, financed and controlled.

Thesis Supervisor: I. Donald Terner

Title: Assistant Professor of City and Regional Planning

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION - I

Unless we alter our current water practices, parts of the United States will suffer a water crisis within 10 years. As a nation, we have enjoyed a considerable abundance of water, a fact which has had tremendous influence in maintaining our high standard of living. However, if the current use and treatment of our water resources continues, sufficient supply of usable water will not be available to full future demand for domestic, industrial and agricultural needs.

The Department of the Interior projects that water demands for 1980 will be about 600 billion gallons a day (bgd).[1] The most that all proposed engineering works across the country will be able to supply at that time will be about 650 bgd. As the water supply is not uniform in quantity or quality across the nation, some arid and urban areas may suffer a shortage by 1980. This shortage will be particularly acute for urban areas because the intial urbanization and continued operation of cities cannot occur without the importation of millions of gallons of water a day to service residential, commercial and industrial needs.

Many perceive water to be a "free" good because of its abundance. It is, however, very much subject to supply and demand market considerations. The supply of our nation's water is 75% drawn from groundwater and 25% from surface water.[2] As these supplies are recharged only by precipitation, our total supply remains relatively fixed to the total amount of rainfall. Our demand for water, however, has skyrocketed. Four conditions are chiefly responsible for the increase in total water use.[3]

A. Compared to 1900 statistics, our population has increased 340%. It will double in the three decades between 1950 and 1980.

B. Per capita use of water has quadrupled since 1900.

C. Industrial water use had increased 11 times since 1900.

D. Irrigation uses have increased 7 times since 1900.

Of these water uses, all but part of the irrigation water is returned as wastewater which must be disposed of in some fashion. Of the 150 gallons per day (gpd) per capita we use as a national average, 120 gpd are returned through the sewage system.[4]

As our demand for water spirals and our supply remains static, it is clear that we cannot afford to be inefficient with our water resources. There is room for minor improvement within the existing water system for increased efficiency through such efforts as greater elimination of unaccounted for water and other operational corrections. It is generally recognized by engineers and planners, however, that in the long run, the only viable solution to adequate supply problems will be the reuse of water already in the system.[5] If wastewater from domestic, industrial and agricultural sources were made directly reusable, the Federal Water Pollution Control Administration estimates that it could supply 70% of our present national water demand.[6]

Current waste treatment practices cannot remove wastes sufficiently for the direct reuse of water. They are simply not designed to do so. In the last 10 years, there have been advances in waste treatment technology, however, which promise more efficient processing of wastewater than is feasible with traditional practices. This new technology involves the use of physical-chemical processes to augment or replace standard biological ones.

Achieving the necessary increases in efficient use of water will not evolve naturally. They will take the concerted efforts of engineers, planners and local citizens to solve their water supply problems.

The technical design of the system is without question the responsibility of the engineer. Such work requires a degree of expertise far beyond the general training of the planner.. The design of the system, however, has vast impacts on the planner's trade. Different types of facilities effect very different settlement patterns. Likewise, differing systems will have varying impacts to the capital expenditure program of a community. The planner should be acutely aware of just what parameters for the community are being utilized in the system design. As Charles Gibbs points out in his article "Basin Management Techniques for Sewerage Agencies," no single factor has a greater overall effect on water quality management than the land use plan which is the guide to functional planning.[7] Very permanent facilities may be constructed by a community on the basis of a given land use plan. If, however, insufficient detail or thinking has gone into the development of that plan, there is very little opportunity for correcting any undesirable development which may have resulted from the sewerage system.

Likewise, a certain sewerage design may result in a system which is ultimately difficult or impossible to adequately administer or pay for.

An acknowledged role for the planner is to serve as a generalist in integrating the efforts of various professions serving the needs of the community, to ultimately to effect a desired future environment. Planners cannot hope to perform this role adequately, however, without some knowledge of the operation of service systems for the community and without some input to their design.

It is the intent of this thesis to deal with a specific design input to wastewater treatment systems which will have important implications for urban development. This input involves the selection of the treatment technology for processing the water wastes.

The use of small treatment plants to handle a community's wastewater has traditionally been dismissed because they were considered to be too expensive and inefficient at that scale. The advent of new physical-chemical technology, however, offers new design processes which suggest that the use of smaller plants should be reexamined. In fact, physical-chemical systems offer 8 reasons for the use of this technology to achieve more efficient handling of a community's water and financial resources:

1. Physical-chemical systems have a proven capability for higher quality of waste treatment. Specifically, these processes can remove a greater percentage wastes and more types of pollutants than standard treatment can.

2. Wastes can be totally reduced at the treatment facility.

Current practices discharge partially treated wastes into water bodies or on land for further assimilation of the wastes. Physical-chemical systems have essentially three products, nearly pure water, sterile ash, and harmless stack gases.

3. Physical-chemical systems can operate with improved monitoring systems which permit less necessary servicing by operators. Hence, one person may operate up to 5 plants a day.

4. The new technology offers higher environmental benefits than standard practices. Specifically, physical-chemical systems can:

A. Help arrest eutrophication by reducing nitrates and phosphates in treatment plant effluents,

B. Remove dangerous and offensive toxins unaffected by biological treatment,

C. Operate without being adversely affected by daily fluctuations or by certain types of pollutants,

D. Complete treatment in less time than standard practices, Also, plant equipment may be compacted so that the land requirements for physical-chemical plants may be ¼ or less than those of biological plants,

E. Operate without offensive impacts to surrounding areas. Hence, physical-chemical plants may easily fit into the residential area it serves,

F. Permit the reuse of treated wastes for drinking, recreational or water supply recharge purposes.

5. Physical-chemical systems permit communities to upgrade their treatment facilities without taking additional property.

6. The small treatment plants feasible with physical-chemical systems permit more efficient expansion of existing municipal capacity. Specifically, small plants permit more efficient increments in the capital expenditure of a community and they reduce the need for large inefficient collection networks.

7. Physical-chemical processes offer new alternatives to waste disposal for subdivisions fostering more efficient land use than rambling subdivisions with septic tanks. The small plants also enhance cash flow considerations for community builders.

8. Future physical-chemical technology promises a unit which can recycle water for a single family. Such a unit may offer benefits in underdeveloped and developed countries alike including:

A. Amelioration of basic health problems,

B. Adaptation to the current process by which low income shelter is built, and

C. Liberating individuals or groups from dependence on governmental assistance in water and sanitary service.

Sections II and III present a brief introduction to traditional waste treatment practices and to the new physical-chemical technology. It is important to note that these are intended to offer an overview of practices and as such provide an oversimplified description sanitary engineering practice. It represents, however, a basic body of information with which planners should become familiar if they hope to effectively understand alternatives and coordinate the inputs of engineers in solving the wastewater problems of the total community.

Section IV presents a comparison of these processes in terms of their effectiveness in waste treatment and their impact on the environment.

Section V presents some of the impacts of the new physical-chemical technology on the process by which wastewater service is supplied. These impacts are discussed from the viewpoint of municipalities, developers, and developing countries.

Section VI presents a relative description of the costs involved in the processes. This section does not present a rigorous cost comparison as the process is still new and cost data is limited. It does, however, describe what the major parameters of such an analysis might be in order to assist in selection of the best wastewater system for a community.

CURRENT PRACTICES - II

The volume of wastewater generated by a community is the single most important determinant in the design of the sewerage network and treatment facilities. This volume is determined by multiplying the population times the per capita use of water. As stated in the introduction, this per capita use of water in the U. S. has skyrocketed. Estimates for the average per capita daily consumption of water range from 130 to 170 gpd.[8] Appendix A lists common rates of consumption for various domestic and commercial uses.

Domestic wastes are composed of five basic elements:[9]

1. Floating debris and large pieces of organic material which cannot be readily reduced by natural biochemical action,
2. Suspended organic sand and grit which easily settle out,
3. Dissolved inorganic materials, such as salts and chemicals which pass through biological treatment,
4. Suspended, dissolved or colloidal organic material which degrade, and
5. Bacteria and disease carrying microorganisms which are treated by disinfection.

Measurement of these elements is generally in three groups. The percent of suspended solids measures the first three elements. A coliform count measures the last element. Biochemical Oxygen Demand (BOD) measures the fourth element. This important term is a measure of the amount of oxygen required by the organic material in the wastewater to be assimilated. Appendix B.gives a breakdown of typical wastewater characteristics..

Lakes, rivers, and oceans go through a natural purification process by which wastes are absorbed, assimilated and rendered harmless. This process works perfectly well as long as dilution factors (the ratios of receiving water to sewage) are sufficiently high. However, it is well known that since the end of the 19th Century, the natural capacity of many water bodies has been overloaded and man has had to imitate this natural process and accelerate the decomposition of wastes in treatment facilities to adjust for the limited capacity of the water body.

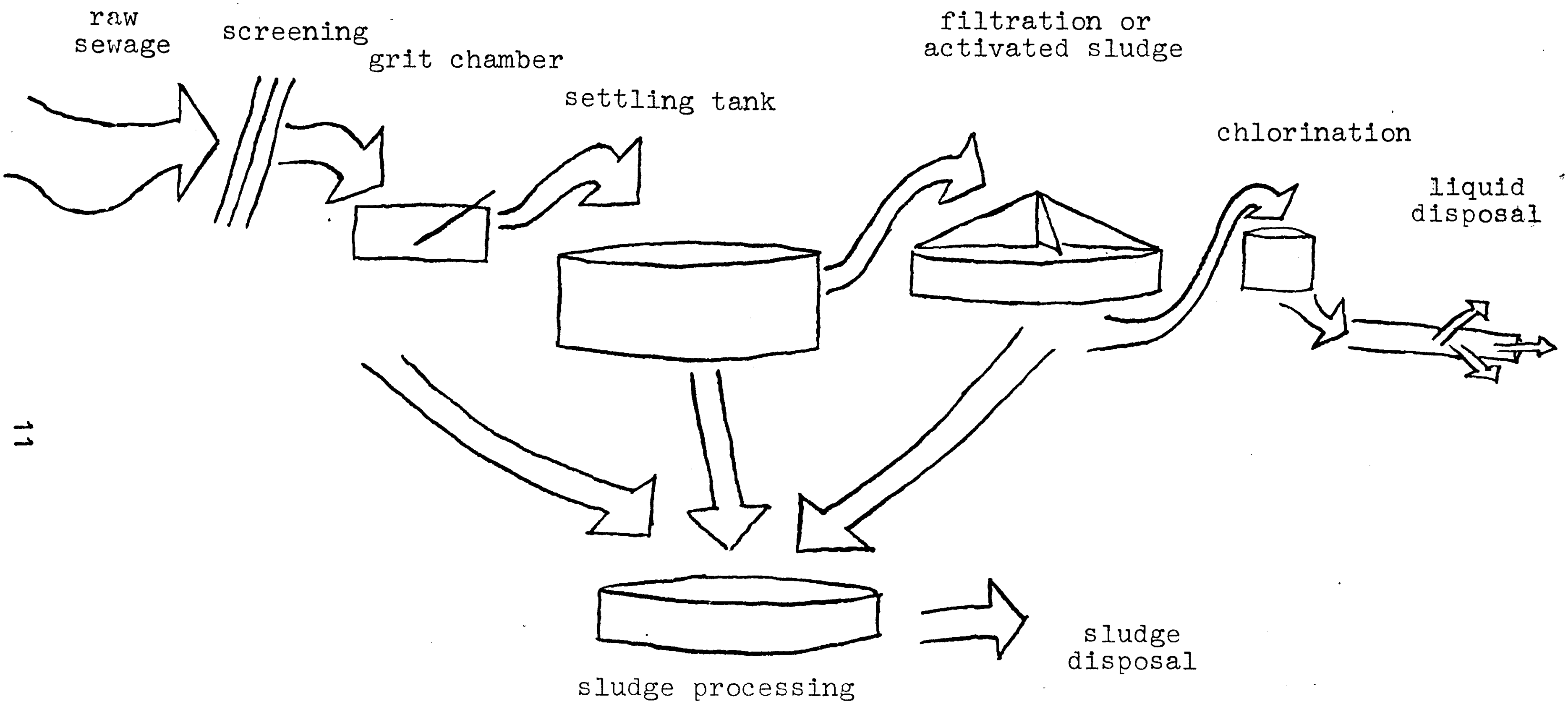
In the past, treatment facilities have been the most economical when they have made the greatest use of this natural water purification process. Therefore, levels of treatment have generally been kept to a minimum. Hence, the water reuse capability essential for adequate water supplies in the future does not exist in current practice.because traditional processes were not designed for that high degree of treatment.

The technology employed in sanitary engineering today was essentially developed by the first quarter of this century. The biological treatment which is central to current practice was perfected in England by Arder and Lockett in 1914.[10] Because of the social and topographic conditions , England was one of the first countries to be plagued with pollution problems. Her typically small streams and surrounding high land use densities caused untreated wastewater to become a nuisance to health, agriculture and manufacturing by the mid 1800's. Several cholera epidemics around 1850 particularly spurred attention to water waste problems.

The early solutions to such problems were primarily concerned with removing infectious bacteria which presented health hazards and suspended solids which disrupted industrial water use and navigation. It is interesting to note that an expressed purpose of the 1899 Rivers and Harbors Act was stated to be the prohibition of any discharged waste material which might be hazardous to navigation. Health hazards were not considered until the Public Health Service Act of 1912.[11]

This traditional treatment process may be accomplished in three stages which are generally termed primary and secondary treatment and disinfection. Figure I represents a flow chart of the process.

In primary treatment, waste is passed through screening devices which remove the large organic material and floating debris. These screenings are then processed as either solid wastes or ground up in a comminutor and resubmitted to the incoming sewage. The sewage may then pass through a grit chamber which has a low enough flow velocity that the suspended organic grit and sand settles to the bottom. The effluent then is detained in a holding tank for several hours. During this period, some of the solids will settle to the bottom or float to the surface. The removed wastes are then handled in a sludge process which will be discussed later. The liquid effluent from the holding tank is then the completed product of primary treatment and is either discharged into receiving waters or sent on to further treatment. Figure II shows the usage of treatment



TYPICAL FLOW CHART OF A BIOLOGICAL PLANT

FIGURE I

processes as a percentage of U. S. population.

FIGURE II

Primary treatment represents the minimum augmentation of natural processes. See Figure IV for treatment efficiencies.

The liquid product from the settling tank then may move on to secondary treatment in which bacteria cultures (generally in the presence of oxygen) accelerate the decomposition and stabilization of the matter remaining in the liquid. This treatment is generally accomplished by either the trickling filter or activated sludge method. The first process trickles the liquid through gravel filters containing bacteria consuming microorganisms. The oxygen necessary for this activity is pumped up through the filter medium. The products of the biological action are washed out and carried by the liquid to a settling basin. In the activated sludge process, the sludge is aerated in a special tank to accelerate digestion of organic matter. Three parts fresh sludge are mixed with one part partially decomposed sludge already rich in microbes. Again, the sludge goes through a final settling tank. The secondary effluent is much more refined than primary effluent (see Figure IV) but the water must still go through continued assimilation by dilution before it is usable. As shown in Figure II, about 40% of the U. S. population is served by secondary treatment.

Generally, any disinfection consists of routine chlorination which destroys 90-95% of the infectious bacteria present in the effluent but has no effect on the BOD or suspended solids. This effluent is then discharged into the receiving water body.

It is important to note a number of other secondary processes which do not have the many million gallons a day capacity of the previous two systems but are gaining in popularity amoung smaller communities.

Package plants are prefabricated treatment works requiring fairly little effort for installation. They utilize an extended aeration process which is a slight variant of the activated sludge method. They are complete plants, providing screening, comminution, aeration, settling, and chlorination. These plants can handle up to 200,000gpd.

Extended aeration plants use the same units as package plants but are constructed on the site and can handle daily flows of a few million gallons.

An aerated lagoon is the simplest form of secondary treatment.

It uses large asphalt lined basins containing about 20-30 days detention of sewage. Air is continuously diffused from the bottom of the tank. The unit processes include screens, grit chambers and chlorination. They can be designed for up to 5 mgd.

Oxidation ponds use the same unit processes as the extended aeration package plants only a less expensive lined pond or ditch is used instead of an aeration tank. They can be designed for up to 400,000 gpd.

Sludge is the solid matter removed during each of these unit processes and forms an offensive concentration of wastes. The general method of sludge treatment is digestion through heated processes without the presence of oxygen (anaerobic) in a container. The digested sludge can ban be buried , burned or sold as loam or a weak fertilizer.[12]

In summary, traditional processes use biological action to imitate and accelerate the natural processes for purifying wastes. The following section will describe how physical-chemical processes work.

PHYSICAL-CHEMICAL PROCESSES - III

The technology necessary to remove enough of the waste in sewage to make it reusable for multiple purposes has existed for at least two decades. Instead of imitating natural purification, it involves the use of chemical and physical processes to strip wastes from the water medium.

This technology has not been employed for two main reasons:

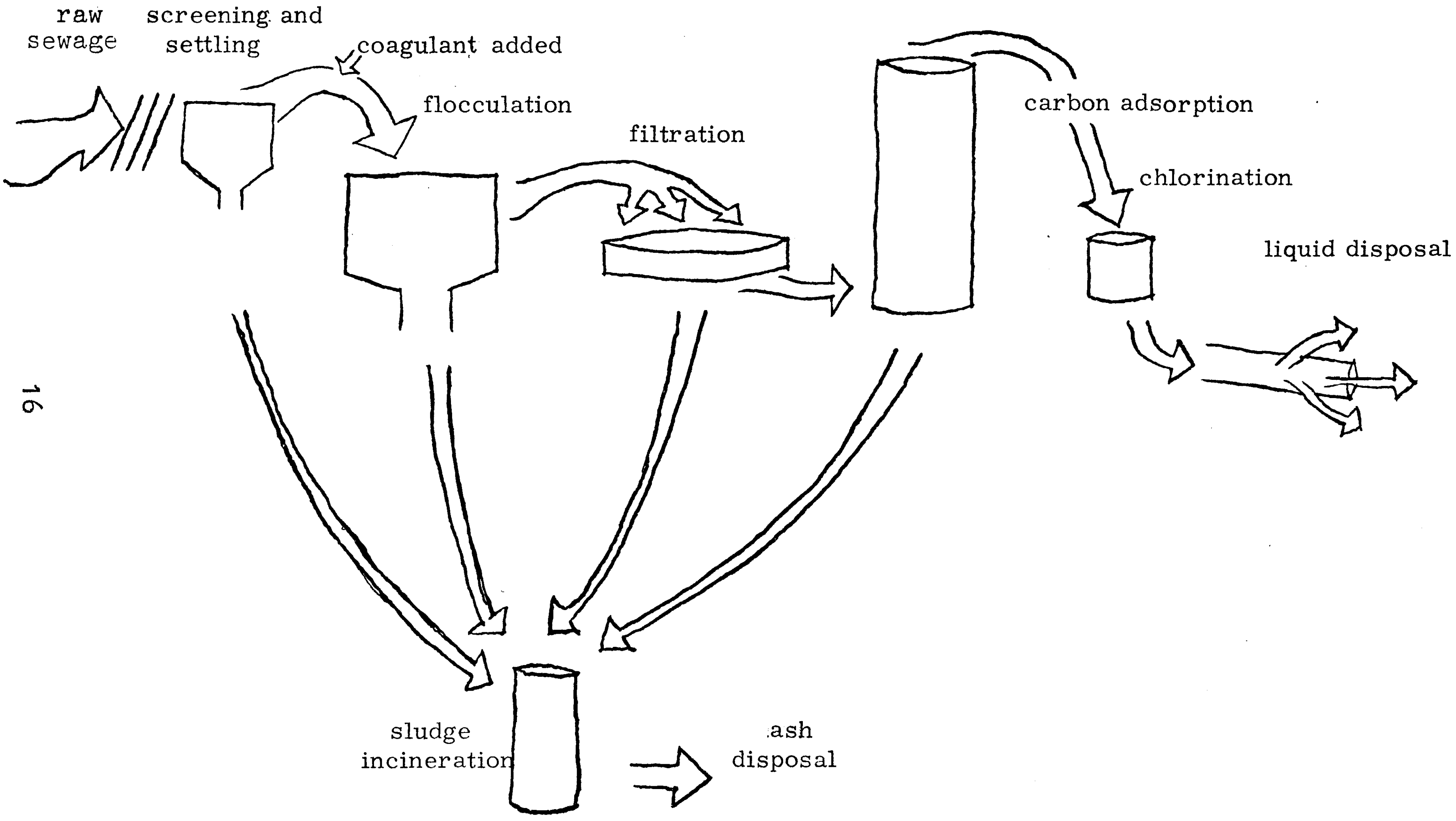
A. The development and operating costs were too high relative to biological processes, and

B. The goal of fully treated reusable water was seen as highly extravagant and unnecessary.

Wastes could be marginally treated and discharged without complaint by anyone downstream, so that was all that was done. This practice is no longer acceptable and water quality demands are slowly reordering priorities in waste treatment methods.

Figure III shows a typical flow chart of the stages in physical-chemical treatment. The screening and settling stages are common to this new process and the primary treatment. The effluent is then treated with coagulant chemicals (such as lime, alum, or iron salts) which cause solid matter particles to cling together and settle rapidly to the bottom. This process is known as flocculation. Virtually all settleable solids are removed in this step.

The remaining solids are removed in the filtration stage when the clarified wastewater is passed through beds of sand and crushed anthracite coal. Then the effluent is passed through columns of activated carbon to remove any dissolved organic material remaining.



TYPICAL FLOW CHART OF A PHYSICAL-CHEMICAL PLANT

FIGURE III

It is in this stage that the organic phosphates and surfactants (detergents) can be removed which are unaffected by traditional waste treatment processes.

Finally, the effluent is disinfected by the addition of chlorine just as in standard treatment processes.

Figure III is typical of a number of plants being marketed today.[13] As in standard treatment, different unit processes may be added or deleted depending on the desired degree of treatment. There are variations to this scheme which increase the sophistication of the plant.

One such additional device involves the application of a magnetic coagulant to the clarified sewage effluent. This liquid is then passed through a magnetic filter which draws out the flocculated particles.

Nitrates can be largely removed by ammonia stripping towers which use forced ventilation and treated hemlock slats.

Microscreening utilizes 23-35 micron screens to remove waste particles.

Alternate physical-chemical processes which are currently being studied but are not ready for economical use involve reverse osmosis and select ion exchange to further separate wastes from the water.

The sludge is reduced to a sterile ash by incineration.

Efficiencies of removal of these processes will be discussed in in the following section dealing with comparisons of the standard and physical-chemical processes.

COMPARISON OF PROCESSES - IV

Sections II and III have presented descriptions of standard and new wastewater treatment practices to introduce the planner to the basic technology involved.

Section IV will deal with the comparison of specific design parameters for the two processes. These parameters have been placed into two major groups, service quality and environmental quality. The first deals with the effectiveness of the process in dealing with wastes. The second deals with the effect of the process on the environment.

Service Quality

As described in Section II, wastewater treatment processes can no longer be content to leave most of the assimilation of wastes to the receiving water body. New processes must be used to accelerate this assimilation so that water may be more readily reused and so the accumulated wastes will not pollute the environment.

The most important service quality feature of the new physical-chemical processes is that they have a proven capability for higher quality waste treatment. As described in the previous section, physical-chemical methods strip waste matter from the water medium rather than attempt to assimilate it. This approach has two main advantages:

A. Physical-chemical systems remove greater percents of waste matter than biological methods, and

B. Physical-chemical methods remove more types of wastes.

Figure IV shows the removal efficiencies of various processes as a percent of waste present. There are dramatic increases in the capacity of suspended solids and BOD removal for the new method. (The chemical chlorination is common to both standard and new processes) These higher results have been consistently achieved in experimental and operating plants across the country.[14]

TYPICAL TREATMENT EFFICIENCIES

	% Removal of			
Process	BOD	SS	Bact.	Phos.
Fine screening	5-10	2-20	10-20	0
Plain sedimentation	25-40	35-65	25-60	7-12
Trickling filters	65-90	70-90	70-95	20-30
Activated sludge	65-95	65-95	80-98	35-45
Chlorination	15-30	0	95-99	0
Package plants	75-90	N/A	N/A	0
Chemical precipitation	60-85	90-98	75-90	90-95
Filtration	75-80	97-98	N/A	98
Carbon adsorption	95	97-99	N/A	97-98

N/A: Not Available

Sources:

Merritt, F., Standard Handbook for Civil Engineers, p. 22-26

Grava, S., Urban Planning Aspects of Water Pollution Control, p. 179.

"Use of New Technology in Municipal Wastewater Treatment," Technology Transfer, p. 5.

Fair, G., et al, Elements of Water Supply and Wastewater Disposal, p. 321.

FIGURE IV

The second advantage deals with the types of wastes removed. As noted, biological processes breakdown organic wastes. However, not all waste matter is organic. Inorganic phosphorous and nitrogen waste compounds are not affected by these processes and as such pass through the plant unaffected and into the receiving water. However, these inorganics are the very nutrients which cause algae growths and accelerate natural eutrophication processes turning lakes into marshes in a matter of years instead of centuries.[15] Likewise, the well documented suds problem for surfactant inorganic detergents can be directly traced to the inability of treatment plants to remove those inorganics. There is also a growing class of industrial wastes which not only are unaffected by standard practices, but actually destroy the essential microorganisms assimilating organic wastes. When this occurs, plants continue to operate, but it may be a period of weeks before the bacteria rebuild and actually treat the wastewater.[16] An example of these industrial wastes can be seen in the Detroit River. The following wastes are discharged directly into the river DAILY [17]

19,000	gallons of oil
200,000	pounds of acid
2,000,000	pounds of chemical salts
100,000	pounds of iron

Biological processes are totally ineffectual in removal of any of these toxins and they remain suspended in the water which discharges into nearby Lake Erie, a lake which many regard as past the point of no return in eutrophication,[18].

With the correct staging of unit processes, physical-chemical methods can strip essentially all of these wastes from water. This in one of the reasons that the Environmental Protection Agency is actively trying to integrate this technology into treatment practices through the use of design manuals, seminars and conferences.[19]

A second service quality advantage of physical-chemical systems is that wastes can be totally disposed of on the site, A hidden cost to any standard plant is the disposal of the partially neutralized sludges. As a general figure, the volume of sludge is two orders of magnitude less than the incoming volume of wastewater. (ie. 1,000,000 gallons of wastewater yields 1000 gallons of sludge) [20] As previously cited, typical disposal can involve composting, or sale as a weak fertilizer, or loam. Standard practices often thicken the sludge by dewatering through a number of practices, but eventually a volume of sludge must be put somewhere.

Physical-chemical processes have essentially 3 products, high quality water, sterile ash, and harmless stack gases.[21] Incineration of the solid portion from the treatment process reduces high volumes of sludge into a few pounds of ash per week. One producer claims that a 3 mgd plant (serving about 30,000 people) would generate less than a dump truck load of ash per week.[22]

Realistically, there are pros and cons to these arguments. Some engineers hold that incineration is merely a method of transferring waste disposal from one medium to another. However, considerable engineeringhas gone into stack scrubbing devices which render harmless exhausts.

Where sanitary landfills or fields needing fertilizing are existent, then sludge spreading represents a useful recycling of the waste matter. A problem here is that where sufficient land for such uses exists, the population is generally not dense enough to need treatment plants. Or if the population is dense, suitable land is protected by wary residents using prohibiting zoning regulations. Thus many municipalities have resorted to incineration of solid wastes (garbage/rubbish) and the same techniques can be used for sludge products from wastewater treatment. Efficient systems for total wastes handling could be set up for incineration of both solid and water wastes.

It is interesting to note that NASA made use of such a combination in its space probes in what it terms a Multiple Integrated Utlity System.[23] This makes use of waste heat to generate electricity for a closed system. Abt Associates, Inc., is currently investigating the use of this technology for development in an urban residential context, but the costs are too high for use in the near future.

A last problem with incineration is that the ash, albeit less voluminous than the sludge, must also eventually be disposed of. Research is investigating various uses of the ash such as a building block material.

As a final service quality comparison for the two systems, it appears that they require comparable input costs for operation and maintenance. Secondary plants involve considerable mechanical equipment beyond pumps. Generally, mixers, aerators, sludge handling equipment and filtering apparatus are involved in standard plants and demand considerable maintenance. Physical-chemical plants have little beyond pumps which can easily be either replaced or equiped with duplicates in critical areas.[24] As the process is only recently being marketed, the existing maintenance costs are still high.

Operating costs for any treatment plant chiefly involve inputs of:

1. Materials (energy, chemicals, powdered carbon etc.) and
2. Labor (skilled operators).

Physical-chemical plants unquestionably involve higher input of materials than standard biological processes. Both demand roughly the same energy inputs but the costs for chemicals and for carbon regeneration are quite high.

Originally it was thought that the new physical-chemical plants would also require more skilled and hence more expensive plant operators. This, however, was not found to be the case in the 7.5 mgd physical-chemical plant at Lake Tahoe, California. In fact, due to improved monitoring and automating capabilities possible with the process, operation of advanced waste treatment at Tahoe was less difficult than operating activated sludge systems. Russel Culp, the general manager for the plant, reports that on the job training of operators lead to satisfactory plant operation, that is, four years of operation without interruption while producing reclaimed water for the lake which has continually met the high local water quality standards with virtually potable water.[25]

This automatic monitoring is an important advantage for physical-chemical processes. Manufacturers promise that plants can operate continually and reliably with only intermittent servicing by operators. If anything goes wrong, plants automatically stop and control panels indicate the source of failure. One producer claims that a single employee can service up to 5 plants located within a reasonable driving distance. As will be discussed in Section V, this is an important implication for the use of the technology.

Section VI will deal more thoroughly with relative costs.

Environmental Quality

The environmental quality aspects of the various treatment processes deal with the impact of the process on the environment. The chief environmental benefits of physical-chemical systems arise from the higher quality of treatment possible with their use. Among these, the higher quality of removal and effectiveness of monitoring the system are the major advances. This is logical as the increases in technology providing the greater service quality have followed the pressure of environmentally concerned groups and the financial and administrative support from the EPA.

A major contribution to the environment of this new process has been a capacity for arresting the eutrophication of rivers and lakes. Eutrophication is a natural condition in which too many nutrients in the water induce algae growths which in turn die, decay and use up oxygen in the water and diminish the life supporting capacity of the waterbody. As previously cited, this process eventually turns lakes into marshes over a period of hundreds of years, depending on the size of the water body. Pollutants, however, have greatly accelerated this process which may now occur in only a matter of a few years.

The main nutrients involved are nitrates and phosphates. As discussed, standard practices have little facility for the removal of such inorganics. The total phosphorous in the effluent from chemical precipitation, however, can now typically be reduced to 1 milligram per liter, or 98% removal.[26] Nitrogen removal, the more difficult of the two, can be operated to remove about 90% of the ammonia nitrogen (NH_3), the predominant form of nitrogen in treated sewage.[27]

The success of this process has been convincingly shown in the physical-chemical plant on Lake Tahoe. The lake had suffered growing algae blooms and other signs of eutrophication. This condition significantly reversed following installation of the plant utilizing many advanced waste treatment techniques. In fact, the final effluent from the plant is of better quality than the drinking water of many towns and villages.[28]

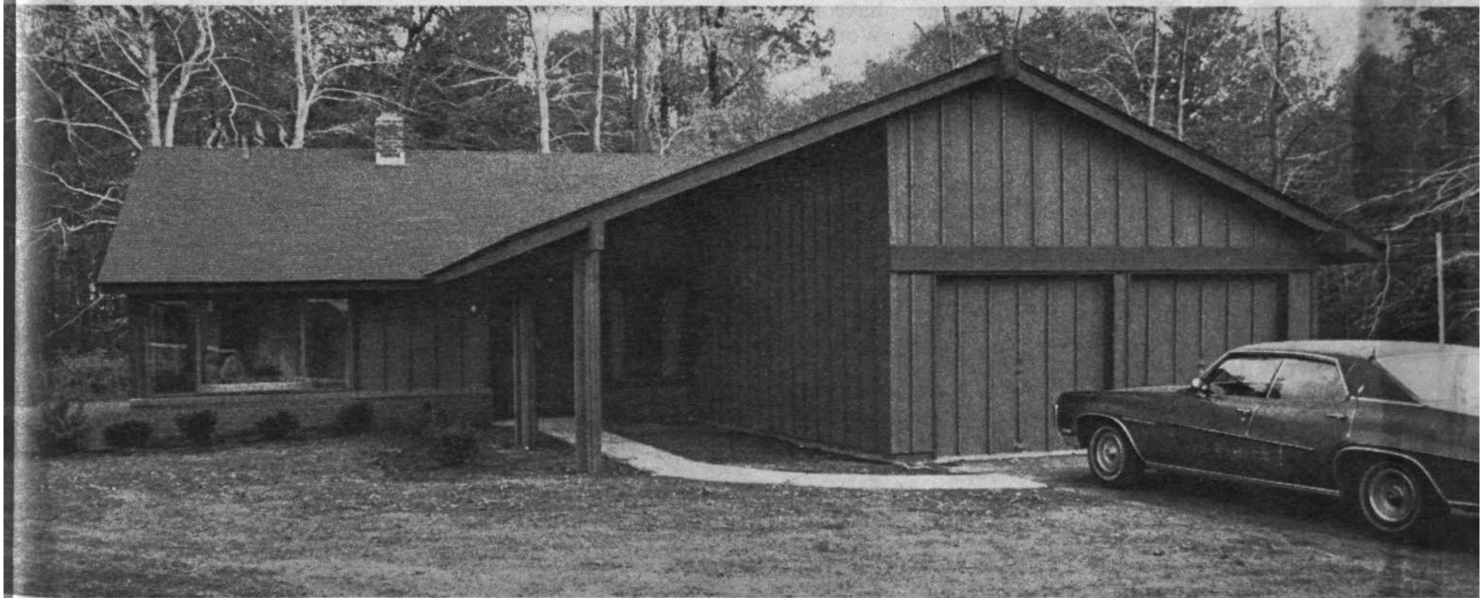
In addition to arresting eutrophication, physical-chemical systems can remove toxins such as grease, metals and acids.which contribute to the fouling of water and soil. Again, the high quality monitoring permits consistent discharge of fully treated wastes. As toxins have no ability to disrupt the treatment, the quality remains high. Another important advantage is that physical-chemical plants are not subject to failures due to "shock loading" or daily fluctuations in rates of flow. To function properly, bacterial activity must be kept at a fairly constant level. Should that level fall, the microorganisms die off and considerable time must elapse before assimilation of wastes can occur at that level again.

Another contribution of the new process to the environment is that physical-chemical treatment can be completed in less time than biological ones on the same unit volume of waste (with higher quality removal of wastes). Where biological action may take 24 hours to reach designed completion on a given volume of waste, physical-chemical processes may be completed in 6 hours. A coupling of design configuration with the faster flow of waste permits significant savings in space requirements for the plant itself. EPA estimates that in general, land requirements for physical-chemical plants will be about ¼ standard plant needs or less.[29]

It was originally thought that this space savings would be even larger, however, to maintain constant flow through the system, storage capacity had to built into the system for about 30% the daily rate of flow. Even with this condition, a plant in Freehold, New Jersey serving a 150 home subdivision was placed on a quarter acre lot (see Figure V) The same capacity in standard design would require 5 acres, including a buffer zone.

Figure V. shows how the Freehold plant appeard in operation. The small space demands for this size plant (15,000 gpd) easily permit camouflage of the building to look like other dwellings in the development. In addition to smaller land requirements, such physical-chemical plants operate with virtually no odors. Theoretically, no treatment plants are odorous if they are working properly. However in biological plants with large tanks and long detention periods, there is a greater chance for anerobic decomposition to begin with its attendant foul odors. The same condition can take

The one without a doorbell is the sewage plant.



Posing as a 1½ bath, three-bedroom home in suburban Freehold, New Jersey, this electrically operated sewage treatment plant can purify 50,000 gallons of raw waste a day from the 125 neighboring houses.†

Electric energy powers pumps, mixers and a "sludge magnet" that will turn out nearly pure water, water vapor and about ten pounds of ash per week, usable as building material.

No air pollution, no stinky ooze, no water pollution.

The one without a doorbell (topmost photograph) may be one answer to the growing contamination of a precious resource—clean water.

An estimated 17 billion gallons of raw sewage pours into America's rivers, lakes, bays and underground streams every day.

Cleaning America's waterways and keeping them clean could cost $30 billion in the coming years. But it's a job that can't be ignored.

And whether it's done with lots of little houses, or lots of conventional plants, lots of versatile electric power will be needed to make them do their stuff.

Our country's ability to clean the air, water and land will depend on an adequate supply of electricity. There's no time to waste. New generating facilities must be built, and built in a way compatible with our environment.

We'll continue working to do this. But we need your understanding today to meet tomorrow's needs.

The people at your Investor-Owned Electric Light and Power Companies:

For names of sponsoring companies, write to Power Companies, 1345 Avenue of the Americas, New York, New York 10019

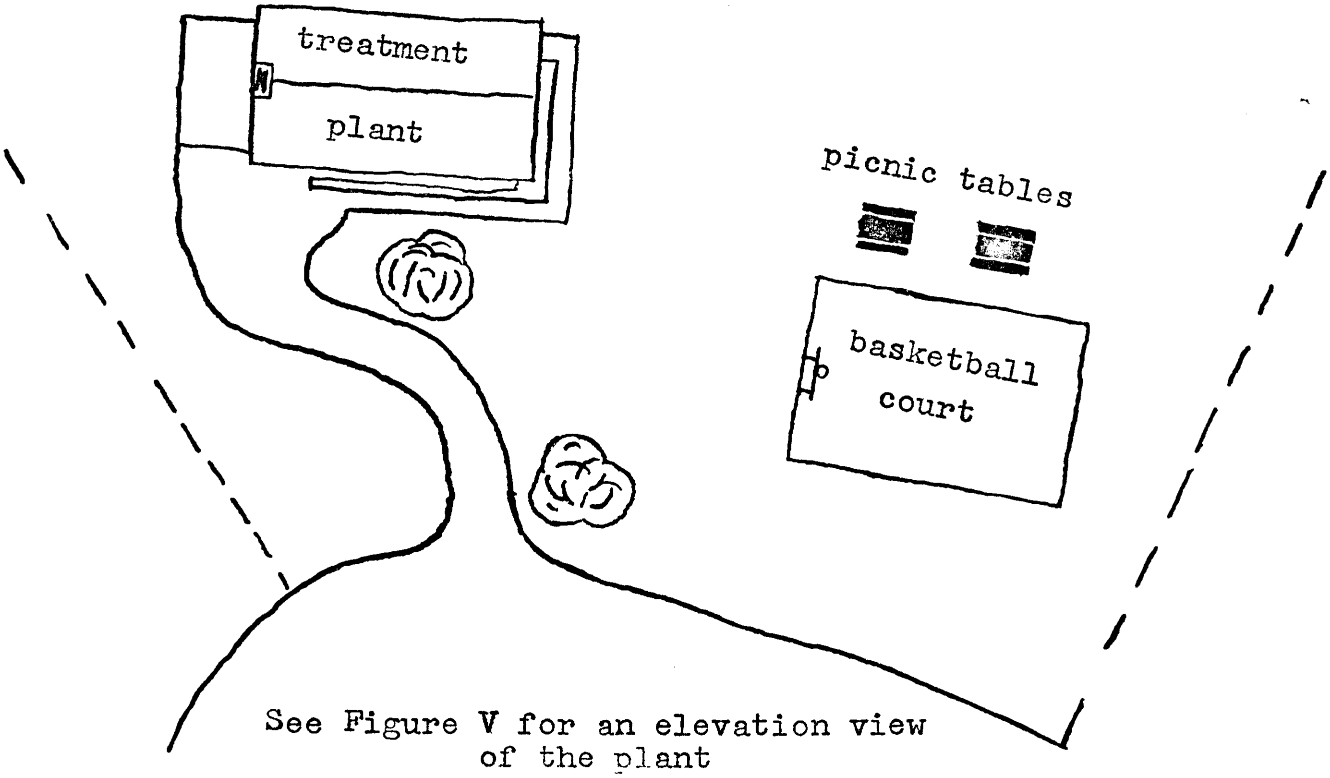
†Concept by Levitt & Sons, Inc. System designed and constructed by AWT Systems, Inc.

FIGURE V

place in the surge tank for physical-chemical plants, but shorter detention times and mechanical aeration reduce the likelihood of that event.

Stack effluents form the incinerator consist of steam and colorless and odorless carbon dioxide. The plants present no excessive noises. The only noise emitted is an electric hum which is not audible off the ¼ acre plant lot.

A final aesthetic advantage is the availability of the remainder of the lot and property to be used for open space or recreation that otherwise would have been needed for a plant. Standard plants are generally located in isolated areas and the availability of the buffer strips for alternate uses is extremely limited. Figure VI shows an approximate plan view of the Freehold plant's lot.



See Figure V for an elevation view of the plant

FIGURE VI

As described in the introduction, some areas of the U. S. are approaching a water supply crisis. Perhaps the greatest contribution of physical-chemical processes to environmental quality is the capacity for the reuse of wastewater.

Some areas of the world less well endowed with water than the U. S. have already used physical-chemical processes for this very purpose. South Africa provides just such an example. South Africa has a short supply of water and the effects of pollution have made reuse a necessity. The only waters available for this purpose were the country's industrial and domestic effluents, comprising about 80% of the original water volume used. The disposal of such effluents could not be allowed to affect downstream users and surface water had to supply drinking water even during long periods of drought. The short supply of water made dilution of wastes impossible so that treatment in this case had to be up to direct reuse quality.

The rapidly growing city of Windhoek, South West Africa, utilized a conventional system, a maturation pond system, chemical units for bulk removal, and an activated carbon filter for removal of inorganics. Figure VII presents the results of this process against the World Health Organization's drinking water standards. An improved process since this mid sixties plant will utilize a lime flocculant for accelerated removal of suspended particles.[30]

Direct reuse of water for drinking in the U. S. has not been encouraged for a number of reasons:

1. There has been a sufficient quantity of quality water available and reuse was not needed.

QUALITY OF RECLAIMED WATER IN RELATION TO
W. H. O. DRINKING WATER STANDARDS
(Windhoek, 1963)

Constituents	Reclaimed	W. H. O. concentrations Acceptable	Allowable
pH	8.0	7.0 to 8.5.	6.5 to 9.2
(in units)			
Color	10	5	50
Turbidity	5	5	25
(in mg/l)			
Total dissolved solids	400	500	1500
Sodium as Na	36	...	...
Chloride as Cl	12	200	200
NO_3	27	...	45
NH_4-N	.2	.5	...
Phosphate as PO_4	0	...	...
BOD	.3	6	...

... : No data

Source:

G. L. Stander and J. W. Funke, "Water Reuse/Drinking Water," Water and Wastewater Engineering, p. 67.

FIGURE VII

Note that the reclaimed water is well within most limits for safe drinking water.

2. The public has rejected the concept of drinking wastewater.
3. There has been skepticism on the part of some engineers as to the real effect of prolonged reuse.

In his review of reuse problems, C. A. Hansen of the U. S. Public Health Service, finds four main obstacles to be passed before reuse is safe:[31]

A. The chronic health effects are simply unknown. Assuming a population of 600,000 and consumption of 1 quart per day, 150,000 gallons would be filtered through the human liver daily and back into the system. It is uncertain what increases in viruses this would cause but the occurences of bladder cancer and death due to cancer are higher in cities drawing water from polluted sources, such as New Orleans, than in cities drawing water from non-polluted.sources,
B. There is a higher potential for toxins in sewer effluents,
C. "Automatic fail-safe" treatment devices don't exist and,
D. Analytic techniques for monitoring treatment have not been developed that work continuously.

Research and development dollars have been going into these problems, particularly the last two, and it is reasonable to assume from a planner's perspective that safe working apparatus will be perfected soon and health questions will be answered more fully as information is made known from actual plants such as the one in South Africa.

Until direct reuse is feasible, however, indirect reuses are possible and already practiced in several ways in the U. S.

The California Water Resources Board has officially approved the reclaimed water from the plant on Lake Tahoe for all water contact sports such as fishing, boating, swimming and water skiing.[32] The plant discharges its treated effluent directly into the lake and, as previously mentioned, has reversed the deleterious algae growths which prevented this recreational use. In addition to solving waste disposal problems, the treatment process has enhanced the recreational value of the lake so that the project offers net financial benefits.

A second indirect reuse practice in the U. S. has been utilized since 1962 through the Whittier Narrows reclamation plant for the Los Angeles area sewer districts.[33] The population of over 7 million in L. A. County is supplied water by three huge aqueducts bringing water from hundreds of miles away. Each day, about 700,000,000 gallons of waste is discharged through marine outfalls into the Pacific Ocean. Much of that wastewater is of higher quality than some of the incoming water. Figure VIII shows a comparison of treated wastewater quality against imported water from the Colorado River. This treated water is in turn sold to the flood control district for recharge of ground waters for unrestricted use. After six and a third years of operation, the project has paid for over half the capital costs.

It appears that physical-chemical processes could be ideal for supplying high quality recharge of water as in the Whittier Narrows case. Cape Cod provides and excellent example for utilization of the process. The Cape has a peculiar problem in that its supply of fresh groundwater rests on top of salt ground-

A COMPARISON OF THE WHITTIER NARROWS WATER RECLAMATION PLANT AND UNTREATED COLORADO TIVER AQUEDUCT WATER

Constituent	Plant	Aqueduct
BOD, mg/1	44	...
Suspended solids	13	...
Total dissolved solids	623	743
Chloride	100	103
Sulphate	125	320
Fluoride	.86	.5
Hardness	175	349
Phosphate	10.1	...
Nitrate	7.4	1.2
Ammonia	9.8	...

Source:

John Parkhurst, "Wastewater Reuse--A Supplemental Supply," Journal ASCE, p.656.

... : No data

Note that in several catagories, the quality of the reclaimed water is superior to the imported drinking water.

FIGURE VIII

water. If withdrawal from fresh groundwater exceeds the natural recharge, then wells in the affected area would be in danger of salt water intrusion.[34] To date, the Cape had practiced principally on-site disposal and recharge through the use of septic tanks and leaching fields. However, as development increases, septic systems will no longer be feasible and wastewater will have to be collected and disposed of in some other way. Dilution by ocean outfall as currently practiced in Falmouth causes a net reduction in ground water supplies and, if practiced Cape-wide, would endanger adequate fresh water supply on the Cape.[35] Unit processes can be chosen in a physical-chemical system which produce an effluent which can discharged directly into the numerous fresh ponds (as in Lake Tahoe) thus maintaining the necessary recharge of groundwater to ensure sufficient drinking supplies and enhancing the ponds' recreational potential.

In summary, it can be seen that physical-chemical plants and their effluents have high service and environmental quality characteristics. Their application in many locations throughout the world has indicated the viability of their use in more efficient processing of water resources.

Section V will treat the impacts of this system on the process by which wastewater service is supplied. and the associated impacts to urban development.

IMPACTS OF THE NEW TECHNOLOGY - V

Wastewater system design demands the inputs of engineers, planners, local government and other team participants. As suggested in the Introduction, effective planning for servicing the sewerage needs of future populations will require a knowledge of the practices which design, finance, and control such facilities. Likewise, the planner will need to predict the impacts to urban development of the various alternatives for that system in order to select the design which is most desirable for that community.

The previous sections are intended to be an introduction to the planner of a minimum of information about design practices and available technology.

The choice of technology to be used in a sewerage system is a specific design input. Planners may wish to participate in the selection of that technology as different alternatives may have very different implications for urban development. This section will attempt to assess some of the specific impacts of the new physical-chemical technology on the process by which wastewater service is supplied and some of the subsequent implications for urban development.

These impacts will be discussed on three levels:

A. Service for municipalities,
B. Service from developers, and
C. Service for developing countries.

MUNICIPALITIES

Cities with large enough populations to already have waste treatment plants may encounter two problems over time:

1. A necessity by new regulations to upgrade treatment facilities, or
2. A necessity by new demand to expand service.

Physical-chemical processes offer partial solutions for each of these problems.

As described earlier, current waste treatment in many areas no longer is acceptable. Dilution of too great a volume of wastes into water bodies has contributed to undesirable environmental conditions. The governmental solution this problem has been to enact legislation on state and Federal levels which sets and enforces higher standards for waste treatment. To comply with these new standards, many municipalities are required to upgrade existing facilities.

This may be complicated in denser areas by the lack of available space for the land-extensive biological practices. Such upgrading would generally occur in the form of an expanded filtering system requiring several tanks. Physical-chemical processes, however, are land-intensive and can be incorporated into existing facilities to meet water quality criteria without the problem of land taking. As discussed in Section IV, physical-chemical processes offer tremendous design flexibility in selection of unit processes to achieve the desired degree of treatment with very small land area requirements.

The community of Rocky River, Ohio offers an example of this problem.[36] This town had no secondary treatment and they were unable to meet new water quality standards. However, upgrading to secondary treatment was not feasible due to the lack of city-owned property at the plantsite. By changing to physical-chemical treatment, it was possible to build the plant within existing boundaries, thus eliminating the necessity to condemn adjacent residential property.

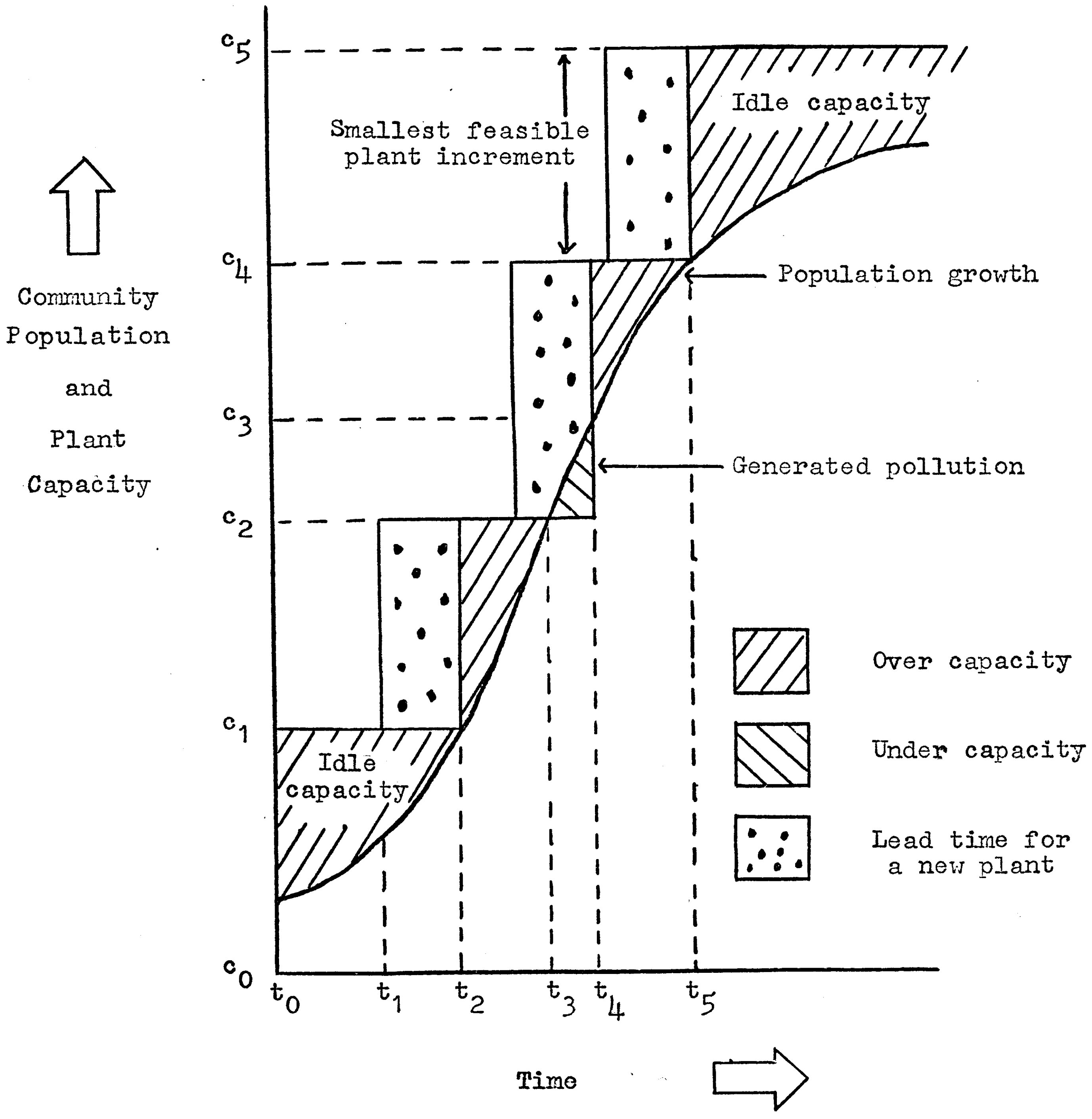
The second and perhaps more difficult problem for municipalities is the one of expansion of service. Figure IX compares the population growth of a community and its treatment capacity over time measured in gallons of water consumed or treated per day.

An initial plant constructed at t_0 may have a design life from t_0 to t_2 during which time the plant may be operating at peak capacity for only a short period. As the population grows from t_0 to t_2, the capacity of the initial plant is used up and a new one is required. Assuming that this growth was predicted, adequate advance planning and design would have an increment in service ready at point t_2. This advance planning takes a minimum period of time for the design and construction of the treatment facility, as shown from t_1 to t_2. If an unexpected increase in the growth rate occurs as shown from t_2 to t_5, then insufficient lead time may exist to supply adequate treatment capacity for the population and an unacceptable condition of pollution may be generated from t_3 to t_4 until a new increment in capacity is supplied.

Communities must select an increment in treatment capacity. This choice is an important one for planners as it will affect the community's capital budget. Traditional treatment practices have generally required large increments in capacity. As Metcalf and Eddy

COMMUNITY POPULATION AND PLANT CAPACITY OVER TIME

(in gallons of water consumed or treated per day)



Source:
Grava, Planning Aspects of Water Pollution Control, p. 143.

FIGURE IX

describe, the notion of smaller or satellite plants has moved in and out of fashion in the last 40 years,[37] but smaller plants (in the neighborhood of 200,000 gpd and less) using biological processes have not been widely accepted for the following reasons:

1. Significant returns to scale for large plants,
2. Offensive character of small plants near residential areas,
3. Better monitoring of the effluent quality in a centralized system.

The validity of these asumptions is likely to change, however, as a result of the technically sound smaller physical-chemical plants. The question of monitoring has been the most significant in determining plant sizes. As discussed earlier, biological practices are highly subject to failures and sewerage officials have not been anxious to decentralize operation and monitoring of plants because of the higher risk of poor quality treatment under many potentially unskilled operators. As presented in Section IV, physical-chemical processes promise higher quality and more reliable monitoring of treatment which enables the safe utilization of small plants. Likewise, the aesthetic conflicts are not as great with physical-chemical plants and they may easily be placed within a residential area, as in the Freehold project.

The real returns to scale for larger plants are also subject to reexamination. Vast collection networks represent tremendous costs to any municipality. In fact, 80% of the capital costs of a sewerage system are involved in collection while only 20% goes to treatment.[38] Larger systems require expensive force mains as gravity flow is not always possible. They also involve large trunk mains to collect waste from incoming laterals. Smaller systems could be placed with greater flexibility in watershed areas so as to eliminate the force mains and expensive trunk lines which were the only option for standard systems.

Longer collection lines offer a number of problems in addition to expense. The basic characteristics of the sewage may vary as a function of the distance of flow. At the point of entry to the system, the wastes are the easiest to separate and treat. However, as Dr. Stanley Dea, director of waste treatment for Levit Corp., suggests, as waste flows along in a pipe, some of the suspended solids may become colloidal, some of the colloids may become dissolved, and under certain conditions of temperature and pressure, the dissolved matter may become gaseous as decomposition takes place.[39]

Passage through force mains tends to homogenize the wastes making the wastewater even more difficult to treat. Thus, the longer the collection system, the greater the difficulty in treatment of the wastewater.

Another frequent problem with larger networks is the seepage of groundwater into the underground pipes. Metcalf and Eddy, Inc., suggest that system design should include 1000 to 40,000 gpd of water per mile to infiltrate.[40] This volume must then be treated along with the actual wastes so the plant's capacity must be that much greater than really necessary. This is equivalent to adding from 10 to 400 more people per mile of pipe without any user repayment.

Since there was not a suitable alternative, sewerage networks were forced to accept these hidden inefficiencies inherent in large collection networks. The advent of physical-chemical technology offers an alternative design using smaller networks which permit more efficient handling of the wastewater and deliver to the plant an easier product to treat.

The impact to municipalities of physical-chemical processes and their smaller plants may readily be seen by returning to Figure IX. The large leaps in capacity necessary with standard processes require associated large increments in capital expenditure. As the graph shows, this capacity may long lie idle while growth catches up to the design capacity (from t_0 to t_2). During this period, the capital suffers high opportunity costs as it is thoroughly committed in a treatment plant but it is greatly under used.

Few communities are so solvent that they have low sensitivity to inefficiencies in capital budgeting, particularly when the expenditure represents very large amounts of money. Smaller increments in capacity through the use of physical-chemical plants permits smaller and more efficient increments in a community's expenditure program.

This efficiency is in a number of forms:

1. Small plants may reach design capacity more quickly than large ones. Hence, a community would not be forced to commit funds for plant capacity which is under used for long periods of time. The costs to this inefficiency are the foregone benefits to the community that could have resulted had the capital for the unused capacity been applied somewhere else. Of equal importance, smaller

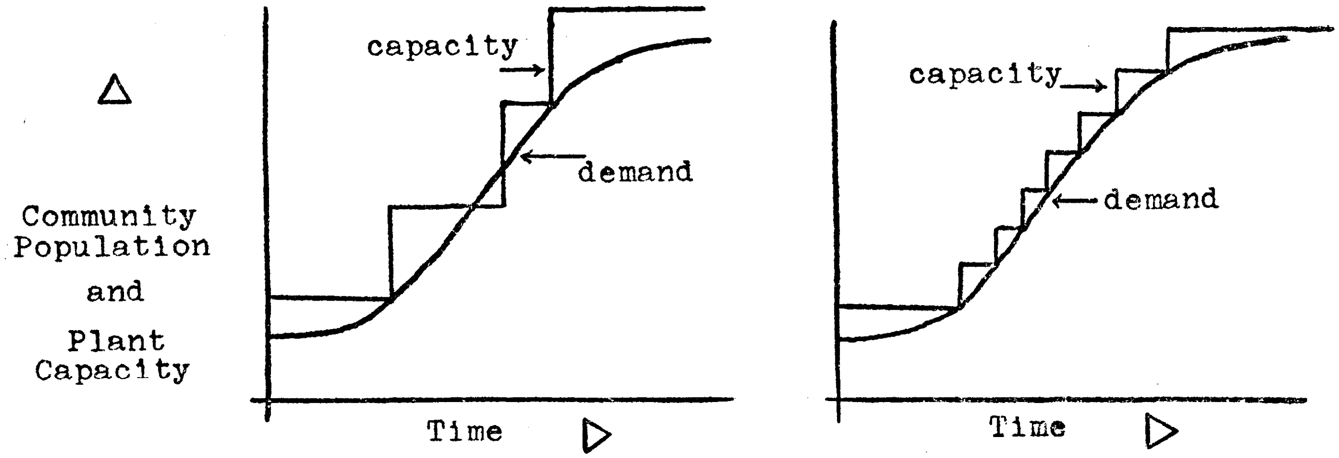
plants provide more rapid repayment for the facilities bacause the capacity is filled faster and the users return dollars to the municipality closer to the initial outlay for the plant. This situation is analogous to the enhanced cash flow for developers which will be discussed in the following section. Further, as smaller plants permit smaller amortization payments and as those payments need not be spread as far into the future as may be necessary with large plants, the discount of value on those future dollars need not be as great.

2. Small plants reduce the uncertainty in user repayment for treatment services. Sewerage systems are designed on the basis of population forecasts. There is no guarantee, however, that the projected population will ever materialize to pay for the large facilities constructed. Generally, the larger the plant, the more distant the design population and the greater the uncertainty in that projection. Small systems may be built on the basis of shorter and less uncertain projections. Thus, there is less risk that the design population will not materialize.

3. Finally, the shorter lead time required for smaller plants permits greater response to shifts in demand, thus minimizing the chances for under capacity generating pollution, as shown from t_3 to t_4 in Figure IX.

The differences between large and small plants may schematically be represented as shown in Figure X. The increase in demand over time may be generally described by a smooth function. The increases in capacity over time may generally be described as a step function.

IMPACT OF SMALLER PLANTS



Large Plants

Small Plants

FIGURE X

A reduction in plant size tends to reduce the increments in the step function so that it is more nearly smooth. Thus, the periods of over and under capacity and their associated costs are reduced.

The use of this scheme does have other important implications for community planning which must be carefully considered. While physical-chemical processes offer advances in monitoring systems, an array of small plants does require an overall plan for coordination of these operations. In the case of municipalities with on-going sewer authorities, this may not present a problem. However, in burgeoning suburban areas, such authority may not be established. Hence, to ensure safe and efficient operation of many small plants, planners will need to ensure a scheme for the design and coordination of those plants and the controlling of their operation.

DEVELOPERS

The supply of wastewater treatment for subdivisions constructed by developers can be in one of the following forms:

A. On-site disposal through the use of septic tanks,

B. "Hook-in" to an existing or proposed expansion of a municipal system,

C. Construction of a plant to serve the subdivision alone.

While capacity remains, the second method offers no problems. A long wait for the extension of service is likely to be too costly and as such, a developer will generally not choose this alternative.

The use of septic tanks in rural circumstances where there exists adequate land area and soil conditions has been found generally acceptable. For subdivisions, however, septic tanks offer a number of problems.[41] They cannot be adequately inspected by municipal authorities during construction to assure proper standards unless the development is under continuous surveillance, which is seldom feasible. Acceptable densities for septic tanks are rarely higher than two houses per acre. However, there are numerous instances when development has intensified following original settlement resulting in unsatisfactory sanitary conditions. It then becomes necessary to replace the septic tank system with a collection system and treatment, in which case the septic tanks have become a complete economic loss. There are also extremely high costs to installing collection networks after streets are in.

If there are no opportunities for "hook-up", the developer also has the option of building his own plant. However, these operations (generally the package plants) are not always reliable and do require continuous operation by skilled personnel. Hence, developers have not generally sought this solution where constrained by costs or effluent standards.

These wastewater disposal conditions have had significant impact on the type of development which has taken place. The necessary soil limitations and the reluctance or inability of communities to build their own collection and treatment systems are major public excuses for the "snob" zoning prevalent in suburban areas today. This zoning generally requires densities of one or fewer houses per acre. A hidden purpose of this may be an effort by the local residents to thwart development in that area. This shortsighted approach, however, has fostered the misuse of land in the form of the familiar rambling subdivisions with only one or two houses per acre. and no open or green space.

The community of Wayland, Massachusetts offers an excellent example of this problem.[42] Wayland lies between Routes 128 and 495 and within the last decade has seen tremendous development. The community lacks public sewerage, but feels that soil conditions prohibit more development. Hence, the local residents are trying to restrict growth because of wastewater disposal constraints and have done this through the implementation of ½, 1, and 1½ acre zoning. A developer, however, now has a tract of 330 acres and is prepared to continue the sprawl and inefficient land use on all of the property, or use a cluster scheme in a "planned" community. Current pollution standards would not permit the use of package plants in this area for the subdevelopemt alone, and the town itself is not willing to install a wastewater collection and treatment system for all of Wayland. Hence, it might appear that the only alternative is to continue the poor solution of septic tanks and large sprawling lots. However, the advent of physical-chemical processes and their associated small plants with high quality treatment would easily enable such a developer to install his own system and discharge virtually drinkable effluent into an ambient stream. This option would eliminate the current restriction of the development on purely sanitary grounds as a safe operation is entirely feasible.

Furthermore, the developer could tightly cluster his units and reserve large tracts of open space which, in the Wayland case, he is willing to donate to the town as a public park. The town's residents have expressed preference for this alternative and want to halt continued sprawl. However, to their knowledge, the technology did not exist that would permit a small, reliable and innocuous treatment plant. It is interesting to note that as a result of the author's contact with the Wayland Planning Commission, members of the commission are continuing investigation of this alternative for their town through observation of the Freehold plant and contact with its manufacturer.

The Wayland situation is very similar to the one in Freehold, New Jersey which led Levitt and Sons, Inc., to build a physical-chemical treatment plant for a 150 home subdevelopment. The local sewerage system was operating at capacity and an extension to service the area would not have been constructed for several years. Soil conditions would not permit septic systems and there was a a high demand for the housing. As Levitt wanted to build, their only alternative was to install their own plant which could discharge its effluent at the site. Hence, Levitt coordinated with town, county, state, and Federal agencies to construct a physical-chemical plant which could treat the wastewater on the site and discharge the effluent into an adjacent ambient stream. Developers using the option of building their own plant, whether biological or physical-chemical, generally arrange to turn operation and maintenance of the plant over to the local municipality at no costs. As the Freehold plant is a special pilot project sponsored in part by the Environmental Protection Agency, Levitt will operate the plant through one year following completion of the development to collect data on the system's operation. Following that period, the plant will be turned over to the local community for further operation and maintenance.[43]

The feasibilty of this new option has important implications for planning and urban development. Like any tool, physical-chemical processes may be used to good or bad ends.

On one hand, the technology enables a different and perhaps more desirable land use scheme for housing and community development. Clustering, which is too dense for septic tanks, would be extrememly well suited for this use of the technology. Grouping housing units would greatly reduce the size and expense of the collection network and the costs to the total sewerage system may be much smaller. Also, the treated water could be safely used to feed a recreation lake or swimming pool, as was done at Lake Tahoe, or eventually could be recycled as drinking water.

On the other hand, the autonomy of developers supplying their own plants could be a serious loss of control by planning or governmental agencies over unwanted growth. The disadvantages of this condition in the hands of unscrupulous profit seekers are clear. Two conditions suggest that governmental agencies should seek control of growth through other means than denying wastewater service. The first is, as cited above, that the advent of physical-chemical technology makes feasible small plants to service subdivisions without negative impacts to the environment. Hence, these may be installed by developers without the assistance (or necessarily the control) of governmental agencies.

The second reason is that the practice of withholding service is an extra-legal device which may not stand the test of litigation. As Charles Haar points out in his casebook on land use planning, there is a denial of equal protection of the laws unless service is available to all in like circumstances on the same terms and conditions.[44] Haar offers a number of examples where governmental agencies have failed in attempts to limit development by refusing to provide services.

These conditions indicate that planners who wish to effectively exercise some control over changes in a community will have to do so through carefully prepared land use plans and service policies based on other inputs than sewerage capabilities. Certainly this has not been the only constraint in land use considerations, but it has been an important one. Now, other factors in designing a desired environment will take on greater weights in the selection of future land uses. Likewise, governing agencies will need to establish control over the design and coordination of sewerage facilities and be prepared to offer that service in an unbiased fashion throughout the community.

A final implication for the physical-chemical technology for developers may be in the formation of new towns. In Columbia, Maryland, for example, $4 million was invested in sewerage before the first income dollar was returned.[45] Here, it was concluded that the most efficient design of treatment facilities for the projected community of 110,000 in 15 years was a single large plant. Columbia, however, consists of several watersheds.[46] Individual plants could have been built for each one utilizing gravity flow instead of more expensive force mains and huge trunk mains. The cash flow for the project could have been enhanced as a section of the community could be built and a corresponding plant could be installed and operating at or near design capacity. Just as for municipalities, there could be small increments in capacity without changing the underground network, there would not need to be the corresponding inefficiency in over capacity, and cash could flow back faster from more rapid occupancy.

DEVELOPING COUNTRIES

A major problem for developing countries is one of basic sanitation. The World Health Organization concludes that one of the prime reasons for the critical conditions in many such countries has been the haste in supplying potable water for residential, industrial, and irrigation uses, but then this haste has been followed by a neglect or impossibility of providing the removal of the wastewater.[47]

Conditions vary from one nation to another, but the basic sanitary features which distinguish developing countries from industrialized ones can be summarized as follows:

1. A limitation of resources, particularly construction funds,
2. Often complete absence of community facilities. In poorer sections, environmental quality is on a primitive level, coupled with extremely high residential densities,
3. A lack of precise control mechanisms, including regulatory codes and administrative organizations,
4. Incomplete data about environmental conditions,
5. A shortage of technical skills needed for construction, maintenance, and operation of complex systems, and
6. Higher tolerance in the population of negative visual and psychological manifestations of pollution and only limited demand for sanitary improvements by local residents since they lack a basis of comparison.

As discussed in Section IV, physical-chemical processes have been put to use in South Africa to reuse wastewater for drinking purposes. (p. 29) This, however, is a special case involving work by a national water research institute. Far more frequent is the case where minimal or no sanitary measures are taken and the remainder of the community's dollars are invested in development.

The current state-of-the-art in physical-chemical treatment is not likely to affect conditions in developing countries. The highly technical and land intensive designs offered by these processes are too sophisticated for the basic sanitary needs. Inadequate waste disposal presents dangers of contamination of drinking water and development of breeding areas for disease carrying insects. These basic problems which exact a high toll in death and disease can adequately be handled by much simpler biological processes. Land and labor are often less dear in these nations than in industrialized ones and elemental schemes such as lagooning or oxidation ponding are appropriate ones for waste assimilation and recovery of sludge matter for fertilizer or loam.

There are, however, important implications for developing countries of future advances in physical-chemical treatment technology.

A current manufacturer of physical -chemical plants projects that one day it will have a single unit capable of recycling the water for single family homes or even boats.[48] If such units, whether by governmental subsidy or some other means, were brought within the economic grasp of individuals in developing countries, the effect could be significant.

Currently the majority of housing in developing countries for those lacking basic sanitation has been produced through the ingenuity of the individual. Particularly among the poor, where health conditions are the most deplorable, the owner/builder must supply his own shelter as no one else is responsive to his needs. Hence, housing will be produced with whatever materials are available and without governmental assistance. This process has created the existence of squatter housing encircling cities in developing countries on whatever land is available. Water and sewer service are peculiar among utilities in that they require fixed grid networks of high cost. Electricity, gas, telephones or any other such service are not tied to any such fixed configuration but rather are in flexible networks. Hence, it is common to see television antennas along roof lines in squatter settlements where the only available water for a whole neighborhood is a central tap and an overflowing community pit latrine is the only waste disposal facility.

The availability of a "black box" for water recycling in such housing would have several benefits for the individuals:

1. Foremost, it could ameliorate the basic health problems. As Sigurd Grava suggests, in many instances it is a question of life or death, not to speak of human dignity and self respect. One cannot teach a child to read if he is debilitated by diarrhea or expect a man to take great interest in improving his shelter if he has to wade through his own, his neighbor's, and his animal's filth.[49]
2. Such units could also easily fit into the current process by which housing is built. Should government assistance for sanitation be absent, the individual who supplies his own shelter would also be able to supply his own water and waste disposal system which presently, he cannot.

Likewise, the same individual could accrue greater equity from his efforts in the structure which he builds. The existence of such an appliance in a home would greatly increase it value should the owner decide to rent or sell.

3. Lastly, it would free individuals or groups without water and sewer service from dependency on expensive governmental sources of water supply. In areas where a well and septic tank system is not feasible, the only alternative for water and sewer service has been costly networks. A limitation of of the traditional technology for supplying these services is that they are simply not feasible without the assistance of government. There are sectors of the population in developing countries, however, which have not enjoyed this assistance essential for supplying basic sanitary services. This situation is analogous to the supply of housing in many developing countries. Governments may not have been responsive to the basic needs for shelter so individuals produce their own, frequently in the form squatter settlements on marginal land. The housing in these settlements may often be mature and, as indicated above, fully serviced with electricity without any assistance from the government. But these houses may never be serviced by traditional systems for two reasons:

    1. It is often difficult for groups to organize and demand governmental services. If they cannot unite and/or government does not respond to their needs,

then their only alternative is the continued lack of basic sanitary service, or

2. Even if government can be made responsive and is willing supply the service, the land may typically be located on such a poor site that it is not feasible to provide the extensive grid networks essential with traditional technology.

Should this new physical-chemical technology be developed such that it is available to individuals or groups in developing countries, then they could be offered another alternative than dependence on government for basic water and sanitary needs.

This freedom from dependency on non-responsive government applies equally in some areas in developed countries as well as in underdeveloped ones. A current situation in San Antonio, Texas offers an example.

Under current development, water and sewer lines have come to the edge of the city and service is supplied on one side of the street while not on the other. The city will not extend their service lines so the only recourse available for waste disposal for the non-serviced side is the use of cesspools, which create significant health hazards. The only supply of water for these individuals is through importation of barrels of water weekly from a nearby lake. The cost of such water supply is $16-25 per month while an equivalent in-town supply would cost about $4.50.[50] A single unit recycling system could eliminate the dependence on government action and permit individuals to receive basic sanitary service through their own autonomous efforts.

RELATIVE COSTS - VI

No discussion of physical plants could be complete without some mention of the relative costs involved for assessing alternatives. An important consideration in a discussion of treatment costs is that there exists a premium for higher quality waste removal. The general public and local and Federal governments have made a commitment to the goal of a higher quality environment and are prepared to pay some increased costs to attain that goal. The question then deals with the willingness to pay for such quality.

For physical-chemical systems, initial engineering research and development costs have been higher than might be attractive to individual communities or developers. However, as more information if fed back into the design process, costs can reasonably be expected to fall.

Figure X shows total cost estimates from the various listed sources. These figures involve different size plants and hence serve as a relative estimate only. However, it would appear that the range of 15-40 ¢ per 1000 gal of capacity is a competitive price with convential systems. Even the most elaborate physical-chemical plant today at Lake Tahoe has operated at costs around twice the low costs of conventional secondary treatment. However, as Russel Culp points out in his article on the plant, the cost benefits resulting from completely pollution free operation are more than doubled.[51]

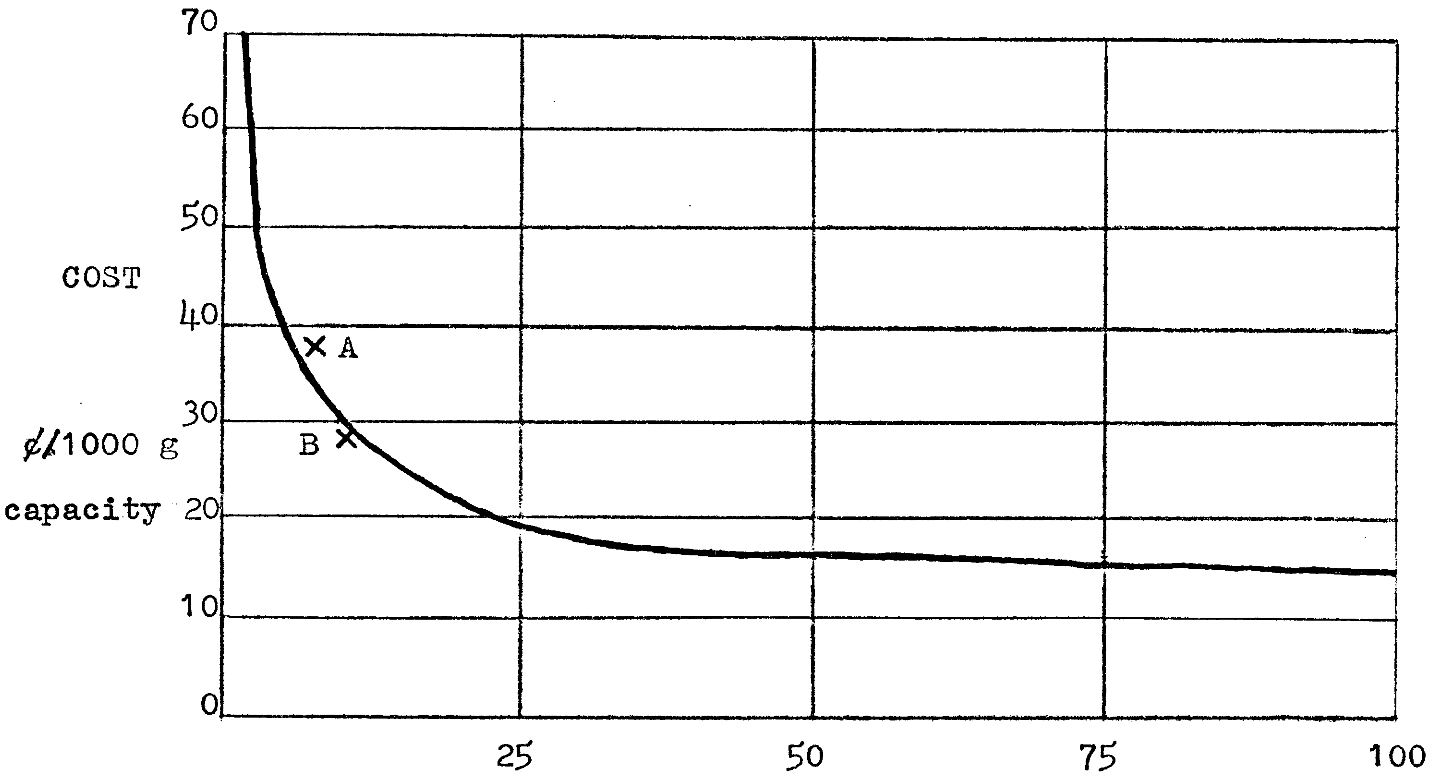
A thorough benefit/cost analysis should consider the following elements; capital costs, land costs, maintenance and operating costs, environmental benefits, resale value, and time savings.

For a discussion of maintenance and operating costs, see page 23.

FIGURE X

TOTAL COSTS FOR PHYSICAL-CHEMICAL TREATMENT

(Cents per 1000 gallons capacity)



A: Lake Tahoe Treatment Plant

B: Technology Transfer estimate for a typical 10 mgd plant

Sources:

"Use of New Technology in Municipal Wastewater Treatment," <u>Technology Transfer</u>, 1 March 1973, p. 8.

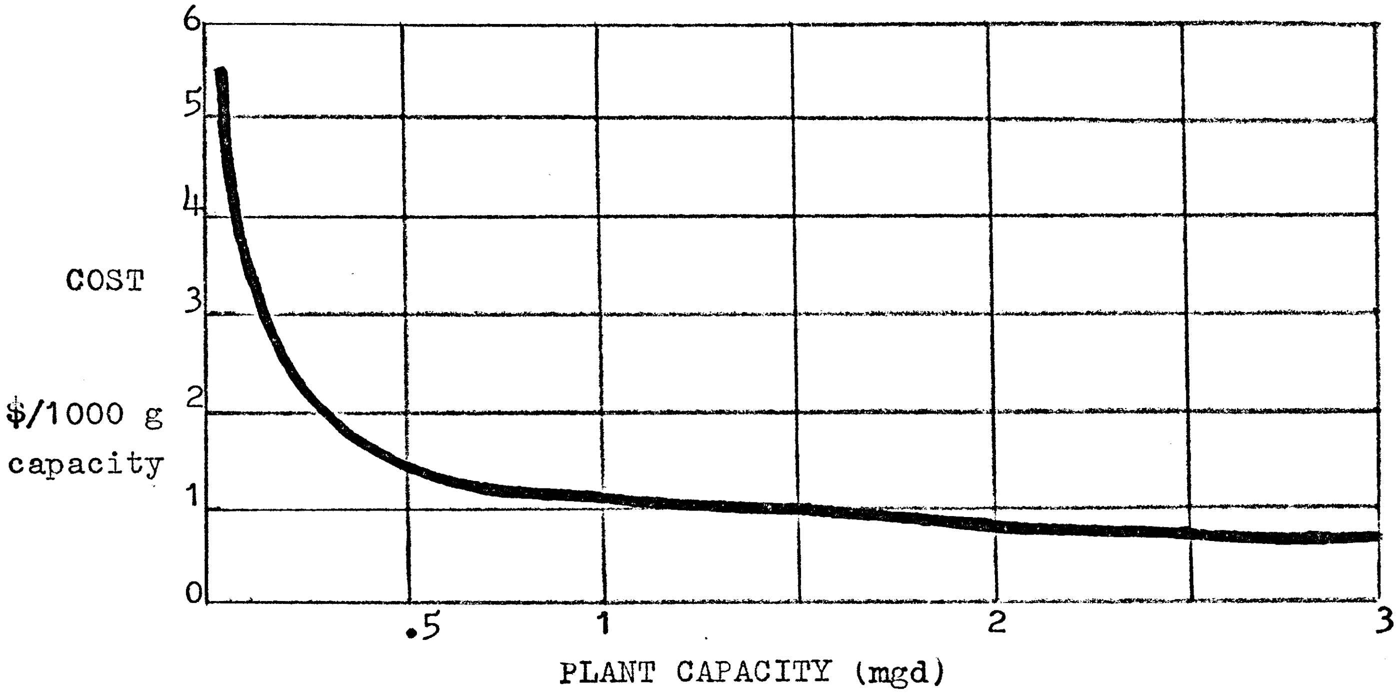
"Physical-Chemical Treatment," Technology Transfer Publication.

Middleton, Francis and Robert Stenburg, "Research Needs for Advanced Waste Treatment," <u>Journal ASCE</u>, June 1972, p. 517.

Capital Costs

As previously mentioned, when dealing with capital costs of the system, it should be kept in mind that plants are only roughly 20% of the total expenditure. Hence, slight increases in plant costs may not significantly alter total sewerage costs. As a rough breakdown, Figure XI presents sample plant prices for complete installation, debugging, and training of operators.

SAMPLE SMALL PLANT CAPITAL COSTS
(Dollars per 1000 gallons capacity)



Source: Advanced Waste Treatment Systems, Inc. Wilmington, Del.

FIGURE XI

It is important to compare just what is included in the purchase price of the plant. Most estimates for treatment costs involve liquid treatment only. This graph includes costs for sludge handling and disposal, which may be very high and particularly so in urban areas.

Land Costs

As the land requirements for physical-chemical plants may be ¼ or less than those for conventional plants, significant savings can accrue. This is important for municipalities needing an upgrading of existing facilities. This also allows alternate income from the land, such as construction of additional housing. In the case of the Freehold project, a plant performing the same treatment as the one installed would have required about 5 acres instead of ¼ acre. Hence, 23 new lots could be realized in the land savings.

Environmental Benefits

Work has already been done by the Corps of Engineers and other groups to assess recreational value of water bodies constructed by the Corps for flood control. The same approach could be applied to benefits from recreation as realized in the Lake Tahoe project. Another consideration is the non-degradation to the shellfish industry which often accompanies ocean outfall disposal.[52] A cost can also be applied to the loss of groundwater and subsequent necessary importing of replacement water in an area such as Cape Cod.

Resale Value

The fully treated water has a definite value for resale. This is demonstrated in the Los Angeles project which, as previously discussed (p. 32) sold its effluent to a flood control district for use in recharge. Unit treatment processes can be selected to render the effluent salable in a variety of uses such as cooling, irrigation, and groundwater recharge.

Time Savings

For developers, time is money. Any reduction in time for construction and operation of utilities returns money that much faster and releases capital tied up with high interest rates. As discussed with new towns, sections could be operated independently and the cash flow enhanced by early occupation of homes and businesses.

It is interesting to note that some manufacturers believe that their plants will be effectively transportable. They estimate that if municipal sewer systems should reach a site serviced by a small plant, the plant could be dismantled in about 5 days and reconstructed at a new site in about the same time.[53] If this were practical, then a municipality or developer could make optimum use over time of a given capacity plant within a larger system by shifting its location and then perhaps selling the equipment to another user.

An important final note about costs is that even with the most advanced treatment, the cost of sewer service is the least of all common utilities, including electricity, water, gas and telephone. Operating charges to the consumer are in fact so low in absolute terms, that they are relatively insensitive to high percentage increases. User rates vary from one community to the next, but the national average service cost is only $30 annually.[54] Even if this were increased by 100%, $60 is still a low annual charge. The benefits of physical-chemical systems could accrue to the community for relatively small changes in cost to the consumer.

SUMMARY AND CONCLUSIONS - VII

As stated in the introduction, there are eight reasons which suggest that physical-chemical technology will provide more efficient handling of a community's water and financial resources.

These systems have a proven capability for a higher degree of treatment than is possible with biological practices. This process can remove greater percentages of wastes than biological practices. It can also remove wastes which are unaffected in standard processes or even disrupt them.

As development densities increase, it becomes more and more difficult to dispose of the products of waste treatment. Physical-chemical systems can effectively reduce these products to nearly pure water, sterile ash and harmless steam and carbon dioxide. This facilitates easier disposal of the water and the ash may be used as a building material.

Physical-chemical systems promise improved operating and monitoring conditions which sustain high quality treatment with a minimum of attention by operators. The experience at Lake Tahoe has convincingly proven this point.

The environmental benefits to the new technology are numerous. By greater removal of nutrients in wastewater, physical-chemical processes can greatly retard the natural eutrophication of lakes. These processes can also remove toxins which are offensive and often dangerous. "Shock" loading which disrupts biological plants does not affect physical-chemical systems so that the plants can sustain higher quality treatment with less likelehood of disruption. The time necessary to complete the process is much shorter than for traditional plants. Efficiencies in design thus permit smaller land requirements for treatment facilities. These plants also operate without the usual nuisances to the surrounding area and thus can be placed closer to the source of waste generation. Lastly, the improved treatment permits safe reuse of water for various purposes. Currently, the Lake Tahoe plant supplies water approved for all water recreation activities in the lake. The Whittier Narrows plant in Los Angèles sells reclaimed water to a local flood control district for groundwater recharge. And finally, the South Africa plant recycles water for drinking purposes. This capacity for reuse is essential if we are to maintain an adequate supply and quality of water for future needs.

Physical-chemical systems offer advantages for municipalities in that existing facilities can be upgraded to achieve higher quality treatment without taking more land. Municipalities also benefit from the small plants feasible with the new technology. The smaller increments in treatment capacity permit more efficient expenditure of capital by the community. Also, the smaller networks offer increased efficiencies in the collection and treatment of wastes.

The development process may also be affected by the new technology. These smaller plants offer a feasible alternative to the widespread use of septic tanks in housing subdevelopments. Clustering of houses to achieve better land use may previously have been dismissed because of soil conditions and local standards prohibiting septic tanks or package plants. Physical-chemical plants may now permit the efficient use of alternate development forms.

Finally, future physical-chemical technology promises single recycling units which may have important impacts to developing countries. If widely available, such units could ameliorate basic health problems in sanitation and could be available for the individual to have water and sewer service without any dependence on government. [illegible]

This thesis has been an effort to suggest the impacts of physical-chemical treatment technology. Investigation into these impacts has suggested a number of questions which planners and engineers may need to address to make the best use of the technology emerging.

1. Planners may wish to investigate the impacts for community development and the environment of relaxing elements various standards which dictate the required quality of treatment. The actual numbers used in codes are generally a matter of scientific judgement. The effects of relaxing the restriction in any one element may have a great deal to do with the type of treatment permissible. Massachusetts offers an example of this argument. The current amount of nitrates allowable for discharges into ambient streams is .5 miligrams per liter. The most sophisticated treatment plant in the U. S. can only remove nitrates down to .8 miligrams per liter. Hence, a plant such as the one built in Freehold, New Jersey would not be permissible under current effluent standards. This removes the alternative

of small physical-chemical plants discharging nearly pure water into ambient streams, thus leaving in many circumstances only septic tanks or municipal "hook-up".

2. Planners may also need to investigate just what would constitute effective means for controlling and coordinating a system of small plants. This situation is likely to require explicit legal and political controls for effective enforcement of service policies.

3. The feasibility of physical-chemical plants suggests that development may no longer be prohibited on the basis of sanitary constraints. This means that other inputs to land use planning will now take on greater importance. Basic sanitary restrictions are certainly not the only constraints in urban planning, but they are important ones. Planners may wish to reassess parameters to optimum land use design in light of their new weights.

4. The small recycling units coming from future physical-chemical technology suggests wide impacts to developing and industrialized countries alike. Section V discussed some of the benefits to developing countries of such units. It is interesting to note that one manufacturer who foresees developing this module has actually postponed further research. Their justification is that considerable research and development effort has gone into producing the plants they are now prepared to sell and they must receive some income from those efforts before they can continue research. It is likely that there will be a vast market for this module should it be developed. Pollution standards now prohibit the discharge of wastes from boats, so on-ship recycling would be ideal. Likewise, thriving

economic activity in squatter settlements attest to the money available to buy such units should they be at a reasonable price. Finally, these units would represent the ultimate in minimizing collection systems. In areas where environmental constraints prohibit other forms of waste disposal or the supply of water is just too difficult, these units would offer alternative means for water supply and wastes handling. The reality of these units awaits only research dollars by private firms or governmental agencies. The benefits from these units seem too large to stall their development when their feasibility appears so close at hand. It appears that both governmental and private benefits would justify continued research into this facet of physical-chemical technology.

5. Lastly, engineers and planners may wish to reexamine our water practices that require all water in a municipal system to be of drinking quality. Average per capita use of water ranges from 130-170 gallons a day. And yet less than a single gallon may be used for food or drinking purposes. Perhaps to solve water problems more efficiently, it might be desirable to have separate supply networks. If dual piping is too extravagant, perhaps house plumbing could use recycled community water for safe bathing, washing and other household purposes. The minimal food use water demands may then easily be met through the use of bottled water. Certainly many areas of the world are accustomed to not drinking tap water, and, as water shortages become even more acute, our extravagance in water use may no longer be feasible.

This thesis has been intended to present some arguments which suggest that physical-chemical technology offers some substantial gains toward more efficient use of water resources. In several cases, the new processes permit alternatives to the accepted costs earlier treatment practices. It is true that physical-chemical processes are not without their own costs. However, it is important to return to the fact that treatment plants constitute only 20% of total capital costs for a sewerage system. Hence, total costs have a low sensitivity to increases in treatment costs and a high sensitivity to decreases collection costs. This suggests that the advent of physical-chemical technology may justify a new examination of wastewater treatment practices that have favored large regional systems.

FOOTNOTES

[1] United States Department of the Interior, "New Water for Old," Washington, D. C., p. 1.

[2] Helene l. Baldwin and C. L. Mcguiness, "A Primer on Groundwater," U. S. Government Printing Office, p. 38.

[3] U. S. Department of the Interior, "Needed: Clean Water," Washington, D. C., p. 1.

[4] "New Water for Old," p. 1.

[5] Ibid.

[6] Ibid.

[7] Charles V. Gibbs, "Basin Management Techniques for Sewerage Agencies," Journal ASCE, p. 493.

[8] Metcalf and Eddy, Inc., Wastewater Engineering, p. 25.

[9] Sigurd Grava, Urban Planning Aspects of Water Pollution Control, p. 35.

[10] Metcalf and Eddy, Inc., p. 6.

[11] Philip R. Micklin, "Water Quality: A Question of Standards," Congress and the Environment, Richard Cooley, ed., p. 97.

[12] Wm. T. Ingram, "Sanitary Engineering," Standard Handbook for Civil Engineers, Frederick Merritt, ed., p. 23-26.

[13] "Here's a Totally New Method of Sewage Treatment," House and Home Reprint, p. 2.

[14] Russel Culp, "No Innovation in Wastewater Treatment?", Civil Engineering, p. 46.

[15] Grava, p. 48.

[16] Metcalf and Eddy, Inc., p. 260.

[17] John Bird,"Our Dying Waters," Life Reprint, p. 2.

[18] Grava, p. 21.

[19] "Use of Technology in Municipal Wastewater Treatment," Tecnology Transfer, p. 4.

[20] Metcalf and Eddy, Inc., 587.

[21] "Here's a Totally New Method of Waste Treatment," p. 1.

[22] This information was received from correspondence with a manufacturer of physical-chemical plants.

[23] This information was learned from direct contact with Abt Associates.

[24] "Here's a Totally NewMethod of Sewage Treatment," p. 1.

[25] Culp, p. 46.

[26] "Use of Technology in Municipal Wastewater Treatment," p. 5.

[27] Ibid.

[28] Grava, p. 76.

[29] "Use of Technology in Municipal Wastewater Treatment," p. 6.

[30] J. Stander, "Water Reuse-Drinking," Water and Wastewater Engineering, p. 67.

[31] C. A. Hansen, "Standards for Drinking Water and Reuse," Water and Wastewater Engineering, p. 44.

[32] Culp, 46.

[33] John Parkhurst, Wastewater Reuse- A Supple mental Supply," Journal ASCE, 655.

[34] Helene Baldwin, p. 25.

[35] Wastewater Impacts: A General Survey of Cape Cod and a Detailed analysis of Falmouth," Bauer Engineering , Inc., p. 1.

[36] "Physical-Chemical Treatment," Technology Transfer Publication, p. 4.

[37] Metcalf and Eddy, Ind., p. 14.

[38] Francis Middleton et al, "Research Needs For Advanced Waste Treatment," Journal ASCE. p. 527.

[39] This information was received in conversation with Dr. Stanley Dea.

[40] Metcalf and Eddy, Inc., p. 40.

[41] Grava, p. 132.

[42] This information was received in conversion with members of the Wayland Planning B oard.

[43] This information was received in conversation with Dr. Stanley Dea.

[44] Charles Haar, Land-Use Planning, p. 367.

[45] Philip David, Urban Land Development, p. 509.

[46] Ernst Requardt et al, "Municipal and Regional Planning," Standard Handbook for Civil Engineers, p. 12-17.

[47] Grava, p. 153.

[48] House and Home, p. 2.

[49] Grava, p. 148.

50 This informationwas gained in conversation with Louis Viramontes, former director of Housing Center, Commission for Mexican American Affairs, San Antonio, Texas.

[51] Culp, p. 47.

[52] Wastewater Impacts," p. 17.

[53] *House and Home*, p. 2.

[54] John Saucier, "Application of Package Plants to Suburban Areas," *Water and Wastes Engineering*, Dec. 1969, p. 33.

BIBLIOGRAPHY

Texts

David, Philip. *Urban Land-Development*, R. D. Irwin, Inc. Homewood, Illinois. 1970.

Fair, Gordon M. et al, *Elements of Water Supply and Wastewater Disposal*, John Wiley and Sons, Inc. New York. 1971.

Haar, Charles. *Urban Land-Use Planning*. Little Brown and Co. Boston. 1959.

Metcalf and Eddy, Inc. *Wastewater Engineering*. Mc Graw-Hill Pub. Co. New York, 1972.

Merrit, Frederick S. *Standard Handbook for Civil Engineers*. Mc Graw-HillCo. New York 1968.

Articles, Pamphlets and Papers

Barth, Edward. "Perspectives on Wastewater Treatment Processes," *Journal ASCE*. Dec. 1969.

Bella, David A. "Environmental Planning and Ecological Possibilities," *Journal ASCE*. June 1972.

Bird, John. "Our Dying Waters," *Life* Reprint.

Boldwin, Helene L et al. *A Primer on Groundwater*. U.S. Gov't Printing Office. 1963.

"Chicago Reclaiming Strip Mines With Sewage Sludge," *Civil Engineering ASCE*. Sept. 1972.

Cohen, Jesse, "Physical-Chemical Processes," EPA Publication. 1972.

Culp, Gordon. "Physical-Chemical Treatment Plant Design," EPA Publication. 1972.

Culp, Russel. "No Innovation in Wastewater Treatment?", *Civil Engineering ASCE*. July 1972.

Guarino, Carmen. "Sewage Sludge Disposal," *Civil Engineering ASCE*. March 1973.

Gibbs, Charles. "Basin Management Techniques for Sewerage Agencies," *Journal ASCE*. June 1970.

Hansen, C. A. "Standards for Drinking Water and Reuse," *Water and Wastes Engineering*. 6.4.44. 1970.

"Here's a Totally New Method for Sewage Disposal," *House and Home* Reprint. 1972.

Henderson, John M. "Water Pollution- Facts and Fantasies," *Journal ASCE*. June 1972.

Hirsch, Allan. "Water for Waste Disposal," Water Management Seminar The Johns Hopkins University. 1965.

Ingram, Wm. "Sanitary Engineering," *Standard Handbook for Civil Engineers*. McGraw-Hill. New York. 1968.

Leopold, Luna. "Hydrology for Urban Planning." Geological Survey U. S. Gov't Printing Office. 1968.

Micklin, Philip. "Water Quality: A Question of Standards," *Congress and the Environment*. R. Cooley ed. U. of Wash. Press. 1970.

Middleton, Francis et al. "Research Needs for Advanced Waste Treatment," *Journal ASCE* . June 1972.

Nemerov, Nelson et al. "Total Dollar Benefit of Water Pollution Control," *Journal ASCE*. July 1972.

Parkhurst, John. "Wastewater Reuse- A Supplemental Supply," *Journal ASCE*. July 1972.

"Physical-Chemical Treatment." Technology Transfer Publication.

Reed, Alonzo B., Inc. *Comprehensive Report on Water Supply and Sewerage for Cape Cod*. Cape Cod Planning and Economic Development Commission. Nov. 1970.

Requardt, Ernst et al."Municipal and Regional Planning," *Standard Handbook for Civil Engineers*. 1968.

Saucier, John. "Application of Package Plants to Suburban Areas." *Journal WPCF*. Dec. 1969.

Stander, J. "Water Reuse- Drinking." *Water and Wastewater Engineering*. May 1969.

Stone, Ralph et al. "Water Quality: Cost Benefits of IrreduciBles." *Journal ASCE*. July 1972.

Swenson, H. et al. *A Primer on Water Quality*. U. S. Gov't Printing Office. 1965.

U. S. Department of the Interior. "New Water for Old," 1966.

" "Needed: Clean Water," 1965.

U. S. Department of the Interior. "Focus on Clean Water," 1967.

" "A New Era for America's Waters," 1966.

"Use of New Technology in Municipal Wastewater Treatment," <u>Technology Transfer</u>. March 1973.

"Wastewater Impacts: A general Survey of Cape Cod." Bauer Engineering, Feb. 1972.

Winblad, Uno. "Evaluation of Waste Disposal Systems for Urban Low Income Communities in Africa." Scan Plan Coordinator. 1972

COMMON RATES OF CONSUMPTION FOR SELECTED USES

	Gallons per person per day
Hotels	50-150
Restaurants	7-10
Camps	25-40
Hospitals	150-250+
Factories	15-35
Airports	3-5
Service stations (per vehicle served)	10
Schools	10-20
Theatres	3-5
Single family homes	50-75
Apartments	100-200
Offices	10-15

Water closet, tank	4-6 gal/use
Garbage grinders	1-2 gpd/person
Lawn sprinkler	120 gph
Bathtub	30 g/use
Shower head	20-35 g/use

Source:

Grava, S., Planning Aspects of Water Pollution Control, p. 177.

Metcalf and Eddy, Inc., Wastewater Engineering, p. 31.

APPENDIX A

TYPICAL WASTE CHARACTERISTICS

	miligrams/liter
Solids, total	700
Dissolved	500
Suspended	200
Biochemical oxygen demand	200
Nitrogen, total	40
Organic	15
Free ammonia	25
Phosphorous, total	10
Organic	3
Inorganic	7
Chlorides	50
Grease	100

Source:

Metcalf and Eddy, Wastewater Engineering, p. 231.

APPENDIX B