Engineering Evaluation of Factors Affecting Quality of Water Sources Available for Saline Water Conversion Plants

United States Department of the Interior

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FOREWORD

This is the one hundred and sixty-eighth of a series of reports designed to present accounts of progress on saline water conversion with the expectation that the exchange of such data processes applicable to large-scale, low-cost demineralization of sea and other saline waters.

Except for minor editing, the data herein are as contained in a report submitted by Sheppard T. Powell and Associates under contract No. 14-01-0001-378, which has been accepted as fulfilling the provisions of that contract. The data and conclusions given in this report are essentially those of the Contractor and are not necessarily endorsed by the Department of the Interior.

Created in 1849, the Department of the Interior—America's Department of Natural Resources—is concerned with the management, conservation, and development of the Nation's water, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department of the Interior works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States—now and in the future.

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INTRODUCTION

Experience in the development of saline water conversion facilities has clearly established the importance of water quality to the technology and economics of process and plant design. The need is recognized for fuller and more comprehensive knowledge of such water quality considerations, particularly contamination, in the planning and design for the larger-scale facilities of the future. Also, the need to evaluate saline water conversion as an integrated part of the broader water supply development has been envisioned. The investigation reported here has been carried out to meet certain of these needs.

The overall objective of the investigation has been to determine the effects of contaminated raw water supplies on conversion processes, and to study potential technical and economic advantages of combination saline water and sewage effluent conversion plants. The nature of the project has been that of an engineering study and evaluation, and did not involve any experiments to determine water quality effects.

SUMMARY

Sources of saline water are considered individually in the first three sections of this report. The sections and the respective saline water sources are as follows:

Section I - Ocean Waters
Section II - Coastal Harbors and Estuaries
Section III - Saline Ground-Waters

Within each section, the respective saline waters are discussed to show the salient quality characteristics of the potential supply. The type and degree of contamination that might be found is described with representative data given in some instances. Both "natural" and "man-made" contamination are considered. Some of the potential effects of such contamination on saline conversion facilities are discussed, and various means for controlling or treating contaminated supplies are presented.

The technical and economic aspects of integrating saline water conversion and waste water recovery in a combination plant are explored in Section IV. In those situations where a converted saline water supply is used, the need to consider the combined plant is noted. The question of waste water availability is discussed. Various dominant factors of specific portions of the combined systems are discussed to indicate the complex interrelated factors which affect the feasibility, design and costs for combined plant systems. The need for specific and detailed engineering investigations and comprehensive technical and economic evaluations in the actual development of a combined plant is stressed. A more pressing need is noted for studies to define the influence of certain factors and to develop the methodology for specific evaluations.

The quality of waste water, particularly sewage, as a source of supply to a combination plant is discussed. Significant data on sewage quality are presented. Caution is expressed on the use of average values - except as general guides. There is indicated a need to reconsider the applicability of long-established water supply design criteria to combined plant situations. Public health aspects of waste recovery are shown to be of major importance and the need for more and better knowledge in this field is noted.

Section V considers the pretreatment of waste waters for recovery in combination plants. The importance of pretreatment in the design and economics of the combined plant is noted. Three general design concepts for pretreatment facilities - viz., flexibility, decreased capital costs, and combined use of various pretreatment methods - are offered.

Adsorption is found to be a promising means of removing undesirable organic materials. Activated carbon is far superior to other tested adsorbents, but the cost is high. Its use will depend largely on the development of an effective and economical method of successive regeneration. Thermal regeneration appears to be suitable, but further study is needed. Chemical regeneration is not now promising. The fluid-bed counter-current adsorption process has strong merit.

Chemical coagulation has distinct merit as a possible means of pretreating waste waters. This application is somewhat limited to suspended and collodial contaminants and, in some instances, would have to be employed with other pretreatment methods, such as adsorption or oxidation. Considerable investigative efforts will be needed.

Data to evaluate the feasibility of chemical oxidation as a pretreatment method are meager. Further study of this method is necessary. The most promising use of chemical oxidation appears to be in conjunction with other pretreatment methods, such as adsorption or chemical coagulation.

Various other potential treatment methods are under study in the Advanced Waste Treatment Research Program of the U. S. Public Health Service. These studies may develop pretreatment methods suitable for combination plants, either separately or in combination with adsorption, coagualtion, or oxidation methods.

Section VI opens with some general considerations and discussion of factors affecting corrosion, erosion and pitting. This is followed by a discussion of the applications and limitations of various construction materials including metals, metal alloys, plastics, coatings, paints and linings in unpolluted and polluted sea water and brackish water service.

Four pertinent exhibits are included to amplify the text.

Much of the material in this section has been drawn from actual field experience or observation of the authors.

I. OCEAN WATERS

Experiences in existing saline water conversion plants have revealed numerous operating problems resulting directly from the quality of the water supply. Many of these problems are specifically identified with soluble or insoluble substances that can be properly called contaminants, although some of them arise from normal characteristics of the saline water supply.

A variety of problems has been troublesome in the operation of the seventeen major installations employing the several forms of distillation, listed in the 1963 Saline Water Conversion Report (p. 78). Causes include trash, marine growth, and the balance of inorganic salts in the water. The 120 - 150 electrodialysis units which have been built have demonstrated the extreme sensitivity of this process to inorganic constituents exclusive of sodium chloride but present in extremely small proportions; organic and microbiological contaminants are also serious. It is also obvious that raw water quality affects desalination processes of other types.

This investigation of water sources for desalination will first consider the basic characteristics of ocean water and its normal constituents which affect conversion processes. This will be followed by a study of coastal harbors and estuaries where salinity is diluted, but pollution creates entirely new problems. Saline ground waters are again different because of the amount and species of dissolved solids. Others types of water supplies requiring consideration involve combination of recovery of sewage or industrial waste waters with desalination processes.

A consideration of all of these problems properly begins with a review of the composition of ocean water, with and without typical pollution to which it may be subject. The basic literature on this subject includes comprehensive studies of oceanography and marine ecology by Sverdrup, Moore and Zo Bell, and papers by a number of investigators on special features listed in the Bibliography. (206)(248)(305)(346)*

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*Numbers in parentheses indicate references given in the bibliography.

A. <u>Basic Chemical and Physical Properties</u>

The practical and economic feasibility of desalination of sea water are limited not only by the burden of salts to be removed, but also by many varieties of interference with the processes available. Knowledge of the quality of ocean water, and the effect of natural fresh water tributaries and man-made pollution is basic to the design of sea water desalination plants.

The chemical and physical properties of ocean waters can be classified as conservative and non-conservative properties. Conservative properties are those which are essentially not influenced by biological activity, namely, salinity, temperature and possibly pH. The non-conservative are oxygen, phosphate, nitrate, silicate and to a lesser extent BOD. These will be considered separately (234).

B. <u>Conservative Properties of Ocean Water</u>

1. <u>Salinity, Chlorinity and Chlorosity</u>

All of these terms are used to rate a sample of sea water, and for consideration of desalination they represent the burden of salts to be removed. <u>Salinity</u> in grams per kilogram (^{0}/00) is the total solids with all halogens expressed as chlorine, the carbonate converted to oxide and all organic matter oxidized. <u>Chlorinity</u> represents the halogens alone, all expressed in grams per kilogram and with bromine and iodine replaced by chlorine. The definition of these terms and techniques for determining their values were established by an International Commission. Since it is difficult to determine salinity as defined but the composition of dissolved solids is relatively constant, an empirical relationship was established, as follows:

SALINITY = 0.03 + 1.805 x chlorinity

These weight ratios are independent of density changes with temperature. The primary standard used in determination of chlorinity is so-called "normal sea water" prepared by the hydrographical laboratories in Copenhagen, Denmark, which is distributed to all oceanographic institutions (305).

Since most analytical determinations give results in milligrams per liter, the term <u>chlorosity</u> (Cl) has been introduced and is defined as the chlorinity expressed as grams per 20° liter.

The major constituents in sea water having a salinity of 35 ^{O}/OO are shown in Exhibit I-1.

The Allan Hancock Foundation of the University of California along with the Sanitary Engineering Department of the University of California at Berkeley have done extensive recent investigative work in measuring the characteristics of ocean water and the effect on marine life of waste discharges. The same university has carried on studies leading to the development of desalination processes. It is therefore appropriate to quote some of their data as examples in discussions of ocean water quality. (4)(5)(6)

The reports of these investigators state that between the months of October and November, salinity varied between 33.48 and 33.85 ^{O}/OO, and the following differences were noted: (1) a general increase in salinity as distance increased from the shore; (2) there was no well-defined gradation in the north-south direction, and (3) rather complex patterns on the shelves consisting of localized areas of higher or lower salinity. The greatest changes in density occurred within the upper 50 foot layer. Vertical differences in salinity in Santa Monica Bay and the La Jolla and the San Diego region were noted between the depth of 100 feet and 200 feet.(296)

Pure water is known to have a maximum density at a temperature of nearly 4oC, but sea water differs in that the temperature of the maximum density decreases with increasing salinity and at salinities greater than 24.7 ^{O}/OO is below the freezing point.

Salinity, temperature and the density relationships are of extreme importance in designing and operating large ocean outfalls. Unfavorable conditions between these relationships may result in adverse bacteriological conditions at the shoreline. Therefore, the location of the intake for a saline conversion plant should be examined carefully with consideration given to these highly important relationships. (296)(297)

Exhibit I-1

MAJOR CONSTITUENTS IN SEA WATER*

Constituent	Sea Water Concentration, milligram per liter
Total Dissolved Solids	35,000
Chloride (Cl)	19,350
Sodium (Na)	10,710
Sulfate (SO_4)	2,690
Magnesium (Mg)	1,300
Calcium (Ca)	419
Potassium (K)	390
Bicarbonate (HCO_3)	150
Total Hardness as $CaCO_3$	6,380

*Mean of 77 analyses of ocean water collected by the Challenger Expedition.

2. Sea Water Temperature

The temperature of sea water is obviously basic to the heat balance of distillation processes and affects sea water quality through its profound influence on marine life. Seasonal ranges of variation in surface temperature are slight in tropical latitudes and on the North American continent reach a maximum at a latitude of about 40°, where the annual range is of the order of 8°C in the Atlantic Ocean and 10°C off the California coast. The range of fluctuation drops sharply with depth and rises somewhat over a shallow continental shelf.

Investigation off the California coast shows that the average temperature ranges over the shelf are about 11°C. Unstable air occurs 10 percent of the time, and this has quite an effect on the surface temperatures. The wind with its changing velocities and directions results in water movements near shore that aid in forming local climatic conditions. Although all influences of variation of the climate are not well established, the original development of cloud covers and temperature and humidity variation are influenced by the temperature of the water. (5)(6)

Yearly ranges of 10 - 15°C occur only in the upper 10 to 20 feet of the water. At increasing depths, the variation of temperature is much smaller so that at 300 feet depth the change is less than 2°. In general, temperature of the water over the shelf is not much different than the temperature further off shore except for upwelling flows that occur at times and are not fully explained. (4)(5)(6)(7)

Surface temperatures during the fall of 1959 on the shelf coast varied between 16.3°C and 20.7°C. The major features noted in the surface temperature distribution were: (1) a marked change in temperature between Point Conception and Elwood in which the temperature increased from less than 16.7°C to more than 19.5°C; (2) the presence of localized areas of higher or lower temperatures on the Santa Barbara, San Pedro and San Diego shelves, in contrast to a relatively simple pattern associated with other and narrower portions of the shelf; (3) a complex temperature pattern on the northern shelf and a relatively simple one on the southern shelf; (4) highest offshore surface temperatures between Point Mogu and Point Duma, and (5) no apparent increase of surface temperature with decreasing latitude. (4)(5)(6)(7)

Sub-surface temperatures were found quite uniform from area to area and approximately 90 percent of those taken did not deviate more than 1.1°C.

The important characteristics between the spring and the fall were that during the spring temperatures were 8.5°C lower than those during the fall, and the temperature measured at 200 feet depth was 1.9°C lower.

It has been shown by investigators that there was an optimum temperature at which the maximum growth rate of diatoms occurred. However, the value of optimum temperature varies for different species. Therefore, it is quite possible that varying temperatures can be more favorable than fixed ones for the completion of the life cycle of some organisms in sea water. Work performed by Hilary Moore, research associate of the Woods Hole Oceanographic Institute, has shown that growth of many species of marine animals is dependent upon temperature and the size to which they grow depends upon the duration of the optimum temperature. It may be reasoned that the length of life of any species is inversely proportional to the temperature. However, the temperature limits will vary for any one marine species. Low temperature will result in reduction of growth particularly in the species of planktonic origin. It seems that fluctuating temperature which will have optimal conditions for the action of various enzymes and their respiration and growth activity will be quite influential on the success of the organisms to survive. (295)(305)

Although the influence of temperature on the growth of algae covers a rather wide range, it does have a critical effect on the rate of growth. Tidal levels which change the time of exposure of algae to constant salinity and temperature conditions may have limiting effects on maturing growth of the algae in the intertidal zone. (112)(113)(234)

3. Sea Water pH - Effect of Carbon Dioxide

The sea is a well buffered solution, the principal contributing substances being bicarbonates, carbonates and borates. Therefore, considerable amounts of gaseous carbon dioxide may be added to or taken away from sea water without appreciably affecting the pH. (129)(305)(346)

The total carbon dioxide in sea water does not follow Henry's law for the solution of gases in inert solutions but is in ionic equilibrium: (161)(305)

$$H_2O + CO_2 = H^+ + HCO_3^- = 2H^+ + CO_3^=$$
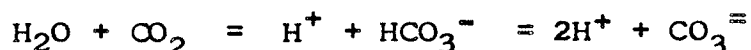
The amount of carbon dioxide dissolved in sea water depends upon pH, salinity and temperature. The total carbon dioxide in solution at a particular pH changes with change in salinity. The variation in pH of shelf waters is of probable significance because it demonstrates that large changes in the amount of dissolved carbon dioxide must occur. An investigation was conducted to determine the hydrogen ion concentration on nearly 200 samples in the Continental Shelf area of southern California. The highest reading at any depth was 8.6 and the lowest 7.6, with an average of 8.1. Sixty five percent of the samples gave a pH of between 8.0 and 8.2. Most of the determinations at depths of 200 feet or greater resulted in a pH of between 7.6 and 7.8. (4)

As a result of plant growth, the partial pressure of carbon dioxide in the water is lowered by a very small amount compared with the increase of partial pressure of dissolved oxygen. (79)(234)

It can be reasoned that because of the dissociation equilibrium and buffering capacity of sea water that a considerable amount of moderately acidic or basic waste can be added to the ocean without a pronounced effect on pH. Therefore, measurement of pH is not a useful parameter by which to detect or trace effluents except in the most immediate vicinity of an outfall where grossly acidic waste is discharged.

It has been found that the total carbon dioxide in solution, at a particular pH, decreases about one percent per rise of one degree Centigrade of temperature. Further confirmation of this was found from a study made of the Corpus Christi Bay by Texas A. & M. Research Foundation. (250)

It is important that the pH of a medium which contains living organisms remain constant. It is quite likely that damage to organisms living in sea water could be caused by an effluent, without it being possible to measure a significant change in the pH of the sea water. (295)

C. Non-Conservative Properties of Ocean Water

The non-conservative or unstable properties of
ocean water are those which are influenced by biological activ-
ity: dissolved oxygen, phosphate, nitrate, silicate and to a
lesser degree BOD. Discussion of these properties will be in-
volved with the interrelation of these substances with each
other and with marine life, particularly with respect to
nutrients and their adequacy for specific organisms. During
the summer months, non-conservative properties will change
value rapidly in surface waters, due to biological activity of
plants, mainly phytoplankton, and there will be large vertical
gradients or changes. Horizontal gradients are often related
to the presence or absence of newly upwelled water from greater
depths. In the winter and fall months, heavy land run-off in-
troduces considerable fresh water to the surface layers,
influencing salinity and turbidity and contributing essential
nutrients to the water for the support of many biological species
and fish life. The most important of the various compounds dis-
solved in sea water which are present as nutrient salts are
phosphate, nitrate, silicate and iron. Where great numbers of
plankton are growing in water, this indicates an abundance of
these salts. (4)(5)(7)(235)

Although turbidity may be increased by the addition
of dissolved compounds to sea water, such as is caused by waste
disposal, the major cause of turbidity in nearshore areas is
from particles of silt, clay and sand or any other solid debris
which is maintained in suspension by the turbulence of the water.

1. Effect of Oxygen Content

Oxygen which is present in sea water as free dis-
solved oxygen is utilized by bacteria and therefore its dis-
tribution and presence is influenced by microbial action. The
combined oxygen present in water occurs mostly in sulfate ions
with smaller amounts in bicarbonate, borate, phosphate, nitrate
and nitrite ions and to a lesser degree in organic compounds.

The fluctuations of dissolved oxygen from the mean
is primarily associated with the cyclical variation of the tidal
motion and, secondarily, with the variations in run-off waste
discharges and temperature. The production and consumption of
oxygen in sea water is an ever-changing process. Surface waters
are always much richer in oxygen than deeper waters. From the
table of the "Average Water Quality Characteristics of San
Francisco and San Pablo Bays" Exhibit I-2, the variation of the
oxygen values for the samples taken indicate that the effect of
plankton respiration is quite significant. (4)(5)(6)(115)(305)

Exhibit I-2

AVERAGE WATER QUALITY CHARACTERISTICS

Period Covered by Samples	Temp. °C.	pH	Dissolved Silica mg/1	Suspended Solids mg/1	Chlorisity CL⁻ g/1	Dissolved Oxygen mg/1	%Sat.	B.O.D. mg/1	Coliform MPN per 100 ml.	Nitrogen NH$_3$-N mg/1	NO$_3$ mg/1	Total Phosphate (PO$_4$) mg/1
South San Francisco Bay (Average of 9 Sampling Stations)
July 11-12, 1961	23.8	7.9	6.8	38	15.9	5.2	72	9.6	450×10^3	0	0.06	4.1
August 24-25, 1961	21.1	7.6	9.7	41.7	16.7	3.7	50	30.3	700×10^3	0.1	0.09	5.2
October 25, 1961	16.4	7.5	11.6	61	17.3	3.9	49	7.4	300×10^3	0.2	0.33	4.5
January 8-9, 1962	10.4	7.4	9.8	71	16.1	5.4	58	6.1	200×10^3	2.0	0.4	4.8
February 28-March 1, 1962	9.7	7.7	9.3	11.3	11.3	6.6	67	5.1	600×10^3	1.59	0.5	2.8
May 2-3, 1962	17.5	7.7	7.0	11.6	11.6	5.6	66	7.2	600×10^3	1.6	0.4	4.7
Suisum Bay - Lower San Joaquin (Average of 10 Sampling Stations)
July 25-26, 1961	21.0	8.1	1.5	59	7.1	7.9	93	1.1	5.3×10^3	-	0.13	0.3
September 13-14, 1961	19.6	7.7	4.9	80	4.8	7.5	85	0.9	8.0×10^3	-	0.14	0.3
November 14, 1961	13.5	7.5	8.5	44	4.0	8.3	83	1.2	1.6×10^3	0.1	0.34	0.4
January 22-24, 1962	6.2	7.5	19.0	68	2.0	10.7	88	1.2	7×10^3	0.24	0.7	0.4
March 20-21, 1962	11.7	7.5	18.1	68	0.36	9.2	85	0.7	3.1×10^3	1.0	0.9	0.2
May 22-23, 1962	17.1	7.5	12.6	71	1.3	8.2	85	0.3	3.0×10^3	0.09	0.11	0.4
San Pablo Bay (Average of 9 Sampling Stations)
August 14-15, 1961	19.7	7.9	2.3	18	15.7	6.8	87	0.7	1.2×10^3	-	0.38	0.5
October 10, 1961	16.4	7.7	3.0	34	15	7.3	86	0.8	2.0×10^3	-	0.25	0.2
December 12-13, 1961	10.3	7.7	8.6	38	11.2	8.4	84	0.8	1.5×10^3	0.1	0.5	0.4
February 14-15, 1962	10.3	7.7	13.3	45	6.9	8.9	85	1.0	4.0×10^3	0.28	0.8	0.3
April 18-19, 1962	15.6	8.0	8.3	87	9.2	7.8	86	0.8	4.0×10^3	0.13	0.4	0.2
June 19-20, 1962	18.0	7.4	6.5	33	11.6	6.9	81	0.1	2.5×10^3	0.13	0.3	0.6

The greatest range between minimum and maximum values occurred in the spring and summer seasons. The lowest oxygen values in surface water were associated with upwelling of water in the spring season.

Since the increase or decrease in oxygen is associated with an increase or decrease in molecular carbon dioxide, it may be assumed that oxygen values are correlated with phytoplankton growth, as well as decrease in pH.

Significant dissolved oxygen deficiencies due to waste discharges are not uncommon in restricted waters such as bays, harbors and estuaries, but no deficiencies have been reported for open coastal waters. (234)(235)(305)

Atmospheric oxygenation of water takes place only at the air-water interface. Measurement of photosyntehtic production of oxygen shows that three times the amount of oxygen is produced by phytoplankton than is gained from the air. In restricted salt waters the effects of wastes in reducing dissolved oxygen will vary greatly depending upon such factors as degree of tidal action, amount of mixing, algae growth, etc.

2. Phosphate Concentration

Phosphorus is found in sea water in the form of organic or inorganic compounds. It is reported both as the element (atomic weight 31) and the phosphate ion (molecular weight 95), and also as mg per liter, microgram atoms per liter or per cubic meter. In the following, conversions have been made to mg per liter of phosphate so that quantities will be on a comparable basis. (5)(206)(346)

In living tissues found in sea water, phosphorus is mainly in the organic form; and by decay of the living tissues, it is released and goes back into the water usually in some soluble form. The amount of phosphorus present as organic phosphate is quite difficult to determine and its distribution does not follow the same pattern as the inorganic phosphate sediments.

The available phosphate in water is considered by many to be the limiting nutritional factor in the ecology of an estuary. At surface temperatures up to 20°C as found in the temperature zone, there is a critical concentration of phosphates with relation to photosynthesis and growth of organisms. While

the minimum inorganic phosphate level at which phytoplankton
will grow has not been completely established, it is believed
that for continued growth the amount required is approximately
0.5 microgram atoms per liter (.0475 mg per liter of phosphate).
Riley and others during their investigation of the productivity
of plankton assumed that the critical level was a concentration
of .55 mg atoms of phosphorus per cubic meter (equivalent to
.05225 mg per liter of phosphate). Irrespective of the quantity
of phosphates, it has been found that nitrogen and phosphorus
tend to be present in sea water at a constant ratio of 15 atoms
of nitrogen to one of phosphorus. The phosphate concentration
in water has been found to decrease to a minimum in the winter
and rise again in the summer. Investigations in the Biscayne
Bay area found that these concentrations in water of phosphate
can be correlated with the concentration found in the sediment
in the bottom of the bay. The insoluble ferric phosphate was
found to be present in the sediment in winter. This was due to
thorough mixing of the water which gave a plentiful supply of
oxygen. Whenever stagnant conditions occur and result in deple-
tion of oxygen in water, there is a reduction of ferric phosphate
to the more soluble ferrous salts. These will diffuse into the
water and, where hydrogen sulfide is present, the iron precipi-
tates as sulfide and liberates the phosphate ions. Upwelling
deeper ocean waters brings characteristic temperature and
salinity changes which may have a temporary effect on coastal
waters. With this upwelling water also comes nutrient supplies
which can include phosphates, and this has a more lasting effect
on productivity of phytoplankton on the inshore areas. There-
fore the interchange of large water masses is of prime importance
to the water of a coastal region with regard to the nutrient
salts found there and the type and growth of plankton in these
waters. (79)(206)(234)(305)(346)

The phosphate content of deep water where
practically all phosphorus is in the inorganic form has been
found to vary from less than 0.5 mg atoms per cubic meter in
the Mediterranean Sea to more than 3.0 in the North Pacific and
Indian Oceans (.0475 to .285 mg/liter). These variations in
composition are produced by biological activities, or the action
of microorganisms and bacteria in the sea. Harvey found as
early as 1939 that natural sea water with an enrichment of
nitrate, phosphate and iron could lack the required growth sub-
stances for the continuous production of some marine diatoms.
Because of the non-uniform distribution of nutrient elements in
the sea, there is a fluctuation in the intensity and production
of marine phytoplankton in areas where these changes occur. The

seasonal variation in color of coastal waters is by large
extent due to the greater or lesser quantities of various types
of plankton organisms found present in the surface waters. It
has been found that run-off from land supplies quantities of
phosphates, nitrates and other nutrient salts to surface layers
of the ocean in coastal regions. However, the main supply
comes by replenishment from vertical circulation or diffusion
from the deeper waters.

3. Forms of Nitrogen

Nitrogen is found in sea water in compounds of
various types and is also found as free gas. However, dissolved
gaseous nitrogen does not react chemically with water or the
salt therein, and its solubility decreases with rise of temper-
ature and salinity. Nitrogen fixation is an important factor in
the depletion of oxygen in polluted water as well as in sewage.
According to Sverdrup, Johnson and Fleming, the inorganic
nitrogen compounds show a wide range in values: (4)(206)(305)(346)

Ammonia-N .... 5 - 50 ug/L

Nitrite-N .... 0.1 - 50 ug/L

Nitrate-N .... 1-600 ug/L

Ammonia varies considerably in surface water de-
pending upon the characteristics of the surrounding water;
however, in deep waters it is found in highest concentration and
quite uniform. Nitrite nitrogen is usually found in or above
the thermocline. Its concentration relative to nitrate is in-
creased during seasons of maximum utilization of nitrate from
the water. The highest content of inorganic nitrogen found in
water is in the nitrate form. The nitrifying bacteria
Nitrosomonas and Nitrobacter oxidize ammonia to nitrite and
nitrate, if the surrounding conditions are aerobic. Growth of
phytoplankton and algae are limited by the amount of nitrate
nutrient in the water. (4)(5)(79)(206)

Since the carbon:nitrogen ratio is comparatively
constant in organic material, the organic nitrogen content is
sometimes used as a quantitative measure of the amount of or-
ganic matter in water and the marine sediments. Also, because
of the close relationship between nitrate and phosphate, it is
possible to forecast with some accuracy the concentration of
nitrate after the phosphate concentration is known.

Investigations of the Allan Hancock Foundation of the Southern California shelf waters, revealed that the nitrate-phosphate ratio differed from waters of the Pacific, Atlantic and Indian Oceans[7]. Here in these shelf waters the ratio of nitrate:phosphate was 1.8:1 milligrams per liter. Von Brand investigated the Northwest Atlantic and found that the maximum variation of nitrogen was in the upper 400 meters of the ocean. Some nitrogen compounds are added to the sea by river run-off. Influence of coastal conditions and shallow waters is associated with the variation of the seasons which result at times in lower salinity and increased sediment. It may be concluded that shelf waters which may receive sewage discharge will have an abundance of nutrient compounds for growth of algae and are of ecological significance to growth of various organisms.

4. <u>Organic Compounds</u>

Organic compounds occur in sea water in wide variety. For the purpose of this section on Ocean Waters, a distinction must be made between the oxygen-consuming pollutants commonly measured in terms of biochemical or chemical oxygen demand (BOD and COD) and the broad spectrum of products of marine life which are characteristic of ocean water in the absence of man-made pollution. In addition to oxygen-consuming capacity, these compounds are revealed by chemical tests which classify them by molecular structure, etc. They have an important bearing on marine biology and may affect the utility of sea water for various purposes. (113)(206)(305)

For example, the formation of calcium carbonate scale is affected by organic inhibitors of crystalline scale formation. Proteins and amino acids in sea waters which appear to form carbamino-carboxylic acids with carbon dioxide or bicarbonate ion would increase the solubility of calcium carbonate as well as calcium phosphate in sea water. The formation of complexes of calcium with organic material in sea water may also be of considerable import in desalination by resin exchange, freezing, reverse osmosis and processes other than evaporation.

Effects harmful or beneficial to marine life in sea water may be related to organic matter. It may form organic complexes with trace metals which may be beneficial or detrimental. Dissolved organic matter may be present in the form of toxins which inhibit or kill organisms. The success of some algae, bacteria and fungi may be predicted and their ecological succession determined on the basis of the organic materials present.

The inventory of organic compounds is so large that it is possible to mention only a few of the more important ones. If comparison is made with lake waters, then one would expect to find that the dissolved organic matter contained proteins, polypeptides and many amino acids; also, traces of thiamine and biotin as well as Vitamin B_{12}. Evidence has been found that enzymes exist in free salt water, and oxidative catalysts have been found in solution. Variable quantities of an organic substance having the characteristics of a reducing sugar have been found in the waters from the Gulf of Mexico; the greatest concentrations occurred in low-salinity water. Approximately seventeen different amino acids have been identified by ion-exchange resin chromatography in acid hydrolyzates of dissolved organic material in sea water to depths of 3500 meters from the central Gulf of Mexico. These are glutamic acid, lysine, glycine, aspartic acid, serine, alanine, leucine, valine plus cystine, isoleucine ornithine, methionine sulfoxide, threonine, tyrosine, phenyl-alanine, histidine, arginine, proline and methionine. The results indicate that the dissolved organic material in deep-sea water may make an important contribution to the organic budget of the sea. (115)(305).

Citric and malic acids have been found present in sea water. Also, isolated from sea water are what appear to be a dehydroascrobic acid and rhamnoside. When concentrated, organic material extracted from sea water shows a substantial buffering action on titration with sodium hydroxide. This indicates that at least part of the organic compounds present are proton acceptors with the highest capacity existing in the pH range between 7.8 and 9.0, as seen in Exhibit I-3. The slight break in the titration curve which occurred at pH 3.5 may be due to carboxylic acid. However, the major break is believed to result from replacement of hydrogen on proteins, peptides or amino acids.

Organic matter in ocean water remote from sea coasts is oxidized by bacteria by the same mechanisms which proceed at a much higher rate where pollution is present, although the BOD of such ocean water is very much lower than that of coastal waters, particularly near outfalls. Where sea water is stored in small vessels, or with sand which presents a large surface, dissolved organic matter is absorbed as a concentration of food for bacteria, and as a result they grow rapidly. It has been observed that 25 - 50 percent of such dissolved organic matter is oxidized to carbon dioxide by bacteria. (115)(206)(289)(346)

TITRATION CURVE OF ORGANIC MATERIAL EXTRACTED FROM SEA WATER

EXHIBIT-I-3
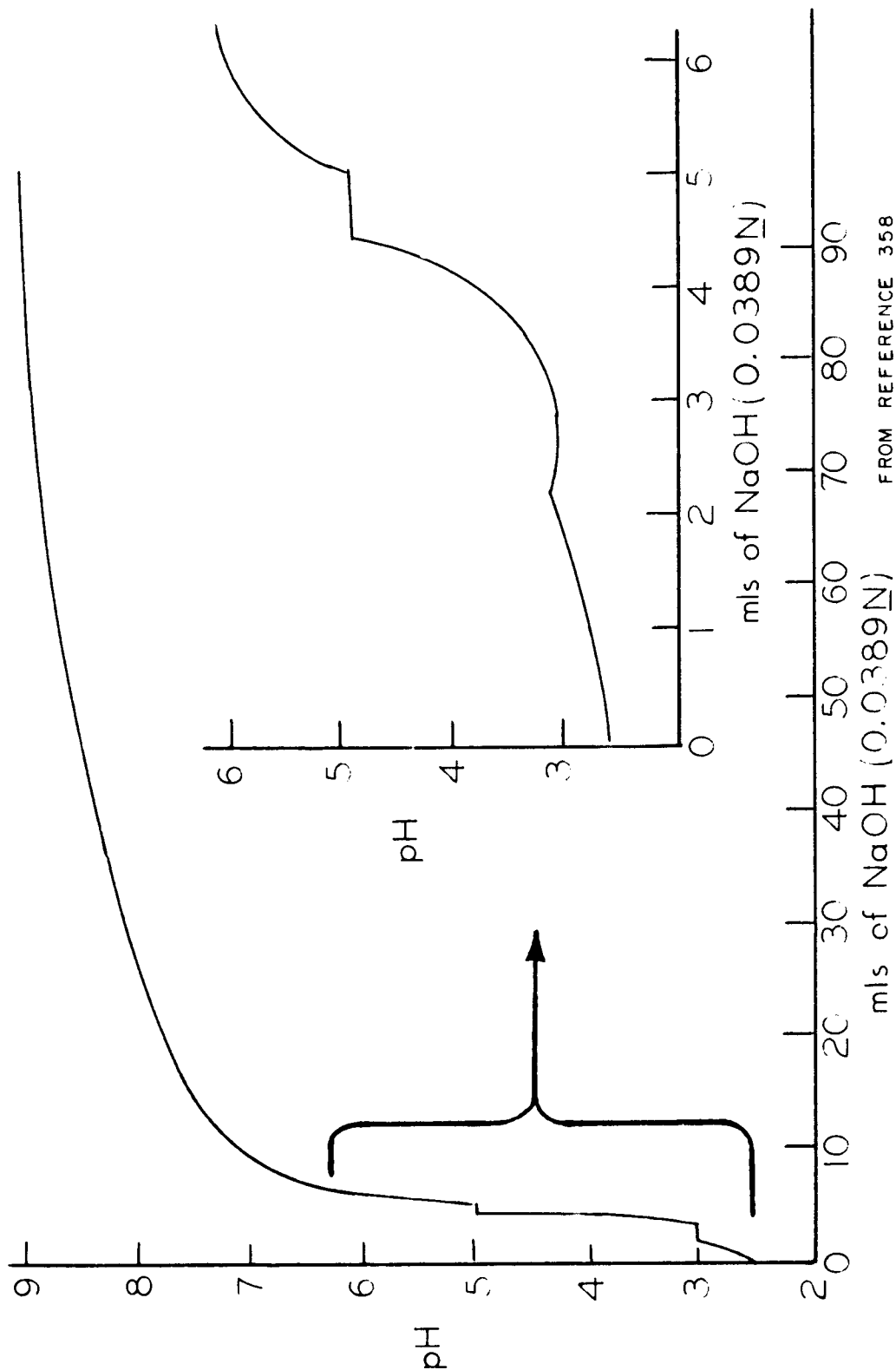
FROM REFERENCE 358

D-1296

D. Evaluation of the Effects of Waste Discharge

Production of fresh water from undiluted ocean
water has been practiced for years in shipboard evaporating
systems, but there are some coastal or island sites where de-
salination plants are needed that would draw an ocean water of
essentially normal salinity. It is necessary to anticipate
pollution varying from rain water run-off to sewage, oil and
liquid wastes affording little fresh water dilution but poten-
tially serious interference with conversion processes.

These factors sometimes cause major modification
in marine biology of coastal waters.

Pollution has an outstanding effect on the food
cycle in sea water. The entire balance of nutrients in sea
water may be upset and the water may become over-fertilized by
nitrogen and phosphate (113)(248). Organic matter from domestic
sewage encourages the growth of the green algae Ulva and
Enteromorpha. Their presence indicates possible contamination
of the water. Changes in the certain chemical wastes may also
encourage the growth of algae. As an example, several inves-
tigators who studied pollution caused by a paper mill on the
west coast discovered that the red liquor, a waste product of
the sulfite process of pulp manufacture, stimulated the growth
of the filamentous diatom Melisora due to the high organic con-
tent of the liquor. When the red liquor discharge stopped, the
Melisora soon disappeared (307).

An outfall discharging into the ocean could con-
ceivably have a number of harmful effects upon a kelp bed
(4)(113)(234)(248)(295):

1. Certain of the constituents of the effluent might
be toxic to Macrocystis sporophytes or gametophytes (or both)
and the plants would die in areas where destructive concentra-
tions of the constituents appear.

2. Turbidities within the discharge field of the out-
fall might be increased, reducing light intensities or altering
spectral distributions within the ocean and altering the balance
between synthesis and destruction of kelp tissue to such a drastic
extent that the plants could no longer maintain themselves.

3. Concentrations of kelp enemies such as grazers,
pathogens or parasites might in some way be encouraged by the ef-
fluent and the increase in their numbers might alter the balance
between synthesis and destruction of kelp tissue.

4. Siltation effects from the settling of suspended matter discharged by the outfall might reduce photosynthesis within the leaves and prevent spores and gametophytes from finding a suitable location to germinate on the bottom.

5. Discharge of the effluent might cause changes in salinity or temperature. Such effects might be significant in the immediate vicinity of an outfall, but it is doubtful if they would extend any great distance. Since studies involved the disappearance of kelp beds over distances measured in miles, this hypothesis seems less promising.

In the winter and fall months, heavy land run-off introduces considerable fresh water to the surface layers, influencing salinity and turbidity and contributing essential nutrients to the water for the support of many biological species and fish life. The most important of the various compounds dissolved in sea water which are present as nutrient salts are phosphate, nitrate, silicate and iron. Where great numbers of plankton are growing in water, this indicates an abundance of these salts (4)(5)(6).

Leaching of land rock is carried out by water of low concentration of salt yet high in free and combined carbon dioxide, which is capable of dissolving materials that would not pass into solution if they were in contact with sea water, because of the dissolved solids already in sea water (39). Therefore, the effect of river waters is to modify the relative composition of the dissolved solids in sea water.

Although turbidity may be increased by the addition of dissolved compounds to sea water, such as is caused by waste disposal, the major cause of turbidity in nearshore areas is from particles of silt, clay and sand or any other solid debris which is maintained in suspension by the turbulence of the water (5).

Intermittent pollution from ships can have very serious effects on desalination plants, as in the case of oil-contaminated bilge water, garbage and trash. Seasonal contamination with leaves, pine needles, etc., as well as dead or living seaweed, has also been troublesome. All these items must be considered under the heading of pollution that may affect ocean water at the site of a desalination plant.

E. Troubles Experienced in Using Sea Water, and Treatment Required

Some salt water conversion processes are not adaptable to ocean water for obvious reasons. Conventional demineralization by ion exchange resins is not practicable because of their limited capacity, making the outage time for regeneration hopelessly overbalance the service period. Electrodialysis of sea water (or any membrance process) would require primary purification to meet drinking water standards (except for mineral solids) and the power cost would be prohibitive. This leaves distillation or freezing processes as the available methods of approach, and the several forms of evaporators and compression stills have dominated practical applications.

The collecting of ocean water for these purposes requires the same precautions that are applicable to its use in condensing and cooling. Cribs and intake screens must be constructed to remove particulate matter, and in general a higher degree of straining is necessary to avoid fouling and erosion. Marine growths such as seaweed, shell fish, and other forms must be kept out of intake pipes and the desalination plant by the effective use of chlorine or other biocides. The use of coagulation and filtration, as in the case of seawater regeneration of zeolite resins, is an extreme step that might be necessary if turbidity or colloidal contaminants should be excessive.

The key problem which is common to all types of distillation equipment is the scale formed on heat transfer surfaces. The scale which forms is composed of magnesium hydroxide, calcium carbonate and calcium sulfate. In a study (162) by Prof. W. F. Langelier et al, it was learned that magnesium hydroxide and calcium carbonate are precipitated from boiling sea water mainly as a result of the conversion of bicarbonates to carbonate with the evolution of carbon dioxide. The bicarbonate content of sea water is approximately 112 ppm (as $CaCO_3$). Prof. Langelier found the following physical factors influenced the evolution of carbon dioxide by the reaction:

$$2HCO_3^- \longrightarrow CO_2 + CO_3^= + H_2O$$
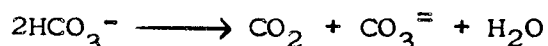
1. Temperature.

2. Boiling rate.

3. Removal of carbon dioxide gas.

4. Surface area between vapor and liquid.

5. Partial pressure of carbon dioxide in the atmosphere above the solution.

These characteristics were further confirmed by the tests performed by F. C. Standiford and J. R. Sinek (473).

Salts like calcium sulfate, formed from strong acids which do not decompose on heating, precipitate as a result of increased concentration of the ions in solution, occasioned entirely by the vaporization of a portion of the water. Three types of calcium sulfate scale can exist in contact with solutions: These are gypsum ($CaSO_4.2H_2O$) alpha hemihydrate ($CaSO_4.\frac{1}{2}H_2O$) and insoluble anhydrite ($CaSO_4$).

The results of the investigation of Standiford and Sinek (473) indicate that calcium sulfate scale will not form at 252°F when the concentration factor in the discharged brine is 1.7, but will form if the concentration is allowed to go to 2.0 at this temperature. They also found that at higher temperatures the concentration factor must be reduced. They have indicated that no heating or evaporation above 300°F can be done without possibility of a scale being formed.

The conclusion that scale formation cannot be entirely prevented by physical methods is based on the fact that the composition of scale cannot be predicted from the equilibrium data of the salts found in solution.

The bicarbonate alkalinity of sea water can be reduced by addition of some acid (usually sulfuric) and the carbon dioxide which is released may be removed by deaeration or degasification. Maintaining a pH of 6.5 to eliminate alkaline scale will directly prevent magnesium hydroxide and the calcium carbonate scale. If sulfuric acid is used for pH control, the rate of deposition of sulfate scale will be only slightly affected, because the increase in sulfate content resulting from the addition of acid is rather small compared to the initial sulfate content of sea water (SO_4 in sea water is approximately 2630 mg/1).

Scale prevention methods have been the object of extensive research efforts.

In existing distillation plants, one of the following well-known methods is used:

1. Adjustment of the pH and bicarbonate content of the feed.

2. Operation at lower temperatures.

3. Use of additives or seeding compounds (sodium hexametaphosphate, sodium tripolyphosphate, ferric chloride, lignin sulfonic acid, etc.).

4. Removal of scale periodically as it is formed.

5. Recirculation of sludge-carrying seed crystals so that scale will deposit preferentially on the seed crystals.

Some methods have proposed the use of precipitating agents (263) and the recovery of the by-products formed. However, all of the intricate chemical equilibria which are present in hot brine, containing scale-forming compounds, are not fully known.

It is the belief of some investigators that suspended matter in sea water will have a catalytic effect on the deposition of scale. The lowering of surface tension by the presence of contaminants, whether in suspension or in solution, will have an unstabilizing effect on brine film on evaporating surfaces. At the Woods Hole Desalination Conference, some suggestions were made for further research in scale control, and one of these suggestions was to study the effect of suspended substances on the precipitation of calcium sulfate.

Another research effort is being directed to uncover techniques which will permit essentially scale-free operation of multi-stage sea water distillation plants at temperatures as high as $300^{O}F$. The present maximum operating temperature of $250^{O}F$ to $265^{O}F$ limits the process efficiency rather stringently.

II.   COASTAL HARBORS AND ESTUARIES

The installation of conversion plants to treat saline water from coastal harbors and estuaries presents problems which are entirely different from those affecting ocean water or saline well water. Some of these may be insuperable, requiring locating the source remote from the point of desalinated water requirement. In other cases, the raw supply might require various pretreatments to make it acceptable as feed to a desalination process.

A variety of effects must be analyzed in considering such an installation. Most of the coastal harbors are in populous areas and are seriously polluted with industrial wastes, oil, and sewage with varying degrees of pretreatment. The estuarine stretches of rivers entering the bays offer possible intakes which may provide water containing a much lower pollution loading but subject to tidal penetration of salinity.

The overall picture of saline water supplies from coastal harbors and estuaries, involving the basic characteristics of ocean water modified by fresh water dilution, is determined by the hydrology of fresh and salt water interchange at various points starting with the bay and proceeding upstream to the limit of salt water penetration. Marine biology is important not only as an index of pollution, but also because of interference by various growths with many water uses. This requires consideration of nutrients or poison supplied by sewage and wastes, which are not normal to ocean water. Finally, there are a number of contaminants such as detergents, heavy metals, etc. which must be surveyed in evaluating sites for desalination plants.

A.   Hydrologic Factors Affecting Water Quality in Harbors and Estuaries

1.   Hydrologic Classification

The capacity of an estuary for diluting and dispersing pollution is an important characteristic affecting treatment and design requirements. An estuary receives "new" fresh water from the tributary river or surface run-off, and from ground water discharge; it receives "new" salt water with each tide. The term "new" is applied to water which, after

entering, flows out again and never returns, so that it carries
with it some of the diluted wastes. Of course, estuaries lose
water by evaporation, which may amount to as much as 50 or
more inches per year in the latitudes where desalination is
under consideration in the United States.

With respect to the mechanisms of receiving and
losing water, and for purposes of pollution evaluation, estu-
aries are classified on the basis of hydrological character-
istics as Positive, Inverse, and Neutral (39). A Positive
estuary receives considerable dilution of seawater by discharge
from the land. An Inverse estuary loses more water by evapora-
tion than is replaced by rainfall or surface run-off and ground
water. Neutral estuaries have a rough balance between fresh
water additions and evaporation. In all three types, the
volume may be replaced by the ebb and flow of salt water from
the ocean, leading to a complete summary of the mechanisms
which will dilute and disperse pollution:

<div align="center">Sources of Dilution</div>

Positive Estuary	1.	"New" fresh-water; surface and subsurface run-off.
	2.	"New" salt water from the ocean.
Inverse Estuary	1.	"New" salt water from the ocean.
Neutral Estuary	1.	"New" salt water from the ocean.
	2.	"New" fresh surface or sub-surface inflow.

A given estuary may change from one type to another
during the year as the current and the salinity patterns change.

2. Effect of Tidal Currents on Water in a Bay

The flushing of a bay is naturally influenced by
the tidal cycle. The direction of tidal flow becomes more
variable along the shores of a bay, and it has been found that
particularly near the head of a bay, the flow may reverse its
direction several times in one tidal cycle. Along the shores
the current velocities are less than along the central axis of
a bay, and at times may become so small as to be difficult to
measure, amounting to no more than eddy currents (41, 141).

Measurements taken of currents in a bay have suggested that flood currents are stronger near the bottom and the ebb currents are stronger at the surface. At times it has been found that deep and shallow currents move in different directions. This in itself would influence the pattern of flushing of a bay. As an example, in the Raritan Bay off the New Jersey coast, flushing of the bay is accomplished by a net tidal drift which is westward along the northern part of the bay and eastward along the southern coast of the bay. This was emphasized by the distribution of iron, a known pollutant existing in the Raritan Bay (140). High concentrations of this pollutant were found in the water extending eastward along the southern shore wheras the water along the northern half of the bay contained little more than the iron content of the lower bay near the ocean. This pattern of flushing is further verified by the transparency of the water, which is an indication of suspended matter present. The transparency of the water was less along the northern coast line. This indicates that the pattern of circulation in a bay will affect the concentrations of contaminants, suspended matter, oxygen and salinity (111, 289).

This characteristic of the effects of advancing tides on a bay should be evaluated before a desalination plant site is selected for any particular bay area.

When river flow is sufficiently great in the spring, because of the higher temperature of the run-off water there is very little mixture in the bay and the fresh water escapes to the sea in a layer extending down from the surface approximately 15 feet. This is undoubtedly due to the lower density of the run-off water. Tidal action causes a counter-current of saltier water to move landward beneath this surface layer (140, 221).

Negligible attention is given in most estuarial systems to the initial-mixing or time-concentration distribution of a waste over one or two tidal cycles. This is of major importance (234, 236).

3. Salt Water Penetration - Effect of Turbulence in an Estuary

The economic consequences of salt water penetration to normal fresh water river intakes are so serious that the hydrology of these phenomena has been studied for many years, and a great deal of statistics and other data have been assembled.

Penetration of salt water to river sites where the water is normally fresh, and used for industrial and potable supplies, has two implications for the saline water conversion program. First, it may create an opportunity for the installation of plants where the fresh water is limited in reliable quantity as a result of salt water penetration. Second, the variations in salinity would make the load on the conversion process variable and techniques for preventing scale formation, marine growths and other causes of trouble would have to be changed constantly to match the quality of the water.

Intermittent high salinity has been a problem at Charleston, South Carolina; West Coast Florida points; Mobile, Alabama; and various locations around the Gulf Coast. The Delaware, Hudson, and Raritan Rivers are notable examples on the East coast, but many others are under surveillance by state and federal agencies. Although there is an obvious inverse relation between river flow and tidal penetration, this is not enough to explain a detailed chronology of such developments in drouth years.

In Exhibit II-1 the variation of chlorides along the Delaware River are shown for the year 1953. Each curve represents the average chlorinity profile for the month indicated. The distance from Paulsboro, New Jersey to the treatment plant at Torresdale, Pennsylvania is a distance of 22 miles. In this year 1953, the penetration of salinity caused many plant to suffer added expense for treatment of water taken from the river.

Normally, the Delaware River has a flow of a minimum of 10,000 cfs. and the concentration of chlorides is small above Paulsboro, as shown in Exhibit II-2. Daily fluctuations of flow are of minor influence on the average chlorides in a river and have no significant effect on the overall picture. Important factors are upstream impounding and release of water from reservoirs. Exhibit II-3 shows more graphically the influence of low flow. Normally there is no stratification in this river because it is a turbulent estuary. The chloride content of the surface and the bottom samples is quite uniform. Exhibit II-4 illustrates the chlorides at various stations of the river which verify the conditions found.

In contrast, Exhibit II-5 will indicate some rivers that are highly influenced by tidal effect. In areas such as New England, a drought might occur that would force the use of some source other than river water, for a potable supply.

EXHIBIT-II-1

THE DELAWARE RIVER
CHLORIDE PROFILES
JULY - OCTOBER, INCLUSIVE, 1953

OCTOBER
FLOW 2392 CFS

SEPTEMBER
FLOW 2687 CFS

AUGUST
FLOW 2428 CFS

JULY
FLOW 3763 CFS

MILES FROM ALLEGHENY AVE.

CHLORIDES, MONTHLY AVERAGE, PPM AS CL

TORRESDALE

RICHMOND
AVE
ALLEGHENY

DELAWARE

SOUTHWARK

PAULSBORO

SHEPPARD T. POWELL AND ASSOCIATES

D-438

EXHIBIT - II - 2
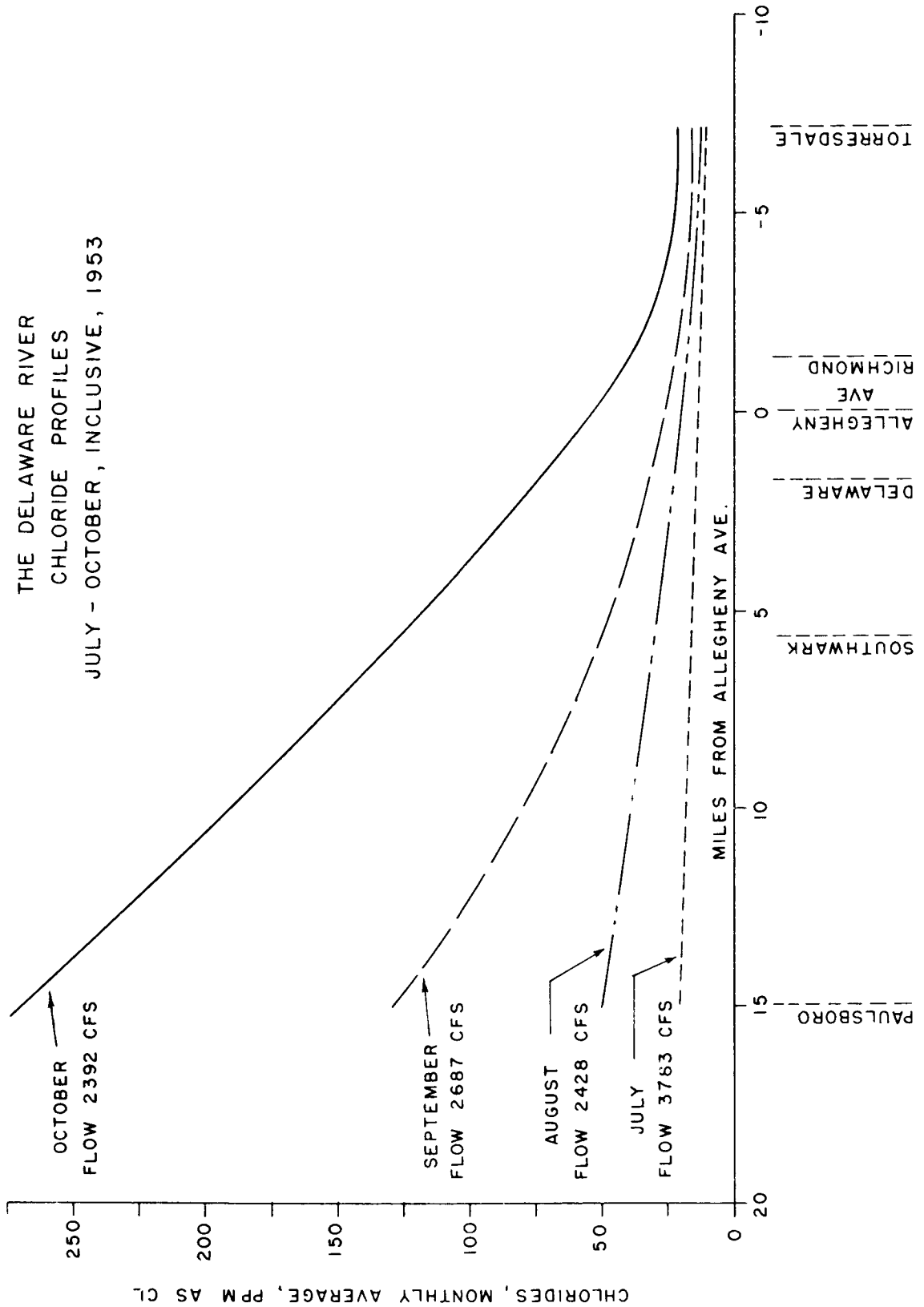
THE DELAWARE RIVER - FLOW VS. CHLORIDES - 1951-1953 INCLUSIVE

SHEPPARD T. POWELL AND ASSOCIATES

DD-521

EXHIBIT - II - 3
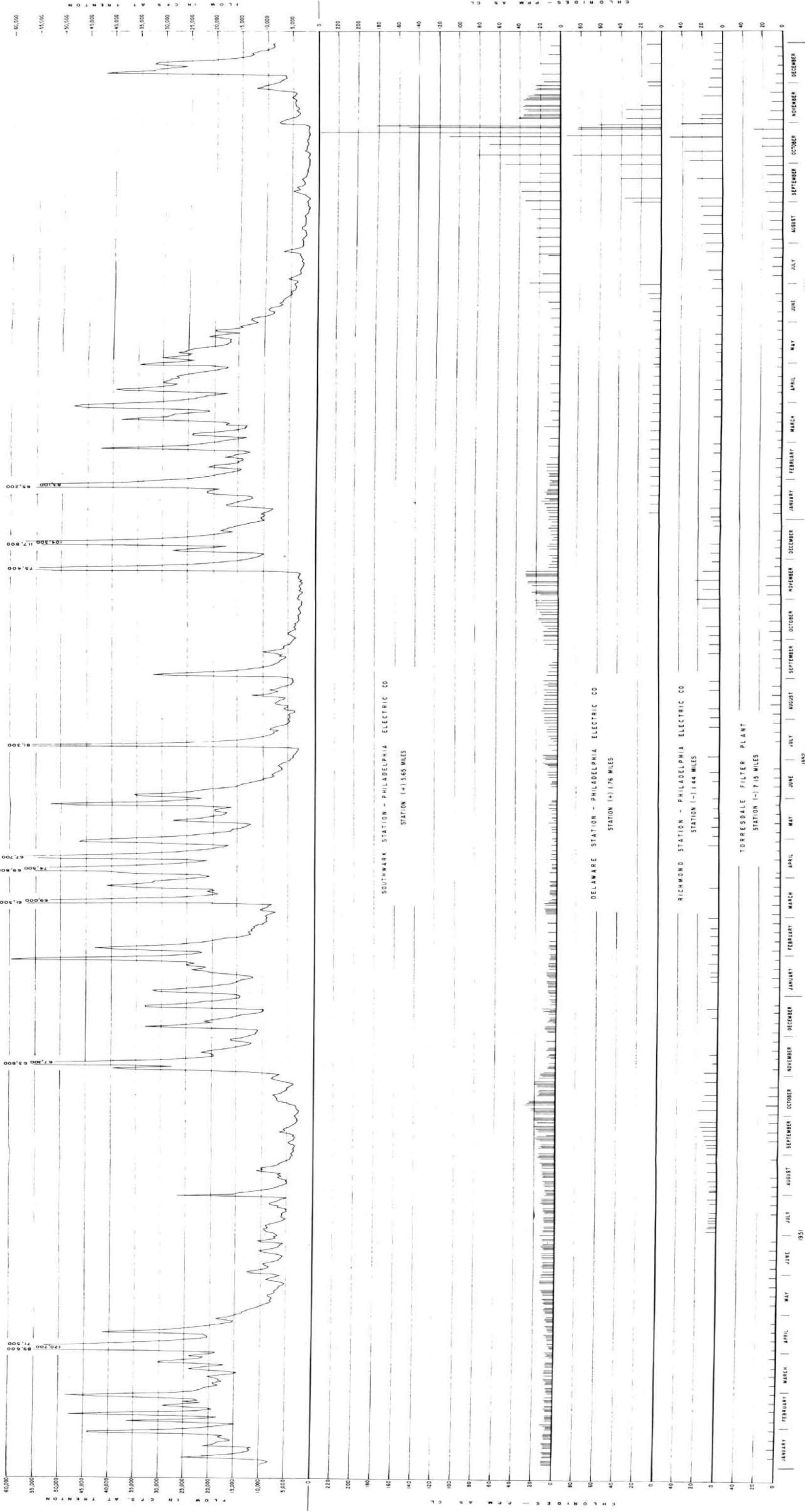
WEIGHTED AVERAGE OF DAILY MAXIMUM AND MINIMUM CHLORIDE CONCENTRATIONS IN THE DELAWARE RIVER AT CHESTER, PENNSYLVANIA

JULY TO NOVEMBER 1954

SIMULTANEOUS ACTION OF FLOW IN A TIDAL RIVER AND THE DAILY MEAN RIVER LEVEL CONTRIBUTE TO THE CHANGE IN CHLORIDE CONCENTRATION. THE PEAK CHLORIDE WHICH OCCURRED IN OCTOBER WAS CAUSED BY TIDAL INFLUENCE THAT CORRESPONDED TO A LOWER FLOW IN THE RIVER AT THAT TIME. FROM THIS INFORMATION, IT CAN BE CONCLUDED THAT PROLONGED PERIODS OF LOW FLOW IN ANY TIDAL STREAM WILL HAVE A MARKED EFFECT ON THE CHLORIDE CONCENTRATION DUE TO PENETRATION OF SALT WATER UP THE RIVER.

INVERTED HYDROGRAPH AT CHESTER, PENNA.

DISCHARGE, THOUSAND CFS

MAXIMUM

MINIMUM

CHLORIDES PPM

1954 JULY AUGUST SEPTEMBER OCTOBER

D-1305

EXHIBIT - II - 4
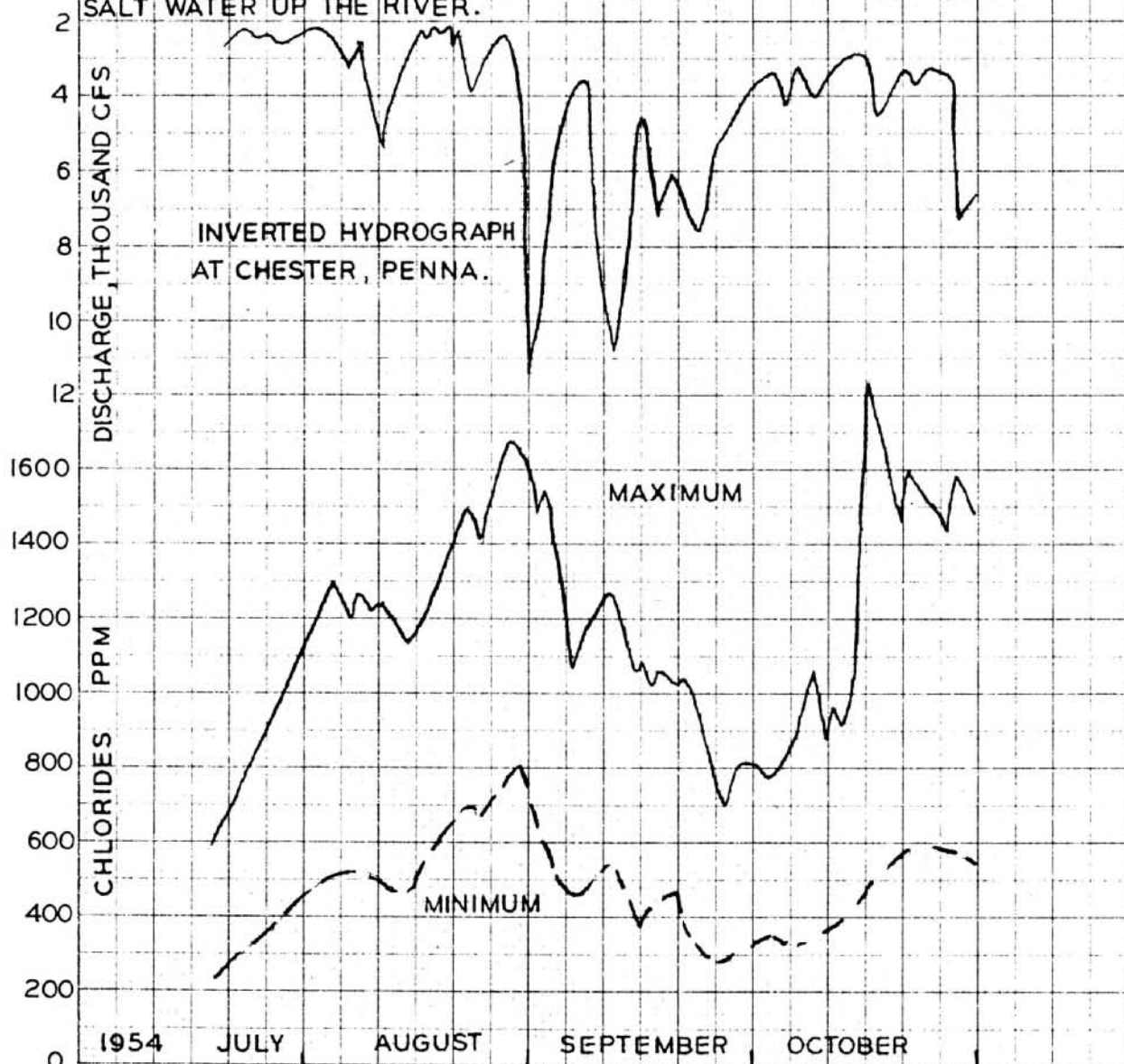
CHLORIDES AT VARIOUS STATIONS ON THE DELAWARE RIVER SHOWING

NON - STRATIFICATION

TORRESDALE TO NEW CASTLE FLATS

1946

CHLORIDES , P.P.M. AS CL

50
45
40
35
30
25
20
15
10
5
0

AUGUST 2
FLOW 4,860 CFS

AUGUST 1
FLOW 4,860 CFS

JULY 31
FLOW 5,020 CFS

TOP SAMPLE

BOTTOM SAMPLE

NOTE:
FLOWS MEASURED
AT TRENTON

TORRESDALE (PHILADELPHIA)   0
PALMYRA BRIDGE   4-1/2
PHILADELPHIA - CAMDEN BRIDGE   11
GLOUCESTER   15
MOUTH OF SCHUYLKILL RIVER   18
BILLINGSPORT   21-1/2
RACCOON ISLAND   29
OLD MAN'S POINT   35
DEEPWATER POINT   40
NEW CASTLE FLATS   43 - 1/2

MILES   DOWNSTREAM

SHEPPARD T. POWELL AND ASSOCIATES

EXHIBIT II-5

SALINITY AFFECTING SOME TIDAL RIVERS

PARTS PER MILLION - CHLORIDES

Distance	River	Date
1 MILE	THAMES RIVER AT NEW LONDON, CONNECTICUT	9-24-63
1.2 MILES	BAYOU LABATRE, ALABAMA	1950
1.5 MILES	NIANTIC RIVER AT NIANTIC, CONNECTICUT	9-25-63
2 MILES	MYSTIC RIVER AT MYSTIC, CONNECTICUT	9-26-63
2 MILES	POQUONOCK RIVER AT GROTON BEACH, CONNECTICUT	9-24-63
2 MILES	PISCATAGUA RIVER AT PORTSMOUTH, NEW HAMPSHIRE	3-28-57
3.5 MILES	WEYMOUTH FORE RIVER AT EAST BRAINTREE, MASS.	8-11-59
4 MILES	MYSTIC RIVER AT OLD MYSTIC, CONNECTICUT	9-24-63
4 MILES	BON SECOUR RIVER AT BON SECOUR, ALABAMA	1950
5 MILES	NIANTIC RIVER AT EAST LYME, CONNECTICUT	9-25-63
8 MILES	THAMES RIVER AT GALES FERRY, CONN.	9-26-63
10 MILES	PAWCATUCK RIVER AT PAWCATUCK, CONN.	9-24-63
10 MILES	THAMES RIVER AT MASSAPEAG, CONN.	9-25-63
11 MILES	THAMES RIVER AT FT. SHANTOCK ST. PARK	9-25-63
15 MILES	YANTIC RIVER AT NORWICH, CONNECTICUT	9-26-63
17 MILES	COOPER RIVER AT MT. HOLLY, S. CAR.	8-27-63
20 MILES	PATUXENT RIVER AT BENEDICT, MD.	1-6-64
20 MILES	CAPE FEAR RIVER AT WILMINGTON, NORTH CAROLINA	10-6-49
35 MILES	HUDSON RIVER AT TARRYTOWN, NEW YORK	9-13-61
80 MILES	DELAWARE RIVER AT CHESTER, PENNSYLVANIA	10-15-54

MAXIMUM SALINITY OF SOME TIDAL RIVERS AT HIGH TIDE

DISTANCES SHOWN ARE FROM POINT OF SAMPLE TO THE MOUTH OF THE RIVER.
REF: U.S.G.S. WATER RESOURCES BRANCH

THIS ILLUSTRATES THE EFFECT OF THE SEA WATER ON SOME OF OUR FRESH WATER STREAMS. THESE VALUES OF CHLORIDE INDICATED ARE NOT AVERAGE ANALYSES AND ARE NOT TO BE SO INTERPRETED. DUE TO THE INCREASED POPULATION IN SOME AREAS THROUGH WHICH THESE STREAMS FLOW, IT IS CONCEIVABLE THAT PROBABLY THEY WILL BE UTILIZED TO SUPPLEMENT THE NATURAL WATER RESOURCES. PRACTICAL TREATMENT METHODS WOULD THEN BE EMPLOYED TO REDUCE THE CHLORIDE CONCENTRATION TO SATISFACTORY LIMITS. IN THIS REGARD, THE PRESENT RESEARCH IN THE FIELD OF DESALINATION COULD BE UTILIZED TO THE FULLEST ADVANTAGE.
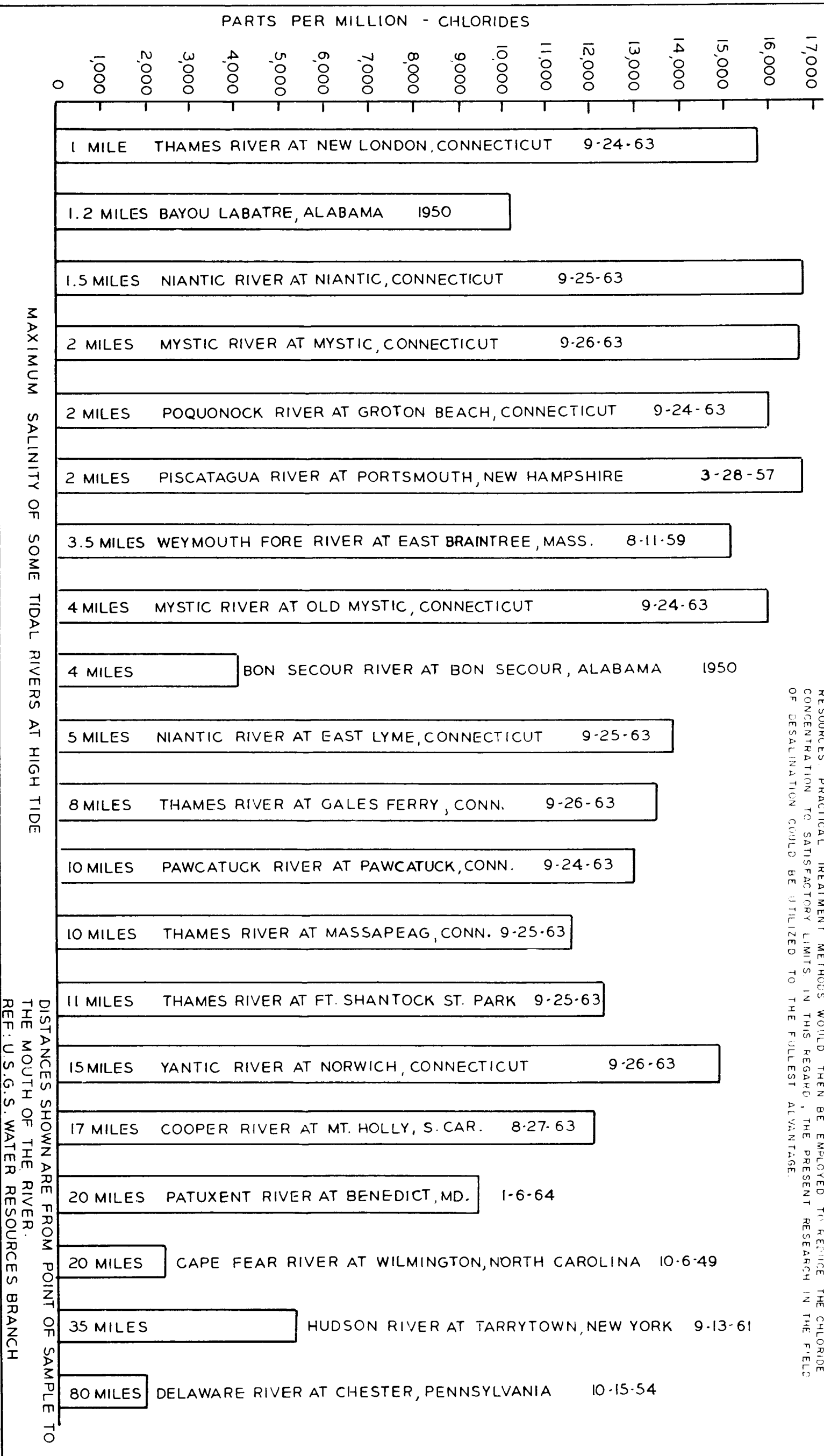
The economic effect of salinity penetration may best be illustrated by Exhibit II-6 which shows the added cost of water treatment when the saline content exceeds the normal expected.

B. Seasonal Changes in Water Quality and Distribution of Nutrients and Marine Organisms in Harbors and Estuaries

1. Temperature

The temperature of sea water, as seen in Exhibit II-7 varies according to the season of the year. The lower values indicated on the graph of the 1961-62 season are caused by the lack of runoff of surface water for that year (299). Surface waters from estuaries have higher temperatures than sea water and when flowing in large quantities will have a definite influence by raising the temperature of a bay and of coastal waters.

Variation in temperature is important from the viewpoint of plankton growth and benthic animal distribution (6, 111). The temperature is a significant part of the "climate" in which marine organisms exist and therefore help to give indications of the vertical and horizontal movement of water masses.

From the observations of temperatures, it appears that the problem of heating sea water for feed to a desalination distillation plant would require the maximum amount of energy expenditure from November until May. In large-scale production plants this could be a significant factor and special investigation may be required to obtain the most favorable temperature advantage.

2. Chlorosity

The changes of chlorosity as shown in Exhibit II-8 indicate a lower chlorosity in San Francisco Bay in the Spring months due to higher run-off (299). Since chlorosity is comparable to salinity, the flow rate into an estuary of surface waters produces the greatest change in composition, with the exception of waste discharges.

The extent to which many marine species penetrate estuaries depends upon salinity. There is a slower rate of growth of these found in lower-salinity water (295).

Exhibit II-6

EFFECT OF SALINITY PENETRATION

ON WATER TREATMENT COSTS

STEAM POWER PLANT - DELAWARE RIVER

Month	Mean Flow* cfs	Chlorides NaCl, ppm	Cost of Treatment	
			Partial Demineralization	Zeolite Softening
February, 1953	19,560	18	$ 4,931	$ 4,376
March	25,690	16	3,524	3,012
April	26,620	17	3,408	2,814
May	20,050	18	3,899	3,113
June	7,224	27	4,095	3,273
July	3,783	40	4,781	3,844
August	2,428	146	6,764	5,391
September	2,687	346	12,020	9,410
October	2,392	669	24,535	22,739
November	5,866	296	12,074	9,402
December	17,830	31	5,548	4,580
January, 1954	7,518	28	6,302	5,385

The actual cost of softening water, including all operating charges and 50% of the fixed charges amounts to $41.65 per grain of hardness removed from the water per millions of gallons of water treated in 1929. (Excerpt from testimony of Sheppard T. Powell in the Delaware Diversion Case before the Special Master, U. S. Supreme Court). Present cost of softening water greatly exceeds this figure.

*Measured at Trenton, New Jersey, by U. S. Geological Survey.

EXHIBIT-II-7

AVERAGE TEMPERATURE VS. TIME
SOUTH SAN FRANCISCO BAY
SEPTEMBER 1960 TO MAY 1962
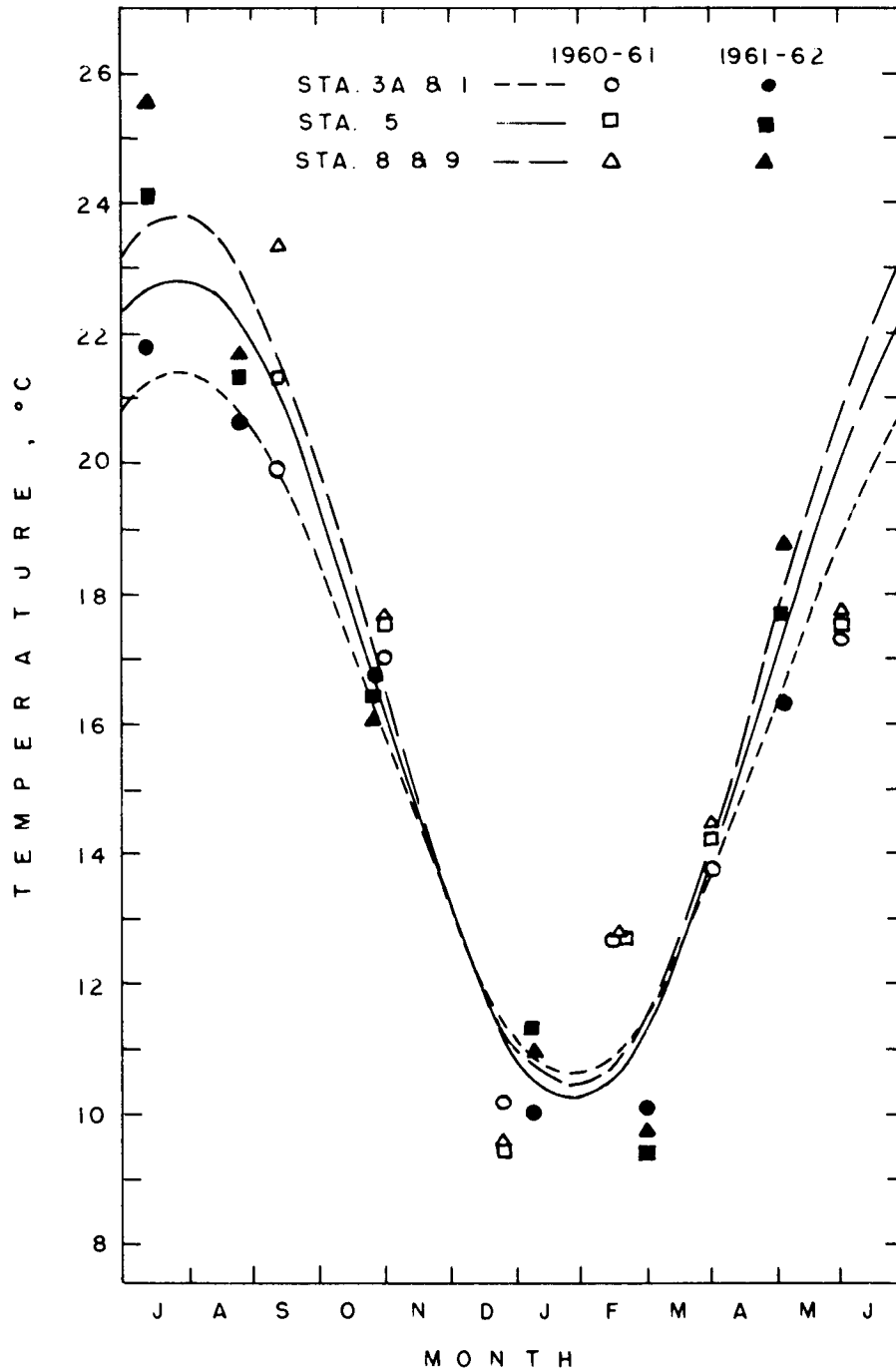
FROM REFERENCE 299

EXHIBIT - II - 8

AVERAGE CHLOROSITY VS. TIME
SOUTH SAN FRANCISCO BAY
SEPTEMBER 1960 TO MAY 1962

FROM REFERENCE 299

D - 1269
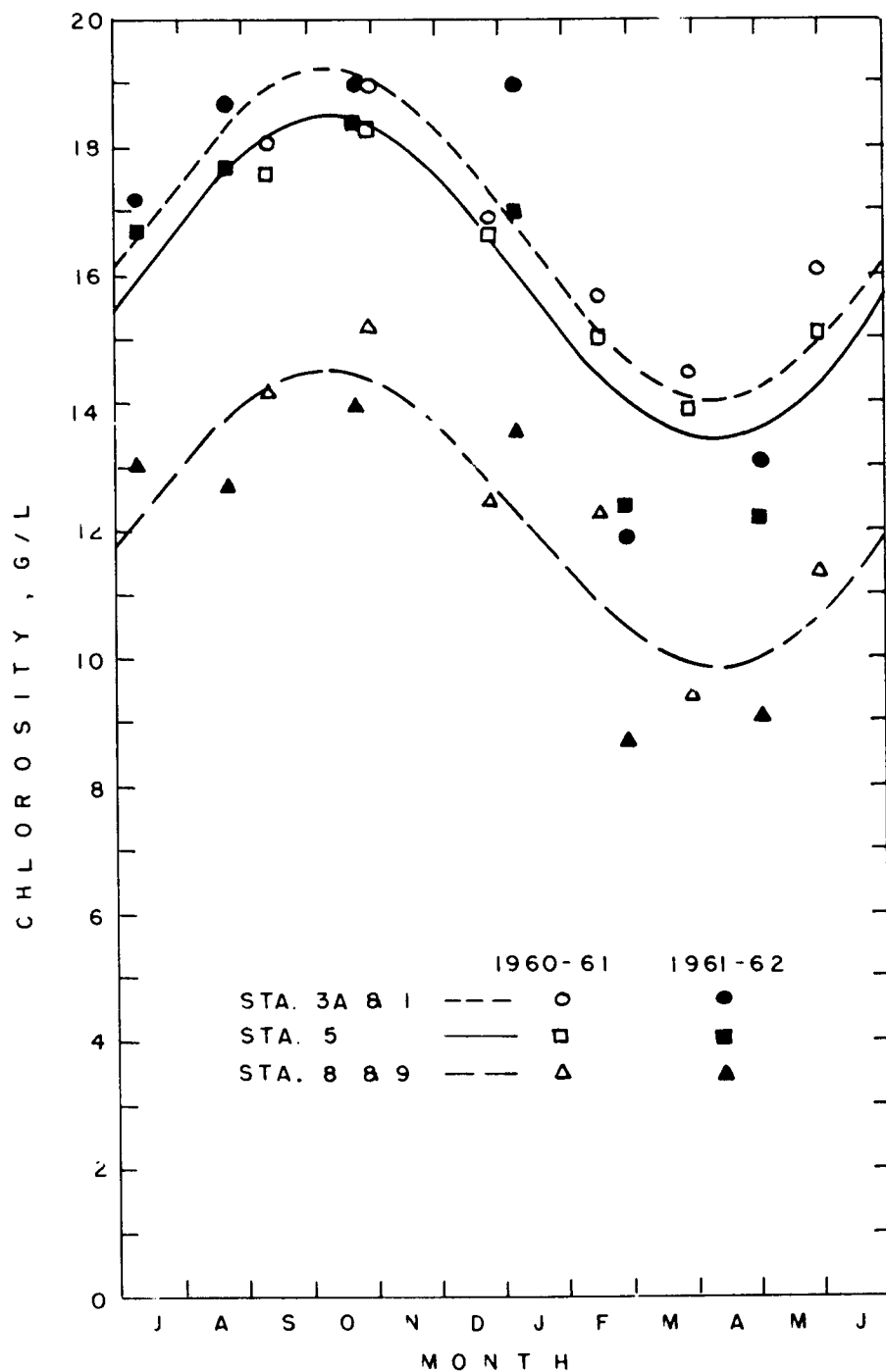
It has been proven that action of many toxic substances and the reaction and ability of the faunal life to survive under toxic conditions are significantly affected by the salinity concentration and the changes in salinity. Studies concerned with the toxicity aspects of marine and estuarine pollution should include quantitative evaluation of the time-effect-concentration function (235, 236).

3. Nitrogen

Nitrogen occurs in minimum concentrations in late summer and tends to be at its maximum in late winter or early spring (Exhibit II-9). In addition, high values of nitrogen occur near a sewage outfall (235, 295, 299). A variable decrease of ammonia, however, has been noted with depth. Ammonia nitrogen is essentially concentrated in the surface water, and below 15 feet the ammonia content approaches the normal value found in shelf waters. High ammonia concentrations, 50 to 100 times the concentration found in normal water, were found as far as 9,000 feet from the sewage outfall in surface waters.

In general, it can be stated that variation in water quality with tidal stage was at a maximum near the major source of waste discharge, and the variation of quality decreased with distance (295).

Investigation of plankton growth in the vicinity of waste discharges indicated a marked increase in growth corresponding to the increase of nutrients of nitrogen and phosphate near the sewage outfall. Therefore, it may be concluded that the presence of sewage has a great effect on the reproductive rate of planktonic organisms (113, 295).

Variations of nitrogen analysis are more impressive indicators of total organic matter present since they are the least subject to outside influence. On the southern California shelf, the nitrogen percents increased in a seaward direction (253, 295). This is in order with other observations which indicated that organic content is related primarily to grain size of bottom sediments and also to the distance through which organic debris discharge may be required to travel. Lower organic contents in the imports of the broad shelf may indicate two things: (1) slower rates of sedimentation, and (2) strong current removal. There is some indication that minor concentrations do exist in the vicinity of the harbor mouth.

EXHIBIT-II-9

AVERAGE NITRATE NITROGEN CONCENTRATION VS. TIME
SOUTH SAN FRANCISCO BAY
SEPTEMBER 1960 TO MAY 1962
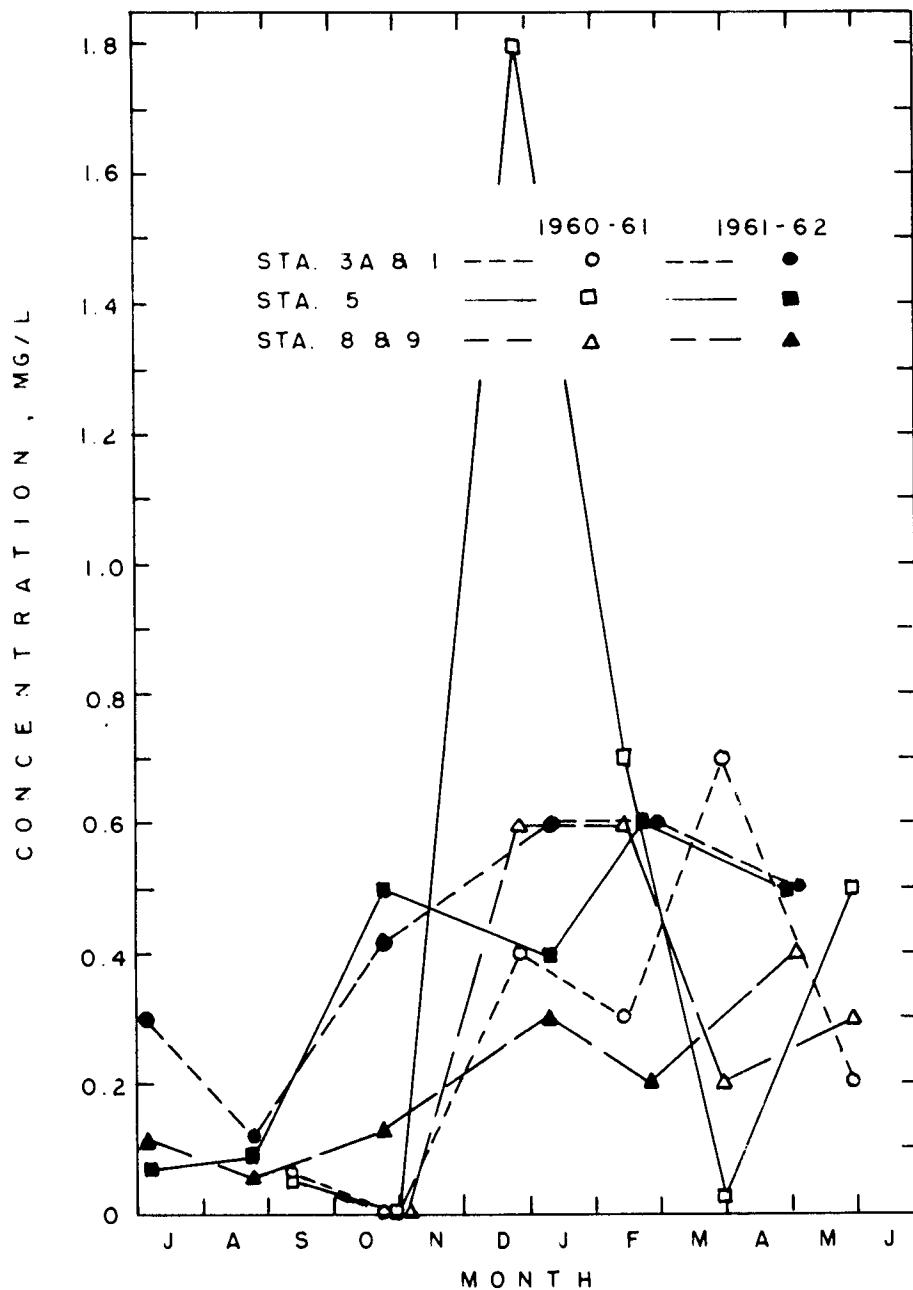
FROM REFERENCE 299

Sanitary engineers are concerned with the dissolved nutrients in the ocean waters because of the possibilities that large quantities discharged from sewage outfalls are responsible for increased phytoplankton growth. Surface waters are depleted of nitrates by organisms and replenishment takes place generally by the return of deeper waters to the surface. A study of marine life prior to 1912 has shown that at Whites Point off the coast of California a minimum of 60 or more species of plants occurred at that locality. Today there are only 21 species found there. The reduction in the flora is considered to be caused by high incidence of waste material. The introduction of foreign materials into the waters from dense human population along the coast is regarded as a probable contributing factor in the disappearance of these species of marine growth (4, 5, 6).

4. Phosphate

Vertical and horizontal distribution of nutrient salts are greatest at an outfall where the effluent rises directly to the surface with no benefit of diffusion. The nutrients rise to the surface with the effluent discharge and spread and diffuse slowly into surrounding waters. The nitrate and silicate similar to the phosphates usually show two layers of high concentrations; one is at the surface and the other is at the bottom. Generally phosphate shows high concentration with depth. The vertical and horizontal changes of phosphate are due to the following three influences: (1) type of treatment, (2) depth of discharge of the effluent, and (3) mechanical method of discharge (4, 5, 6, 299).

Pockets of high concentration of phosphates when observed at considerable distance from an outfall is explained by these two parameters: (1) variation in the effluent, and (2) inadequate mixing. Variation on phosphate determinations have been found in a 24 hour period. This indicates that a large daily variation will occur in an effluent discharge. These variations in phosphate concentrations are usually found in restricted areas such as harbors and estuaries, however, characteristics of sea water do not show these radical changes.

A plankton bloom does not begin merely by the increase discharge of nutrient salts near an outfall. The plankton begins to grow as a rule because of some other condition which is characteristic of the water. However, reproduction of the plankton is greatly influenced by the nutrient salt of phosphate when it is present. (6, 295)

Enrichment Factors of the Maximum Phosphate
Concentrations Based on Surrounding Normal Sea Water*

ORANGE COUNTY, CALIF.
December

Nutrient	Distance From Outfall	Depth	μg-a/L	Enrichment Factor
PO_4-P	Outfall	Surface	13.0	21.6

HYPERION, CALIF.
January

PO_4-P	2,000'	Surface	10.0	25.0

WHITES POINT, CALIF.
February

PO_4-P	700'	125'	3.8	7.6

μg-a = microgram atoms

It has been found that the formation of phosphate in water is most rapid in the water after the decomposition of zooplankton (II-10). Highest values of phosphate occur in the winter, and are lowest in the summer when the growth of phytoplankton is at the highest.

It is apparent that seasonal variations of concentrations may not be strictly similar if there are disturbances to the animal growths resulting from waste discharge.

5. Indicators of Pollution

The use of coliform bacteria as an indicator of pollution is of importance only if the wastes are of biological origin and the areas nearby are used for recreational purposes or the water is used in food production processes (295).

*Reference 295 in bibliography, Table II.

EXHIBIT - II -IO

AVERAGE TOTAL PHOSPHATE CONCENTRATION VS TIME

SAN PABLO BAY

OCTOBER 1960 TO JUNE 1962
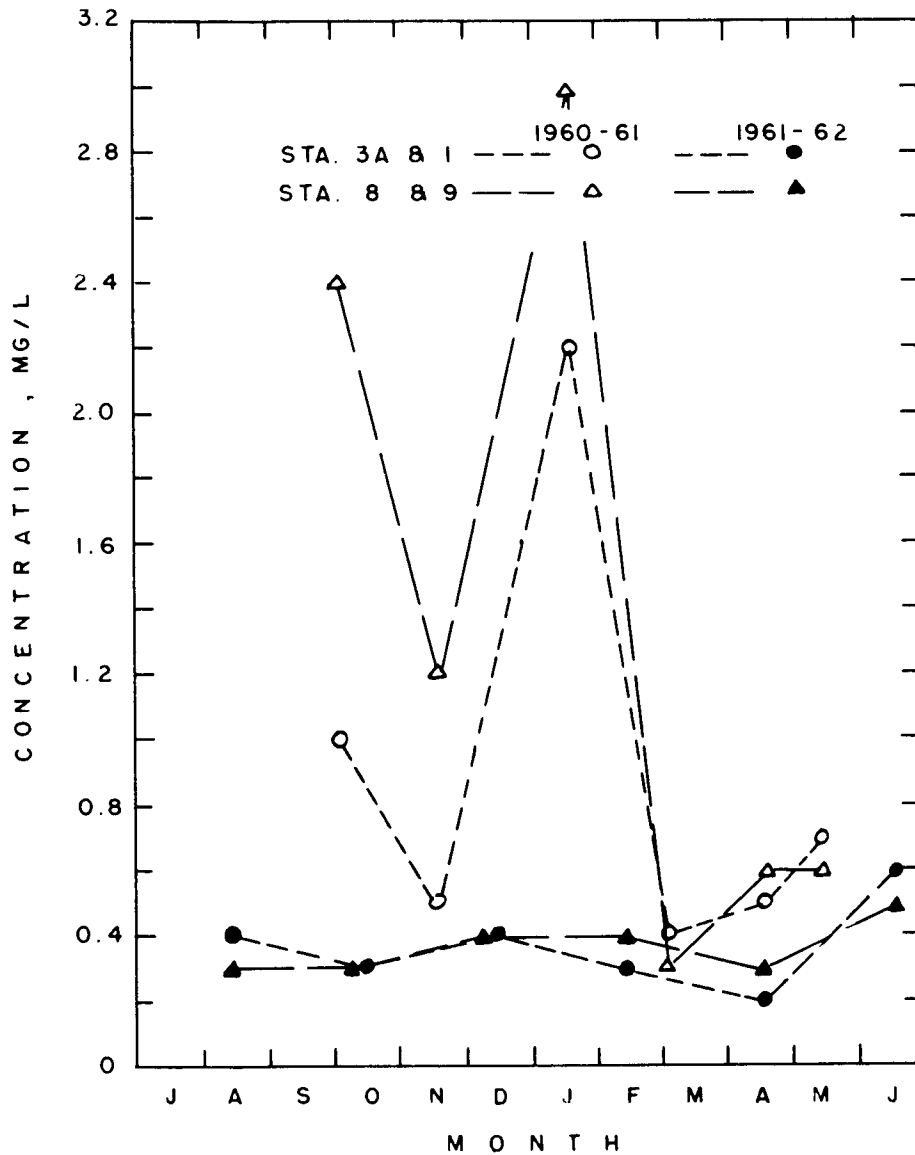
Bottom-dwelling marine invertebrates are perhaps more true indicators of pollution. For example, some species, such as Capitita Ambiseta, a small polychaete which are found on the bottom of a healthy harbor, reflects notonly conditions at the time of sampling but those which prevailed for some time previously (111, 234).

Because different assemblages of organisms indicate different conditions, a yearly survey would show whether conditions were improving or becoming worse. The organic carbon content of the substrate may be applied as a general indicator of pollution. Heavily polluted conditions exist in harbors where the amount of organic carbon is found to exceed 5 percent. A sulfide odor may indicate a polluted condition, dissolved sulfides being the result of activity of sulfate-reducing bacteria that emit sulfides when the oxygen content of the water is very low or absent (5, 111, 112, 186).

The dissolved oxygen content of water, because of the ease with which the sample may be collected and determined, is widely accepted as an indicator of pollution. However, in some instances it has been discovered that the amount of oxygen found was not related to the bottom conditions (111, 234). In fact, high dissolved oxygen has been found in some waters, where the bottom substrate indicated pollution. This no doubt was due to high circulation of cleaner surface waters from the ocean (4, 5, 296).

C. Contaminants Common to Surface Waters Which Will
     Reach Estuaries and Coastal Harbors

It is apparent that as much factual information as possible should be developed relative to the type and concentration of contaminants in estuarine waters, because some of them will contribute to the operating problems of desalination plants, or make them entirely unfeasible.

In a study of San Francisco, San Pablo, and Suisun Bays by the Sanitary Engineering Department of the University of California in 1961-1962, it was revealed that the reliability of sampling methods and laboratory analyses was of paramount importance (299, 300). "Standard" oceanographic procedures were not entirely suitable for characterizing the variable quality of estuarine waters.

The investigation of these bays in California gener-
ated a tremendous amount of data. It is apparent from these
data that quite a number of variations occur in industrial
waste discharges which could affect saline water recovery.
An example is the phenol discharged by an oil company which
averaged 3,897 ppm.

1. Heavy Metals

The metals are reported in a gross quantity. How-
ever, it can be realized that a variety of compounds could be
formed by localized reactions in an estuary which may have
toxicity of several orders of magnitude above the original
pollutant.

An example of this is the presence of chromium
in the hexavalent state. The U. S. Public Health Service
limits this metal to less than .05 mg per liter so that
concentration of .05 ppm constitutes grounds for rejection
of the drinking water supply. The effect of this metal,
and many other, would be to poison the membranes in an
electrodialysis plant, or a reverse osmosis desalination
plant.

Investigation of the effects of copper in trace
amounts upon kelp photosynthesis show there is a strong
response to 0.1 ppm within four days and greater responses
at higher copper concentrations. The interest in the effects
of copper on kelp is because of the fact that copper could
be concentrated in sediments as the sulfide or basic car-
bonate or in organic combinations. Thus, this effect would
be that the copper would perform as a algicide for a long
period of time and at considerable distances from a waste
discharge.

The effects of copper and of mercury at very
low concentrations can be shown as a function of time of
exposure.

Concentrations of various inorganic ions which
cause 50 percent inactivation of photosynthesis in water
are listed on the next page.

Heavy Metal	ppm
Mercury	0.05
Copper	0.1
Nickel	2.0
Chromium (hexavalent)	5.0
Zinc	10
Chlorine	5-10

Lead is precipitated out of sea water and is ineffective as a poison to kelp but, without tidal movement, could be concentrated in the substrate. While the composition of industrial wastes may vary considerably, their effect upon marine organisms is the same. The presence of sufficient foreign material in the discharge will kill the animal populations which are significant to the ecology of a harbor or estuary. There may be a direct toxic effect or an indirect toxic effect through the change in the environment, such as oxygen depletion (235).

2. Trace Elements

The U. S. Geological Survey has investigated the presence of minor elements in various rivers of this country (See Exhibit II-11). Some of these occur in trace quantities and the sampling stations include inland as well as estuarine locations.

From these results, we may interpret that barium occurs in all waters. Aluminum and iron appear in greatest quantity in all the rivers. This implies that the drainage area of these waters leaches from the soil the soluble compounds of these metals.

The presence of these metals in water which is saline must be evaluated with respect to their economic effect on pretreatment of saline water before conversion.

3. Contaminants Causing Tastes and Odors

There are four general sources of organic compounds

EXHIBIT - II - 11

OCCURRENCE OF MINOR ELEMENTS IN WATER

Spectrographic analyses for minor elements in waters from principal rivers of the world

[Spectrographic analysis in micrograms per liter except as indicated] a

(45) Mississippi River just above bridge on U. S. Highway 190, near Baton Rouge, La., U. S. A.

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
May 10, 1958	865,000	0.13	1,050	29	78		5.8	2.6		10	~1,670		4.9	185	1.1	0.x	x00	4.0				34	62			
Oct. 14	262,000	.22		22	127			8.5		6.9						19	223	7.8	2.5			105	6.7	<5.5	0	0
Mar. 13, 1959	655,000	0	1,010	15	72		0	4.6		9.0	828		1.8	46	0	13	<184	4.0	7.4			61	72		0	0
May 18	415,000	0	281	6.1	84		0	84		74	663		2.4	12.2	2.6	33	0	9.4	<2.6			97	12	0	0	0

(46) Atchafalaya River from railroad bridge, 0.6 mile below bridge on U. S. Highway 190, at Krotz Springs, La., U. S. A.

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
May 10, 1958	323,000	0.33		14	43	0.x	0.x	2.4		3.6			4.5		0.x	0.x		1.1				11	10			
Oct. 14	130,000		725	17	132	<.22	5.2	30		9.9	1,230			100	<0.93	47	<186	11	2.2		•	154	20	<6.5	0	0
Mar. 13, 1959	276,000	0	1,635	19	52		0	2.6		3.7	1,240		1.9	68	0	6.5	0	2.6	2.4			22	107		0	0
May 18	166,800	0	462	14	122		0	4.9		10	517		2.6	12	<2.7	10	0	11	<2.7			139	14	0	0	0

a For samples obtained in 1959, looked for but generally not detected: As, Au, Be, Bi, Cd, Ce, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Lu, Nb, Nd, Os, Ph, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, and Zr.

b Daily mean discharge.

e Approximate.

< Detected, but less than figure indicated.

x Refers to semi-quantitative determination in the digit order shown.

FROM REFERENCE 69

EXHIBIT -II-11

OCCURRENCE OF MINOR ELEMENTS IN WATER

Spectrographic analyses for minor elements in waters from principal rivers of the world

[Spectrographic analysis in micrograms per liter except as indicated] a

(54) Hudson River at Ford Motor Company power plant, at Green Island, N.Y., U.S.A.

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
Oct. 29, 1958	23,000	0.15	304	9.0	28	0	0	30		8.6	207		2.2	35	0	12	0	2.9	1.9			106	<1.4	--		0
Jan. 22, 1959	63,000	.18	775	15	46		<1.3	15		15	650		1.1	150	.65	8.6	0	11	1.6			84	55	5.6	<125	
Aug. 17	1,940	.59	251	20	60		<1.1	40		44	414		.28	78	1.7	71	0	9.4	<1.1			72	10	4.3		0
Oct. 19	3,790	<.13	225	10	49		0	19		4.5	300		.89	56	.55	5.5	0	6.6	2.1		0	106	18	3.8		0

(55) MacKenzie River about 3 miles upstream from separation, at Arctic Red River, Northwest Territory, Canada

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
July 24, 1958	470,000	0	1,410	13	65		5.0	12		11	1,390		1.1	60	0	36	250	2.9	1.6			96	8.4		0	0
Oct. 2	270,000	<0.16	440	8.6	70		0	5.7		3.9	1,030		1.0	20	0	8.2	0	6.4	<1.6			228	6.0	0	0	0
June 9, 1959	360,000	0	869	4.7	85		0	11		4.2	706		2.5	36	.80	22	0	7.6	2.4		0	125	24			0

(56) Nelson River near Amery, Manitoba, Canada (observations on Jan. 20, Apr. 9, and June 3, upstream at Kelsey power site)

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
Oct. 5, 1958	e85,000	0	226	2.5	45	--	0	5.7		2.3	287		2.9	9.6	0	5.9	0	5.3	2.3			121	9.2	--	0	0
Jan. 29, 1959	e49,000	0	664	7.6	50	--	0	2.5		1.0	389	--	4.8	8.7	.87	4.1	0	1.1	0			73	32	0	0	0
Mar. 9	e38,000	0	105	21	58	0	0	1.9		2.5	38	--	7.5	<2.8	1.3	5.5	0	0	0			105	5.3	0	0	0
Apr. 9	e36,000	0	89	3.6	56	--	0	4.7		4.2	81	--	8.1	<2.8	2.0	7.8	0	22	<2.8			86	5.9	0	0	0
May 1	e75,000	0	81	7.8	57	--	0	3.4		6.0	198	--	3.9	3.4	4.0	8.8	0	4.9	<2.6			107	14	0	0	0
June 3	e84,800	<.18	--	58	53	--	5.1	21		11			1.7	177	<.53	55	425	5.0	5.1		2.1	55	67	5.7		0

(57) Susquehanna River at hydroelectric plant spillway at Conowingo, Md., U.S.A.

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
May 7, 1958	126,000	0.3	--	10	24		0.x	1.9		5.1	--		--	--	--	x.0	--	3.6	--			12	3.2		x00	
June 10	19,600	--	--	12	38			4.5		4.0	--		--	--	0.x	0.x	--	1.1	--			40				
Sept. 11	10,000	.25	27	16	25		0	3.7		5.3	31		3.5	<2.1	0.x	11	0	<2.1	<2.1			25	<2.1	0	0	
June 5, 1959	17,300	<.15	102	4.3	37	0	0	1.3		105	154		3.4	79	.54	3.9	0	7.2	<1.5			74	5.7	0	0	0

(58) Churchill River east of island off Drachm Point, 8 miles south of Churchill, Manitoba, Canada

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
June 24, 1958	e40,700	0.078	148	3.7	19		0	5.5		2.0	172		1.0	17	0	4.1	0	2.5	0.78			22	8.6	0	0	0
Sept. 25	e42,500	.37	103	13	38		0	3.6		9.5	79		.95	2.6	0	5.6	0	4.0	1.1			37	3.1	--		0
Feb. 20, 1959	e27,000	.21	183	16	49	0	0	2.8		8.5	157		2.6	4.4	.49	11	0	4.3	1.2			33	7.1	0	<122	
June 27	e61,000	<.084	134	4.5	33		5.1	12		2.9	185		.51	8.4	<.25	14	0	2.4	0		0	23	5.8	0	0	0

(59) Apalachicola River at State Highway 20, near Blountstown, Fla., U.S.A.

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
Dec. 17, 1958	11,000	0.11	73	5.0	42		0	2.2		2.1	96		0.096	5.0	0	4.6	0	6.2	1.0			34	<0.8	0		
Mar. 30, 1959	54,000	<.058	2,550	11	21	<0.058	0	2.2		7.0	1,220		.70	25	<.17	2.6	<58	2.1	2.1			7.5	99	2.2		
Aug. 24	11,900	.098	173	5.5	29		<.75	6.9		51	150		<.075	20	.46	23	0	3.6	<.75			28	8.3	0		
Sept. 29	9,030	<.071	135	5.6	26		0	7.8		6.2	85		.12	4.0	.62	34	0	2.7	2.1		1.3	25	6.9	0		

a For samples obtained in 1959, looked for but generally not detected: As, Au, Be, Bi, Cd, Ce, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Lu, Nb, Nd, Os, Pb, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, and Zr.
e Approximate.
< Detected, but less than figure indicated.
x Refers to semi-quantitative determination in the digit order shown.

EXHIBIT -II-11

OCCURRENCE OF MINOR ELEMENTS IN WATER

Spectrographic analyses for minor elements in waters from principal rivers of the world

[Spectrographic analysis in micrograms per liter except as indicated] a

Date of collection	Discharge (cfs)	Silver (Ag)	Aluminum (Al)	Boron (B)	Barium (Ba)	Beryllium (Be)	Cobalt (Co)	Chromium (Cr)	Cesium (Cs)	Copper (Cu)	Iron (Fe)	Germanium (Ge)	Lithium (Li)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Phosphorus (P)	Lead (Pb)	Rubidium (Rb)	Silicon (Si)	Tin (Sn)	Strontium (Sr)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)	Zirconium (Zr)
(47) St. Lawrence River at water works plant at Levis, Quebec, Canada																										
Aug. 25, 1958	342,000	0.94	276	13	30	0	0	12		4.3	580		0.41	21	1.7	13	0	3.7	1.4			66	21	--	0	0
Sept. 3	340,000	0	186	6.3	26		0	9.6		4.7	257		.40	6.7	2.4	11	0	4.9	1.4			92	6.6	--	0	0
Sept. 24 c	342,000	<.14	1,050	11	46		4.0	23		59	1,190		.60	30	2.6	22	173	55	2.9			78	50	--	<144	0
Dec. 3	348,000	<.14	828	11	36		0	5.8		4.7	718		1.1	18	2.1	13	0	3.2	1.4			86	51	<4.1	0	0
Apr. 20, 1959 c	551,000	<.11	--	7.8	39		<1.1	6.8		--	--		.27	69	<.34	13	<112	7.3	<1.1			45	--	<3.6	<112	0
Apr. 23 c	550,000	<.11	--	5.8	40		<1.1	9.7		--	--		.36	60	.37	12	112	3.6	<1.1			58	--	3.9	0	0
June 16 c	404,000	0	206	4.1	29		0	7.0		8.1	288		.55	16	.60	16	0	3.6	1.5		0	69	12	0	0	0
(48) Columbia River below the Dalles River, about 3 miles above the Dalles Dam, Oreg., U.S.A.																										
June 11, 1958		0.09	--	11	33		--	9		3	--		--	--	0.x	x.0	--	1.2	--			30	2.9	--	--	--
Dec. 1		.15	238	3.9	48		0	18		3.8	280		3.9	14	2.1	10	0	5.0	1.4			112	5.2	--	0	0
Sept. 8, 1959		<.11	82	5.0	44		<1.1	20		27	131		.59	5.5	1.0	36	0	3.4	<1.1			60	2.1	4.0	0	0
(49) Yukon River at Mountain Village, Alaska, U.S.A.																										
May 28, 1958	d450,000	0.31	82	11	26	0	0.x	2.3		6.3	--		2.0	181	1.2	x.0	x00	1.5	--			15	16	--	0	
Jan. 7, 1959	d30,000	<.2		13	109		0	7.0		2.5	1,130					17	<195	8.6	0			129	<2.0	--		
(50) Fraser River at Mission City, British Columbia, Canada																										
July 1, 1958	255,000	0	327	2.6	17		<1.9	2.9		1.6	1,180		0.5	26	0	5.0	<62	<0.82	2.6			16	17	0	0	
Oct. 1	166,000	<.07	526	11	18		1.9	6.0		2.5	635		.18	32	0	12	73	1.8	.95			18	16	--	0	
Feb. 12, 1959	37,100	0	261	2.6	20		0	23		3.0	363		.40	23	.79	13	<79	3.9	.79		0	40	18	0	0	
June 12	275,000	0	51	1.4	14		0	2.8		.83	52		1.3	3.0	<.21	2.6		1.3	.90			23	2.6	0		
(51) Sacramento River at tower bridge on Capital Street, at Sacramento, Calif., U.S.A.																										
May 1, 1958	b49,900	--	--	22	9	0	--	0.7		1.4	--					0.x	--	--	--			6.3	3.1	--	--	
Nov. 25	b13,300	<0.086	60	10	31		--	4.4		2.9	112		2.1	6.3	<0.43	7.1		4.5	1.0			46	<.86	<.86	<110	
May 1, 1959	b11,800	0	286	9.8	25		<3.3	2.4		7.0	1,210		.77			6.6	<110	4.2	1.1			15	14	--	--	
Sept. 16	b9,900	<.16	1,110	25	56		<1.6	7.0		14	764		.66	34	<.47	20	<110	4.4	<1.6			61	106	6.7		
(52) Mobile River at Mt. Vernon Landing, Ala., U.S.A.																										
Dec. 16, 1958	b24,000	0.13	186	3.3	75	0	0	2.0		3.5	392		1.7	41	0	6.9	<98	15	1.3			68	3.6	0	0	0
Apr. 1, 1959	b92,000	.28	818	17	47		0	3.4		5.6	735		2.4	20	.28	6.1	<93	3.1	3.9			39	38	--	0	0
Aug. 25	b12,000	<.089	84	1.6	64		<.89	6.8		28	125		.14	7.4	.35	29	0	1.5	<.89			59	2.7	0	0	0
Sept. 30	b15,500	<.085	289	4.3	52		0	1.9		2.7	204		.70	6.7	.27	6.8	0	1.2	2.6		1.4	51	12	0	0	0
(53) Colorado River on bridge on U.S. Highway 80, at Yuma, Ariz., U.S.A.																										
Sept. 16, 1958	b1,020	1.0	12	52	152	0	0	24		8.8	160		35	21	6.9	30	0	<8.0	<8.0		0	802	<8.0	0	0	0
Jan. 20, 1960		0	153	34	128		0	10		8.5	111		37	37	6.5	0	0	.16	0			715		0	0	

a For samples obtained in 1959, looked for but generally not detected: As, Au, Be, Bi, Cd, Ce, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Lu, Nb, Nd, Os, Pb, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Y, Yb, and Zr.
b Daily mean discharge.
c At Quebec.
d Estimated discharge at Kaltag.
< Detected, but less than figure indicated.
x Refers to semi-quantitative determination in the digit order shown.

which will cause taste and odor difficulties:

> (1)   Natural run-off: decaying vegetation,
>   animal waste products, and natural
>   farmland drainage.
>
> (2)   Industrial wastes from food processing,
>   oil refining, coke ovens, etc.
>
> (3)   Municipal or domestic sewage.
>
> (4)   Products of biological degradation
>   of many organic materials occurring
>   in the streams.

A number of the substances (particularly phenol) become more offensive when chlorinated. By the time surface water reaches the estuarine section of a river, it will have accumulated wastes from an entire drainage basin, therefore the total quantity will be largest where it discharges into a bay, however, this is the point of maximum flow which will provide great dilution of contaminants added upstream. Nevertheless, when water from such sources is supplied to a saline water conversion process, organics and particularly those which cause taste and odors will require attention. Considerable data are available on organic contamination of inlet rivers which, will not specifically be applicable to coastal harbors and estuaries but will furnish illustrations of the condition that can occur.

One example is the Missouri River, serving many municipalities and industries. The lower reaches of this river extend some 841 miles from Yankton, South Dakota to its confluence with the Mississippi. This river traverses, borders, or flows thru seven states and supplies drinking water to more than 3,100,000 people and many industries. In this stretch of river of 841 miles, it is estimated that the industrial use alone amounts to two billion gallons per day (316). A program initiated to obtain data on the concentration of organic constituents of this river that affected taste and odor was initiated in 1958. The organic material causing or having the potential of causing taste and odor was determined in raw and tap water from several plants along this 841 mile course of the river.

The Missouri River is selected as an example of a stream carrying organic materials because it has a high

concentration of silt at certain times. The organics which are adsorbed on the silt may be "stored" in the mud banks to be washed out later. The effect of these "stored" organics is to add to the normal stream load at points further down the river during high water flows.

Shown in Exhibit II-12 is the yearly average concentration of soluble organic extracts found in the Missouri River during the years 1958, 1959 and 1960 (316).

Two items in this exhibit are of great importance to water management and industrial water users in general. The first is the fact that there exists a significant concentration of soluble organic extracts in tap water even after extensive treatment. Second, the concentration of soluble organic extracts is considerably reduced at Lexington, Missouri only 25 miles downstream from the Kansas City Power and Light Company. This would indicate that there is a considerable reduction in soluble organics by the influence of the natural factors in this stretch of the river. It may be concluded that although the river apparently has a large capacity to remove or assimilate organic materials, sufficient concentrations remain in water after presently accepted treatment practices, to give significant tastes and odors. Also, the soluble organic extracts, on the basis of this three-year study, increase by four and one-half times in this passage of 841 miles.

4. Insecticides

Chlorinated hydrocarbon insecticides are among the most important organic compounds found in our natural water resources. Of these insecticides, the following have the greatest potential for damage: aldrin, benzene hexachloride, DDT, endrin, dieldrin, heptachlor, toxaphene and trichlorodiphenylethane. All of these have long residual activity and are of low solubility in water. It is known that a substantial quantity of the chlorinated hydrocarbons applied to farm crops is washed from the soil into stream and lakes (83, 197, 198, 307).

Compounds of chlorobenzene do not affect the color, clearness, and taste of the water, but do impart a characteristic odor. The odor persists for one or two days depending upon the concentration. The BOD and processes of bacteriological purification and nitrification are not materially affected by nitrochlorobenzene (126, 258).

Exhibit II-12

YEARLY AVERAGE CONCENTRATION OF SOLUBLE ORGANIC EXTRACTS

"CHLOROTRACTS" IN MISSOURI RIVER WATERS - PARTS PER BILLION*

Sampling Station	1958		1959		1960		3-Year Average	
	Raw	Tap	Raw	Tap	Raw	Tap	Raw	Tap
Yankton	36.8	38.6	36.6	48.4	48.7	51.5	40.7	46.2
Omaha	35.7	45.2	38.3	27.3	37.7	24.5	37.2	32.3
St. Joseph	41.0	37.0	29.0	31.4	41.4	38.5	37.1	35.6
Kansas City	38.4	34.3	23.2	27.3	31.3	29.2	31.0	30.3
Kansas City Power & Light	-	-	133	-	261	-	197 **	-
Lexington	30.8	39.9	42.1	46.7	27.4	31.6	33.4	39.4
Jefferson City	32.1	45.8	31.9	44.8	20.7	38.9	28.2	43.2
St. Louis City Howard Bend Plant	40.2	47.4	36.5	47.6	41.4	54.7	39.4	49.9
St. Louis County Central Plant	39.5	46.5	43.8	56.4	34.9	50.6	39.4	51.2

*From Reference 316.

**Two-year average.

In contrast to the above mentioned compounds, the ortho and para isomers of nitrochlorobenzene in contaminated water supplies have a limit of odor detection of 0.3 mg per liter, however, the taste of bitter almonds persists after no odor can be detected at concentrations as low as 0.05 mg per liter (107). Also, the taste becomes more pronounced with the rise in temperature of the water and cannot be eliminated by chlorination. As in the case of ordinary chlorobenzene, concentrations of these isomers causing odor and taste do not affect the BOD, nitrification and bacteriological purification (198, 201, 307).

Phenols and phenolic compounds in water result from pollution from oil refineries, chemical plants, and coke plants, and also from the underground degasification of coal. Phenols decompose in the presence of oxygen and organic material and their persistance downstream from the point of entry in most cases is short. However, the rate of decomposition is dependent upon the concentration as well as the environment (199, 200).

The potential hazard of these organic materials such as those mentioned above must be considered when evaluating saline conversion processes.

5. Detergents

A surfactant, more commonly known as a detergent, is a substance which, in small quantities, appreciably changes the surface tension of the liquid in which it is dissolved. Some aspects of surfactant properties are: (1) wetting, (2) emulsifying, (3) suspending, (4) dispersing, and (5) foaming. All surfactants have all these properties to some extent, but have them in different ratios.

General problems caused by the presence of detergents in public water supplies are: foam on settling basins, interference with coagulation and sedimentation, taste and odor control, presence of iron, foaming of finished waters, and quality deterioration in the distribution system.

Because of the foaming which will occur in a saline conversion process such as distillation, a carry-over of the impurities present in saline water would no doubt occur unless the detergents were first removed from the feed water to a distillation unit (230). Also, since the presence of

detergents cause increased turbidity, there will be available more nutrients for the growth of algae and other forms of aquatic life such as plankton, in waters which will be considered for desalination.

    D. <u>Troubles Anticipated When Using Water From Coastal Harbors and Estuaries for Salt Water Conversion Plants, and Treatment Required</u>

It was pointed out in Section I, Ocean Waters, that the various salt water conversion processes are susceptible to specific operating difficulties that impose quality requirements on the saline water feed. This discussion can be projected to water obtained from coastal harbors and estuaries, with certain modifications:

    (1) Conventional demineralization by ion exchange might be at least evaluated for waters of very moderate salinity but would probably be economically unattractive because a high degree of primary treatment would be necessary to prevent fouling, and the costs and frequency of regeneration would be burdensome.

    (2) Electrodialysis would require primary polishing of the water, and many contaminants in harbors and estuaries would poison the membranes.

    (3) Distillation in some form again emerges as the practical possibility.

As in the case of ocean waters, the main troubles experienced will be scale in the higher temperature areas, and marine fouling in all sections where the temperatures are not high enough to kill organisms.

    1. <u>Scale</u>

We will not repeat the intensive discussion of scale control setforth under ocean water since the same consideration applies. It should be added, however, that when surface water of lower salinity is available, consideration has been given to various forms of partial softening. This also applies to the desalination of saline ground water which will be discussed in the next section.

2. Marine Fouling and Methods of Prevention

Where there is little tidal variation in salinity, a greater number of organisms extend into lower salinities. Since an estuary receives sea water at the mouth and fresh water at the head, mixing of the two waters establishes a gradient. The salt concentration of the coastal water varies with the region but is usually between 3.0 and 3.5 percent. At any one point in an estuary, salinity usually increases from the surface to the bottom, except in those estuaries that are turbulent.

The extent to which marine growths penetrate estuaries depends not only on the actual salinity at various points, but also on the degree to which the salinity varies with the tide. Salinity, as well as temperature, affects the growth of marine species and thereby limits its distribution. Since the salinity of estuaries is greatly affected by the seasonal differences in precipitation and fresh water run-off, it can be expected that these variations will give rise to sequences of expansion and contraction of the areas occupied by these growths.

It may be safely concluded that mean annual salinity of an estuary is a poor guide to expectancy of fouling by these marine growths.

Typical of the organisms that will cause fouling are the Sponges, the Bryozoa, the Barnacles, the Tunicates, and the Mollusca. Where in fresh water pipe lines the aquatic organisms which cause fouling are the algae and some fresh water grasses, in salt or brackish water lines the Bryozoa and Hydroids, Mollusca and Tunicates are all responsible for fouling. Sponges may be of the fiber type or calcareous type and either one may cause fouling of pipe lines. Growths of organisms which are the shell type, such as the Mollusca and the Tunicate, continue to enlarge until finally their exposed area becomes large enough to be torn free by the velocity of the water and they plug screens, pumps and tube sheets (343).

Various methods have been tried for control of fouling. These have been: (1) increasing the water velocity, (2) use of antifouling paint, (3) screening of water entrance, (4) heating the water, (5) poisoning with chemicals, (6) increasing the salinity or decreasing the salinity, (7) creating anaerobic conditions in the water, and (8) use of chlorine.

The method to be chosen depends upon the particular plant being considered, whether it be a saline water conversion plant or a power plant cooling system. Several factors should be considered. The method selected should be low cost in order to not increase plant operating cost. It should insure that all organisms which may be present will be prevented from growing to a size which will be detrimental to plant operation or general efficiency. The treatment should be such that its use will not interrupt the full operation of the plant at maximum capacity.

Mechanisms of Fouling by Organisms

Of the fouling organisms which are known to be responsible for fouling of commercial power installations, the single shelled organisms of the Gastropoda class such as snails, mussels, clams and oysters cause far the most trouble. The organism is capable of swimming, is able to crawl on solid surfaces, vertical walls and the tops of intake tunnels. When the organisms are completely submerged, the greatest growth occurs. The shells vary in length to a maximum of 4 inches.

The Sponges, which are considered a macroorganism, are the colony of organisms which have pores on the outer surface. Budding or growth occurs within the cell and the result is an increase in size, but the formation of other groups at some distance from the point of attachment does not occur. During the larval stage the sponge is most susceptible to destruction by poisons, and it is a known fact that it is particularly sensitive to changes of pH. The larvae which actively swim about in the water attach themselves to the surfaces of pipes or tunnels, and after a state of quiescence, develop into the adult sponge.

The Bryozoa which are small animals that are often confused as a "sponge" or seaweed are brown or purple in color and are groups of dead stick-like organisms. The often observed jelly-balls observed in fresh water lakes are also Bryozoa. Colonies grow as long as 4 inches. Since many Bryozoa in fresh water grow in the dark, they can cause serious fouling in water mains. The larvae, like those from the sponge, when released from a colony usually are free swimming for a 4 to 6 hour period, before attaching themselves and beginning another colony development. Colonies of 1-1/2 to 1-3/4 inches in diameter can successfully hibernate from November to May when they again resume growth.

The Barnacles which are a well known fouling organisms of ship bottoms, have a hard shell and are closely related to other marine life such as the crayfish, lobster, etc. The tissue growth occurs all year but is found to be most rapid in the spring and fall. The larvae are released as free-swimming forms after the eggs have been developed. When the barnacles settle on a suitable place of attachment, they begin to form a shell. The barnacles unlike the Bryozoa prefers a place of optimum light, and will not be found in extremely dark places or bright sunlit areas. B. H. Graves of Woods Hole Oceanographic Institute made an extensive study of the barnacles, and some specie have a male form which is very small and lives parasitically within the shell of the female. Barnacles react to salt water dilution or change in salinity.

Consideration of Control Methods

The combination of low salinity and low pollution in circulating water supplies has been found to keep marine growths at a minimum. Control by screening of intakes is very impractical, except to eliminate kelp and sea grass, when it is known that larvae forms of some fouling organisms are less than .01 inch in diameter in the stage of early development.

Addition of poisons to the water to control marine growth, such as cyanide which is used sometimes to free a ship's bottom of fouling, is out of the question for use in a desalination plant. Also, kerosene, creosote and similar materials which would impart taste to the water could not be used in a saline water conversion plant.

Chlorination of sea water, when properly controlled, has been found to be the most successful method of preventing slime and marine growths from developing (343, 383). In the design of any plant, the nature and extent of the fouling organisms to which the equipment will be exposed should be surveyed. The sessile organisms are dependent upon water motion to carry their food to them. Barnacles, as an example, will grow three times as fast in wave-swept waters as they will in quiet tidal waters. In tunnels, or piping, where faster rates of water flow are found and any amount of domestic pollution is present, year-round growth will be encouraged. Plants have been known to experience severe

fouling after an elapse of time in which there was no fouling. Changes in industrial and domestic pollution in the water have been known to encourage the growth of organisms not originally found in the water.

The use of chlorine to control marine fouling may easily be justified from improved operation and a reduction in cleaning costs. Continuous chlorination of salt water may have an adverse effect on steel lines, but if alloys or cast iron pipe lines are used for sea water intake, bacteriological corrosion will be prevented and the metal life extended.

III. SALINE GROUND-WATERS

The occurence of saline ground-water is generally
a function of the depth to which wells are drilled, the for-
mations or aquifers through which the ground-water passes,
and the rates of evaporation in the region of ground-water
supply. In most instances salinity increases with the depth
of the well. Salinity of a ground-water supply can be in-
creased from upward leakage of water from older rocks contain-
ing water with higher salinity. In a similar way overdevelop-
ment of a coastal aquifer will result in saline water intrusion
and degradation of the aquifer. Where irrigation is practiced,
water used for irrigation picks up salts and other contamination
and returns these to the aquifer making the ground-water more
saline.

Major producing saline water bearing aquifers are
found in the western half of the United States where a number
of areas are largely dependent upon ground-water for both
domestic and industrial supplies. In the eastern half of the
United States, saline ground-water is found primarily in coastal
regions where seawater has been induced into the water bearing
aquifers by overpumping.

Saline ground-water quality in the western half of
the United States generally remains relatively unchanged where
it is drawn from vast ancient geological formations formally
submerged under saline seas. Exceptions to this rule will be
found in valleys where irrigation and evaporation are factors
in control of the quality of the water recharging the aquifers
in these locations. Saline ground-water in the eastern half of
the United States will change in quality depending upon the
extent to which intrusion from the oceans or other source of
brackish water is occurring. (156)

In the western half of the United States where
many ground-water supplies are saline, there is also a lack of
rainfall. (488) In the eastern half of the United States
rainfall is more plentiful thus lessening dependence for water
on ground-water supplies. However, where ground-water is
becoming saline in this area, it is frequently a principle
source of water supply, and is gradually becoming contaminated
with saline water from the ocean. (400) (380)

Ground-waters change in quality from one location
to another depending on the aquifer from which the water is
drawn. Usually ground-water quality at a particular location

does not change appreciably with pumping except where salt water intrusion or pollution from man made sources occurs. Pollution of saline ground-water supplies from man made sources has been a practice for sometime. Removal of this pollution, which can be both in organic and inorganic forms, could present some unique treatment problems depending upon how this water would be used.

Any water, whether it be surface water or ground-water, responds best to a certain type or types of treatment. The treatment selected must also provide the quality required for the end use of the water treated. Therefore, all characteristics of any water supply should be carefully studied before a scheme for treatment is selected.

A. Specific Areas of Occurence

Highly saline ground-water supplies are usually found in areas deficient in rainfall. There are ten states in the United States that have less than twenty inches of rainfall a year. Two large and important states, with respect to size and industrial growth-California and Texas, have only an average of twenty inches of rainfall per year. (488) These states are also principal users of saline ground-water.

Many of these states have quantities of saline ground-water available but limited supplies of fresh water. States in this catagory are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, South Dakota, Texas, and Utah. A major source of the water used in Arizona and Texas is derived from ground-water supplies.

Exhibit III-1 illustrates typical ground-waters found in the above states. In these waters, the lowest total dissolved solids concentrations are about 1000 ppm. In many of these ground-waters the nitrate and fluoride concentrations as well as the chloride and sulfate concentrations exceed the U.S. Public Health Service, Drinking Water Standards - 1962.

For comparison purposes Exhibit III-2 illustrates the quality of public water supplies in 100 of the largest cities in the United States. Attention should be given to the criterion for Class A water in this exhibit. In a Class A domestic water supply the criterion for total dissolved solids is 500 ppm, the limit for total dissolved solids established in Drinking Water Standards for 1962.

Exhibit III-1

CHEMICAL ANALYSES OF TYPICAL SALINE GROUND WATERS

	SiO₂	Fe	Ca	Mg	Na	K	HCO₃	SO₄	Cl	F	NO₃	B	DS	CaCO₃	% Na	Spec. Cond.	pH
Arizona																	
Coconino County	19	.01	264	79	513	23	964	147	815	0.2	3.2	0.1	2340	984	52	3940	6.5
Narajo County	12		64	32	569		241	186	805	.6	.9		1790	291	81	3180	
Navajo County		.73	176	47	2160		330	294	3360	.1			6200	633			
Graham County	36		936	161	498		306	870	2050	.1	40		4740	3000	27	7410	
Maricopa County			348	128	523		145	521	1240	1.0	149	.9	2980	1400	45	4960	
Maricopa County	37		307	82	1100		327	575	1820	2.5	82	3.2	4180	1100	69	6860	
Yuma County			388	212	926		264	426	2260	1.3	3.8	.2	4350	1840	52	7380	
Cochise County	26		380	212	766		249	1140	1790	1.0	4.2		4640	1820	54	7130	
Mohave County	22		19	9.9	842		191	309	1010	4.8	2.9		2310	88	95	4030	
California																	
Sutter County			237	204	154		336	16	1030				2000		19	3390	
Sacramento County			76	54	445		244	4.8	830		1.4		1800		70	2970	
Fresno County	27		94	29	975	50	145	520	1330			2.5	3060		85	5140	8.3
Kern County			620	0.9	870	3.6	23	1700	1300			2.7	4700		55	6400	
San Bernardino County			158	25	625	13.4	166	241	1060		14		2310			•	
San Bernardino County			158	31	653		85	237	1170	1.0	4.8	.85	2650		73		7.4
Imperial County			492	169	3010		1680	40	5010			22	10410				
Imperial County			42	42	717		531	334	768	1.1		2.7	2490			4300	
South Dakota																	
Butte County					5060		467		2820								

Exhibit III-1

CHEMICAL ANALYSES OF TYPICAL SALINE GROUND WATERS - (Continued)

	SiO2	Fe	Ca	Mg	Na	K	HCO3	SO4	Cl	F	NO3	B	DS	CaCO3	% Na	Spec. Cond.	pH
North Dakota																	
Walsh County	24	0.40	44	22	1640		881	605	1720		9.0		4560	200	95		
Pembina County	10	10	1280	517	8970	177	174	3170	15000		4.0		20300	5330	79		
Traill County		2.1	202	80	876		222	1380	870		104		3620	830	70		
Le Moure County	15	.3	26	16		717	317	1140	172	.8	2.2		2300	130	92		
Wells County	33	3.2	5.6	2.4		1250	1120	764	710				3400	22	99		
Utah																	
Beaver County	52		333	96		203	226	647	572		2.3		2020	1230	26	3060	
Juab County			86	32		711	293	165	1050				2190	346	82	2970	
Tooele County			539	377			114	147	6100				10300	2900		16000	
Davis County	8.2		66	20		331	125	3.3	610				1100	246	74	2100	
Wayne County			124	62		1020	179	257	1680	.8			3230	564	80	5030	
New Mexico																	
Torrence County			1140	1610			242		6300					9460		19600	
Chaves County	18	0.13	231	71	867	7.2	206	639	1380	6.0	1.0		3330	869			
Socorro County	54		236	64		598	197	1050	635	0.7	0.7		2740	852	60	3950	
Montana																	
Fallon County			529	165	1420		195	1940	2060				6210				8.5
McCone County	13	.13	15	36	1330		544	1.9	1850	1.0	1.0	5.2	3550	186	93	6510	7.8
Treasure County	10	.5	5	1.0		826	1090	5.2	636				2080	16			
Nevada																	
Washoe County			54	13	780		524	378	749						90	3570	
Pershing County							390		858							3680	
Elco County			109	41		742	348	33	1230						79	3500	

Exhibit III-1

CHEMICAL ANALYSES OF TYPICAL SALINE GROUND WATERS - (Continued)

	SiO₂	Fe	Ca	Mg	Na	K	HCO₃	SO₄	Cl	F	NO₃	B	DS	CaCO₃	%Na	Spec. Cond.	pH
Texas																	
City of Dawson Navarro County			30	32	2,000		95		2640				5170				
12 miles NE from San Antonio	14		652	259		532	313	2040	1040		2.5		4690	2690	30	6060	8.0
San Jose		.79	130		366		256	137	724		19		1590	592			
18 miles Se of Lufkin Angelina County		4.6	197	61		636	390	740	730		6.0		2560	743			
11 miles S. from Linn., Hidalgo	6.8		74	36		993	177	492	1300		1.5	5.8	3050	332	87	5130	
1 mile S. from Sebastion Cameron County	44		104	109	1140		469	1060	1200	.6	15	5.8	3910	708	78	6090	8.5
Galveston County	35		87	53		2130	330	0	3400				5870	435	91	10500	7.5
Mission Higaldo County	21	.04	88	44	756	11	286	461	950	.9	3.0	3.7	2480	400	80	4160	7.5
7 miles E. from Childress	16		620	232		730	220	2400	1040		.2	4.7	5150	2500	39	6490	7.5
Reeves County			306	86		574	330	881	835					1120			
El Paso County			339	143		1230	284	579	7310		5.8		4740	1430			
Wyoming																	
Johnson County	14	.16	430	129	1830	29	116	1500	2830	1.6	2.7	0.3	6820	1600	71	9970	6.7
Albany County	14		17	15	1600	7.6	1530	1090	805	2.8		.90	4320	104	97	6260	7.6
Idaho																	
Oneida County	34		234	122	1570		588	66	2780		30		5130	1090		876	

From Reference (156)

Exhibit III-2

CHEMICAL ANALYSES OF PUBLIC SUPPLIES OF 100

LARGEST CITIES IN UNITED STATES, 1962

1	2	3	4	5	6
Constituent or Property	Maximum	Median	Minimum	Criterion Value*	Percentage of Supplies With Concn. Col. 5
		Concentration - ppm			
Silica	72	7.1	0.0	30	94
Iron	1.30	0.02	0.00	0.25	98
Manganese	2.50	0.00	0.00	0.10	95
Calcium	145.	26.	0.0	50.	93
Magnesium	120.	6.2	0.0	20.	96
Sodium	198.	12.	1.1	50.	93
Potassium	30.	1.6	0.0	5.0	93
Bicarbonate	380.	46.	0.0	150.	91
Carbonate	26.	0.	0.0	1.0	86
Sulfate	572.	26.	0.0	100.	93
Chloride	540.	13.	0.0	50.	93
Fluoride	7.0	0.4	0.0	1.0	92
Nitrate	23.	0.7	0.0	5.0	93
Dissolved solids	1580.	186.	22.	500.	97
				250.	86
Hardness (as $CaCO_3$)	738.	90.	0.0	200.	94
Noncarbonate hardness (as $CaCO_3$)	446.	34.	0.0	75.	94
Turbidity	13.	0.	0.0	3.	94
Specific conductance- mho at 25°C.	1660.	308.	18.	500.	93
pH	10.5	7.5	5.0	9.0	90
Color units	24.	2.	0.0	10.	96

*Class A water-excellent source of domestic water supply requiring
    disinfection only, as treatment.

From Reference (384)

In those states where average rainfall is equal
to or less than 20 inches per year, ground-water is obtained
principally from certain formations. When these states are
grouped into their respective drainage areas or regions, as
established by the U.S. Geological Survey, these formations
can be further defined. (156)

States in the Western Mountain Region are Utah,
California, Nevada, Idaho, Arizona and parts of Colorado,
New Mexico, Wyoming and Montana. In these states ground-
water comes primarily from undifferentiated Quaternary and
Tertiary systems of recent eras. In Arizona, Utah, and
Wyoming, a small number of ground-water supplies are taken
from formations of more ancient eras down to and including
formations of sedimentary rock from the Paleozoic Era.
Formations in the Quaternary and Tertiary systems are made
up of alluvial deposits filling the river valleys.

States in the Great Plains Region include North
and South Dakota, and parts of Montana, Colorado, New Mexico,
and Texas. Principal formations in this region from which
ground-water is obtained are located in the Cretaceous,
Quaternary, and Tertiary Systems. In New Mexico and Texas,
formations in the more ancient Permium System are sources of
water. In the Great Plains Region most saline ground-water
is obtained from formations of more ancient eras which include
sedimentary rock, such as sandstone, and important limestone
formations of the Cretaceous Systems.

In the Coastal Plain Region, saline water
bearing formations are found principally in the states of
Texas, Louisiana, Mississippi, Alabama, Florida, Georgia,
South Carolina, North Carolina, Maryland, New Jersey, and
New York. In this region the saline water bearing formations
are found principally in the Tertiary and Cretaceous Systems
into which saline water has been induced by overdevelopment.

Typical examples of saline ground-water in the
Western Mountain Region are found in the Gila River and
Rainbow Valleys of Arizona. The concentrations of dissolved
solids range anywhere from 950 ppm to 7,000 ppm. Most of the
water is quite high in fluoride content. The quality of
water in shallow wells on the flood plain seems to respond to
changes in the flow of the Gila River.

Surface water from the Gila River during periods
of low flow contains more than 5,000 ppm of dissolved solids
composed principally of sodium, calcium, magnesium, and chloride
ions. It is estimated that in the first 300 feet of saturated

fill there is available 50,000 to 100,000 acre feet of water available per 100 feet of depth. The concentration of dissolved solids in most of the ground-water in the Gila River Basin, obtained from the alluvial deposits, ranges from 1,000 to 3,000 ppm.

The dissolved solids content in one irrigation well varied from 2,000 ppm in 1946 to almost 5,000 ppm in 1954 and then decreased to 3,600 ppm in 1955. The change in solids content was related to river flow, because 1952 and 1953 were years of low flow in the Gila River. (331)

In western Arizona, the McMullen Valley has an annual rainfall of nine inches. The ground-water samples from fifty-three wells contained from 200 to 7,410 ppm of dissolved solids. This water, in general, contains more than 1.5 ppm of fluoride. Wells 800 feet deep or more in this area contain almost 800 ppm of dissolved solids and are recharged through lake deposits. (418)

Ground-waters in the Jordan River Valley, Utah, also in the Western Mountain Region, are relatively high in dissolved solids. Within 2 miles of Great Salt Lake, and east of Saltair, the chloride content of the ground-water is greater than 14,000 ppm. North of this area, the chloride content varies between 100 and 1,000 ppm. Along the west side of the valley and also on the east side in the southern part of the valley, the chloride content of the waters shows little uniformity, but in most cases, it is between 100 and 750 ppm. The high chloride content of the waters in the southern part of the valley may reflect the relatively high chloride content of irrigation waters from Utah Lake, which range in chloride content from about 200 to 400 ppm.

Carbonate hardness is also an important constituent in well waters in the Jordan Valley. Most of the ground-water is hard, varying in hardness from 150 to 1,000 ppm. (331).

Typical formations which are important sources of saline ground-water in North Dakota and South Dakota, and portions of Montana and Wyoming, in the Great Plains Region are the Fox Hill sandstone and the overlying Lance formation of the uppermost Cretaceous system. Wells in these formations range in depth from less than 100 feet to more than 1,100 feet, and yield water whose dissolved solids content approaches 5,000 ppm even at shallow depths.

One of the most extensive aquifers throughout most of the Great Plains Region is the Dakota sandstone of the basal Cretaceous system. Ground-water from this formation is used generally for domestic, stock, and irrigation purposes despite its relatively high mineral content. The concentrations of dissolved solids in this formation range from 1,000 ppm or more. Because of the high sodium content present in water from this aquifer, it is unsuitable for irrigation. (156)

Geologic formations in South Dakota furnish hot waters, in some instances, at temperatures up to 130 F. As a rule, these waters have concentrations of dissolved solids as high as 3700 ppm, high sulfates and chlorides, fluorides up to 7 ppm, and iron and manganese concentrations of almost 8 ppm. It is interesting to observe that there are more saline waters in South Dakota than in most of the arid states.

Analyses of ground-water samples collected in the eastern half of Colorado in the Great Plains Region indicate fairly wide differences in chemical quality of the water from the various aquifers. Samples of ground-water differed not only in total concentrations of mineral constituents, but also in chemical type.

There are four principal geological formations or aquifers in northeastern Colorado. These are the Alluvium and Terrace deposits, Ogallala formation, Brule formation, and the Fox Hills sandstone. Ground-water from the Alluvium and Terrace deposits are characterized by high concentrations of sodium and sulfate. In the Ogallala formation the concentrations of calcium and magnesium hardness range from 127 to 215 ppm, while water in the Brule formation is low in dissolved solids concentrations having a specific conductance of only approximately 335 micromhos.

The Coastal Plain Region is underlain by Cretaceous, Tertiary, and Quaternary formations. From New York through the Carolinas, the principal aquifers are the Tertiary and Quaternary formations, while from Florida to Texas the Cretaceous formations are principal sources of ground-water.

Saline water is usually a function of depth in most of the above aquifers, and also where they are in contact with saline surface water bodies. Most, if not all of Florida, is underlain by formations containing saline water. In general, it can be stated that the mineral content of ground-water in the Coastal Plain Region increases with depth

in any given aquifer, with the salinity of the water approaching that of seawater even in many inland areas as well as in coastal areas.

B.   Contamination of Ground-Water Supplies

        In addition to high salinity in many ground water supplies, man made pollution is also a problem. In many instances, the deeper aquifers are targets for pollution, since they are purposely used for the disposal of many wastes. Some of these wastes are highly toxic.

        Contamination of ground-water by sewage and industrial wastes has been occurring for some time. A questionnaire issued to various states developed the information presented in Exhibit III-3. This information indicates the need for careful consideration of sources for water supply and current waste disposal practices.

        Organic contaminants present a specific problem. The following tabulation illustrates to some degree the extent to which organic contamination of ground-water has occurred:

Number of States Reporting Specific
Occurences of Organic Contamination of Ground-Water (479)

Organic Contaminants	To 1957	1957-1959
Gasoline	9	7
Oil and fuel oil	6	6
Other Petroleum products	2	4
Detergents	3	8
Other petro-chemicals	2	3
Phenolic compounds	8	1
All types	19	20

        The increasing number of states reporting experiences of detergent contamination of ground-water is evidence of the drawing interest and concern about organic chemical contaminants. Information now available indicates such problems have been encountered in about 20 states.

EXHIBIT - III - 3

SURVEY OF GROUND WATER CONTAMINATION AND WASTE DISPOSAL PRACTICES

STATE	SEWAGE	OIL, GAS	CHEMICAL INDUSTRIAL	OTHER	NONE	SOURCE OF CONTAMINANTS	DISPOSAL WELLS	IMPOUNDMENTS LAGOONS	SURFACE WATER DUMPING	CESS-POOLS SEPTIC TANKS	GROUND SURFACE	OTHER
ALABAMA					X	DIESEL FUEL						LEAKAGE OF STORAGE TANK
ALASKA		X			X							
ARIZONA		X	X			SALT WATER	X	X			X	IMPROPERLY CONSTRUCTED WELLS
ARKANSAS *	X	X	X	X		SULFIDES, SALTWATER, DETERGENTS IN SEWAGE, OIL FIELD BRINE, REFINERY WASTES		X			X	
CALIFORNIA *	X	X	X	X				X				
COLORADO			X			DETERGENTS, GASOLINE, CHROMIUM		X				
CONNECTICUT	X		X					X		X		
DELAWARE †	X					SEWAGE, DETERGENTS	X	X				ACCIDENTAL SPILLS
FLORIDA	X	X			X	SEPTIC TANK EFFLUENTS, REFINED GASOLINE AND OIL				X		
GEORGIA	X					COLIFORM ORGANISMS, PETROLEUM PRODUCTS	X	X		X		
HAWAII						BRINE, HEAVY METALS, DYANIDE, PETROCHEMICAL PETROLEUM				X		PIPELINE LEAKAGE OR BREAK
IDAHO	X	X	X									
ILLINOIS	X	X				CHROME WASTES, BRINES, GASOLINE, FUEL OIL, PYRIDINE, PICOLINE	X	X	X			DITCHES
INDIANA		X	X			SEWAGE	X	X			X	
IOWA	X		X			CHLORIDES FROM CHEMICAL PLANT, OIL FIELD BRINES	X	X		X		UNKNOWN SEWAGE SOURCE POSSIBLY FROM DISPOSAL WELLS SURFACE STREAM DRAINAGE INTO SINKHOLE
KANSAS	X	X	X			FLUORIDES, CONCENTRATED BRINE	X	X		X		
KENTUCKY	X			X		OIL FIELD BRINES OR SEA WATER						HIGHWAY SALT PILES
LOUISIANA	X			X		SEWAGE, CHLORIDES				X	X	UNDERGROUND STORAGE TANKS
MAINE	X			X		GASOLINE, OIL, SEWAGE			X	X	X	LEAKING STORAGE TANK
MARYLAND	X	X	X			CHLORIDE COMPOUNDS, SEWAGE, PHENOLS		X		X		
MASSACHUSETTS	X	X	X	X		DETERGENTS, GASOLINE, DRY-CLEANING FLUID, CHROMIUM, DISEASE-PRODUCING ORGANISMS				X		ACCIDENTAL SPILL
MICHIGAN	X				X	GASOLINE, SEWAGE				X		
MINNESOTA	X					OIL, SEWAGE				X		LEAKAGE OF GASOLINE STORAGE TANKS
MISSISSIPPI	X	X				GASOLINE				X	X	
MISSOURI	X	X	X			DETERGENTS		X	X	X		
MONTANA	X				X			X		X		
NEBRASKA			X	X		DETERGENTS	X	X		X	X	LEAKAGE OF GASOLINE AND FUEL OIL TANKS
NEVADA	X	X	X	X		OIL BRINES, CHEMICAL, INDUSTRIAL CONTAMINANTS, URANIUM		X		X	X	
NEW HAMPSHIRE	X	X	X	X		SEWAGE, DETERGENTS, NITRATE				X		
NEW JERSEY	X				X	GASOLINE, FUEL OIL, SEWAGE, SURFACE WATER, VERMIN					X	
NEW MEXICO	X	X		X		SEWAGE		X		X		
NEW YORK	X		X	X		SODIUM CHLORIDE		X		X		
NORTH CAROLINA	X					TURBIDITY, BARNYARD DRAINAGE	X					CHLORIDE STOCKPILE
NORTH DAKOTA	X			X		SEWAGE, CHLORIDES				X		STREAM CONTAINING SEWAGE
OHIO	X			X		SEWAGE					X	
OKLAHOMA	X			X		TURBIDITY, SEWAGE, PETROLEUM PRODUCTS, CHLORIDES	X	X	X	X		
OREGON	X	X				OIL FIELD BRINE		X				
PENNSYLVANIA	X					SEWAGE	X				X	UNKNOWN SALT WATER SOURCE
RHODE ISLAND	X					SALT WATER, SEWAGE						
SOUTH CAROLINA	X					SEWAGE, BRINE, DYE WASTES		X		X		
SOUTH DAKOTA	X	X	X			SEWAGE, SYNDETS, PETROLEUM FRACTIONS, ORGANIC INDUSTRIAL WASTES	X	X		X	X	

* TOTALED RESPONSE FROM 8 REGIONS
† NO REPLY

FROM REFERENCE 202

The variety of organic contaminants reported in ground-water supplies is illustrated by the following tabulation:

Organic Contaminants Found In Ground-Water (479)

ABS
Creosols
2, 4-Dichlorophenoxy acetic acid
Dichlorophenol
Gasoline
Hexachlorocyclohexane
Kerosene
Methane
Oil
Pentachlorophenol
Phenol
Phosphonates
Picoline
Picric acid
Pyridine
Trichloroethylene

A survey in Minnesota of 29 communities involving 54,000 private water supplies revealed that 11 percent of those tested contained nitrates exceeding 10 ppm. This indicated recirculation of contaminants of sewage origin, further confirmed by the finding of coliform organisms in the water.

Geographic location of manufacturing facilities has many times been a parameter for ground-water pollution. In New Mexico six uranium ore processing mills have created hazards in ground-water supplies by their chemical waste disposal practices.

Man makes water saline in many places where irrigation is practiced. When water used for irrigation, or precipitation, is applied to cultivated land, some of it runs off as surface water or is lost by direct surface evaporation, while the remainder infiltrates the soil. Water which infiltrates the soil for subsequent evapotranspiration, and the remaining surplus, if any, moves downward or laterally through the soil and substrata. The water which is retained in the soil is known as "soil solution". This soil solution tends to become more concentrated with dissolved constituents as relatively pure water is used by the plants or is lost by upward capillary action and evaporation. As the soil solution remains in the soil, it also is enriched by the leaching of fertilizers,

insecticides, and excretions of carbon dioxide. The soil solution can only be rendered less saline by dilution with fresh irrigation water or rain, and by downward leaching of excess water. Where there is a lack of fresh irrigation water or rain, subsequent users of the irrigation water released from the soil into surface bodies of water or aquifers are faced with an even greater salinity problem. They must apply increasing quantities of water to their lands to maintain the essential salt balance. As can be readily seen, successive reuse of the water for irrigation can increase the dissolved solids content of water from irrigated areas many times. It is almost universally true that soil solution contains at least three to eight times the dissolved solids concentrations contained by the water which replenishes it, and in some cases, the dissolved solids may be as much as 100 times more concentrated than in this water. (33) (479)

The manner in which irrigation influences ground-water quality is far more serious than seawater intrusion, and creating problems in many important river basins in the western states. It has been estimated that about two-thirds of the water is consumed in the irrigation process. Most of this water is returned to the atmosphere by evaporation and transpiration. To illustrate this condition, a portion of the Rio Grande River Valley is an example of the close relation of surface and ground-water quality to irrigation practices. Wells in the Rio Grande River Valley at one time were too saline to support agriculture. After completion of Elephant Butte Dam, irrigated agriculture was expanded. At one time water released from the Elephant Butte Reservoir amounted to about 830,000 acre feet, of which only 16 percent reached Fort Quitman, 200 miles from the Dam. In 1951 about 429,000 acre feet were released from the Reservoir and less than 6 percent reached Fort Quitman.

Although the sodium content of the water leaving the Reservoir average 42 percent of the total dissolved cations expressed in milliequivalents per liter, the sodium content of the water reaching Fort Quitman increased to 62 percent in 1946 and 64 percent in 1951. In 1951, 82 percent of the calcium in water leaving the Reservoir was being retained in the valley fill, a large part of it probably displaces sodium from the soil, in turn enriching the soil solution in sodium. Subsequent users of this soil solution, either after it returns to the River or is pumped from the ground through wells, are faced with serious sodium hazards through irrigation.

Calcium bicarbonate in the river water upon passing through formations containing sodium clays, gives up

calcium to the clay and gains sodium, thus making sodium the predominant cation in the water leaving these formations. (479)

C. Quality Characteristics of Saline Ground-Water

Depth into an aquifer as well as its type are both functions of ground-water quality. A review of saline ground-water analyses indicates that the deeper a well penetrates a formation for water, the higher will be the percentage of sodium salts, in particular sodium chloride. As hard water percolates down through an aquifer, calcium and magnesium ions in the water, under proper conditions, can displace sodium ions from the aquifer. Thus, as a well draws water deeper from an aquifer, the percentage of sodium in the water can increase.

Water from limestone formations would be harder than water from sandstone or other older formations in the late Mesozoic or Paleozoic Eras. In most instances, limestone aquifers used for water supplies are not normally saline or high in sodium content. As these aquifers dip toward the oceans, the salinity of the water in these aquifers increases, particularly in areas of overdevelopment along the coast.

The quality of seawater differs in many respects to saline ground-waters. Whereas, seawater is high in chloride concentrations, most saline ground-waters are high in bicarbonate and sulfate ion concentrations. With reference to Exhibit III-4, exceptions to this rule would be saline ground-waters from the Quaternary-Tertiary System, which consists largely of valley fill irrigated for agricultural purposes, and the very old formations of the Paleozoic Era of which the Permium System is typical. The ground-water from the latter two systems, with respect to their relative order of ion concentrations, resemble seawater in quality with exception of the total dissolved solids concentration.

D. Saline Ground-Water Conversion Problems

Divalent and bicarbonate ions interfere with membrane techniques used for desalinization. High concentrations of these same ions are troublesome to evaporative schemes for desalinization but in a different manner. When electrodialysis is used to desalt water, high concentrations of divalent ions increase the power requirements for desalinization. High concentrations of bicarbonate ion in the presence of hardness in the water forms deposits which foul the electrodialysis system. Divalent and bicarbonate ions form scale in evaporative

Exhibit III-4

RELATIVE ORDER OF ION CONCENTRATIONS [2]
IN SALINE GROUND-WATERS
COMPARED WITH SEA WATER

Sea Water [1]	Quaternary System		Quaternary-Tertiary System		Tertiary System		Cretaceous System		Permian System
	Glacial Drift	Alluvium	Valley Fill	Valley Fill	Ogallala Limestone	Fort Union	Fox Hills	Dakota Sandstone	San Andres
Chloride	Bicarbonate	Bicarbonate	Chloride	Chloride	Sulfate	Bicarbonate	Bicarbonate	Sulfate	Chloride
Sodium	Sulfate	Sulfate	Sodium	Sodium	Bicarbonate	Sodium	Sulfate	Sodium	Sodium
Sulfate	Calcium	Calcium	Sulfate	Sulfate	Sodium	Chloride	Calcium	Bicarbonate	Sulfate
Magnesium	Sodium	Sodium	Calcium	Bicarbonate	Calcium	Sulfate	Sodium	Chloride	Calcium
Calcium	Magnesium	Magnesium	Bicarbonate	Calcium	Magnesium	Calcium	Magnesium	Calcium	Bicarbonate
Potassium	Silica	Silica	Magnesium	Magnesium	Chloride	Silica	Silica	Magnesium	Magnesium
Bicarbonate	Chloride	Iron	Nitrate	Silica	Silica	Magnesium	Chloride	Silica	Silica
Bromine	Nitrate	Chloride	Fluoride	Boron	Nitrate	Nitrate	Iron	Nitrate	Fluoride
Strontium	Fluoride	Nitrate	Boron		Fluoride	Iron		Fluoride	Iron
Boron		Fluoride			Iron	Fluoride		Iron	
Fluoride									
Silica									
Iron									

(1) From Reference (331)

(2) From Reference (156)

systems, but in addition, the presence of heat in evaporative systems breaks down the bicarbonate ion, forming carbon dioxide and making the vapor acidic. The acidic vapor adds to the engineering problems for recovering the desalinated water.

When water is evaporated at high rates there may be a tendency for some complex salts to volatilize and materially greater carry over of salts in the vapor may be expected. The higher the concentrations of dissolved solids, the greater their tendency to carry over in the vapor.

In a similar manner organic contaminants in the water will volatilize and carry over in the vapors. Frequently these organic materials form undesirable by-products in the process of evaporation, some of which are as toxic or more so than the original contaminants.

Traces of minor elements and organic materials are often more troublesome to remove than many of the common inorganic ions from saline waters. Small concentrations of many trace elements as well as organic materials can be highly toxic, even in very low concentrations. If they can not be removed in the process of desalinization, they can make the desalted water unsuitable for domestic purposes, even though the total dissolved solids may be greatly reduced. Such minor elements are selenium and arsenic which are highly undesireable in waters used for potable purposes.

There are conventional water treatment processes which can be used to condition saline ground-water for the desalinization process under consideration. However, addition of these conventional treatment processes to the desalinization processes can greatly increase the over all cost for desalting the water. These additional processes can only be justified if they can improve the quality of the desalted water sufficiently to avoid problems which constituents remaining in the finished water might incur.

Treatment of the water first with an oxidizing agent before evaporation or deionization can appreciably reduce organic contamination before treatment. Oxidation can be accelerated by the addition of heat to help destroy the organic contaminants.

A major problem in any desalinization process is disposal of the concentrated brines remaining after the desalted portion of the water has been removed. Disposal of brines containing relatively high concentrations of such constituents as selenium and arsenic raise serious disposal

problems because of their extremely toxic properties.
Disposal of these brines into deep wells might only serve
to further contaminate a saline water producing aquifer.
Ground disposal might have similar affects. Therefore,
brine disposal problems can conceivably be as involved as
developing means for economically producing desalted water.

Silica in saline ground-water is high
because of the relatively high alaklinity of these waters.
Membrane techniques do not efficiently remove silica and
evaporative techniques will volitalize silica. Deposits
resulting from silica interfer with heat transfer, in some
instances are corrosive, and are difficult to remove.

E. Advantages of Ground-Water with Respect to
     Saline Water Conversion Processes

Saline ground-water from some deep formations
will have temperatures exceeding 100 F. This elevated tempera-
ture would be advantageous when considering evaporative type
desalinization processes. Certain ground-waters also contain
constituents which when concentrated, could prove to be
valuable by-products of a desalnization process. Spectro-
graphic analyses of the total dissolved solids in the particu-
lar water under consideration for desalinization would indicate
what these constituents might be.

IV. INTEGRATING SALINE WATER CONVERSION AND WASTE WATER RECOVERY

The integration of waste water recovery and saline water conversion into a combined water supply system appears to present a promising means of meeting increasing needs for fresh water supplies. Either portion of the integrated system, taken separately, has been explored in depth in the past. Extensive studies of each phase are currently underway and major investigations are planned. The purpose of this section of the report is to present and comment on various technical and economical aspects of combined water supply systems integrating saline water conversion and waste water recovery.

The combined system under discussion here is conceptually simple, involving the coordinated use of saline water conversion and waste water recovery to provide, after necessary treatment, a satisfactory supply of water for beneficial use. As will be shown later in this section, the actual application of the combined system is quite complex and influenced directly and indirectly by many factors. One of the dominant factors is found to be water or waste quality and this is stressed herein. Numerous other factors are more than remotely related and these, too, are discussed.

The need to consider the combined plant appears to be basic in those situations where a converted saline water supply is used. Realistically, a converted saline water supply could be considered as a "manufactured product" of considerable value. This value is only partially decreased by the contamination attained through most uses, particularly normal community use. Where possible and practical, this "dirty product" should be considered for recovery in potential combination plants.

The sources of saline water for potential use in the conversion phase of the combined system are fully developed in the preceeding sections of this report. This matter is reviewed here in only a cursory manner. The greatest emphasis is on the source of the waste water, its quality characteristics, and the influence on the overall combined system. As a primary step, the availability of waste waters, both sewage and industrial wastes, is discussed.

The potential combined systems for integrating saline water conversion and waste water recovery are subject to many interrelated influences. It is not feasible to develop complete systems. Rather, the various dominant factors of specific portions of the system are discussed and, in some instances,

data or partial flow sheets are given. As will be shown, complete objective analyses of actual proposed combined systems will require specific and detailed engineering investigations, and comprehensive technical and economical evaluations.

To complement the earlier presentations regarding the general quality characteristics and potential contamination of saline water sources, waste water as a source of supply is fully considered here. The recovery of sewage is emphasized because of the greater knowledge in this area, as opposed to industrial wastes.

The presentations of this section indicate many advantages which may accrue to combined systems for saline water conversion and waste water recovery. A preliminary appraisal of such systems indicates a complexity of many interrelated factors which influences the technical and economical aspects of potential systems. There is a need to reconsider the applicability of long-established water supply design criteria to the potential combined plant situations. Public health aspects of waste recovery are shown to be of major importance and the need for more and better knowledge in this field is noted.

Available data are revealed and areas of limited or meager knowledge are specified. The need for more comprehensive investigation into specific phases of combined systems is shown.

A. **Availability of Waste Waters**

For the purposes of this discussion, waste waters are considered to be sewage and/or industrial wastes. Sewage represents waterborne wastes resulting from man's domestic activities, together with similar wastes produced by his general community activities. Industrial (waterborne) wastes are those which result from man's specific industrial activities and which are conveyed separately from his other wastes.

For the most part, waste water is generally available wherever there are significant community or industrial complexes. It must not be automatically presumed, however, that such wastes are available as a source of supply to the combined systems under consideration. There are a number of factors which mitigate against potential use and they are worthy of comment here.

Waste quality is one factor affecting the availability of a particular waste stream. This is usually of minor significance when the waste is domestic or municipal sewage; as discussed more fully later. Many industrial wastes, however, are grossly contaminated with respect to potential recovery. Although treatment could render any waste suitable for recovery, the costs for such treatment could be excessively great. For practical purposes, therefore, grossly contaminated industrial wastes may be considered as "not available" to potential combined systems.

Not all communities, and to a lesser extent industries, convey their waste waters to common points where necessary connections could be made to direct the waste to the combined system. The most obvious example, of course, is where many individual household disposal systems are used and the sewage is discharged to the ground. In such a case the sewage is not "available" and expensive sewerage facilities would be required to make it so.

It must be remembered, too, that waste water flows are highly variable in most cases. In the absence of waste storage facilities, the dependable yield of the waste supply is the minimum flow; usually only a small portion of the average waste flow over extended periods. This is discussed more fully later.

A final item for comment is concerned with water rights. In many areas, particularily in the arid and semi-arid regions usually in need of water supply augmentation, the waste discharges from communities and industries represent all or most of the dry weather flow in some rivers and streams. Waste water recovery is largely consumptive and may invoke water rights infringements. Such a situation may, in effect, render the wastes as "non-available" for recovery.

Any investigation for the actual development of a combined system would, of course, include specific consideration of the availability of the waste waters involved. Preliminary information for specific instances, and data for studies of a more general nature are available in Inventory Reports prepared by the U. S. Public Health Service (478). Additional information is available in several reports on the U. S. Public Health Service Advanced Waste Treatment Research Program (481, 445).

It has not been the intention of this discussion to suggest that waste waters are not available for recovery in combination plants. For the most part they are. However, as evidenced by these discussions, it should not be automatically

presumed that all waste waters are "available." These consid-
erations should be borne in mind in the following presentations
of factors and concepts of the combined saline water=waste
recovery systems.

B. Potential Conversion=Recovery Systems

There are a great number of complex interrelated factors
affecting the feasibility, design, and costs for combined systems
of saline water conversion and waste water recovery. The purpose
of this discussion is to present and comment on many of these
factors to indicate their significance, the available knowledge
and data relating to them, and the need for further, more detailed,
investigations.

This evaluation indicates a need for added emphasis on
the potentialities of combining saline water conversion systems
and waste water recovery systems. Further studies are required
to define and evaluate specific water quality considerations as
they directly or indirectly influence such combination plants.
Also, the broader aspects of such systems should be appraised
in greater detail to assemble necessary data and to indicate the
requirements for specific investigations of important factors.
Consideration should also be given to investigations of actual
or model situations where the full, integrated system could be
evaluated.

The actual development of integrated saline water-
waste recovery systems by communities or industries will require
long=range planning if the most practical and most economical
systems are to be realized. Findings from the studies outlined
above are necessary to advance the technologic and economic
knowledge to the point where such planning can be envisioned.
The present state of knowledge is inadequate.

1. General Water Supply Requirements

The development of any water supply system is
influenced to a large degree by the amount and quality of water
required. In the case of an integrated system of saline water
conversion and waste water recovery, these factors assume even
greater significance. Also, the interrelationship between
water quantity and water quality, which is evident in some
supplies, becomes very important when the combined system is
considered.

a. Quantity Considerations

The amount of water used by a community or an industry, and particularly the variability in use, is a primary consideration in the design and evaluation of combined plants. The effects of this factor are complex and interrelated with several other factors, notably the water quality requirements.

Industrial water use is so tailored to the particular industry and the design of the plant or process that a general discussion is not possible. In many industries, particularly those with seasonal production schedules, the quantity of water used and the pattern of use will have significant effects on the potential development of combined plants. Individual detailed studies of the actual situation will be required.

The quantity of water used by a community depends on many factors such as climate, character of the community, quality of the supply, family incomes, water rates, use (or nonuse) of meters, etc. Numerous studies have been made (351, 401, 433, 457, 469) to show the variation in water use, usually on a per capita basis, in various communities. A recent continuing study at The Johns Hopkins University (399) is providing data on residential water use.

Variations in water use throughout the year are of great importance to the design and economics of potential combination plants. Exhibit IV-1 shows the actual variations in water use in Buckeye, Arizona as reported by Kirkham (428). He notes:

> "It was also obvious that the design must incorporate sufficient flexibility to economically cope with the threefold change in average monthly load from winter to summer, and the fourfold change between peak day load in the summer and minimum day load in the winter."

Overall, the design of this brackish water conversion plant and various components of the system was very significantly affected by the variations in water use. It is most likely that the design of combination plants would be even more influenced by variations in water use.

The importance of water use variations can be shown by noting the findings after two years of operation of the Buckeye, Arizona saline water conversion plant. In a recent report, Katz (422) notes the importance of the annual plant

VARIATION IN WATER USE
BUCKEYE , ARIZONA

EXHIBIT -IV-I

D-1350

ADAPTED FROM REFERENCE 428
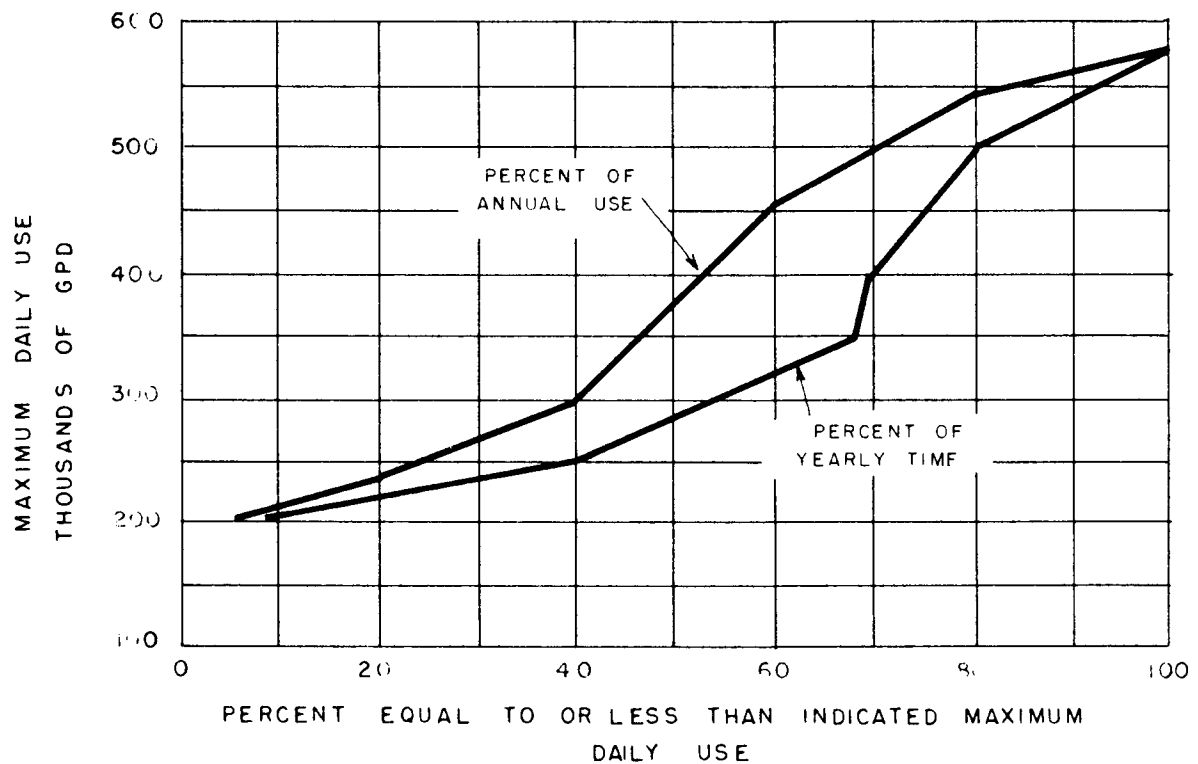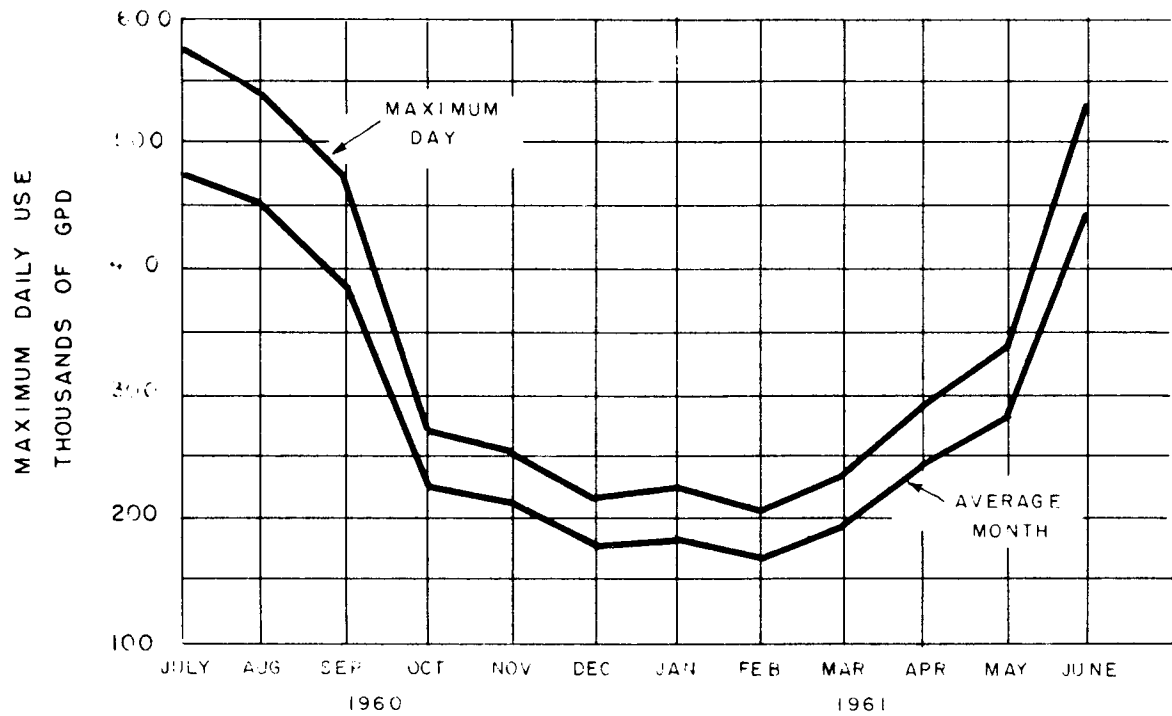
load factor to the economics of saline water conversion pro-
cesses. With an allowance for maintenance outages, the annual
water production as a percentage of the annual plant capability
is the annual load factor. Katz gives the variation of unit
cost with annual load factor as presented in Exhibit IV-2 and
makes the following observation:

> "Load factor has a profound effect on unit
> saline-water conversion costs, and load factors in
> the 90 percent range will rarely be met in real
> systems."

The potential use of treated water storage in conjunction with
a smaller capacity plant operated at a higher load factor is
noted, but apparently the costs of providing large treated
water facilities were found to be excessive.

In the case of potential combination plants,
there may be a possibility of meeting peak seasonal demands
more economically by increased feed ratios of waste-to-saline
waters, or by other techniques. Combination plants would seem
to have an inherent degree of flexibility that could permit
the attainment of more favorable load factors for the saline
conversion part of the plant, perhaps even in the 90 percent
range.

This consideration of load factor points up
a more general observation concerning the overall design of
combination plants. It seems very apparent that many of the
long-established design criteria and concepts of conventional
water treatment systems do not necessarily apply to potential
combination plants. Some areas where possible departure may
be economically favorable are design capacity of treatment
plant, storage of treated water, balance between capital and
operating costs, etc.

Of special note in this discussion are the
effects that potential combination plant developments may have
on the rate of water use in a community or, in some cases, in
an industry. For example, there was a decrease in water use
in Buckeye, Arizona following the improvement in water quality
(362). In this case, the water quality was greatly improved
by the installation of an electrodialysis conversion process.
The total dissolved solids concentration was reduced from
2,100 ppm. Also, the water rates were increased. Barnhill

Exhibit IV-2

Brackish Water Conversion Plant, Buckeye, Arizona

VARIATION OF UNIT WATER CONVERSION COST

WITH ANNUAL LOAD FACTOR

(Adapted from Reference 422)

Annual Load Factor, Per Cent	34.4	48	75	100
Annual Production, Million Gallons	80	112	175	233

Cost Items	Unit Costs per 1,000 Gallons of Production, cents			
Electrical Energy*	12.9	11.8	12.0	11.2
Acid	0.6	0.6	0.6	0.6
Filters	3.2	3.0	3.0	2.7
Membrane Replacement	7.5	8.8	5.7	4.2
Other Replacement	5.0	3.8	2.4	1.8
Miscellaneous	1.4	1.0	0.8	0.6
Labor	6.9	4.6	2.9	2.2
Bond Amortization and Interest	25.5	18.3	11.7	8.8
Total Unit Costs	63.0	51.9	39.1	32.1
Total Annual Costs - Dollars	50,499	58,200	68,400	73,700

*Electrical energy costs vary for the indicated load factors.

makes the following observations on the influence of these changes (362):

> "Greater than normal rainfall in 1963 and higher rates had some effect in reducing estimated water usage, but the over-riding reason for lower than estimated consumption in 1963 is attributed to the installation of recirculation pumps by most users of evaporative coolers. Prior to treatment, recirculation was not feasible. The cooler pads would have scaled up in a matter of a few weeks. Upgrading water quality has thus resulted in reducing consumption and stretching available supplies."

Both of these considerations, overall water use and variations in water use, will be major factors influencing the design and economics of combination plants. Invariably, each specific instance will require detailed study and evaluation. There exists, however, a more immediate need for comprehensive investigations to define the influence of certain factors and to develop the methodology for specific evaluations. Existing data from previous studies will be most valuable, but further study is needed.

b. Quality Considerations

The acceptable or permissible quality of the treated water for a community or an industry will also influence the design and economics of a combined system. Within limits, the quality of the water supply from a combined system may be selected by the user. The quality may be maintained constant or it may be varied. All of these factors may be significant.

Drinking water quality requirements are usually considered with respect to the U. S. Public Health Service "1962 Drinking Water Standards" (480). While these criteria are certainly valuable guides to establishing the quality requirements of a combined system, it appears that the values should not be rigidly applied in all instances.

In some cases it may prove desirable to provide water having a higher quality than that given by the Drinking Water Standards. Where permissible, the quality requirements could be established at a less demanding level. A most interesting concept is that of permitting the quality of the treated supply from the combined plant to vary between established limits.

This concept of varying the treated water quality appears to have great economic potential in certain instances. Where large variations in water use exist, the size of the combination plant could be significantly reduced by permitting reasonable quality deterioration during periods of maximum demand. Furthermore, the smaller plant could be operated at a higher annual load factor, thereby decreasing the unit cost of the treated supply.

Satisfying the increased demand for water, with an intended sacrifice in water quality, may be possible in several ways. In some cases the saline conversion facilities can be operated at higher rates to produce more water but with poorer quality. The amount of recovered waste water could be increased or the raw saline water feed may be bypassed around the conversion facilities.

The potential economic advantages of quality variations would also be significant in cases where the quality of the raw feed to the combination plant, saline water and/or waste water, is subject to major variations. This might be the case with estuarine waters, coastal groundwaters, inland surface waters, and inland groundwaters directly recharged by rivers having variable quality.

Where large facilities are provided for storing treated water the change to poorer quality water would be moderated considerably. This would lessen the overall impact of such operations on the water user.

It should be noted here that many existing community and industry water supplies show significant water quality variations. Numerous water supplies drawn from "fresh water" rivers show severalfold variations in major water quality characteristics, such as total dissolved solids, hardness, etc. For example, the unregulated Youghiogheny River serving McKeesport, Pennsylvania had over a fourfold variation in hardness with the flow in the river being the controlling factor. This relationship is shown by Exhibit IV-3. In this example, it is very interesting to note the important effect of low-flow augmentation by Youghiogheny Reservoir on water quality variations. This is only one example of many situations where the raw or treated water supply is subject to wide variations in major water quality characteristics.

HARDNESS AND DISCHARGE OF THE YOUGHIOGHENY RIVER, 1941-1950

YOUGHIOGHENY RESERVOIR
PUT INTO USE JANUARY, 1948

ADAPTED FROM REFERENCE 4ᶜ 2

HARDNESS AS Ca CO3 — PARTS PER MILLION

DISCHARGE — CUBIC FEET PER SECOND

D-1354
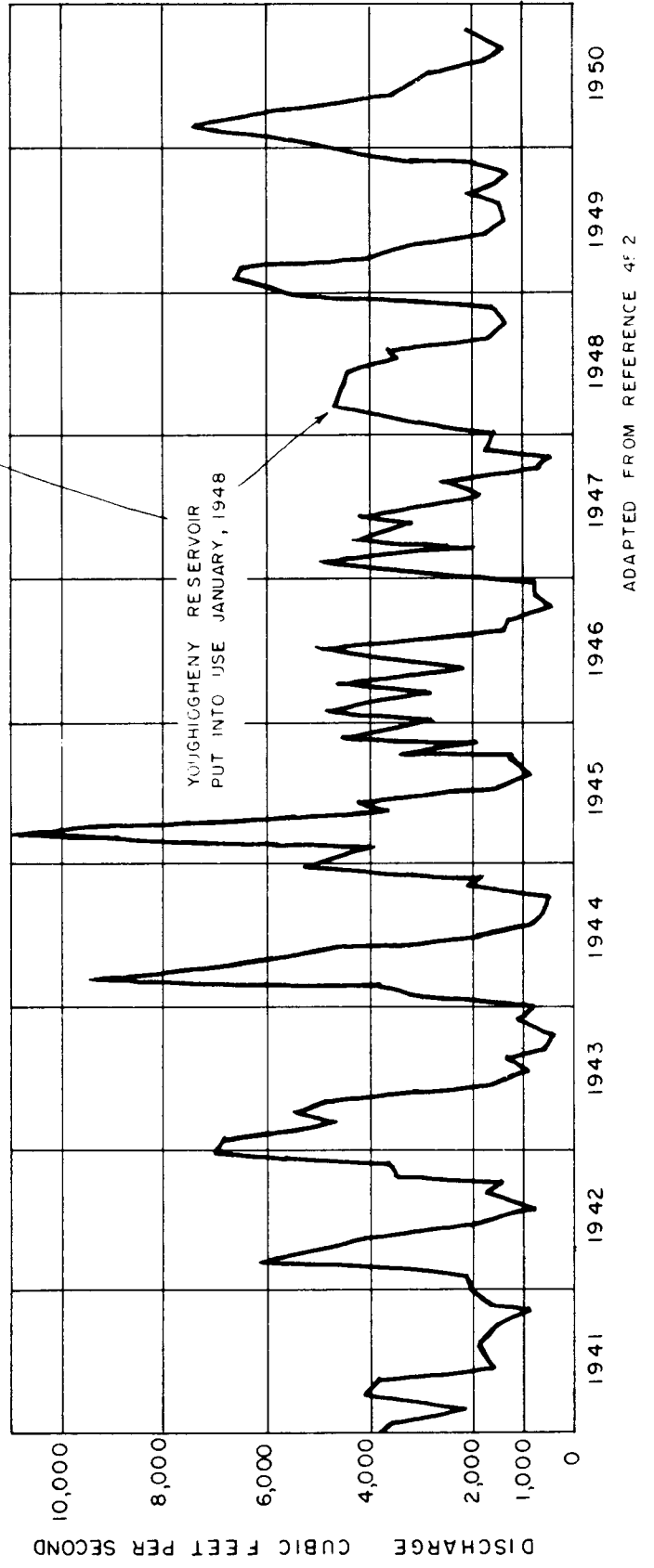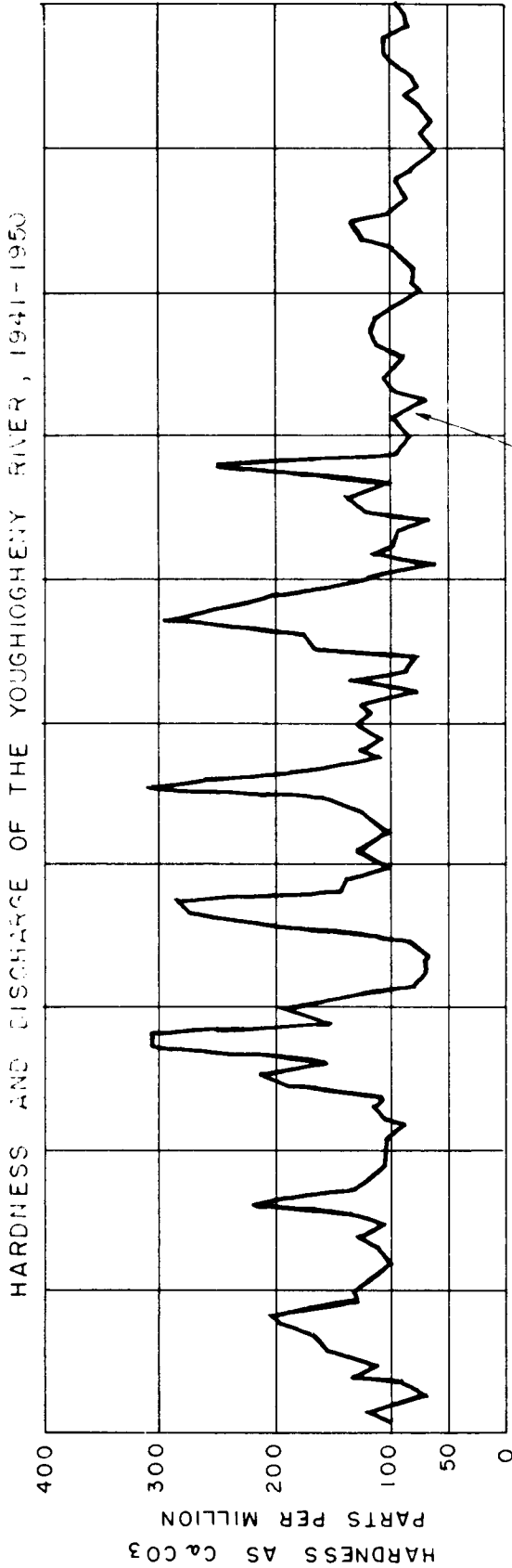
The needs for further study on the question of treated water quality parallel those previously noted for water use. Comprehensive studies are required to develop necessary data and methodology which will permit specific evaluations for potential combination plants. A promising area of study may be in determining fully the economic and other effects of water quality variations in various communities where such conditions now exist.

2. Saline Water Supply

The source of the saline water supply is a major factor in the evaluation and design of a combined system. Each source of supply has different water quality characteristics and exhibits specific variations in quality on a seasonal or other temporal basis. It will be most important to recognize these characteristics of the various sources, and to develop and evaluate the combined system accordingly.

The potential sources of saline water supplies for the combined systems may be grouped as follows:

        a. Ocean
        b. Coastal Waters
        c. Inland Surface Water
        d. Coastal Ground Water
        e. Inland Ground Water

The general water quality characteristics of these supplies have been previously described in the earlier sections of this report. These sections, in addition, describe the variations in quality and indicate some of the contaminants which might be present that would interfere with saline water processes. Only cursory descriptions of the water quality characteristics for the saline supplies listed above will be given here. The influence of the saline water source on the potential development of a combined system is revealed in a later portion of this section.

a. Ocean

Except in areas where land run-off is a major factor, ocean water exhibits uniform quality characteristics. The differences in quality are small from one location to another, and from one time to another. Furthermore, the relative chemical composition of ocean water is essentially constant. The burden of dissolved solids to be removed from the water is great.

b. Coastal Waters

Coastal waters - namely estuaries, bays, and harbors - exhibit water quality characteristics representative of the mixture between ocean water and the fresh water inflow. The overall quality can vary greatly from one location to another. Vertical differences at the same location are sometimes significant. The overall quality, and the relative chemical composition, is influenced greatly by the inflow of fresh water (usually seasonal). In general, estuaries exhibit more variable water quality characteristics than do coastal harbors or bays.

c. Inland Surface Water

Inland surface waters have widely fluctuating quality characteristics, especially those waters which exhibit high salinities during periods of low flow. Not only does the overall quality vary greatly, but the relative chemical composition changes too. Very generally, the greatest amount of surface water is of good quality (low solids) but it usually occurs for only a brief period during times of high river flows or flooding conditions. The amount of poor quality (high solids) water is small but it can often occur over extended periods of low river flow. The principle source of water during dry seasons is from groundwater seepage. These relationships are important where storage is provided or contemplated in the development of saline surface waters.

d. Coastal Ground Water

The quality of brackish coastal ground water reflects, to some degree, the quality characteristics and variations of the saline coastal water encroaching upon the aquifer. Generally, the quality variations will be less severe than those for the coastal surface water. The relative water composition may be dissimilar depending upon the amount of fresh water recharge to the aquifer.

e. Inland Ground Water

The quality characteristics of water from deep aquifers will generally remain essentially constant over extended periods. A slow deterioration in quality might be expected with heavy pumping. Shallow wells, particularly those recharged from alluvial deposits close to surface streams, may yield water showing quality characteristics patterned after the surface water quality. Some moderation in quality

variations would be expected. It may also be noted that nearby wells - usually drawing from different aquifers - may produce water having strikingly different quality characteristics.

3. Waste Water Supply

Certain considerations with respect to the waste water supply are significant to the development of combined plants. These matters will be touched on briefly here to provide the basis for the various combination plant schemes to be presented. Fuller discussions on waste water as a potential source of supply are given later.

a. Waste Quality

Because of the varied uses of water, it is obvious that the quality of potential waste water supplies will be highly variable. Industrial waste waters, of course, would present the greatest extremes in quality variations. Attempting to describe the quality of industrial wastes would constitute an enormous and fruitless task. Consideration of industrial waste with regard to waste recovery must include specific study of the quality characteristics of the particular waste.

Consideration of sewage recovery, on the other hand, does not present such great extremes in waste quality. It should not be presumed, however, that the quality characteristics of sewage are constant. Changes in the quality of the water supply are, of course, reflected in the quality characteristics of the sewage. The change in quality brought about by community use may vary from one city to another, and from time to time and place to place within a particular city.

In considering the use of a waste, such as sewage, in a potential combination plant, care should be taken to establish the waste quality characteristics by actual study. The studies should take into account the potential variations in sewage quality. The need for comprehensive investigations to establish specific parameters on waste quality, and to develop the methodology for waste investigations and evaluations, is discussed later in this section.

b. Selective Waste Use

The economic benefits to be attained by possible combination plants will be materially influenced by waste quality. As noted in the discussion immediately preceding this,

the quality of waste may vary significantly within the waste system of any particular community. Under certain circumstances it may be possible to use only that waste which exhibits favorable quality characteristics.

It is not possible to estimate the overall potential merit of this selective waste use concept since the necessary data are not presently available. At Los Angeles, California, a thorough survey of waste quality was made throughout the sewerage system and only portions of the community's sewage were used in the project that was developed. Exhibit IV-4 shows a simplification of the sewerage system at Los Angeles and indicates relative waste quality in various portions of the system. Selected waste data are given in Exhibit IV-5.

Individual study will be required to establish the potential benefits of selective waste use for any particular situation. A general investigation of this concept may have some merit.

c. Waste Pretreatment

The degree of waste pretreatment required to permit satisfactory use of various wastes in combination plants will be a major factor in the design, economics, and operation of the system. Conventional sewage treatment will not, in most cases, be adequate. Additional treatment measures will be required.

The degree of waste pretreatment necessary will depend on several factors. Quality of the raw wastes will, of course, be a major factor. The quality requirements of the combination plant design will also influence the degree of treatment necessary. In some instances, the need for extensive treatment of wastes to control stream pollution will influence the schemes for both the pretreatment system and the combination plant system. Further, the design of the waste pretreatment system must take into account the potential variations in the amount of waste to be used in the combination plant.

d. Waste Storage

The amount of sewage flow that may be available for waste recovery has been previously discussed. Assuming that the waste is available, there is need to establish the dependable yield of the waste flow. Because waste flows are variable, the question of the need for storage facilities becomes apparent.

EXHIBIT - IV - 4

VARIATION IN MUNICIPAL WASTE QUALITY - LOS ANGELES COUNTY

LEGEND

SUITABLE WATER QUALITY
UNSUITABLE WATER QUALITY
SAMPLING STATION

SCALE: MILES
0 2 4

ADAPTED FROM REFERENCE 45.4
SEE ALSO EXHIBIT IV - 5

SAN PEDRO BAY

PACIFIC OCEAN

SHEPPARD T. POWELL AND ASSOCIATES
D - 1360
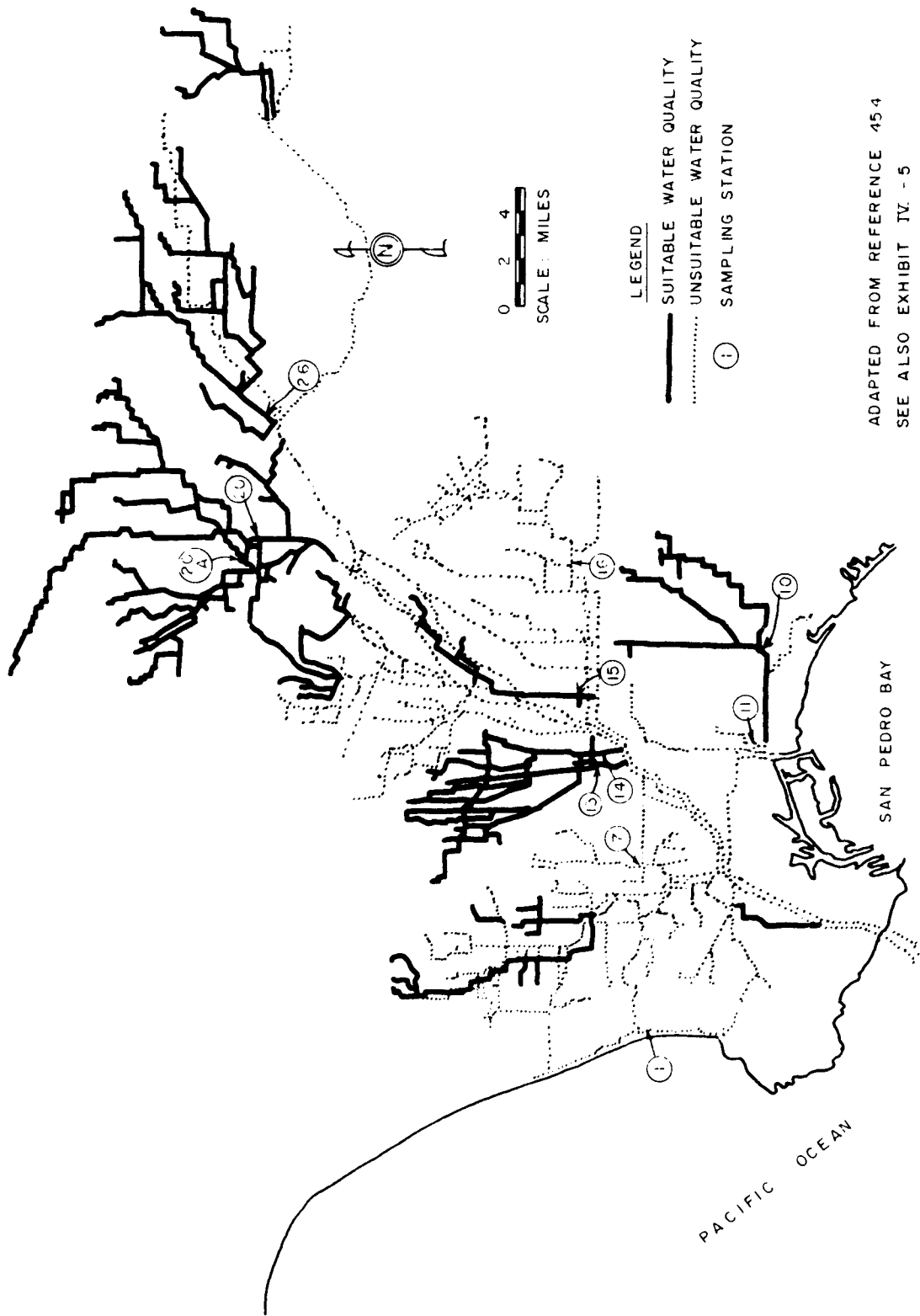
Exhibit IV-5

SELECTED WASTE SURVEY DATA - LOS ANGELES COUNTY*

	24-Hour Average Analyses for Indicated Stations								
Constituents	1	7	10	11	13 & 14	15	16	20 & 20A	26
Dissolved Solids (ppm)	1367	2714	649	3463	807	933	1852	644	688
Suspended Solids (ppm)	200	519	247	223	339	327	333	169	-
Total Solids (ppm)	1679	3233	917	3621	1146	1205	2185	813	-
BOD, 5-Day, 20°C (ppm)	335	376	263	289	279	336	464	408	-
Ammonia (ppm as N)	33.2	51	32.6	19.3	22.9	29.6	45	26.0	19.6
Nitrogen, Total (ppm N)	50.1	-	50.7	49.8	38.9	47.9	-	39.0	37.5
Tot. Hard. (ppm as $CaCO_3$)	186	272	123	345	271	276	250	163	194
Sodium (ppm Na)	487	350	135	1150	157	184	335	137	150
Potassium (ppm K)	37.6	48	28	44	21.5	40	100	21.1	27
Chlorides (ppm Cl)	465	1233	108	1591	127	169	355	99	119
Sulfates (ppm SO_4)	252.8	171	71	232	165	150	142	88.1	72
Phenols (ppm)	0.303	0.05	0.28	0.30	0.30	0.89	2.1	0.066	0.11
Lead, Total (ppm Pb)	0.31	0,02	0.16	0.08	0.55	0.28	0.12	0.67	0.27
Copper, Total (ppm Cu)	0.15	-	0.07	0.05	0.53	0.34	-	0.14	0.21
Zinc, Total (ppm Zn)	0.50	-	0.52	0.23	4.69	0.36	-	0.28	2.95
Iron, Total (ppm Fe)	0.78	-	0.73	0.62	0.59	0.78	-	0.31	0.18
Mangan. Total (ppm Mn)	0.029	-	0.04	0.02	0.14	0.05	-	0.029	0.01
Fluoride (ppm F)	0.49	0.6	0.64	0.88	0.74	1.10	0.5	1.28	0.58
Arsenic (ppm As)	0.129	0.07	0.005	0.01	0.03	0.01	0.21	0.00	0.00
Selenium (ppm Se)	0.00	0.00	0.00	-	0.00	0.00	0.00	-	-
Hexav. Chrom. (ppm Cr)	0.00	0.00	0.37	0.00	0.11	0.66	0.00	0.21	0.65
ABS (ppm)	9.52	-	12.86	13.0	7.44	9.37	-	9.30	8.4
General Quality Rating**	U	U	S	U	S	S	U	S	S

*Adapted from Reference 454. See also Exhibit IV-4.

**Unsuitable for reclamation (U); Suitable for reclamation (S).

Just as the amount of water used in a community varies, the amount of sewage flow will also vary. The sewage flow will, to some degree, reflect the rate of water use. Superimposed over this basic factor, however, will be several other influences such as relative amounts of consumptive use (lawn sprinkling, car washing, etc.), seepage into or out of the sewers, and type of sewerage system (separate or combined), etc.

Some indication of the variability in sewage flows is shown by Exhibit IV-6. Average daily flows for a residential subdivision during 1962 (398) are shown to vary severalfold. The major factor causing the extreme flow variations is the entry of groundwater and other extraneous water into the sewers. Sanitary sewerage systems serving municipal complexes would probably show wider variations. Waste flows in combined sewer systems would show even greater variations.

These factors, together with the intended dependable yield of waste, will determine the need for and size of storage facilities for sewage. The need for waste storage is recognized in a recent study under the Advanced Waste Treatment Research Program. The report on this study states (449):

> "Flow rates from a municipal sewerage system may vary as much as 100 percent, depending upon the time of day, day of week, and season of the year. Economics will dictate maximum design capacity. The waste water must be impounded for about 2 to 4 days to insure a relatively constant feed supply to the advanced waste treatment plant."

The amount of potential waste storage will actually depend on the particular situation. Storage requirements for industrial wastes will require specific individual study.

Further considerations on this matter involve the optimum location of the storage facilities within the overall combination plant system. Storage of raw sewage seems unlikely, but there are relative merits to storage of wastes following conventional sewage treatment or advanced "polishing" treatment.

EXHIBIT - IV - 6

DAILY AVERAGE SEWAGE FLOWS - PINE VALLEY GAGING AREA

BALTIMORE COUNTY , MARYLAND

NOTE GAGING AREA IS 66 ACRE RESIDENTIAL
SUBDIVISION ; 200 HOMES , 750 PERSONS

GALLONS PER MINUTE
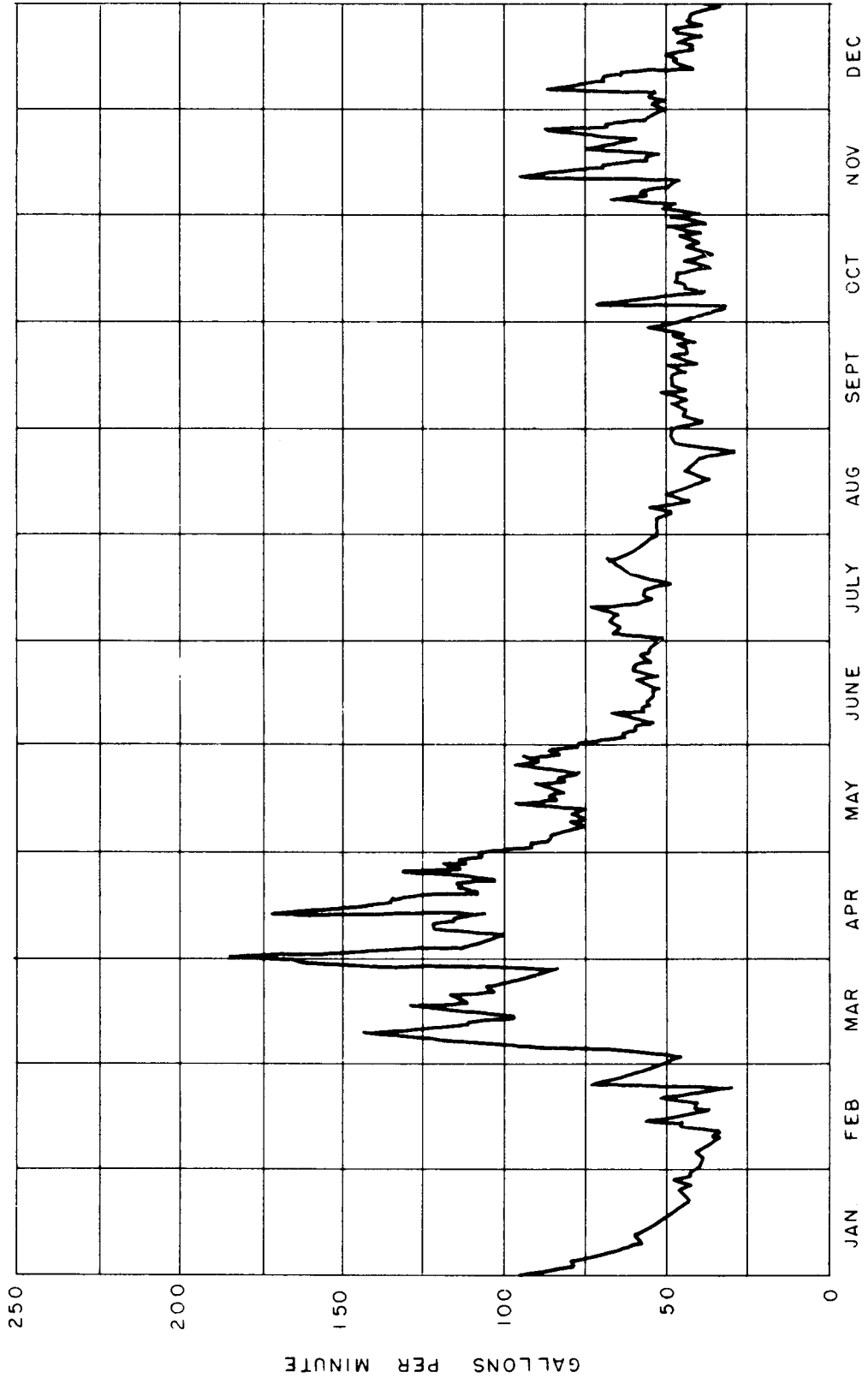
1962

ADAPTED FROM REFERENCE 398

4. Pretreatment Requirements

Pretreatment, as used here, is concerned with the treatment of waste water, saline water, or both to prepare the supply for eventual use. It includes treatment of the saline water supply to overcome deleterious effects on the conversion process or the converted effluent, but does not include treatment in the conversion process itself. Conventional waste treatment methods are more or less essential under any conditions and are not considered to be pretreatment for the purposes of this discussion. However, in some instances the pretreatment scheme for a combination plant may be interrelated with final phases of conventional waste treatment facilities (such as, chemical coagulation, adsorption, oxidation, etc.) in the final settling of a secondary waste treatment plant.

Pretreatment requirements for saline water have been discussed in the earlier sections dealing specifically with these sources of supply. The pretreatment of waste water is covered in detail in the next section. Significant considerations from these discussions are reviewed here to indicate the importance of pretreatment requirements to the design and economics of potential combination plants.

Many saline water sources will have quality characteristics or contaminats that would interfere with the conversion process, result in high operating costs, or affect the quality of the converted effluent. The basic factor establishing pretreatment requirements will be the type and design of conversion process. In some cases, such as with estuaries or harbors, the quality characteristics or contaminant levels may vary considerably. Where the waste water is combined with the saline water ahead of the conversion facilities, the pretreatment requirements may be unique. Further, if this blending is performed at varying proportions, the pretreatment requirements may vary too.

Pretreatment of wastes may be a significant economic factor in many potential combination plants. The pretreatment requirements will depend on initial waste quality (probably after conventional sewage treatment) and the criteria established for the treated waste. Treated waste criteria would be very stringent in situations where the recovered waste is returned directly to a potable water supply system. Pretreatment requirements may be less demanding where the waste is combined with the saline supply ahead of the conversion process.

As the above discussions point out, pretreatment requirements for combination plants are involved in complex relationships between raw supplies, conversion processes, water supply criteria, mixture of saline and waste supplies, and other factors. Little is known of these individual factors and even less is available to evaluate them on an interrelated basis. Pretreatment requirements have been found of major importance in saline water conversion and it is clear that they will have even greater significance with regard to potential combination plants. Studies on these matters are necessary.

5. Saline Conversion Processes

The design and economics of combination plants will influence and be influenced by the saline water conversion process used. Each process has capabilities and restrictions with regard to potential applications in combined plants. It would be an arduous task beyond the scope of this study to fully explore these capabilities and restrictions. Because of their importance, however, some of the major factors are briefly discussed here to indicate some of the considerations involved in combination plants. There is need for further study.

The ability of the conversion processes to operate effectively and economically under varying conditions of saline water quality, production rate, or both may be an important factor in the combination plant scheme. The general water quality characteristics of various sources, and the expected seasonal and other variations, have been noted. Contamination of saline water supplies, particularly major variations in contamination level from time to time, may seriously affect the operation of some conversion processes.

6. Waste Disposal

Unquestionably, the problems of disposing of wastes produced by the combined plants will be extremely important in the evaluation of such systems. Disposal of waste brines from the saline conversion process has been recognized as a major problem in some locations (153, 485). Concentrated wastes from pretreatment facilities for contaminated saline water or waste water will pose similar problems with regard to disposal. Extensive studies on concentrated wastes of this type are presently underway as part of the Advanced Waste Treatment Research Program of the U. S. Public Health Service (481, 445, 431, 432).

The present state of knowledge relating to the disposal of wastes from potential combination plants is lacking. Investigations of considerable scope are needed to provide information and data on these problems. Evaluation of specific projects will require detailed attention to the waste disposal considerations.

C. Recovery of Waste Waters

The preceding discussions have generally indicated the manner in which sewage may be recovered in the combined system. An outstanding aspect of such a system is the quality of sewage, either before or after conventional sewage treatment, and the public health considerations involved in sewage recovery. These matters are discussed here. The necessary pretreatment, or conditioning, of the sewage for satisfactory use in the potential combination plants is developed in the next portion of this report (Section V).

1. Quality of Raw Sewage

Establishing the quality characteristics of raw sewage, i.e., before any treatment, is an initial point in evaluating the potential recovery of wastes in combination plants. In the following discussions it is shown that the general quality characteristics and the concentration levels of certain pollutants for untreated sewage can vary widely. The influences of water supply quality, incremental degradation resulting from use, and several miscellaneous factors are noted. The impact of these factors on sewage quality points out the need for specific field studies of representative wastes during planning for a combined plant.

a. Water Supply Quality

Obviously, the quality of the community water supply will have a major influence on the quality of the sewage. Evaluating sewage quality, therefore, should begin with a thorough appraisal of the general quality characteristics of the water supply, as well as the variability of the quality.

In this regard it is most important to evaluate the effects of changing the water supply quality on the resultant raw sewage quality. Related factors associated with upgrading water supply quality, such as high water rates, may also have an influence on sewage quality characteristics. Changes in the water-use practices in a community could affect sewage characteristics, and these might be brought about by improvements in the quality of the water supply.

Evaluations with regard to water supply quality will not provide specific design data on the quality characteristics of the raw sewage to be produced. Such studies, however, will provide useful information and this should be the starting point. A program for developing a combination plant integrating saline water conversion and waste water recovery should not overlook this aspect.

b.   Incremental Quality Degradation

Perhaps the most important consideration with regard to sewage quality is the incremental degradation resulting from the use of the water. This factor has been studied by previous investigators and the findings have been generally used by many workers in the sewage recovery field.

This discussion will present some of the findings of earlier work and evaluate the adequacy of such data to provide necessary design criteria for potential combination plants. Various factors influencing incremental quality changes resulting from community use of water are discussed. The needs for further investigations on this matter are outlined.

Relatively little work of a comprehensive nature has been done to show the incremental water quality changes between water supply and raw sewage for representative communities. One study (368) provided such data for 15 California communities and the findings are showns by Exhibit IV-7. A general summary of incremental values, as determined by the investigators, is given by Exhibit IV-8. In presenting these findings the investigators state (368):

> "In any given situation, it would be, of
> course, highly desirable to determine mineral
> increments (and decrements) by actual test...
> Obviously, it would be unwise to use average
> values blindly; however, the data do indicate
> orders of magnitude that can be expected and
> that would be useful in making rough calcula-
> tions and in checking laboratory results."

In another study (475) the incremental quality changes for water use were as shown in Exhibit IV-9. It should be noted that some of these data are for treated sewage effluents. A summary of the reasonable range for incremental values is shown by Exhibit IV-10. The investigators note that (475): "The available data have been critically reviewed and the reasonable values utilized."

EXHIBIT - IV - 7

MINERAL INCREMENTS IN MUNICIPAL WASTE WATER
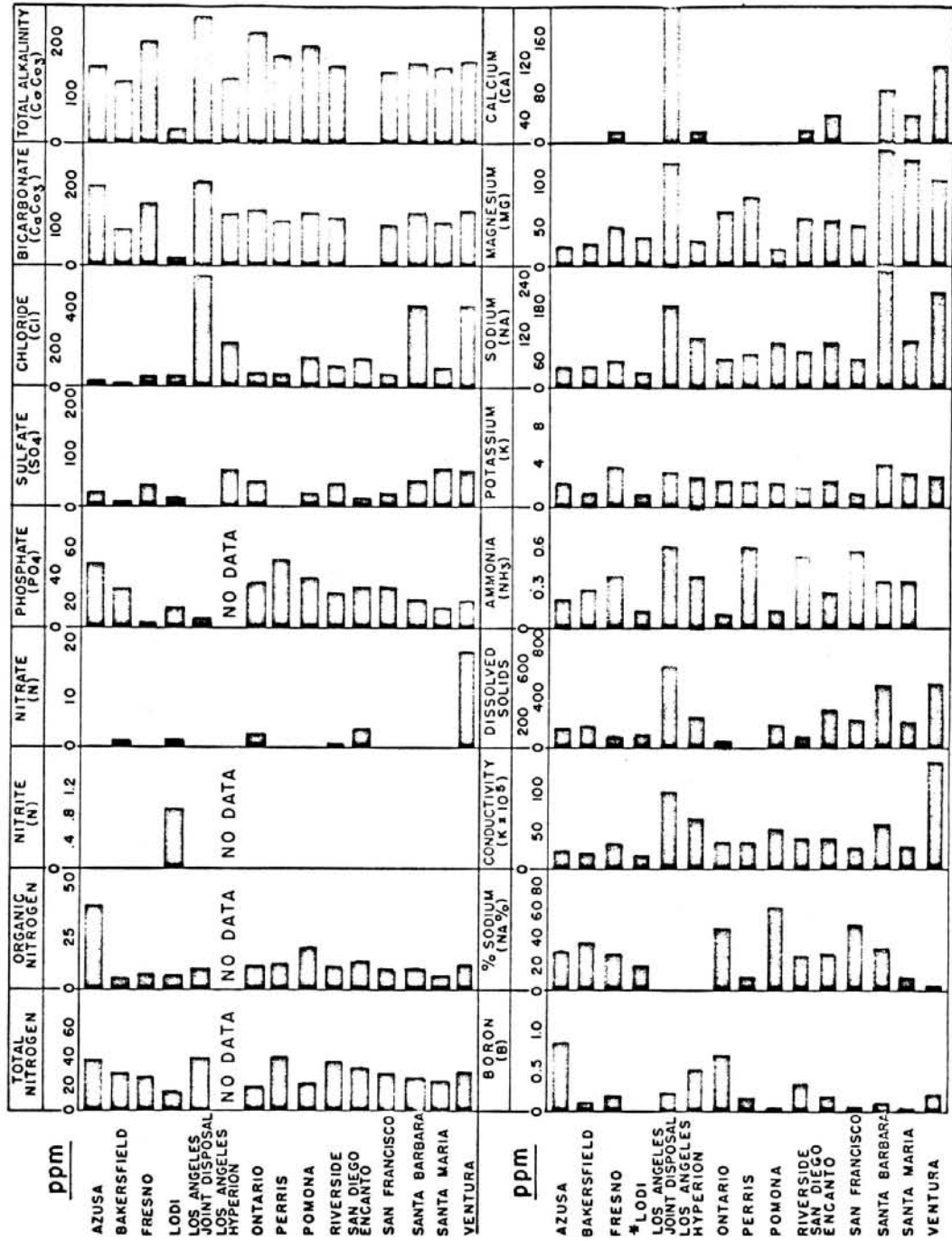
ADAPTED FROM REFERENCE 368

Exhibit IV-8

SUMMARY OF MINERAL INCREMENTS

IN MUNICIPAL WASTE WATER*

| Constituents | Increase in Constituents by One Community Use | | |
	Minimum	Maximum	Normal Range
Dissolved Solids, ppm	Trace	1200	100-300
Conductivity, $K \times 10^5$	30	240	30- 60
Boron (B), ppm	0.1	3.8	0.1-0.4
Percent Sodium, percent	1	42	5- 15
Sodium (Na), ppm	30	290	40- 70
Potassium (K), ppm	--	22	7- 15
Magnesium ($CaCO_3$), ppm	--	110	15- 40
Calcium ($CaCO_3$), ppm	--	250	15- 40
Total Nitrogen (N), ppm	12	42	20- 40
Phosphate (PO_4), ppm	2	50	20- 40
Sulfate (SO_4), ppm	--	75	15- 30
Chloride (Cl), ppm	20	550	20- 50
Total Alkalinity (as $CaCO_3$), ppm	--	230	100-150

*From Reference 368. Data are for untreated sewage from
  15 California communities (see Exhibit IV-7).

EXHIBIT - IV - 9

MINERAL INCREMENTS IN MUNICIPAL SEWAGE

ADAPTED FROM REFERENCE 4-75

CALCIUM

MAGNESIUM

SODIUM

BICARBONATE

SULFATE

CHLORIDE

TOTAL DISSOLVED SOLIDS

PARTS PER MILLION

SHERRARD, T. POWELL AND ASSOCIATES
DB 1139

Exhibit IV-10

SUMMARY OF MINERAL INCREMENTS

IN MUNICIPAL SEWAGE*

Constituents	Increase (Reasonable Range) in Constituents by One Community Use, ppm
Calcium (Ca)	7 to 109
Magnesium (Mg)	1 to 90
Sodium (Na)	14 to 742
Bicarbonates (HCO_3)	12 to 392
Sulfates (SO_4)	10 to 191
Chlorides (Cl)	22 to 1,262
Total Dissolved Solids	120 to 450
Silica (SiO_2)	4 to 18

*From Reference 475. See also Exhibit IV-9. Data are for treated and untreated sewage.

Various other reports are available to provide similar, but generally more limited, data on incremental water quality changes brought about by community use. The data presented in Exhibits IV-7 and IV-9 are sufficient, however, to indicate the wide range in values that might be expected. In evaluations of potential combination plants, where waste quality may have major importance, the general use of "average" values, such as given by Exhibits IV-8 and IV-10, will probably not be satisfactory. The investigators reporting the data presented here (Exhibits IV-7 thru IV-10), and others, have cautioned against the blind use of the findings.

There is a need for investigative efforts to better establish the incremental water quality degradation which results from community use of water. Coordinated studies need to be made of water supply quality versus raw sewage quality. Increased attention should be given to defining the various factors which affect this relationship, such as climate, type of community, wealth of community, type of homes, cost and control of water supply, sewer regulations, etc. Any such studies should be coordinated with investigations on water use and sewage flows, and variations in the two.

It is not to be expected that the general findings of such investigations will alleviate the need for individual and specific studies of each situation where a combination plant is being considered. The general investigations will, however, provide useful data to guide the detailed studies. Also, the results will provide better means of evaluating the detailed findings and extrapolating the results to conditions as they may exist with a combination plant in operation.

c. Miscellaneous Factors Affecting Sewage Quality

Preceding discussions have indicated that the quality of untreated sewage is highly variable. Primary factors in this regard are water supply quality and incremental changes brought about by community use of the supply. There are, in addition, certain other miscellaneous factors which should not be overlooked in an evaluation of raw sewage quality.

The general layout and design of the sewerage system will influence sewage quality characteristics in some instances. Where sewer lines are not tightly laid or are broken, there may be significant amounts of ground water infiltration into the system. Severe contamination of the sewage will result if the infiltration water is of objectionable

quality. In one instance (403) sewers located in tidal marsh-
lands near Baltimore, Maryland were subject to infiltration.
Brackish water entered the sewers, contaminating the sewage
and decreasing the value of the sewage in a reclamation pro-
ject for the Bethlehem Steel Company at Sparrows Point. A
survey disclosed the portions of the sewerage system where
infiltration was prevalent and the necessary repairs were
made. Thereafter, the sewage was of acceptable quality.

The general type of sewer system - separate,
combined, or both - will have very pronounced effects on
sewage quality at times. Separate systems have sanitary
wastes and storm drainage in individual sewerage facilities.
The two types of waste water are conveyed together in a com-
bined system. In some cases, separate and combined systems
are intermixed within a community. It is not unexpected to
find illicit storm drainage in a sanitary system, and vice verse.

It is obvious that the quality characteristics
of waste waters from the various systems will differ greatly.
While extreme variations may occur only periodically, and be
of relatively short duration, in some potential combined plants
this factor may be of considerable importance. The type of
sewerage system should not be overlooked in evaluating a
specific situation. A recent comprehensive study (482) pro-
vides much information to guide specific investigations in
the field.

In some areas of the country, especially
where the topography is relatively flat and the climate is
warm, the sewage may become septic, or nearly so, before it
reaches treatment facilities. This condition is brought
about by the warm temperature of the sewage and the long
detention time in the sewerage system where grades are low
and the flow is sluggish. Septic sewage has several undesir-
able quality characteristics, notably the frequent presence of
hydrogen sulfide, which could have significant effects on a
potential combination plant system. Several studies (456)
provide guides to evaluating such a condition in a particular
situation.

2. Quality of Treated Sewage

The quality of treated sewage is an important
consideration in this discussion of potential combination
plants for two reasons. First, in most instances, treated
sewage effluent will be under consideration as the waste

supply to the combination plant. Secondly, conventional sewage treatment methods may possibly serve as "initial pretreatment" for waste waters to be used in some combination plants. This discussion, therefore, will note the conventional methods of sewage treatment, indicate the quality changes brought about by each, and summarize data on the quality characteristics of treated sewage in general.

a. Description of Sewage Treatment Methods

There are two major types of conventional sewage treatment systems currently in use, and these are broadly termed primary treatment and secondary treatment. In addition, there are several miscellaneous treatment schemes which are commonly referred to as intermediate treatment. While this breakdown is on the basis of the overall degree of treatment provided, it is more in order here to present the methods of treatment in terms of the facilities and equipment involved.

A primary sewage treatment system will generally include preliminary facilities for the removal of gross solids and heavy grit. Bar racks, coarse or fine screens, or various combinations of these extract gross solids which are then removed manually or automatically. Heavy solids are removed in grit chambers.

The main part of a primary sewage treatment plant is the settling basin. Here the sewage is detained for a period of several hours under low flow velocity conditions. Some of the suspended materials settle as sludge which is removed for subsequent treatment. It is common practice to chlorinate the effluent from the primary settling tank prior to final disposal.

Secondary sewage treatment methods commonly employed are either activated sludge or trickling filters. The usual practice is to provide primary treatment - preliminary removal of gross solids and grit followed by plain sedimentation - ahead of the secondary system. Chlorination of the settled effluent would generally not be employed if secondary facilities are to be provided. Chlorination of the final effluent is usually practiced.

Activated sludge treatment is described thus (349):

> "A biological sewage treatment process in
> which a mixture of sewage and activated sludge
> is agitated and aerated. The activated sludge is
> subsequently separated from the treated sewage
> (mixed liquor) by sedimentation, and wasted or
> returned to the process as needed. The treated
> sewage overflows the weir of the settling tank
> in which separation from the sludge takes place."

There are several variations on the activated sludge process, such as "modified aeration" or high-rate activated sludge, but exploration of these details is beyond the intent of this discussion.

Another secondary sewage treatment method commonly employed is the trickling filter. Beds of coarse filter media are provided and the primary treated effluent is distributed uniformly over the filter. The effluent from the filter is further processed in a settling basin.

Miscellaneous methods of sewage treatment are sometimes used and it is not uncommon to have such facilities operated in conjunction with conventional primary or secondary facilities. Very fine screens are sometimes used for treatment of sewage. In some instances, particularly where commercial and industrial wastes are a significant portion of the municipal sewage, floatation has been used to accomplish solids removal instead of the more commonly used sedimentation process.

Flocculation of sewage solids, both with and without chemical coagulation, is sometimes employed. Flocculation is the coalescence of finely divided suspended matter by gentle stirring. In some instances, chemicals may be added ahead of the flocculator to promote the formation of flocculant particles. Typical chemcial coagulants are ferric chloride, aluminum chloride, ferric sulfate, chlorinated copperas, alum, and copperas. Settling facilities are provided to remove the solids and produce a clarified effluent.

Intermittent sand filters, contact aeration processes, and Imhoff tanks are other examples of miscellaneous sewage treatment methods. A special note should be made on the use of stabilization or oxidation ponds. In some areas of the country this method of treatment has been employed to a relatively large extent.

b. Effects of Treatment on Sewage Quality

The several conventional means for sewage treatment will have certain effects on quality characteristics of municipal sewage. General changes in quality and/or contaminant level are indicated here, as well as reductions that may be expected for specific pollutants of major importance to potential combination plants as a whole. For these presentations, sewage treatment methods are grouped as primary, intermediate, and secondary.

1) Primary Treatment

Very generally, primary treatment of municipal sewage can usually be expected to remove 50 to 60 percent of the suspended solids and 25 to 35 percent of the BOD (biochemical oxygen demand, 5-day, 20°C) (350). It should be noted that conventional primary facilities are simply sedimentation basins and only the settleable suspended matter can be removed. Reductions in BOD result from the settling of suspended matter, and soluble BOD is essentially unaffected.

The performance of primary sewage treatment facilities can vary greatly. Exhibits IV-11 and IV-12 present performance data for suspended solids and BOD, respectively, as tabulated in a comprehensive sewage design manual (350). It should be noted that these data are for varied treatment plants throughout the country and there is no uniformity of design. The two exhibits show that percentage reductions of suspended solids and BOD are highly variable and there is no strong relationship with the strength of the raw sewage. Indiscriminate application of generally accepted treatment efficiencies may not provide reliable estimates on the expected quality of primary treated sewage.

Primary treatment will have little or no effect on dissolved organic or mineral constituents. One widely used text (389) indicates that less than 30 percent of the total organic matter in raw sewage is settleable. Thus, some 70 percent of the organic matter in raw sewage will be found in the primary effluent. Most of the organics (about 75 percent) in the effluent will be dissolved. Synthetic detergents will be relatively unchanged by conventional primary sewage treatment.

EXHIBIT -IV-M

SUSPENDED SOLIDS REDUCTIONS IN
PRIMARY SEWAGE TREATMENTS PLANTS

EXHIBIT - IV - 12

BOD REDUCTIONS IN

PRIMARY SEWAGE TREATMENT PLANTS
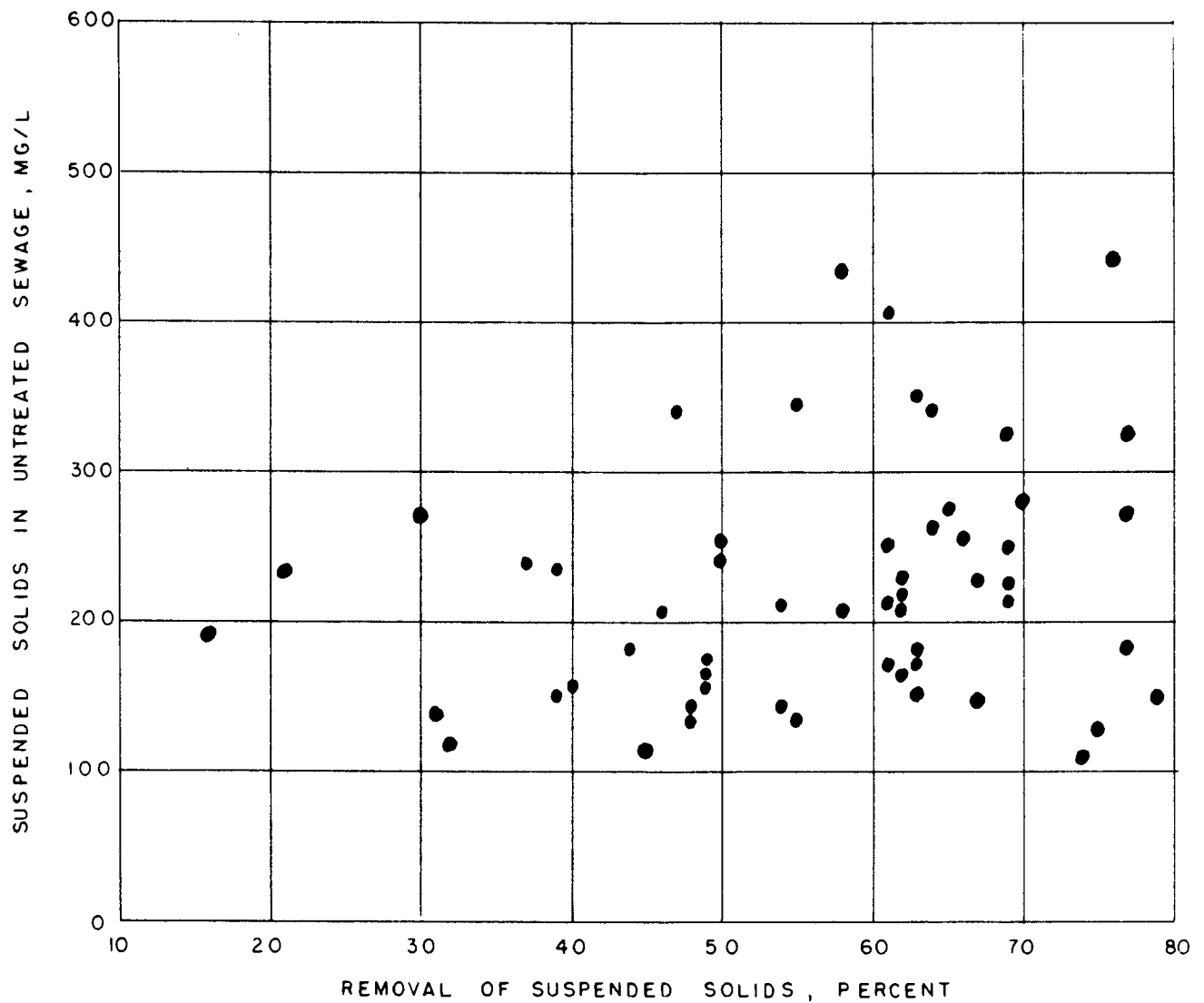
ADAPTED FROM TABLES 9,10 & 11
OF REFERENCE 350

SHEPPARD T POWELL AND ASSOCIATES

D - 1355

2) <u>Secondary Treatment</u>

As a general rule, secondary treatment using conventional biological processes (activated sludge or trickling filters) can usually be expected to remove up to 90 percent of the suspended solids and 75 to 90 percent of the BOD (350). There are numerous variations and innovations in secondary sewage treatment plants and these values should be used with caution.

With respect to the possible use of treated wastes in combination plants, there are more meaningful data available on quality characteristics of secondary effluents. Data recently reported under the Advanced Waste Treatment Research Program (449) of the U. S. Public Health Service are presented in Exhibits IV-13, IV-14, and IV-15. Tap water analyses for numerous cities are given in Exhibit The respective analyses of secondary treated sewage effluent' are given in Exhibit IV-14. Variations between tap water and secondary effluent concentrations, mostly increases but some decreases, are presented in Exhibit IV-15.

The concentration and nature of organic contaminants found in secondary effluents is of major interest. Bunch and others (29) report analytical results for eight samples of secondary effluent taken from five cities. These findings are summarized in Exhibits IV-16, IV-17, and IV-18. The investigators make the following observations and conclusions regarding this study and the results obtained (29).

"A sufficient number of samples has not been examined to make firm conclusions concerning the nature of the constituents. However, from the data on hand, these studies on secondary effluents indicate the following trends:

1. The suspended solids accounted for 20 to 30 percent of the total COD of the effluent.
2. More than one-half of the ether extractable matter falls in the strong acid classification.
3. The majority of the constituents giving COD are dialyzable, but about 40 percent of the material is indicated to be of high molecular weight because it resists dialysis.
4. The ratio of volatiles to COD, corrected for chlorides, is approximately 1.5.
5. The ratio of constituents identified to volatiles is approximately 0.20.
6. The ratio of COD, corrected for chlorides, to constituents identified is approximately 3.0."

Exhibit IV-13

WATER SUPPLY QUALITY FOR SELECTED U.S. CITIES*

Reference	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AVG	MAX	MIN
Organics, ppm:																									
BOD	0	-	-	-	-	-	-	-	-	-	-	-	-	6	0.5	-	-	-	-	-	1	-	2	6	0
COD	0	-	-	-	-	-	-	-	-	-	-	-	-	27	8	42	4	1.4	0	27	-	2	12	42	0
AOS	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.02	4.2	0.04	0.02	0.02	0.02	0	0.01	0.37	4.2	0
Cations, ppm:																									
Na^+	27	21	33	97	259	-	-	-	103	33	17	25	-	-	-	-	8	18	17	14	-	10	49	259	8
K^+	-	-	-	-	-	-	-	-	5	4	2	2	-	-	-	-	2	2	2	1.6	-	2	3	5	1.6
NH_4^+	0	-	-	0	-	0	-	0	-	2	0	0	-	-	-	-	0	0	0	0	-	0	0.1	2	0
Ca^{++}	33	23	55	23	17	37	45	-	87	22	53	53	17	-	-	13	20	22	12	103	-	55	42	103	12
Mg^{++}	37	1	17	7	3	Tr	25	-	23	15	7	8	4	-	-	35	5	11	11	30	-	21	16	37	0
Fe^{+++}	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anions, ppm:																									
Cl^-	13	35	59	53	250	49	150	23	97	32	13	16	15	22	22	518	12	17	9	22	6	16	65	518	6
NO_3^-	9	-	-	-	-	9	22	0	5	2	4	9	-	0.5	0.1	3.0	0.1	6.2	5.3	0.37	-	2.7	5	9	0
NO_2^-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	0.18	0.03	0.01	0.13	0.31	-	0.03	0.14	0.30	0.01
HCO_3^-	312	35	263	201	317	149	342	263	143	137	176	131	65	-	210	210	27	46	49	379	-	353	198	379	27
$CO_3^=$	0	10	0	0	0	0	0	19	0	17	0	0	0	-	-	5	1	0	0	0	-	0	0.1	10	0
$SO_4^=$	34	19	21	8	0	53	75	-	231	-	43	47	12	-	-	84	55	79	55	55	-	53	55	231	0
$SiO_3^=$	71	13	30	35	35	-	-	-	11	-	-	-	8	0.5	-	-	-	-	-	-	-	-	29	71	11
$PO_4^=$ (Total)	0	2	0	0	3	0	0	0	-	2.5	0	0	0	-	-	3.8	0.04	0.05	0.03	0.02	-	-	0.8	3.8	0
$PO_4^=$ (Ortho)	0	0.5	0	0	1.5	0	0	0	-	-	0	0	0	-	-	3.3	0	0.01	0.01	0	-	-	0.3	3.3	0
Other:																									
Hardness (as $CaCO_3$), ppm	239	74	210	101	55	120	215	220	337	121	174	164	59	-	185	178	71	100	75	150	-	326	153	337	55
Alkalinity (as $CaCO_3$), ppm	255	45	210	230	234	122	230	220	122	112	131	133	54	-	-	160	24	38	40	311	-	234	164	311	24
Total dissolved solids, ppm	354	161	650	734	917	327	500	255	700	-	271	317	100	214	-	1,130	98	177	150	520	155	344	332	917	98
pH	7.8	8.8	7.7	7.8	7.3	7.2	7.8	-	8.0	-	7.7	7.6	8.3	-	-	9.0	8.8	8.2	8.3	7.8	-	7.4	8.0	9.0	7.2

*From Reference 449

Exhibit IV-14

SECONDARY SEWAGE EFFLUENT QUALITY FOR SELECTED U.S. CITIES*

Reference	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AVG	MAX	MIN
Organics, ppm																									
BOD	10	-	18	45	10	-	-	-	-	10	-	-	8	33	9	33	-	-	-	-	18	-	19	45	9
COD	-	-	-	-	-	-	-	-	-	-	-	-	-	135	44	158	163	99	79	49	-	78	101	163	44
ABS	-	-	-	-	-	-	-	..	..	-	6	9	-	2.9	2.4	10.0	10.1	7.2	6.3	4.6	7	9	6.8	10.1	2.4
Cations, ppm																									
Na^+	85	29	-	160	334	-	232	-	200	67	118	99	-	-	-	-	50	68	63	112	-	55	124	232	29
K^+	-	-	-	-	-	5	-	8	20	11	-	-	-	-	-	14	14	9	11	10	-	12	12	20	9
NH_4^+	22	-	-	15	3	-	-	-	44	8	63	60	-	-	-	36	9	21	29	25	-	0	17	44	0
Ca^{++}	96	78	62	45	42	40	58	-	97	33	13	16	-	-	-	-	64	53	54	109	-	97	66	109	33
Mg^{++}	12	16	23	16	17	Tr	26	-	30	17	-	-	-	-	-	-	14	20	22	33	-	22	19	30	Tr
Anions, ppm																									
Cl^-	85	55	121	90	450	165	260	173	197	69	143	79	137	77	64	532	52	67	49	124	90	62	143	532	52
NO_3^-	26	-	-	-	-	-	-	4	2	11	-	-	-	0.04	3.9	6.2	26	22	0.62	26	-	20	12	26	0.04
NO_2^-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	0.62	2	0.3	0.26	1.1	-	1.8	1.5	2	0.26
HCO_3^-	333	203	-	420	335	110	298	293	388	260	219	403	146	-	-	327	212	243	314	428	-	409	286	428	110
$CO_3^=$	0	0	0	0	0	0	0	0	0	-	-	-	0	-	-	0	0	0	0	0	-	-	0	0	0
$SO_4^=$	42	57	45	43	20	115	93	70	303	33	75	69	31	-	-	105	95	91	108	111	-	99	84	309	20
$SiO_3^=$	80	30	43	57	49	-	53	25	25	-	-	-	22	-	-	-	-	-	-	-	-	-	43	80	22
$PO_4 \equiv$ (Total)	41	9	37	33	25	59	29	25	-	10	35	43	22	8	5	29	35	19	20	18	-	29	25	59	5
$PO_4 \equiv$ (Ortho)	40	8	34	33	23	32	27	12	-	-	-	-	21	-	-	21.8	33.8	17.9	19	15.9	-	28	25	40	8
Other:																									
Hardness (as $CaCO_3$), ppm	280	259	250	175	175	153	250	230	365	153	224	213	160	-	-	-	218	215	227	411	-	332	235	411	100
Alkalinity (as $CaCO_3$), ppm	263	172	-	344	316	90	244	240	326	164	180	331	120	-	-	268	174	198	257	351	-	335	242	351	90
Total solids, ppm	727	477	844	872	1,362	730	1,041	510	1,065	-	683	566	410	519	410	1,302	472	525	597	648	400	492	703	1,362	410
Suspended solids, ppm	-	-	-	-	-	-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-
pH	6.5	7.1	7.5	7.8	7.3	7.0	8.0	-	7.0	-	-	-	6.9	-	-	7.6	7.5	7.3	7.8	7.8	-	7.4	7.4	8.0	6.5

*From Reference 449

Exhibit IV-15

INCREMENTAL QUALITY VARIATIONS IN SECONDARY SEWAGE EFFLUENTS*

Reference	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AVG	MAX	MIN
Organics, ppm																									
BOD	10	-	-	-	-	-	-	-	-	-	-	-	-	27	8.5	-	-	-	-	-	17	-	16	27	8.5
COD	-	-	-	-	-	-	-	-	-	-	-	-	-	108	36	116	159	98	79	22	-	76	87	159	22
ABS	-	-	-	-	-	-	-	-	-	-	-	9	-	3	2.4	5.8	10	7.2	6.3	4.6	7	9	6.4	10	2.4
Cations, ppm																									
Na$^+$	58	8	-	83	115	-	-	-	100	34	101	74	-	-	-	-	42	50	46	98	-	45	66	101	8
K$^+$	-	-	-	-	-	-	-	-	15	7	-	-	-	-	-	-	12	7	9	8	-	10	10	15	7
NH$_4^+$	22	-	-	15	3	5	-	8	-	6	-	-	-	-	-	36	9	21	29	25	-	0	15	36	0
Ca^{++}	-	50	6	16	25	3	13	-	10	11	10	7	-	-	-	-	44	31	42	1	-	1	18	50	1
Mg^{++}	-	15	6	9	14	Tr	1	-	1	1	6	8	-	-	-	-	9	9	11	3	-	1	6	15	Tr
Anions, ppm																									
Cl$^-$	72	20	62	37	200	116	110	153	100	37	130	6	122	55	42	14	40	50	40	102	84	46	74	200	6
NO$_3^-$	17	-	-	-	-	-	-	4	-3	9	-	-	-	0.5	3.8	3.2	25.9	15.8	-4.7	25.6	-	17.3	10	25.9	-4.7
NO$_2^-$	-	-	-	-	-	-	-	-	-	1.7	-	-	-	-	-	0.4	2	0.3	0.1	0.8	-	1.8	1	2	0.1
HCO$_3^-$	-9	174	-	139	38	-39	-44	25	249	63	43	222	80	-	-	117	185	197	265	49	-	51	100	265	-44
CO$_3^=$	0	-10	0	0	0	0	0	-	0	-	0	-	0	-	-	-5	-1	0	0	0	-	-	-1	0	-10
SO$_4^=$	8	38	24	35	20	57	21	51	9	13	31	22	19	-	-	21	39	12	52	15	-	46	28	57	12
SiO$_3^=$	9	20	13	22	14	-	-	-	11	-	-	-	14	-	-	-	-	-	-	-	-	-	15	22	9
PO$_4^=$ (Total)	41	7	37	33	22	50	29	12	-	7	35	43	21	8	2	25	35	19	20	18	-	-	24	50	7
PO$_4^=$ (Ortho)	40	7.5	34	30	21.5	32	27	-	-	-	-	-	-	-	-	18.5	33.8	17.9	19.0	16.9	-	-	25	40	7.5
Other:																									
Hardness (as CaCO$_3$), ppm	41	185	40	74	120	33	35	10	29	32	50	49	41	-	-	-	147	115	152	261	-	6	79	261	6
Alkalinity (as CaCO$_3$), ppm	-7	127	-	114	32	-32	-36	20	204	52	36	183	66	-	-	88	150	160	217	40	-	41	81	217	-36
Total solids, ppm	363	316	194	368	445	403	541	275	365	-	412	249	310	305	225	172	374	348	457	128	325	148	320	541	128
pH	-1.3	-1.7	-0.2	0	0	-0.2	-0.2	-	-1.0	-	-	-	-1.4	-	-	-1.4	-1.3	-0.9	-0.5	0	-	0	-0.6	0	-1.7

*From Reference 449

Exhibit IV-16

QUALITY CHARACTERISTICS OF SECONDARY SEWAGE EFFLUENTS*

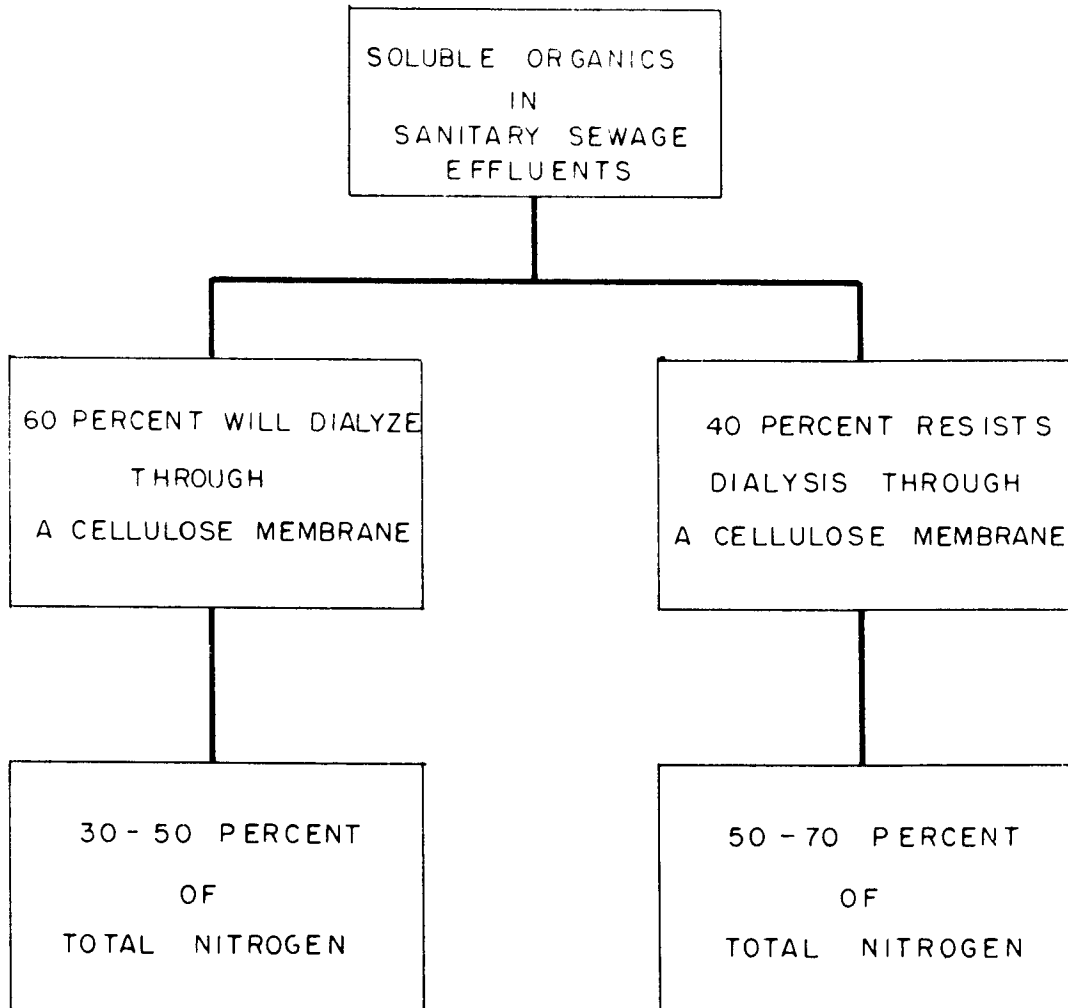| Characteristics, mg/l (except ratios)	Source of Sample**						
	Dayton	Richmond	Chicago	Hamilton	Loveland No. 1	Loveland No. 2	Loveland No. 3
COD - unfiltered	76.7	55.6	--	70.0	145.6	145.0	96.4
COD - filtered (Whatman No. 5)	51.3	44.6	41.6	58.1	65.6	99.5	76.0
COD - filtered, corrected for Cl⁻	40.4	23.7	25.3	48.9	53.3	85.7	65.1
Chloride (Cl⁻)	47.6	91.0	71.1	40.0	53.4	60.1	47.5
Total Kjeldahl nitrogen	0.79	0.34	0.52	1.71	1.51	1.82	1.70
Residue at 105°C, filtered	435.	485.	336.	395.	494.	583.	507.
Residue at 600°C, filtered	365.	354.	283.	336.	394.	463.	413.
Volatiles	70.	131.	53.	59.	100.	120.	94.
Suspended matter (Gooch)	--	17.	4.	16.	76.	31.	--
Protein - Non-dialyzable	3.9	1.6	1.7	4.8	6.9	7.4	5.8
Carbohydrates	2.4	2.0	1.3	1.1	2.2	1.5	0.8
ABS	4.2	1.5	2.6	4.6	7.5	12.5	8.3
Ether extractable material	3.3	0.8	1.2	3.2	5.2	4.9	3.0
Tannin and lignin	0.94	0.51	0.52	0.93	0.82	1.70	1.40
Sum of organics	14.74	6.41	7.32	14.63	22.62	28.00	19.30
Ratio organics to volatiles	0.21	0.05	0.14	0.25	0.23	0.23	0.21
Ratio volatiles to COD (corrected for Cl⁻)	1.7	5.5	2.1	1.2	1.9	1.4	1.4
Ratio COD (corrected for Cl⁻) to organics	2.7	4.3	3.5	3.3	2.4	3.1	3.4

*Adapted from Reference 29.

**Dayton, Ohio; Monday, 5/25/59 (Trickling filter).
Richmond, Indiana; Wednesday, 6/17/59 (Activated sludge).
Chicago, Illinois; Tuesday, 7/7/59 (Activated sludge).
Hamilton, Ohio; Wednesday, 8/19/59 (Activated sludge).
Loveland, Ohio No. 1; Monday, 4/20/59 (Trickling filter).
Loveland, Ohio No. 2; Monday, 7/27/59 (Trickling filter).
Loveland, Ohio No. 3; Tuesday, 9/8/59 (Trickling filter).

EXHIBIT -IV-17

NATURE AND COMPOSITION OF EFFLUENTS
FROM SECONDARY SEWAGE TREATMENT PLANTS

```
┌──────────────┐
│   EFFLUENT   │        20 OR 30 PERCENT OF ORGANIC
└──────┬───────┘          SOLIDS ARE FILTERABLE
       │              ┌──────────────────┐
       └──────────────┤    FILTRATION    ├────────────────┐
                      └──────────────────┘                │
                                                          │
LESS THAN 10 PERCENT OF SOLUBLE   ┌──────────────────┐    │
ORGANIC MATERIAL , 65 PERCENT     │ ETHER EXTRACTABLE ├───┤
STRONG ACIDS                      └──────────────────┘    │
                                                          │
LESS THAN 10 PERCENT OF           ┌──────────────────┐    │
SOLUBLE ORGANICS                  │     PROTEINS     ├────┤
                                  └──────────────────┘    │
                                                          │
LESS THAN 5 PERCENT OF SOLUBLE    ┌──────────────────┐    │
ORGANICS (NO SIMPLE SUGARS)       │ CARBOHYDRATES AND│    │
                                  │ POLYSACCHARIDES  ├────┤
                                  └──────────────────┘    │
                                                          │
LESS THAN 5 PERCENT OF            ┌──────────────────┐    │
SOLUBLE ORGANICS                  │  TANNINS AND     │    │
                                  │  LIGNINS         ├────┤
                                  └──────────────────┘    │
                                                          │
ABOUT 10 PERCENT OF               ┌──────────────────┐    │
SOLUBLE ORGANICS                  │      A B S       ├────┤
                                  └──────────────────┘    │
                                                          │
ABOUT 65 PERCENT                  ┌──────────────────┐    │
                                  │   UNIDENTIFIED   ├────┘
                                  └──────────────────┘
```

ADAPTED FROM REFERENCE

EXHIBIT - IV-18

NATURE AND COMPOSITION OF SOLUBLE ORGANICS IN EFFLUENTS FROM SECONDARY SEWAGE TREATMENT PLANTS

```
┌─────────────────────────┐
│   SOLUBLE  ORGANICS     │
│          IN             │
│   SANITARY  SEWAGE      │
│      EFFLUENTS          │
└─────────────────────────┘
```

```
┌──────────────────────────────┐        ┌──────────────────────────────┐
│  60 PERCENT WILL DIALYZE     │        │  40 PERCENT RESISTS          │
│         THROUGH              │        │   DIALYSIS  THROUGH          │
│  A CELLULOSE MEMBRANE        │        │  A CELLULOSE  MEMBRANE       │
└──────────────────────────────┘        └──────────────────────────────┘
```

```
┌──────────────────────────────┐        ┌──────────────────────────────┐
│     30 - 50  PERCENT         │        │     50 - 70  PERCENT         │
│           OF                 │        │           OF                 │
│     TOTAL   NITROGEN         │        │     TOTAL   NITROGEN         │
└──────────────────────────────┘        └──────────────────────────────┘
```

Data on secondary sewage treatment efflu-
ents are probably of greatest value to potential combination
plants. Considerable amount of data on such wastes are pre-
sently available, for the most part, as a result of the work of
the U. S. Public Health Service in the Advanced Waste Treatment
Research Program. Additional data will become available as this
Program continues.

It is very important to note, however, that
the quality characteristics of municipal sewage are highly vari-
able. Even through various stages of treatment, this degree of
variability persists. In the three samples of secondary effluent
from Loveland, Ohio (see Exhibit IV-16), there are wide variations
in essentially all of the measures of sewage quality.

This persistence of variation in sewage
quality, even through secondary bio-oxidation treatment, will
probably be of major importance in the design and economics of
combination plants. It is unlikely, however, that comprehensive
country-wide studies of sewage effluent quality, even if varia-
tions are determined, will satisfy the needs for design and
evaluation of combination plants. Generalizations may be possi-
ble, but actual field investigations of the waste water supply
will be required.

3) Miscellaneous Treatment

On the whole, the various miscellaneous
methods of sewage treatment have not found widespread applica-
tion. There are no available data of a comprehensive nature to
indicate the effectiveness of these methods. In general, the
degree of treatment ranges between that for primary or secondary
treatment.

As will be discussed in the next section
of this report, one miscellaneous method of sewage treatment -
namely, chemical precipitation - appears to have potential merit
with regard to possible combination plants. Such use would
probably be in conjunction with primary, and possibly secondary,
sewage treatment.

Stabilization ponds also have special merit
with regard to potential combination plants. The special advan-
tage is not so much the degree of treatment provided, but the
fact that the ponds represent a major storage basin (about 20-30
days). This may be a necessary or desirable adjunct to the over-
all combined plant system. Furthermore, the large storage facil-
ities will tend to reduce the variability in the quality of the
waste.

3. Recovery of Industrial Wastes

While the major emphasis in these discussions has been on the recovery of sewage wastes, it is not the intention of this report to minimize the recovery of industrial waste waters in the potential combination plants. The importance of waste water recovery in industry is attested by the current widespread operation of such systems. There is every indication that industrial re-use of waste water will continue to expand as an economical conservation practice (373, 354, 437, 423, 458). The potential merit of combination plants which integrate saline water conversion and industrial waste water recovery should not be overlooked as an important means of increasing available water supplies.

The important benefits to stream pollution control that might be possible in a program to recover and reuse industrial wastes should not be overlooked. The growing needs and concern in this area will result in more favorable economics for consideration of waste water recovery. This, coupled with the increased competition for fresh water supplies, will tend to make combination plants more practical and economical in many situations.

It is not feasible, in an investigation of this scope, to detail the technological and economical aspects of industrial re-use of waste waters. Many of the factors discussed in connection with sewage recovery apply at least partially to the recovery of industrial wastes. For the most part, each situation requires a tailormade study to consider the feasibility, technology, and economy of waste reclamation. Numerous reports of such studies for the pulp and paper industry (396), steel industry (468, 366, 461, 412), electronics industry (442), coal industry and refining industry have been presented.

D. Public Health Aspects

The purpose of this section is to discuss the various
health factors attendant to the use of industrial and sewage
waste waters as water sources for combined saline waste water
conversion systems. The practice of renovating waste water for
potable water supply and other beneficial uses instinctively
elicits concern as to the potential health hazards involved in
such practice.

Sewage is the source of all the major known infectious
agents which cause waterborne diseases as well as a multitude
of chemical substances whose toxic potentials are, for the most
part, unknown. Industrial waste water which may serve as a
supplemental source of water for conversion processes or be
manifest as a component of domestic sewage, contains substances
such as pesticides, detergents, organics, unknown organics and
reaction products as well as heavy metals and other inorganic
substances. These potential sources of toxicity and pathogenicity
stress the importance of public health considerations in potential
combined conversion processes. Before treated sewage or industrial
waste effluents can be considered for use in combined conversion
systems, the quality of these waste waters will have to be assessed
in the light of the various potential health hazards present and
suitable treatment provided in each instance to assure a safe pro-
duct for use. In the following section, these chemical and bio-
logical health factors are discussed. The indications are that
extensive research and development programs are needed to fill
the obvious gaps in our present knowledge.

1. Chemical Pollutants

The widespread concern in recent years which has
centered on the presence of increasing amounts of alkyl benzene
sulfonate (ABS) detergent residues in sewage and in treated
effluents, has served to direct attention to the fact that
sewages may harbor chemical substances which have far greater
public health significance. With each passing year, there is
an increasing number of various organic chemicals which alters
the chemical characteristics of our domestic and industrial
wastes. In 1961, the U. S. Public Health Service adopted the
carbon chloroform extraction procedure (CCE) in order to affect
some control and measure of the continuing increases of these
substances in our drinking water supplies. Based upon the
levels of these substances in presumed safe water supplies, a
recommended limit of 0.2 ppm (0.2 milligrams per liter) was
imposed. This procedure involves the concentration of organic
substances from a given quantity of water by adsorption on

activated carbon, reflux extraction of the adsorbates from the adsorbent with chloroform and a gravimetric determination of the organic residue after the solvent is removed by distillation.

Most of the substances recovered by this technique are those which are incompletely removed by conventional waste treatments and are thus termed refractory substances. The following list of substances recovered from waters using the carbon chloroform extract procedure gives some indication of the nature and variety of these compounds (440) (441).

1. Phenolics
2. Insecticides - Endrin, DDT, DDD, chlordane, methoxychlor, dieldrin, aldrin, and alpha conedendrin
3. ABS
4. Xylene
5. Polycyclic aromatic hydrocarbons - such as: Benzpyrene, Chrysene, Anthrocene, and Phenanthrene
6. Orthonitrochlorobenzene
7. Tetralin
8. Naphthalene
9. Chloroethyl ether
10. Acetophenone
11. Diphenyl ether
12. Pyridine and other nitrogen bases
13. Nitriles
14. Acidic materials
15. Miscellaneous hydrocarbons including substituted benzenes
16. Kerosene
17. Aldehydes, ketones and alcohols

The toxicity of the great majority of these and other refractory type compounds is not completely known, particularly from the standpoint of chronic or long term toxic effects. Unfortunately, only about 30 to 40 percent of the organics present in some of our domestic sewages have been identified and the major portion of this known fraction are detergents. The chemical substances contributed directly by industrial wastes similarly present a complex picture. Waste raw materials, process intermediates, and final product as well as reaction mixtures of the foregoing can be present. To further complicate the picture, organic materials such as chelating agents and other substances can alter the toxicity of some metals. Ethylenediaminetetraacetic acid complexes metal ions with varying toxiological results (474). It intensifies the toxic effects of cadmium and diminishes the toxicity of lead.

Zapp (497) in discussing the toxic effects of refractory contaminants, indicates that in the case of chemical carcinogens (cancer producing agents), the time required for the disease to manifest itself is inversely proportional to the dose of carcinogen; that is, if the dose is small enough there is insufficient time for tumors to develop over the natural life span of the test animal. This concept may be extended to the consideration of the toxicity of any chemical substance. Unfortunately, at this time, in most instances it is not possible to define the level to which these and other similar materials must be reduced to render them harmless. Stokinger and Woodward (474) indicate that although no recognizable health effects as yet have been demonstrated from the increasing amounts and varieties of chemical water pollutants contributed to our water supplies by wastes, it is conceivable that these effects are actually taking place in our population. Little or no direct data are available to indicate what the fate of these toxic substances would be in a combined conversion process and to what extent they might appear in the product water from various combination systems. Considerable research must be directed towards defining the types and extent of integrated treatments which will be needed to effectively remove these chemical substances. In addition, a great deal of research is needed to further identify these constituents and what the innocuous toxicological levels are. Despite the recognized usefulness of the carbon chloroform extract procedure as a separatory technique and the increasing use of qualitative and quantitative techniques such as gas chromatography, ultraviolet and infrared spectrometry and related techniques, there is an immediate need for the development of more direct and informative analytical methods.

As stated in an earlier portion of this report, our drinking water quality requirements are based upon the U. S. Public Health Service "1962 Drinking Water Standards" (480). These chemical standards are presented in Exhibit IV-19. The limits for chemical compounds are divided into maximum permissible concentrations or mandatory limits and recommended criteria. Thus a cyanide limit of 0.01 milligrams per liter is recommended but a concentration exceeding 0.2 milligrams per liter is not permitted. These limits are based upon observed physiological and aesthetic reactions of man and related toxicological data. They pertain to less than twenty of the more toxic inorganic substances and several of the organic substances which are commonly encountered in water.

Exhibit IV-19

USPHS DRINKING WATER STANDARDS 1962*

Substance	Concentrations in mg/l
A. Maximum permissible concentrations:	
Arsenic***	0.05
Barium	1.0
Cadmium	0.01
Chromium (hexavalent)	0.05
Copper	**
Cyanide***	0.2
Fluoride***	1.6-3.4#
Lead	0.05
Selenium	0.01
Silver	0.05
Zinc	**
B. Recommended limiting concentrations (provided that other more suitable supplies are or can be made available):	
Alkyl benzene sulfonates	0.5
Arsenic***	0.01
Carbon chloroform extract	0.2
Chloride	250
Copper	1.0
Cyanide***	0.01
Fluoride***	0.8-1.7#
Iron	0.3
Manganese	0.05
Nitrate, as NO_3	45
Phenolic compounds, as phenol	0.001
Sulfate	250
Total dissolved solids	500
Zinc	5.0

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*U. S. Public Health Service Drinking Water Standards adapted from Reference 33.

**Maximum permissible concentrations were replaced by recommended limits after the 1925 standards.

***These substances have both recommended limits and maximum permissible concentrations.

#Recommended limits and maximum permissible concentrations for fluoride vary with the annual average of maximum daily air temperature, from the lowest concentrations at 79.3-90.5°F to the highest at 50.0-53.7°F.

In combined conversion processes it will be necessary to provide adequate treatment to maintain the product water quality within the scope of these limits where domestic consumption is anticipated. In instances where the product water is intended for industrial purposes the water quality requirements of the specific industry will be the controlling factor. Adequate analytical techniques are available to demonstrate these more common toxic or deleterious substances in waste effluents. Where industrial waste waters are used or where they represent a significant fraction of the sewage, additional safeguards and appropriate liaison with the waste producers will have to be provided for contingencies and process changes in the industrial operation which might significantly change the chemical characteristics of the waste.

It is conceivable that in certain areas ground-water supplies or waste waters might contain sources of ionizing radiation. This detailed subject is beyond the scope of this discussion. It is mentioned here only in connection with Public Health Service's "Drinking Water Standards." These limits permit the use of a water supply when the concentrations of Radium 226 and Strontium 90 do not exceed 3 and 10 uuc* per liter, respectively. If such limits are exceeded, total intake of radioactivity from all sources in the area must be considered and approval of the supply will depend upon the total intake being within the limits recommended by the Federal Radiation Council. In instances where Strontium 90 and Alpha emitters are neglible, the water supply is acceptible if the gross Beta concentrations do not exceed 1000 uuc/liter. When the gross Beta concentrations exceed this limit, the rejection of the supply will depend upon the concentrations of nuclides and the associated exposures as they relate to the Radiation Protection Guides of the Federal Radiation Council.

2. Pathogenic Micro-Organisms in Waste Waters

Heukelekian and Faust (408) indicate that the following principal pathogens or organisms associated with

---

*uuc - unit of radiation equivalent to 10^{-12} curies or 1 micromicro curie (picocurie). A curie is equivalent to 3.7×10^{10} disintegrations per second and approximates the number per second from one gram of radium (actual 3.61×10^{10}).

waterborne disease may be found in sewage:

1. Cholera Vibrio
2. Typhoid and paratyphoid bacteria (Salmonella)
3. Dysentery bacteria (Shigella)
4. Amoebic dysentery (Endamoeba histolytica)
5. Tuberculosis bacteria (Mycobacterium tuberculosis)
6. Viruses causing infectious hepatitis and poliomyelitis
7. Parasitic worms such as roundworms, tapeworms and hookworm, Ascaris and Schistosoma.

Heukelekian points out that the causative agent of cholera is not normally present in the United States but if it were it would be destroyed in company with the typhoid, paratyphoid, and dysentery bacteria by the residuals of chlorine commonly used in sewage disinfection. These organisms are less resistant to germicides than the coliform group bacteria which are used routinely as an index of bacteriological quality for water and sewage effluents.

As the name implies, coliform bacteria flourish in the intestine of man where enteric pathogens originate. The presence of coliforms in a water indicates the potential presence of pathogenic organisms. Coliforms discharged in human waste matter far out-number the pathogens and the higher the coliform density the greater the probability that pathogens are present. To demonstrate the presence of pathogenic micro-organisms is a complex task which involves intricate and time consuming bacteriological procedures. Coliform group densities are determined with relative ease and are therefore used to set standards of quality for drinking waters and sewage effluents. As a rule, coliform group organisms are more resistant to disinfection than are the bacterial enteric pathogens, and the absence or reduction in numbers of coliforms to appropriate limits is usually taken as a reliable index of disinfection (480).

Heukelekian and Albanese (407) report that the causitive agent of tuberculosis required a residual of 2 ppm chlorine during a 30 minute contact for effective disinfection. The presence of this organism in sewage or polluted waters, however, is not widespread and they are usually concentrated in sewage effluents from sanitariums. Chang and Fair (408) indicate that the cysts of E. histolytica requires 3 milligrams per liter of free chlorine residual at pH 7. Parasitic worms, particularly Ascaris, are quite resistant to chemicals and disinfectants. Mills, et al (443) reported that Ascaris eggs were resistant to 5000 ppm chlorine solution, and that 2000 ppm produce no effects. Bhaskaron, et al (365) reports that

treatment by trickling filters and activated sludge showed complete removal of ascaris from sewage. Heukelekian and Faust (408) cite that chlorination as usually practiced does not destroy tuberculosis bacteria, viruses, amoebic dysentery cysts, and the parasitic worms. Chang (374) discusses the resistance of viruses to chemical water disinfectants such as chlorine, chlorine dioxide, iodine, and ozone. In general he indicates that free chlorine is much more effective than combined (chloramines) chlorine. Ozone and chlorine dioxides are presumably good viricides but additional data are needed to fully evaluate these agents. Iodine shows promise as an effective viricidal agent for emergency use.

Heukelekian (408) further indicates that with the exception of the viruses, most of the other pathogens are removed by other methods of sewage treatment such as sedimentation, flocculation and filtration.

Recent observations tend to shed some doubt on removal efficiencies of these processes for amoebic cysts and the significance of non-pathogenic nematode worms in the effluents. Metzler, et al (438) report that during the recycling of sewage for domestic water supply use at Chanute, Kansas in 1956-57 cysts of free-living amoebas were detected in both the treated and raw water supplies. Before reuse in the water treatment plant, the raw sewage received secondary biological treatment by trickling filtration, final clarification, post chlorination and storage in a stabilization lagoon for 17 days. Berger (364) indicates that if the pathogenic amoeba E. histolytica had been present in the sewage, it is presumable that they also would have been present in the finished water. The free-living cysts are approximately the same size and have presumably the same resistance to chlorination as the parasitic form.

Metzler also indicates that the treated sewage effluents contained free-living worms. Chang (371) reports that effluents from aerobic sewage treatment processes, particularly those from trickling filters, carry large numbers of non-pathogenic nematodes which potentially can ingest Salmonella, Shigella and pathogenic enteroviruses. In the ingested state these pathogens could be shielded from chlorination and be carried into the water distribution system. Chang (369) further indicated that of 22 municipal water supplies tested in a study of these forms, 16 were found to contain nematodes. No pathogenic bacterial forms were found in the nematodes isolated. Further research on the significance of these forms in sewage and treated effluents is urgently needed.

a. <u>Enteric Viruses</u>

Enteric viruses are those viruses found in human waste and in sewage. They have been classified into five groups by Clarke and Kabler (375) as follows:

Subgroup	Number of Types	Disease
Infectious hepatitis	1 (?)	Infectious hepatitis
Coxsackie		
Group A	25	Herpangina, aseptic meningitis
Group B	6	Pleurodynia, aseptic meningitis
Poliovirus	3	Paralytic and non-paralytic poliomyelitis
Adenovirus	28	Respiratory and eye infections, diarrhea
ECHO	25	Aseptic meningitis, diarrhea, rash diseases

Of the foregoing viruses only the agent of infectious hepatitis has been proven to be waterborne, although the presence of these viruses in sewage suggest they all potentially could be transmitted through contaminated waters.

An epidemic of infectious hepatitis in New Delhi, India, in 1955 and 1956 involved an estimated 30,000 to 50,000 persons (486). The outbreak was traced to the city water supply which was fully treated and met quality control standards including the coliform test. The upset in the water system was attributed to a massive sewage contamination of the city's water supply. The treatment procedures applied, including super-chlorination, were not adequate to inactivate the infectious hepatitis virus. The negative coliform results which normally indicate water of safe quality thus did not exclude the presence of virus and the reliability of the coliform tests with respect to these infectious agents is currently not known. Continuing research is needed to clearly establish the relationship of our water quality standards to the virus problem.

b. Biological Characteristics

Chang (370) describes viruses as the smallest and simplest living organism, 10 to 450 mu in size (mu - millimicron). The infectious particle consists of a core of nucleic acid surrounded by a jacket of protein.

These forms are strictly parasitic and can reproduce only at the expense of the host cell which they invade. The relationship between the viruses and its host is characterized by a high degree of specificity; that is, specific viruses only infect specific hosts. The infectious process consists of penetrating the cell wall of the host and the organization of the cell machinery for the production of new virus particles. When this has been completed, the host cell ruptures and the newly formed virus particles are released.

c. Study of Viruses

Early studies of viruses were conducted with the aid of suitable laboratory animals and chick embryos which some viruses were capable of infecting. In recent years, virus studies have been greatly expanded and accelerated through the development of tissue culture techniques using living monkey kidney and other mammalian cells. Virus growth in such tissue culture results in a localized degeneration of host cells and the formation of visible "plaques," in the living host cell sheet. This permits the virus to be qualitatively and quantitatively studied. As already pointed out, the virus-host relationship is a highly specific one. This is of particular importance in the case of infectious hepatitis. No animal other than man has as yet been found capable of being infected by this virus. For this reason, the infectious hepatitis virus does not respond to laboratory studies and our knowledge is limited to epidemiological aspects and a few studies conducted with human volunteers.

d. Waterborne Virus Diseases

Hudson (413) points out that the study of waterborne virus disease is complicated by the following factors which make it difficult to relate water quality with

disease incidence:

1. Incomplete reporting of disease outbreaks.
2. A lack of direct means for measuring virus concentration.
3. The transmission of viruses by media other than water.
4. The masking effects of immunity.

Despite these difficulties, numerous cases of waterborne infection through virus transmission have either been proven or strongly indicated. It has already been indicated that one of the modes or transmission of infectious hepatitis is through water. Neefe and Stokes (450) showed that an outbreak of infectious hepatitis at a small camp involving 350 persons in 1944 was related to the use of well water contaminated by a nearby cesspool. Reports as early as 1916 through 1943 described epidemics of jaundice in which water use could be reasonably linked have been reported from Sweden (447) and an outbreak of 173 cases probably due to waterborne transmission was reported in Canada by Fraser (393) in 1931. Mosley (448) reports that during the period 1945-1962, there have been 31 epidemics attributed to water and there is no question that waterborne transmission of this virus does occur.

The poliovirus is the only other viral agent strongly suscepted of being waterborne. In 1929, Kling (430) suggested that drinking water could be a means of polio transmission and he demonstrated this connection in 1939 by isolating poliovirus from a well water used by a polio patient. Unfortunately, the virus was isolated after the patient had contracted the disease and direct proof was lacking. Epidemics of poliomyelitis attributed to water occured in Sweden, Alberta, Canada in 1953. In the foregoing outbreaks, the evidence was strongly indicative that the disease was waterborne but true proof is lacking. Clarke and Chang (374) report that the outbreak in Edmonton, Alberta was correlated with the pollution of the city water supply from the Saskatchewan River by the failure of the sewage treatment facilities at a town upstream. This information strongly indicates that even with our current mass immunization against poliomyelitis, the possibility still exists for waterborne outbreaks.

The adenoviruses are chiefly associated with infections of the upper respiratory tract and eye afflictions but these viruses can be isolated from fecal matter. Clarke and Chang (374) indicate that incidence of waterborne infections have not been recorded but three outbreaks of clinical disease associated with swimming pools have been reported.

The Coxsackie and ECHO (enteric cytopathogenic human orphan) viruses comprise a group which have not been associated with waterborne infection. These agents, however, can be readily isolated from feces, sewage, and sewage effluents. They have been shown to be related to diarrhea in children (386). Because of this, they must be considered as viruses which could potentially transmit disease through water.

e. Sewage Treatment Processes and the Removal of Pathogenic Microorganisms

The general aim of sewage treatment and associated industrial waste treatment is to reduce the amounts of organic matter in the raw sewage. This is accomplished in varying degrees by several processes so that the amount of organic matter capable of depleting oxygen from a receiving water to which the final effluent is discharged is minimized. These processes are not specifically designed for the removal or reduction of the numbers of pathogenic microorganisms which might be present in the raw sewage. Kabler (417) indicates that the various methods of biological treatment will markedly reduce the number of pathogenic enteric bacteria and viruses in sewage, but the resulting effluents will always harbor some of each microorganism. Additional treatments will be needed to assure safe effluents.

In the following sections, some consideration is given to the effects of storage, a description of the sewage treatment processes and the associated removal of pathogenic organisms.

1) Storage

The need for retention of treated waste effluents before use in combined conversion processes is discussed in another section of this report. Such storage will serve three purposes:

1. Waste effluent equalization to provide an essentially uniform feedwater quality.
2. Storage capacity to compensate for low flow periods to meet quantity requirements.
3. Reduction of numbers of pathogenic microorganisms through natural "die away" processes.

Storage may in some instances be achieved through recharge of ground-water. Shuval (470) reports that in Israel, secondary effluents from stabilization ponds will be placed into the ground-water aquifer and after a detention

time of approximately six months, recovered and pumped from wells for domestic and agricultural use. Storage for approximately 70 days in the stabilization ponds and the time in the aquifer is considered ample to provide a safe water. Breakpoint chlorination before use may be used if it is considered necessary.

2) Primary Treatment

These processes are designed to remove suspended solids from the sewage by various screening or straining operations and sedimentation in settling basins. The separated solids are conveyed to tanks where they undergo anaerobic decomposition by bacterial action. Further treatment may be applied to the liquid effluent or it may be disposed of through dilution or land irrigation. Separation of solids may be furthered by the additions of chemicals such as alum or lime to coagulate colloidal solids.

3) Secondary Processes

The basis of biological oxidation techniques is described by Klein (429) as an artificial intensification and acceleration of the ordinary aerobic biological processes of natural purification that take place in polluted rivers. The two most important modern biological processes for treating settled sewage are the trickling filter and activated sludge process. Fundamentally, both processes convert soluble putrescible organic matter to a solid form which can be removed from the effluent.

Trickling filter units consist of circular or rectangular beds of crushed coarse graded rock or some similar material. Primary sewage effluent is distributed uniformly over the surfaces of the contact medium and allowed to percolate through the beds which are usually about 6 feet in depth. The crushed medium provides surfaces upon which microorganisms collect and form gelatinous films. As the sewage passes over this biological film, the bacteria, fungi and other microorganisms break down and stabilize the putrescrible organic impurities in the sewage in the presence of oxygen. Adequate ventilation of the filter beds to provide sufficient oxygen to accomplish this is induced by the difference in temperature between the air and sewage. The products of this biological treatment are carbon dioxide, water, nitrates, sulfates, phosphates, and the insoluble biological film itself which periodically sloughs off the surfaces of the contact medium.

This continuous or intermediate stripping off of the film and its solid end products keeps the trickling filter from becoming clogged with the gelatinous film substance. These solids in the filter effluent must be removed by secondary sedimentation or clarification in retention basins.

When sewage is appropriately aerated in detention tanks, the activated sludge process takes place. Active biological clumps or flocs develop as a result of the aerobic growth of bacteria and related forms. The organisms present in activated sludge grow and feed at the expense of dissolved, colloidal and suspended organic matter in the settled sewage. Organic matter is continuously converted to cell substance, building up the floc matrix until it reaches a weight which renders it settleable. The continuous activated sludge process involves:

1. The return of a portion of the activated sludge to the aeration tank influent and the wasting of sludge in excess of this amount.

2. The aeration of the sewage sludge mixture to keep it aerobic.

3. The stirring of the mixed liquor by air or other means to maintain the floc in suspension and bring it continuously in contact with suspended and dissolved matters that are adsorbed from the sewage by the floc.

4. Sedimentation of the effluent to separate the activated floc or sludge from the flowing sewage.

4) Tertiary Processes

Effluents from biological treatment processes may be chlorinated before release or receive tertiary treatments such as coagulation with alum or other chemicals, filtration, or treatment with activated carbon to improve the quality with respect to dissolved organic substances.

f. Removal of Enteric Bacterial Pathogens During Sewage Treatment Processes

The effectiveness of enteric pathogen removal by the various processes used for sewage treatment is usually measured by the reduction in the numbers of coliform bacteria.

Ettinger (387) indicates that primary sedimentation is relatively ineffective and under favorable conditions, approximately 50 percent of the enteric organisms are removed. Trickling filters remove about 80 percent and activated sludge can remove 90 percent of the enteric bacteria. Stabilization ponds can affect reductions of better than 99 percent, but this depends primarily upon retention time and the management of the basin. Kabler (417) indicates in an extensive review of this subject that the reductions in microbial population in secondary sewage treatment processes are accomplished through physical factors, nutritional deficiencies, predation, and antimicrobial substances. The effluents will, however, contain a portion of all the organisms present in the original raw sewage. Appropriate chlorine dosages and retention times are needed to produce satisfactory final effluents. A chlorine residual of 1 ppm or less applied for 15 minutes will disinfect effluents with respect to enteric bacteria and 1 ppm residual applied for one hour kills tuberculosis bacilli (417).

Separated sewage solids and solids produced in the secondary processes are usually further treated by the process of anaerobic digestion and reductions of enteric bacteria are a function of retention time and temperature. McKinney, et al (439) reported an 84 percent reduction of Salmonellae typhose (the causative agent of typhoid fever) in six days digestion and 92.4 percent with 20 days digestion.

g. Efficiencies of Sewage Treatment Processes for the Removal of Viruses from Sewage

Clarke and Kabler (375) studied the survival time in stored raw sewage of various viruses and three bacterial forms which are routinely used as indicators of pollution. The purpose of their study was to gain information as to the reliability of the usual bacteriological quality control tests as they would relate to the presence of viruses. These studies indicated that with the exception of one strain of Coxsackie A-9 virus, the average survival time for poliovirus I and ECHO 7 and 12 was about twice that of A. aerogenes, Escherichia coli and Streptococcus fecalis. These data are presented in Exhibit IV-20. Neefe and Stokes (450, 451) reported that well water known to have been responsible for an outbreak of infectious hepatitus was able to infect human volunteers after the water had been stored for ten weeks. The storage times necessary for 99 percent reductions of virus in water at two temperature levels is presented in Exhibit IV-21.

Exhibit IV-20

TIME IN DAYS FOR 99.9 PER CENT REDUCTION

OF INDICATED ORGANISM IN RAW SEWAGE*

| | Temperature | |
Organism	28°C	4°C
Poliovirus I	17	110
ECHO 7	28	130
ECHO 12	20	60
Coxsackie A9	6	12
Aerobacter aerogenes	10	56
Escherichia coli	12	48
Streptococcus fecalis	14	48

*From Reference (375)

Exhibit IV-21

REDUCTION OF COXSACKIE, POLIO, THEILER'S AND

INFECTIOUS HEPATITIS VIRUS IN WATER BY STORAGE*

Type of Water	Virus	Probable Storage Necessary for 99 Per Cent Reduction---days		
		8°-10°C	20°C-23°C	30°C
River water, some or moderate pollution	Coxsackie A2 Theiler	14 56	5 18	9
River water with gross pollution	Coxsackie A2		47	
River water with added feces (1:200)	poliovirus	*		
Autoclaved river water	Coxsackie A2	160	102	
Distilled, tap, or spring	Coxsackie A2 Coxsackie A5 Theiler poliovirus	272 280 315 100	100 210+ 132	21
Contaminated well water	Infectious hepatitis		‡	

* Virus present after 188 days' storage
+ Storage at 20°-30°C
‡ Produced illness in volunteers after 10 weeks' storage

*From Reference (374)

Clarke and Kabler (375) indicate that virus survival is longer in clean water than in moderately polluted waters. However, virus survival seems to be much longer in grossly polluted waters. They conclude that there is a limited amount of data available and this is insufficient to allow for any generalizations to be made concerning the effectiveness of storage in reducing enteric viruses in waters or sewage. Kelly and Sanderson (426) indicate that the use of treated waste effluents should be proceeded by the assurance that they have been rendered harmless. The action of chlorine on bacteria in sewage effluents has received considerable study and the general feeling is that the effluents in contact with 0.5 ppm combined residual chlorine for 15 minutes will be free of pathogenic bacteria and protozoa (390). The exceptions to this are that amoebic cysts and viruses as indicated earlier require more extensive treatment than coliform bacteria.

Knowledge of the destruction of the viruses in sewage treatment is limited to some laboratory studies and a few plant studies. Kelly and Sanderson (426) studied virus removals during sewage treatment. Samples of sewage and effluents for these studies were obtained from various treatment plants in New York State. They found that the rate to which viruses could be isolated from raw sewage was seasonal. During the summer 80 percent of the raw sewage contained viruses while 50 percent were positive in June and November; less than 10 percent contained viruses during the period between January and May. Primary treatment did not decrease the frequencies at which viruses could be isolated from the effluent. These data are presented in Exhibit IV-22. Plaque counts indicated that a decrease in the total number of infectious particles did occur. This reduction is probably due to removal of viruses in the settleable solids.

Treatment on trickling filters did not remove viruses completely. Since samples of sewage which had passed the filters contained viruses as often as did raw sewage plaque counts; however, the numbers were reduced as much as 40 percent. Clarke (376) investigated the removal of various viruses using a laboratory bench model activated sludge unit and found that with retention times of 6 and 7 hours, 98 percent of Coxsackie virus were removed and 90 percent of poliovirus. Kelly, et al (427) indicate that the viruses removed by activated sludge may be inactivated through the action of biological antagonists. Clarke (376) found that only a very small percentage of the virus removed with

Exhibit IV-22

ISOLATION OF VIRUSES FROM PRIMARY TREATMENT EFFLUENTS*

Sewage Treatment Plant	Number of Samples Containing Viruses		
	Raw	Imhoff Tank	Effluent Mechanically Cleaned Settling Tank
Albany	37	34	-
Delmar	6	7	-
Schenectady	8	9	-
Coloric-Schenectady Road	9	-	7
Scotia	9	-	7

*From Reference (426)

activated sludge could be recovered suggesting that the virus-sludge adsorption complex was exceedingly stable. Considerable studies are needed to further explain the mechanisms of virus removal by this process.

Kelly, et al (426) found that chlorinated effluents from the secondary treatment plants contained viruses about a third of the time. These residual chlorine values were near the recommended value of 0.5 ppm. This level of chlorination destroyed some of the viruses since the plaque counts were low. Raw sewage chlorinated in several of the plants to concentrations of 0.1 to 0.3 ppm contained viruses as often as did the raw sewage. Kelly and Sanderson (426) concluded that our present methods of sewage treatment do not destroy enteric viruses and that secondary treatment combined with chlorination may destroy viruses. Laboratory studies (426) indicate that depending upon the hydrogen ion concentration and temperature that 9 ppm of residual combined chlorine for 15 minutes are necessary for virus inactivation. With combined chlorine at 0.5 ppm, contact periods of 5 hours will be needed. Clarke and Kabler (375) summarize the efficiencies of our current sewage treatment processes with respect to virus removals as follows:

1. Primary sewage treatment has little or no effect on enteric viruses.
2. Secondary treatment on trickling filters removes about 40 percent of the viruses.
3. Activated sludge treatment removes about 90 to 98 percent of the viruses.
4. Chlorination of treated sewage effluents reduces the number of viruses but they can still be detected in the effluents.

The fact that our conventional waste water treatment processes do not completely remove pathogenic microorganisms cites the need for pertinent evaluations of the various potential pretreatment processes which are described in a later section of this report. Robeck, et al (462) found in pilot plant studies that significant reductions of virus in water could be achieved by alum flocculation and filtration. At low alum dosages of 10-50 ppm and filtration through sand that 98 percent of the initial virus concentration could be removed. Similar work by Robeck, et al (463) compared the effectiveness of granular activated carbon and sand as filtering media. The result of this study indicated that activated carbon removed about 85 percent of the virus while sand affected a reduction of 20 percent. Robeck con-

cluded that activated carbon would be best employed in combination with alum pre-flocculation and emphasized the value of removal of organic matter through carbon adsorption as it would influence post-chlorination procedures.

Insufficient data is available to permit evaluations of the potential pretreatment processes as they would relate to disinfection of secondary waste effluents.

    h. <u>Conversion Processes - Potential for the Removal of Infectious Microorganisms</u>

Of the various conversion processes the thermally based distillation techniques appear to offer the greatest advantages for disinfection. The freezing processes will reduce microorganisms to some degree due to temperature changes and concentration in the waste saline phase. Surface contamination of the ice crystals would, however, have to be expected. Low temperatures would also favor the preservation of pathogenic bacteria and viruses. Electrodialysis and other processes based on the use of membranes could be expected to exhibit filtering and adsorptive capacities which would reduce bacterial numbers and perhaps viruses. This function, however, would have some limiting effect on the service life of the membrane.

The distillation processes can be expected to have great potential due to the principle of phase separation and the application of heat. Thermal disinfection is one of the most widely used techniques and finds application in the pasteurization of milk, the canning industry and aseptic medical technology.

The lower temperature evaporative techniques which are carried out under reduced pressure might permit organisms to be "carried over" into the distillate during foaming. Adequate design of conversion units and pretreatment of feedwater to remove traces of substances which could induce such foaming will have to be considered.

With higher temperature conversion processes in the range of 120.1°C (250°F), these effects would be mitigated by the shortened thermal death times. The thermal death point of <u>Salmonella Typhosa</u> is commonly given as 55°C (131°F) (460). What this actually means is that at 47°C (116.6°F) 120 minutes would be required for inactivation; 48 minutes at 49°C (120.2°F), 18 minutes at 51°C (131°F) and 21 seconds at 59°C (138.2°F). At higher temperature ranges,

inactivation would be extremely rapid. The inactivation of bacterial forms, however, would in most instances be carried out by the application of appropriate levels of chlorination.

With the enteric viruses and amoebic cysts which show higher tolerances to chemical disinfectants, great advantage could be had by utilizing thermal inactivation.

Lawson and Melnick (434) reported 99.9 percent or greater destruction of a mouse adapted strain of polio virus at 60°C (140°F) for thirty minutes in water. Kaplan and Melnick (419) later reported that three strains of polio virus and one strain of Thieler's virus were killed by exposure to heated water at 55°C (131°F) in 15 to 30 minutes and at 71.1°C (160°F) for $7\frac{1}{2}$ seconds. Three strains of Coxsackie virus (A_1, A_4 and B_1) were similarly inactivated in $7\frac{1}{2}$ to 10 seconds at 71.1°C (160°F) (420). Robinson's (464) data on two strains of Coxsackie virus were in general agreement with Melnick's results although Robinson found one strain of polio virus which needed exposure at 62°-64°C (143.6°-147.2°F) for substantial inactivation. Berg (363) indicated that in general the enteric viruses would be inactivated rather quickly at 70°C (158°F). The rate of thermal destruction would depend on the presence in water of substances which would tend to protect the viruses. This fact could be of consequence in the conversion of waste water or secondary sewage effluents which contain such substances and needs to be studied.

The virus of infectious hepatitis appears to be more resistant to heating but the picture is not clear at this time. This is due to the fact that the virus has never been cultured outside of the living human body and studies can only be conducted with human volunteers. Haven's (402) work showed that 56°C (132.8°F) for 30 minutes failed to render an infectious hepatitis serum non-infectious. Three of the four volunteers contracted the disease after ingesting the heated suspension. It should be noted, however, that viruses suspended in protein fluids are more difficult to destroy by heat than they are in water. Berg (363) pointed out that the studies so far conducted with infectious hepatitis virus have been made with suspensions in fecal matter or in serum. No thermal inactivation studies in water are available but it is to be expected that the rate of inactivation in water would be much higher than in the protective mediums.

This action is predicted on the basis of extrapolation of thermal death data using other viruses. However, until more and better studies are completed, no reliable statement regarding the thermal inactivation of infectious hepatitis virus can be made.

Data for the thermal inactivation of the cysts of Endamoeba histolytica is available. Chang (369) reports that the thermal death times in water for pathogenic amoebic cysts to be as follows:

Temperature	Time Required
45°C (113°F)	150 minutes
47°C (116.6°F)	30 minutes
49°C (120.2°F)	7½ minutes
50°C (122°F)	2 minutes
52°C (125.6°F)	12 seconds
65°C (149°F)	1-2 seconds

Chang indicated that the thermal inactivation of pathogenic and free-living nematodes would also take place in a matter of seconds at 70°C (158°F).

Of interest in the application of heat for disinfection purposes is the "Pasterilizing" process as described by Karassik (421). This commercially available process utilizes thermal processing to eliminate potential health hazards from microorganisms in the reclamation or recovery of treated sewage effluent for domestic purposes. The process involves the intake of a treated effluent, a polishing step employing either activated carbon treatment or diatomaceous earth filtration followed by heat treatment at pasteurizing and sterilizing temperatures to completely destroy all microorganisms. After heat treatment, the product water is aerated to return oxygen and reduce taste and odor.

3. Disposal of Wastes from Potential Combined Conversion Processes

The conversion of saline waters and the potential use of pretreated waste waters of domestic or industrial origin as a portion of the process feedwater will yield in either case product water and a concentrated waste stream containing the separated impurities. This process waste must be disposed of by suitable means so that further public health problems are not created. In this respect, it would not be desirable to

dispose of such wastes in a manner which would allow pollution of usable surface waters or ground-water supplies. Effective disposal will involve the necessary treatment, handling, and removal of the wastes so that they are rendered innocuous and permanently isolated from the available water supplies and human contact.

In areas where ocean disposal or other obvious types of waste sinks are not available, definitive information for process waste disposal is lacking and comprehensive research programs are needed which will permit workable systems to be devised.

E. Potential Combination Plant Schemes

The preceding discussions have indicated the host of interrelated influences affecting the design and operation of potential combination plants. Because of these many influences, there are numerous general schemes for combination plants and even more variations on these general designs. It would be impractical to describe all possible systems here. For clarity, and in the manner of a summary, several general combination plant schemes are presented here with brief discussions.

The following four schemes are prepared to generally show potential combination plant designs for the several types of saline water supply. These types, which have been briefly described in this section (see also Sections I, II, and III), are: 1) ocean, 2) coastal waters, 3) inland surface water, 4) coastal ground water, and 5) inland ground water. A potential combination plant scheme (only one of many possibilities) has been shown as a flowsheet for each type of supply in the exhibits. Because of similarities, both surface and ground coastal waters have been combined into one scheme.

A general combined plant scheme for an ocean water supply is given by Exhibit IV-23. Treated water storage and treated sewage storage are indicated to reduce the peak demands on the saline conversion unit, thereby reducing capital costs. The recovered waste is not processed in the conversion unit since the salinity reduction would not be of major consequence. A very high degree of waste pretreatment would be required.

EXHIBIT- IV-23

COMBINED PLANT SCHEME - OCEAN WATER SUPPLY

D-1060
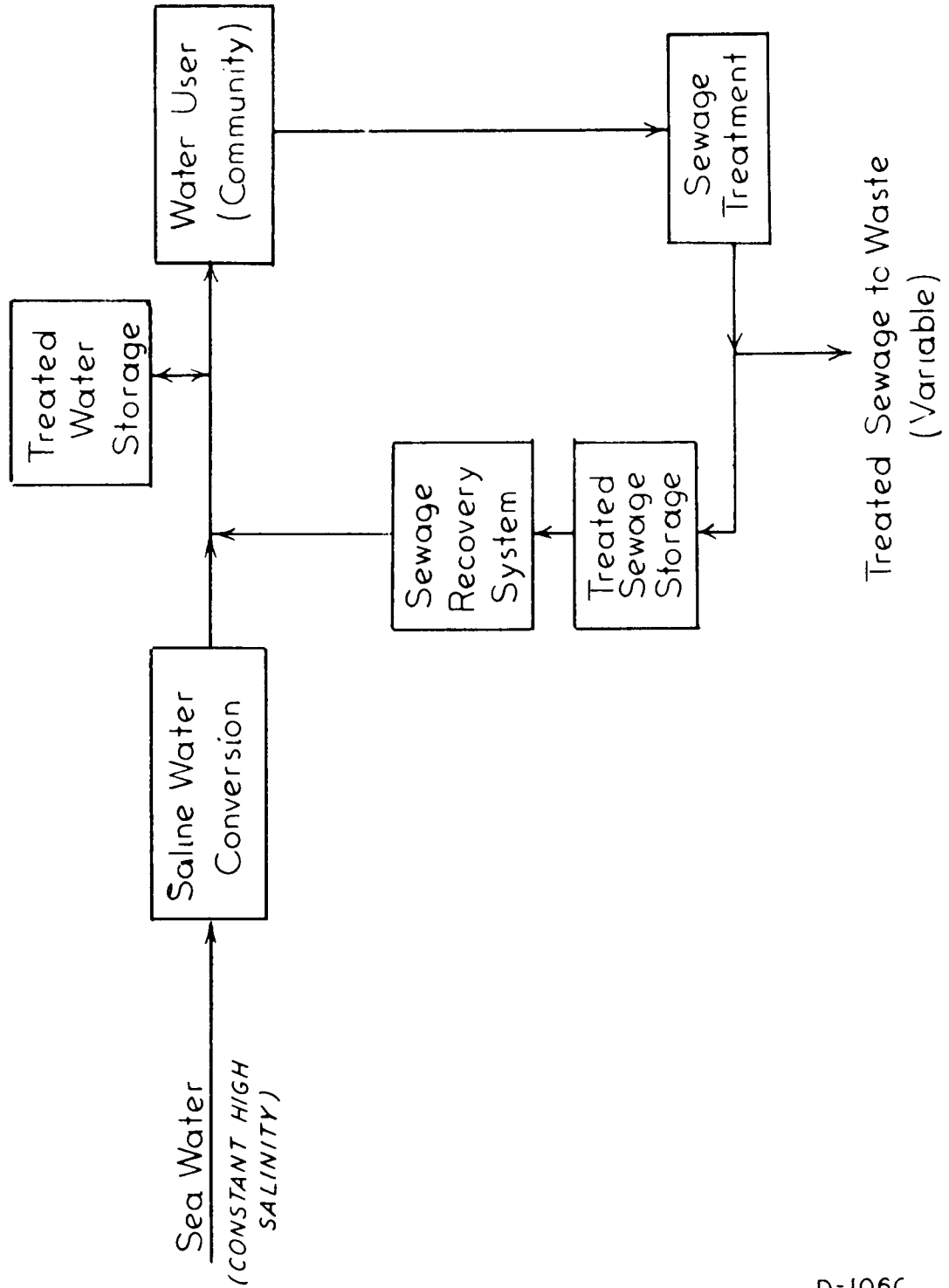
Exhibit IV-24 shows a potential combination plant scheme for a brackish saline water supply from surface or ground coastal sources. Pretreatment of the saline and waste water supplies is accomplished in a single facility. Provision is made to bypass part of the combined supply; this may be likely during low salinity periods. Extensive waste storage provisions (stabilization ponds) are indicated.

A potential scheme for an inland surface water supply is given by Exhibit IV-25. A major impounding reservoir is provided, but this is bypassed during periods of very high river salinity. The waste water intended for recovery is selected from the community's total sewage and processed separately from objectionable wastes. The recovered waste is directed to the impounding reservoir, with an alternate bypass to the converted saline supply.

The combination plant scheme for an inland ground water supply is shown by Exhibit IV-26. This scheme is very similar to that for an ocean supply (see Exhibit IV-23). The recovered waste, however, is shown with alternative feed before and/or after the saline conversion process. In addition, a bypass of brackish water around the conversion unit is shown. A variable degree of treatment is indicated for the conversion unit. These innovations are possible because of the low burden of salts to be removed from such a supply.

COMBINED PLANT SCHEME- COASTAL (SURFACE AND GROUND) WATER SUPPLY

EXHIBIT IV-24

Coastal Supply
(VARIABLE SALINITY)

Combined Pretreatment

BYPASS

Saline Water Conversion

Water User (Community)

Sewage Treatment

Waste Storage Stabilization Basin

To Waste
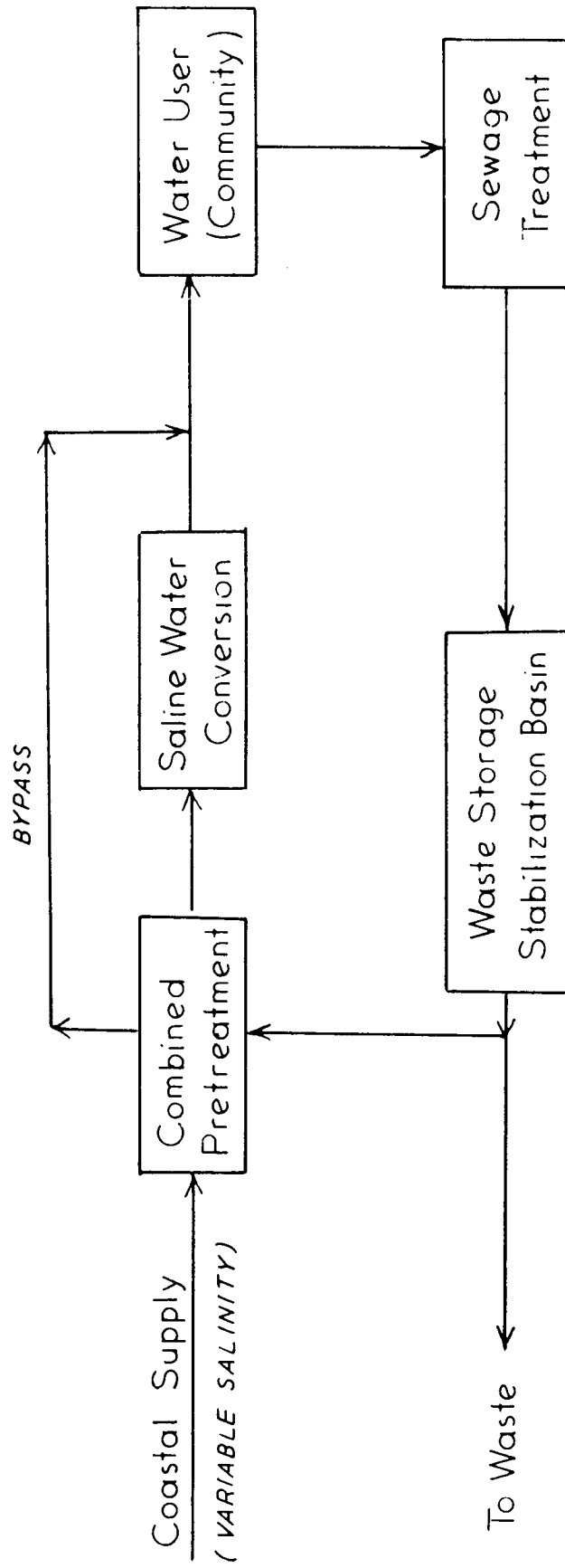
EXHIBIT IV - 25

COMBINATION PLANT SCHEME - INLAND SURFACE SUPPLY

Inland Surface Supply
(VARIABLE SALINITY)

BYPASS DURING HIGHEST SALINITY

Reservoir Storage

Saline Water Conversion

Water User (Community)

Sewage Treatment

Treated Sewage to Waste

SELECTED SEWAGE

Modified Sewage Treatment

Sewage Recovery System

J - 1063

EXHIBIT IV·26
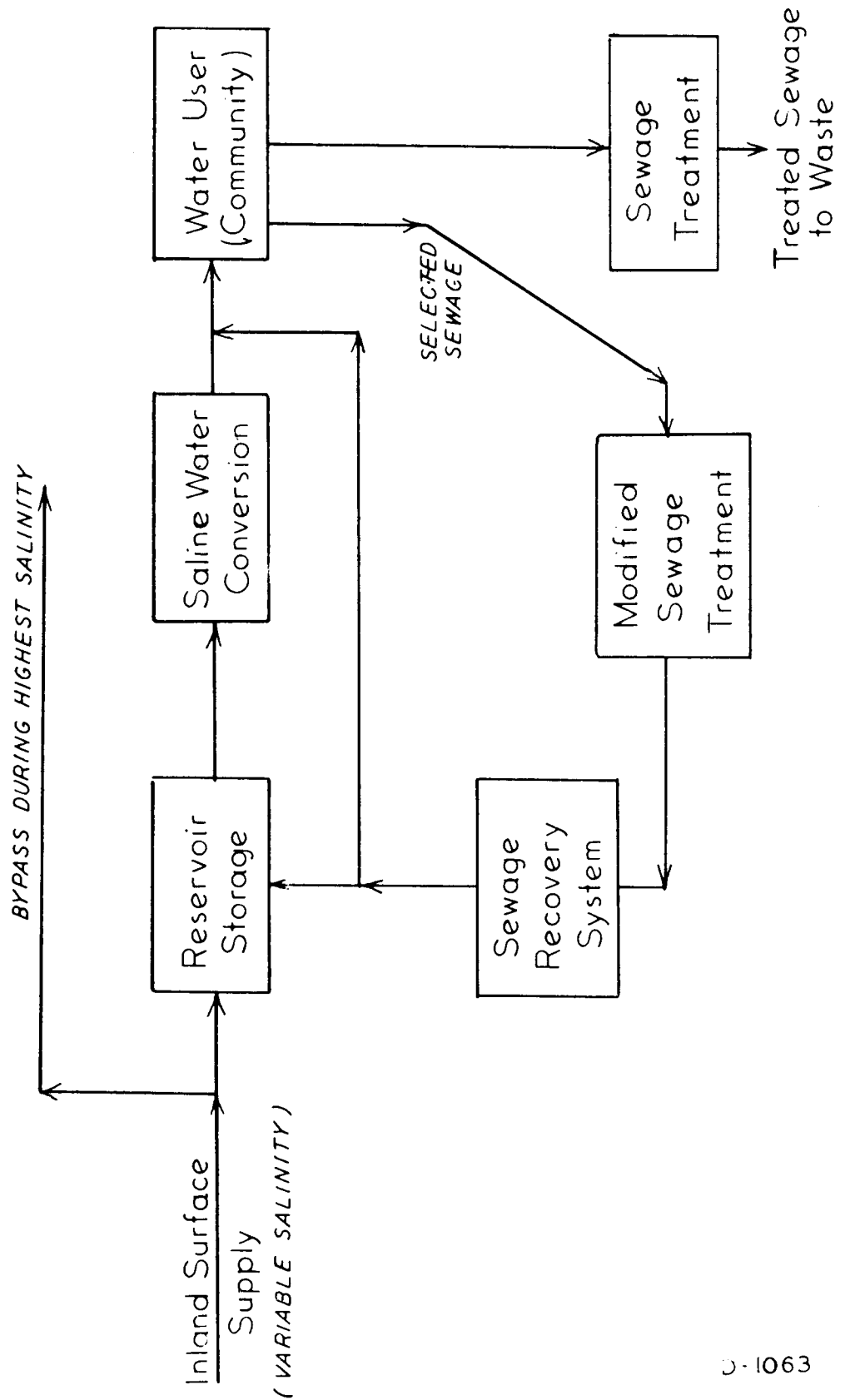
COMBINATION PLANT SCHEME – INLAND GROUND WATER SUPPLY

Water User (Community)

Treated Water Storage

Sewage Treatment

Treated Sewage to Waste
(*VARIABLE*)

Treated Sewage Storage

BY-PASS

Saline Water Conversion
(*DEGREE OF TREATMENT VARIABLE*)

VARIABLE

Sewage Recovery System

Inland Ground Water
CONSTANT SALINITY)

D-106c
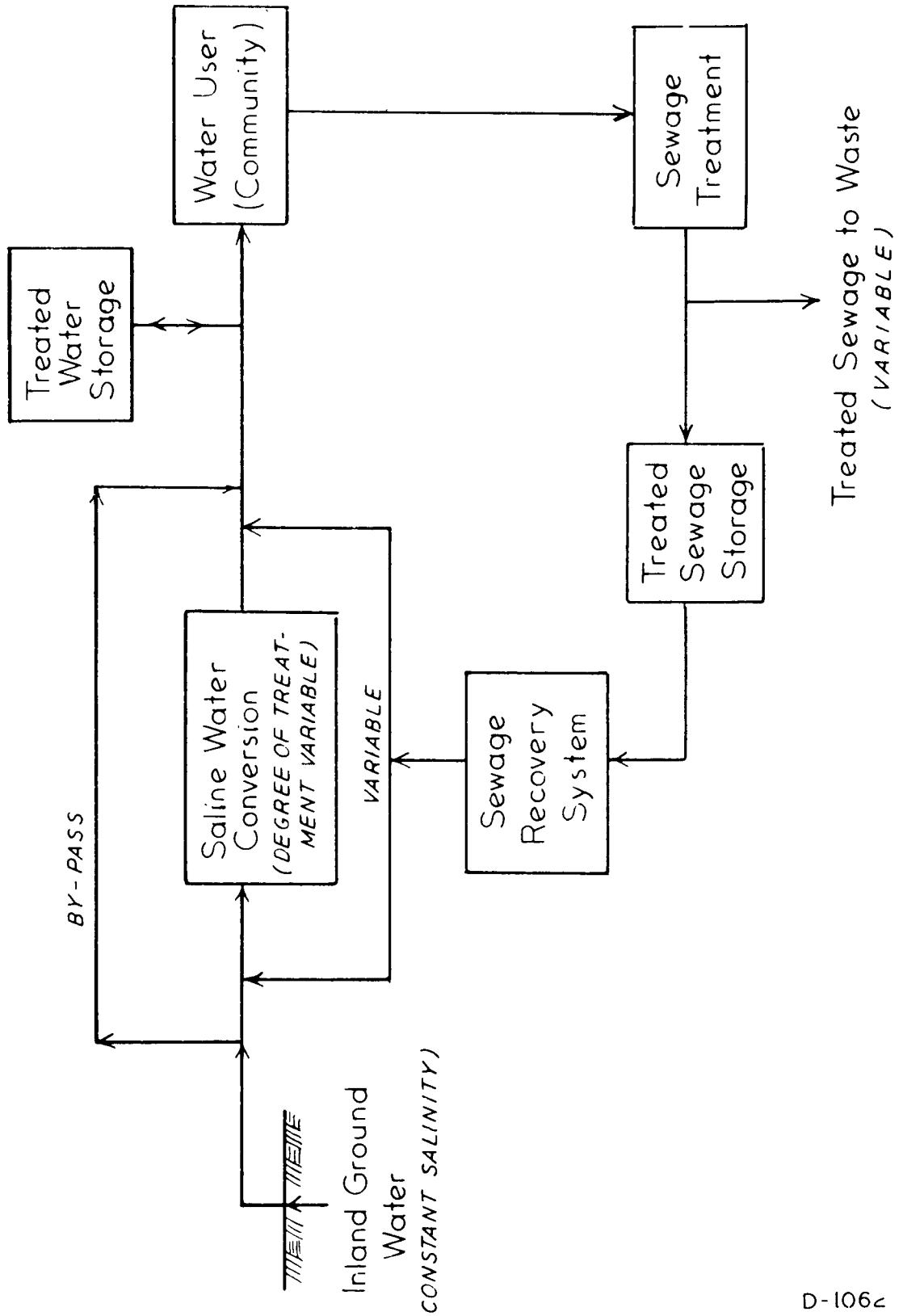
V. PRETREATMENT OF WASTE WATERS FOR RECOVERY IN COMBINATION PLANTS

The recovery of waste waters, both sewage and industrial wastes, in potential combination plants integrating saline water conversion and waste water recovery may require pretreatment of either or both of these supplies. The required pretreatment facilities may, in many instances, be a major factor in the design and economics of the combination plant. Quite possibly, the pretreatment requirements may even determine the feasibility of proposed combination plant pretreatment.

The potential pretreatment requirements for the saline water supplies have been developed and discussed in preceding sections of this report. This section deals with the treatment of waste water, mainly sewage for use in potential combination plants.

There are many factors which influence the type and degree of waste water pretreatment that may be required. To a large extent, these factors have been discussed in the preceding section and only a cursory review will be given here.

In this section, various processes having potential merit as pretreatment measures are reviewed and their possible applications in combination plant schemes are developed. Adsorption, chemical coagulation, and chemical oxidation are discussed in detail. Several miscellaneous methods having potential application are noted. The advances in the field of tertiary waste treatment by the Advanced Waste Treatment Research Program of the U. S. Public Health Service are reviewed. Application of this work to the potential combination plant program is indicated.

In general, there will be no substitute for specific study of potential combination plant schemes to establish pretreatment requirements. There exists a more pressing need, however, to develop and carry out coordinated and comprehensive investigation to establish and quantitatively define factors affecting pretreatment requirements, to evaluate potential pretreatment measures, and to develop the methodology of conducting specific studies. There is a special need to consider pretreatment with regard to public health aspects of the potential combination plants.

A. Pretreatment Requirements

Before considering the specific means of pretreating waste waters for recovery in potential combination plants, it is important to review some of the major factors which establish the overall requirements. These factors have been considered in the preceding section and are only briefly reviewed here.

The quality of the waste water is obviously important. This will be influenced by the source of the waste and the degree of treatment already provided. Of special note is the variability in waste quality.

The quantity of waste water involved in the combination plant scheme is also important. Variations in both the available supply and the demand will influence the design, operation, and economics of pretreatment facilities.

The source and quality characteristics of the saline water supply may be a major factor. This is especially true where the contaminant level in the saline supply makes extensive pretreatment necessary.

Pretreatment requirements will depend on the saline conversion process used and the general arrangement of the combined plant scheme. Blending the waste water with the raw or converted saline water will influence pretreatment criteria.

These, and other, factors will be of major significance in the actual design, operation and economics of various pretreatment facilities that may be required as part of potential combination plants. It is important to recognize that these factors indicate the type of general investigations that will be needed to evaluate various pretreatment methods. The current work of the U. S. Public Health Service in the Advanced Waste Treatment Research Program is providing much valuable data on various "tertiary" treatment methods for sewage. This Program, however, is not designed to consider various aspects of waste treatment that will play an important part in potential combination plants. As is shown later, further investigation is needed and this work should be designed to provide information and data relating to the specific factors noted here. (See Section IV also.)

B. General Pretreatment Design

On the whole, available information and data are inadequate to enable the presentation of specific design criteria for pretreatment facilities serving combination plants. The host of variables influencing the potential combination plant schemes, and, as will be discussed, the lack of adequate data on the possible pretreatment methods makes it difficult to present even general comments. However, since there are very definite needs for major investigative efforts on wastes pretreatment, several general design criteria are offered to serve as guides to this work.

Perhaps one of the most important general design criteria is flexibility. It appears that the quality, and possibly the quantity, of waste to be pretreated will be highly variable in most cases. Any pretreatment system should be designed to accomodate these potential changes with a minimum of disturbance or upset. The facilities should be able to maintain production of a uniform quality effluent even though the quality of the influent, the rate of operation, or both, should vary.

Further, in some instances it may be very desirable to have facilities that are flexible with respect to the quality of the effluent. If a combination plant were designed to have the pretreated waste water blended at varying amounts with the raw or converted saline water, or perhaps both, the pretreatment requirements would vary. In such a case the ability to vary the degree of pretreatment may be important to the technology and economics of the conversion process, and the economy of the combination plant as a whole.

Another possible example where flexibility in the degree of pretreatment might be to advantage is the case where the waste water is to be recovered only during certain periods of the year. During recovery periods, the facilities should produce an effluent of exceptionally fine quality. The degree of treatment during the remainder of the year when the effluent is discharged to waste could be lessened somewhat.

Another general design criteria of importance is the relative balance between capital and operating costs. It appears quite likely that there will be some reasonable latitude available to design facilities for selected balances between capital and operating costs. Again, the factors bringing this about are quality and quantity variations in waste waters.

In many instances, pretreatment facilities should be designed for minimal capital costs. The treatment should be attained through operating cost expenditures. Although a more thorough evaluation of this concept is needed, this general design criteria seems most suited for the type of pretreatment facilities under consideration here.

The combined use of various pretreatment methods is another general design criteria that should be noted. This has been previously suggested in connection with the Advanced Waste Treatment Research Program (481). It is a design concept having significant potential merit since it seems to promote the other concepts of flexibility and balance between costs. Thus, the evaluation of potential pretreatment methods should not overlook the possibilities of combining the methods in series, in parallel, or in integrated units.

C. <u>Adsorption</u>

The use of solid adsorbents to remove impurities from solutions is a long-established and proven technique. Adsorption is recognized as one of the most promising means of removing organic refractory materials from waste waters or other contaminated supplies (445). Major studies on the potential application of adsorption processes are being carried out as part of the Advanced Waste Treatment Research Program of the U. S. Public Health Service (481, 446, 416, 415, 493). Morris and Weber make the following observation (445):

> "There yet remains to be found a simple, inexpensive adsorbent that may be regenerated with ease or that may be discarded completely after one use. If and when this is done, it seems likely that adsorptive processes will be left nearly unchallenged as the logical choice for the further treatment of sewage effluents."

Activated carbon is the most widely recognized adsorbent considered for potential application in the advanced or "tertiary" treatment of both sewage and industrial wastes. Present costs of treatment using available activated carbons are high, however, and considerable attention has been given to the prospect of finding or developing less expensive materials. In general, these studies have indicated that certain less expensive adsorbents are satisfactory for removing specific materials, but they are not adequate for the general organic complexes normally found in sewage. Williamson and others (493) have studied the potential application of many materials in several adsorptive processes and they conclude:

> "No cheap, commercially available solid (such as a mineral or a manufacturer's by-product or scrap) is likely to remove all refractory contaminants found in secondary effluents, at least not as economically as does activated carbon. These solids can, however, be expected to make contributions to advanced waste treatment through removal of specific contaminants."

Adsorbents tested included the following materials: aluminates, carbonates, carbons and coals, ion exchange resins, flyash, metal oxides, phosphates, silicas, silicates, and sulfates.

1. Activated Carbon

Activated carbon has been used in water treatment processes since 1927. The removal of organic matter causing tastes and odors in potable water supplies has been a major use of activated carbon over the years. Corollary to this application is the use of activated carbon to remove organic matter causing operation or process difficulties in industry.

The ability and capacity of activated carbon to remove a wide range of organic contaminants from water is reflected by the adoption of the "carbon filter" as an analytical standard by the U. S. Public Health Service. In this technique, a large quantity of water (the amount depending on the suspected organic loading) is filtered through a column of granular activated carbon. The carbon is air-dried and the adsorbed organics are extracted by chloroform. More detailed information on the development and application of this technique is available in the literature (474, 440).

The organic materials removed from the carbon by chloroform extraction are termed the "Carbon Chloroform Extract" (CCE). The 1962 U. S. Public Health Service Drinking Water Standard (480) established a recommended limit of 0.2 mg/l on CCE. It should be noted that the carbon filter does not adsorb all organics from the sample, nor does the chloroform solvent recover all of the adsorbed material. Reportedly, the CCE method does account for the taste- and odor-producing components of water.

The significance of the use of the CCE methods is twofold. First, it emphasizes the ability of activated carbon to adsorb organic materials; second, it provides a well-established basis for measuring contamination levels in contaminated waters.

In general, previous studies on the use of activated carbon in "tertiary" waste water treatment have indicated relative advantages for this process as compared to others. Perhaps its greatest advantage is the ability to effectively remove a great variety of organic materials such as may be found in secondary sewage effluents. Other notable treatment processes require the presence of specific materials in the waste to assist in the process or follow through with the reaction. Various foaming techniques, for example, require the presence of surface active materials and, to a large extent, the treatment is effective in removing only such materials. Oxidation is effective only for those materials which are susceptable to oxidation by the chemicals used. Chemical coagulation is influenced greatly by the presence or absence of certain material in the waste.

The distinct advantage of activated carbon treatment methods is widely recognized. However, the overriding disadvantage - cost - is also widely recognized and many of the current investigations are directed toward this consideration. Studies are also being directed toward the development of preliminary design criteria for the various methods of utilizing adsorbents, particularly activated carbon, in teritary waste treatment. Most of this work is being conducted or sponsored by the Advanced Waste Treatment Research Program of the U. S. Public Health Service (481, 445). Some industrial and private investigations are also being carried out.

The initial cost of activated carbon is relatively high. Schanz and Parry (467) indicate typical delivered prices (1961) for various grades of activated carbon. Powdered carbon for municipal water treatment is shown to cost 7 to 9 cents per pound. Granular carbon for industrial water treatment is shown to cost 25 to 50 cents per pound. This consideration, the high initial cost of the activated carbon, detracts from the prospects of using this material in waste treatment.

2. Regeneration

As evidenced by the technique employed in Carbon Chloroform Extract analytical procedure, the organic materials adsorbed on and into the activated carbon may be removed, at least partially. The possibility of economically regenerating the carbon by removing the adsorbed organics is a major factor in the overall economics of waste treatment by activated carbon processes. There are two basic methods or regenerating activated carbon, thermal and chemical, both of which cause the adsorbed organics to be removed from the carbon and destroyed (oxidized). The potential application of regenerative procedures in waste treatment systems is not yet established. In the water treatment field, regeneration is seldom practiced.

Flentje and Hagen (391) report on the status of activated carbon regeneration in the water treatment field. They note that the only known and acceptable means of completely restoring carbon is by thermal reactivation. The capital investments required are great, however, and thermal reactivation is seldom done in water treatment practice. In general, it is found cheaper to replace the exhausted carbon. Carbon filters are sometimes steamed or chemically treated and backwashed, but this is only a partial or intermediate regeneration and the capacity of the activated carbon is only partially restored.

The potential application of regenerative procedures for activated carbon may be feasible. Chemical regeneration is unlikely, however, based on recent studies by Johnson and others (415). Of the following chemical oxidants evaluated as regenerants:

> Chlorine
> Bromine
> Potassium Permanganate
> Sodium Dichromate
> Sodium Persulfate
> Potassium Persulfate
> Sodium Peroxide
> Hydrogen Peroxide
> Ozone

only hydrogen peroxide appeared to have regeneration potential. In an approximate cost analysis based on the use of hydrogen peroxide, the investigators found (415):

> ".....calculations can be made of the cost required to regenerate carbon by chemical oxidation. On a pound-for-pound basis, it would cost $0.53 to regenerate activated carbon costing $0.50. Obviously, these figures indicate that it would be cheaper to discard the exhausted carbon than to attempt to regenerate it by means of chemical oxidants. If further calculations are made on the basis of 70 percent oxidant efficiency and declining efficiencies with multiple loading and regeneration steps, the economics appear even more unfavorable."

> "It is apparent that this uneconomical aspect of chemical-oxidant regeneration of carbon for use in advanced waste treatment could be altered if cheaper carbon and a cheaper, more efficient chemical regenerant could be found."

Thermal regeneration, on the other hand, has greater promise. Although there is some loss of carbon and some decrease in adsorption capacity, regeneration is effective. The capital costs for thermal regeneration facilities may not be excessive where very large quantities of activated carbon are involved. Studies of a preliminary nature have been conducted (416) but further investigations are needed to establish the technical and economic parameters of thermal regeneration.

3. <u>Process Design</u>

Adsorptive processes may be arranged in three basic ways - packed bed, slurry, or fluid bed. A potential packed-bed arrangement is shown by Exhibit V-1. Theoretically, the use of an adsorbent is most efficient when packed-bed column operations are used. The loading on most of the carbon in the bed is at or near the maximum as controlled by the contamination level in the waste influent. Exhibit V-2 describes the relationship between contamination levels in the waste influent and effluent and the condition of the bed during the adorption process. It should be noted that the effluent from the bed remains free of contaminate until the "front" has approached closely the effluent end of the bed.

There is considerable experience with the use of activated carbon in a packed-bed column process, but very little is in the waste treatment field. Extensive research and development is underway in the Advanced Waste Treatment Research Program, but suitable design data are not yet available for large-scale facilities. Significant pilot-plant studies have been conducted and reported (59) for carbon columns to be used following other waste treatment at Lake Tahoe in California. The data obtained from these investigations indicate the carbon columns to be an effective and efficient treatment method. It is hoped that the full-scale facilities will be studied in detail and the results reported.

Adsorption by the slurry process is described in Exhibit V-3. Here the carbon (usually powdered) is blended with the contaminated waste and then separated by sedimentation or by filtration. This process is commonly used with good success in water treatment to remove organics associated with tastes and odors. Usually the carbon treatment is a minor adjunct to the general treatment facilities and little, if any, special equipment is necessary.

Theoretically this type of treatment is inefficient. The contaminant loading on the carbon is essentially at or near a minimal level since this would be controlled by the allowable contaminant level in the effluent. Where the carbon is removed by filtration, this is not necessarily true since the carbon layer built up on the filter tends to act somewhat as a packed-bed column.

SCHEMATIC DIAGRAM OF PACKED - BED
ADSORPTION COLUMN

EFFLUENT

ADSORPTION

MEDIA IN

PACKED BED

FLOW

INFLUENT

EXHIBIT - V - 2
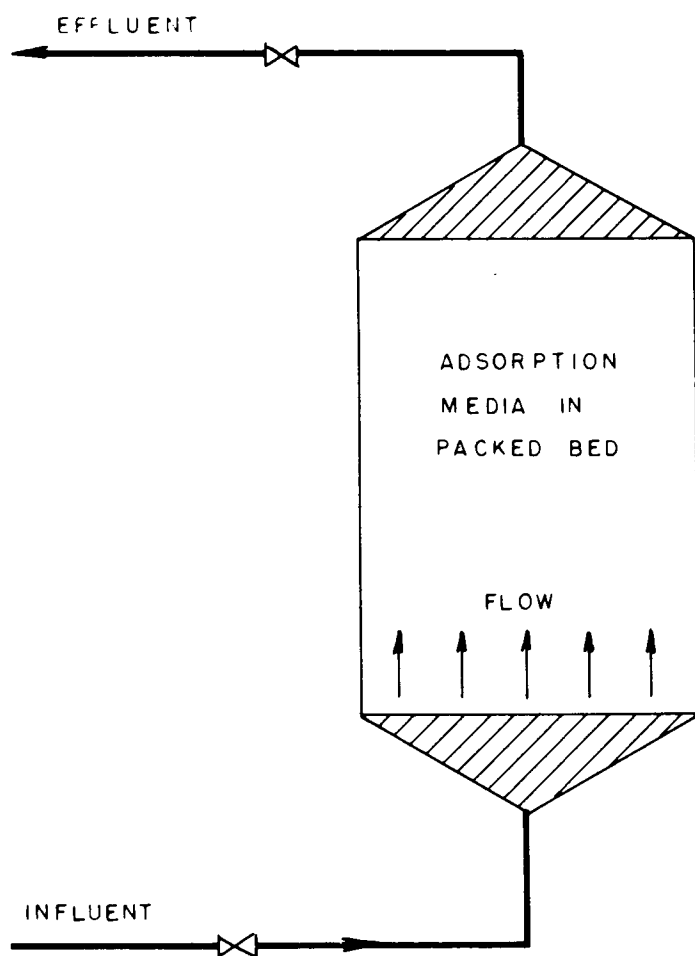
MECHANISM OF CONTAMINATE REMOVAL IN A PACKED - BED ADSORPTION COLUMN

C = 0   EFFLUENT CONTAMINATE LEVEL   C = 0

VIRGIN ADSORBENT

FLOW

TRANSITION

ADSORBENT EXHAUSTED

TIME = 5
(SHORTLY AFTER START OF OPERATION)

TIME = 10

C = 0   EFFLUENT CONTAMINATE LEVEL   C = 0 (+)

VIRGIN ADSORBENT

FLOW

TRANSITION

ADSORBENT EXHAUSTED

TIME = 20

TIME = 40 (-)

SHEPPARD T. POWELL AND ASSOCIATES

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EXHIBIT-V-3
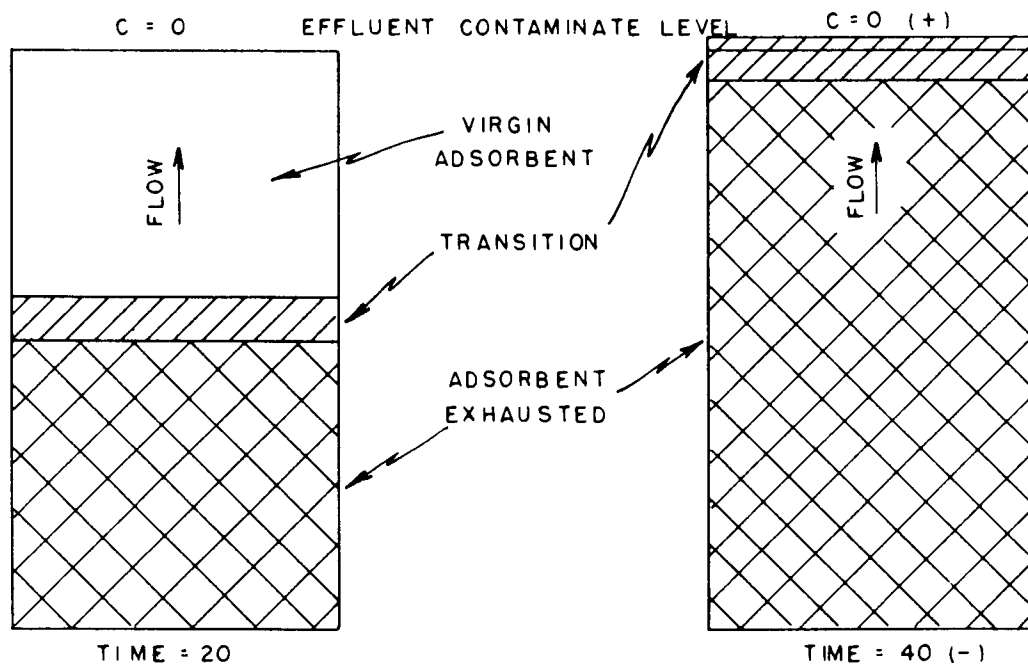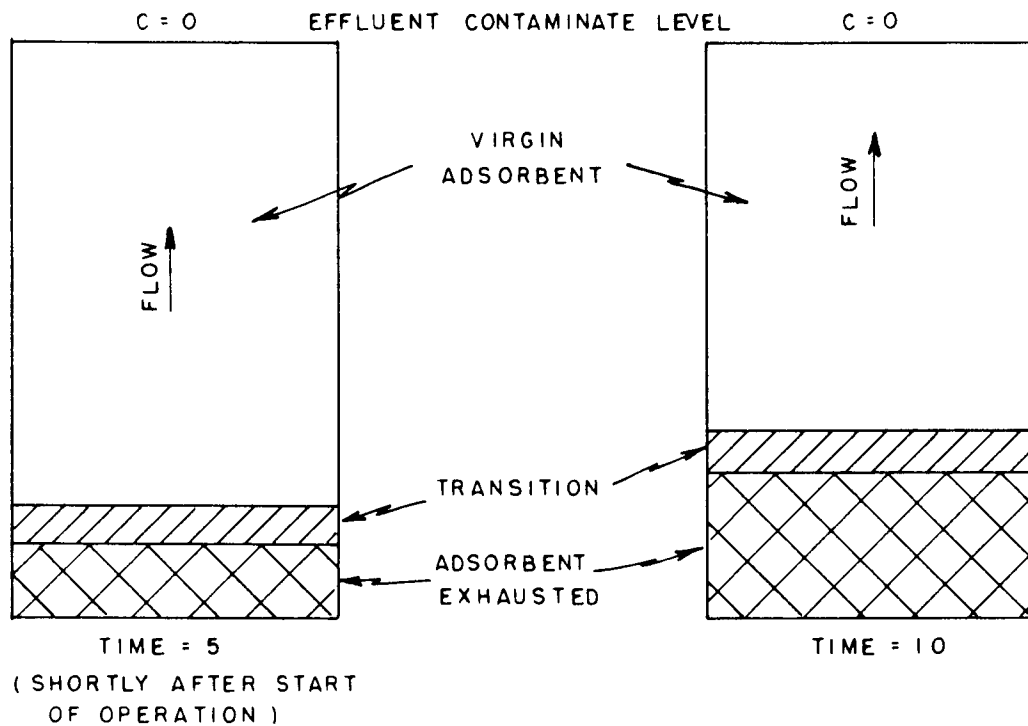
SCHEMATIC DIAGRAMS OF SLURRY
ADSORPTION PROCESSES

SHEPPARD T. POWELL AND ASSOCIATES

B-1050
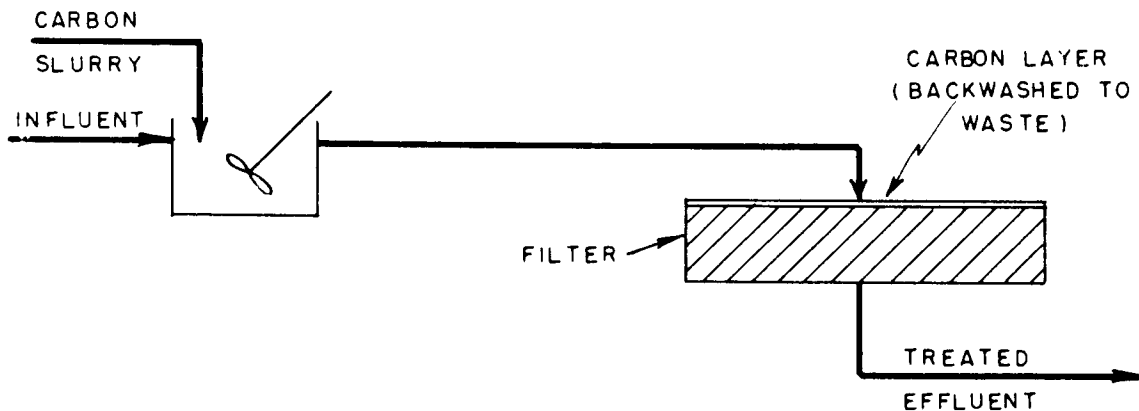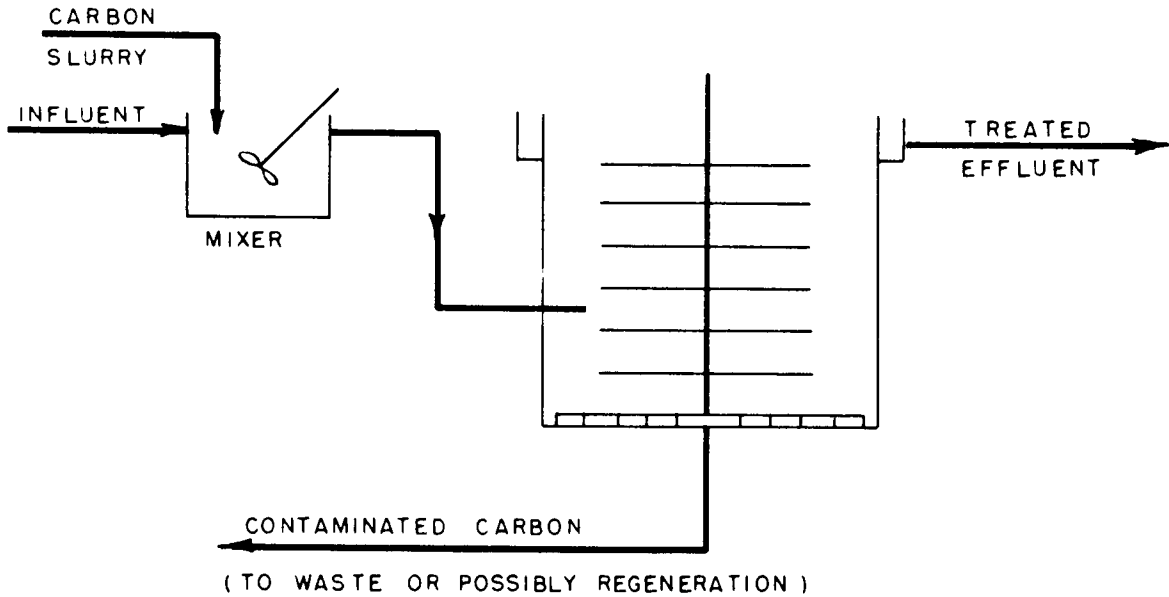
Very generally, the design concepts for using slurried carbon in the water treatment field do not seem applicable to the pretreatment of wastes for potential combination plants, except in unusual cases. In one particular instance a powdered carbon slurry is fed to extensively treated refinery waste water ahead of final filters (392). This is a polishing treatment to remove final traces of phenol and color from the waste water. Potential applications of carbon in this manner will no doubt occur, but extensive use in this fashio appears unlikely.

A most promising application for slurry carbon (or other adsorbent) treatment of waste waters has been noted by Williamson and others (493). They have conducted, as part of a broad study, preliminary experiments with solids adsorbents in a sludge blanket process and state (493):

> "This study demonstrated the feasibility, at least from a mechanical standpoint, of incorporating solid adsorbents into the sludge blanket process for water treatment in the presence or absence of coagulants. The sludge blanket process can combine the virtues of the finely divided, large-surface-area forms of solids and flocs (normally associated with batch treatment techniques or vacuum filtrations) with the maintenance of relatively high flow rates, normally associated with columnar-bed techniques."

To some extent, some potential applications of slurry carbon treatment to waste waters do not differ greatly from fluid-bed processes. Where counter-current* systems are employed, there is little to distinguish between the two, except perhaps the method of removing the exhausted adsorbent from the waste. A process which might be considered as being somewhat in this borderline catagory is one of several under investigation by an industry-process firm** (381). A general description of the type of process found most promising - counter-current slurry adsorption - is given by the schematic diagram of Exhibit V-4. Other adsorption contact systems considered by the investigators were: (1) flotation, (2) diffusion, (3) packed-bed column, and (4) upflow column.

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*In adsorption processes, counter-current refers to a system where the adsorbent and the liquid move in direction opposite to one another (see Exhibit V-4).

**Dorr-Oliver, Inc. under the sponsorship of the U. S. Public Health Service Advanced Waste Treatment Research Program.

SCHEMATIC DIAGRAM OF COUNTER - CURRENT
SLURRY ADSORPTION PROCESS
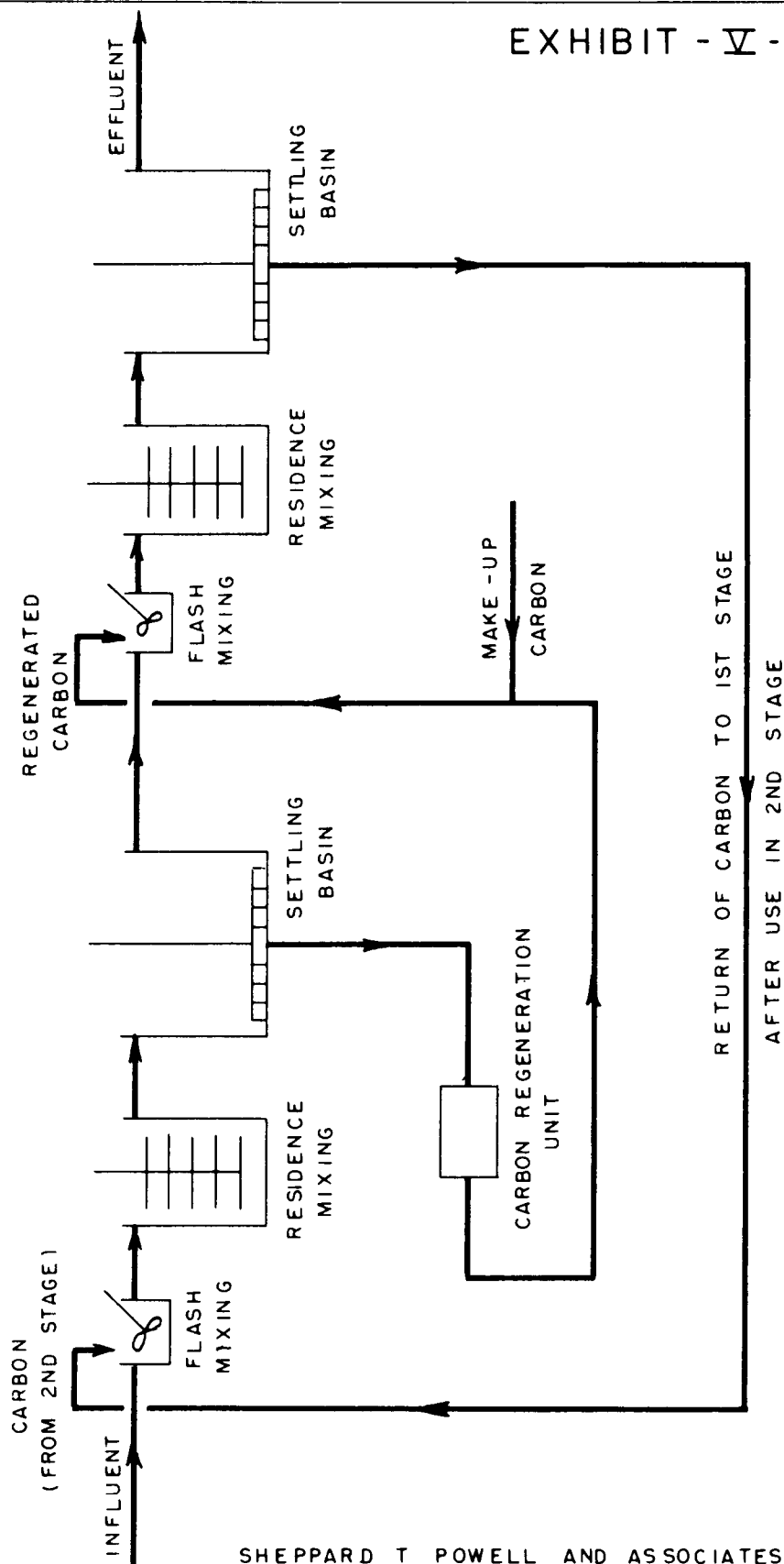
FIRST STAGE

SECOND STAGE

INFLUENT

CARBON
(FROM 2ND STAGE)

FLASH MIXING

RESIDENCE MIXING

SETTLING BASIN

REGENERATED CARBON

FLASH MIXING

RESIDENCE MIXING

SETTLING BASIN

EFFLUENT

MAKE-UP CARBON

CARBON REGENERATION UNIT

RETURN OF CARBON TO IST STAGE

AFTER USE IN 2ND STAGE

SHEPPARD T POWELL AND ASSOCIATES

B - 1054

Fluid-bed counter-current processes for waste pre-treatment seem promising for application in potential combination plants. The basic elements of such a process are described by Exhibit V-5. This process is able to efficiently and effectively utilize the adsorption capacity of the carbon. In general, the process incorporates the respective advantages of the packed-bed and the slurry processes. It differs from the counter-current slurry process shown by Exhibit V-4 only to the extent that it is continuous and does not involve successive stages.

This process seems to offer considerable promise as a means of waste (or saline water) pretreatment. The general design criteria noted previously would probably be satisfied by this process, although the technology and economics cannot yet be fully developed.

Joyce and Sukenik (416) have investigated the requirements of a fluid-bed counter-current adsorption process. Exhibit V-6 shows the general aspects of such a system based on a flow sheet prepared by these investigators.

A somewhat similar concept of adsorption treatment has been presented by Morris and Weber (446) in another report of the Advanced Waste Treatment Research Program. The system differs only in that the direction of waste flow is upward. They state (446):

> "For full-scale application, columnar operation is envisaged, preferably continuous. Continuity of operation might be achieved by backflow operation with fresh carbon being fed to the top of the column and exhausted carbon being withdrawn from the bottom. The polluted water would flow counter-currently to this, entering at the bottom and overflowing at the top after renovation. The advantage of this form of operation is that it allows the use of small particles without excessive headloss through the bed."

One of the process manufacturers offers an activated carbon system (436) which is designed generally along the lines of that proposed by Morris and Weber. One exception is the intermittent removal and replacement of carbon from the fluid-bed.

EXHIBIT - V - 5

SCHEMATIC DIAGRAM OF FLUID - BED COUNTER - CURRENT ADSORPTION PROCESS

INFLUENT

ACTIVATED CARBON

FLUID BED

USED CARBON

(TO REGENERATION
OR POSSIBLY TO WASTE)

CARBON SLURRY

(USUALLY GRANULAR)

BED SUPPORT

EFFLUENT
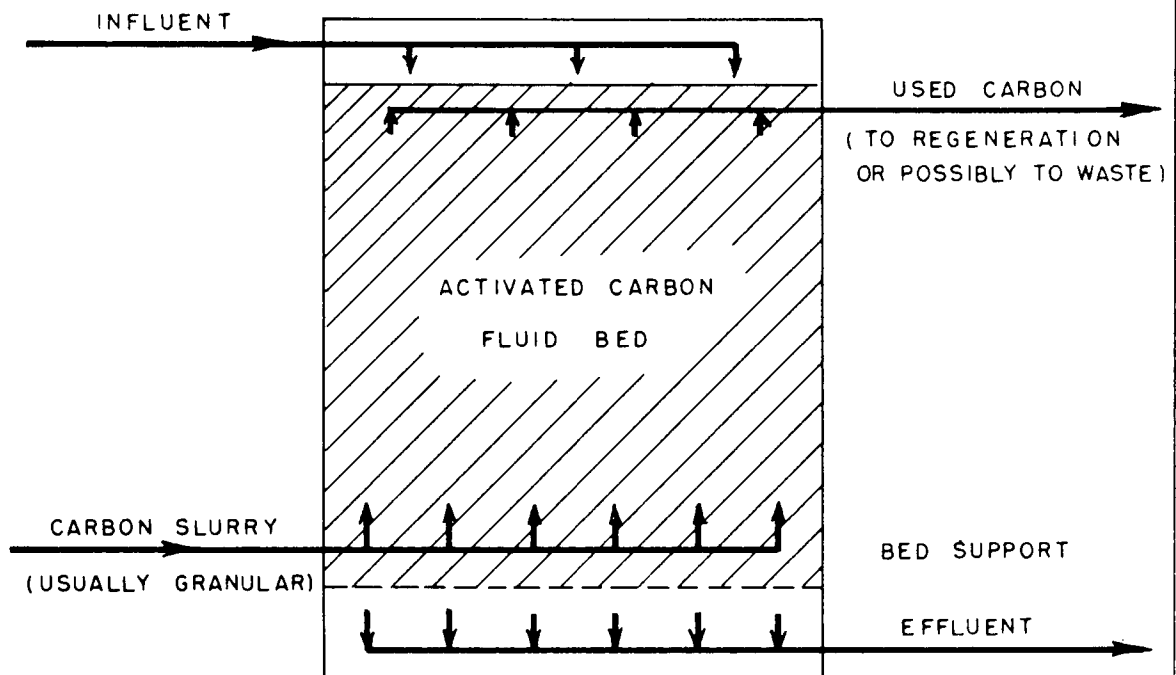
EXHIBIT - V - 6

WASTE PRETREATMENT FLOWSHEET

FLUID - BED COUNTER - CURRENT ADSORPTION SYSTEM

ADAPTED FROM REFERENCE 416

CARBON REGENERATION

DEWATERING SCREEN

EXHAUSTED CARBON

EFFLUENT

ADSORPTION BED

MAKE - UP CARBON

INFLUENT

CARBON STORAGE
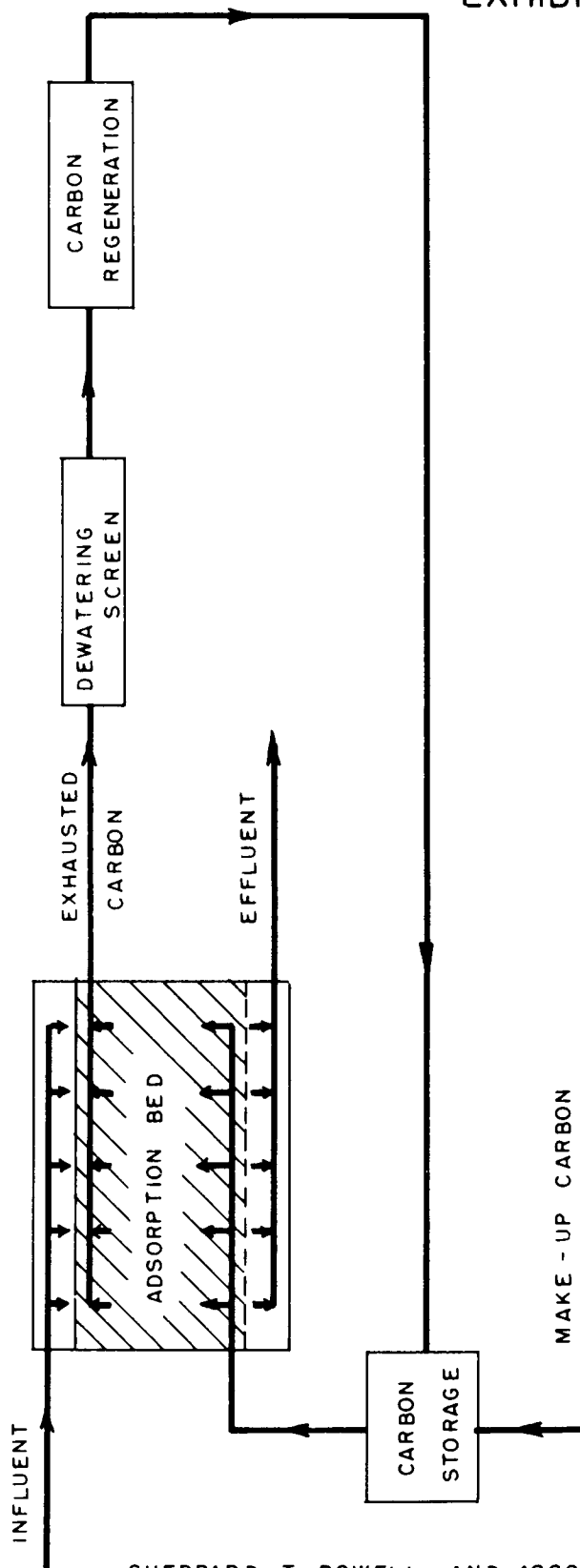
SHEPPARD T POWELL AND ASSOCIATES

In summary, these general discussions indicate that pretreatment of waste waters by adsorption is a promising means of removing undesirable organic materials. Activated carbon is far superior to other tested adsorbents, but the cost of carbon is high. The economics of adsorptative processes using activated carbon will depend to a large degree on the development of an effective and economical method of successive regeneration. Chemical regeneration is not now promising. Thermal regeneration appears to be suitable, but further studies are necessary.

Although adsorptive processes appear promising and have been widely used in process industries, generally for purposes other than waste treatment, their current application on a major scale to waste water treatment is very limited. Research and development is underway and valuable information is being generated, but data are not presently available to evaluate adsorption processes as potential schemes for pretreatment of waste waters for use in combined plants.

C. Chemical Coagulation

Chemical coagulation is a long-established and widely used method of treating water supplies to remove suspended and collodial materials. Briefly described, the process involves the addition of specific chemicals (called coagulants) to the water causing aggregation and adsorption of the materials into larger particles called "floc." The floc particles are usually allowed to grow in the gentle mixing conditions of flocculation vessels and they are then removed by sedimentation. In recent years, the use of polyelectrolytes as coagulant aids has become an important technique in water clarification.

Chemical coagulation is not new in the waste treatment field. Early application in Europe date back some 100 or more years. There are some sustained interest in chemical coagulation of sewage in the United States in the 1930's and early 1940's, but this interest has generally subsided as biological treatment methods have been more fully developed (350). This method of treatment is still being used at some locations, but in several instances it is used only seasonally. Chemical coagulation is broadly classed as an intermediate sewage treatment method (see Section IV).

The use of chemical coagulation for industrial waste treatment appears to be increasing over recent years. This is largely due to the development of the newer synthetic polyelectrolytes for use as coagulant aids. Another major factor, of course, is the increasing pressure for better industrial wastes treatment and the inability of biological processes to effectively cope with some wastes.

Chemical coagulation has distinct merit as a possible means of pretreating waste waters prior to their use in potential combined plants. This application is somewhat limited, however, since chemical coagulation is relatively ineffective in removing dissolved organic materials. The process would, under some circumstances, have to be employed with other pretreatment methods, such as adosrption or oxidation. This appears to be the most promising role of chemical coagulation in waste pretreatment, and it is in this area that studies are necessary. Where dissolved organic materials are not deleterious, of course, this process may be adequate by itself.

Some work has been reported by the U. S. Public Health Service Advanced Waste Treatment Research Program on chemical coagulation of sewage. Williamson and others (493) studied the use of various coagulants and coagulant aids as a means of treating sewage effluents from secondary treatment facilities. While this work was preliminary, and did not yield conclusive results for detailed evaluations of chemical coagulation, there appears to be considerable merit to this type of treatment. Of particular note is the recognition by Williamson and his co-workers of the combination of various treatment methods into a combined pretreatment scheme. They state (493):

> "Coagulation agents fed as liquids or in solution hold more promise than do solid adsorbents in advanced waste treatment. Batch coagulations are not practical for waste treatment, such as tertiary waste treatment, but continuous coagulation procedures such as the sludge blanket process should make substantial contributions to this field.

> "Lime, ferric chloride, and ferric sulfate, in conventional use now, should continue to contribute to waste treatment technology. These materials contribute inorganic anions to the treated effluents, and these must be disposed lest they, too, build up in objectionable concentrations with re-use of the water.

> "Coagulation in the presence of most adsorption and ion exchange materials is technically feasible in the sludge blanket process for water treatment. Combining the specific properties of solid adsorbents and ion exchangers with those of coagulants might result in single tertiary treatments for the removal of residual or refractory contaminants from various secondary effluents. Separating the components employed in such mixtures could be accomplished by differences in their settling characteristics. Regeneration of the components by the burning off of adsorbed contaminants, or by other techniques, could then be accomplished. This process could be as cheap as, or cheaper than, treatments involving activated carbon."

The potential merits of such treatment are also pointed
our in a report by Morris and Weber (445). They note the use of
chemical coagulation in industrial processes and in industrial
waste treatment. The potential use of chemical coagulation in
sewage effluent treatment is recognized by the authors, who
state (445):

> "The main problem with the use of coagulation
> in the further treatment of sewage effluents is
> its relative ineffectiveness, or lack of knowl-
> edge concerning its effectiveness, in the removal
> of soluble impurities. ... However, the operation
> of the process of coagulation is so simple and
> economic factors appear so attractive that
> further investigations of modified processes
> or of new coagulating substances seems warranted."

Adequate data are not presently available to evaluate
the use of chemical coagulation as a pretreatment method for
waste waters used in potential combination plants. Some general
comments may be offered to indicate the potential applications
of this process and to describe the nature and scope of inves-
tigative efforts that would be necessary.

It has been previously noted that chemical coagulation
of sewage, in most instances, would have to be used in con-
junction with another method of pretreatment. Two basic schemes
for such conjunctive use seem appropriate.

The first scheme involved the chemical coagulation of
a secondary treated sewage effluent to remove suspended and
collodial materials. The waste thus treated would then be
passed to a second stage of the pretreatment process for
removal of organics. This second stage could possibly be an
adsorption or oxidation process. This scheme is generally
described by Exhibit V-7.

The type of system described by Exhibit V-7 may be
economically desirable for some combination plant designs.
Where the saline water supply also requires clarification by
chemical coagulation, the two supplies could be combined into
the same facilities. Combining the saline and waste supplies
may be beneficial to the coagulation process. Clarifying the
waste water may considerably reduce the capital and operating
costs of the second stage system. The actual value of such a
scheme would have to be evaluated on the basis of the specific
features of the potential combined plant.

CHEMICAL COAGULATION OF WASTE IN A TWO-STAGE SERIES
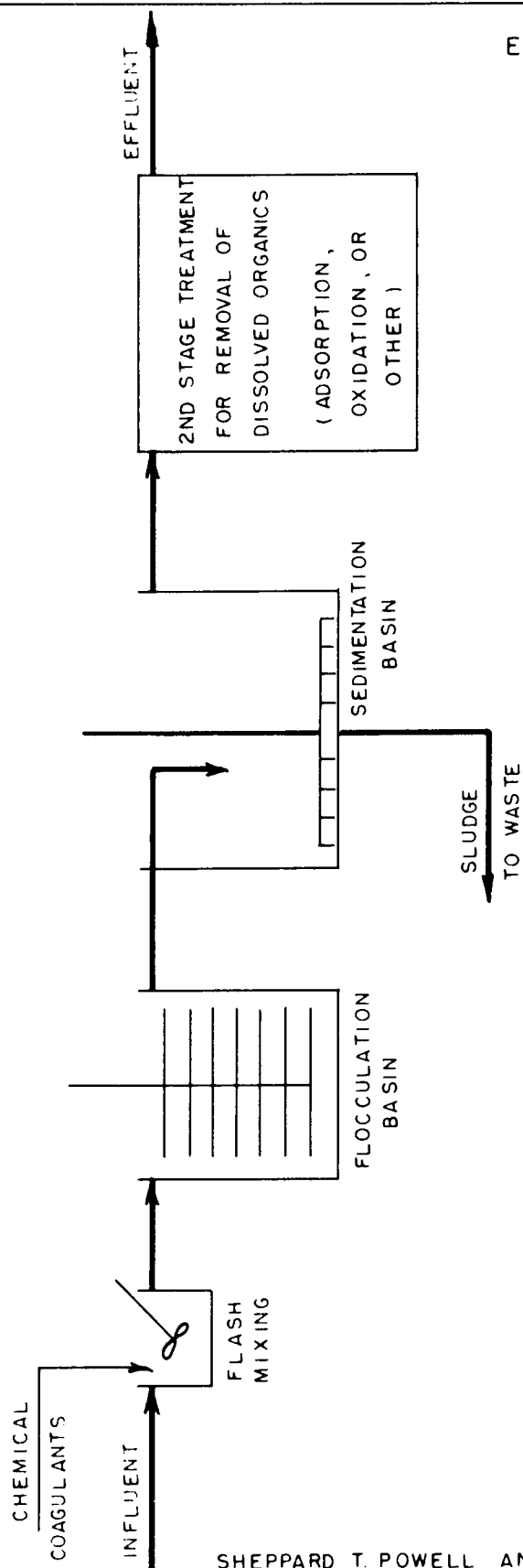PRETREATMENT SYSTEM

EXHIBIT - V - 7

CHEMICAL COAGULANTS

INFLUENT

FLASH MIXING

FLOCCULATION BASIN

SEDIMENTATION BASIN

SLUDGE TO WASTE

2ND STAGE TREATMENT FOR REMOVAL OF DISSOLVED ORGANICS
(ADSORPTION, OXIDATION, OR OTHER)

EFFLUENT

SHEPPARD T. POWELL AND ASSOCIATES

A second general scheme would be the integration of chemical coagulation and some other process to effect removal of suspended, collodial, and dissolved (organic) materials. This is generally shown by Exhibit V-8 where activated carbon is applied to remove the dissolved organics. This would seem to be a very flexible system that could be operated to achieve specific effluent quality as desired. Also, the integrated system may involve a minimum of capital costs.

A considerable amount of general study, followed by bench- and pilot-scale investigations, will be necessary to clearly establish the technology and economics of chemical coagualation as a pretreatment method. This appears to be a promising pretreatment method, especially if used in conjunction with other treatment methods to remove soluble materials.

D.   Chemical Oxidation

Suitable data on the potential use of chemical oxidation as a method of pretreating waste waters prior to their use in combination plants are meager. Chemical oxidation has been found effective in treating water containing some interfering organic materials, particularly those associated with taste and odors in water supplies. Both atmospheric and chemical oxidation have been employed to assist in precipitating iron and manganese from water supplies.

In the treatment of waste waters, however, it is anticipated that some, if not most, of the organic materials will effectively resist chemical oxidation with practical and feasible oxidants. Such treatment possibilities have been reviewed under the Advanced Waste Treatment Research Program of the U. S. Public Health Service (445) and little promise is offerred based on available data. Williamson and others (493) attempted chemical oxidation of treated sewage, but found poor results. Considerable difficulty was experienced in evaluating the experiments because the measure of contamination (COD) is, in itself, a chemical oxidation procedure.

Some indication of the ineffectiveness of chemical oxidation is given by the discouraging results of attempts to chemically regenerate activated carbon containing organic matter adsorbed from treated sewage (415). The oxidants tested were: chlorine, bromine, potassium permanganate, sodium dichromate, sodium persulfate, potassium persulfate, sodium peroxide, hydrogen peroxide and ozone. Chlorine dioxide, a well-known oxidant, was not tested.

INTEGRATION OF CHEMICAL COAGULATION AND ACTIVATED CARBON ADSORPTION
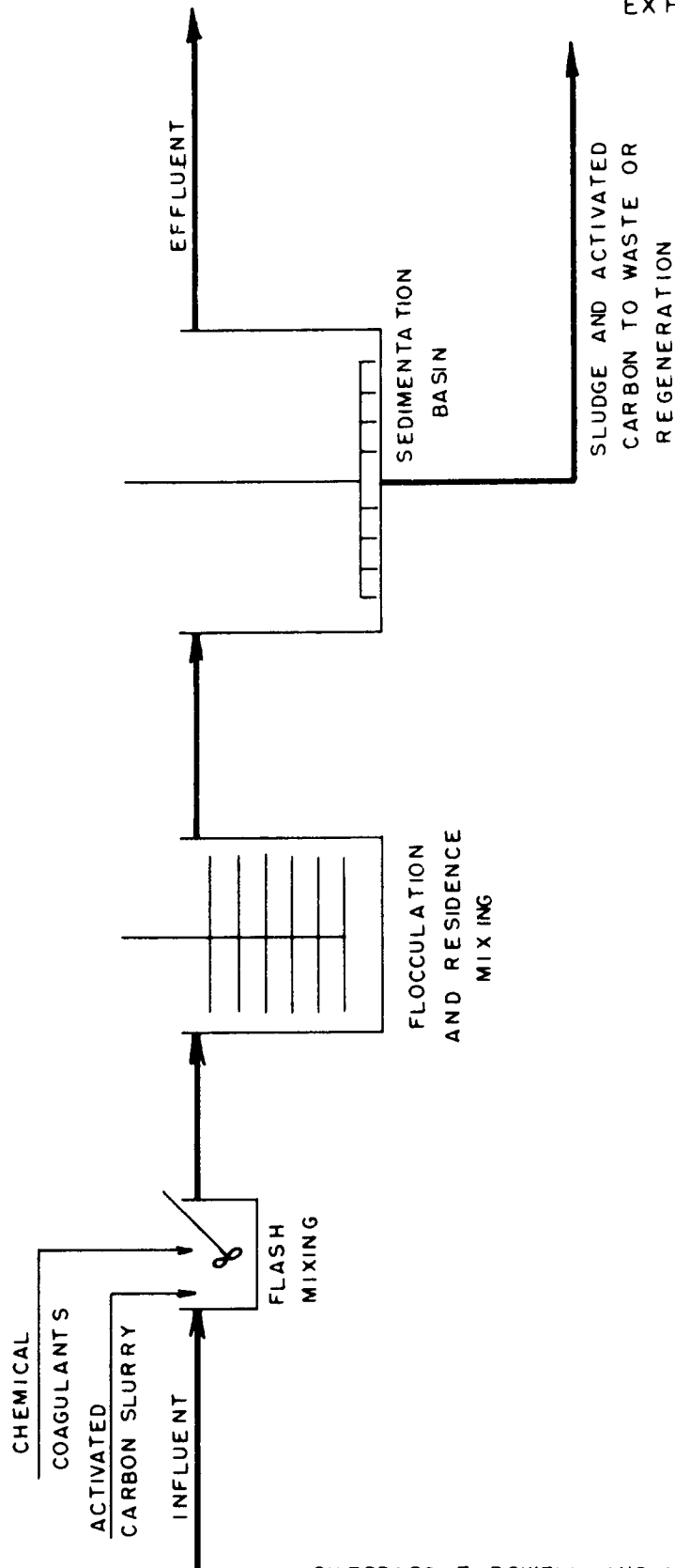
IN SEWAGE PRETREATMENT

EFFLUENT

SLUDGE AND ACTIVATED
CARBON TO WASTE OR
REGENERATION

SEDIMENTATION
BASIN

FLOCCULATION
AND RESIDENCE
MIXING

CHEMICAL
COAGULANTS

ACTIVATED
CARBON SLURRY

INFLUENT

FLASH
MIXING

SHEPPARD T. POWELL AND ASSOCIATES

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While chemical oxidation appears to lack real potential as an individual pretreatment method, there may be some merit to this type of treatment when used in conjunction with other methods. Chemical oxidation may be effective in removing organic materials from sewage previously treated by chemical coagulation and settling (see Exhibit V-7). The use of chemical oxidation following an adsorption process may make it possible to use adsorbents less expensive than activated carbon. These concepts are still somewhat speculative. Some limited study of chemical oxidation in conjunction with other pretreatment methods is justified. Existing data are inadequate to evaluate the potential effectiveness of such treatment.

E. Miscellaneous

There are a number of miscellaneous methods of treating water that may have potential application as pretreatment methods in combination plants. For the most part, these potential methods have not been explored in more than a preliminary fashion by various investigators. In general, none of the miscellaneous methods would be adequate individually in effectively removing detrimental materials from typical waste waters.

The U. S. Public Health Service has studied "tertiary" treatment with saline water conversion processes as part of the Advanced Waste Treatment Research Program. The processes under study are electrodialysis, evaporation, solvent extraction, emulsion separation, freezing, hydration, ion exchange, and electrochemical degradation. Brief descriptions of these processes are given in a Summary Report (481) on the Program. A foaming process is also under consideration.

Specific investigations have been carried out on the freezing process (361), foaming process (465), and distillation process (397, 449). All of the reported work is in the early stages of development.

It should be pointed out that the conversion processes being studied for waste water treatment are not likely to be used for waste pretreatment where a combined plant scheme is involved. A conversion process of some kind would be used, but this would be primarily for treating the saline water supply. Of course, the waste water may be treated in a conversion process, along with the saline water, but this is not "pretreatment" in the sense of this report. Of the several miscellaneous methods mentioned, therefore, only foaming has any significance here.

Foaming will remove certain organic materials from waste waters. This method of waste treatment is now employed in some instances. In activated sludge treatment foaming is incidentally achieved. There is some possibility that foaming techniques may be applicable in waste water pretreatment, but this would most likely be in conjunction with other treatment methods. In such cases, foaming would probably be used as a preliminary treatment. There may be some limited instances where foaming would be adequate if it were followed by treatment within the conversion process. At the present time, it is not possible to objectively evaluate the place that foaming might have in wastes pretreatment.

Another possible treatment method is the "separation bed." This bed resembles outwardly the conventional rapid-sand filter used extensively in water treatment. There is a major difference, however, in that the gradation of filtering material (sand and gravel) is reversed. In the separation bed, the coarser materials are at the top and the finer sands are at the bottom. This permits the entire depth of the bed to effectively act as a filter.

Conley and Pitman (378, 379) have recently presented results of tests on such filters for water treatment. They reported favorable results for the "inverted filter" as compared to the conventional sand filter. In a discussion of one report (378), John R. Baylis noted experiments in the 1930's on such filters. A recent report notes the marked increase in water treatment plant capacity by the modification of the conventional filters and the use of a flocculent immediately ahead of the filters.

The findings of these studies seem to indicate that such filters may have application in waste water treatment, whereas the conventional rapid-sand filter is normally not suitable. Pilot studies of the separation bed for waste treatment system have been carried out by Culp (59) in the work at Lake Tahoe. He has reported that pilot studies indicate these beds to provide effective treatment of secondary effluent ahead of carbon adsorption columns.

It appears that such filters have potential merit as a pretreatment method. Some preliminary treatment of the waste water may be necessary before it is applied to such units, even when the waste is secondary sewage effluent. Furthermore, some after-treatment may also be required, such as in the case of the Lake Tahoe studies.

VI. APPLICATIONS AND LIMITATIONS OF CONSTRUCTION MATERIALS

It is well recognized from industrial and other experience that the materials used in process design are a major factor in the technology and economics of water-related processes. Difficulties experienced in fresh water systems are multiplied several fold in brackish or sea water systems, especially in the presence of added contaminants. These matters have not gone unnoticed in the design and operation of existing saline water conversion facilities and the operating reports have attested to the importance of materials selection in such designs. A major factor has been the corrosion of metals.

The selection of particular materials, metals or alloys for use in saline water conversion plants has been influenced in large measure by their performance, relative cost and the effect of their cost on the overall cost of a particular plant or process. The designers of the demonstration plants undoubtedly would have preferred to use non-ferrous materials, for many services, but by so doing would have skyrocketed the capital cost of the plants with the danger that the projects might never have proceeded. Instead, they trod a narrow path using non-ferrous materials on only the severest services of the systems and took calculated risks with ferrous materials elsewhere.

A. General Considerations

The chemical, biological and fouling characteristics of sea water or brackish water must be evaluated over a sufficiently-long period to establish the effects of a particular water source on materials of construction. This must include evaluation under different conditions of operation. For example, the effects of temperature, velocity and geometric arrangement of the parts involved are important matters for consideration when selecting the more suitable materials for particular locations in the unit. Rates of corrosion or other types of material disintegration are of particular interest.

A survey of available information has established that:

1. Tabulation and classification of data on corrosion or other significant action by saline waters requires a search of scattered, widely distributed information.

2. The preponderance of information on sea water concerns scale control with lesser amounts available on the effects of saline waters, particularly when heated, on various materials.

3. Assembly of comprehensive information on per-
formance of metals and other materials in brackish water and
sea water, especially when heated and containing variable
amounts of contaminants, requires very detailed investigation.

Assemblies of such information should include the
less-expensive metals or other materials in common use. These
include carbon steel, steel alloys with low percentages of
alloying elements, copper, copper alloys, and alloys of
aluminum. Also there should be included non-metallic materials
such as concrete, re-inforced fiber glass and other synthetic
resins.

Plastic or plastic-lined materials may be classified
as inexpensive when used in certain equipment under suitable
water and operating conditions that may be more aggressive to
the metals commonly in use. However, as a general rule, most
plastic materials have lower service temperature limitations
than many of the metals.

B. Factors Influencing Corrosive or Erosive Action

It is known that some major chemical and/or
mechanical factors influencing corrosive or erosive action
on metals and some other materials by sea water or brackish
water are the concentrations of:

1. Total solids or salinity, as compared with
less aggressive non-saline fresh water

2. Chlorides

3. Chlorine as hypochlorite

4. Bicarbonates

5. Dissolved oxygen

6. Ammonia

7. Sulfides

8. Organic or other acids

9. pH - hydrogen ion concentration

10. Water velocities

11. Stress or alternating stress and strain

12. Unfavorable or favorable metal couples

13. Temperature

The relative importance of these items will, of course, vary with the nature, the extent of pretreatment of the feedwater supply, design features of the process, completeness of deaeration and other water conditioning and concentration control features included in the system, velocity effects in sensitive areas, applied stresses on critical parts of the equipment, and the cleaning, maintenance and operating programs.

Replacement costs are an important consideration in any economic study on the economics of equipment maintenance. Experience has shown the atmosphere to be a very corrosive environment for metals used in processing equipment.

C. Pitting

Frequently, pitting is the more common type of corrosive attack on metals, including many steel alloys, stainless steels, and copper nickel alloys that are used in sea and brackish waters. When stress is applied, the attack may result in stress corrosion cracking, pitting at local anodic areas or both. Cracking can be of intergranular or transgranular type, depending on the material, corrosive action and stresses applied. Under cyclic or other stress conditions, the action can start as intergranular corrosive attack that can become a focal point for transgranular stress cracking.

There are many conditions that start or accelerate pitting, and sometimes pitting plus cracking, or general surface corrosion. Those most apparent are:

1. Surface deposits, including carbonate scales and the like, especially of a semi-adherent and porous nature.

2. Mill scale

3. Non-metallic and other foreign inclusions that act as focal points of attack.

4. Sand holes or porous structures in castings or other fabricated metals that create ready-made crevices and promote localized corrosion.

5. Crevices or depressions, such as at corners, joints and bolted connections.

6. Welded areas not made with a suitable metal, or by the best welding and stress relieving practice.

7. Imbalance of the alloying elements in the metal to resist localized corrosion.

8. Lack of sufficient corrosion inhibitor, commonly added to many copper-zinc alloys that may result in dezincification, leaving plugs or layers of copper behind.

9. Deposition of mussels, barnacles, slimes, or other organisms that can cause large differences in aeration at the metal surfaces and set up relatively small area anode oxygen deficient corrosion cells that can be especially active and cause rapid failures.

D. Other Factors Contributing to Metal Attack

Life processes and decomposition products of micro-organisms and other organic matter which deposit from natural or contaminated brackish or sea waters will contribute to metal attack. In some cases, deposition of protective type scale on the metal by less soluble constituents in the sea water will prevent, at least temporarily, corrosive attack.

The scale thickness, however, must be controlled to prevent resistance to heat transfer or severe restriction of flow in heat exchangers. For example, bicarbonates in water decompose when boiled to produce carbon dioxide and the less soluble carbonate compounds principally calcium carbonate. When the concentration of ionized calcium carbonate exceeds the solubility limit, a protective layer of calcium carbonate scale can be formed that will adhere to the metal unless cracked off as the result of temperature changes. This type of scale develops in evaporators at all boiling temperatures. This often is objectionable if it forms on heat transfer surfaces and affects efficiency of the unit. The equilibrium conditions for calcium carbonate in aqueous solution are shown in Exhibit VI-1.

The history of fabrication, annealing and finishing of a metal may often be correlated with pitting corrosion, corrosion fatigue and cracking of the metal. It has been reported that, in some cases, the lubricant or other residues left from the manufacture of condenser tubes have contributed to corrosion problems. It is recognized good practice to provide that all heaters and other equipment be thoroughly cleaned and maintained under corrosion-free conditions, with special attention to protection during idle periods.

The conclusion reached by Robert Moore of the Westinghouse Electric Corporation in an article entitled, "MATERIALS FOR WATER DESALTING PLANTS" that deals with general evaluation of the non-ferrous alloys in sea water (444), is that much more corrosion research and testing are required to develop the basic data necessary to better utilize non-ferrous alloys in hot sea water service. He added that the upper temperature and velocity limits for aluminum and copper alloys must be established for more efficient use in heat exchangers and for optimum design.

TYPICAL CALCIUM CARBONATE EQUILIBRIUM CURVE
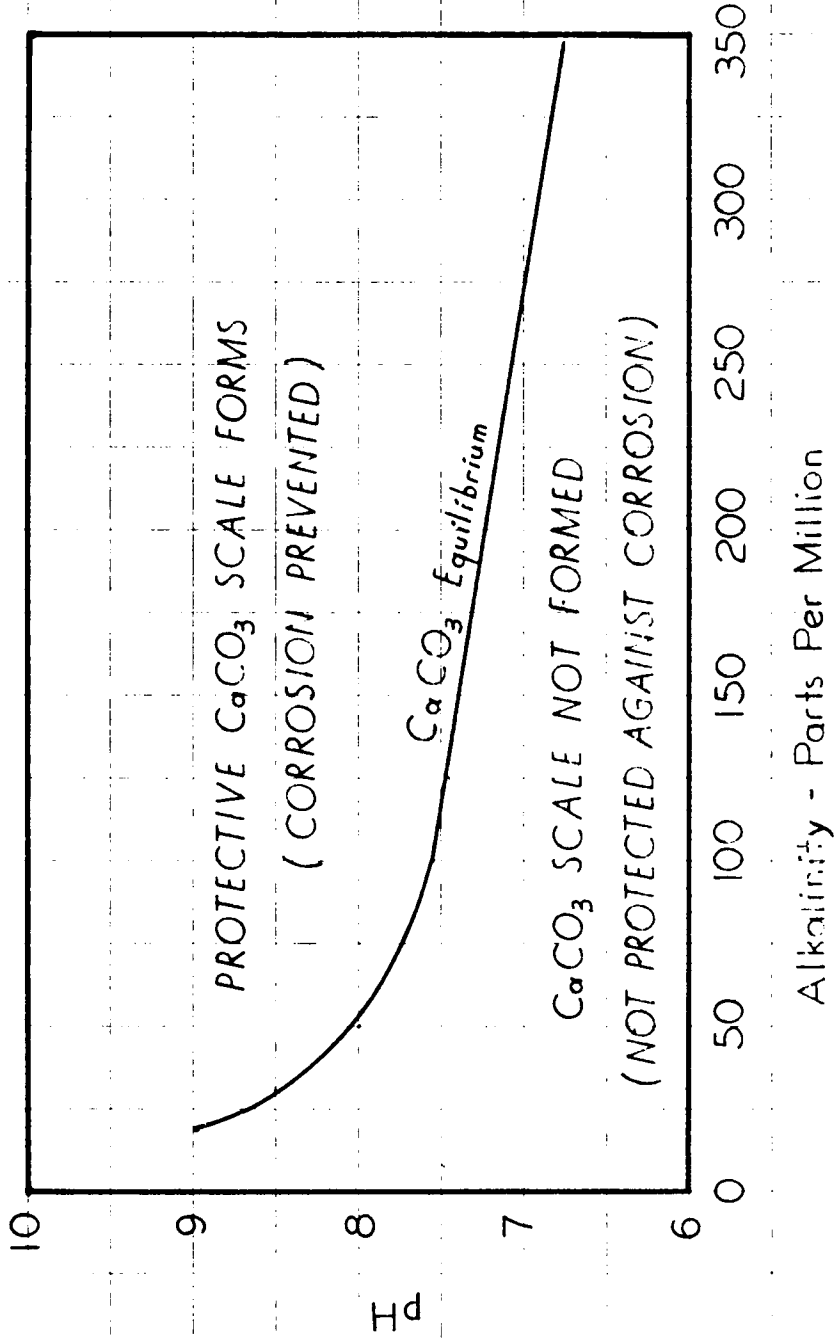
EXHIBIT VI-1

Condenser and Heat Exchanger Tube Handbook (1953)
Bridgeport Brass Company, Bridgeport, Conn.

D - 1353

Mr. Moore has prepared a list of typical non-ferrous alloys subjected to fairly high velocity and hot sea water, classified as to corrosion resistance beginning with the one having maximum resistance followed in descending order by others having less resistance.

Metal or Metal Alloy	Resistance to Corrosion	Maximum Velocity Limitations
Titanium	Best	10
Hastelloy C	Good	10
Inconel	Good	10
Inconel X	Good	10
Monel	Good	8-10
K-Monel	Good	(7)-10
70-30 Copper-Nickel (0.5 Iron)	Good	(7)-10
90-10 Copper-Nickel (0.5-2 Iron)	Good	(7)-10
Arsenical-Aluminum Brass	Fair	7
Aluminum or Tin Bronze	Fair	7
Arsenical-Admiralty Metal (Brass)	Fair	5-(7)
Alclad Aluminum	Fair	7
Unclad Aluminum Alloys*	Fair	(5)

*Pitting excessive for sea water.

Note: Velocities in ( ) are editorial. Not by the author.

The general rating is based largely on resistance to corrosion-erosion and impingement attack by sea water at elevated temperatures and velocities. For design purposes, velocities for all of the copper, nickels and brasses should not exceed 7 feet per second and in some cases, not over 5 feet per second. This rating does not imply the same degree of resistance of the above metals to localized attack in semi-stagnant or polluted sea water. It is the belief that there is no inexpensive material available that is highly resistant to hot sea water or to adversely polluted water. Most all of the saline conversion plants operate at temperatures that generally do not exceed about 250°F, where the metal comes in contact with the incoming sea water.

E. Discussion of Resistance by Various Metals

1. Steels

a. Carbon Steels

Carbon steel not used for heat exchange service has in some instances registed saline water corrosion at ordinary operating temperatures under the following favorable conditions:

(1) pH 9 or above

(2) low dissolved oxygen

(3) continuous protective films

(4) absence of unfavorable metallic couples

However, depending on cost considerations, more corrosion-resistant metals of selected alloys may be preferred for sections of the equipment where the additional materials cost is justified.

Studies of corrosion characteristics of iron and steel in aqueous solutions with dissolved oxygen and chloride ions, performed at the University of California Saline Water Research Laboratory indicated two important corrosion parameters:

(1) Corrosion rate of iron increases as the oxygen content of the solution increases.

(2) Above a concentration of 60 ppm of sodium chloride, the corrosion current (in the passive region) is substantially increased as the chloride ion concentration increases.

It has been shown by tests conducted at Wrightsville Beach that mild steel in sea water can have a moderate rate of corrosion. However, mild steel, when tested in the polluted waters of San Diego Harbor, indicated a pitting rate of 60 mils per year could be expected. Similar severe attack on steel cooling water inlet structures, pump parts and unprotected cast iron or steel condenser water boxes was observed in the polluted Los Angeles Harbor water.

b. Austenitic Stainless Steels

Austenitic stainless steels, especially of the 300 series, such as Type 316 with 3 percent molybdenum and Type 304 with no molybdenum are corrosion resistant only when the surfaces have reached a passive state created by a protective film, and the water is not too stagnant. For horizontal surfaces where deposits can collect easily, velocity of water flowing over the surface should preferably not be less than about 5 feet per second. The molybdenum present in type 316 and some other stainless steels improves greatly their incidence of pitting, but if pitting occurs, the pits are just as deep as in steels with no molybdenum. The molybdenum improves stainless steel resistance to sulfuric acid, sulfurous and organic acids, the halogens, salts and pitting in sea water. In some environments, molybdenum is said to strengthen the passive film.

When low velocities occur, deposits of silt, floating debris and fouling organisms accumulate more readily on horizontal metal surfaces and often pitting or other corrosion will develop under such coatings; especially at local spots where oxygen is excluded or becomes exhausted in the liquid. It has been established that the normal surface finish is not a significant factor in this type of localized corrosive attack, provided the surface is not seriously roughened.

When stainless steel surfaces are well aerated, they often remain passive or are more easily passivated than when continuously immersed in sea water deficient in oxygen, as in polluted harbor waters. Stainless steels in the passive condition, when protective films exist, exhibit satisfactory noble potentials in sea water, as indicated in the table, Exhibit VI-2. When the passivated film is destroyed and no replacement occurs, due to lack of oxygen or a number of other reasons, the metal reaches an active state and the relative electrical potentials will be definitely less noble and favorable to corrosion.

Exhibit VI-2

GALVANIC SERIES IN SEA WATER AT

77 F AND FLOWING AT 13 FT/SEC**

Metal	Steady Potential, Volts (Negative to Sat'd Calomel)
Zinc	1.03
Aluminum 3003	0.94
Carbon Steel	0.61
Gray Iron	0.61
Type 304 Stainless Steel (Active)	0 .53
Copper	0.36
Admiralty Brass	0.29
70/30 Copper-Nickel (0.47% Fe)	0.25
Nickel 200	0.20
Type 316 Stainless Steel (Active)	0.18
Inconel* Alloy 600	0.17
Titanium	0.15
Silver	0.13
Type 304 Stainless Steel (Passive)	.08
Monel* Alloy 400	.08
Type 316 Stainless Steel (Passive)	.05

Increasing corrosivity is indicated by increases in potential.

*Inco Registered Trademark   LaQue[8]
**From Reference 138

When cathodic protection as by polarization of cathode areas is established, localized corrosion by electrochemical actions on exposed stainless steel or other metal surfaces is reduced or practically arrested except in self-sustaining active corrosion pits that are not easily reached. The corrosion rate of some steels and other alloys reaches maximums in saline water of about 10,000 ppm sodium chloride concentration, which serves as an active electrolyte that increases flow of current from anodic to cathodic areas. Frequently, the cathodic areas are much larger than the anodic areas and this has the effect of accelerating localized corrosion or pitting.

Exhibit VI 3 illustrates the increase of corrosion resulting from coupling of several dissimilar metals.

Some stainless steel alloys are definitely more sensitive than others to corrosion pitting or stress corrosion cracking when in contact with waters high in chloride, such as sea water. Even the preferred alloys should be used only when based on satisfactory experience in the service intended. If severe corrosion due to chlorides or other sensitising chemicals is to be avoided, selection of austenitic stainless steels found in the 300 series containing 13% to 15% nickel and 19% to 20% chromium, with the lowest carbon content and a favorable balance of other alloying materials, including addition of 2% to 3% molybdenum should be selected. For still further resistance to pitting corrosion in salt water, use has been made of the more expensive stainless alloys containing concentrations of nickel and chromium, in excess of 20% plus favorable amounts of compatible alloying materials. The ferritic type stainless steels, such as the 400 series, have a less favorable record than the more resistant types of austenitic steels.

The use of suitably annealed alloys to produce favorably unstressed metallurgical conditions to resist corrosion and cracking is another important feature in service life of the alloy selected. This condition should not be destroyed by the methods of final fabrication of the equipment, such by bending or excessive cold work that would cause corrosion or cracking. Good maintenance, including periodic cleaning when required is another necessary step in prolonging the service life of all metal alloys selected for saline water conversion.

2. Inconel and Inconel X

These alloys have outstanding resistance to aerated sea water, at temperatures up to 350°F and 10 feet per second velocity. Inconel is practically immune to chloride stress corrosion cracking, unless other factors are involved, but it is susceptible to pitting in stagnant semi-aerated sea water. If the sea water is deaerated, localized anodic attack should practically stop unless the pits have become corrosion sustaining.

Exhibit VI-3

GALVANIC CORROSION OF MEDIUM CARBON STEEL

IN CONTACT WITH TYPE 304 STAINLESS STEEL,

TITANIUM OR COPPER IN SEA WATER

FLOWING AT 7.8 FT/SEC AT 50 F FOR 16 DAYS*

Couple	Corrosion Rate of Steel, mpy	Increased Caused by Galvanic Effect, mpy
Steel (Uncoupled)	31	--
Steel-Type 304	36	5
Steel-Titanium	42	11
Steel-Copper	100	69

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*Area of Steel = area of other metal in couple.

mpy = mils penetration per year.

*From Reference No. 138.

Because Inconel has lower thermal conductivity than Inconel X, somewhat higher velocity flows are required to obtain the same heat transfer rate when using Inconel X. In this respect, it is probable that under certain operating conditions and consistently favorable water conditions, an optimum velocity can be found that will result in less corrosive action. The more concentrated saline waters have been known to increase the probability of tube end erosion at some lesser critical velocity than with less concentrated lower gravity water; a condition that can apply to most alloy materials likely to be employed in this service.

3. Monel & K-Monel

These metals have excellent resistance to hot flowing sea water, but are subject to pitting in hot, stagnant saline water. Monel metals will perform equally well in aerated or deaerated sea water at reasonably high velocities. They are considerably more expensive than the lower nickel content and copper-zinc alloys. Therefore, some definite justification may be required for their installation unless the less expensive alloys are expected to give too limited service life, especially in polluted saline waters.

Experimental data has established that at elevated temperatures, approximating 350°F and 10 feet per second velocity, the pitting rate is excessive. At lower temperatures, in the range of 250°F or lower, a satisfactory pitting rate has been indicated.

4. Copper-Nickel Alloys

Copper-nickel alloys have been used successfully for many years in heat exchangers installed for both fresh and salt water contact or for brackish waters with varying concentrations of sea water infiltration and the presence of pollutants that are more corrosive to copper-zinc alloys. The more popular, cupro-nickels that have suffered much less from tube end erosion and corrosion are those containing 10%, 20% and 30% nickel with addition of 0.4 to 0.7% iron in 30% nickel, 0.5 to 1.0% iron in 20% nickel and 0.5 to 2.0% iron in 10% nickel. The balance of the above alloys, except for the needed addition of not over 0.6% manganese and other minor constituents, is copper. Previously cupro-nickels containing little iron suffered excessively from tube end erosion.

Recently, a new 30% nickel containing approximately 5% iron, a maximum of 0.6% manganese and the balance copper has been found useful in the higher temperature heat exchangers. Previously, 30% nickel plus smaller percentages of iron suffered oxidation corrosion known as exfoliation on the steam side of heat exchangers. Here during shutdown periods, air entered and accelerated this action, which at times resulted in grooving, especially at stressed tube ends.

The cupro-nickels generally have shown favorable corrosion resistance in sea water, as in steam condensers, heaters, evaporators and other services. In this connection, they are rated as being superior in corrosion resistance to inhibited Admiralty metal and aluminum brass.

As is well known, there is a definite water velocity limitation for all heat exchanger tubes, especially those carrying salt water. Normally, the design flow limit for heat exchangers is not over 7 feet per second, with definitely lower flow rates for the less resistant nickel alloys.

One principal advantage of copper-nickel and some other related alloys is their tendency to remain reasonably clean and thereby prove to be much more efficient as heat transfer media, after evaluating the "dirtiness factor" than many other heat exchanger tube materials like the brasses and bronzes.

5. Titanium

This metal is reputed to be superior for sea water service under the severest conditions of temperature and velocity. Its high strength-to-weight ratio and superior corrosion resistance make it potentially attractive despite its high cost. Titanium might be used on the highest temperature situations. If the original investment could be amortized over a long enough period, Titanium would be more attractive as a construction material.

6. Hastelloy Alloy C

This alloy containing 15% chromium, 58% nickel, 17% molybdenum, 5% tungsten and 5% iron has similar corrosion resistance to titanium in sea water and has exceptionally good tensile properties. It is reported to resist corrosion by hypochlorite, free chlorine, and other halogens, hydrochloric acid, hydrogen sulfide, ammonia, wet and dry corrosive gases, and oxidizing salts like ferric chloride and cupric chloride at reasonably low temperatures. Experimental evidence indicates that it is unaffected by sea water at temperatures up to 550°F, at a velocity of 10 feet per second. It can resist most readily the more severe conditions in a conversion plant. However, its use is limited by its high cost as compared with other alloys at lower price, that can be employed with reasonable satisfaction. Other Hastelloy alloys designated as A, B and D are less corrosion resistant under all environmental conditions. Hastelloy C is less expensive than titanium and is more weldable. Therefore, it would be more attractive for use in saline water plants.

Both Hastelloy C and Titanium are among the more noble metals and should not be coupled to steel or the other non-ferrous alloys unless there is a high anode to cathode area ratio.

7. <u>Aluminum and Aluminum Alloys</u>

Aluminum and its alloys, particularly the alclad type, have a potential utility in sea water conversion plants, within their temperature and velocity limitations. Unclad aluminum alloys are extremely susceptible to pitting in hot sea water so thatonly alclad type aluminum should be considered. Aluminum alloys have the following advantages over copper and nickel alloys which make them attractive as heat exchange materials:

a. Lower cost

b. Light weight

c. High thermal conductivity

d. No need for deaeration

e. Resistance to CO_2 or carbonic acid

f. Strong resistance to ammonia

g. High resistance to hydrogen sulfide

h. Reasonably good resistance to pollutants

Aluminum needs oxygen to provide a protective film and should be more resistant to pitting attack in aerated water. However, these good factors are offset by the following disadvantages:

a. Pitting tendencies

b. Galvanic attack when coupled with more noble metals

c. Corrosive sensitivity to deposited heavy metals or their ions, as copper and nickel, in solution

d. Relatively poor erosion resistance

Where aluminum components are used in a sea water plant, great care must be taken to reduce these adverse effects. In an all-aluminum conversion plant, some of the conversion problems would be eliminated, however, even clad aluminum alloys would probably be limited to relatively low temperatures of about 100°F water temperature for maximum service life and low water velocities not much in excess of 5 feet per second. In one instance, alclad tubes handling sea water at metal temperatures up to 100-120°F, the service life was over 10 years, which coincided with life of the cladding material. In some cases, the cladding can act as sacrificial metal to protect small areas where the cladding has been consumed.

Some carefully made alloys have shown by test that higher temperature materials may become available.

8. Copper-Zinc, Aluminum-Brass, and Admiralty Metal

Arsenic inhibited aluminum brass is used as tubing in all types of heat exchangers in existing conversion plants with good success, but like other copper-zinc alloys, including Admiralty metal, it is subject to pitting in polluted waters, especially if sulfides are present. This brass has good corrosion-erosion resistance in reasonably clean saline waters and has withstood sea water velocities of up to but not exceeding 6 to 7 feet per second; the lower velocity being preferred.

Admiralty metal, preferably with arsenic as the inhibitor, has adequate corrosion resistance, but definitely less resistance to erosive attack by high velocity flow than aluminum brass. It can be expected to have a more useful service life when water velocities are not over 5 feet per second. It has the advantage of remaining somewhat cleaner than aluminum brass and normally can maintain efficient heat transfer rates for longer periods between cleaning.

Since usually both of these copper-zinc brass alloys are inhibited with arsenic plus other alloying materials against corrosion and apparent dezincification, both are useful alloys for less severe saline or sea water service. Although lower in strength than cupro-nickels, both brasses have better heat transfer characteristics than cupro-nickel, provided they are maintained in a clean condition.

Both copper-zinc alloys have served very well in typical deaerated sea water feed heat exchangers for conversion units. Please refer to exhibit VI-4 for the effective temperature of corrosion of muntz, naval brass and red brass.

EXHIBIT VI-4

EFFECT OF TEMPERATURE ON CORROSION OF SEVERAL BRASSES

(in 2N*Sodium Chloride Solutions (249 Day Water-Line Tests)

Condenser and Heat Exchanger Tube Handbook (1953)
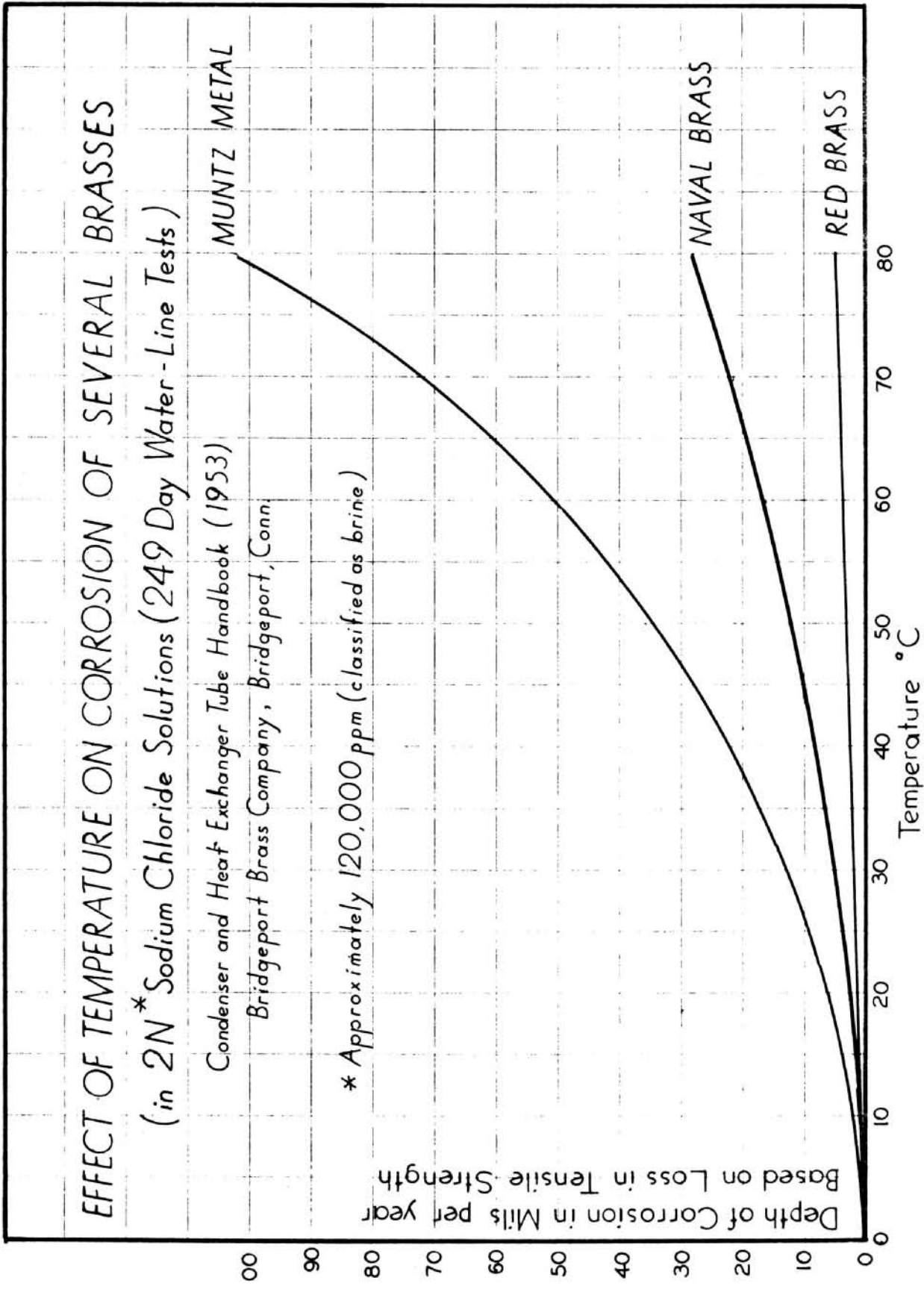
Bridgeport Brass Company, Bridgeport, Conn.

*Approximately 120,000 ppm (classified as brine)

MUNTZ METAL

NAVAL BRASS

RED BRASS

Temperature °C

Depth of Corrosion in Mils per year Based on Loss in Tensile Strength

The normal upper working limit of 400°F for these metals should be lowered for the more corrosive conditions in sea water conversion units. The most useful high temperature range for these alloys is probably about 200-250°F at moderate water velocities.

9. Bronze

Bronze alloyed with 5% to 10% aluminum has good resistance to sea water at about 7 feet per second, but rather poor resistance to pitting at very low velocities. Frequently, this alloy will start pitting early, followed by a long period of inactivity and good service life. Its velocity and temperature limitations approximate those of aluminum brass.

Bronze alloyed with aluminum has good corrosion-erosion resistance, particularly to sea water containing abrasive matter. The bronzes are not as widely used as the brasses or cupro-nickels in sea water processing, but they do find certain applications as tube and tube-sheet material.

Bronzes are not rated as having superior resistance to corrosion in highly polluted water, but aluminum bronze has given long service in cold, polluted sea water. The bronzes are subject to severe attack by sulfides in the water.

Silicon bronze is used sometimes as a shell material, but is subject to corrosion-erosion when the water velocity is much over 3 feet per second. This bronze would not be considered as suitable for tubing or inlet tube sheets of heat exchangers.

F. Protective Coatings, Linings, Plastics, Piping, Tubing, etc.

1. Coatings

In many cases where a relatively inexpensive material is used, such as steel or cast iron, or when a material installed starts to corrode locally, frequently good use can be made of a protective coating of which there are a good number of practical varieties available.

One of the most satisfactory classes of coatings for metals, some of which require the least amount of heating to obtain proper drying and final corrosion protection, are the synthetic epoxy resins, which unlike many other coatings, contain no volatile solvents. It is, of course, obvious that absence of a volatile solvent in the epoxy coating provides more useful solid coating material in each gallon of coating applied.

This makes it possible to apply thicker coatings with fewer coats to give a total thickness usually of about 10 mils. Because of its superior properties, the epoxy coating can give better protection than some thinner coatings that often result from applying the same number of coats of other resinous materials containing less residual solid material. A still heavier epoxy coating than 10 mils can be applied as required, but for cold water storage tanks and similar equipment, a coating thickness of about 7 to 10 mils is adequate, unless after testing electrically   pinholes or "holidays" are found and these areas require re-coating.

Other types of coatings containing no volatile thinners have been produced, but are not known to be used as extensively for the same range of temperatures as epoxy coatings. Most frequently the epoxy coating comes in two parts, 1 part of which is a catalytic solution, which causes the applied solution to set. Therefore, once having mixed the catalyst with the epoxy material, it is necessary to apply the mixture within a reasonably short time before the setting reaction takes place. The epoxy materials have been recommended for metal tanks, marine equipment, and concrete surfaces in reasonably low temperature service or higher temperature not exceeding the rated limit of 300°F, or preferably lower, depending on experience with the type used. Frequently, epoxy coatings have been applied to the ends of steam turbine condenser tubes to prolong their life, when tube end erosion has weakened that part of the tube wall to a dangerous point. The epoxy coatings are not resistant to certain solvents or to highly concentrated acids, but will resist dilute acids. They are resistant also to alkalies and all types of water and are not generally susceptible to chalking that occurs frequently with other coatings. There are certain preferred epoxies, of which there are several that should be selected for underwater use.

Another class of underwater coating material that has been used frequently in the past is selected from those compounded with a phenolic resin, originally known as Bakelite, but now available in modified forms. The more useful of these for temperatures up to 450°F max., but definitely lower in saline water, are the baked-on type, such as Heresite of which there are several formulations.

The air-dried type is rated at only 150°F, max. as compared with the higher temperature limit for a baked-on coating. The baked-on type of coating has been used frequently in water treating equipment with generally satisfactory results. In general, it would be advisable to base design on multiple baked-on coatings of not less than 7 mils total thickness and to apply a safety factor to any maximum rated temperature.

Another class of materials are made with Alkyd resins which have been used in protecting steel tanks from corrosion by water with reasonably satisfactory results. Unlike the epoxy resins, they have a tendency to chalk, although there may be some products available that are more resistant to this type of surface deterioration than others.

There are a large number of coatings made from bitumastic materials, both from treated coal tar and petroleum residuals that in general are of somewhat doubtful value for long-term underwater protective coatings, especially when the temperatures may be in excess of 150°F, or above the melting point of the coating. A more useful life has been reported for the epoxy base bitumastic compounded coatings, but care must be taken to specify a particular type that already has been used successfully under the same or similar conditions. A suitable primer should be applied first to insure better adhesion.

2. Plating Coatings.

Methods have been developed for plating coatings on the more noble metals. For example, nickel, silver and gold have been plated, over copper alloys or other metals to be protected against corrosion by waters high in chloride and pollutants. According to experimental reports, some methods of nickel plating leaving multiple hair line voids in the coating, can aid heat transfer rates significantly.

At this time, there has been no large market or production of plated piping for industrial use, but there is a large market mainly for decorative purposes on external surfaces, especially the plumbing materials. However, in many cases, the usual chrome or nickel plating applied affords corrosion protection.

3. Fluorocarbon Base Coatings

Some progress has been made in the use of fluorocarbon base coatings such as a Teflon liquid coating material that as a class, is rated as stable up to 550°F maximum service temperature. Data on the use of such liquid applied coatings in underwater or sea water conversion equipment requires investigation with regard to temperature limitations and adhesion under different operating conditions. Teflon is a good example of a type of highly resistant stable material when in contact with many chemicals and salt water in distillation or conversion processes. However, for liquid form application some further operating data is required before more definite recommendations can be made regarding the best formulations and methods of application.

As is generally known, satisfactory service life of any coating material is dependent on application only to previously cleaned, often sand blasted metal, or other surfaces to remove surface soil, rust, mill scale and the like. This is an essential first step in obtaining a satisfactory adherent protective coating. The primer, if needed, must be strongly adherent to the surface and be compatible with the top coating and the surface to be protected.

4. Sheet Lining Materials

There are a large variety of organic materials that can be used in sheet form to line steel or similar vessels or extruded inner linings for small piping that are not lined easily with sheet stock to resist severe corrosive surface conditions caused by clean or polluted salt water. Among the more promising are the well-known synthetic and other rubber linings applied by use of a cement to hold the lining to the metal. Teflon or equivalent in sheet form is another possibility that would be good for temperatures above 150°F, but the cost and method of making it adhere to the metal can be a problem that may require some further development work and practical experience to obtain full advantage of this type of fluorocarbon material. Otherwise, the first cost and maintenance expense could outweight the savings obtained by the long service life to be expected.

One or more companies are offering fluorocarbon lined piping at service temperatures up to 275°F for wet chlorine dioxide and acid chlorides. One such produce has the tradename, Kynar.

In some lower temperature services, fiber glass epoxy or other resin-impregnated linings have been used in sea water service as a substitute for sheet linings, or liquid coatings but sometimes unsatisfactory results have been obtained due to poor adhesion of the cemented lining to the surfaces being protected. This resulted in costly replacements that may have been avoided by better preparation of the metal surface and improvement in the cementing procedure, using the most suitable cement and lining support.

5. Plastic Tube and Pipe

In general, the resistance of plastic piping materials to corrosion is largely a relative factor and there is considerable variation in chemical resistance and costs between the various plastic piping material available. Therefore, a cost evaluation should be made, based on experience with the materials being considered.

The physical properties are another important consideration with respect to tensile or bursting strength of the pipe and temperature range in which the particular plastic can be used satisfactorily.

With the continued advances in chemistry of plastics production, one can look forward to many changes in the relative values of the plastics now available and the development of better and stronger materials for use in desalting saline waters containing varying amounts of pollutants.

Teflon tubing and other plastic, less expensive tubing materials have been used successfully in the feeding of chemicals for water treatment. There are, of course, a number of plastic materials, some of which will withstand chemicals and salt water at various temperatures, but suitable materials for use in saline water service need to be stipulated for each operating condition.

6. Asbestos Cement Pipe

In some cases, asbestos cement piping such as Transite, with or without a protective coating or plastic liner has been used for transporting cold saline water to or around the saline water conversion unit; due consideration being given to the rather low temperature limitation, not significantly higher than 110°F and much lower pressure limitations than for steel or cast iron piping. Likewise, great care has to be exercised in laying asbestos cement pipe. It must be laid in level trenches and not subjected to bending stresses. Under-railroad track crossings should be avoided.

7. Fiber Glass Epoxy Piping

There are presently sources of fiber glass epoxy piping suitable for handling corrosive waters at moderate temperatures and pressures. Alternately, there is available from one large chemical and glass manufacturer glass fiber reinforced plastic pipe and tanks for satisfactory handling of brine and acid solutions. Some solutions contained abrasive materials that did not cause wear of the plastic over a long period as compared with short life of metal alloy piping used previously.

8. Molded Rubber Piping

Some molded rubber piping high in carbon filler has been used successfully to withstand corrosive and abrasive conditions at medium high temperatures and pressures under conditions that ordinary rubber would break down. However, its experience record in saline water conversion plants is not readily available.

9. Polyethylene Formulations

Various polyethylene formulations that are impervious to chlorine and other chemicals found in saline sources are available that can be used to fabricate piping, linings and holding vessels. Piping is available in schedule 40 pipe sizes from 1/2 inch to 6 inche for low pressure and generally low temperature conditions, but piping good for 75 to 125 psi at 74°F has been listed in the literature. The temperature can be raised to 212°F if the pipe is given continuous support. For satisfactory results, the suppliers recommendations as to service conditions and installation must be followed in all cases.

10. Chlorinated Polyethers

Chlorinated polyethers display better mechanical strength and higher temperature limitations without distraction (distortion) than polyethylene or polyvinyl chloride (PVC). Chlorinated polyethers are rated as lying between PVC and Teflon with respect to their various properties.

11. Asbestos Synthetic Resin Mixtures

A group of asbestos synthetic resin mixtures sold under the trade name Haveg have been made in about four listed grades for working temperatures between 78°F and 300°F for each grade, but with ascending strength properties for tension, compression and shear. The maximum tensile strength for grade 61 is 4,100 psi at 78°F and 1,800 psi at 300°F. Haveg is said to be good for continuous operation at 285°F. It is sold in various thicknesses of pipe wall, but, as a general rule, will require support at not less than five foot intervals.

12. Epoxy and Polyester Resin Products

These products have similar characteristics with respect to good corrosion resistance. When laminated with glass or other inorganic fibers for reinforcement, the fabricated tube or pipe has relatively superior strength, the maximum working strength occurring between 78°F to 265°F. For example, the expoxy resin material has a tensile strength of about 9,600 psi, whereas, at 265°F, the polyesters have a tensile strength of about 7,300 psi. There is little change at lower temperature for either type of resin. Piping is said to be available in sizes from 2 to 8 inch but all sizes are made to order.

13. Saran or Parian

This organic thermoplastic resin is available as tubing or piping in 10 foot lengths of up to 4 inch diameter. It has a working temperature range between 0 and 180°F. At lower temperatures, it becomes brittle and at higher temperatures, its normal properties are lost. It has a well defined melting point which can be used for bonding tubes together.

Saran pipe is said to have a tensile strength between 4,000 psi and 6,000 psi and has a relatively high bursting strength, but it is not as strong as the epoxy glass fiber laminated piping.

Saran has been used widely as a liner for steel piping up to 6".

Parian, saran or saran lined pipe has been used extensively as a replacement for less corrosion resistant steel or other metal piping. It is resistant to a rather wide range of organic and inorganic materials. It is not recommended for use with ammonium hydroxide, especially at significant concentrations.

14. Paints

Field applied paints with synthetic resin or graphitic bases have been used with some success or corrosive services. Several of the more common trade names are Tygon, Heresite, Amercoat, and Apexior. The usual temperature ranges of these paints is 140°F to 175°F with the exception of Apexior which has been extensively used in the spray section of deaerating heaters at temperatures from 215°F to 300°F.

In general, the success of field applied paints is dependent upon preparing the surfaces to be covered very carefully, i.e., following the manufacturers instructions to the letter.

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