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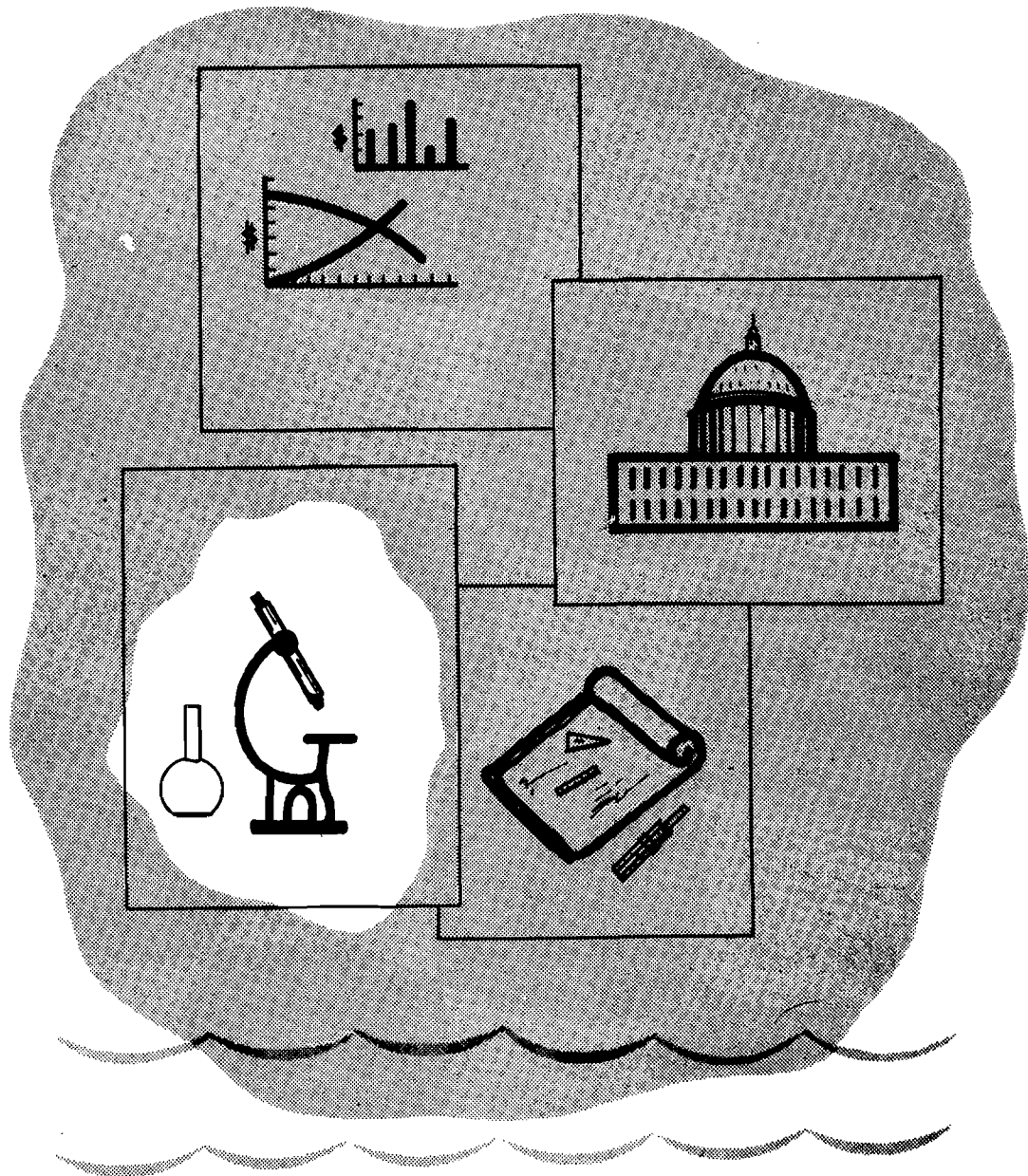


Logan, Utah 84321

Proceedings of a Summer Institute in Water Resources

**VOLUME III - WATER QUALITY CONTROL
AND MANAGEMENT**

CIVIL ENGINEERING DEPARTMENT SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION



99940

PROCEEDINGS
of a
National Science Foundation Supported
SUMMER INSTITUTE IN WATER RESOURCES

VOLUME III
WATER QUALITY CONTROL AND MANAGEMENT

Civil Engineering Department

Utah State University

April 1966

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Lectures
on
WATER QUALITY CONTROL AND MANAGEMENT, CE 293

Presented at the
SUMMER INSTITUTE IN WATER RESOURCES
UTAH STATE UNIVERSITY

by
P. H. McGauhey
Director, Sanitary Engineering Research Laboratory
University of California

Logan, Utah
June 21 - August 13

1965

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FOREWORD

Recognizing the need for training of individuals to meet the rapidly rising problems connected with water resources development, Utah State University, with National Science Foundation support, organized a Summer Institute in Water Resources for college teachers. It was hoped that participants carefully selected from all regions of the country would receive additional insight and stimulation to improve and enlarge water resources training programs at their own institutions. Thus, the accelerated dissemination of such knowledge on a national scale could be facilitated.

Realizing further that the key to a successful institute of this nature lay in the excellence of its staff, efforts were made to obtain instructors with intimate knowledge and broad experience in the subject matter areas they were asked to present. In nearly every case those selected willingly accepted the invitation to participate, although this meant considerable monetary sacrifice and major adjustment of busy schedules.

The subject matter treated paralleled regular offerings listed in the University catalog and is considered to be "central" or "core" to a water resources planning and management training program. One course treated the philosophical, historical, institutional, political, and legal aspects of water development. The responsibility for this course was shared jointly by Cleve H. Milligan, Charles E. Corker, and Wayne D. Criddle. The second course considered the principles of water resource economics and was presented by B. Delworth Gardner. The third course dealt with concepts of water quality management and this was under the direction of P. H. McGauhey. The final course was on principles and procedures of regional resource planning and was presented jointly by Aaron Wiener, W. R. Derrick Sewell, and Harvey O. Banks.

Having assembled a distinguished and diversified staff to present some of the best current professional thinking in the topics suggested in the preceding paragraph, it was felt most appropriate to attempt to put their lectures into writing. A proceedings of the Institute would have considerable utility beyond the Institute itself. Hence, the instructors were encouraged to prepare written material for the proceedings and were given secretarial and other assistance to aid them. This material has been organized according to the four major courses and is issued in four companion volumes.

Clearly, this has been a prodigious effort which required Institute staff and others to "go the extra mile." Special thanks and recognition are due Mrs. Dorothy Riley who not only typed the entire proceedings but also attended to many details necessary for the successful operation of the Institute.

Jay M. Bagley served as director of the Institute and assumed a general coordinating and editing role in the development of these proceedings.

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INTRODUCTION

The material herein presented represents a slightly edited version of lecture notes somewhat hastily prepared by the author and used in presenting the subject of water quality control and management to participants in the first Summer Institute in Water Resources for College Teachers in Engineering and Earth Sciences held at Utah State University, Logan, Utah, during the period June 21 to August 13, 1965. It is by no means a finished dissertation on the subject, nor are all of the data used the most up to date that a thorough search of the literature might reveal. It is, however, released by the author in an unrefined form in the hope that it may prove useful to participants in the Institute while a more sophisticated version is being prepared.

Because of the limitations of time imposed by the scale of the course, the scope is confined largely to a consideration of the interrelationships between beneficial uses and the quality of the fresh water resource on the earth's surface and underground. Although it is recognized that saline and salt waters represent a major factor in our overall water resource, discussion of the renovation of water is confined to fresh water quality which can be achieved or maintained by measures other than deionization or desalination processes.

The subject is presented in two parts. Part I deals primarily with changes in quality of water resulting from beneficial use. The fresh water resource is conceived as a resource pool from which water is withdrawn for various beneficial uses and into which these uses return that fraction of their withdrawals that is not consumed. Specific concern is directed to the quality aspects of these return waters, as well as to the effect of consumptive use on the quality of the resource pool.

The quality needs of various beneficial uses are then discussed in relation to the ability of the resource pool, with all its waste water inputs, to meet this need. Finally, Part I deals with the concepts, nature, and limitations of standards, requirements, and criteria by which society establishes and attains its waste water objectives.

Part II is directed to both new and conventional methods of changing the quality of water. Messrs. W. J. Oswald, R. E. Selleck, and D. Anderson were enlisted to make presentation of much of the material contained in this section. Special attention is directed to the changes in water quality resulting from either haphazard or engineered systems which make use of the biologically active soil mantle of the earth. Similar attention is directed to the scientific and engineering aspects of lagoons and stabilization ponds for changing the quality of waste waters. The role of saline estuarial and ocean waters in the overall water resource is discussed. Particular emphasis is directed to the quality changes and phenomena, from both an engineering and scientific viewpoint, of mixing, or sequestering, waste waters in estuaries and oceans.

The final portion of Part II deals with natural self-purification of streams and the use of both streams and conventional engineered systems for upgrading the quality of waters withdrawn from or returned to the resource pool by beneficial uses. Emphasis is placed on principles, practical considerations, and process evaluation in the light of water quality objectives of society.

PART I

I

QUALITY AS A DIMENSION OF WATER

More than half a century ago a Mississippi jurist said, "It is not necessary to weigh with care the testimony of experts--any common mortal knows when water is fit to drink." Yet today we find it necessary to assemble, each in the role of both expert and common mortal, to consider just how it is that we know when water is fit to drink. Moreover, in the intervening years interest in the "fitness" of water has gone beyond the health factor and we are forced to decide on its suitability for a whole spectrum of beneficial uses involving psychological and social as well as physiological goals. The dilemma of water quality today is that quality is an attribute that must be measurable. Those of us who are unwilling to go along with the Mississippi jurist must express "quality" in numerical terms.

Let us consider further the origins and implications of this dilemma.

In the early days of America, men were motivated to appropriate a portion of the region's fresh water resource; to hold it through the establishment of "water rights," public policy, or other property ownership device; and to defend it against all others by every possible means. Quantity was the dimension of water to which men sought title. Definition of its quality was not necessary as long as the water was "fresh." There was, of course, one exception to this general rule--water for human consumption. Definite quality goals were established in the interests of the public health, and protection of public water supplies became an objective of water management. However, only about 7 percent of the water used by man was ever involved in public water supply, hence there resulted surprisingly little understanding of quality as a major aspect of water which required evaluation. Until quite recently, therefore, acre-feet defined much of the beneficial use of water.

The following, quoted from my recent talk (2), traces in rather broad strokes the rise of the concept of quality as a dimension of water necessitating the application of numbers to an aspect of water which is not by nature susceptible to measurement in the gross by mathematical parameters.

The idea that quality is a dimension of water which requires measurement by any sort of "yardstick" is of such recent origin that even the current catch phrase "water resources management" is heavily dependent upon the concept of quality control for any meaning it may convey. True we have been concerned for three-quarters of a century with means to make small amounts of water safe to drink, but neither in the "riparian rights" concept inherited from ancient British common law nor in the "first in use" concept established in Gold Rush days at the muzzle of a forty-four does quality appear as a dimension of the property at stake. True the riparian concept speaks of the requirement that it not be diminished in quantity or quality but such was so patently absurd that no one took it seriously. Nor does the idea that ownership of land surface include everything except minerals from the zenith to China recognize water, however mineralized, as a material having value by reason of quality. The result is that a whole fabric of tradition, law, judicial decision, and gunfire has established a property right in quantity of water without considering quality except in the grossest of terms or in a context too impractical to warrant consideration. Consequently, consternation is the normal reaction today when the owner and user of water realizes that his "right" in water does not cover a dimension--quality--that has become important, and often critical, as a burgeoning urban-industrial-agricultural economy forces repeated use of a relatively fixed quantity of water. Hence, as the percentage of the water resources represented by "second hand" water increases, so does the need for attention to water quality and to parameters by which to describe it.

The Bard of Avon has said, "The quality of mercy is not strained. . . ." And, indeed it is not, as long as mercy is defined in qualitative terms. One can scarcely conceive, however, the problems which might arise if it were required that justice be tempered with 1.16 quanta of the mercy in one case and 100 quanta in another. Yet this is precisely the sort of thing we are confronted with in establishing water quality parameters. In the jargon of 1965, it may be said that a problem arises whenever we try to quantitate values which are qualitative in nature.

Although the preceding discussion of quality as a dimension of water may convey the impression that quality was ignored during the struggles that codified and institutionalized water quantity and the rights thereto, such is not strictly the case. The fact is that quality was defined mostly in qualitative terms, generally as gross absolutes or at best as discrete rather than as a continuous variable. Common parameters of water quality in this context arose in the English language by free combination of words. Thus, dishwater, bilgewater, limewater, stumpwater, swampwater, blackwater, sweetwater, and even firewater came to convey meaning in the daily lives of citizens, but only the last--firewater--has ever been classified on the 200-proof scale of numerical values.

In general, the gross concept of water quality was described by such parameters as "fresh" versus "salt" water, the measure being the sense of taste of humans rather than the analytical techniques of chemists and biologists; or in similar gross terms, such as "sweetwater" on the one hand in contrast with such opposites as "alkali water" or "mineral water." Occasionally the term "sour well" cropped up to describe unpotable water. In general, potable water was both "sweet" and cool. However, if it tasted bad enough and was naturally hot, the vilest of waters from the standpoint of taste and odor became highly respected by reason of this very aspect of quality....

A need to quantitate, or give precise numerical values to, the dimension of water known as quality derives from almost every aspect of modern industrialized society. For the sake of man's health we require by law that his water supply be "pure, wholesome, and potable." The productivity and variety of modern scientific agriculture requires that the sensitivity of hundreds of plants to dissolved minerals in water be known and either water quality or nature of crop be controlled accordingly. The quantity of irrigation water to be applied to a soil varies with its dissolved solids content, as does the usefulness of irrigation drainage waters. Textiles, paper, brewing, and dozens of other industries using water each have their own peculiar water quality needs. Aquatic life and human recreation have limits of acceptable quality. In many instances water is one of the raw materials the quality of which must be precisely known and controlled.

With all the myriad activities suggested above going on simultaneously and intensively, each drawing upon a common water resource and returning its waste waters to that common pool, it is evident to even the most casual observer that:

1. Water quality must be identifiable and capable of alteration in quantitative terms if the term "quality" is to have any meaning or be of any practical use.
2. Quality can be defined in qualitative terms such as acceptable or non-acceptable, clear or polluted, etc., only when the quantitative quality requirements of the beneficial use to which it is to be put is known. Thus, the need for quantitative parameters of water quality becomes inescapable.

References

1. McGauhey, P. H. "Quality--Water's Fourth Dimension." Proceedings, Water Policy Conference, University of California, Davis, January 11-13, 1961.
2. McGauhey, P. H. "Folklore in Water Quality Parameters." Civil Engineering, June 1965.

II

QUALITY OF NATURAL WATERS

Introduction

The point has been made that whereas tradition and legal actions to institutionalize tradition have established a property right in water in terms of gallons or acre-feet, no such rights to quality were involved, the principal reason being that man got along quite well with general rather than specific characterizations of water quality. Of course, there were important exceptions in the area of public health, once the relationship of water to disease was understood, but in general water was used only once and discarded. If local water supplies became too polluted, it was always possible to go further for a source of clean water.

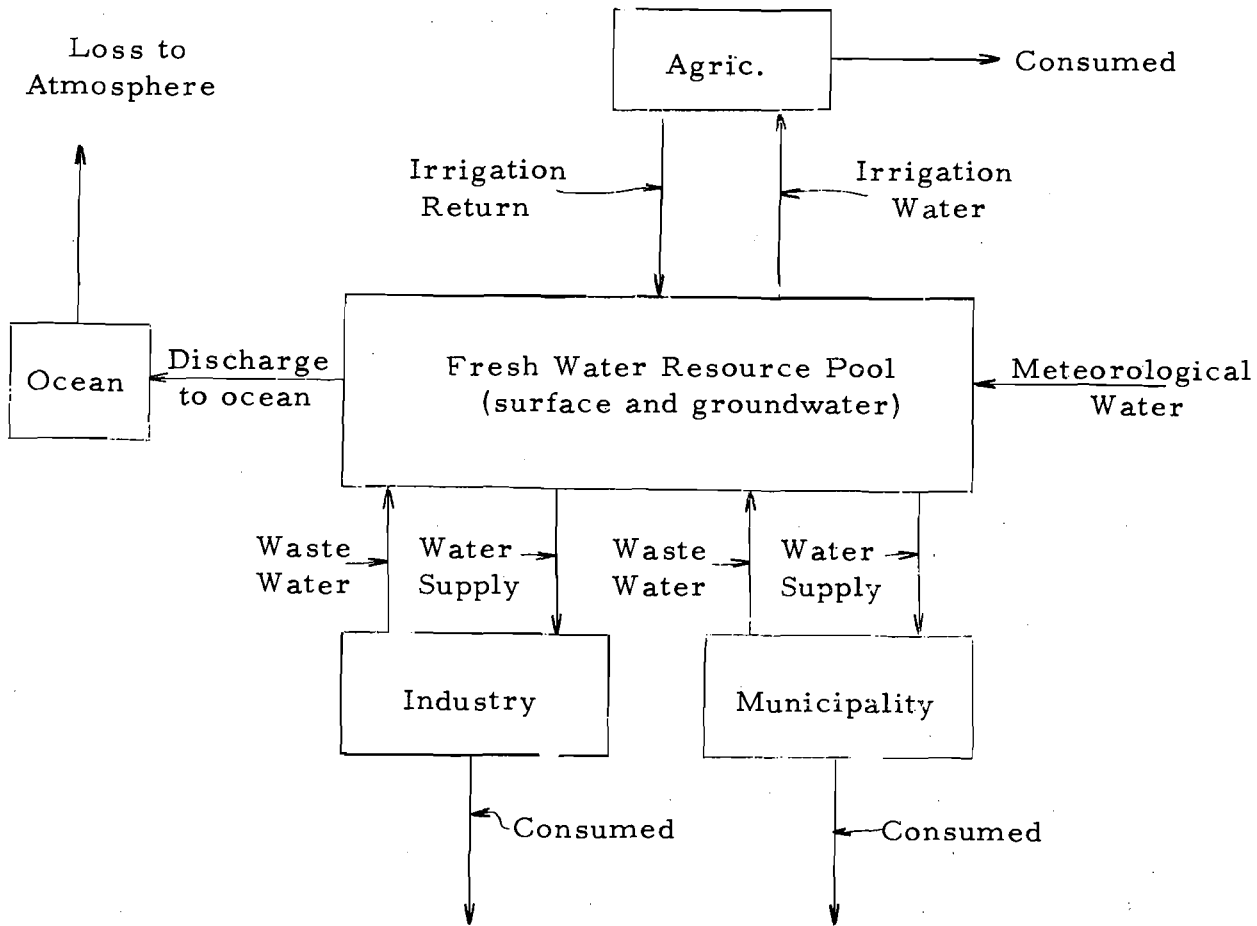
You may recall, for example, that the Romans built their first aqueduct, the Appia, in 313 B. C., not because the bountiful springs were drying up or inadequate in quantity, but because the ground disposal of filth for generations had finally polluted the groundwater beyond the tolerance of the aesthetic sense of the Romans. Thus water quality has been of concern to mankind for a long time. But my point was that in America, with the exception of water-borne disease considerations, the need to apply precise numbers to the attribute of water called "quality" is an outgrowth of the rising pressure of an ever-expanding urban-industrial-agricultural society against a relatively fixed water resource.

In this context the fresh water resource may be considered as a pool from which water supply is drawn and into which waste waters are discharged. Its input is meteorological water--its output is bleed-off to the oceans and losses to the atmosphere.

Quality Cycle in Nature

The well-known hydrologic cycle might be paraphrased in a diagram of water quality in which the fate of water utilized by various

sectors of the economy is considered in relation to quality. First let us view it in the gross--then in specific detail, isolating and identifying those things which are described and limited by numerical factors in water quality. However, we should be forewarned that once we launch into a quantitative appraisal of water quality "quality" becomes a term to describe the composite chemical, physical, and biological characteristics of a water with respect to its suitability for a particular use.

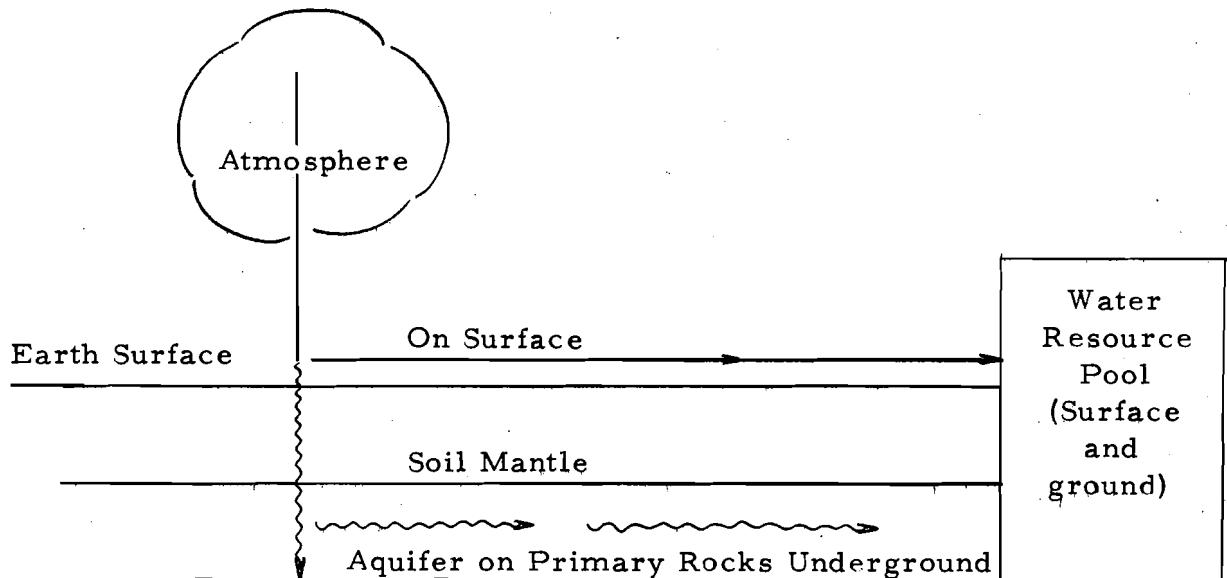


Keeping in mind the resource pool with its various inputs and outputs, and recalling that the three major users, agriculture, municipalities, and

industry are growing whereas neither the pool nor its meteorological input is increasing, we can now examine the quality relationships involved. From these we may proceed toward placing numbers on quality factors and to justifying such numbers.

Quality of the Meteorological Input

Looking at the meteorological input in detail, it becomes evident that it splits into several quality altering streams. Diagrammatically it might be represented as follows:



The quality effect of this phenomenon may be illustrated as follows. The water resource pool is represented by the surface water and the groundwater. From the standpoint of quality it is important to remember that the dry weather flow of streams is returned or outcropping groundwater, hence the quality of surface water may vary from the characteristics noted on page 12 for surface waters to essentially that of the groundwater.

Quality of natural waters

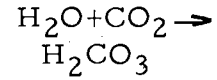
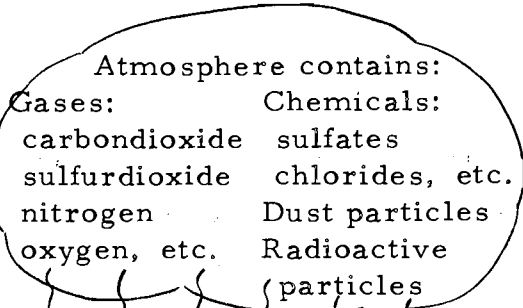
1. Meteorological waters
 - Suspended matter--dust
 - Dissolved matter--gasses chemicals

(Not much used as water supply, require chlorination)

Surface

Surface runoff

earth near surface contains CO_2 and other gases, O_2, H_2, NH_3



2. Surface waters
 - Suspended matter--clay, mineral & organic debris, bacteria, algae, protozoa.
 - Dissolved matter--gasses, organic extractives causing color, org. acids, ammonia, nitrites, nitrates.
 - Colloidal matter --silica, org. acids, org. matter.

Limestone ($CaCO_3$)--most common mineral. Slightly soluble in H_2O , highly soluble in $H_2O + CO_2$
 $2CaCO_3 + H_2CO_3 \rightarrow 2Ca(HCO_3)_2$
 Magnesite ($MgCO_3$)--5 to 20% as much as $CaCO_3$. Soluble in H_2O , more soluble in H_2CO_3 .
 $2MgCO_3 + H_2CO_3 \rightarrow 2Mg(HCO_3)_2$
 Gypsum ($CaSO_4$)--quite common. Highly soluble in H_2O .
 Epsom salts ($MgSO_4$)--very highly soluble in H_2O . Not common in earth.

How ground-water becomes hard.

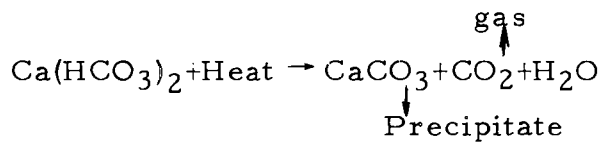
Objections to hard water:

Deposits as boiler scale causing burst coils, waste of fuel.

Precipitates soap to cause rings in bathtub, grease stains on laundry, cloudy glassware, etc.

Soap will not lather until water softened by soap--most expensive method of softening.

Groundwater containing calcium and magnesium bicarbonates, known as temporary hardness because removed by boiling.



Treatment: Filtration to move suspended matter, color, odor, bacteria. Chlorination to kill bacteria.

Permanent hardness, calcium and magnesium sulfates which can be removed only by chemical treatment.

3. Groundwater
 - Suspended matter--clay, fungi
 - Dissolved matter--hardness producers (shown at right) nitrates and chlorides of calcium, sodium, potassium, and magnesium; bicarbonates, sulfates, & hydroxides of iron (stain porcelain fixtures, discolor laundry); florides (stain teeth); gases--carbon dioxide, oxygen, nitrogen, hydrogen sulfide, and hydrogen.

Treatment: Softening, chlorination.

III

QUALITY CHANGES THROUGH MUNICIPAL USE

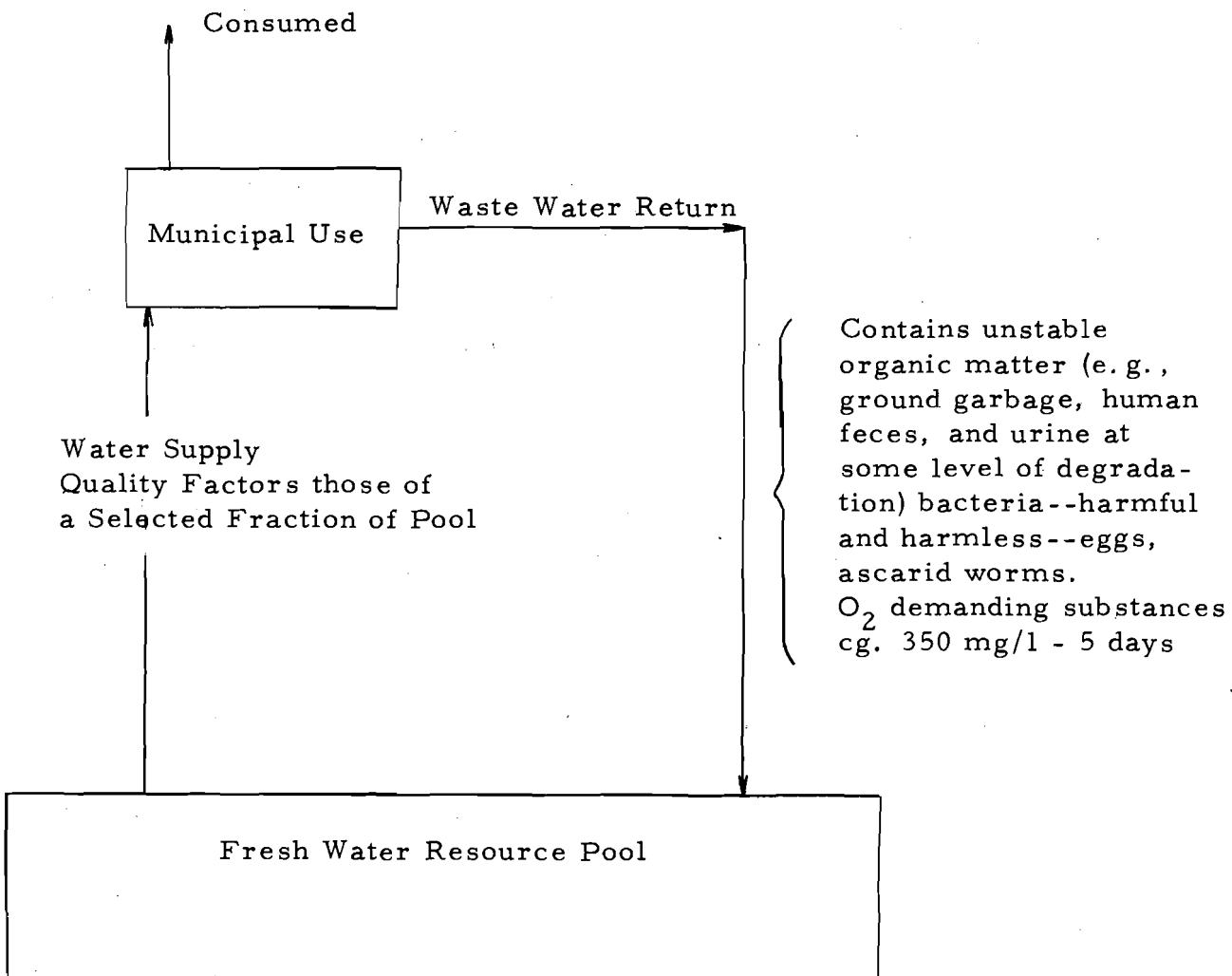
Introduction

Leaving for a later discussion the changes in quality which occur in the fresh water resource pool in the natural course of events, we may examine the separate uses which draw upon the pool and which return effluents to it. Being the most necessary for the continuance of human life, domestic water supply is generally considered the highest beneficial use of water. Therefore it seems logical to give it our first attention.

Domestic use of water is normally considered nonconsumptive. However, lawn sprinkling, street flushing, evaporative cooling, steam heating, and similar activities may account for as much as one-third of municipal use, exclusive of industrial use. Thus a water demand of 150 gallons per capita per day (gpcd) may result in a waste water return flow of only 100 gpcd. The principal task of this return flow is to transport wastes resulting from the life processes of man and of the activities attendant to preparing and managing his food. Although as later explained the biochemical instability of these wastes may make them extremely objectionable, it is hard to justify the dedication of some 2000 tons of water to transport a single ton of solids which has survived waste treatment processes. Certainly it is without parallel in the history of transportation to send so vast a train to carry so small a load. However, our concern at this time is the nature of that load in terms of the quality factors it returns to the fresh water resource pool.

Quality Factors

The water quality factors in municipal use may be diagrammed as follows. The model is far too simple to define the quality aspects of municipal water use. Three additional diagrams may be helpful in



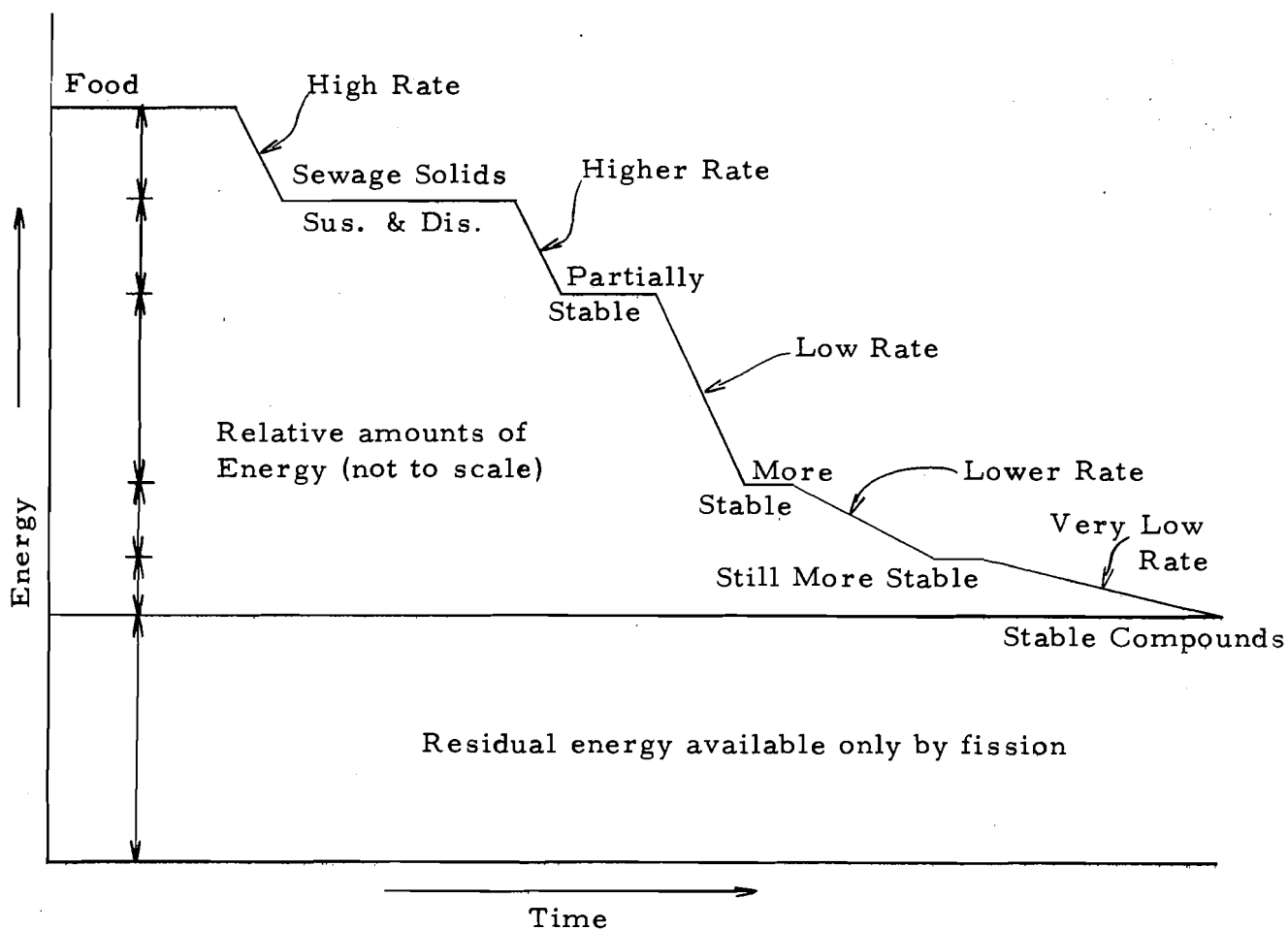
establishing the concepts I seek to convey:

1. The energy sequence
2. The quality spectrum in municipal use
3. Cycles of growth and decay

The Energy Sequence

When you and I eat our dinner we are interested physiologically in two things: obtaining energy and repairing worn out cells. We get this energy by burning up some of the carbon and by unlocking the bonds in molecules such as those of protein. We assimilate a little nitrogen and

phosphorus and other elements to replace worn out cells in our bodies, but the worn out cells themselves are discharged with our wastes. The result is that for adult animals and humans the amount of these elements (nitrogen, phosphorus, etc.,) leaving our bodies each day is as great as the intake of such elements. The truth then is simply that we eat a variety of foods and about all we extract from them by our digestive systems is carbon and some of the bound energy. All the rest of the material passes out as a waste containing all the original elements less some of the original carbon. It differs from our food essentially only in a lowered carbon content and a reduced energy level.



Food - (energy) - (carbon) = Sewage
 Sewage - (energy) - (carbon) = Stable Compounds
 Stable Compounds + Solar Energy + Carbon = Food

The energy content of the original proteins and other materials we consumed is still relatively high. Therefore other organisms can get energy from further digesting it. These organisms are the bacteria, each group of which in turn lives on the residue or sewage of a higher or previous group, until finally what is left is a material of such low energy content that almost no organism can derive energy from further changing the chemical structure of the molecules. This residual material is then said to be "stabilized," and the process by which this situation was brought about is known as digestion, biodegradation, etc., depending upon what circumstances surround the process. But in any case it is biochemical degradation that has occurred. The "biochemical" refers to the fact that chemical reactions have been brought about by biological agents (bacteria), while the word "degradation" refers to the lowering of energy contained in the molecular structure or to the simplifying of the molecular structure.

This stabilized material is by no means useless simply because bacteria no longer are attracted to it as a substrate. It is the fertilizer from which crops derive their nutrients. These nutrients plus carbon dioxide from the atmosphere plus water are all the plant needs in the way of building blocks. Through the agency of chlorophyll, these materials are locked together again with solar energy. The result this time is an increase in the energy level and the addition of carbon. And so here again we find food from which we may burn carbon and derive energy.

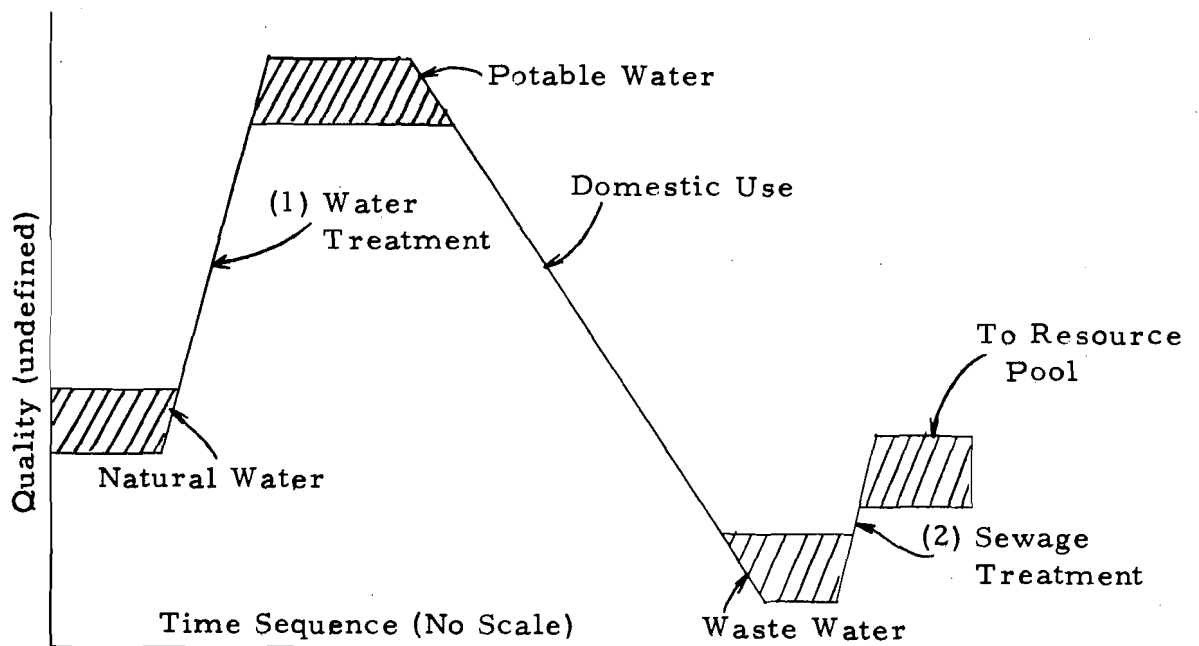
When you think of sewage in this light--think of it as nutrients for bacteria bent upon developing fertilizer for other plants which in turn add solar energy and atmospheric carbon dioxide to complete a cycle--it is hard to consider it again as something objectionable per se, even though along the way the fragrance of some of the products may be objectionable. Whether we like it or not, today's waste is tomorrow's lunch.

The energy cycle shown in the foregoing diagram omits one important source of wastes which reach the sewer. This is the vegetable trimmings,

meat scraps, and other organic matter discarded in the process of preparing our meals, cleansing our dishes and our clothing, and by various industries, e.g., slaughterhouses, etc. This material has not been degraded in energy by our digestive tracts, hence it appears at a higher energy level than our bodily wastes. From it bacteria, nevertheless, can derive the energy that might have been ours had we eaten it. Here we find more energy to be released by bacteria than in our own partially digested wastes and a wider variety of bacterial species are involved in its reduction.

The Quality Spectrum

The waste treatment process is normally carried only to the point demanded by regulatory agencies for protecting other beneficial uses. This, however, is another story for which the following concept may prepare us.



Note: Natural water has a whole spectrum of quality
Potable water has a whole spectrum of quality

- (1) Processes such as sedimentation, chemical coagulation, filtration, and sterilization.
- (2) Processes such as sedimentation, activated sludge, trickling filters, chlorination, oxidation ponds.

Cycles of Growth and Decay

As a prelude to an understanding of the effects of domestic wastes and of organic industrial waste on water quality and consequently on other beneficial uses of a stream, it is important to have in mind two well-known cycles of organic growth and decay. They lead to an understanding of any of the processes of wastes management which we shall discuss later. At this time I wish to introduce or perhaps simply review them for you.

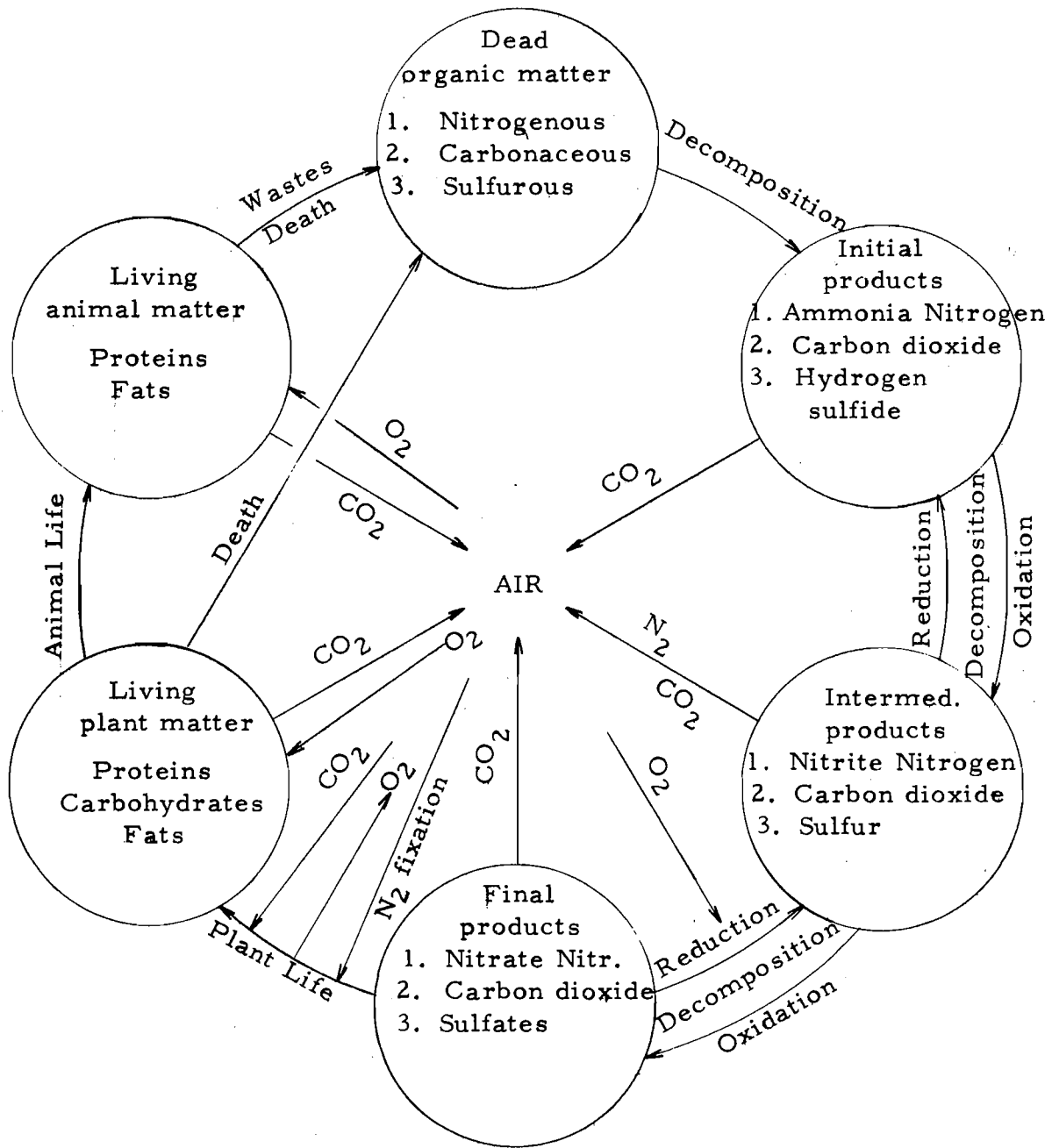
The following charts represent typical cycles of growth and decay under two conditions of biodegradation:

1. By aerobic organisms under circumstances where free atmospheric oxygen is available in quantities required by microorganisms.
2. By anaerobic organisms which must unlock from chemical compounds the oxygen needed to obtain energy from the oxidation of carbon.

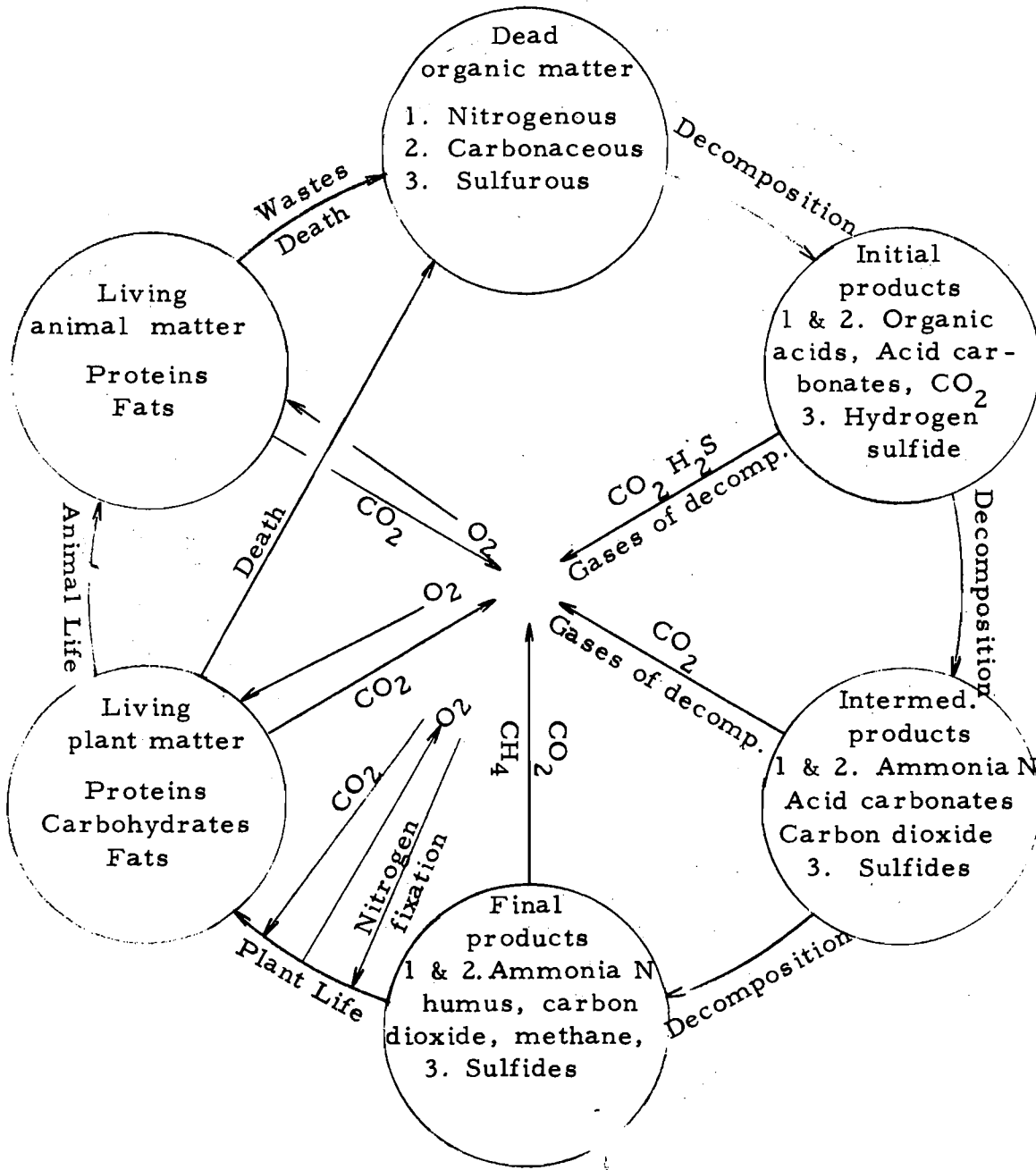
At the present state of technology and economics the use of both aerobic and anaerobic systems is inescapable in the treatment of organic domestic and industrial wastes because such wastes contain both dissolved and suspended solids, and we have as yet found no good way to make the nutrients in settleable particles available to a mass culture of aerobic bacteria. Hence, we commonly settle out the most readily separated suspended solids and lock them up in a closed anaerobic system. The liquid portion with its unstable burden of dissolved and finely divided particulate matter is treated in an aerobic system.

The energy released by bacteria under aerobic conditions is about 30 times that available to bacteria under anaerobic conditions. This accounts for the speed of stabilization. Furthermore, an anaerobic end product is far from stable and is subject to subsequent aerobic digestion when the environmental conditions are right.

In a later discussion (Section II) the details of how the right half of



Nitrogen, carbon, and sulfur cycles in aerobic decomposition.



Nitrogen, carbon, and sulfur cycles in anaerobic decomposition.

these cycles is carried out in nature will be considered, with particular reference to their effects upon the quality of water. For the moment it is sufficient to note that they will be carried out in nature in receiving waters if we permit, in concrete tanks if we prefer and are willing to pay the cost.

Of particular significance is the fact that the anaerobic cycle does not complete the energy sequence previously discussed and hence does not achieve the level of stable compounds as end products. However, the residues of anaerobic decomposition are still subject to aerobic stabilization when the conditions are right.

For purposes of the present discussion it is sufficient to note that the untreated return water from municipal use may go into the resource pool with unstable compounds which must, and will, undergo the changes depicted by the right hand half of the cycle of growth and decay. Whether the anaerobic or aerobic cycle predominates governs the extent of quality degradation of the resource pool, but in either case the effect is important and its implications various and profound as will be brought out in the discussions to follow throughout the course.

The factor about which you will hear most in this matter of waste water treatment, stream pollution, and related subjects is something known as biochemical oxygen demand, or BOD as we call it. Within quite acceptable limits of definition we may say that the ultimate BOD of sewage is the amount of oxygen necessary to carry out the right hand half of the aerobic cycles of nitrogen, carbon, phosphorus, sulfur, etc., -- the amount of oxygen needed by bacteria in reducing the organic matter to stable compounds. As you will see later, it is not necessary that we meet all this demand in the sewage treatment plant. Some of it is exerted only slowly as the going gets tougher for bacteria -- and the rate at which energy can be obtained from organic matter gets lower and lower as the end of the cycle is approached. Hence some of this oxygen demand proceeds so slowly that the natural reaeration of receiving water far

exceeds the rate at which bacteria can demand oxygen to carry out biochemical degradation of their substrate.

It should now be obvious to you that the BOD test is one that we consider of great importance in the field of sewage treatment and disposal.

Characteristics of Domestic Return Flows

Assuming for the moment that the return flows from domestic use of water from the resource pool have not been subjected to waste treatment processes, the quality of this return water may be described by a consideration of the characteristics of municipal sewage.

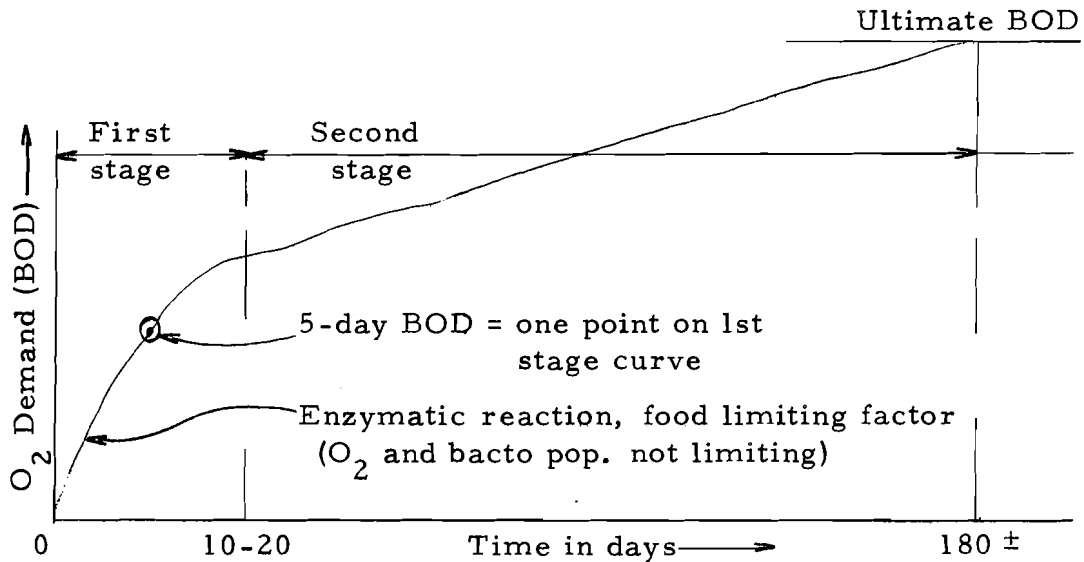
Reference has already been made to the biochemical oxygen demand (BOD). This is perhaps the most significant characteristic of domestic wastes as they affect the quality of receiving waters. The term, incidentally, is used quite loosely in the literature; BOD generally refers to the oxygen demand under standard conditions of 5 days at 20° C. It is expressed in units of mg/l of oxygen demand.

The BOD curve. The BOD, or oxygen demand, of decomposing organic matter is exerted in two distinct stages. Thus the curve of BOD exhibits:

1. A typical unimolecular reaction curve during the period when energy is being derived from
 - (a) oxidation of readily available sugars (carbohydrates)
 - (b) splitting of protein molecules, etc., to unlock energy, producing NH_3 .
2. A somewhat straight-line curve during "nitrification stage" in which NH_3 is oxidized to (NO_2) and (NO_3) .

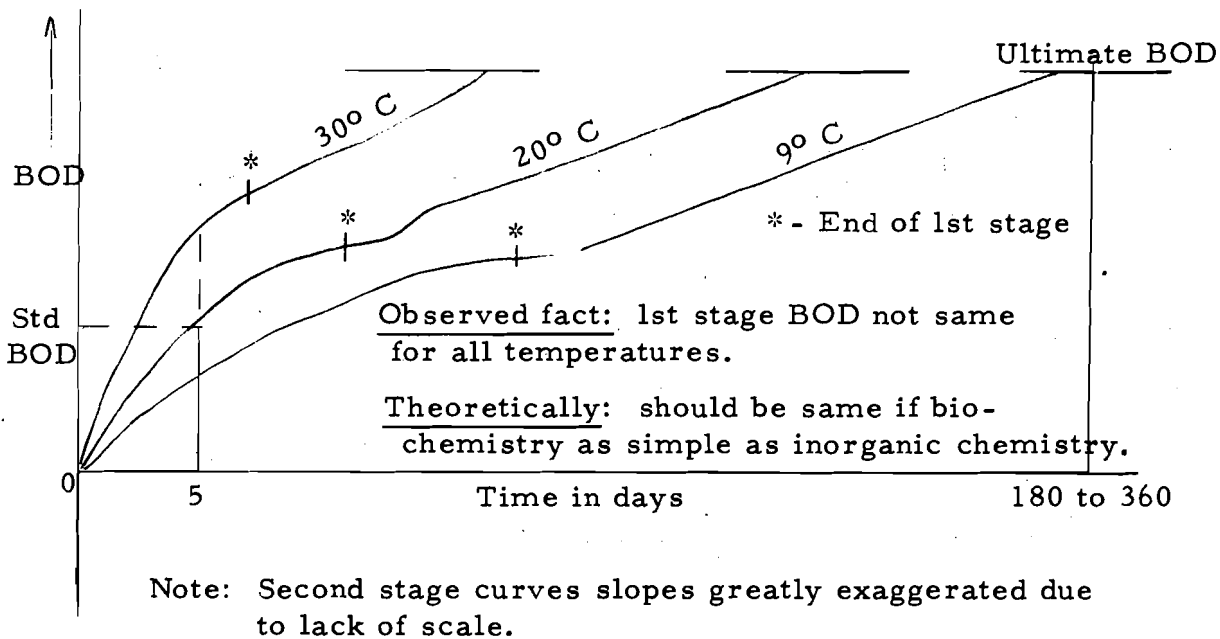
Only the first of these two stages has been well explored, because

1. Oxygen demand is great in first stage (10-20 days); hence critical in receiving waters.
2. Oxygen demand during second stage (3-6 months) is slower than normal processes of reaeration in nature.



At all temperatures likely to obtain outdoors at which biological activity takes place, the first stage BOD extends beyond 5 days. Hence, 5 days might be, and is, used in a standard BOD laboratory test. 20° C being a typical outdoor summer water temperature, and hence near optimum for bacteria found in such an environment, it has also been adopted as standard. The 5-day BOD of sewage varies with temperature somewhat as shown in the sketch on the following page.

From the results of the standard BOD test, a consideration of the equation of the 20° C deoxygenation curve during its first stage, and the relationship between curves for various temperatures, we are able to calculate the BOD exerted in any number of days inside the first stage, and for any desired temperature. The 5-day 20° C BOD test then becomes, subject to certain limitations, a practical device for estimating the ability of an organic material to demand oxygen from an aquatic environment.



When we consider that a normal domestic sewage has a 5-day 20° C BOD of 200 to 250 ppm and the BOD of industrial wastes may range from 3000 ppm upward, while a stream fully saturated with oxygen at 20° C contains only 9.2 ppm of oxygen (20 percent less in salt water), it is easy to anticipate the quick depletion of the dissolved oxygen in any receiving water unless the dilution factor is quite large.

The first stage proceeds rapidly hence is the critical one. Mathematical treatment makes it possible to compute the BOD for any day other than 5 and for any temperature other than 20° C (within first stage). Thus, the BOD test becomes a practical tool for estimating the probable effect on dissolved oxygen in a receiving water of discharging sewage having any observed BOD.

Other sewage characteristics and their general significance are as follows:

1. Temperature

(a) Cause: Ambient air temperature

Hot water discharged into sewer from home or industry.

(b) Significance: Influences rate of biological activity.

Governs solubility of oxygen and other gases.

Affects magnitude of density, viscosity, surface tension, etc.

2. Turbidity

(a) Cause: Suspended matter such as sewage solids, silt, clay, finely divided organic matter of vegetable origin, algae, microscopic organisms.

(b) Significance: Excludes light, thus reducing growth of oxygen producing plants. Impairs aesthetic acceptability of water. May be detrimental to aquatic life.

3. Color

(a) Cause: Dissolved matter such as organic extractives from leaves and other vegetation (tannins, glucosides, iron, etc.), industrial wastes.

(b) Significance: Harmless generally, but impairs aesthetic quality of water.

4. Odor

(a) Cause: Volatile substances, dissolved gases, often produced by decomposition of organic matter. In water it may result from the essential oils in microorganisms.

(b) Significance: May indicate presence of decomposing sewage. Affects aesthetic quality of water. As a test of sewage it may serve as a guide to condition of sewage when it reaches the plant for example.

5. Taste

(a) Cause: Materials producing odors. Dissolved matter, various ions.

(b) Significance: Impairs aesthetic quality of water. Not a test used in physical examination of sewage.

6. Solid Matter (Important in sewage analysis. Sewage = H_2O + added solids)

(a) Cause: Dissolved and suspended organic and inorganic solids.

(b) Significance: Measures amount of organic solids, silt, etc., hence is a measure of the extent of sewage pollution or the concentration of a sewage.

In sewage treatment and analysis we are interested in:

Total solids: As a measure of the amount of total dissolved and suspended matter.

Total volatile solids: As a measure of the decomposable organic matter.

Total fixed solids: As a measure of inorganic grit and dissolved inorganic matter plus ash of organic matter.

Suspended solids: As a measure of material which might be removed by settling.

Volatile and fixed suspended solids; as a measure of the decomposable organic matter and of inorganic matter.

Dissolved solids: As a measure of material to be removed by secondary sewage treatment processes.

Volatile solids; as a measure of organic matter which may be decomposed (may exert BOD).

Fixed solids; as a measure of residues which may add to the burden of the effluent (lower its quality).

General Description of Sewage (Condition, Concentration, Composition)

Three terms are used to describe sewage generally. These are of significance in the matter of sewage treatment, although not all are equally

rigidly defined. These are: condition, concentration, composition.

Condition refers to age of sewage. It is defined as follows:

1. Fresh sewage: Sewage in which the dissolved oxygen is not materially less than that of the municipal water supply which goes into it.
2. Stale sewage: Sewage in which the oxygen has been depleted to near zero.
3. Septic sewage: Sewage in which decomposition has set in and in which a stable population of decomposition-producing organisms has been built up.

The condition of a sewage in a sewer line may govern the measures necessary to protect the sewer and other structures from hydrogen sulfide damage. It may also govern the nature of pretreatment necessary in the plant itself, such as pre-aeration.

Concentration refers to the strength of a sewage, usually measured by BOD, but might also be measured by total volatile solids.

1. Weak sewage: One in which BOD (5-day 20° C) is below about 180 ppm.
2. Average or medium sewage: BOD from say 200 to 250 ppm.
3. Strong sewage: BOD above 280 to 300 ppm.

Composition refers to the analysis of sewage such as presented in the table* on page 28, which presents a typical analysis of strong, average, and weak domestic sewage (values in parts per million).

Bacteria in Sewage

Sewage contains vast numbers of bacteria, up to 20 million or more per ml originating in the wastes discharged from the human body and on other material introduced into the sewer. The feeding activities of some of these organisms result in the decomposition of sewage as

* After Babbitt (1).

Constituent	Strong	Medium	Weak
Solids, total	1000	500	200
volatile	700	350	120
fixed	300	150	80
Suspended, total	500	300	100
volatile	400	250	70
fixed	100	50	30
Dissolved, total	500	200	100
volatile	300	100	50
fixed	200	100	50
BOD (5-day, 20° C)	300	200	100
Oxygen consumed	150	75	30
Dissolved oxygen	0	0	0
Nitrogen, total	86	50	25
organic	35	20	10
free ammonia	50	30	15
nitrites (NO ₂)	0.10	0.05	0
nitrates (NO ₃)	0.40	0.20	0.10
Chlorides	175	100	15
Alkalinity	200	100	50
Fats	40	20	0

discussed in connection with the cycles of growth and decay of organic matter. They cause the composition of sewage to change constantly.

Some of the bacteria in sewage are pathogens, and the number of pathogens necessary to produce disease is often quite small. The range of enteric pathogens in sewage depends upon the diseases endemic in the contributing population. Thus gastro-enteritis may be common in U.S. sewage, whereas elsewhere typhoid, paratyphoid, and cholera might be equally likely. The same may be said of other biological agents such as the eggs of stomach and intestinal worms.

Viruses of several types appear in raw sewage and in most treated sewage as well. Of particular note are the virus of polio and that of hepatitis. Discussion of the significance of biologic agents in sewage is reserved for a later session.

Status of Quality of Municipal Return Waters

From the preceding discussion of the characteristics of municipal or domestic wastes it may be concluded that the return water from municipal use carries organic matter typical of that found in the normal cycle of organic growth and decay in nature. It reaches the water resources pool at various levels of energy residual depending upon the degree of treatment or length of time it has been undergoing biodegradation. It carries oxygen demanding unstable organics on which bacteria feed. In addition it carries microbial agents which may be pathogenic.

The following table gives a rough idea of the status of the organic matter in domestic return water subjected to various treatments:

Type of Return Water	5-day, 20° C BOD	Suspended Solids, mg/l
Raw sewage	200	300
Primary settled sewage	130	150
Secondary effluent	20 - 30	20

Thus it is evident that the return water from domestic use varies in nature in accord with imposed requirements of treatment. A rough estimate of the contribution of quality factors to the water resource pool by domestic return water may be drawn from random statistics. For example, the withdrawals of water for domestic use in 1965 were about 25 billion gallons. At about the same time (1964) ORSANCO reported the following data for the combined states of Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia. (4)

These data probably mean that about 94 percent of the sewage from the urban population is being given primary or secondary treatment, whereas 6 percent discharge raw sewage.

Municipal and Institutional Sewage-Treatment Facilities

Control currently acceptable	63.5 % of seweried communities 80.3 % of population served	
Treatment provided	1.6 %	(as above)
Improvements under construction	6.3 %	
Treatment provided	5.8 %	"
Improvements needed	3.2 %	
New treatment works under construction	7.0 % 4.3 %	"
No treatment	22.1 % 5.9 %	"

Putting the load in terms of BOD to the resource pool in 1960 (Senate Select Committee Print No. 9, 86th Congress) the following estimate was published (page 3) for the combined organic load from domestic and industrial use. (5)

		1954	1980	2000
Population served	Million	100	192.6	279.4
Industries served	Million PE*	36	96.8	139.7
Total municipal load	Million PE	136	289.4	419.1
Removal of BOD	Percent	44	70.0	80.0
Residual BOD to water resource	Million PE	75	86.8	83.8

*PE (Population equivalent) based on 100 gal with BOD of 200 mg/l = 1 person.

From this table it is estimated that the combined BOD returned to the water resource by domestic and industrial use in 1980 will be equivalent to the raw sewage from 86.8 million people.

Assuming that the 70 percent reduction in BOD is attained by 1980 through a great increase in the number of secondary plants, and assuming also that the value applies equally to domestic and industrial wastes, we

may compute the division of the 86.8×10^6 to be:

(= 66 percent) 58×10^6 ascribable to domestic return water

(= 34 percent) 29×10^6 ascribable to industrial wastes

By a straight line interpolation of the values in the foregoing table, 1965 values would appear to be:

BOD removal: 55 percent

Residual BOD PE = 80×10^6 people

55×10^6 , or 69 percent ascribable to domestic return water

25×10^6 , or 31 percent ascribable to industrial return water

Similar calculations may be made from data presented on page 8 of "88th Congress Committee Print. A Study of Pollution - Water," 1963. Here it is shown that in 1960, 83.6 percent of the 110 million population served by sewers also had treatment at some level or another. 18×10^6 people discharged raw sewage while the population equivalent of the total discharge (return flow) from domestic and industrial users was 75×10^6 .

Other interesting data abstracted from Appendix I of the Committee Report (1963) are as follows:

Population Size Group	Discharging Untreated Wastes		Discharging Inadequately Treated Wastes	
	No.	Pop. Millions	No.	Pop. Millions
Under 500	233	0.07	184	0.06
500 - 1000	284	0.21	279	0.20
1000 - 5000	742	1.60	712	1.60
5000 - 10,000	151	1.03	156	1.06
10,000 - 25,000	85	1.30	122	2.80
25,000 - 50,000	25	0.90	31	1.20
50,000 - 100,000	20	1.90	21	1.34
Over 100,000	10	6.04	30	8.80

The approximate values presented in the table are indicative of the scale of the water quality affecting potential of water returned to the resource pool from domestic use.

Considering again the committee print, "A Study of Pollution--Water," (4) plus the fact that some 26×10^6 people used septic tanks (30×10^6 in 1964), we might estimate:

$$\begin{aligned}
 110 \times 10^6 @ 83.6\% &= 92 \times 10^6 \text{ with primary or secondary} \\
 &\text{treatment (68\%)} \\
 &18 \times 10^6 \text{ without treatment (13\%)} \\
 &26 \times 10^6 \text{ with septic tanks (urban) (19\%)} \\
 \hline
 &136 \times 10^6 \text{ urban dwellers} \\
 &*44 \times 10^6 \text{ rural} \\
 \hline
 &180 \times 10^6
 \end{aligned}$$

References

1. Babbitt, Harold E., and E. Robert Baumann. Sewerage and Sewage Treatment. 8th ed. John Wiley & Sons, Inc., New York, 1958.
2. Fair, Gordon M., and John C. Geyer. Water Supply and Waste Water Disposal. John Wiley & Sons, Inc., New York, 1954.
3. Imhoff, Karl, and Gordon M. Fair. Sewage Treatment. 2nd ed. John Wiley & Sons, Inc., New York, 1956.
4. Ohio River Valley Water Sanitation Commission. "A Study of Pollution--Water." Sixteenth Annual Report. Committee Print, 88th Congress, First Session, 1964. (Staff report to the Committee on Public Works, 1963.)
5. U. S. Senate. Select Committee. Water Resources Activities in the United States. Pollution Abatement. Print No. 9, 86th Congress, 2nd Session, 1960.

*Probably not more than 30×10^6 rural.

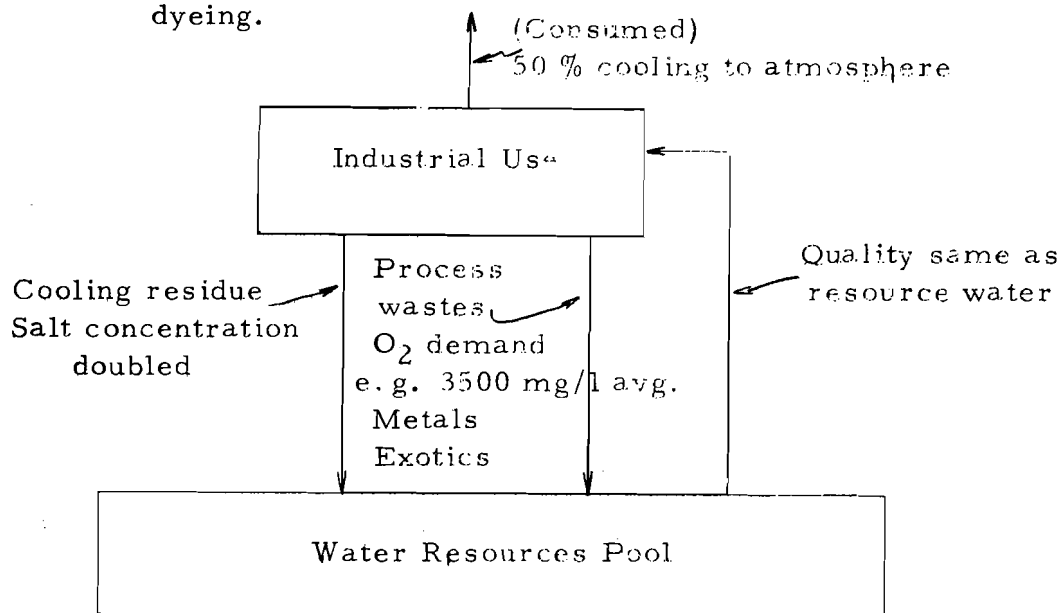
IV

QUALITY CHANGES THROUGH INDUSTRIAL USE

Industrial Use vs. Quality

Industrial use of water has quality effects similar to that of municipal use in that it increases the concentration of salts in the water. It has, however, a number of significant differences.

1. About 66 percent of industrial water use is for cooling purposes. (Varies from 10 to 95 percent.)
2. On the average, about half of cooling water is consumed, i. e., lost to atmosphere. The other 50 percent \pm returns to the resource pool with its original salt concentration doubled. The consumption of water by evaporation, however, varies from 0 to 85 percent in different industries.
3. Whereas domestic sewage returns to the resource pool material characteristic of nature's cycle of organic growth and decay, industrial wastes from process waters include compounds never found in nature and in a vast spectrum of variety--and an ever changing one at that, e. g., metal ions (mostly toxic) exotic organic and inorganic compounds, refractory compounds. They also include normal organic compounds--e. g., canning industry, meat processing, color dyeing.



In order to assess the relative importance of industrial use of water as a factor in determining the quality of the overall water resource pool, some factors of scale should be considered. The following table abstracted from a United Nations release (5) published in 1958 and entitled "Water for Industrial Use" gives an idea of the quantity and variability of the water requirements of selected U. S. industries.

Water Requirements per Unit of Product, Selected U. S. Industries
After Unesco (5)

Industry and Product	Unit of Product ^a	Water Required per Unit (gallons)
Food:		
Bread	ton	555 ^b to 1,110 ^b
Canned food:		
Apricots	ton	5,600
Asparagus	ton	5,410
Beans, green	ton	2,460
Beans, lima	ton	18,430
Beets, corn, and peas	ton	1,850
Grapefruit juice	ton	740
Grapefruit sections	ton	4,120
Peaches and pears	ton	4,780
Pork and beans	ton	2,460
Pumpkin and squash	ton	1,850
Sauerkraut	ton	250
Spinach	ton	13,040
Succotash	ton	9,190
Tomato products	ton	5,410
Tomatoes, whole	ton	580
Gelatin (edible)	ton	14,550 to 22,040 ^b
Maize (wet milling)	gallon of maize	15.0 to 25.5 ^b
Maize syrup	gallon of maize	3.8 to 4.3 ^b
Meat packing	ton, live weight	4,540
Milk and milk products:		
Butter	ton	5,520
Cheese	ton	4,410
Molasses distilling	gallon of 100 proof	8.4

Water Requirements per Unit of Product, Selected U.S. Industries (cont.)

Industry and Product	Unit of Product ^a	Water Required per Unit (gallons)
Oil (edible)	gallon	22.0
Sugar	ton of beet sugar	2,380
	ton of cane sugar	1,110
Beverages:		
Beer	gallon	15.2
Whiskey	gallon	80.0
Pulp and paper:		
Groundwood pulp	ton of dry pulp	4,410 to 55,180 ^c
Kraft pulp	ton of dry pulp	102,430
Soda pulp	ton of dry pulp	93,720
Sulphate pulp	ton of dry pulp	77,090
Sulfite pulp	ton of dry pulp	77,090 to 146,520 ^c
Paper	ton	43,030
Paperboard	ton	16,530 to 99,260 ^c
Strawboard	ton	28,780
Petroleum:		
Aviation gasoline	gallon	25.0
Gasoline	gallon	7.0 to 10.0
Gasoline, polymerization	gallon	34.0
Synthetic gasoline	gallon	377
Oilfields	gallon of crude petroleum	4.0
Oil refineries	gallon of crude petroleum	18.0
Synthetic fuel:		
From coal	gallon	265
From natural gas	gallon	88.9
From shale	gallon	20.8
Chemicals:		
Acetic acid	ton of HAc	110,090 to 264,000
Alcohol, 100 proof	gallon	140 ^d
Alcohol, 190 proof	gallon	52.0 to 100.0
Alumina (Bayer process)	ton	6,940
Ammonia, synthetic	ton of liquid NH ₃	34,060
Ammonium sulphate	ton of salt	220,440
Calcium carbide	ton	33,000

Water Requirements per Unit of Product, Selected U.S. Industries (cont.)

Industry and Product	Unit of Product ^a	Water Required per Unit (gallons)
Calcium metaphosphate	ton of $\text{Ca}(\text{PO}_3)_2$	4,410
Carbon dioxide	ton	22,040
Caustic soda	ton of NaOH (11% solution)	19,830 to 23,130
Cellulose nitrate	ton	11,010
Charcoal and wood chemicals	ton of crude CaAc_2	71,540
Glycerine	ton	1,210
Gunpowder	ton	105,860 to 220,440
Hydrochloric acid (salt process)	ton of 20 Be HCl	3,190
Hydrochloric acid (synthetic process)	ton of 20 Be HCl	530 to 1,110
Hydrogen	ton of H_2	726,000
Lactose	ton	220,440 to 242,350
Magnesium carbonate, basic	ton of basic MgCO_3	4,750
	ton of MgCO_3	43,030
Oxygen	cubic yard of O_2	49.0
Potassium chloride (sylvinite)	ton of KCl	44,090 to 55,180
Smokeless powder	ton	55,180
Soap (laundry)	ton	255 to 555
Soda ash (ammonia soda process), 58%	ton	16,530 to 19,830
Sodium chlorate	ton	66,000
Sodium silicate	ton of 40 Be water-glass	175
Sulfuric acid (chamber process)	ton of 100% H_2SO_4	2,750
Sulfuric acid (contact process)	ton of 100% H_2SO_4	715 to 5,360 ^c
Textiles:		
Steeping, dressing, scouring, and bleaching:		
Scouring and bleaching woollens	ton	44,090
Cotton bleaching	ton	66,000 to 88,180
Dyeing:		
Cotton	ton	8,820 to 17,640
Naphthol process	ton	10,560
Aniline black	ton	34,370

Water Requirements per Unit of Product, Selected U.S. Industries (cont.)

Industry and Product	Unit of Product ^a	Water Required per Unit (gallons)
Weaving, dyeing, and finishing:		
Rayon	1,000 yards	15,000
Printing	ton	9,930
Synthetic fibers:		
Rayon cuprammonium (11% moisture)	ton of yarn	99,000 to 176,090 ^b
Rayon viscose	ton of yarn	220,440
Iron and steel products:		
Pig-iron	ton	4,410
Finished steel	ton	71,540
Fabricated steel	ton	46,200
Ingot steel	ton	19,830
Rolled steel	ton	88,180
Cold rolled strip	ton	6,600
Cold rolled high carbon strip	ton	68,380
Steel sheets and coils	ton	14,310
Hot rolled steel plates	ton	16,530
Misc. products or processes:		
Aluminum	ton	353,760
Boilers, steam	horsepower-hour	4.0 ^e
Cement, Portland	ton	820
Coal, coke, and by-product coke	ton	1,660 to 3,960 ^b
Coal washing	ton	220
Condensers, surface	lbs. of condensed steam	2.4 to 7.2
Distilling, grain	gallon	64.5
Electric power (thermal)	kilowatt-hour	79.2 to 170 ^c
Explosives	ton	220,440
Iron ore (brown)	ton	1,110
Leather tanning, vegetable	ton of raw hide	17,690
chrome	ton of raw hide	17,690
Rock wool	ton	4,410 to 5,520
Rubber, synthetic:		
Butadiene	ton	22,040 to 726,000 ^c
Buna S	ton	33,000 to 694,320
Grade GR-S	ton	30,890 to 739,200 ^c

Water Requirements per Unit of Product, Selected U. S. Industries (cont.)

Industry and Product	Unit of Product ^a	Water Required per Unit (gallons)
Sulphur mining	ton	3,300

^aOr where specified, unit of raw material.

^bRange covers various products or processes.

^cRange from maximum recycling to no re-use.

^dOf which 31.7 gallons are cooling water.

^eRating 100 percent. Boiler makeup 100 percent.

Some Factors of Scale

An idea of the past and anticipated increase in industrial use and its comparison with similar increases in other uses may be obtained from the table on the following page. From this table the percentage increase in the next ten years may be estimated.

Percent Increase by Decades

Year	Irrigation	Public Water Supply	Industrial	Steam Electric Power	Total
1955	-	-	-	-	-
1965	23	47	46	54	37
1975	15	20	32	42	27
1975 in terms of 1965	115%	120%	132%	142%	127%

Some estimates of the 1980 demand in terms of 1960 for California are as follows:

1960-1980

Total per capita increase	170%
Industrial use increase	250%
Irrigation use	18%

United States: Estimated Water Use, 1900-1975
(Billions of gallons; daily average)¹

Year	Irrigation ^a	Self-supplied			Steam- electric Power	Total
		Public Water Supplies	Domestic ^b	Industrial and Misc. ^c		
1900	20.2	3.0	2.0	10.0	5.0	40.2
1910	39.0	4.7	2.2	14.0	6.5	66.4
1920	55.9	6.0	2.4	18.0	10.0	92.3
1930	60.2	8.0	2.9	21.0	18.4	110.5
1940	71.0	10.1	3.1	29.0	22.2	135.4
1944	80.6	12.0	3.2	56.0	35.9	187.7
1945	83.1	12.0	3.2	48.0	28.8	175.1
1946	86.4	12.0	3.5	39.0	26.9	167.8
1950	100.0	14.1	4.6	46.0	38.4	203.1
1955	119.8	17.0	5.4	60.0	59.8	262.0
1960	135.0	22.0	6.0	71.9	77.6	312.5
1965	148.1	25.0	6.5	87.7	92.2	359.5
1970	159.0	27.8	6.9	103.0	107.8	404.5
1975	169.7	29.8	7.2	115.4	131.0	453.1

^aTotal take, including delivery losses but not including reservoir evaporation.

^bNon-farm domestic use and farm domestic as well as farm stock wells.

^cManufacturing industry, mineral industry, commercial, air conditioning, resorts, motels, military, and miscellaneous.

Source: United States Department of Commerce, "Water Use in the United States, 1900-1975," BSB-136 (Washington, D. C., January 1956).

Editor's Note: The above figures probably more nearly represent diversions of "withdrawal" uses rather than consumptive uses.

These tables show clearly the growing importance of industry as a user of water. Consumptive use by steam power is the fastest growing. Its effect is to reduce the resource pool and hence to increase the effect of wastes discharged by other users.

Industry's waste return to the pool may be roughly estimated as:

1. One-third of its withdrawals returned with the salt content in the withdrawn water approximately doubled.
2. One-third of its withdrawals contaminated with a spectrum of organic and inorganic solids of a nature suggested in the tables on pages 41, 42, and 43, which are taken from "Theory and Practice of Industrial Waste Treatment," by Nemerow, Addison Wesley, 1963. (4)

The remaining one-third of the withdrawal is consumed by incorporation in product or loss to the atmosphere.

The tables show also that the load on the resource pool in terms of pollutional intensity through consumptive depletion and return of used water is growing some 30 percent per decade.

Similar data were prepared by Mr. M. B. Ettinger (2). He lists the types of industrial wastes and the sources of each by type of industry (see table on page 44).

Klein (3) also lists wastes in relation to origin, and the harmful effects of organic and inorganic quality factors (tables on pages 45 and 46).

Status and Quantity of Wastes

Estimates of the degree of control exercised by industry in reducing the amount of quality factors in its return water are hard to make. The 1963 ORSANCO Report showed that about 82 percent of industries in the eight member states had currently acceptable control facilities, and another 17 percent had either some type of facility or were in various

SUMMARY OF INDUSTRIAL WASTE: ITS ORIGIN, CHARACTER,
AND TREATMENT

Industries producing wastes	Origin of major wastes	Major characteristics	Major treatment and disposal methods
Food and Drugs			
Canned goods	Trimming, culling, juicing, and blanching of fruits and vegetables	High in suspended solids, colloidal and dissolved organic matter	Screening, lagooning, soil absorption or spray irrigation
Dairy products	Dilutions of whole milk, separated milk, buttermilk, and whey	High in dissolved organic matter, mainly protein, fat, and lactose	Biological treatment, aeration, trickling filtration, activated sludge
Brewed and distilled beverages	Steeping and pressing of grain, residue from distillation of alcohol, condensate from stillage evaporation	High in dissolved organic solids, containing nitrogen and fermented starches or their products	Recovery, concentration by centrifugation and evaporation, trickling filtration; use in feeds
Meat and poultry products	Stockyards, slaughtering of animals, rendering of bones and fats, residues in condensates, grease and wash water, picking of chickens	High in dissolved and suspended organic matter, blood, other proteins, and fats	Screening, settling and/or flotation, trickling filtration
Beet sugar	Transfer, screening and juicing waters, drainings from lime sludge, condensates after evaporator, juice, extracted sugar	High in dissolved and suspended organic matter, containing sugar and protein	Reuse of wastes, coagulation, and lagooning
Pharmaceutical products	Mycelium, spent filtrate, and wash waters	High in suspended and dissolved organic matter, including vitamins	Evaporation and drying; feeds
Yeast	Residue from yeast filtration	High in solids (mainly organic) and BOD	Anaerobic digestion, trickling filtration
Pickles	Lime water, brine, alum and tumeric, syrup, seeds and pieces of cucumber	Variable pH, high suspended solids, color, and organic matter	Good housekeeping, screening, equalization
Coffee	Pulping and fermenting of coffee bean	High BOD and suspended solids	Screening, settling, and trickling filtration
Fish	Rejects from centrifuge, pressed fish, evaporator and other wash water wastes	Very high BOD, total organic solids, and odor	Evaporation of total waste, barge remainder to sea
Rice	Soaking, cooking, and washing of rice	High in BOD, total and suspended solids, (mainly starch)	Lime coagulation, digestion
Soft drinks	Bottle washing, floor and equipment cleaning, syrup-storage-tank drains	High pH, suspended solids and BOD	Screening, plus discharge to municipal sewer
Apparel			
Textiles	Cooking of fibers, desizing of fabric	Highly alkaline, colored, high BOD and temperature, high suspended solids	Neutralization, chemical precipitation, biological treatment aeration and/or trickling filtration
Leather goods	Unhairing, soaking, deliming and bating of hides	High total solids, hardness, salt, sulfides, chromium, pH, precipitated lime and BOD	Equalization, sedimentation, and biological treatment

(Continued)

SUMMARY OF INDUSTRIAL WASTE: ITS ORIGIN, CHARACTER,
AND TREATMENT (Continued)

12

Industries producing wastes	Origin of major wastes	Major characteristics	Major treatment and disposal methods
Laundry trades	Washing of fabrics	High turbidity, alkalinity, and organic solids	Screening, chemical precipitation, flotation, and adsorption
Chemicals			
Acids	Dilute wash waters; many varied dilute acids	Low pH, low organic content	Upflow or straight neutralization, burning when some organic matter is present
Detergents	Washing and purifying soaps and detergents	High in BOD and saponified soaps	Flotation and skimming, precipitation with $CaCl_2$
Cornstarch	Evaporator condensate, syrup from final washes, wastes from "bottling up" process	High BOD and dissolved organic matter; mainly starch and related material	Equalization, biological filtration
Explosives	Washing TNT and guncotton for purification, washing and pickling of cartridges	TNT, colored, acid, odorous, and contains organic acids and alcohol from powder and cotton, metals, acid, oils, and soaps	Flotation, chemical precipitation, biological treatment, aeration, chlorination of TNT, neutralization
Insecticides	Washing and purification products such as 2,4D and DDT	High organic matter, benzene ring structure, toxic to bacteria and fish, acid	Dilution, storage, activated carbon adsorption, alkaline chlorination
Phosphate and phosphorous	Washing, screening, floating rock, condenser bleed-off from phosphate reduction plant	Clays, slimes and tall oils, low pH, high suspended solids, phosphorous, silica and fluoride	Lagooning, mechanical clarification, coagulation and settling of refined waste
Formaldehyde	Residues from manufacturing synthetic resins, and from dyeing synthetic fibers	Normally has high BOD and HCHO, toxic to bacteria in high concentrations	Trickling filtration, adsorption on activated charcoal
Materials			
Pulp and paper	Cooking, refining, washing of fibers, screening of paper pulp	High or low pH; colored; high suspended, colloidal, and dissolved solids; inorganic fillers	Settling, lagooning, biological treatment, aeration, recovery of by-products
Photographic products	Spent solutions of developer and fixer	Alkaline, contains various organic and inorganic reducing agents	Recovery of silver, plus discharge of wastes into municipal sewer
Steel	Coking of coal, washing of blast-furnace flue gases, and pickling of steel	Low pH, acids, cyanogen, phenol, ore, coke, limestone, alkali, oils, mill scale, and fine suspended solids	Neutralization, recovery and reuse, chemical coagulation
Metal-plated products	Stripping of oxides, cleaning and plating of metals	Acid, metals, toxic, low volume, mainly mineral matter	Alkaline chlorination of cyanide, reduction and precipitation of chromium, and lime precipitation of other metals
Non-foundry products	Wasting of used sand by hydraulic discharge	High suspended solids, mainly sand; some clay and coal	Selective screening, drying of reclaimed sand
Oil	Drilling muds, salt, oil, and some natural gas, acid sludges and miscellaneous oils from refining	High dissolved salts from field, high BOD, odor, phenol, and sulfur compounds from refinery	Diversion, recovery, injection of salts; acidification and burning of alkaline sludges

(Continued)

SUMMARY OF INDUSTRIAL WASTE: ITS ORIGIN, CHARACTER,
AND TREATMENT (Continued) *

Industries producing wastes	Origin of major wastes	Major characteristics	Major treatment and disposal methods
Rubber	Washing of latex, coagulated rubber, exuded impurities from crude rubber	High BOD and odor, high suspended solids, variable pH, high chlorides	Aeration, chlorination, sulfonation, biological treatment
Glass	Polishing and cleaning of glass	Red color, alkaline non-settleable suspended solids	Calcium chloride precipitation
Naval stores	Washing of stumps, drop solution, solvent recovery, and oil recovery water	Acid, high BOD	By-product recovery, equalization, recirculation and reuse, trickling filtration
Energy Steam power	Cooling water, boiler blow-down, coal drainage	Hot, high volume, high inorganic and dissolved solids	Cooling by aeration, storage of ashes, neutralization of excess acid wastes
Coal processing	Cleaning and classification of coal, leaching of sulfur strata with water	High suspended solids, mainly coal; low pH, high H ₂ SO ₄ and FeSO ₄	Settling, froth flotation, drainage control, and sealing of mines
Nuclear power and radioactive materials	Processing ores, laundering of contaminated clothes, research-lab wastes, processing of fuel, power-plant cooling waters	Radioactive elements, can be very acid and "hot"	Concentration and containing, or dilution and dispersion

* Reprinted, with permission, from Theories and Practices of Industrial Waste Treatment, by Nelson L. Nemerow. Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1963.

Types of Industrial Waste Waters [Ettinger (2)]*

A. Chiefly mineral, or partly mineral-partly organic

- | | |
|-----------------------------------------------------------------------|---------------------------|
| 1. Brine wastes | 7. Cooling water |
| 2. Mineral washings, e. g., stone
sawing, sand and china clay wash | 8. Boiler blow-off |
| 3. Mine drainage (coal pit water) | 9. Inorganic chem. wastes |
| 4. Pickle liquor (Fe, Cu, & Zn) | 10. Battery mfg. |
| 5. Electro-plating | 11. Inorganic pigments |
| 6. Water softening | 12. Coal washing |
| | 13. Photographic wastes |

B. Chiefly organic materialsI. Hydrocarbons

- | | |
|-----------------------|-------------------------------|
| 1. Oil wells | 5. Processing natural rubber |
| 2. Petroleum refining | 6. Gasoline stations, garages |
| 3. Styrene mfg. | 7. Co-polymer rubber plants |
| 4. Butadiene plants | |

II. Misc. organic chemicals

- | | |
|------------------------------|-------------------------------|
| 8. Munition plants | 11. Organic chemical mfg. |
| 9. Synthetic pharmaceuticals | 12. Paints and varnishes |
| 10. Synthetic fibers | 13. Oil and grease processing |

III. Phenolic wastes

- | | |
|-------------------------------------|----------------------------|
| 14. Gas and coke byproducts | 17. Synthetic resin plants |
| 15. Tar distillation and creosoting | 18. Wood distillation |
| 16. Chemical plants | 19. Dye mfg |

IV. Biological wastes

(a) Biological processing

- | | |
|------------------------------------|----------------------|
| 20. Tanneries and leather trades | 25. Wool scouring |
| 21. Pharmaceuticals | 26. Textile mfg. |
| 22. Alcohol industries | 27. Floor cloth mfg. |
| 23. Misc. fermentation ind. | 28. Paper mfg. |
| 24. Glue, size, and gelatin plants | 29. Laundries |

(b) Food processing

- | | |
|---------------------------|--------------------------|
| 30. Canneries | 34. Beet sugar factories |
| 31. Meat packing, etc. | 35. Cane sugar factories |
| 32. Milk and dairy wastes | 36. Fish processing |
| 33. Corn products plants | 37. Food dehydration |

*Reprinted, with permission, from July 1950 Water & Sewage Works.

Chemicals in Industrial Wastes [Klein (3)]*

Chemical	Industry
Acetic acid	Acetate rayon, pickle and beetroot mfg.
Alkalis	Cotton and straw kiering, cotton mfg., mercerizing, wool scouring, laundries
Ammonia	Gas and coke mfg., chemical mfg.
Arsenic	Sheep-dipping, fell mongering
Chlorine	Laundries, paper mills, textile bleaching
Chromium	Plating, chrome tanning, aluminum anodizing
Cadmium	Plating
Citric acid	Soft drinks and citrus fruit processing
Copper	Plating, pickling, rayon mfg.
Cyanides	Plating, metal cleaning, case-hardening, gas mfg.
Fats, oils, grease	Wool scouring, laundries, textiles, oil refineries
Fluorides	Gas and coke mfg., chem. mfg., fertilizer plants transistor mfg., metal refining, ceramic plants, glass etching
Formalin	Mfg. of synthetic resins and penicillin
Hydrocarbons	Petro-chemical and rubber factories
Hydrogen peroxide	Textile bleaching, rocket motor testing
Lead	Battery mfg., lead mining, paint mfg., gasoline mfg.
Mercaptans	Oil refining, pulp mills
Mineral acids	Chemical mfg., mines, Fe and Cu pickling, DDT mfg. brewing, textiles, photo-engraving, battery mfg.
Nickel	Plating
Nitro comp.	Explosives and chemical works
Organic acids	Distilleries and fermentation plants
Phenols	Gas and coke mfg., synthetic resin mfg., textiles, tanneries, tar, chem. and dye mfg., sheep dipping
Silver	Plating, photography
Starch	Food, textile, wallpaper mfg.
Sugars	Dairies, foods, sugar refining, preserves, wood process
Sulfides	Textiles, tanneries, gas mfg., rayon mfg.
Sulfites	Wood process, viscose mfg., bleaching
Tannic acid	Tanning, sawmills
Tartaric acid	Dyeing; wine, leather, and chemical mfg.
Zinc	Galvanizing, plating, viscose mfg., rubber process

* Reprinted, with permission, from River Pollution. 2: Causes and Effects, by Louis Klein. Butterworths, Inc., Washington, D. C., 1962.

Harmful Effects of Domestic and Industrial Wastes [Klein (3)]*

Type of Material	Effect
Fermentable organic matter	Deoxygenate water; kill fish, objectionable odors
Suspended matter	Deposit on river bed; if organic may putrify and float masses to surface by gas; blanket bottom and interfere with fish spawning or disrupt food chain
Corrosive substances	(e. g., cyanides, phenols, metal ions) may kill fish and other aquatic life; destroy bacteria and so interrupt self-purification of streams
Pathogenic micro-organisms	Sewage may carry pathogens, tannery wastes, anthrax
Substances causing turbidity, temp., color, odor, etc.	Temperature rise may injure fish; color, odor, turbidity may render unacceptable for public use
Substances or factors which upset biological balance	May cause excessive growth on fungi or aquatic plants which choke stream, cause odors, etc.
Mineral constituents	Increase hardness, limit use in industry without special treatment, increase salt content to level deleterious to fish or vegetation

stages of planning or construction. In all 89.7 percent were complying with ORSANCO minimum requirements.

Here as in the case of municipal wastes acceptable is an interpretation of compliance with some type of regulation.

The magnitude of the return water load from industry, in terms of BOD, has been included in tables and computations presented in the preceding section. They show that the organic load in terms of oxygen demand is currently equivalent to raw sewage from some 25 million people; a value destined to increase for a

* Reprinted, with permission, from River Pollution. 2: Causes and Effects, by Louis Klein. Butterworths, Inc., Washington, D. C., 1962.

number of years regardless of the higher degree of treatment which will progressively be imposed.

Although the data herein presented interpret the strength of organic industrial wastes in terms of BOD, there is a growing tendency to utilize instead COD (chemical oxygen demand test) in which the oxygen is consumed by the waste in the presence of a chemical oxidizing agent such as a permanganate. It is a more rapid test and by many thought to be more pertinent to oxidizable matter not commonly a part of the normal animal and vegetable life cycle, i. e., not involved in the BOD measurement.

Presently it is essentially impossible to amass reliable figures on either the potential or current contribution of inorganic or exotic organics to the water resource pool via industrial return water. Production figures of varying degree of reliability can be obtained, but in-plant practices are variable within any single industry as well as from industry to industry. The whole matter of waste discharges from industry is only partially investigated, understood, or policed. For the purpose of this course, therefore, I shall have to be content with fragmentary data on the magnitude of industry's use of water, and the variety of quality-affecting materials which its return waters may bring to the fresh water resource pool.

References

1. American Association for Advancement of Science. Water for Industry. Washington, D. C., 1956.
2. Ettinger, M. D. Water and Sewage Works 97(7):292-294. July 1950.
3. Klein, Louis. River Pollution. 2: Causes and Effects. Butterworths, Inc., Washington, D. C., 1962.

4. Nemerow, Nelson L. Theory and Practice of Industrial Waste Treatment. Addison Wesley Publishing Co., Inc., Reading, Massachusetts. 1963.
5. United Nations. Water for Industrial Use. Department of Economic and Social Affairs, New York, 1958.

QUALITY CHANGES THROUGH AGRICULTURAL USE

Introduction

Historically, every civilization that has depended upon irrigated agriculture for its existence has failed. The story is fascinating in the extreme but unfortunately beyond the objective of our Institute this summer. For our part, we like to tell ourselves that our superior knowledge of the soil-water-crop relationship insures immunity from the fate of Mesopotamia. And perhaps we are right. It does seem likely that we shall not by our irrigation practices kill the land as did our forebears. Nevertheless, the possibility exists that by killing the water we may achieve the same ultimate end. And if such should prove the case it may be agricultural and industrial return waters which overwhelm the water resource, although in our zeal to re-establish Indian days without turning the country back to the Indians, we may have rendered water sterile by the exclusion of nutrients from sewage. For the moment, however, the objective is to explore the nature and scale of quality-related factors introduced into the fresh water resource pool by return water from agricultural use.

Magnitude of Irrigation Practice

The table on page 50, reproduced from reference (1), presents data regarding the magnitude and distribution of irrigation in the United States. Several notable facts are evident from the table:

1. A 17 percent increase in irrigated acreage occurred in the two-year period, 1954-56. Almost 5.5×10^6 acres were added, with about 4.6×10^6 of this total occurring in the 17 Western States.
2. About 41 percent of the land under irrigation is in California and Texas.
3. Six states, five of which are in the humid areas of the

United States, increased irrigation acreage over 100 percent, signifying the emergence of supplemental irrigation as a phenomenon in American agriculture.

U. S. Irrigated Acreage*

	Acreage 1956	Acreage 1954	Increase %	Sprinkler**
U. S. Total	36,002,627	30,711,453	17	3,064,463
17 Western States	32,661,501	28,092,947	16	2,010,062
Other States	3,341,126	2,618,506	28	1,054,401
1. California	7,750,000	7,048,792	10	400,000
2. Texas	6,962,234	5,439,000	28	575,015
3. Idaho	2,405,089	2,324,571	3	130,000
4. Colorado	2,382,000	2,263,000	5	33,110
5. Nebraska	2,012,320	1,393,733	44	201,230
6. Montana	1,890,000	1,890,000	--	28,000
7. Utah	1,612,108	1,072,682	50	3,325
8. Oregon	1,575,000	1,490,397	6	157,500
9. Wyoming	1,300,000	1,262,632	3	8,000
10. Arizona	1,150,000	1,250,000	-9	1,000
11. Washington	947,000	778,135	22	228,000
12. Arkansas	892,936	857,390	4	54,756
13. Florida	821,282	428,282	92	180,000
14. New Mexico	800,000	649,615	23	3,000
15. Kansas	722,575	420,000	72	100,000
16. Louisiana	711,000	707,818	1	39,650
17. Nevada	700,000	567,498	23	12,000
18. Oklahoma	285,175	107,981	164	100,882
19. Mississippi	157,000	132,490	19	54,000
20. South Dakota	120,000	90,371	33	20,000

Increase of over 100% in:

Iowa	20,000	2,396	818	20,000
Maine	6,900	1,097	529	6,850
Georgia	80,000	27,701	189	79,200
Oklahoma			164	
Virginia	45,500	21,805	116	45,050
Delaware	11,000	5,553	100	11,000

* Taken from the 1957 Directory and Buyers Guide (2).

** 31.5% of irrigation in "other states" use sprinkler while only 6.1% of area in 17 Western States is sprinkled.

Estimates are that 51.5×10^6 acres will be under irrigation in the 17 Western States by 1966 or 1967. Eventually, supplemental irrigation may be applied to much of the 125×10^6 irrigable acres in the humid Eastern States.

The implications of both primary and supplemental irrigation are of major importance to quality maintenance of the water resource pool.

The 1949 Census of Agriculture estimated that 99.44×10^6 acre-feet of irrigation water was used during that year (75 percent from surface supplies; 25 percent from groundwater).

Comparison with Other Major Uses

In the preceding section tables were presented to show that although irrigation usage is greater than either industrial or domestic, its comparative rate of growth is diminishing (see tables pages 38 and 39). The same pattern is revealed in a table based on data from the U. S. Public Health Service (4).

Pattern of Water Use in the United States (1960)

Year	Total Water Usage (billion gallons)	Distribution of Water Usage		
		Agriculture %	Industry %	Municipal %
1900	40	55.0	37.5	7.5
1960	324	43.6	50.0	6.5
1980	547	27.6	65.6	6.8

A decline in the predominance of agricultural water is evident in the table. Nevertheless, agricultural return waters, and the consumptive loss of water from the resource pool which it occasions, will continue to have a profound effect on the overall quality of the pool.

Quantity Considerations

Estimates (3) of the total withdrawals of irrigation water at various times have been previously presented (page 39). Estimates vary from one reference to another but are generally consistent. For example, the U.N. estimate of 169.7×10^9 gallons in 1975 is somewhat greater than the Public Health Service estimate (computed from foregoing table) of 157×10^9 in 1980.

The general magnitude of irrigation needs can be computed for any area from the data available locally on the rates of application of water. The 1949 Census of Agriculture estimated that the use of water on land in the 17 Western States averaged 3.4 acre-feet/acre/year, with variations from 2.2 in the Rio Grande Valley to 6.1 in Idaho. The rates are governed not only by the nature of the crop irrigated, but also by cost of water, soil types, local climatic conditions, and water quality. For humid climates the rates vary from 0.5 to 1.25 acre-feet/acre/year.

Source of Irrigation Water

It has been estimated [1949 Census of Agriculture (5)] that 75 percent of agricultural water comes from surface sources and 25 percent from groundwater.

General Quality Considerations

In the simple logistics of handling irrigation water a number of losses occur which affect the quality of the water and hence of irrigation return waters. Canal losses vary from 15 to 40 percent of the water diverted; 5 to 25 percent is wasted from canals and laterals; farm wastes, from 5 to 10 percent; and seepage from 5 to 60 percent. Overflows from canals and laterals runoff from land, and seepage will return water either to the surface or groundwater sectors of the resource pool at an increased salt concentration due to evaporation. Transpiration by plants growing along irrigation works depletes the supply in quantity and leaves

salts available for pickup by percolating water. Evaporation from reservoirs accounts for about 15 million acre-feet per year. This is about 35 percent of the total reservoir capacity available for irrigation. Its effect is to concentrate the salts in the reservoir. Thus it is evident that the water works utilized in irrigation themselves increase the salinity of the resource pool.

Return Irrigation Water.

The disposition of water diverted to agricultural use from surface and from ground sources is illustrated in the following flow diagrams [Eldridge (1)]. There is considerable variability in the quantity of return flows (20 to 60 percent) but the average in the Western U. S. is considered to be about 33 percent of the water diverted. The variation is governed by the same factors that determine rate of application.

In general the quantity of return water has a significant influence on its quality; the greater the quantity, the less the salt concentration, except where insufficient water applied in one period has left salts in the soil which are removed when more water is applied.

The diagram identifies three major sources of return water as overflow, runoff, and seepage.

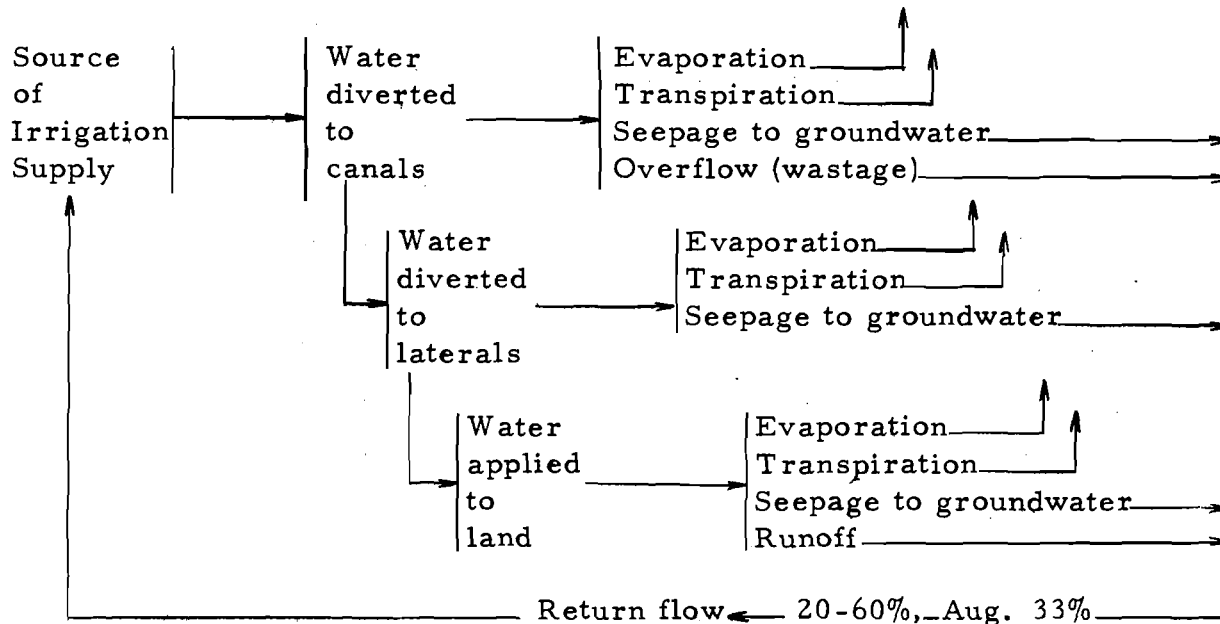
Factors Affecting Quality of Return Waters

1. Evaporation and transpiration. Salts contained in the irrigation water are concentrated by the removal of water and retained in this concentrated form in the soil water.
2. Leaching. Water must be applied in sufficient amounts to remove excess salts from the soil and varied from 6 to 25 percent of the water applied.

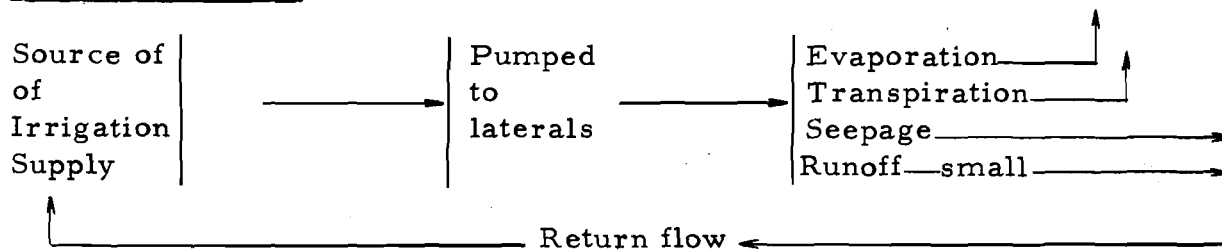
During the period of reclaiming of soils having a high salinity, one foot of water per each foot of soil depth will remove about 80 percent of the salt. Three feet may be necessary to remove boron.

FLOW DIAGRAMS

SURFACE SUPPLY



GROUND SUPPLY



Quality of Irrigation Return Water

The following table [Table IV, Eldridge (1)] shows the change in quality of irrigation return waters, as regards salts and ions, from 7 areas in the Western States. From the observation that about one-third of the irrigation water returns to the resource pool it might be expected that the salt concentration is multiplied by three unless there is a significant quantity of the salts already contained in the soil or

Increase in Salts and Ions as a Result of Irrigation
[Eldridge (1)]

Location	Number of times greater than in irrigation water						
	Salinity	Ca	Mg	Na	HCO ₃	SO ₄	Cl
1	10.8	5.1	7.5	21.4	2.4	10.5	129.0
2	7.0	---	---	---	4.3	4.7	3.0
3	5.0	4.4	4.2	8.1	1.8	1.9	---
4	5.9	3.7	5.5	14.7	1.8	8.6	11.5
5	7.1	4.6	6.9	12.7	2.9	4.6	40.0
6	5.6	4.4	14.0	3.5	1.6	15.0	*
7	7.8	5.3	6.0	17.2	5.2	18.0	8.0

* Decrease

1. Rio Grande between Otowi bridge and Fort Quitman
2. Yakima River between Easton and Prosser
3. Average of 1943-44 input and output on an irrigation district
4. Average of 1940-41 data on Arkansas River between Pueblo and Holly
5. Average of five years of data on input and output of an irrigated area
6. Data collected on a short stretch of the Colorado River between Cameo and Grand Junction
7. Input and output data of an irrigation project in Boise River Basin

subsurface water. In all of the examples summarized in the table the overall increase in salinity was greater than three times. In fact, the lowest is five times. This means that either:

1. the water was used more than once, or
2. the return flow was less than 33 percent, or
3. a significant portion of salts contained in the soil was dissolved by percolating water.

Another important change in water quality resulting from irrigation is a shift in the relative concentration of the various ions. The proportion of sodium to calcium and magnesium is always higher in the return water than in the applied water, possibly due to the precipitation of calcium carbonate and to ion exchange. With few exceptions magnesium remains fairly constant in quantity though changes in concentration.

Effect of Return Water on Receiving Water

The observed effect of irrigation return waters as reported by Eldridge (1) is summarized in the table on the following page.

References

1. Eldridge, Edward F. Return Irrigation Water, Characteristics and Effects. U. S. Public Health Service, Region IX, May 1, 1960.
2. Irrigation Engineering and Maintenance. "1957 Directory and Buyers Guide." August 31, 1957.
3. United Nations. Water for Industrial Use. Department of Economic and Social Affairs, New York, 1958.
4. U. S. Public Health Service. Clean Water: A Chart Book of America's Water Needs. 1960.
5. U. S. Department of Commerce. Bureau of the Census. United States Census of Agriculture, 1949.

Summary of Effects of Agricultural Return Waters
on Receiving Waters
[Data from Eldridge (1)]

Quality Factor	Observed Effect
Salts & ions	Increased more than 5 times
Hardness	Greatly increased; most significant effect
Total dissolved solids	Greatly increased
Temperature	Significant increase in Yakima River. Similar effects to be expected in other areas.
Turbidity	High in some return waters. Little studied effect. Small effect in Yakima River due to dilution.
Color	Little studied factor. Increase observed in Yakima River due to large irrigation return.
Nutrients	Generally somewhat increased
Nitrates	Conflicting evidence. Evidence of increase in nitrogen but the relative importance of natural and irrigation return flows not investigated.
Phosphorus	May be brought in what plant leaves in return water. Little doubt that amount increased.
Tastes & odors	Evident in return flows as result of mineral salts and organic decomposition products, often from aquatic growth stimulated by nutrient content.
Insecticides & herbicides	Problem exists in surface waters but the relative contribution of irrigation return water and surface runoff not clear. Potential problem exists.
Bacteria	Not a significant factor in agricultural return waters as compared to domestic.

VI

QUALITY CHANGES IN FLOWING AND STORED WATER

Introduction

Having now examined in a general way the nature of the inputs to the fresh water pool, let us now summarize these inputs and turn our attention to the quality aspects of the fresh water resource pool itself. For the purpose of examining the inputs and identifying the factors which each might contribute to the quality of the overall resource, it was sufficient to lump all aspects of surface waters and ground waters together as though the resource pool were a common tank into which everything is dumped and thoroughly mixed. As we come now to examine the quality changes which take place in the resource pool through natural phenomena it is necessary to abandon this simple and comfortable fiction and to separate the various compounds of the fresh water resource for individual examination. Later on, as we discuss the subjects of "standards" and "quality requirements of beneficial uses" even this break-down will not be enough and it will be necessary to examine both the magnitude and nature of inputs and of the resource on a local basis.

Summary of Inputs

The inputs in terms of quality controlling factors contributed to the fresh water resource pool by meteorological waters, domestic use, industrial use, agricultural use, and consumptive use of water might be summarized as in the table on pages 59 and 60.

Quality Changes in Surface WatersA. Flowing streams

In order to understand in even an elementary fashion the quality changes normal to a stream, either with or without return waters from man's activities, it is necessary to have a concept of it as a living thing. As hydrologists and hydraulic engineers, I am sure you already have a

Contributing Factor	Principal Quality Input to Surface Waters
Meteorological Water	<ol style="list-style-type: none"> 1. Dissolved gases native to atmosphere. 2. Soluble gases from man's industrial activities. 3. Particulate matter from industrial stacks, dust, and radioactive particles. 4. Material washed from surface of earth, e. g., <ol style="list-style-type: none"> (a) Organic matter such as leaves, grass, and other vegetation in all stages of biodegradation, (b) Bacteria associated with surface debris (including intestinal organisms), (c) Clay, silt, and other mineral particles, (d) Organic extractives from decaying vegetation, (e) Insecticide & herbicide residues.
Domestic Use (exclusive of industrial)	<ol style="list-style-type: none"> 1. Undecomposed organic matter, such as garbage ground to sewer, grease; etc. 2. Partially degraded organic matter such as raw wastes from human bodies. 3. Combination of (1) and (2) after biodegradation to various degrees by sewage treatment. 4. Bacteria (including pathogens), viruses, worm eggs. 5. Grit from soil washings, egg shells, bones, etc. 6. Misc. organic solids, e. g., paper, rags, plastics, and synthetic materials 7. Detergents.
Industrial Use	<ol style="list-style-type: none"> 1. Biodegradable organic matter having a wide range of oxygen demand. 2. Inorganic solids, mineral residues. 3. Chemical residues ranging from simple acids and alkalies to highly complex molecular structure. 4. Metal ions.

Contributing Factor	Principal Quality Input to Surface Waters
Agricultural Use	<ol style="list-style-type: none"> 1. Increased concentration of salts & ions 2. Fertilizer residues 3. Insecticide & herbicide residues 4. Silt and soil particles 5. Organic debris, e. g. , crop residues
Consumptive Use (all sources)	<ol style="list-style-type: none"> 1. Increased concentration of suspended and dissolved solids by loss of water to atmosphere.
Principal Quality Input to Ground Waters	
Meteorological Water	<ol style="list-style-type: none"> 1. Gases, including O₂ and CO₂, N₂, H₂S, & H. 2. Dissolved minerals, e. g. , <ol style="list-style-type: none"> (a) Bicarbonates and sulfates of Ca & Mg dissolved from earth minerals, (b) Nitrates and chlorides of Ca, Mg, Na, & K dissolved from soil and organic decay residues, (c) Soluble iron, Mn, and F salts.
Domestic Use (principally via septic tank systems and seepage from polluted surface waters)	<ol style="list-style-type: none"> 1. Detergents. 2. Nitrates, sulfates, and other residues of organic decay. 3. Salts and ions dissolved in the public water supply. 4. Soluble organic compounds.
Industrial Use	<p style="text-align: center;">Not much direct disposal to soil</p> <ol style="list-style-type: none"> 1. Soluble salts from seepage of surface waters containing industrial wastes.
Agricultural Use	<ol style="list-style-type: none"> 1. Concentrated salts normal to water applied to land. 2. Other materials as per meteorological waters.
Land Disposal of Solid Wastes (not properly installed)	<ol style="list-style-type: none"> 1. Hardness producing leachings from ashes. 2. Soluble chemical and gaseous products or organic decay.

Note: The foregoing list includes the types of things that may come from any contributing factor. Not all are present in each specific instance.

good understanding of the living stream and so merely for purposes of communication I will summarize my concept of a stream within the context of water quality.

From a relatively broad, and at the same time, short, point of view as measured by geologic time, a stream in its natural setting may be said to be in dynamic equilibrium with other elements of the environment. Nevertheless a complex set of transients make up that equilibrium. At one season it gathers strength directly from meteorological waters, which rush in with a burden of soil and organic material stripped from the surface of the earth. At that time it tears at its banks, snatches up deposits from its own bed, pounds stones together, and generally destroys its former state of equilibrium. Then as the rain gods depart for their holidays the stream grows weary, laying down its burden somewhat in the same areas it recently ripped up. Too weak to carry a load, it finally takes on the characteristics of the groundwater on which it now depends for life.

However, the old degraded deposits have been replaced with new fertilizer elements and a crop of higher energy organic matter, hence the foundation is maintained for continuance of the biological food chain in the stream.

With never ending variety the stream itself is a succession of environments replicated many times. In the rapids it picks up oxygen and carries it into more quiet pools which act as both sedimentation basins and life sustaining systems. Here the nutrients and CO_2 released by bacteria (mostly aerobic), carrying out the biodegradation of organic sediments, support the microscopic plants which serve as food for small animal life, in a dog-cat-dog society that ranges from bacteria to the fishes and other higher forms. Even in the shallows, the downstream shadow zone of each stone harbors sediments in which life abounds.

To the biologist unconcerned with the destiny of individual species in the food chain this may seem an idyllic situation. The philosophical

attitudes at other levels of the food chain have not been reported. Nevertheless it is well understood that interruption of the food chain at any level is catastrophic to all forms above that level. Eliminate, for example, the nutrients and the water becomes a biological desert, destroy the fly larvae, etc., and fish life disappears.

The whole matter of stream pollution hinges on this factor of the maintenance of an uninterrupted food chain. On a later occasion the water quality factors necessary to maintain such a situation will be discussed. At the moment we are concerned with the way a stream reacts in terms of water quality to classes of materials without particular regard to their origin, although in the interest of our overall understanding there is no reason not to identify various sources.

Reaction of flowing water to seasonal precipitation under wilderness conditions has been implied in the foregoing paragraphs. Fundamentally it cleans out its bed and replaces old deposits with others freshly mined from the earth minerals and from newly dead vegetation. There is a good balance here in which the organic load does not reach such proportions that aerobic decomposition of that load sets in. Neither does the load of sediment become inimical to the equilibrium, chiefly because it comes at a time when the stream has the physical strength to manage the load. This does not mean that individuals in the aquatic society do not live dangerously. The elements are no kinder to them than they are to us. But it does mean that the society goes on after the flood with renewed vigor just as does man's.

Let us now consider the reaction of a stream, both in a physical and biological sense, to the introduction of other materials from other causes.

1. Excessive amounts of suspended matter.

(a) Scientific agriculture. The very act of ploughing up the natural sod and so uncovering large areas of the land surface has had the effect of vastly increasing the sedimentary load introduced to streams by meteorological waters. Nothing new is introduced here as far as the

stream is concerned. It accepts the burden and lays it down when it grows weary. The difference is that this time there is an abundance of fine material which has at least two major effects: it hastens the buildup of elevation of the river bed and so increases its aggression on its own banks; and it obliterates much of the littoral environment in which fish spawn and their food chain flourishes.

(b) Irrigation. Irrigation practice which results in runoff or overflow may likewise introduce sediments eroded from the surface of agricultural soil. In this case a burden of fines is introduced to the stream at a time when its transporting power is at its lowest value. Consequently fine material that would ordinarily be carried to the ocean is deposited in the pools and on the little bars behind stones, choking out the habitat of many organisms. Likewise, the constant turbidity over perhaps 128 days of irrigation cuts out much of the light utilized by plants which supply both food and oxygen to the water. The amount of silt produced has been estimated by Geyer (2) at from 0.03 to 3.0 acre-feet per square mile per year. Probably one foot in 4000 years is his best guess. This amounts to about 7×10^6 ft³/year from a 1000 square mile drainage area; and represents the contribution from row agriculture, highway construction, building sites, etc.

(c) Industrial activity. Certain industries such as quarrying, mining, stone cutting, and construction, for example, contribute sediments at times of low stream flow with the same effects as irrigation return water [(b) above] .

2. Insufficient suspended matter.

The wilderness stream, as has been noted, picks up its old sediments when it finds the strength but drops new ones in their place as it later weakens. Thus a migration of sediments from the source to the mouth of a stream is characteristic of flowing water.

Ponding of water behind dams, a feature of man's use of water for industry, agriculture, municipalities, flood control, recreation,

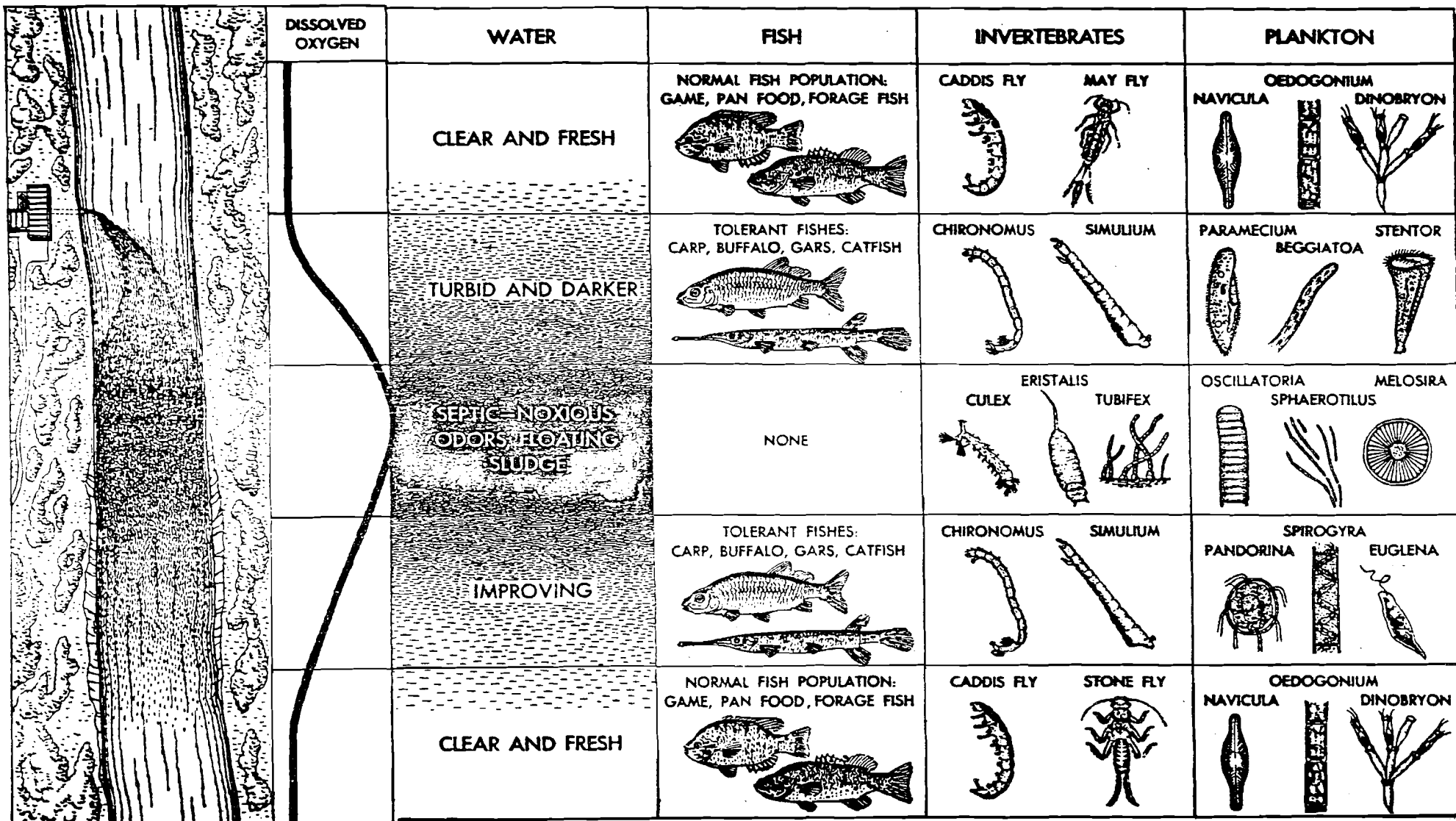
and all other beneficial uses, has the effect of interrupting this intermittently advancing bed load of the stream. The result is that sediments originally laid down as high flows declined, are picked up by the first high flow following the construction of the dam but they are not replaced in amount. Hence the cycle of deposit and resuspension is phased out as the old load advances to the sea. Thus the stream reduces its gradient and an entirely new equilibrium of a different type is approached. It has a profound effect on the original stream ecology. The results are not always predictable.

The lesson which man never has to cease learning is that no simple problem in water resources management can be solved by a single solution. Any interruption of a dynamic equilibrium results in a shift toward a new equilibrium in which some of the elements in the old may be eliminated.

3. Excessive organic loading.

Organic loading which introduces a demand for oxygen (BOD) in excess of the dissolved oxygen (DO) available in the stream will lead to anaerobic conditions such as depicted by the cycle of growth and anaerobic decay previously discussed. Such a situation would represent an extreme case of excessive organic loading of a stream. An interruption of the food chain, however, can occur by a serious depression of the DO below levels (usually taken as 5 or 6 mg/l) needed by higher forms of aquatic life. Again this is a subject to be discussed in relation to needs of beneficial uses rather than stream reaction.

The overloaded stream behaves somewhat as shown in the following diagram. It abandons aerobic decomposition of organic matter in favor of anaerobic processes. At some reach in the stream, however, anaerobic organisms run out of substrate and aerobic organisms finish the job. Diffusion of oxygen into the flowing water is encouraged by the lowered oxygen tension. Later the nutrients from the stabilized organic matter support a richer aquatic society than the stream originally held. This society includes the green algae which also produce abundant oxygen.



POLLUTION AND RECOVERY of a stream is reflected in an intricate

physical, chemical and biological system. As the oxygen dissolved in the water decreases (curve at left),

so do certain microorganisms and, in turn, the invertebrates and fishes that depend upon them for food.

Leaving to a later discussion the full implications of a stream as a waste treatment process, it is sufficient to note here that a stream can recover from excessive organic loading but it must do so at the expense of quality characteristics acceptable to man, who wishes to use the water for other purposes; and at the expense of aquatic life which depends upon free (dissolved) oxygen.

This is the reason why BOD has been so much a factor in stream pollution control discussions and measures. If the beneficial effects on aquatic life of the nutrients in sewage could be attained without the catastrophe of oxygen depletion, it is possible that the wildlife biologists might welcome raw sewage being discharged to the surface waters. However, health and other water use considerations would continue to require waste treatment.

4. Miscellaneous factors.

Reactions of a stream to various wastes may have the effect of changing water quality. Added nutrients increase aquatic life and the tastes and odors which may result. Toxic ions and compounds reduce aquatic life, but there is not a reaction of the river itself to this factor. Various ions and materials may be precipitated in a stream or adsorbed on colloids in the season when sediments are transported most abundantly. Tannery wastes at low pH may turn brown at the higher pH of surface waters. In general, such miscellaneous factors are not profoundly involved in changes of quality due to flow of water.

B. Stored water

On page 91 of the American Water Works Association Manual (1) Professor Sedgwick is quoted on an important facet of quality of natural waters. "It is therefore not so true that 'running water' as that 'quiet water' purifies itself. We may even go so far as to say that the first requirement for the natural establishment of purity in surface waters is quiescence; but quiescence in rivers is ordinarily impossible." As I have previously noted, the oxygen picked up in the rapids is utilized in the

pools in streams. Pools, however, are far short of reservoirs in their depth, detention, and other characteristics; hence the quality aspects of stored water are worthy of separate consideration.

Changes in the quality of water resulting from the phenomena associated with ponded water take place in natural lakes and ponds as well as in artificial impoundments. To some degree these are heightened or extended by water resource management techniques.

Reference has already been made to the increase in salts and total solids resulting from evaporation (agricultural use). Some 35 percent of the storage available for irrigation was estimated as lost by evaporation. Evaporation losses throughout the United States average some 3 feet and in the Southwest the value may be as much as 10 feet. Thus it may be said that stored water increases in salinity to a marked degree.

Reaction to high temperature water discharged to a reservoir has been observed to route the lighter water to the top where evaporation cooled the surface and no temperature change in the reservoir occurred. A somewhat similar situation exists with silt discharges which commonly sink to the depths and channel through a reservoir with little effect on the quality of water withdrawn for beneficial use, for more pertinent reasons, from a higher elevation.

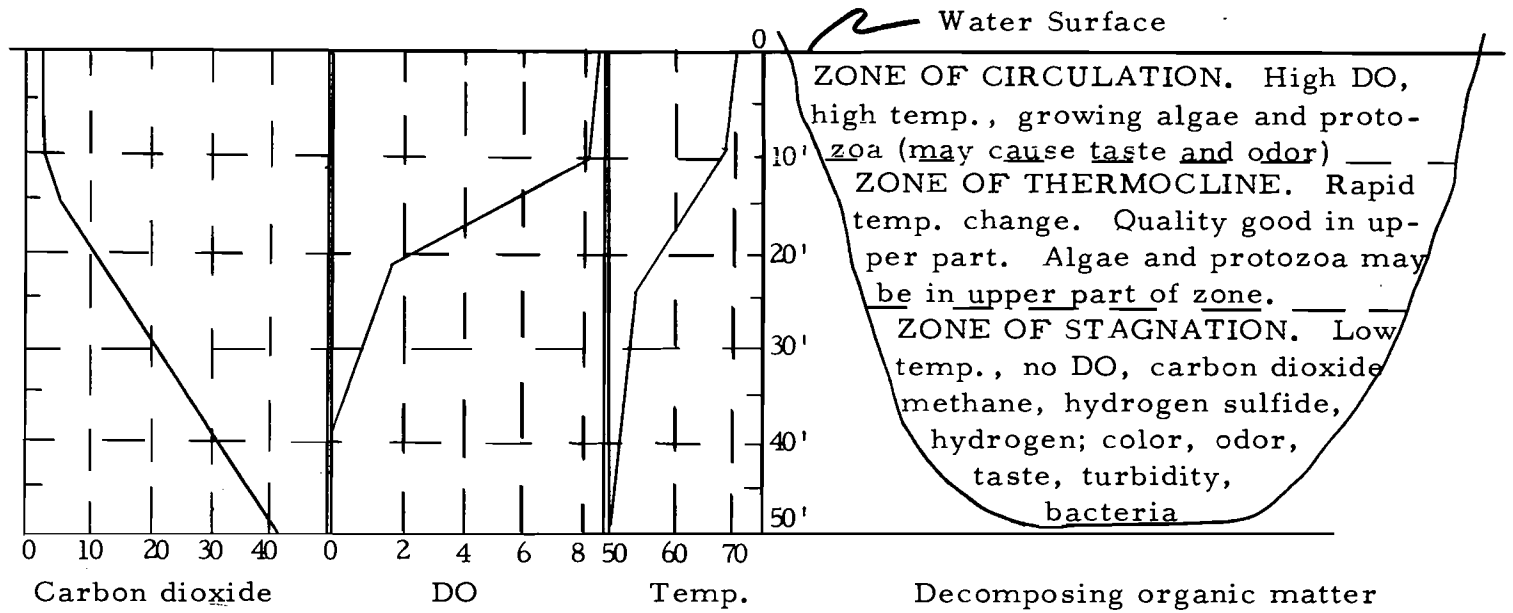
The American Water Works Association Manual (1) calls attention to the decrease in bacterial content of stored water as lack of proper food, effects of sedimentation, disinfecting action of sunlight, depredations of other organisms, and devitalization take their toll.

The principal phenomenon having an impact on quality of stored water is that of stratification and vertical mixing. Therefore it is reviewed here and its implications briefly discussed.

The changes in quality resulting from storing water have a profound effect upon the engineering of surface water supplies. An

interesting cycle of water quality takes place. Since it is a cycle, any discussion of the cycle must begin at some arbitrary point. In the following figure the situation in a deep reservoir is depicted in late summer just prior to a situation of mixing of the reservoir contents commonly known as the fall overturn.

Stratified reservoir before fall overturn



Fall overturn results when temperature of water approaches 39.3° F (point of maximum density). Heavy water at top sinks to bottom when wind disturbs surface causing the entire reservoir to go into vertical circulation. Decomposing organic matter (leaves, surface washings, dead algae and protozoa) produce organic acids and organic extratives. Extratives produce color; gases may be odorous; acids may produce tastes, odor, and color; organic debris is finely divided and causes turbidity; lack of dissolved oxygen causes water to taste "flat."

Stratified water as illustrated is subject to tastes and odors if algal growth and protozoa are numerous. Organisms (called plankton) give off essential oils in life processes. These have bad taste and odor (some fishy, some like cucumbers, some like muskmelon, some musty, etc.). Death of organisms releases oil globules which in combination with chlorine give bad iodoform taste (medicinal taste). High temperature accentuates tastes and odors. In great numbers, plankton may cause turbidity and color as well as tastes and odors, and produce overload on filters. Copper sulfate, chlorine, or other chemical may be used to control growth of organisms in reservoirs.

Water is often taken from the Thermocline zone because of better temperature, if DO content is sufficient.

Some physical factors and general considerations are important to the quality of stored water. To begin with, a reservoir site should be stripped of vegetation and the forest duff lest tastes and odors from such vegetation persist for decades. Wave action induced by winds tends to produce turbid waters which may be carried out into the pond by circulation or by ice floes. Such turbidity also involves microscopic organisms and bacteria, as the littoral zone is the most active biologically.

It may be said in conclusion that stored water changes in quality quite profoundly, some of the quality factors being favorable and some unfavorable to beneficial uses--the favorable being predominant.

References

1. American Water Works Association. Water Quality and Treatment. A Manual. American Water Works Association, Inc., New York, 1950.
2. Geyer, John C. "Water Quality Concepts and Low-Flow Augmentation." Proceedings, Invitational Seminar on Advanced Water Resource Topics. University of Texas, Austin, April 1964.

VII VARIATIONS IN WATER QUALITY

Introduction

The quality aspects which have been related to meteorological waters, and to the effects of domestic, industrial, and agricultural use on water returned to the resource pool are by no means constant in time. Neither are the quality attributes of the surface and ground-water resources themselves, although the latter is least affected by diurnal, seasonal, or annual above-ground variations.

Factors in Quality Variation

Variations in quality occur in water from the same type of source as a result of a number of conditions, of which the following are among the most significant:

1. Climatic conditions
 - (a) Runoff from snow melt--muddy, soft, high bacteria count.
 - (b) Runoff during drought--high mineral content, hard groundwater quality.
 - (c) Runoff during floods--less bacteria than snow melt, may be muddy (depending upon other factors listed below).
2. Geographic conditions

Steep headwater runoff differs from lower valley areas in ground cover, gradients, transporting power, etc.
3. Geologic conditions
 - (a) Clay soils produce mud.
 - (b) Organic soils or swamps produce color.
 - (c) Cultivated land yields silt, fertilizers, herbicides, and insecticides.

3. (d) Fractured or fissured rocks may permit silt, bacteria, etc., to move with groundwater.
(e) Mineral content dependent upon geologic formations.
4. Season of year
 - (a) Fall runoff carries dead vegetation--color, taste, organic extratives, bacteria.
 - (b) Dry season yields dissolved salts.
 - (c) Irrigation return water, on growing season only.
 - (d) Cannery wastes seasonal.
 - (e) Aquatic organisms seasonal.
 - (f) Overturn of lakes and reservoirs seasonal.
 - (g) Floods generally seasonal.
 - (h) Dry period, low flows, seasonal.
5. Resource management practices
 - (a) Agricultural soils and other denuded soils are productive of sediments, etc. (See section 3c.)
 - (b) Forested land and swamp land yield organic debris.
 - (c) Overgrazed or denuded land subject to erosion.
 - (d) Continuous or batch discharge of industrial wastes alter shock loads.
 - (e) In-plant management of waste streams governs nature of waste.
6. Diurnal variation
 - (a) Production of oxygen by planktonic algae varies from day to night.
 - (b) DO in water varies in same fashion.
 - (c) Raw sewage flow variable within 24-hour period, treated sewage-variation less pronounced.
 - (d) Industrial wastes variable--process wastes during productive shift; different material during washdown and cleanup.

References

1. American Water Works Association. Water Quality and Treatment.
A Manual. American Water Works Association, Inc., New York,
1950.
2. Eldridge, Edward F. Return Irrigation Water, Characteristics and
and Effects. U. S. Public Health Service, Region IX, May 1, 1960.

VIII

STANDARDS AND CRITERIA OF WATER QUALITY

Introduction

The preceding series of lectures has been directed to an identification of the kinds of things--the factors--which change the quality of water, to relate them to sources, and to note the conditions under which they vary. The time has now come to talk about the effect of the quality factors on the various beneficial uses of water drawn from the resource pool. To do so, however, requires that we first describe quality in quantitative terms. It is not enough to say, for example, that turbidity is aesthetically objectionable. We are not going to have crystal clear water in our resource pool, so we shall have to decide how much turbidity the eye can detect and how much we are willing to pay to achieve such a limit.

We are confronted with the necessity for quality control, both as regards the nature of return water we shall permit users to discharge, and the nature of water acceptable for any beneficial use.

Control of water quality for any purpose, be it protection of the supply for some beneficial uses or conditioning of process water, involves treatment. The goal of water treatment thus becomes that of altering or upgrading quality to a level appropriate to the intended use. Water treatment is accomplished by engineered systems; and the goal of sound engineering includes a concern for minimum cost consistent with health, safety, and product requirements. Therefore if quality is to be changed, some way must be found to decide when the change has been carried far enough, both in the interests of economy and suitability of the finished water to its intended use. This way involves two concepts--"standards," or "requirements," and "criteria"--which should be clearly understood.

Professor Jack McKee in his monumental work of "Water Quality Criteria" notes that "the term 'standard' applies to any definite rule, principle, or measure established by authority.... The fact that a

standard has been established by authority makes it quite rigid, official, or quasi-legal. An authoritative origin does not necessarily mean that the standard is fair, equitable, or based on sound scientific knowledge, for it may have been established somewhat arbitrarily on the basis of inadequate technical data tempered by a cautious factor of safety." (2) The danger of such standards has been pointed out by someone else (Frank Stead*) who notes that "today's estimate is tomorrow's law."

Nevertheless some sort of parameters are necessary. "We need a yardstick, even if it is made of rubber," is one point which has been expressed. To this end Professor McKee suggests that "a far better way to describe an administrative decision by a regulatory body is 'requirement.' It represents a requisite condition to fulfill a given mission. It does not necessarily have the connotation of scientific justification nor does it give an impression of immutability."

"A criterion," notes McKee, "designates a means by which anything is tried in forming a correct judgment respecting it." He notes the need for applying numbers to criteria but warns against letting them ripen into rigid standards.

When water is drawn from the resource pool its quality in quantitative terms can readily be determined by physical, chemical, and biological analyses of varying precision. And, except in the case of human health and the welfare of other biota, the minimum acceptable change in each of these characteristics can be established through experimental procedures. This exception, however, is a serious one because our chief interest in this whole matter concerns ourselves and the flora and fauna in our own food chain. Therefore, our experiments get involved with epidemiology, which involves time and disaster; statistics, which involves more of the same; and with biological

* Director, Division of Environmental Sanitation, California State Department of Public Health.

responses, which get involved with adaptations and secondary responses that are difficult to evaluate. The values thus obtained can then be utilized as criteria for judging the suitability of the water for specific beneficial use. Assuming that the change necessary to make a water suitable for the intended use is attainable by known and economically feasible processes, the treatment system can be engineered. However, when used water is to be returned to the resource pool with the goal of protecting the interests of all beneficial uses, looking out for the public health, and keeping the quality of the pool such that reuse by all is within attainable limits, standards normally become the parameter used. These may be either stream standards or discharge standards.

Value of Standards

Standards which can be kept dynamic and flexible have certain recognizable values:

1. Measurement of quality factors is encouraged.
2. They permit self-control by dischargers.
3. They preserve fairness in application of police power.
4. They furnish an historically documented story of an event and thus assist in controlling the future.
5. They make possible the definition of a problem.
6. They establish goals for design of systems.
7. In setting standards one must face his ignorance, or in facing arbitrary standards one must say definitely why they are inappropriate.
8. They assess what we are getting from a system.

Where Standards are Needed

In a subsequent lecture the standards of water quality currently used in relation to public water supply, agriculture, and industry are outlined. There are, however, several areas in which it is generally conceded

that standards are yet needed. These include:

1. Chlorinated hydrocarbons in aquatic environments.
2. Transparency of water.
3. Nutrients in water.
4. Safety in fresh water recreation.
5. Safety of reclaimed water.

Classes of Standards

There are four major classes of standards:

1. Standard for etiological agent itself, e.g., pesticides.
2. Index standard, in cases where some associated factor is easier to measure than agent itself, e.g., coliform organisms which measure potentiality for disease producing organisms.
3. Precursor, or element that enters into a reaction which affects quality, e.g., BOD and nutrients are precursors; in themselves not important agents.
4. Major environmental factors which produce some results worthy of concern, e.g., solar energy which drives biochemical reaction.

Bases of Public Policy

The adoption of standards involving numerical specifications of a spectrum of quality factors grew out of the goals of society as expressed in public policy. Protection of the public health was the first goal to be so implemented. Originally public health concern was directed to the prevention of specific illnesses. However, as time went on, aesthetic goals became associated with health and standards for prevention of nuisance, or offense to the senses of sight and smell became common. The words "pure, wholesome, and potable" appeared in public health laws. Now they call for the expression of quality in numerical terms which can be interpreted as defining pure,

wholesome, and potable; all noncontinuous variables which are ill-defined qualitative concepts.

But public health did not forever define the goals of water quality control. New agencies were created to deal with the quality of water where protection of the interests of beneficial uses not directly involving public health was concerned--aquatic life, recreation, industrial, and agricultural supply, etc. These agencies, like the health agencies, must establish suitable criteria and standards.

Currently, a totally new goal of water quality has been added to that of protecting the public health and other beneficial uses. This is a social goal represented by organized and unorganized citizens who demand "clean" or "pure" water per se. How shall the demands of citizens be expressed in "standards" without turning history back to Indian days--an eventuality little advocated by the "pure water" enthusiasts-- is a question for which the answer has not yet unfolded. But it does foretell the day when the return waters from beneficial uses are going to be required to look more and more like the natural water which might exist if the uses did not. Particularly do these "true believers" express a concern for aquatic life. In fact, Professor McKee's researches into the literature revealed that the number of references pertaining to the effects of pollutants on aquatic life far exceeds that relative to any other beneficial use.

To put this increasing social goal into perspective, Mr. Frank Stead of the California State Department of Public Health lists five zones of concern for the control of any aspect of the environment, including the water resource. In descending order of urgency they are as follows:

1. Zone of aesthetic enjoyment (top zone)
2. Zone of physical comfort at bottom of which man becomes aware of non-well being.
3. Zone of chronic illness or morbidity (chronic ill effect)-- impaired performance of man or system.

4. Zone of acute morbidity (ill effects acute and serious).
5. Zone of simple survival (bottom zone), at bottom of which is death or failure of a system.

The objectives of society may be to achieve the boundary between any two of these zones in any, or in all, cases. For example, the standards of water for public consumption have crept up from the bottom zone to Zone 2, or in cases where the taste, odor, hardness, and other uncomfortable factors are economically infeasible, to Zone 3.

A similar goal is developing for other beneficial uses as time goes on. And, as has been noted, the achievement of the zone of aesthetic enjoyment may well come to dominate the standards imposed on all beneficial uses of water--i. e., domestic, industrial, and agricultural return waters. Hence it is extremely important that standards be more like the "requirements" of McKee's definition: not permanent in magnitude for all time, but suited to the goals, the technology, and the economics of society at each stage of its development.

Bases on Which Standards are Established

At whatever level public policy is directed it can only establish the goals which are to be achieved by the adoption of standards, regulations, or criteria. Someone must eventually express quality factors in numbers which presumably will establish the desired boundary condition. One or more of the following bases may be used:

1. Established or going practice
2. Attainability, either easily or reasonably
 - a. Technologically
 - b. Economically
3. Educated guess, making use of best information available
4. Experimentation (e.g., animal exposure).
5. Human exposure
 - a. Take advantage of occurring catastrophe

b. Experiment with humans directly

(Note: The same concept applies to plants and animals, including aquatic life.)

6. Mathematical model or treatment [e. g. , probability, mode, percentile (MPN coliforms)]

(Note: Biological events are geometric, hence single standard cannot be used to describe the phenomenon in any case.)

In the existing water quality standards detailed in the next section of this report, the educated guess and attainability have figured heavily.

A thorough study of the origins of standards of water quality reported by Professor J. E. McKee in 1952 revealed the sources to be "technical personnel" or "a committee of representatives of the interested departments," either with or without the added obscuring factor of statewide hearings. In one case the frank reply to Professor McKee's questionnaire was that "we have no records or minutes to show the development of these standards and the former executive secretary-engineer who handled these matters is no longer with the Commission." More recently the Bureau of Sanitary Engineering of the California State Department of Public Health endeavored to trace to its origins the value of 500 mg/l which appears as the recommended upper limit for total dissolved solids (TDS) in the Public Health Service drinking water standards. While rational men might agree that it is a reasonable standard, the search revealed that the mind of man does not recall nor do his records reveal its origin. Most likely it represents a value widely attainable in the surface waters of an America much less populated than today. As 500 mg/l is becoming increasingly unattainable in many cases, it is now important either to document its validity or to develop some new value to take its place. The former, as has been noted, is impossible; the latter is doubly difficult. To base the parameter on attainability one must first determine just what is attainable in a water resource pool subject to an ever-increasing recycling of waste waters; and he who would base it on some rational or experimental curve of TDS number versus water quality can only yearn for a former less number-minded era.

Attainability itself is by no means an easily identified parameter, except in instances of some specific constituent of water for which no scientifically feasible process of removal is known. Therefore, attainability has not always been accurately

estimated and subsequent embarrassment has accrued to the standard bearer. In one case where the presence of a lead-using industry suggested the need to set a standard for lead in the waters receiving the industry's waste discharges, only intelligent alertness on the part of the technical staff prevented an unhappy decision. In this case those charged with the responsibility of setting the standard suggested 0.1 mg/l lead as a reasonable value for the receiving waters in view of what is known about lead pollution and the beneficial uses to be protected. However, a survey revealed that the muds upstream from the plant naturally contained 10 to 250 mg/l of lead. Eventually a more realistic and liberal standard was established on the grounds of attainability.

Perhaps the best researched parameter of water quality is the MPN of coliform organisms. Even it involves an element of the attainable; else why accept one organism per 100 ml when no organism at all is the goal. The answer, of course, lies in the epidemiological evidence that at this statistical level of contamination other vectors of intestinal diseases far outweigh the hazard of water. The parameter is therefore adequate under United States conditions but it is by no means exportable as a criterion of water quality to regions such as, for example, South Africa where the intensity of typhoid and cholera pollution of sewage is far greater than in the USA and where these diseases are not the only major health hazards of waste waters.

Avenues of approach to the problem of establishing a quantitative degree scale to each of the many significant factors which affect the quality of water for each of a wide spectrum of uses, of course, transcend attainability and epidemiologically demonstratable catastrophe. Bioassay with 50 percent kill of test organisms must be translated into zero kill concentrations. Results of tests on rats and dogs must be escalated to protect their larger cousin--man.* Social science must replace chemistry in defining "pure" water, and so on. (2)

*The method here is illustrated by the following formula:

$$\frac{\text{Lifetime (z yr) tolerance of healthy rat}}{10} = \text{ditto for healthy man;}$$

$$\frac{\text{healthy man}}{10} = \text{frail man.}$$

The foregoing concepts underlying the standards applied to water to define its quality suitability for beneficial use have their counterpart in their discharge streams and the waters which receive them. These are commonly called "pollution control standards," "receiving water standards," or, more generally, "water pollution criteria." The nature and underlying rationale in this case is outlined in the following summary.

Pollution Control Standards

Two general types of standards have been used to control water pollution:

1. Those which set "stream standards" for receiving waters.
2. Those which set "effluent standards" for wastes discharged.

Stream standards are of two classifications:

1. Dilution requirements (no longer a popular method)
2. Standards of receiving water quality, which:
 - (a) depend on establishment of threshold values for various pollutants, or
 - (b) depend on the beneficial use to which the water is to be put.

Effluent standards are likewise of two classes:

1. Those which restrict strength or amount of pollutants to be discharged (e. g., Delaware River Commission).
2. Those which specify degree of treatment required.

Standards of receiving water quality often involve a system of stream classification or zoning. This has the advantage over effluent standards in that these standards take into account dilution and assimilative capacity of the stream and hence make for economy of treatment works for pollution abatement. On the other hand, standards are hard to define, and cumbersome and difficult to administer.

An example of stream standards based on dilution are those set by the British Royal Commission in 1912 for sewage and sewage effluents. These standards have served satisfactorily for many years. They were

developed to satisfy the requirements of small streams in populous areas receiving strong sewage (2 to 4 times that of U.S. sewage). As set forth by Imhoff and Fair, these standards are as shown in the following table.

Classification of Standard	Required Condition of Sewage or Effluent		Type of Sewage Treatment Presumably Satisfying the Standards
	5-day, 65°F. BOD ppm	Suspended Solids ppm	
(a) General standard	≤ 20	≤ 30	Complete treatment
(b) Special standards			
Ratio of receiving water to sewage flow			
150 to 300	--	≤ 60	Chemical precipitation
300 to 500	--	≤ 150	Plain sedimentation
Over 500	--	--	No treatment required

Imhoff and Fair also present an example of standards which specify the required treatment as well as classifying receiving streams according to use. These standards are shown in the table on page 84.

Similar water quality criteria were recommended by the Interstate Commission of the Potomac River Basin, and by Water Pollution Control Boards of states such as New York, Pennsylvania, South Carolina, West Virginia, etc.

The table on page 85, derived from the Potomac River Commission data is illustrative of receiving water quality criteria which set minimum stream requirements for arbitrary classes without attempting to dictate the treatment measures by which they shall be achieved. These criteria, it is explained by the commission, are to be used as a guide, and only then in connection with a sanitary survey. Pollution agencies are to regulate waste discharges so that these standards are maintained. No rigid standards are set because of the wide variations in natural river conditions.

Class	Use	Standards of Quality at Low-water Stage	Required Treatment of Sewage	Emergency Treatment
(1)	(2)	(3)	(4)	(5)
D (Bad)	For rough industrial uses and for irrigation	Absence of nuisance, odors and unsightly suspended or floating matters; dissolved oxygen present	Sedimentation, except in large receiving waters	Chlorination; ferri chloride treatment to remove hydrogen sulphide; addition of nitrate to supply oxygen
C	For fishing	Dissolved oxygen content not less than 3 and preferably 5 ppm; CO ₂ not more than 40 and preferably 20 ppm*	Sedimentation; chemical or biological treatment where necessary	Aeration; addition of diluting waters
B	For bathing, recreation, and shellfish culture	No visible sewage matters. A bacterial standard such as B. coli less than 100 per 100 ml.	As in class C; chlorination if necessary	Chlorination
A (Good)	For drinking water after chlorination	In the absence of filtration** a bacterial standard such as B. coli less than 50 per 100 ml. Chemical standards for substances not removable by common treatment methods	As in class B; removal of certain taste producing substances such as phenols	Treatment of drinking water with heavy doses of chlorine and with activated carbon

* At high temperatures the tolerance of fish to low DO and high CO₂ is decreased; high temperatures are also objectionable in themselves.

**With complete purification in modern filtration works, a bacterial standard such as 5,000 B. coli per 100 ml. will normally permit production of a safe drinking water.

Class	Use	Minimum Requirement
A	Water supply with chlorination only (Fish life, bathing, recreation, process also)	Coliform bacteria MPN, 50/100 ml maximum. Color < 10 ppm. Turbidity < 10 ppm. pH - 6.0 to 8.0 range DO not less than 7.5 ppm. No single obs < 6.0 ppm. No toxic substances, free acid, debris, odor or taste producers (except natural sources). No sludge deposits of any kind.
B	Bathing, fish life, recreation. Water supply after complete treatment.	Coliform bacteria MPN (monthly average) between 50 and 500/100 ml. Color - 20 ppm max. desirable. Turbidity - 40 ppm max. desirable. pH - 6.0 to 8.5 5-day BOD - max. any sample = 3.0 ppm. Average < 1.5 ppm. DO - monthly average > 6.5 ppm. - no sample < 5.0 ppm. Other conditions - same as Class A.
C	Water supply after complete treatment Ind. process, navigation, etc.	Coliform bacteria - monthly average 500 to 5000/100 ml. Color & turbidity - removable by filtration. pH - 6.0 to 8.5 5-day BOD - monthly average < 2.0 ppm. - single sample < 4.0 ppm. DO - monthly average > 6.5 ppm. - single sample > 5.0 ppm. Other conditions - same as Class A.
D	Navigation, cooling water, etc.	Shall not constitute nuisance. pH - 6.0 to 8.5 5-day BOD - monthly average < 3.0 ppm. - single sample < 5.0 ppm. Other conditions - no toxic substance, free acid, floating debris.

Water Quality Criteria and Control in California

California has deviated appreciably from the more customary type of standards of receiving water quality which depend on the beneficial use to which the water is to be put, in that it does not sanction the grouping of receiving waters into classes A, B, C, D, etc. While its rulings may in time have a similar practical effect, the classification of water quality will be controlled by the land and water use growth rather than by some preconceived, and often arbitrary, system of classification.

California's water pollution control act of 1949 has two distinct goals:

1. Protection of the quality of the waters of the state for present and future beneficial use.
2. Maximum use of those waters for waste disposal.

The act set up a State Water Pollution Control Board of 14 men, divided the state into 9 regions, and provided for a 5-man regional board in each region. The stated objective of the State Board is "the prevention and control of pollution and contamination of the waters of the state at a minimum of expense consistent with obtaining this objective. In achieving this objective, it will be the policy of this board that its actions and those of the regional water pollution control boards shall be so directed as to secure that degree of care in the planning and operation of works for the treatment and disposal of sewage and industrial wastes as will adequately protect the public health and all of the beneficial uses of waters in this state and at the same time permit the legitimate planned usage of those waters for receiving suitably prepared wastes so that an orderly growth and expansion of cities and industries may be possible."

Each regional board is autonomous in its region. Each consists of representatives from water supply, irrigated agriculture, county government, city government, industrial waste.

As regulatory agencies they have 3 principal duties:

1. Formulating and adopting long-range plans and policies.
2. Setting and enforcing waste discharge regulations.
3. Coordinating the interests of other agencies.

The state board serves in a coordinating and appellate capacity to:

1. Formulate a state-wide policy for control of water pollution with due regard to the authority of the regional boards.
2. Review acts of a regional board where the regional board has failed to take or obtain appropriate action to correct a condition of pollution.
3. Administer state-wide programs of research or of financial assistance for water pollution control.
4. Allocate funds for the administrative expenses of the regional boards.

In controlling pollution a regional board follows 4 steps:

1. Enunciates beneficial water uses which it intends to protect.
2. Defines water quality criteria to protect beneficial water uses.
3. Prescribes waste discharge requirements.
4. Checks compliance and enforces requirements.

In "enumerating beneficial water uses" the board takes cognizance of the fact that the law defines pollution as an impairment of the quality of water by sewage and industrial waste to a degree which adversely and unreasonably affects waters for domestic, industrial, agricultural, navigational, recreational, or other beneficial use.

The law establishes what beneficial water uses are--the board states only which of these water uses it intends to protect in any case. In doing this it considers:

1. established water use,
2. planned future uses, and
3. need for economical waste disposal.

In doing this it holds public hearings and takes its action at a public meeting.

After setting forth the water use to be protected, the board must establish limits of chemical, physical, and biological characteristics beyond which impairment for beneficial use occurs. In setting these standards the board consults authorities in the proper fields (agriculture, water supply, recreation, etc.). It expects the criteria, with a reasonable margin of safety, to represent maximum concentrations of pollutants which may be achieved, and a continuing study of water quality is made with the idea that as maximum values are approached the possibility of unreasonable impairment will exist and careful checks on waste discharges and enforcement procedures may be in order.

A greatly simplified hypothetical case is shown graphically in the accompanying figure (page 89).

In carrying out the last two steps in the control of pollution--prescribing discharge requirements and enforcing these requirements--the board makes use of periodic checks and, if necessary, of the courts of law. Waste dischargers may appeal decisions of the regional boards to the state board, which may hear or refuse to hear the case as its merits seem to warrant.

Discussion

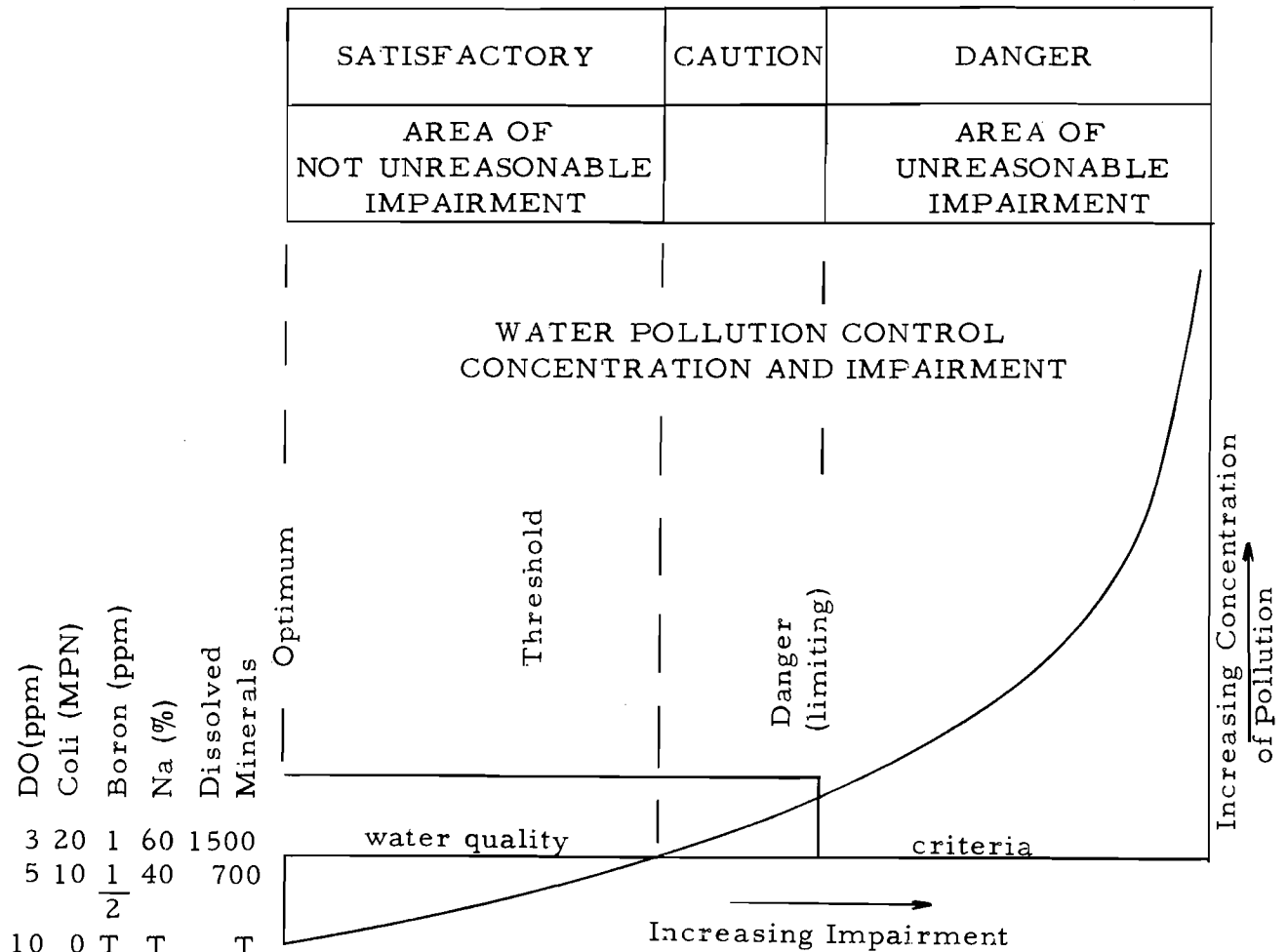
In recent years the tendency has been to set standards for receiving waters rather than to specify the exact degree of treatment required of each municipal or industrial waste discharger. It is generally understood that the criteria shall serve as a guide in analyzing each problem of effluent discharge as it arises. Furthermore, they are intended to apply only for some reasonable time in the future.

In establishing criteria or standards, considerations should include:

1. Not all streams were of the same quality before pollution began.
2. All beneficial uses of the stream, including waste disposal, should be taken into account.

Definition of Water Quality Criteria
(From ASCE Paper by V. W. Bacon and C. A. Sweet)(1)

Beneficial use to be preserved in river water	Water quality criteria prescribed by Control Board to prevent pollution		Possible conditions if pollution not controlled
Irrigation	700 ppm dissolved minerals, maximum 40% sodium ratio, maximum 0.5 ppm boron, maximum		High concentrations; crop damage and loss of production
Bathing	10 coliform bacteria per ml, maximum		High coliform counts; an actual hazard to public health. (contamination)
Fishing	5 ppm of dissolved oxygen (DO), minimum		Low dissolved oxygen; reduced fisheries resources of fish kills



3. In a dynamic civilization, standards must be revised in time to meet changed needs.

Serious disadvantages of any stream standard include the fact that:

1. Minimum permissible quality of water tends to become its maximum quality, as waste dischargers seek to get by with the least possible treatment which will meet the standards.
2. Standards tend to become fixed values rather than guides to judgment, hence may result in arbitrary decisions.
3. If stream classification is involved, future use of the stream tends to be frozen in advance.

The advantages include such considerations as:

1. The industry or town fortunately located on a stream or reach of water having a large assimilative capacity is not penalized, as is the case with effluent standards.
2. The degree of treatment imposed on a small industry with a small waste volume is less than would be required for a large installation of the same type in the same location.
3. Provision may be made for an orderly revision of regulations as conditions require, with less administrative difficulty.

References

1. Bacon, V. W., and C. A. Sweet. "Setting Water Quality Criteria in California." Proceedings, American Society of Civil Engineers, Paper No. 698, April 1955.
2. McGauhey, P. H. "Folklore in Water Quality Parameters." Civil Engineering, June 1965.
3. McKee, J. E., and H. W. Wolf. Water Quality Criteria. 2nd ed. Report to California State Water Quality Control Board (SWQCB Publication 3A.) 1963.
4. U. S. Public Health Service. Drinking Water Standards. 1962.

IX

QUALITY NEEDS OF BENEFICIAL USES

Introduction

Having discussed in a somewhat sketchy way the nature and variation of quality factors contributed to the fresh water resource pool by major water-using sectors of the economy and the self-purification process of natural waters, let us now consider what the quality of that pool means in terms of its beneficial use. In such a condition we should address our considerations in the days ahead to several related questions:

1. Is it feasible to maintain the quality of the resource pool at such a level that all beneficial users find it satisfactory for their purposes?
2. If not, what is the optimum quality which should be required by the public so that each beneficial use can adapt the resource to its own particular needs by current technology and within the scope of economic feasibility?
3. By what legal and institutional concepts and procedures can the public enforce its wishes or gain its objectives?
4. By what quantitative parameters, numbers, standards, etc., does the public and its representatives define its objectives and measure the degree of attainment?
5. Can all local sectors of the water resource ever be made suitable for every beneficial use which the fresh water resource may serve?
6. How does the saline water resource fit into the pattern of water resource management and what are its peculiar problems of quality management?
7. What are the technologically feasible means by which users of water can alter the quality of their return waters to conform to imposed requirements? How do they function? What are their limitations?

While these questions are not going to be taken up one at a time in the sessions to come, it is proposed to keep them in mind in developing the course presentations. Obviously some questions, such as No. 1 for example, are simple "straw men" to be knocked down with a single blow. Others are going to take a lot of knocking before water quality management is continuously responsive to the needs and desires of society.

The first step in getting at answers to questions such as the foregoing is to inquire into the quality requirements of beneficial uses, including several which themselves contribute little, if anything, to a change in the quality of the fresh water resource.

A. Quality Requirements of Industry

By far the most varied spectrum of quality requirements is found in industrial water needs when the quality requirements of beneficial uses are considered. The accompanying table (page 93) reproduced from the American Water Works Association Manual, 1950 edition (1) gives an idea of the water quality tolerances for several industrial applications. A study of the table and its numerous footnotes leads to the conclusion that the needs of industry cannot possibly be the criterion by which the quality of the fresh water resource is managed. Certainly a water with the zero oxygen needed in high pressure boiler feed, the pH limit of 6.5 - 7 of brewing, the 0.3 turbidity limit of rayon manufacture would be a wierd concoction indeed and a bit awkward to manage in metal pipes.

Therefore it would seem axiomatic to suggest that industry will have to continue to treat water in accord with its own needs for process water, and to locate its plants where the local resource can be suited to its process and cooling water requirements. Generally the siting of a new plant is governed more by the quality of return water it is permitted to discharge than the quality of the water at its intakes. However, the movement of industrial plants from the heavily industrialized northeast

has often been triggered by the low quality of the intake water as a result of upstream discharge of wastes by numerous other industrial plants.

B. Quality Requirements of Agriculture

Literature on the subject of the quality requirements of agriculture is quite extensive. Some of the more important factors which define the quality of water acceptable to growing of crops are outlined herein. They are, of course, based on the limitations of current species of plants and presuppose the maintenance of a situation in which the choice of crops to be planted by the farmer is governed by factors other than water quality. At the present state of our national development, one of the goals of water quality management should be, in my opinion, the maintenance of such a freedom as long as it is possible to do so.

In a previous lecture I have called attention to the fate of past civilizations which have depended upon the irrigation of crops for their prosperity, and have speculated that if ours should go the same route it may well be because intensive multiple repeated use of the water resource will have salted the water rather than the soil. In any event, it is of more than normal concern to us that the quality of the fresh water pool be suited to the needs of agriculture.

What factors limit the usefulness of a water for agriculture and the concentrations at which their effects are felt either in a minimal or a catastrophic way have been the object of much research and many publications with which I am not thoroughly familiar. In what I have to say I am drawing heavily upon the writings of Eldridge (2) and of Wolf and McKee (4).

Salinity. Eldridge (2), in his summary of "Quality Considerations," states that:

Criteria for irrigation water are developed on the basis of salinity, sodium, boron, and bicarbonate concentrations.... Irrigation water should be relatively high in calcium and magnesium...; boron in irrigation water should not exceed one to two ppm...; and silica, nitrate, and fluoride are undesirable in domestic water but in the normal concentrations present no hazard to irrigation water.

Relative Tolerance of Crop Plants to Salt Constituents
in the Soil Solution

	<u>Group I</u>	<u>Group II</u>	<u>Group III</u>
	Crops which may be grown on soils of weak salinity	Crops which may be grown on soils of medium salinity	Crops which may be grown on soils of strong salinity
Sensitive ↓	Beans, wax, pods		
	Beans, navy, tops		
	Red clover		
	Field peas		
	Horsebean		
	Vetch		
	Proso		
	Oats (grain crop)		
	Emmer (grain crop)		
	Wheat (grain crop)		
	Onions	Onions	
	Squash	Squash	
	Carrots	Carrots	
	Ladino clover	Ladino clover	
	Sunflower	(B)-Sunflower	
	Rice	Rice	
	Rye (grain crop)	Rye (grain crop)	
	Barley (grain crop)	(B)-Barley (grain crop)	
	Oats (hay crop)	Oats (hay crop)	
	Wheat (hay crop)	Wheat (hay crop)	
Grain sorghums	Grain sorghums		
Foxtail millet	Foxtail millet		
Strawberry clover	Strawberry clover		
Asparagus	Asparagus		
Cowpeas	Cowpeas		
Flax	Flax		
Sweet clover	Sweet clover		
Barley (hay crop)	Barley (hay crop)		
Tomatoes	(B)-Tomatoes		
Cotton	(B)-Cotton	Cotton	
Alfalfa	Alfalfa	Alfalfa	
Sorgo	Sorgo	Sorgo	
Kale	Kale	Kale	
Rape	Rape	Rape	
Tolerant ↑	Meadow fescue	Meadow fescue	Meadow fescue
	Italian ryegrass	Italian ryegrass	Italian ryegrass
	Crested wheatgrass	Crested wheatgrass	Crested wheatgrass
	Slender wheatgrass	Slender wheatgrass	Slender wheatgrass
	Tall oatgrass	Tall oatgrass	Tall oatgrass

Relative Tolerance of Crop Plants to Salt Constituents
in the Soil Solution (cont.)

<u>Group I</u>	<u>Group II</u>	<u>Group III</u>
Crops which may be grown on soils of weak salinity	Crops which may be grown on soils of medium salinity	Crops which may be grown on soils of strong salinity
Smooth bromegrass	Smooth bromegrass	Smooth bromegrass
Bluestem	Bluestem	Bluestem
Bermuda grass	Bermuda grass	Bermuda grass
Rhodes grass	Rhodes grass	Rhodes grass
Sugar beets	Sugar beets	Sugar beets
Milo, tops and grain	Milo, tops and grain	Milo, tops and grain
Garden beets	Garden beets	Garden beets

Tentative Guides for Evaluating the
Quality of Water Used for Irrigation
(After McKee and Wolf, original manuscript)

Determination	Threshold (a) Concentration	Limiting (b) Concentration
Coliform organisms, MPN/100 ml	1000*	(c)
Total Dissolved Solids (TDS), mg/l	500*	1500*
Elec. conductivity, micromohs/cm	750*	2250*
Range of pH	7.0-8.5	6.0-9.0
Sodium adsorption ratio (SAR)	6.0*	15
Residual sodium carbonate (RSC), mg/l	1.25*	2.5
Arsenic, mg/l	1.0	5.0
Boron, mg/l	0.5*	2.0
Chloride, mg/l	100*	350
Sulfate, mg/l	200*	1000
Copper, mg/l	0.1*	1.0

(a) Threshold values at which irrigator might become concerned about water quality and might consider using additional water for leaching. Below these values water should be satisfactory for almost all crops and almost any arable soil.

(b) Limiting values at which the yield of high-value crops might be reduced drastically, or at which an irrigator might be forced to less valuable crops.

(c) Aside from fruits and vegetables which are likely to be eaten raw, no limits can be specified. For such crops, the threshold concentration would be limiting.

* Values not to be exceeded in more than 20 percent of any 20 consecutive samples, nor in any 3 consecutive samples. The frequency of sampling should be specified.

The growth of plants is affected by salt content in the soil water. Plants differ in their tolerance to salinity. Electrical conductivity is normally used to measure concentration. It is measured as conductivity in micromhos per centimeter at 25° C [EC x (EC x 10⁶)] . Four classes are designated:

Low (C ₁)	Less than 250 micromhos/cm
Medium (C ₂)	250 - 750
High (C ₃)	750 - 2250
Very High (C ₄)	Above 2250

About one-half of the waters used for irrigation in the west come within the range of 250-750 micromhos/cm, which in terms of dissolved minerals is about 175 to 500 ppm.

Plants have difficulty in obtaining water from saline solutions. The characteristic(s) of soils, however, are not adversely affected by high concentrations of salts, if sodium is low in comparison with calcium and magnesium. Sodium renders soils impermeable to air and water, and when wet these soils become plastic and sticky. The effect of sodium on the soil is measured by the "sodium-absorption ratio" which is the ratio of sodium ion to calcium and magnesium ions.

The formula used is:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

A value of SAR = 8 is considered satisfactory; 12 to 15 is marginal; and more than 20 is serious and requires special management practices, i. e., the application of gypsum (CaSO₄) to the soil.

"SAR must be used in combination with total salt content since the higher the salts the more sodium can be tolerated." This fact has led to a classification of irrigation waters on a scale of C₁ to C₄ as follows:

1. Low salinity water (C₁) can be used on most crops and soils.
2. Medium salinity water (C₂) can be used on most crops but requires a moderate amount of leaching.

3. High salinity water (C_3) requires good drainage, permeable soils, and salt resistant crops.

4. Very high salinity water (C_4) is not normally good for irrigation. Similarly sodium factors ranging from S_1 to S_4 have been designated and related to C_1 to C_4 salinities in terms of micromhos/cm.

Boron. Boron is toxic to plants in certain concentrations but varies with species and climate factors. In general:

Sensitive crops (fruits, nuts, beans) - 0.33 to 1.25 mg/l

Semi-tolerant crops (cereals, vegetables, cotton) - 0.67 to 2.50 mg/l

Tolerant crops (alfalfa, sugar beets, asparagus) - 1.00 to 3.75 mg/l

Bicarbonates and carbonates.

Bicarbonates in irrigation water tend to render calcium more soluble. When calcium bicarbonate enters the soil an increase in temperature or evaporation may precipitate the calcium as $CaCO_3$ which tends to hold the calcium in the soil. This is of importance since it keeps the calcium content of the soil high. This reduction of calcium in the drainage water results in an increase in the sodium-absorption ratio.

Some waters contain "residual sodium carbonate" which is defined as the sum of the equivalents of normal carbonate and bicarbonate minus the sum of the equivalents of calcium and magnesium. (2)

It is generally concluded that water containing less than 66 mg/l residual normal sodium carbonate (Na_2CO_3) can be safely used in irrigation.

Between 66 and 132 mg/l is marginal; and above 132 mg/l is not suitable for agriculture.

C. Quality Requirements of Domestic Use

The quality of water which must pertain in the resource pool if it is to be suitable for domestic use varies widely with the individual quality factor under consideration. In general, it may be said that as a matter of principle:

1. To be suitable for domestic purposes the raw water supply must be of such quality that the public health drinking water standards, in all factors where absolute limits are specified, are achievable by normal water treatment technology, i. e., coagulation, filtration, chlorination.
2. The quality standards which are recommended but not obligatory should be exceeded only as a result of characteristics of the natural water and not as a result of the increments added by return waste waters, e. g., softening or de-ionization, or simply human tolerance of such things as salinity and hardness should not be imposed as a result of quality depression by previous beneficial use of the raw water.

In the table on page 116, McKee and Wolfe (4) present the water quality objectives of raw water supplies for various beneficial uses. Reference is made to the Public Health Service drinking water standards.

"Drinking water standards" present a considerable amount of explanatory data on general environmental sanitation, sampling techniques, and frequency, and methods of analysis. Maximum permissible limits of coliform bacteria and certain chemical factors are specified. Recommended maximum limits of other chemicals are presented. (The reader is referred to the original reference and to "Water Quality Criteria (4) for a full presentation of the significance of various quality factors.)

Bacteriological standards are summarized in the following table. In general they mean one coliform organism/100 ml.

Sample Examined	Limits
Standard 10 ml portions	Not more than 10 percent in one month shall show coliforms. (Subject to further restrictions specified.)
Standard 100 ml portions	Not more than 60 percent in one month shall show coliforms. (Subject to further specified restrictions.)

Physical characteristics: No material present offensive to senses of sight, taste, or smell.

Turbidity	5 Units
Color	15 Units
Threshold odor number	3 Units

Chemical standards, both recommended and absolute, are summarized in the accompanying tables (pages 101 and 102). One shows by comparison of the 1946 and 1961 standards the immutability of some standards, or perhaps the slow progress made in establishing epidemiological bases for standards. The other presents the same data as tabulated in "Public Health Service Drinking Water Standards," 1961 (6).

Radioactivity: Added radiation shall not bring total from all sources above maxima specified by the Federal Radiation Council and approved by the President. Water supplies shall be approved without consideration of other sources of radiation from Radium-226 and Strontium-90 when the water contains these substances in amounts not exceeding 3 and $10 \mu \mu$ c/liter, respectively.

In the known absence of Strontium-90 and alpha emitters, the water supply is acceptable when the gross beta concentrations do not exceed $1000 \mu \mu$ c/liter. In excess of this amount the water shall be rejected for public use.

D. Quality Requirements of Recreational Use

Recreational use of water as herein discussed refers primarily to bathing, swimming, and other water-contact sports; boating, and aesthetic enjoyment. Fishing is, of course, a recreational use of water but the quality considerations in that case are those required for the protection of aquatic life and are hence discussed in that context.

The general criteria of quality for recreational use are obvious: freedom from obnoxious suspended or floating material, objectionable color, or foul odors. Furthermore they should be free of substances

Revision of Chemical Limits

	Recommended Maximum Limits ^a (mg per liter)		Concentrations Which Constitute Grounds For Rejection of Supply (mg per liter)	
	1946	1961	1946	1961
		Revision		Revision
Alkyl benzene sulfonate (detergent)	-	0.5		
Arsenic	-	0.01	0.05	0.05
Barium			-	1.0
Cadmium				0.01
Carbon chloroform extract (exotic organic chemicals)	-	0.2		
Chloride	250.	250.		
Chromium			0.05	0.05
Copper	3.0	1.0		
Cyanide	-	0.01	-	0.2
Fluoride	-	1.7 ^b	1.5	2.2 ^b
Iron + manganese	0.3	-		
Iron	-	0.3		
Lead			0.1	0.05
Manganese	-	0.05		
Nitrate	-	45.		
Phenols	0.001	0.001		
Selenium			0.15	0.01
Silver			-	0.05
Sulfate	250.	250.		
Total dissolved solids	500.	500.		
Zinc	15.	5.		

^aConcentrations in water should not be in excess of these limits when more suitable supplies can be made available.

^bFluoride temperature concentration relationships are discussed in detail in the text.

Chemical Characteristics--Recommended Mixima (6)

Substance	Concentration (mg/l)
Alkyl benzene sulfonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250
Copper (Cu)	1.0
Carbon chloroform extract (CCE)	0.2
Cyanide (CN)	0.01
Fluoride (F)	0.6 to 1.7 range
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO ₃)	45
Phenols	0.001
Sulfate (SO ₄)	250
Total dissolved solids (TDS)	500
Zinc (Zn)	5

Chemical Characteristics--Maximum Permissible (6)

Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (hexavalent) (Cr ⁺⁶)	0.05
Cyanide (CN)	0.2
Fluoride	-
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

(including pathogens) which are dangerous to swallow.

Specific standards in terms of numbers, however, are not so easily established. Largely because of the need for some sort of a standard, coliform organisms have often been considered. The possibility of infection certainly exists when fecal organisms abound in the water, although British studies of the North Sea failed to show any correlation between disease and sewage polluted water and beaches. The result is that standards set by regulatory agencies have generally been related to aesthetic considerations and ability of compliance rather than on any sound epidemiological evidence. A general disinclination of people to come in contact with sewage together with uncertainty of the mode of transmission of infectious hepatitis suggest that some coliform standard or criterion should be utilized. Natural agents such as the organisms which produce schistosome dermatitis and leptospirosis occur in some waters and so render them unfit for recreation involving contact, but the methods of preventing such infestation of waters does not appear in standards. The table on page 104, compiled from data in McKee and Wolf (4) reflects the rather uncertain quality limits suggested by various agencies for recreational waters.

E. Quality Requirements for Livestock and Aquatic Life

Livestock and wildfowl. Animals react very much the same as humans to highly mineralized waters. Generally no animal will choose to drink saline water when better water is available. I have found cattle with access to a heavily sewage polluted stream so excited over fresh water offered in a bucket that the safety of myself, the bucket, and the smaller of the animals was threatened. (Incidentally, I caused city water to be piped to these animals, and it was evident to me on seeing the results that these animals were drinking sewage only with the same survival motive as a human might.) Sudden changes from slightly mineralized to highly mineralized waters has been known

Tentative Guides for Evaluating Recreational Waters

Determination	Water-Contact		Boating & Aesthetic	
	Noticeable Threshold	Limiting Threshold	Noticeable Threshold	Limiting Threshold
Coliforms, MPN/100 ml	1000*	**	--	--
Visible solids of sewage origin	none	none	none	none
ABS (detergent) mg/l	1*	2	1*	5
Suspended solids, mg/l	20*	100	20*	100
Flotable oil & grease, mg/l	0	5	0	10
Emulsified oil & grease, mg/l	10*	20	20*	50
Turbidity, silica scale units	10*	50	20*	***
Color, Std. cobalt scale units	15*	100	15*	100
Threshold odor number	32*	256	32*	256
Range of pH	6.5-9.0	6.0-10.0	6.5-9.0	6.0-10.0
Temperature, Max. °C	30	50	30	50
Transparency, Secchi disk, ft.	--	--	20*	***

* Value not to be exceeded in more than 20 percent of 20 consecutive samples, nor in any three consecutive samples.

** No limiting concentration can be specified on basis of epidemiological evidence, provided no fecal pollution is evident.

*** No concentrations likely to be found in surface waters would impede use.

Note: Noticeable threshold represents level at which people begin to notice and perhaps to complain.

Limiting threshold is level at which concentrations prohibit or seriously impair use of water for recreation.

to kill livestock from salt poisoning. However, the tolerance of animals depends upon many factors including health, salt content of the diet, and the nature of the salts involved. McKee and Wolf discuss this point in some detail, but the conclusion is that the maximum concentrations of salts that can be tolerated by domestic animals without danger of injury by the osmotic effect of salts lies between 15,000 and 17,000 mg/l. However, a value of 10,000 mg/l is more realistic for sheep and perhaps 7,000 mg/l for milk cows in production. Obviously, these values are considerably higher than can be tolerated by humans who, as I have noted previously, have to practice a bit to get along on 3,000 mg/l.

Toxic algae and protozoa cultured in heavily sewage polluted water are dangerous to both livestock and wildfowl. (See section on Effect of Nutrients.) Wastes from dairies and slaughterhouses have been suspect in the spreading of animal disease through water. Oily substances are detrimental to livestock if the unavailability of fresh water forces them to drink it. Wildfowl losses are particularly great when contact fouls up their feathers. (See McKee and Wolf (4) for full discussion.)

Aquatic life. The extensive literature on the effects of pollution on aquatic life is such as almost to discourage one who would summarize it. As has been previously pointed out in these discussions, anything that interrupts the food chain at any level is serious to all organisms higher up the chain. Thus a lack of fertilizers may lead to an aquatic desert. However, as discussed in another section on Eutrophication of Water, the likelihood that man's activities are going to wipe out the fertilizers in water where they already exist is quite remote. The danger lies in toxicity acting in different ways on different creatures, or in suffocation of organisms as a result of lowered or completely obliterated oxygen content of the water. It is for this reason that BOD and oxygen relationships have been featured most prominently in assessing the quality of water for aquatic

Tentative Guides for Evaluating the Quality
of Water Used by Livestock

Determination	Threshold* Concentration	Limiting** Concentration
Total dissolved solids (TDS), mg/l	2500	5000
Cadmium, mg/l	5	--
Calcium, mg/l	500	1000
Magnesium, mg/l	250	500***
Sodium, mg/l	1000	2000***
Arsenic, mg/l	1	--
Bicarbonate, mg/l	500	500
Chloride, mg/l	1500	3000
Fluoride, mg/l	1	6
Nitrate, mg/l	200	400
Nitrite, mg/l	none	none
Sulfate, mg/l	500	1000***
Range of pH	6.0-8.5	5.6-9.0

* Threshold values represent concentrations at which poultry or sensitive animals might show slight effects from prolonged use of such water. Lower concentrations are of little or no concern.

** Limiting concentrations based on interim criteria, South Africa. Animals in lactation or production might show definite adverse reactions.

*** Total magnesium compounds plus sodium sulfate should not exceed 50 percent of the total dissolved solids

life, and why domestic sewage has been the first line of attack whenever the protection of aquatic life is one of the beneficial uses of water to be protected by public agencies. Quality management for aquatic life, therefore, revolves about oxygen; although with the advent of organic pesticides, their effects on the water resource have been a matter of concern.

Bacterial pollution of water has been a factor in relation to aquatic life, not because of its effects on the organisms themselves but rather because of the danger to human beings from eating raw shellfish or by contaminating the food or drink of the fisherman through carelessness. Shellfish, being nature's little sewage treatment plants, can concentrate bacteria and evidently virus to a degree that is dangerous to the gourmet.

On the other hand, the possibility that wastes may produce disease in fishes cannot be ruled out. Recently it has been found that the English Sole in San Francisco Bay caught near the sewer outfalls have growths on their heads and mouths which are evidently cancerous. Virus in sewage is suspect but the results of investigative work are not yet in. Nevertheless it seems evident that something in the sewage-contaminated environment is the cause.

McKee and Wolf (4) summarize tentative guides for evaluating water quality in the context of fish propagation. (See table on page 108.) They also summarize work which leads to the general conclusion that salinities below 12,000 mg/l are definitely detrimental to oysters; that oysters and clams are critically affected by temperature but different species have different ranges of tolerance. Concentration of radionuclides, and in some cases of exotic organics, is also a factor in considering the suitability of water for aquatic life.

Most of the concern of our discussions has been with the fresh water resource, whereas shellfish are brackish or salt water organisms. This brings to attention that little has yet been said concerning the resource implications of the discharges from the fresh water resource pool, which

Tentative Guides for Evaluating the Quality of Water
Used for the Propagation of Fish
[After McKee & Wolf (4)]

Determination	Threshold Concentration	
	Fresh Water	Salt Water
Total dissolved solids (TDS), mg/l	2000*	--
Elect. conductivity, micromhos/cm at 25 °C	3000*	--
Temperature, maximum, °C	34	34
Maximum for salmonoid fish	23	23
Range of pH	6.5-8.5	6.5-9.0
Dissolved oxygen (DO), minimum, mg/l	5.0**	5.0**
Flotable oil and grease, mg/l	0*	0*
Emulsified oil and grease, mg/l	10*	10*
Detergent, ABS, mg/l	2.0	2.0
Ammonia, free, mg/l	0.5*	--
Arsenic, mg/l	1.0*	1.0*
Barium, mg/l	5.0*	--
Cadmium, mg/l	0.01*	--
Carbon dioxide, free, mg/l	1.0	--
Chlorine, free, mg/l	0.02	--
Chromium, hexavalent, mg/l	0.05*	0.05*
Copper, mg/l	0.02*	0.02*
Cyanide, mg/l	0.02*	0.02*
Fluoride, mg/l	1.5*	1.5*
Lead, mg/l	0.1*	0.1*
Mercury, mg/l	0.01	0.01
Nickel, mg/l	0.05*	--
Phenolic compounds, as phenol, mg/l	1.0	--
Silver, mg/l	0.01	0.01
Sulfide, dissolved, mg/l	0.5*	0.5*
Zinc, mg/l	0.1	--

* Values not to be exceeded in more than 20 percent of any 20 consecutive samples, nor in any three consecutive samples. Other values should never be exceeded. Frequency of sampling should be specified.

** Dissolved oxygen concentrations should not fall below 5.0 mg/l more than 20 percent of the time and never below 2.0 mg/l.

Note: Threshold concentration is value that normally might not be deleterious to fish life. Waters that do not exceed these values should be suitable habitats for mixed fauna and flora.

McGauhey note: Recent data indicate also that rate of change of oxygen tension is an important factor, and that diurnal changes in DO may, in sewage polluted water, render the value of 5.0 of questionable merit.

incidentally, in any degree of purity constitutes a pollutant if introduced either by design or inadvertence into a saline environment. (The significance of the marine and estuarial water resource is the subject of a subsequent section.)

Klein (3) lists a series of coal tar derivatives which lead to objectionable tainting of fish flesh, and which at the same time are toxic to fish. He notes that phenols, chlorphenols, and similar compounds from industrial wastes may thus damage the value of fisheries. He also presents a quite comprehensive list of the effects of various substances on fish. A recent publication of the Robert A. Taft Center of the Public Health Service (7) gives a wealth of information on the response of lower creatures in the aquatic food chain, particularly the aquatic insects, protozoa, and bacteria, as indicated by numbers of organisms present, to a whole spectrum of ions, compounds, and environmental conditions. These findings, and those of the numerous references from which they are drawn, are too voluminous to summarize here and to interpret as quantitative measures of quality. The important factor is that a great deal of investigative work is being directed to the matter of the water quality needs of aquatic organisms, and we may expect that as time goes on and the data become more conclusive, such quality considerations will be reflected in an increasing stringency of requirements to be met by beneficial users of the water resource which return used water to the resource pool.

For the present purpose, the tables compiled by McKee and Wolf (4) and by Klein (3) may serve to indicate the general criteria by which water can be judged as to its suitability for aquatic life.

F. Other Beneficial Uses

The spectrum of beneficial uses of water extends beyond domestic, industrial, agricultural, recreational uses, and the preservation of useful or even useless aquatic life. It includes also navigation,

Tabl. 51. Lethal limits to fish for some important polluting substances *

In this table the concentration values are the lowest at which definite toxic action is indicated by the data in the reference cited. Wherever possible the exposure time is given. It must not be assumed that lower concentrations are harmless and for further information the works cited should be consulted as many include survival curves or tables. Where no reference is given the figures are based on unpublished work by the writer. Most of the data is for temperatures between 15° and 23° C. Concentrations are parts per million unless otherwise stated. Exposure times have been approximated in some cases. For the pH values tolerated by various fishes, see Figure 30.

Substance	Fish tested	Lethal concentration	Exposure time hours	Ref.
Acetic acid	goldfish	423	20	1
Aluminium potassium sulphate (alum)	"	100	12-96	1
Aluminium nitrate	stickleback	0.1	144	15
Ammonia	goldfish	2-2.5 NH ₃	24-96	1
"	perch	3 N	20	55
"	roach	3 N	5	55
"	rainbow trout	3 N	2	55
Ammonium chloride	" "	500	17	79
Ammonium sulphate	" "	1000	14	79
Amyl alcohol	goldfish	1	161	1
Aniline	minnow	200	48	
"	brown trout	100	48	
Arsenic compounds				
Sodium arsenite	minnow	17.8 As	36	79
Sodium arsenate	"	234 As	15	79
Barium chloride	goldfish	5000	12-17	1
"	salmon	158	?	80
Barium nitrate	stickleback	500 Ba	180	15
Bromine	goldfish	20	15-96	1
Butyl alcohol	"	250	7-20	4
Cadmium chloride	"	0.017	9-18	4
Cadmium nitrate	stickleback	0.3 Cd	190	15
Calcium hydroxide	goldfish	100		
Calcium nitrate	"	(pH 11.1)	?	81
"	stickleback	6061	43-48	4
"	stickleback	1000 Ca	192	15
Carbon dioxide	various spp.	100-200	?	2
Carbon monoxide	"	1.5	1-10	2
Chloramine	brown trout fry	0.06	?	82
Chlorine	rainbow trout	0.03	?	83
"	"	0.08	?	46
"	brook trout	0.5-1.5	?	84
"	goldfish	1	96	1
Chromic acid	"	200	60-84	1
Citric acid	"	894	4-28	1
Cobalt chloride	"	10	168	1
Cobalt nitrate	stickleback	15 Co	160	15
Copper nitrate	"	0.02 Cu	192	14
"	rainbow trout	0.08 Cu	20	72
"	salmon	0.18	?	80
Copper sulphate	stickleback	0.03 Cu	160	
Cupric chloride	goldfish	0.019	3-7	4

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Table 51—cont.

Substance	Fish tested	Lethal concentration	Exposure time hours	Ref.
Cresylic acid	goldfish	1	6-48	1
Cyanogen chloride	rainbow trout	0.1	?	85
Ethyl alcohol	goldfish	0.25 c.c./l.	6-11	4
Ferric chloride	stickleback	pH 4.8	144	15
Herbicides*				
Aminotriazole	coho salmon	325	48	86
"	bluegill	10,000	48	86
Baron	chinook salmon	2.3	48	86
"	largemouth bass	4.6	24	86
Dowpon	coho salmon	340	48	86
Diquat	chinook salmon	28.5	48	86
"	rainbow trout	60	96	86
Diuron	coho salmon	16	48	86
Endothal	chinook salmon	136	48	86
F.98 (Acrolein)	" "	0.08	24	86
"	rainbow trout	0.065	24	86
Hyamine 1622	coho salmon	53	48	86
Kuron	chinook salmon	1.23	48	86
"	largemouth bass	3.5	24	86
Monuron	coho salmon	110	48	86
"	various spp.	40	240	86
Omazene	chinook salmon	0.83	48	86
Phygon XL	largemouth bass	0.07	48	86
Simazine	chinook salmon	6.6	48	86
Sodium TCA	" "	> 870	48	86
Hydrochloric acid	stickleback	pH 4.8	240	15
"	goldfish	pH 4.0	4-6	1
(See also Figure 30)				
Hydrogen sulphide	"	10	96	1
Insecticides*				
Aldrin	"	0.028	96	87
"	rainbow trout	0.05	24	60
BHC	goldfish	2.3	96	87
BHC (6.5 per cent gamma isomer)	rainbow trout	3	96	88
Chlordane	goldfish	0.082	96	87
"	rainbow trout	0.5	24	60
Chlorothion	fathead minnow	3.2	96	87
Co-ral	bluegill	0.18	96	87
DDT	goldfish	0.027	96	87
"	rainbow trout	0.5	24	60
"	" "	0.32	36	63
"	salmon	0.08	36	63
"	"	0.072	?	89
"	brook trout	0.032	36	63
Dieldrin	goldfish	0.037	96	87
"	bluegill	0.008	96	87
"	rainbow trout	0.05	24	60
Dipterex	fathead minnow	180	96	87
Di-syston	bluegill	0.064	96	87
Endrin	goldfish	0.0019	96	87
"	carp	0.14	48	65

* The references cited should be consulted for the chemical names of these compounds, the degree of purity of the preparations used for the tolerance tests, and the methods employed for making the test solutions.

Table 51—cont.

Substance	Fish tested	Lethal concentration	Exposure time hours	Ref.
<i>Insecticides (cont.)</i>				
Endrin	fathead minnow	0.001	96	87
EPN	" "	0.2	96	87
Guthion	bluegill	0.005	96	87
"	fathead minnow	0.093	96	87
Heptachlor	rainbow trout	0.25	24	60
"	goldfish	0.23	96	87
"	bluegill	0.019	96	87
Malathion	fathead minnow	12.5	96	87
Methoxychlor	rainbow trout	0.05	24	60
"	goldfish	0.056	96	87
OMPA	fathead minnow	121	96	87
Parathion	" "	1.4-2.7	96	87
Para-oxon	" "	0.33	96	87
Sevin	" "	13	96	87
"	bluegill	5.6	96	87
Systox	fathead minnow	3.6	96	87
Toxaphene	rainbow trout	0.05	24	60
"	goldfish	0.0056	96	87
"	carp	0.1	?	90
TEPP	fathead minnow	1.7	96	87
Lactic acid	goldfish	654	6-43	1
Lead nitrate	minnow	0.33 Pb	?	7
" "	stickleback	0.33 Pb	?	7
" "	brown trout	0.33 Pb	?	7
" "	stickleback	0.1 Pb	336	14
" "	goldfish	10	1-2	14
" "	rainbow trout	1 Pb	100	72
Lead sulphate	goldfish	25 Pb	96	6
Magnesium nitrate	stickleback	400 Mg	120	15
Mercuric chloride	" "	0.01 Hg	204	15
Methyl alcohol	goldfish	0.25 c.c./l.*	11-15	4
Naphthalene	salmon	3.2	?	80
"	perch	20	1	51
Nickel chloride	goldfish	10	200	1
Nickel nitrate	stickleback	1 Ni	156	15
Nitric acid	minnow	pH 5.0	?	7
Oxalic acid	goldfish	1000	1	1
Oxygen	rainbow trout	3 c.c./l.*		45
"	eel	1 c.c./l.*		45
"	coho salmon	2	720	41
Nascent oxygen	various species	0.033	?	91
Ozone	" "	0.01	?	91
<i>Phenolic substances</i>				
ortho-cresol	minnow	60	2	92
para-cresol	" "	50	2	92
" "	rainbow trout	5	2	21
phenol	minnow	20	4	92
"	rainbow trout	6	3	21
"	perch	9	1	51
"	goldfish	10	72	1
Potassium chromate	rainbow trout	75	60	79

* These are said to be the minimum tensions at which the animal is able to extract its normal requirement of oxygen from the water.

Table 51--cont.

Substance	Fish tested	Lethal concentration	Exposure time hours	Ref.
Potassium chromate	large-mouth bass	195 Cr	68	93
Potassium dichromate	rainbow trout	57	72	79
" " " "	goldfish	500	72	1
Potassium cyanide	" "	0.4 CN	118	4
" " " "	" "	0.1-0.3	96	1
" " " "	rainbow trout	0.13 CN	2	21
" " " "	" "	0.07 CN	70	18
Potassium nitrate	stickleback	70 K	154	15
Potassium permanganate	goldfish	10	12-18	1
" " " "	various species	3-5	?	68
Pyridine	perch	1000	1	51
" " " "	goldfish	1.87 c.c./l.	10-30	4
Quinoline	perch	30	1	51
Silver nitrate	stickleback	0.004 Ag	180	15
Sodium chlorate	goldfish	> 1000	120	1
Sodium chloride	" "	10,000	240	1
Sodium cyanide	stickleback	1.04 CN	2	11
" " " "	various species	1	?	20
Sodium fluoride	goldfish	1000	60-102	1
Sodium hydroxide	" "	pH 10.6	168	2
(See also Figure 30)				
Sodium nitrate	stickleback	6000 Na	180	15
Sodium sulphide	" "	4.5 S	2	11
" " " "	brown trout	1 S	?	29
" " " "	goldfish	100	96	1
Sodium sulphite	" "	10,400 Sr	17-31	4
Strontium chloride	" "	1500 Sr	164	15
Strontium nitrate	stickleback	1500 Sr	164	15
Sulphuric acid	goldfish	pH 3.9	5-6	1
Tannic acid	" "	100	180	1
" " " "	salmon	4.8	?	80
Tartaric acid	goldfish	100	200	1
Zinc sulphate	stickleback	0.3 Zn	204	14
" " " "	goldfish	100	120	1
" " " "	rainbow trout	0.5	64	10

Table 52. Lethal limits to fish for Synthetic Detergents and Soaps

This Table is based upon the data in HENDERSON, PICKERING and COHEN⁵⁶ and *Water Pollution Research, 1955*⁵⁷

Substance	Fish tested	Lethal concentration p.p.m.	Water type	Exposure time hours
Entire packaged detergents	fathead minnow	41-85	soft	96
" " " " "	" "	15-87	hard	96
Surface active agents				
alkyl benzene sulphonates	" "	4.5-23	soft	96
" " " "	" "	3.5-12	hard	96

Table 52—cont. *

Substance	Fish tested	Lethal concentration p.p.m.	Water type	Exposure time hours
<i>Surface active agents (cont.)</i>				
polyoxyethylene ester	fathead minnow	37	soft	96
" "	" "	38	hard	96
sodium lauryl sulphate	" "	5.1	soft	96
" " " "	" "	5.9	hard	96
sodium tetrapropylene benzene sulphonate	rainbow trout	12	?	6
<i>Builders</i>				
sodium perborate	" "	320	?	24
sodium pyrophosphate	" "	1120 PO ₄	?	24
sodium silicate	" "	> 256	?	24
sodium sulphate	" "	> 704	?	24
" " " "	fathead minnow	9000	soft	96
" " " "	" "	13,500	hard	96
sodium tripolyphosphate	rainbow trout	1120 PO ₄	?	24
" " " "	fathead minnow	140	soft	96
" " " "	" "	1300	hard	96
<i>Soaps</i>				
household soaps	" "	29-42	soft	96
" " " "	" "	920-1800	hard	96
pure sodium stearate	" "	100	soft	96
" " " "	" "	> 1800	hard	96

Table 53. Check list of fishes used in experimental work with polluting substances *

Common name	Scientific name
bleak	<i>Alburnus alburnus</i> (L.)
bluegill	<i>Lepomis macrochirus</i> Rafinesque
brown trout	<i>Salmo trutta</i> (L.)
carp	<i>Cyprinus carpio</i> (L.)
catfish (American)	<i>Ameiurus nebulosus</i> (Le Sueur)
chinook salmon	<i>Onchorhynchus tshawytscha</i> (Walbaum)
chub	<i>Squalius cephalus</i> (L.)
coho salmon	<i>Onchorhynchus kisutch</i> (Walbaum)
dace	<i>Leuciscus leuciscus</i> (L.)
eel	<i>Anguilla anguilla</i> (L.)
fathead minnow	<i>Pimephales promelas</i> Rafinesque
goldfish (common)	<i>Carassius auratus</i> (L.)
goldfish (crucian carp)	<i>Carassius carassius</i> (L.)
largemouth bass	<i>Micropterus salmoides</i> (Lacépède)
minnow	<i>Phoxinus phoxinus</i> (L.)
perch	<i>Perca fluviatilis</i> (L.)
rainbow trout	<i>Salmo gairdnerii</i> Richardson
roach	<i>Rutilus rutilus</i> (L.)
salmon (Atlantic)	<i>Salmo salar</i> (L.)
speckled trout, brook trout or American char	<i>Salvelinus fontinalis</i> (Mitchell)
stickleback (3-spined)	<i>Gasterosteus aculeatus</i> (L.)
stickleback (12-spined)	<i>Pygosteus pungitius</i> (L.)
tench	<i>Tinca tinca</i> (L.)

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power production, flood control, and wastes transportation. General statements might be made about the quality of water required for each of these benefits, but they would be relatively meaningless from a practical viewpoint. Specifically, the quality control measures necessary to protect other beneficial uses today would become overriding long before metal ships are cut off at the waterline or turbine runners are converted to lace--although both have happened in the past. The same may be said for water used as a transport system. If transport were the only objective a fluidity adequate to insure downhill movement a bit faster than molasses is about all that is required. And quality as a factor in flood control is essentially meaningless.

Therefore, these uses are not discussed here in detail. Instead, attention is directed to the following summary sheet from McKee and Wolf (4) which lists the principal objectives and treatment requirements appropriate to the major beneficial uses.

TABLE 3-4

WATER QUALITY OBJECTIVES AND MINIMUM TREATMENT REQUIREMENTS

Water Quality Objectives, Applicable to Receiving Waters, for Salt and Fresh Surface Waters and Underground Waters

Water quality → water uses ↓	Organisms of the coliform group	Floating, suspended & settleable solids & sludge deposits	Taste- or odor-producing substances	Dissolved oxygen	pH	Toxic, colored, or other deleterious substances	Phenolic compounds	Oil	High temperature wastes	Minimum treatment requirements for domestic sewage
A. WATER SUPPLY, DRINKING, CULINARY & FOOD PROCESSING Without treatment other than simple disinfection and removal of naturally present impurities	Most probable number coliform bacterial content of a representative number of samples should average less than 50 per 100 ml. in any month	None attributable to sewage, industrial wastes or other wastes or which, after reasonable dilution & mixture with receiving waters, interfere with the best use of these waters for the purpose indicated	None attributable to sewage, industrial wastes, or other wastes	Greater than five (5) parts per million except for underground waters	Hydrogen ion concentration expressed as pH should be maintained between 6.5 and 8.5	None alone or in combination with other substances or wastes in sufficient amounts or of such nature as to make receiving water unsafe or unsuitable for use indicated (U.S.P.H.S. Stds.)	Less than five (5) parts per billion	None	Not in sufficient quantity alone or in combination with other wastes to interfere with the use indicated	Sedimentation and effective disinfection
B. WATER SUPPLY, DRINKING, CULINARY & FOOD PROCESSING With treatment equal to coagulation, sedimentation, filtration, disinfection and any additional treatment necessary for removing naturally present impurities	M.P.N. coliform bacterial content when associated with domestic sewage of a representative number of samples should average less than 2000 per 100 ml. and should not exceed this number in more than 20 per cent of samples examined in any month	Same as for use "A" above	None attributable to sewage, industrial wastes, or other wastes which, after reasonable dilution & mixture, will increase the threshold odor number above eight (8)	Greater than five (5) parts per million except for underground waters	Same as for use "A" above	Same as for use "A" above	Less than five (5) parts per billion	None alone or in combination with other substances or wastes as to make receiving water unfit or unsafe for the use indicated	Same as for use "A" above	Sedimentation and effective disinfection
C. BATHING, SWIMMING AND RECREATION Notes: When waters are used for recreational purposes such as fishing & boating, exclusive of bathing & swimming, the number "1000" may be substituted for "500" in statement of coliform objective	Coliform bacterial content of a representative number of samples should average less than 240 per 100 ml. and should not exceed this number in more than 20 per cent of samples examined when associated with domestic sewage (see note under "C" at left)	Same as for use "A" above	None attributable to sewage, industrial wastes, or other wastes which, after reasonable dilution & mixture, will interfere with the best use of these waters for the purposes indicated	Greater than five (5) parts per million	Same as for Use "A" above	Same as for Use "A" above	Less than 25 parts per billion or none in sufficient amounts such as to impart a residual taste to recreational or commercial fish, shellfish, or other aquatic forms	Same as for use "B" above	Same as for use "A" above	Sedimentation and effective disinfection
D. GROWTH & PROPAGATION OF FISH, SHELLFISH & OTHER AQUATIC LIFE	Coliform bacterial content of a representative number of samples should not have a median concentration greater than 76 per 100 ml. in waters used for the growth & propagation of shellfish	Same as for use "A" above	None attributable to sewage, industrial wastes, or other wastes which will interfere with the marketability or propagation of recreational or commercial fish, shellfish, or other edible aquatic forms	Greater than six (6) parts per million	Same as for use "A" above	None alone or in combination with other substances or wastes in sufficient amount or of such character as to make receiving waters unsafe or unsuitable for use indicated	Same as for use "C" above	Same as for use "B" above	Not in sufficient quantity as to be injurious to or interfere with the normal propagation of fish, shellfish, or other aquatic life	Sedimentation for all uses under this group but disinfection required in addition only if discharged into waters used for the growth & propagation of shellfish, either commercial or recreational
E. AGRICULTURAL AND INDUSTRIAL WATER SUPPLY Without treatment except for the removal of natural impurities to meet special quality requirements, other than those indicated under "A" above. Notes: For agricultural water supply, salinity and sodium hazards are determined by electrical conductivity (EC x 10 ³) and sodium adsorption ratio (SAR). Waters with EC x 10 ³ values and SAR values which are generally unsuitable for irrigation purposes are those having EC x 10 ³ values greater than 2.5 and SAR values greater than 13.		Same as for use "A" above	None attributable to sewage, industrial wastes, or other wastes which will adversely affect the marketability of agricultural or industrial produce	Greater than three (3) parts per million	Hydrogen ion concentration expressed as pH should be maintained between 6.0 & 9.5	Same as for use "A" above	None in sufficient quantity as to make receiving water unsuitable for use indicated	Same as for use "B" above	Same as for use "A" above	Sedimentation and effective disinfection

References

1. American Water Works Association. Water Quality and Treatment. A Manual. American Water Works Association, Inc., New York, 1950.
2. Eldridge, Edward F. Return Irrigation Water, Characteristics and Effects. U. S. Public Health Service, Region IX, May 1, 1960.
3. Klein, Louis, River Pollution. 2: Causes and Effects. Butterworths, Inc., Washington, D. C., 1962.
4. McKee, J. E., and H. W. Wolf. Water Quality Criteria. 2nd ed. Report to California State Water Quality Control Board (SWQCB Publication 3A.) 1963.
5. U. S. Public Health Service. Proceedings, Conference on Physiological Aspects of Water Quality, Washington, D. C., September 8-9, 1960. U. S. Public Health Service, Division of Water Supply and Pollution Control, 1960.
6. U. S. Public Health Service. Drinking Water Standards. 1962.
7. U. S. Public Health Service. Biological Problems in Water Pollution. 3rd Seminar, August 13-17, 1962. Public Health Service Publication No. 999-WP-25, Robert A. Taft Engineering Center, 1965.
8. Wilcox, L. V., and O. C. Magistad. Interpretations of Analysis of Irrigation Waters and the Relative Tolerance of Crop Plants. U. S. Department of Agriculture, Regional Salinity Laboratory, Riverside, California, April 1, 1944. Mimeo.

EUTROPHICATION OF SURFACE WATERS:
THE EFFECT OF NUTRIENTS
(1) (2) (3) (4)

Introduction

In a previous lecture it was pointed out that under "wilderness " conditions mineral salts brought in from weathered soil, plus degradable organic matter of terrestrial and aquatic origin, furnish the nutrients which support the normal aquatic food chain. It was particularly noted that such materials seldom are present in sufficient concentrations to lead to anaerobic conditions. This is to say that the amount of mineral and organic matter is the limiting factor in the abundance of aquatic life. And whenever such factor is limiting, the system is nutrient sensitive and can be expected to react quickly to the addition of fertilizer compounds at a low energy level; or to change in population characteristics if the compounds enter at a high energy level. In terms of the aerobic cycle of growth and decay, it is the left-hand half of the cycle which reacts first to the introduction of stable nutrients, whereas the right hand sector will be first to react to unstable organic materials possibly going into the anaerobic cycle with catastrophe to the aquatic society.

Highly treated domestic and organic industrial wastes; return water from irrigated agriculture; and runoff from farm land, golf courses, lawns, and other land areas to which commercial fertilizer is applied are the principal outside sources of the bio-chemically stable nutrients entering surface waters. Exerting little or no BOD, these compounds have the effect of enriching the aquatic life. Incompletely treated domestic and organic industrial waste waters, surface wash from vegetated land and from organic swamps, and dead aquatic organisms within the receiving water itself are the principal sources of unstable organic matter which must first be degraded through an oxygen-demanding process before they appear as nutrients to other than the microbial population of the water.

Eutrophication of Lakes and Rivers

It is reported that the Swedish biologist, Neuman, in 1919 was first to designate nutrient-poor waters as "oligotrophic" and nutrient-rich waters as "eutrophic." Utilizing Neumann's concept, the term "eutrophication" may be used to describe the process of maturation of a lake from a nutrient-poor to a nutrient-rich body of water. The "wilderness" lake in its early years is almost universally oligotrophic, unless it is created in an organic swamp. If it is of appreciable size and depth so that the inflow-outflow relationships are small in comparison with the volume of the lake, many centuries may be required for the organic buildup to reach such proportions that the lake is nutrient rich and continues to remain so through recycling of nutrients regardless of the relatively small annual influent of such materials. In other words, eutrophication, although the ultimate destiny of a lake, may be very slow in developing. If, however, artificial enrichment occurs as a result of human activities, lakes may become eutrophic within a very short period of time.

Thomas (4) notes that "In northern Switzerland... all lakes of 20 meters depth or more with at least 500,000 square meters of surface area belonged to oligotrophic types until a few decades ago... Today most of these lakes are in a eutrophic state as a result of artificial fertilization."

An extensive list of lakes showing early eutrophy was published by Hasler in 1947. A partial summary of this list is given in the table on page 120 (1). It includes lakes ranging from 286.1 to 0.18 square miles in surface area and from 414 to 4.2 meters in depth.

The advance of eutrophication of a lake receiving artificial fertilization is dramatically demonstrated by Zurichsee in Switzerland. It consists of two basins--the Obersee and the Untersee--separated by a narrow passage. Hasler (1) states that in the past fifty years "The Untersee, the deeper of the two basins, at one time a decidedly

List of Lakes Showing Early Eutrophy owing to Domestic Drainage (1)

Lake	Area in Sq. Miles	Max. Depth in Meters
Alpine Lakes		
Zurichsee (Unter)	25.86	143
Hallwilersee	3.90	48
Rotsee	0.18	26
Zugersee	15.01	198
Murtenersee	8.81	46
Freifensee	0.33	35
Worthersee	7.50	85
Lago di Como	56.33	414
Finnish Lakes		
Lohjanjarvi	47.10	56
Vesijarvi	56.37	40
Mommilanjarvi	1.46	100
Lehijarvi	286.10	19
England		
Windermere	5.72	67
United States		
Mendota (Wisconsin)	15.20	25.6
Wingra "	0.31	4.2
Monona "	5.44	22.5
Waubesa "	3.18	11.1
Kegonsa "	4.91	9.6
Geneva "	8.53	43.2
Delavan "	2.83	17.2
Nagawicka "	1.43	28.8
Pewaukee "	3.59	13.8
Lake Washington (Wash.)	33.83	65.2

oligotrophic lake, has become a strongly eutrophic lake apparently owing to urban effluents originating from a group of small communities (the city of Zurich is located at the downstream end of the lake but contributes no sewage). The shallower of the two received no major urban drainage and has retained its oligotrophic characteristics."

Objections to Eutrophication

Implied, if not indeed explicitly, in the foregoing paragraphs is the concept that eutrophication, like sin, is something to be abhorred by all right-minded water resources management people. What, in terms of water quality, do we have to lose by accelerating the natural process of nutrient buildup in ponded waters? To answer this question it is only necessary to consider the quality characteristics of a lake water before and after it has become eutrophied.

Large lakes in their original or "wilderness" state have, as Thomas (4) explains, a very large volume of water in the hypolimnion (zone of stagnant water). Characteristically such lakes appear blue or greenish blue, the water is clear and transparent, and the phosphorus content of the water is so low that plants cannot make use of all the available nitrogen. "There is only a quantitatively moderate development of phytoplankton organisms even in the surface water, and littoral plant production is also slight. The high permeability of light prevents the formation of a distinct thermocline and provides the plants with good conditions for development even at great depths."

In such lakes the alkalinity and dissolved oxygen vary but little from top to bottom and there is no production of ammonia, hydrogen sulfide, or other gases of decomposition in the depths. Although some of these conditions are conducive to organic growth, nutrients are the limiting factor; hence, the production of plants and phytoplankton is slight during the entire year. In contrast the deep fauna is comparatively rich, whitefish (*Coregonen*) being the predominant

species. The fall overturn of such a lake would produce none of the adverse quality conditions discussed in a previous section.

It should be pointed out that small lakes, even in the original state may be subject to the seasonal low quality limitations described in a previous section. In them the ratio of water volume to influent organic matter--leaves, surface wash, pollen grains, insects, etc.,--may be quite small, leading to anaerobic conditions in the depths and to quality degradation previously described in connection with the turnover of reservoirs.

The objections to eutrophication, however, are not limited to the degradation of the quality of stratified water. The nutrient substances present in sewage effluents frequently lead to the production of explosive "blooms" of algae of such intensity that clear sparkling lakes are transformed to turbid colored bodies of water. Decomposition of the algae then produce obnoxious odors and floating decomposing mats of organic matter. Thomas (4) graphically describes the conditions in these terms: "Plankton algae make the water turbid and discolored with unpleasant shades of green, yellow, brown, and violet. The floating layers of plankton algae are particularly disagreeable to swimmers, boaters, fishermen, inhabitants of the banks, and people walking nearby. Shore algae also are often unpleasant."

He goes on to describe the growths of diatoms on stones in eutrophied Swiss lakes, and the masses of Oscillatoria which overgrow the mud or lake chalk bottom of the shallows. Part of the oxygen from this growth is held back in the tangled mass of algal filaments. "These gas bubbles finally result in patches larger than hand size being detached from the bottom so that they float on the surface and form repulsive flat cakes there that look like the skin of a toad. This unpleasant phenomenon is overcome only by rain and wind in April or May. The original biotopes of the 'toad's skin' are then overgrown by other algae ... which then rise to the surface of the lake in summer and disfigure

the shores." He describes in detail the coating of stones in water 0 to 3 meters deep with diatoms and algal filaments to a depth of several centimeters. Algal pads of Cladophora rise to the surface annoying everyone who comes in contact with them. In Lake Zurich such masses constrain the natural motion of reeds in the wind with the result that the reeds break at the surface of the restraining mat and themselves contribute to a mass of decomposing organic matter. The result is a situation disadvantageous to fishermen, aesthetically objectionable to the public, and conducive to gasses of decomposition such as hydrogen sulfide which are in themselves objectionable.

The fish population of sewage fertilized, i. e., eutrophied, lakes has been observed to change from whitefish to coarser species. In the United States eutrophication of lakes has caused great concern. The lakes at Madison, Wisconsin, and Lake Washington at Seattle have probably been given widest publicity. More recently national attention has been drawn to Lake Tahoe, one of the finest of the few remaining non-eutrophic lakes in the world, where the problem of managing man's occupancy of the lake basin without creating the conditions which would lead to early eutrophication of the lake present some unique problems.

Concerning the Wisconsin lakes, Rohlich (1) has noted that: "As early as 1882, algal blooms were reported as having occurred in Lake Mendota and Monona. . . . Over a period of more than twenty-five years argument and debate continued in regard to the odor nuisances, the fertilization of lakes, and the extensive algae growths."

In the case of Lake Washington it remained a relatively clear oligotrophic lake until quite recently. Anderson (1) noted that since 1950 "prominent changes have occurred, particularly in 1955 when for the first time there appeared an increased growth of phytoplankton made up mainly by the blue-green alga Oscillatoria rubescens, a notorious indicator of pollution in many lakes." He points out that

since 1955 the annual crop of algae has increased with the result that with "the increase in productivity the transparency of the water has decreased and oxygen consumption and nutrient release in the hypolimnion (zone of stagnation) during summer stratification has progressively increased." The oxygen deficit has increased threefold in the depths since 1933 and in 1957 the deepest waters became anaerobic for a short period for the first time.

The consequences of enrichment of rivers are similar to those of lakes in their effects upon beneficial use. In the "wilderness" state there are sufficient nutrients brought into the stream to support aquatic life without detracting from the appearance and other qualities of the water. In fact a river in its original state is suitable for fishing, swimming, and development for public water supply. Enrichment of such stream has little effect on the reaches where velocity is high. In the pools and quiescent zones, however, algae and higher aquatic plants soon develop. A thick growth of weeds depreciates the sport of fishing. Swimming is impossible. And tastes, odors, and other factors compound the problem of reclaiming it for water supply.

Exclusion of further nutrient discharges to a river will result in its reverting in time to its original state of nutrient limited aquatic life. The lake, however, is essentially irreversible because of recycling of nutrients. Solar energy is the only input needed to keep the cycle going indefinitely, since the normal influx of fertilizer compounds is more than enough to offset the discharge losses. As previously noted, there is a slow accumulation of nutrients in a lake even under wilderness conditions, but "instant eutrophication" is the result of human activities.

Factors Influencing Eutrophication

Although the amount of nutrients is an influencing factor, there is no simple relationship between the maturing process of a lake and the amount of nutrients present in its waters. The rate at which eutrophication

occurs is governed by a combination of factors related in a complex fashion which is not fully understood. Nevertheless, there is no doubt that urban drainage is one of the most critical factors. Rohlich (1) has noted that: "Essentially all climatic, physical, and biological factors have an influence on the eutrophication process particularly as they relate to the distribution, availability, and utilization of the nutrients required by the algae in their metabolism." Rawson (1) stresses the complexity of the relationship of environmental factors which lead to eutrophication of lakes. Geology, geometry of the lake, temperature, dissolved oxygen, pH, calcium, iron, nitrogen, phosphorus, silica, and organic material seem all to be involved in a complex fashion of unknown nature. Sawyer (1) and others, however, stress the predominance of nitrogen compounds and phosphorus as determinants of algal blooms. In a report authored by Sawyer and Lackey in 1943 (See reference 1), nitrogen and phosphorus were identified as the culprits in the eutrophication of the Madison lakes, the major source for Lake Mendota being the disposal plant for the city of Madison. The report further stated that "inorganic nitrogen and phosphorus were found to be critical factors in the productivity of the lakes, and that for during the year 1942-1943, Lake Waubesa, the most heavily fertilized lake in the survey, at least 65 percent of the inorganic nitrogen and 89 percent of the inorganic phosphorus entering the lake were derived from non-agricultural drainage." Later studies by other observers in 1949 found the less frequent blooms in Lake Mendota, in comparison with its companion lakes, to be related to its lesser intake of nutrients. However, there are sufficient inputs from non-urban sources to produce algal blooms in the lake when other environmental factors are favorable.

Rohlich (1) calls attention to another case in which algal blooms are not triggered by the return waters from irrigation, industry, or cities. This is the upper Klamath Lake which for sixty years has

developed unsightly and offensive smelling conditions each summer. "The precise explanation," Rohlich notes, "for the unusually high productivity is as yet not fully explained, but it was noted that the drainage water from 92,000 acres of muck soil agricultural land which has been drained and diked as well as drainage from 136,000 acres of essentially natural marsh land contains humic leachates from the marsh soil, and analysis of the leachate shows that the nitrogen content in summer is more than double that in the winter. Algae culture studies using media enriched with humic water showed that the production, measured by weight of algae, was 70 percent greater in the humic-enriched cultures than in the unmodified controls."

Thomas (4) reported results of experiments in which nitrogen and phosphorus were added to samples of water from forty-six different lakes, in the amounts of 20 mg/l nitrogen and 2 mg/l phosphorus. Over a two-month period the plankton had greatly increased in all cases. The results demonstrated that "only nitrates and phosphates come into question as minimum substances in such lakes...the addition of nitrogen and phosphorus compounds to lakes and rivers is sufficient to stimulate some types of algae to greatly increased growth, which can, however, have very detrimental results."

Maloney (4) of the U. S. Public Health Service attempted to determine the minimum concentrations of nutrients necessary to support the growth of algae. His tentative conclusions were that nitrogen should be below 0.1 mg/l and phosphorus below 0.01 mg/l, with essentially no iron present if nutrient scarcity is to prevent algal growth. Similar conclusions have been reached by other observers (1).

It is generally conceded today that phosphorus is more important than nitrogen in causing algal blooms. In fact, an algal bloom may result from excess phosphate out of all scale with the normal ratio of nitrogen to phosphorus in plant growth. This is the result of the development of types of algae which can fix nitrogen from the atmosphere provided there is plenty of available phosphate.

The Problem of the Engineer

The entire concept upon which treatment of domestic wastes has been predicated is the matter of BOD reduction. Standards, of course, specify a limit on suspended solids as well, but the sewage treatment process has been built around satisfying the oxygen demand of degradable organic matter before releasing domestic waste water to the resource pool. This simply means that the right half of the aerobic cycle of growth and decay must be more nearly completed by the treatment process as the demand for higher and higher quality of effluent is imposed by regulatory agencies. Until quite recently, however, the prevention of eutrophication of receiving waters has not been considered as an objective of sewage treatment, nor has it been a goal of water quality regulation. Historically each time the water quality objectives have been tightened, the discharger of organic wastes was required to bring the state of nitrogen and phosphates in his effluent nearer to that of stable inorganic nitrates and phosphates. Within the past two or three years, however, pollution control agencies notably in the eastern and southern United States, have begun to set receiving water standards which simply cannot be met by extending the degree of oxidation of nitrogen and phosphorus in the discharge. It is not clear whether the regulatory agencies are aware of this, but the consulting engineer confronted with a requirement that cannot be met because organisms are quite as happy with nitrate as with ammonia is in a quandry. We have simply not yet come up with any technologically and economically feasible method of nitrogen removal, nor has nitrogen removal been generally recognized as an objective of waste treatment. Deionizing of water, distillation, anaerobic fermentation with denitrification, and other procedures can, of course, remove nitrogen. However, the parameters necessary to design engineering systems, as well as the economics of such systems, have yet to be developed.

A similar problem exists in the case of phosphates. Phosphate

removal methods were developed and published more than a dozen years ago. Currently, one installation based on the method of phosphate removal by alum precipitation is going into operation in the Lake Tahoe basin on what is patently an experimental basis as far as operational parameters and economics are concerned. Although techniques for removing phosphorus have been developed, some very difficult problems may arise if phosphate removal becomes an objective of waste water treatment. To a large degree these relate to the sources of phosphorus in sewage.

Phosphorus finds its way into domestic wastes via a number of routes. As previously noted, phosphates are concentrated in the leaves of growing plants; thus the household garbage grinder introduces a portion of the phosphate content of sewage. Milk contains an important amount of phosphorus, and the use of milk on a large scale in the diet of Americans makes an important contribution of this element to the waste waters. The builder in the more than four billion pounds of synthetic detergents sold each year in the United States is phosphates. In fact, possibly 30 to 50 percent of the phosphorus content of sewage comes from household detergents. There are already indications that within a year or two phosphates rather than ABS may be the whipping boy of the public. This time, however, industry cannot respond in the fashion it did when the nuisance of ABS froth on water was abhorred by the public by rearranging the carbon atoms in the molecule. There is no known way to formulate detergents without phosphates, nor does there appear to be any satisfactory answer beyond phosphate removal--a prospect which under current costs may well confront the public with some difficult choices along the road to its goal of "unpolluted," "pure," or "clean" water.

There are other ways than nutrient removal from sewage which might theoretically overcome the eutrophication of lakes, but they do not seem of practical importance. Such things as harvesting of fish crops, removal of algal growths and plants from lakes, siphoning off deep water from lakes to remove the nutrients produced by bio-degradation of organic matter,

artificial aeration of deep water, and chemical poisoning of algae are among the expedients sometimes suggested. While each of these techniques may have some role in the management of water quality, control of eutrophication by engineered systems must either involve prevention of sewage discharges or nutrient removal from the waste water in the long run. Expedients might then be helpful in re-establishing oligotrophic conditions in certain instances, but in general the control of aquatic growths must depend upon nutrient removal before a waste water is returned to the fresh water resource pool.

References

1. Engineering Science, Inc. Lake Tahoe Waste Disposal Study. Arcadia, California, 1963.
2. Klein, Louis. River Pollution. 2: Causes and Effects. Butterworths, Inc., Washington, D. C., 1962.
3. Lee, W. L., G. A. Rohlich, and W. J. Katz. "Removal of Phosphates from Treated Sewage." Sewage and Industrial Wastes 26: 261-275. 1954.
4. U. S. Public Health Service. Biological Problems in Water Pollution. 3rd Seminar, August 13-17, 1962. Public Health Service Publication No. 999-WP-25. Robert A. Taft Engineering Center, 1965.

XI

PESTICIDES AS A FACTOR IN WATER QUALITY

Introduction

The question of the role of synthetic organic pesticides in the environment first came to widespread public attention with the publication of Rachael Carson's "Silent Spring" in 1962. Since that time savant and "true-believer" alike have repeatedly been heard from in public print. Although a full discussion, or even a fully documented expression of opinion or prejudice, is beyond the scope of this discussion, it might be well to give some scale and concept to the problem as it concerns the quality of our water resource.

In spite of alarmist reports, synthetic organic pesticides are not commonly used with reckless abandon. Nevertheless, the objectives of use of pesticides have generally been limited to quite narrow concepts. That is, not enough thought has been given to the shift in equilibria which must necessarily follow the upsetting of an existing one. It is in this fact that a real danger of unknown consequences lies. Specifically, in rationalizing the use of synthetic pesticides only two ecological streams seem to have been considered--man and his insect and botanical enemies. What might be the effects of introducing pesticides into other ecological streams which bear less direct, but eventually profound, effects on man, is the great unknown factor which we can ill afford to ignore.

Toxicity of Pesticides

There is no doubt that pesticides of several varieties have extremely high indices of toxicity--that is, the purpose for which they were created. Of the pesticides, the herbicides have given least concern in terms of water quality, although some can damage plants at a distance when they migrate through soil with percolating water. However, by far the most important are the insecticides which in some cases have contaminated irrigation water long after the chemical has been applied.

Most of the modern insecticides fall into two broad classes, the chlorinated hydrocarbons and the organic phosphates. The former include such materials as DDT, BHC, and dieldrin, endrin, heptachlor, toxaphene, TDE, aldrin, methoxychlor, and chlordane. Such compounds are often thought to have the greatest potential for damaging the water resource because of their long residual activity. On the other hand, their low solubility in water is an offsetting factor and hence the true significance of insecticides on agricultural soils or forest plants is difficult to assess in terms of water quality.

The organic phosphate insecticides are believed to be less dangerous to fish than the chlorinated hydrocarbons because they are less stable, some breaking down quickly in water. Examples of organic phosphates include malathion, parathion, TEPP, EPN, chlorthion, diazinon, quthion, dipterex, and demeton.

Of the hydrocarbons endrin appears to be the most toxic, and TDE and BHC the least toxic to fishes. Of the phosphates quthion seems by are the most toxic.

Lethal concentrations observed in experiments have been presented in a preceding section in a table from Klein's book (pages 110-114).

The Scale of Production and Use

In 1960 there were more than 100 organic insecticides available. Estimates of production range from 500 to 1000 x 10⁶ pounds of organic pesticides, plus 1 x 10⁶ pounds of non-organics (e. g., arsenals, Cu and Zn sulfate, etc.) annually. Similar estimates of the acres of land to which pesticides were applied in 1959 range from 100 x 10⁶, or about 5 percent of the United States, to 30 x 10⁶ acres sprayed at least two times each year.

How Pesticidal Water Pollution Might Occur

There are several ways in which pesticides, particularly

insecticides, might find their way into the fresh water resource:

1. By surface wash or runoff into streams
2. By movement with percolating water into ground waters.
3. By direct application to bodies of water for pest control
4. By drifting onto surface waters from adjoining treated areas
5. By return irrigation waters
6. By spills and wastes from pesticide manufacturing
7. From cannery and other food processing waste waters

Evidence of Danger to Water Quality

DDT in concentrations of 5 to 20 parts per billion (ppb) has been observed in the Detroit, Missouri, Mississippi, and Columbia Rivers. Aldrin at a concentration of 1 ppb was found in the Snake River. As early as 1950, fish were decimated in fifteen streams tributary to the Tennessee River in Alabama by an insecticide applied over a wide area. In 1953, sanitary engineers from the Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service recovered DDT from the Detroit River and St. Clair Lake in both raw and treated water. DDT was present in the Detroit River and persisted in samples taken over a six-month period.

In 1955, in St. Lucie County, Florida, 2000 acres of salt marsh were treated for the sandfly larvae by the application of dieldrin at a rate of one pound per acre. It is estimated that 20 to 30 tons of fish were killed in canals bisecting the marshes.

TDE used to control the Clear Lake gnat on a lake of the same name in California appears to have led to the death of hundreds of grebes. Samples of fat from one bird showed a high concentration of the chemical. Similarly, samples of visceral fat from several species of fish taken over a period of six to eight months after the last spraying showed from 40 to 2000 mg/l of TDE.

Recent observations in widely separated incidents suggest the

probability that DDT now pervades the entire aquatic environment of the earth. It has been found in local fishes 2000 miles from land in the Pacific Ocean. My own laboratory has sought unsuccessfully to find cultures of Chlorella that are DDT free. Even pure cultures nurtured for hundreds of generations in laboratories are found to contain measurable quantities of DDT.

Tarswell and Henderson of the U. S. Public Health Service have described a runoff study conducted near Atlanta, Georgia. Here 4.66 pounds of dieldrin were applied per acre of grassland to control white fringed beetle. Bio-assays showed that the first runoff from rain was toxic to fathead minnows in dilutions of one to three. On the third rain fish mortality was less than 50 percent. The concentrations of dieldrin were estimated at 0.128 mg/l. Evidently only a small fraction of the chemical was washed out by the rain. It is not known whether the remainder was lost by weathering or remained in the soil to be washed out by future rains.

Walton of the U. S. Public Health Service has described a case of underground water pollution near Henderson, Colorado. Groundwater contaminated by arsenals which eventually formed 2-4-d traveled some three miles in eight years to affect crops. Seven years later some sixty square miles had been affected seriously.

At Montebello, California, seepage of 2-4-d from a manufacturing plant contaminated the city's water supply. The plant was shut down within thirty days but taste and odor persisted in the water for five years.

Various similar instances of water pollution by pesticides are to be found in the literature.

Significance of Findings

Although the potential of water pollution by pesticides can be shown by theoretical considerations and actual incidents to be worthy of

deep concern, it must be recognized that the known deleterious effects on aquatic life are quite small considering the quantity and extent of use of pesticides in the United States. It is therefore necessary to consider the relation between the risks and the benefits to be derived from the use of pesticides. It is impossible to gainsay that modern agriculture's ability to feed an opulent society would certainly fail if it were necessary to return to the "man with the hoe" to control weeds, or to compete with insects for the wormy apple or the tassel end of every ear of corn. There is only one instance on record where grasshoppers were cut down by the sea gulls. On countless occasions they have taken a serious toll. I recall one season in my own boyhood when every head of wheat at harvest time enshrined one or two grasshoppers. As the mower sickle toppled the stalk, these fellows took wing to rush forward to occupy as yet undisturbed grain. This somewhat unintelligent routine eventually led to their physical exhaustion and when the wheat was in the granary it consisted of about one part fried grasshopper to ten parts of grain.

In California, weeds are cut and insect pests controlled by aeroplane dusting. The same is true elsewhere in America. The integrity of U. S. forests depends upon similar procedures. In 1963 a representative of the University of California Agricultural Extension Service estimated that 90 percent of the food grown by man could be destroyed by pests if continual wars were not waged against the pests.

It is my personal judgment, therefore, that the calculated risk is worth the toll that may occasionally be taken of aquatic life as a result of the use of synthetic pesticides. However, we must devote a greater amount of effort to a determination of just how to calculate this risk, and to reduce it by the production of time-unstable compounds that will do their appointed task and then decay prior to reaching the water resource pool.

References

1. California League of Commerce. "Agriculture and Industry." Bulletin, California State Chamber of Commerce, November 1963.
2. Egler, Frank E. "Pesticides in our Ecosystem." American Scientist 52(1):111-136. 1964.
3. Klein, Louis. River Pollution. 2: Causes and Effects. Butterworths, Inc., Washington, D. C., 1962.
4. O'Donnell, R. M. Review of the Effects of Pesticides upon Water Pollution. Unpublished paper, University of California, January 24, 1961.
5. U. S. Public Health Service. Proceedings, Conference on Physiological Aspects of Water Quality, Washington, D. C., September 8-9, 1960. Division of Water Supply and Pollution Control, 1960.
6. U. S. Public Health Service. Proceedings, National Conference on Water Pollution, December 12-14, 1960. Washington, D. C.
7. U. S. Senate. Select Committee. Water Resources Activities in the United States. Pollution Abatement. Print No. 9, 86th Congress, 2nd Session, 1960.

PART II

XII

WASTE WATER TREATMENT AND DISPOSAL BY SOIL SYSTEMS
(2) (3) (4) (5)Introduction

The existence and replenishment of groundwater as a geological and hydrological phenomenon demonstrates that it is possible to infiltrate water into the soil surface and for it to percolate through unsaturated soil or be translated laterally through aquifers. Furthermore, the relative absence of bacteria and suspended solids in spring and well waters gives us advance notice of important phenomena relative to pollution travel. There are several other phenomena from which we may draw lessons regarding the surface and subsurface introduction of water into the soil mantle of the earth.

1. Surface runoff during rainfall forewarns that infiltration rates have some finite limit.
2. Failure of intense short-duration rains to wet dry soils to any appreciable depth reveals the factor of air-locking or gas-binding.
3. A pond can be created only by applying water to the soil at a rate in excess of its infiltrative capacity, hence ponding, whether in a trench or on the surface, bespeaks either a temporary or a permanent overloading of the soil.
4. It is possible, as demonstrated by the engineering science of soil mechanics, to rearrange soil particles and control soil moisture in such a way as to make a soil essentially water tight. Inadvertant management of a soil system can result in loss of infiltrative or percolative capacity in accord with the same laws.

Unfortunately, man's record of comprehension of the implications of these facts does him little credit. For example, in spite of the fact that rain has been falling through the bacteria-laden atmosphere and passing through the biologically active zone of the earth for centuries,

only to return to the surface bacteria free, we have assumed that bacteria may travel freely with percolating water. And to protect ourselves from this assumption, every state has passed laws prohibiting the introduction into the groundwater, in any systematic engineered way, waste water of a quality unsuited for public supply. Haphazard ignorant discharges via septic tanks was not included in the concept. There are, however, several reasons why such laws were formulated and interpreted as they were.

1. Lack of scientific knowledge of the behavior of bacteria in soils in relation to percolating water.
2. The need for large factors of safety (ten or more) where health considerations are involved and no precise knowledge exists.
3. The certainty that in fractured and fissured rock, in dissolution caverns and channels in limestone, and in very coarse materials bacteria do indeed travel freely with moving water.
4. The problem of enforcement and administration of the law. Specifically: If the law is to differentiate between underground conditions where bacterial travel is and is not a hazard, a whole set of guides, parameters, and "thou-shalt-nots" have to be spelled out; a permit system has to be established, and staff, budget, and procedure set up for managing the system.

The simplest, and perhaps wisest, course was to prohibit all groundwater recharge with unpotable water. The difficulty is that there has developed in the semi-arid southwest a compelling need to salvage the water fraction of domestic and industrial wastes which is hindered by continued adherence to laws based upon erroneous assumption but adhered to on the rationale of convenience of enforcement.

However, leaving for a moment the matter of pollution travel, let us look into the matter of ground disposal of waste water in a systematic manner.

Ground Disposal or Recharge

Disposal of waste waters to the soil has been undertaken for several purposes:

1. Reclamation, salvage, and storage of:
 - (a) Flood water
 - (b) Stabilization pond effluent
 - (c) Secondary sewage plant effluents
2. Utilization of underground storage capacity

(These two purposes I shall discuss further in relation to the subject of water reclamation.)

3. Convenient method of making possible the use of pressure water systems in homes remote from public sewers
 - (a) Rural homes (originally)
 - (b) Urban and suburban subdivisions (since World War II)

(In the first case, necessity was the compelling factor. In the second, low cost, lack of legal restraints, ease of supplying pressured water, difficulty of ownership and management of community sewage treatment systems, etc., were the compelling factors.)

4. Use of soil mantle of the earth as an engineered waste water treatment system with objectives of:
 - (a) Protecting groundwater quality
 - (b) Reclaiming or conserving water

Types of Engineering Problems Investigated

In relation to ground disposal or recharge of waste waters two types of engineering problems have been investigated:

1. How to get water into the soil at a maximum rate
2. How to achieve optimum quality change

The first of these two objectives has been given the most attention for obvious reasons. First, man cannot afford to sprinkle a relatively small amount of water over a vast area. Besides he is

greedy. Consequently he has sought to inject water into the earth continuously and at rates vastly greater than occur in nature. The dimension of his failure has called attention to the lessons to be learned from nature, which are summarized in the introduction to this section.

Attention to the second type of problem began with a study of the travel of pollution intended to determine what types of pollutants travel with underground waters and under what conditions. Currently, the inverse of this objective is being studied, i. e., the management of the soil mantle to produce an optimum change in water quality. The rationale here involved derives from two important points of view:

1. Given a quality of groundwater to be preserved, what quality of water, and hence what degree of pre-treatment, may be applied to the soil surface without endangering the quality objective. (Laws have said no application unless suited to groundwater quality.)
2. Given an applied water of certain quality aspects, what will be the quality of that same water upon reaching the groundwater table.

Types of Systems

The types of engineered systems which may be utilized for ground disposal of waste waters include:

1. Surface infiltration ponds or trenches
2. Subsurface percolation systems
 - (a) Narrow trench
 - (b) Wide trench (seepage bed)
 - (c) Seepage pit
3. Sand filters (effluent returned to the surface)

Fundamental Principles of Spreading Ponds

Before undertaking a discussion of engineered or haphazard systems, let us first take a look at what has research taught us of the fundamental

principles of ground disposal or recharge of waste waters.

It is obvious to even the most casual observer that in order to create a pond it is necessary to apply water to soil faster than the soil can accept it and transport it away. The phenomena involved, however, are far from obvious, yet the whole problem of disposing of water successfully by use of spreading or percolation ponds hinges upon a knowledge of these phenomena and the methods of operation required to manage them in a particular situation.

Of course, if water is to be disposed of by percolation it must be applied to a soil that is pervious enough to carry it away at an acceptable rate. It is well known that clays are quite watertight and hence unsuitable for percolation beds, whereas coarse gravel may accept water at such a rate that ponding of applied water may not occur. Curiously enough, the porosity of the two media may be quite similar; it is their perviousness that is different. For practical purposes these two terms may be defined as follows:

Porosity is the percentage of a material that is void space.

Perviousness is the size of the void spaces.

Perviousness of a soil to which water is to be disposed is important for two major reasons:

1. It controls the maximum rate at which water can percolate downward to the water table, or be translated laterally as moving groundwater.
2. It controls the minimum elevation of the pond bottom above the water table in any soil having pore spaces small enough to establish surface tension of water across the pore as a significant force. Specifically, the water table must be located far enough below the pond bottom that the pond and the soil itself will drain when no more water is added to the pond. If such is not the case a column of water will remain in the soil pores suspended by the surface tension of water

across the pores. This, as explained later, is catastrophic to the percolative system. In good agricultural soils in California this distance is of the order of 2 to 2-1/2 feet. In coarse gravel it is zero and in clays it is infinity.

To understand the behavior of a spreading pond or any inundated pervious soil, two additional concepts should be clearly defined:

The infiltrative capacity of a soil is the rate at which liquid will pass through the soil-water interface. It measures the ability of a soil to accept water.

The percolative capacity of a soil is the rate at which water moves through the soil once it has passed the interface. It measures the ability of a soil to transport water.

Several important facts concerning infiltrative capacity and percolative capacity of an homogenous soil should be borne in mind:

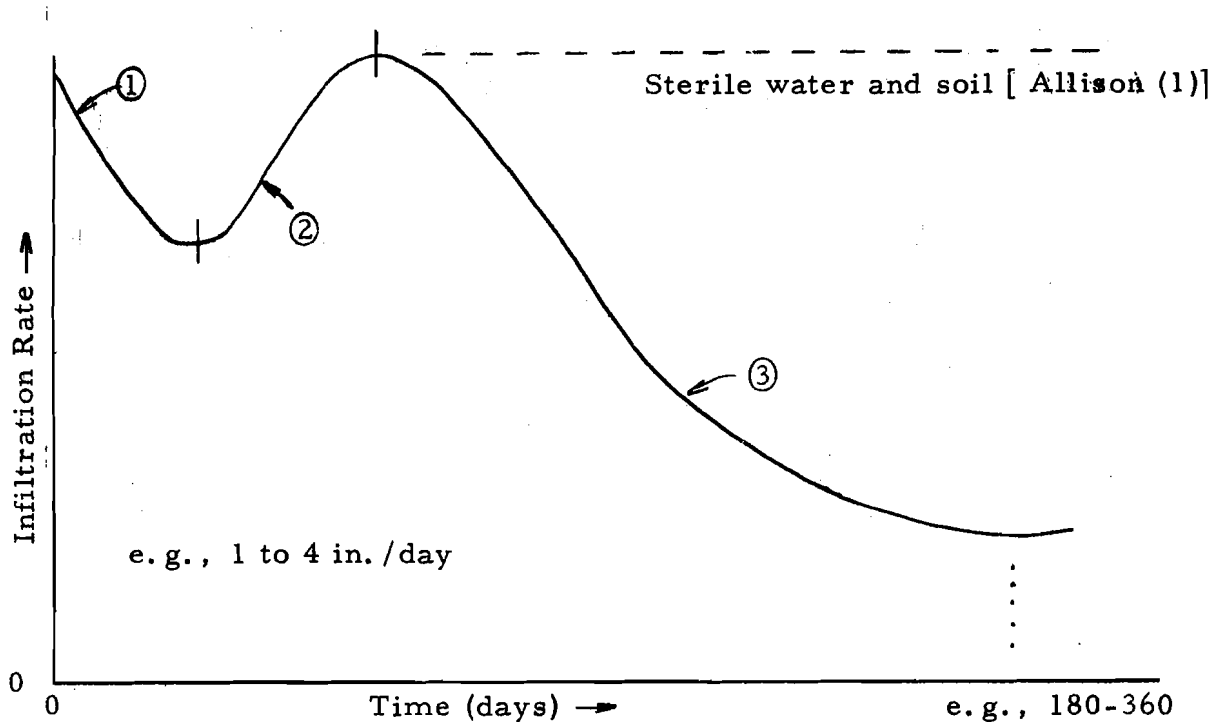
1. The percolative capacity of a soil may be measured by a standard percolation test if properly conducted at a sufficient number of locations on the percolation area.
2. The infiltrative capacity of a soil, except at the moment water is first applied, is always less than the percolative capacity by reason of soil clogging which, as later explained, is largely a surface phenomenon.
3. The infiltrative capacity is variable and is a function of the numerous factors which are involved in clogging. Hence it can not be predicted in advance by currently known tests, although it is readily measured from day to day by the rate of outflow from the pond to the soil.
4. Since the infiltrative capacity of soil is less than its percolative capacity:
 - (a) The soil between the infiltrative surface and the water table is unsaturated by percolating water (a desirable condition).

(b) The problem of design and operation of a spreading pond is to maintain the infiltrative capacity as near as possible equal to the percolative capacity.

5. The percolation test identifies a soil capable of transporting water (and hence suitable for spreading purposes) at an observed rate, provided infiltrative capacity can be maintained.

Time-Rate of Infiltration

One of the most fundamental of all phenomena of surface application of water to soil is the well-known time-rate infiltration curve. If even a clear water without suspended solids or dissolved organic matter is applied continuously to a pervious soil, the time-rate curve will appear somewhat as shown in the following figure.



The phenomena predominant in the three sectors of the infiltrative curve have been identified as follows:

- ①. Soil slaked due to:
 - (a) affinity of internal soil surface for water
 - (b) overcoming of cohesive forces which hold soil together
- ②. Entrapped air removed by solution in percolating water
- ③. Decline due primarily to microbial action in soil. [Allison (1) noted that decline does not occur with sterile water in a sterile soil--a situation not possible of achievement with septic-tank systems.]

As shown in the example, infiltration rates become negligible in periods quite short when compared to the life span of a sewage disposal project. This has repeatedly been shown to be the case even though the percolative capacity of the soil is high. From it may be drawn an important criterion: Any soil continuously inundated will fail as a percolation system due to loss of infiltrative capacity. How it may be overcome is best understood after a review of the phenomena of clogging.

Clogging of Soils

A soil of such characteristics that it has some positive percolative capacity may become clogged as a result of physical, chemical, and biological factors, although in the end the exclusion of water is a physical phenomenon.

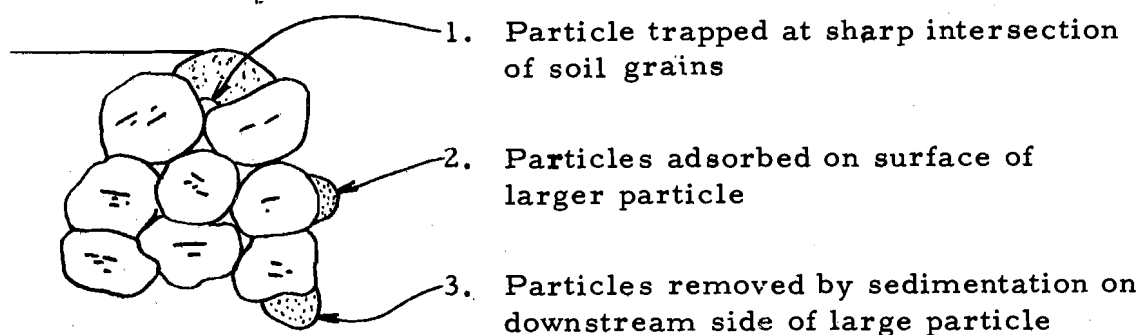
A. Physical Factors in Clogging

There are several ways in which clogging may result from predominantly physical phenomena. They include:

1. Compaction of soil by superimposed loads (e. g., pond water, heavy equipment, etc.)
2. Migration of fines by vibration of dry soil during preparation of site area.
3. Migration of fines due to rainfall beating surface

4. Washdown of fines perched on larger particles
5. Smearing of surface by excavating equipment

The travel of particles in a porous medium is inhibited by at least three major factors which lead to clogging by particulate matter. These are illustrated in the following figure:



B. Chemical Factors in Clogging

Of the purely chemical, as opposed to biochemical, phenomena ion exchange is by far the most important. The swelling of clay colloids by sodium is a well-known way in which either soil surfaces or aquifers may become clogged. However, in areas where soils suffer from this limitation the fact is soon well known and spreading ponds are simply not usable. Assuming, therefore, that soil, sewage effluent, and groundwater are compatible, we may turn to the most important factor in clogging--the biological.

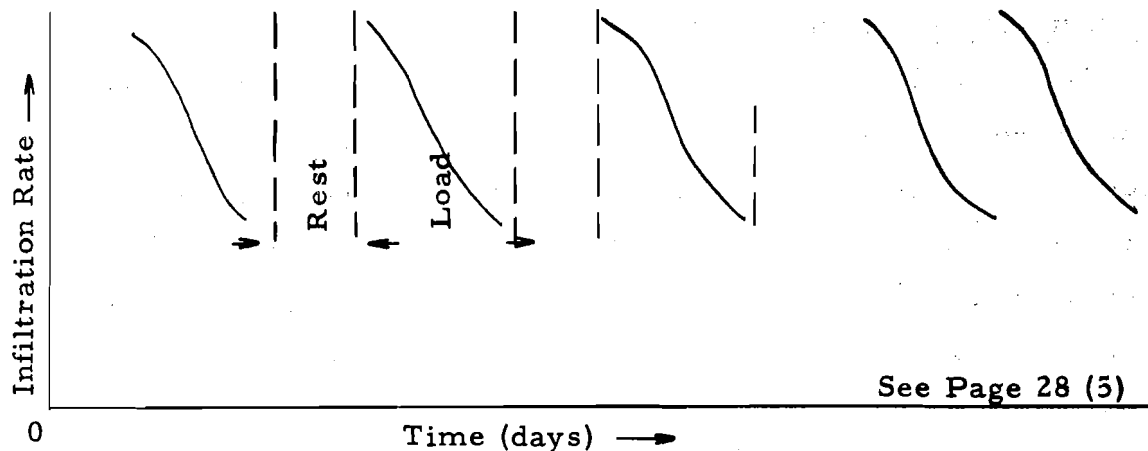
C. Biological Factors in Clogging

Clogging by biological factors is essentially a surface phenomenon. In soils up to approximately 1 mm in diameter the organic mat seldom exceeds 0.5 to 1 cm in depth. Primarily this mat consists of organic solids taken out by the three factors illustrated above, plus an overgrowth of bacteria which feed on particulate and dissolved organic

matter. As the porosity of the mat decreases, it becomes itself a filtering medium catching smaller and smaller solids and so decreasing the infiltrative capacity of the soil. It is alleviated by intermittent resting of infiltrative surface during which time the:

1. surface is drained and oxygen drawn in to maintain high-rate aerobic decomposition;
2. clogging material is degraded to liquids and gases; and
3. drying and cracking improve soil texture and increase its infiltrative capacity.

In contrast with the typical time-rate curve previously shown, periods of rest and loading will reproduce the upper section of Sector ③ in a pattern such as the following, thus permitting long-time use of an infiltrative surface at acceptable infiltration rates.



The optimum cycle of resting and loading must be determined for each situation. However, it is generally of the order of days (3-7) rather than minutes and hours which might occur in the normal pattern of household use of water.

Note: Restoration rate by periodic loading and resting at Lodi, California,
 7-10 times equilibrium rate
 Net gain, 5 times equilibrium rate
 For 163 days, gain was 10 times equilibrium rate.
 Winter rate restoration rate smaller than summer.

In the absence of a loading pattern which maintains aerobic conditions, anaerobic conditions set in. Excessive clogging then develops from two major factors:

1. Rapid growth of slimes
2. Deposition of ferrous sulfide

Ferrous sulfide is a black particulate matter that gives the characteristic color to digested sewage sludge, anaerobic compost, clogged septic-tank percolation systems, etc. It is the result of anaerobic decomposition of organic matter and its presence in serious amounts indicates an unsatisfactory condition of operation of the pond intended to dispose of sewage effluent to the soil. It may account for one-half of the loss of infiltrative capacity of a soil.

In contrast with the biological clogging mat which may be only 1/2 to 1 cm in depth on a fine pervious soil, ferrous sulfide may penetrate 3 to 10 cm below the surface just as any other finely divided inert material. In coarser media it may penetrate to much greater depths, as may the bacteria which produce it. Deep penetration of ferrous sulfide in a soil is indicative that the soil has a good capacity to accept water if properly managed.

Fortunately ferrous sulfide is readily oxidized to the soluble sulfate form upon resting and draining of the soil to bring in atmospheric oxygen. However, a pervious soil that becomes deeply clogged with ferrous sulfide to the extent that it remains waterlogged may remain clogged indefinitely. Drainage to fill the pore spaces with air is a necessary factor in removal of ferrous sulfide.

Interestingly enough the formation of ferrous sulfide cannot be prevented by simply blowing air through a septic sewage, the medium itself must be drained and rested.

Another criterion of systems operation and design then is: Maintain an aerobic system by alternate periods of resting and loading on an optimum cycle. Such a system can accept septic effluent.

D. Clogging During Construction

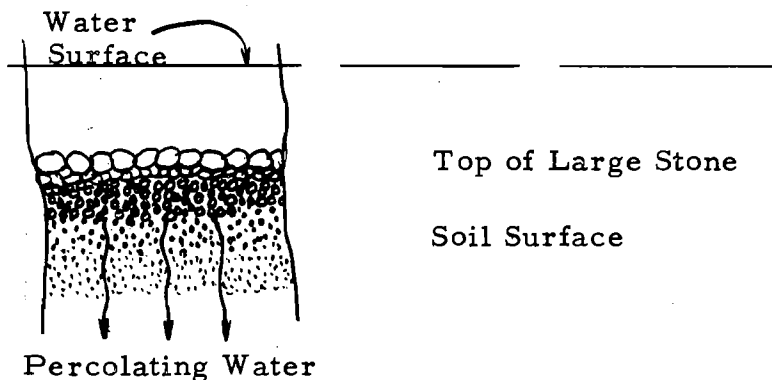
One of the major causes of failure of percolation systems is the damage done by the careless and ignorant methods used in construction. Among the most serious causes of permanent loss of infiltrative capacity are:

1. Smearing of sidewall and bottom surfaces during construction.
2. Compaction of trench bottom by human feet or by dozer tracks or wheels.
3. Silting of open excavation during rain, by spalling of walls, or by windblown loess.

Damage by smearing and compaction is most severe where soil particles are small and soil moisture is high. The criterion here must be that of keeping the infiltrative surface as near as possible representative of an internal plane in the undisturbed soil.

E. Clogging in Depth

Since clogging is essentially a surface phenomenon and the depth of penetration of particles into the soil has been shown to be a function of soil grain size, the possibility of dispersing the clogging mat through a greater depth of soil readily suggests itself. A theoretical method of accomplishing this, which as been demonstrated (5) to be correct is depicted in the sketch:

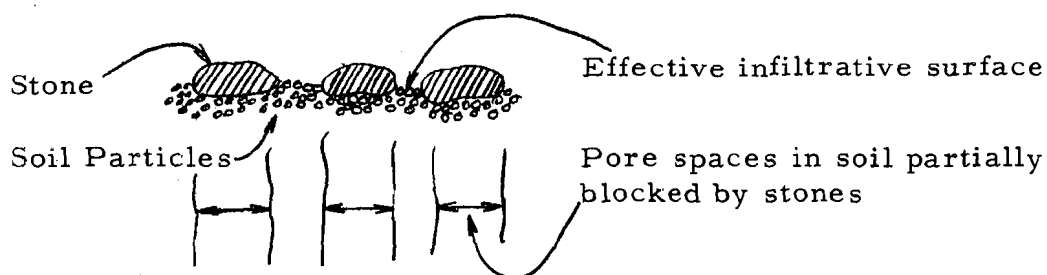


The sketch illustrates an overlay of the soil surface with particles graded in size from quite large to only slightly larger than the largest particles in the soil. In passing through this overlay the particulate matter is removed by entrapment, adsorption, and sedimentation. The particulate matter, the microbial life which depend upon it, and dissolved solids from substrate are dispersed in depth with three major beneficial effects:

1. Any given amount of clogging material which might clog the soil surface is insufficient to clog the system.
2. Clogging of coarse material in depth still fails for a prolonged period to reduce the percolative capacity of the clogged zone to that of the soil. Hence the percolative capacity of the soil is the control.
3. Liquid reaches the liquid-soil interface minus its clogging potential, hence the infiltrative capacity of the soil and its percolative capacity are essentially equal.

Of course, the infiltrative capacity of the overlay will eventually become the controlling factor and resting and draining will be necessary. However, the system will function much longer than one in which the liquid-soil interface is the clogged zone, and when clogged will drain and recover more readily.

Used in a trench in which a stone fill is customary, the graded-size system would overcome a serious interruption, or decrease, of the infiltrative surface such as is illustrated in the following sketch:



In actual field practice the infiltrative capacity of spreading ponds has been observed to increase after drying. The reason is that cementing together of surface particles by zoogel gels and surface cracking in a crude way leads to clogging in depth. Roots of growing plants accomplish a similar increase by a combination of clogging in depth and increasing the area of infiltrative surface, i. e., area of contact between water and soil.

F. Sidewall Effects

Except in shallow ponds where infiltration of the soil depends upon the ability of the pond bottom to accept water, the sidewalls are the most effective infiltrative surface. Until experiments demonstrated this truth it was largely overlooked. In fact, the whole practice of trench (tile field) disposal of septic tank effluents, complete with design tables, etc., was built up and codified without discovering that its principal criterion--the area of trench bottom--was completely irrelevant and meaningless.

The evidence from which an erroneous conclusion was drawn relative to the role of the bottom vs. sidewall is well known to all of us., e. g.,

1. There is little evidence of plant growth beyond the margin of an irrigated area.
2. On a smaller scale, watering of individual plants in a flower bed does not sustain nearby unwatered plants.
3. Shallow surface ponds used for flood water or other waste water reclamation function with very little sidewall area in comparison with bottom area. (Their operation does indeed depend upon management of the bottom area.)

From these observations we can correctly conclude that percolating water flows vertically downward from the infiltrative surface of a homogeneous medium.

On the other hand, we have equally conclusive observations that lateral flow takes place when a limiting zone is encountered, e. g., the

watering of an area underlain by a boulder does not result in producing a column of water extending from the boulder to the surface.

Where then is the dilemma? The answer is that in the trench we often fail to recognize the trench bottom as the limiting zone as a result of its clogging. Outward flow from the sidewalls then must be effective if evaporation is not to be the only outlet. While the reader is referred to reference (5) for a full discussion of this phenomenon, the principal reasons for the effectiveness of sidewall areas in trenches and pits are as follows:

1. Sedimentation is not an important factor in sidewall clogging.
2. Declining water depth in the trench permits alternate resting and loading of the sidewalls, whereas the bottom may be continuously inundated. (although not all increments of wall get the same periodicity).
3. Gravity assists in stripping sidewalls of clogging material as it decays during periods of resting.

Although the trench or pit cannot be loaded in an ideal fashion, another criterion for the optimum maintenance of infiltration rates and for ground recharge of water is: The entire infiltrative surface to be utilized in one operation should be loaded simultaneously. In trench systems this means that a dosing tank should be utilized so that localized overloading does not lead to system failure. Obviously, the requirement that periods of resting and loading be maintained, dictates that the infiltration system consist of at least two sections.

Spreading Ponds vs. Stabilization Ponds

A careful distinction must be made between the pond intended to dispose of sewage by infiltration to the soil and subsequent percolation to a moving groundwater mass, and the pond intended to carry out the cycles of biodegradation which remove its BOD. This does not preclude the possibility of disposing of septic or decomposing sewage

through a spreading pond, but it does mean that operation of the pond will necessitate optimum loading and resting to keep the soil sufficiently aerobic to prevent or oxidize ferrous sulfide and to dry out the organic surface mat.

The optimum sequence of ponds would be:

1. Anaerobic ponds (if utilized) of sufficient capacity to handle the organic load. The bottoms of these may be expected to clog quickly until outflow rates by infiltration are insignificant from the viewpoint of disposal of liquid.
2. Stabilization ponds in which oxidation is completed to a high degree; bottom clogged by constant inundation and other factors.
3. (Possibly) secondary ponds to minimize the algal carryover to the spreading area. These may not be necessary if effluent is well oxidized, and might even be detrimental if low nitrogen, high phosphate, and low dissolved oxygen should encourage the growth of nitrogen-fixing algae. Continuous inundation clogs the bottom of such ponds.
4. Spreading ponds operated on alternate periods of loading and resting on an oxidized effluent probably with a minimum of algae. However, the pressure of algae is no great handicap.

In general spreading ponds should be shallow with a minimum of excavation unless it is necessary to strip the surface to remove an impervious overlayer of material.

Spray Irrigation

In cases where wind carriage of polluted spray is no consideration and vegetation is of no commercial importance, spray irrigation offers a very good alternative to spreading ponds. It is not necessary to remove vegetation, which, incidentally, is generally beneficial to the infiltrative capacity, and no leveling of the surface is required. Alternate loading and resting is necessary since the soil must drain to remain aerobic.

References

1. Allison, L. E. "Effect of Microorganisms on Permeability of Soil Under Prolonged Submergence." Soil Science 63:439-450. 1947.
2. McGauhey, P. H. Summary of Principles of Spreading Ponds. Unpublished paper, June 1965.
3. McGauhey, P. H., and S. A. Klein. Water Quality Implications of New Type Detergents. Paper presented before the California Pollution Control Association, San Diego, California, October 1964.
4. University of California. "Studies in Water Reclamation." Sanitary Engineering Research Laboratory. Technical Bulletin No. 13, LER Series 37.
5. University of California. "Summary Report on Causes and Prevention of Failure of Septic Tank Percolation Systems." Sanitary Engineering Research Laboratory Report No. 63-5, May 1963. (FHA Publication No. 533.)

WATER RECLAMATION. TRAVEL OF POLLUTION

Introduction

The term "reclamation" has long been associated with water management activities although in the historic sense it is the land that is to be reclaimed by irrigation water. More recently attention has been turned to the recovery of water itself; water which has been degraded in quality to the extent that it is no longer suited to beneficial use, yet is too valuable to throw away in many a water-deficient area. The term "water reclamation" has therefore come into quite wide use although without precise meaning. In some cases it has been considered as synonymous with re-use of water; in others its intended meaning is more accurately described as water renovation. For the purpose of this discussion we may think of water reclamation as the objective of engineered systems, although the processes by which it is accomplished may be renovation techniques.

Sources From Which Water may be Reclaimed

The sources from which water might be reclaimed include:

1. Oceans and estuaries
2. Saline groundwaters
3. Agricultural return waters
4. Industrial return waters
5. Domestic waste waters

In some of these cases the need is to desalt waters which have acquired by dissolution a solids content too great for beneficial uses. In others, it is desired to recover water which has acquired unsuitable materials during use as a transportation device intended to remove wastes from the environment of their origin. Generally, only domestic wastes fall into this latter category, although in some instances desalination of domestic waste waters would be required to renovate it.

Incidental versus Purposeful Reclamation

For the most part the reclamation of water from domestic wastes has been incidental rather than purposeful. That is, in the process of complying with effluent or receiving water standards, wastes have been so upgraded in quality that when mingled with the receiving waters they have been incidentally subjected to use more than one time. The approach, however, has been one of disposal rather than of water reclamation.

There have been numerous deterrents to purposeful water reclamation in the past. Among the most significant are the following:

1. The concept of waste treatment as a device for meeting the requirements of regulatory agencies concerned with the public health or water pollution problems rather than as a measure in conserving water resources.
2. Associating reclamation with disposal of waste effluents.
3. Unclear concept of just what beneficial use is to utilize reclaimed water.
4. Over-restrictive legislation predicated upon assumptions of pollution travel now known to be invalid.
5. Preoccupation with the needs for agricultural water which are far beyond the quantity of waste water available.
6. Inertia--a tendency to persist in accustomed habits.
7. Tradition of wastefulness and rejection of second-hand or other unwanted materials.
8. Cheapness of water (approximately five cents per ton, delivered).
9. Doubt regarding the role of detergents, exotic organics, virus, etc., in the quality of reclaimed water.
10. Unknown economics of reclamation.

While a thorough analysis of the foregoing factors is beyond the scope of this discussion, a few salient points should be emphasized.

1. Direct re-use above ground, which seems the most likely from the standpoint of economics, requires that either industry agriculture, or recreational activities be the user.

Since 60 to 80 percent of industrial water is used for cooling, treated domestic waste water might be used for this purpose with only slime control. However, in this case all the deterrents previously noted apply plus some which are peculiar to the problem of industrial use. For example, delivery of water from the waste water treatment plant to the industrial area of the city involves installing a separate system of pipes in paved streets already underlain with a network of conduits. In addition, the maintenance of two separate piping systems within an industrial plant is a nuisance and is hard to police by health agencies concerned with cross-connections.

2. Direct use by agriculture and other land areas is not a good prospect for reasons of both geography and quantity.

Sewage effluents have in a number of cases been applied to crop and grass lands successfully. Instances of irrigation of pasture land, cotton, citrus fruits, grains, golf courses, etc., are noted in the references (7). Generally in these cases the motive has been disposal of waste water where no receiving water exists, or an extremely acute water shortage in the immediate locale. The major drawbacks to agricultural use are that crop-type is limited if the farmer must take effluent on a year-round basis at a constant rate rather than on a seasonal basis as required by crops. Thus disposal of waste water by the community cannot be tied to agricultural use. More important, agricultural activity is generally located both up hill and remote from any important volume of reclaimable waste water. And finally, the total quantity of water in domestic use, although impressive in amount, is but a few percent of agriculture's projected needs.

3. Direct re-use in recreational activities presents some possibilities.

Planned reclamation of water from domestic wastes for recreational use has been demonstrated and practiced in Golden Gate Park at San Francisco for almost a generation. Here planted areas and a series of

ponds are supplied directly with reclaimed water. At Las Vegas and several other places in the Southwest, golf courses are watered with sewage effluents. At the Santee Project near San Diego reclaimed water for recreational use is first passed through a soil system. In fact, because of concern for viruses and exotic organics as factors in the safety of reclaimed water, there is an increasing tendency to require passage through a soil system before using water for recreation. This may well place a new limitation on the direct re-use of water reclaimed from domestic wastes.

Fundamentals of Purposeful Reclamation

A number of the drawbacks to direct re-use of water outlined above are inherent in the concept of re-use as a method of disposing of sewage treatment plant effluents. The first step in purposeful water reclamation, therefore, is to separate the sewage disposal and water reclamation functions of a system. The normal system of disposal is based on health and aesthetic considerations; hence it cannot be tied to continual acceptance of effluent by beneficial uses. That is, there is no way in which the duty of public agencies to protect the public health can be sub-contracted to private users through agreements requiring them to take all the effluent at all times. Separation of the two functions can be attained in several ways.

1. Reclaiming water from the sewer at the site of its use at rates and at times suited to the user and returning the effluents of the reclamation plant to the sewer.
2. Reclaiming water from the sewer prior to introduction of industrial wastes which might preclude reclamation.
3. Reclaiming water from domestic wastes for recharge of groundwaters, or underground storage, with proper arrangements for control of its withdrawal.

Methods of Reclaiming Water from Domestic Wastes

There are several methods of reclaiming water from domestic return waters. They include:

1. Dilution--discharge of adequately renovated effluents into surface waters.
2. Algal ponds in which the nutrients in waste waters are converted to separable algal cells, rendering the water suitable for direct re-use of groundwater recharge.
3. Groundwater recharge by:
 - (a) over-irrigation
 - (b) surface spreading
 - (c) direct injection into underground aquifers

Practical Considerations in Reclamation

Parkhurst (6), on the basis of field experience in water reclamation, states that four conditions are necessary to justify the construction of separate facilities for the purpose of water reclamation.

1. The chemical quality of the water must be suitable for re-use.
2. The quality available must be sufficient to permit economical production costs.
3. Reclaimable water must be produced near a project which can utilize it.
4. There must be a benefit derived from the project to provide interest in the purchase of water at a price to compensate for all or a part of the cost of production.

Concerning the chemical quality of the waste water, it should be noted that desalinization is not yet economical, certainly in the small quantities involved in domestic wastes. Until an economical desalinization procedure is developed, the reclamation of domestic waste water

will continue to be practical only where salinity is not the controlling factor.

Parkhurst points out that the increment added by domestic use in terms of total dissolved solids is about 300 mg/l. Taking 1000 mg/l TDS as the limit of useful water, as is customary today, this means that raw water supplies may not contain more than 700 mg/l TDS if the water is to be reclaimed by methods other than desalination after domestic usage.

Applying this criterion to waters in the Los Angeles Basin, Parkhurst's findings concerning reclaimable water in the area may be summarized as follows:

1. City of Los Angeles

83 percent of water from Owens Valley with TDS of 200 mg/l.

17 percent of water from Colorado River with TDS of 600-800 mg/l.

Approximately 95 percent of nearly 300 mgd is reclaimable.

2. Los Angeles County

70 percent of water from Colorado River, plus heavy industrial contributions of brine discharges.

Hence, only 33 percent of some 285 mgd (i. e., 100 mgd) are reclaimable. 90 percent of the reclaimable water, however, could be put to practical use--above ground re-use, or recharged to the groundwater.

Groundwater Recharge

1. Technical Feasibility

As noted in reference (7), Goudy first demonstrated in 1930 that a highly treated sewage effluent (activated sludge followed by sand filtration) could be returned to the groundwater by surface spreading. Later, in 1949, Arnold, Hedger, and Rawn (7) demonstrated at Azusa and Whittier, California, that groundwater recharge with sewage effluents was practical. Later (1950) studies at Lodi, California (7) (4)

and at Bakersfield (7) developed the operational and management techniques for recharge with sewage effluents and flood waters. In 1954 (7) similar parameters were developed at Richmond, California, and Manhattan Beach, California, for direct injection of water into underground water-bearing formations.

[Data on the following subjects (2 through 7) for both surface spreading and direct injection are discussed in detail in reference (7). Hence they are not summarized here, except for pollution travel, which is discussed briefly in subsequent paragraphs.]

2. Rates achieved
3. Operational techniques
4. Prediction of rates by lysimeter studies
5. Effect of surface treatment
6. Engineering problems
7. Pollution travel

Extent of Current Practice

Perhaps the most extensive development of surface spreading of water reclaimed from domestic wastes is the Whittier Narrows Project of the Los Angeles County Sanitation Districts. Here the Sanitation Districts produce 10 mgd of reclaimed water. The Los Angeles County Flood Control District spreads this water on its existing spreading grounds. The Central and West Basin Water Replenishment District pays the Sanitation District for reclaimed water at the same rate charged by the Metropolitan Water District for Colorado River water used by the Replenishment District for groundwater recharge purposes.

This plant has proved to be an outstanding success and is currently being enlarged. At an early date it and other water reclamation plants of the District will be producing 65 mgd of reclaimed water.

The problem of ownership of recharged water has been resolved by the water replenishment districts of the area by charging a withdrawal fee

to all who pump from the underground waters of the district. This fee is then used to purchase reclaimed or untreated Colorado River water to make up the overdraft on the groundwater basin.

Direct injection of water is a growing practice throughout the United States. Oil and chemical companies have for some years been disposing of chemical and brine wastes by injection into deep strata below the groundwater. Certain radioactive wastes are likewise being so discharged. As a water reclamation or conservation technique, however, examples range from the California coastal areas where injected reclaimed water is holding back intruding saline water from the ocean, to Long Island, where water withdrawn for cooling purposes is returned to the groundwater resource. Similar examples are to be found in many other states throughout the nation. The point here is simply that water reclamation by groundwater recharge, together with the use of the soil mantle as a water renovation device, is becoming an important facet of the water resources and water quality management program, and is destined to increase in importance in the years ahead.

Travel of Pollution

As previously noted, legal restraints upon groundwater recharge with domestic waste water effluents were predicated upon the possibility that bacteria would travel underground with percolating and moving groundwater, in spite of the general evidence to the contrary. Random evidence of limited movement of bacteria and long distance travel of chemicals was to be found in the literature (7) when systematic investigations of pollution travel were initiated in California in 1950. At that time experiments (4) (7) directed to both the public health and engineering aspects of surface spreading of sewage effluents were initiated at Lodi, California, and continued for twenty-eight months. Previous experiments at Whittier, California, had shown a reduction from 110,000 coliforms/100 ml to 40,000/100 ml in three feet of soil,

with none appearing at lower horizons. In a coarser soil at Azusa, California, 120,000 coliform/100 ml was reduced to 60 at 2 1/2 and 7 feet below the surface. At Lodi the observed penetration of coliforms was as shown in the table on page 165.

In all cases bacteria behaved as particulate matter, penetrating to a maximum depth in the soil initially and regressing as surface clogging developed and organisms died.

When sewage effluents were injected directly into an underground aquifer at Richmond, California (5), the distance of travel under quite high wellhead pressure was as shown in the table on page 165.

These data, together with those of other researchers, demonstrated quite conclusively that the danger of travel of bacteria with percolating water or moving groundwaters in a soil or sand medium is not a deterrent to the reclamation of waste water by groundwater recharge.

In the case of chemicals it was found that nutrients, whether stable or unstable, move quite readily with percolating water once they escape or are injected beyond the biologically active zone. Phosphates and ammonia tend to be adsorbed on soils, but nitrates and other ions normal to groundwater are not removed, and many inorganic and organic ions, ABS, and other chemicals move with groundwaters.

The Problem of Virus

Demonstrations of the removal of bacteria in soil systems did not result in profound changes in the laws concerning the quality of water suited to recharge, although by 1965, 1000 coliforms/100 ml began to be acceptable. The reason, beyond the innate conservatism of health departments, was the unknown behavior of viruses in soils.

Significant data on the removal of viruses by soil systems has now been produced at the Santee Project in California, in which the safety of waters reclaimed from domestic wastes is being demonstrated.

For those who are not familiar with the Santee Project, it might be

MPN of Coliform Organisms in Observation Wells During Continuous Recharge with an Average of 2.4×10^6 Organisms per 100 ml (7)

Distance from Recharge Well	MPN 3rd Day	MPN 12th Day	MPN 32nd Day
13 feet N	240	240,000	230
28 " N	2,400	240	5
47 " N	240	38	5
63 " N	23	8.8	None
88 " N	None	None	None
138 " N	-	None	None
39 " NE	2,400	240	8.8
45 " NE	None	8.8	None
63 " NE	None	38	None
106 " NE	None	None	None
39 " NW	2,400	240	2,300
45 " NW	240	None	5
63 " NW	None	2.2	8.8
13 " E	24,000	24,000	8.8
50 " E	240	5.0	None
13 " W	23	None	2,300
50 " W	23	>240	2.2
13 " S	95	2,400	230
63 " S	None	None	9.4
100 " S	23	5.0	None
188 " S	None	None	None
192 " S	None	None	None

MPN of Coliform Organisms as a Function of Depth in Hanford Fine Sandy Loam at Lodi, California (7)

Basin	Sewage Effluent Spread	Average MPN at Indicated Depth						
		Surface	1 ft.	2 ft.	4 ft.	7 ft.	10 ft.	13 ft.
A	Primary	414×10^4	1.6	32*	0.6	0	0	
	Final	179×10^3	1.2	285*	2.1	0	0	
B	Primary	570×10^4	20	0	0	0	0	0
	Final	188×10^3	482	5.6	0.5	0.2	0.1	0
C	-	-	-	-	-	-	-	-
	Final	188×10^3	148	305	2.0	0.2	0.1	0.3
D	-	-	-	-	-	-	-	-
	Final	164×10^3	0.2	-	-	0	-	0

*Sand channel from surface to 2-foot depth.

noted that domestic waste water is being renovated and used successfully for recreational purposes under the careful management and study of various state and national agencies. Domestic waste water is first treated in a conventional sewage treatment plant involving primary treatment followed by activated sludge. It is then retained for thirty days in an oxidation pond from which it is pumped to a spreading ground in coarse gravel which fills an old river bed to a depth of ten to twelve feet. After traveling through the gravel a distance of some 2500 feet it is collected, chlorinated, and introduced into a series of ponds in which fishing and boating are permitted, and around which picnicking and other recreational activities are encouraged. Currently a special pond for swimming activities has been authorized and is about to go into operation. Restraints on the recreational use of the water were, of course, imposed pending the outcome of studies of travel of viruses.

General Information on Viruses (3)

Enteroviruses found in sewage include more than sixty types belonging to three groups:

1. the polioviruses
2. the ECHO viruses
3. the coxsacki viruses

Also adenoviruses and reoviruses, clinically considered respiratory, are found in sewage. The virus of hepatitis must be presumed to be present, although propagation of this virus in the laboratory has not been confirmed.

Recovery of Virus in the Santee System

Virologic tests reported in 1962 and 1963 gave the following results:

1. Samples of raw sewage, primary effluent, and activated sludge

effluent were 100 percent positive. (Thirteen different viruses were identified.)

2. Effluent from oxidation pond (thirty days detention) showed 30 percent of samples positive.
3. Recreational pond influent, after 2500 feet in soil system, 100 percent negative.

In 1964 a special study involving the introduction of attenuated polio virus in the water reaching the spreading ground was conducted. Sampling wells were located at distances of 200, 400, and 1500 feet down the wash. No virus was recovered at any of the sampling wells.

On the basis of these data it may be concluded that the soil mantle of the earth removes viruses, as it does bacteria. They would seem to justify the growing feeling among health authorities that reclaimed water should be passed through soil before being mingled with the water resources from which water supply may be drawn.

References

1. Askew, J. B. First to ninth Quarterly Reports, County of San Diego, Department of Public Health, to California State Water Quality Control Board, 1962-1964.
2. Askew, J. B. Microbiology of Reclaimed Water From Sewage for Recreational Use at Santee, California. American Public Health Association, 1963.
3. Askew, J. B. Virological Study Report for Santee Water Recreational Project. Report to California State Department of Public Health, January 28, 1965.
4. California State Water Pollution Control Board. Waste Water Reclamation in Relation to Groundwater Pollution. Publication No. 6, Sacramento, California, 1953.
5. California State Water Pollution Control Board. Investigation of Travel of Pollution. Publication No. 11, Sacramento, California, 1954.

6. Parkhurst, John D. Progress in Waste Water Re-Use in Southern California. American Society of Civil Engineers, Environmental Engineering Conference, Salt Lake City, Utah, May 11-15, 1964.
7. University of California. "Studies in Water Reclamation." Sanitary Engineering Research Laboratory, Technical Bulletin No. 13, LER Series 37, 1955.

XIV

QUALITY CONSIDERATIONS IN ESTUARINE WATERS

by R. E. Selleck

Introduction

Although the subject of estuarine and marine resources transcends the scope of this volume, both the objectives and the techniques of quality management of the freshwater resource must take into account the quality considerations relevant to such waters. This is particularly true of the estuarine waters, which are an integral part of the quality interchange system.

For obvious reasons great industrial and commercial cities are located on estuaries and hence millions of people have an intimate concern with the resource values of such bodies of water. Many of these resource values depend upon the quality characteristics of the water, hence however concerned the citizen may be for "pure" water at the intakes of his freshwater supply, he is never oblivious to the effect of stream discharges on the estuaries which funnel it into the ocean. In fact, the estuary is a more than normally sensitive spot because its aquatic life must always live dangerously. Floods may overwhelm life with freshwater, or shift and obliterate the bottom deposits on which it lives. Diversions may lead to an increase in salinity for lack of flush-out; industrial wastes may increase in concentration; or the residence time of domestic effluents increase, with consequent abnormal oxygen depletion.

To the human being, what happens upstream as a result of water quality or quantity management in his behalf, may lead to the irrigation of his favorite beach, the disappearance of fish he sought for sport and recreation, increased concentration of pollutants in the estuarine waters, or as in the case of California's Delta Area, encroachment of salinity on his most valuable agricultural land. It is therefore pertinent that

the engineer concerned with management of the quality of the freshwater resource have some understanding of the constraints which may arise as a result of quality considerations in estuarine waters.

What Constitutes an Estuary

A somewhat poetic definition of an estuary is presented by Webster-- "The passage where the tide meets the current of the river." Actually, an embayment is also commonly called an estuary even when there are no significant tributary streams. Often estuaries are classified into three categories; inverse, neutral, and positive. An inverse estuary has generally a net landward flux of water, and a positive estuary a net seaward flux. A neutral estuary is one which fits into the definition somewhere between the negative and the positive. An estuary is always tidal, hence in the common term "tidal estuary" the "tidal" is redundant.

In the context of water quality management the positive estuary would be most affected by landward control of surface water and water quality, since the seaward flux is a result of freshwater inputs, usually above ground. The negative estuary might be expected to have the most profound effect on the freshwater resource if its landward flux is the result of saline recharge of underground aquifers as well as of evaporation and transpiration. In any event, it has the least ability of any type of estuary to cope with return flows from beneficial use, although its mere presence is a temptation to beneficial users seeking a cheap transport of wastes to the ocean.

For the purpose of this discussion both bays and more purely defined passages are considered to be estuaries. Furthermore, in evaluating the quality considerations in estuarine waters it is difficult to exclude entirely the interchange between estuarine and marine waters. Therefore, effects on beach and nearshore waters, beyond which the effects of freshwater pollution are undetectable, are associated with the estuary.

Nature of Estuarine Resources

The quality factors which are of importance to estuarine environments and which may be directly concerned in freshwater quality management undertakings are related to aesthetic values, recreation, commercial and sport fishing, industrial water supply, pleasure boating, transportation, and to a lesser extent, oil reserves and underwater mineral deposits. These, at least represent the principal resource values of estuarine waters which place limitations on the free use of estuaries either as recipients of wastes discharged into influent streams after treatment, or directly into the estuary to avoid mingling of fresh and return water supplies. Associated with some of these resource values are considerations of public health and aquatic ecology which impose further constraints.

A full evaluation of the economic and social worth of estuarine resources in the U. S. is beyond the scope of this writing. Nevertheless, a few random examples and general relationships, together with more detailed discussion of such subjects as quality criteria, eutrophication, etc., contained in other chapters, may serve to underscore the role of estuarine water quality considerations in the overall problem of water quality management.

Considerations of Aquatic Life

Protection of aquatic life from adverse water qualities is far more complicated in estuarine waters than in the streams which discharge into them, both because of the diversity of life itself and of the shifting and subtle environmental relationships in estuarine equilibria. For example, freshwater itself may be a pollutant in an estuary. An estimated loss of 90 percent of the oyster crop in Mobile Bay occurred in 1963 when unusual rainfall inland dropped the salinity of the bay below 10,000 mg/l for a prolonged period at a critical time.

Although considerable experimental work has been done on the effect of toxic materials on fishes, much of this relates to standard test species or to the most valuable of freshwater species exposed to a single type of material. In the estuary, however, where numerous species may exist, and where all quality factors from all upstream beneficial uses are mingled, the data are difficult to evaluate. Each species of fish has its own period of life when it will be most susceptible to toxic compounds in the aquatic environment. In general, the younger fish are the most sensitive. Moreover, when several different toxic agents are present strange effects can result. One agent may either enhance or decrease the toxic activity of another agent. This might be particularly true in saline waters where comparatively large concentrations of many ions are already present. In general, however, there seems to be a tendency for most poisons to be less toxic to fish in a brackish or marine environment than in a freshwater environment. This may result from either the adaptation of species to ions or to an antagonism between ions, or both. On the other hand, it may be more apparent than real since it is based on mortality rather than productivity observations. In this connection Butler (2) states:

Although acute toxic levels of natural and man-made pollutants are quite simple to demonstrate, the effects of low levels of toxicants are much more obscure, and disastrous changes in productivity levels might occur without significant mortality. Our ability to delineate the individual factors that are deleterious to estuarine forms will determine in large measure our success in preserving this part of the marine environment, which is so sensitive to pollution.

Fortunately many saltwater fish do not propagate in regions readily accessible to waste water outfalls, but to some extent this only makes it more important to know the life history of each species of fish in determining the effects of waste discharges on fish life. An example may be drawn from the ecologies (3) (6) of some saltwater species found in the waters of California, Table 1-14.

Table 1-14. Ecology of Some Saltwater Species Found in California Waters

Type of Species	Species	Remarks: Possible Effect of Water Quality in Estuary
Freshwater spawners	1. Steelhead trout	Minimal effect as passage through Bay (e.g., San Francisco Bay) is made by adult or near-adult fish.
	2. Striped bass	
	3. King salmon	
	4. Perches	
Estuarine spawners (S. F. Bay)	1. Herring	Spawn in spring in shallow flats, could be very susceptible to adverse quality factors.
	2. English sole	Flatfish, bottom dwellers may be particularly affected by benthic conditions not characteristic of overlying water. English sole observed to develop malignant growth on heads when dwelling in vicinity of sewer outfalls in S. F. Bay.
	3. Sand dab	
	4. Starry flounder	
	5. Bay smelt	
	6. Sturgeon	Response to benthic and water quality conditions uncertain.
Estuarine residents	1. Perches	Presence in Bay as adults observed to increase when sewage pollution reduced.
	2. Striped bass	
Migratory from remote ocean centers	1. Jack mackrel	Practically unaffected by estuarine or near-coast water quality conditions.
	2. Bonito	
	3. Tuna	

To some extent the mobility of fishes enables them to escape to a limited degree from some adverse water quality factors. Shellfish, however, cannot escape from or avoid an adverse climate. Oysters are essentially obliged to live in estuarine waters since they seem to prefer brackish water in the 10 to 30 gm/l range of salinity. Some species of clams are also estuarine dwellers. While adaptation to a wide range of salinity is characteristic of such shellfish, they are sensitive to many other quality factors in both gross and subtle ways. For example, oysters show considerable tolerance to low D.O. levels, but growth and fattening may be inhibited and shells deformed when D.O. sinks to 3 or 4 mg/l for prolonged periods of time. As yet unknown factors affect their response to carbohydrates and temperature. From the viewpoint of aquatic biologists and conservationists the "maintenance of habitat" is becoming an increasingly important objective of water quality control. It is more and more being reflected in public policy and scientific parameters for judging it are being refined. The latter are based on the important ecological rule (4) that "if the normal climate of an ecological system is changed, the number of species will decrease while the number of individuals will increase." This can be brought about by the addition of a waste water of somewhat different quality aspects to a natural water more or less in a state of equilibrium, without the addition of nutrients or a toxic agent. Such refinement of objectives and subtlety of response must inevitably suggest that increasing knowledge of the environmental responses of aquatic life to water quality factors will further intensify rather than relax the constraints which quality needs of estuarine waters may impose upon freshwater quality management routines.

Public Health Factors

Concern for the effects of pollution on aquatic life involves questions of human health as well as of the welfare of aquatic species. Shellfish

are typically filter feeders. Some species are capable of pumping up to 50 liters of water per hour, hence concentration of organisms characterizes their life process. Coliform organisms found in shellfish, on an MPN/100 gram basis, are from one to ten times the MPN/100 ml of water in which they are immersed. These organisms may persist in the shellfish for 15 to 60 days after removal from polluted water. McKee (5) correctly suggests that "... shellfish constitute one of the weakest links in our defense against enteric infection, whether bacterial or viral." Further, a committee of the American Public Health Association stated in 1963 (1) "... there is ample evidence that failure to conform to coliform standards for drinking waters and shellfish harvesting waters has produced disease outbreaks." For this reason the quality of water entering an estuary from which shellfish are harvested is a matter of great concern.

No particular public health problem has been observed with fish except during canning. However, fish can become contaminated with coliform organisms within one hour of exposure and require six or seven days to rid themselves of these organisms when transferred to clean water.

Health and its closely related factor of aesthetics are a consideration in the recreational use of estuarine waters. Epidemiological evidence to support water quality requirements for bathing beaches, water skiing areas, etc., is essentially nonexistent. Nevertheless, the level of general sanitary standards expected by the public, plus the problem of engendering a high degree of sewage treatment if not applied "across the board," generates requirements for estuarine waters that are reflected in upstream quality management objectives.

Economic Factors

Of the several estuarine resource values having economic implications, fisheries and recreation are the two most concerned with water quality factors. Commercial fishing in California is not particularly an activity in estuarine waters. Prior to 1900, however, the 435 square

mile area comprising San Francisco Bay accounted for 93 percent of the State's commercial fishing production--oysters, clams, mussels, crabs, and various species of fish (7). After 1900, fishing pressure, siltation, and pollution led to a rapid decline in commercial activity. The contribution of water quality alone to this decline is impossible to assess with accuracy. Nevertheless, it is known that reduction of sewage pollution after 1950 restored an important amount of aquatic life, and the area became dedicated to sport fishing instead of commercial fishing.

The economic value of sport fishing in California is difficult to determine. Angling licenses in 1963 numbered 1.7 million (7). In 1961, 20 percent of the 1.5 million license holders for that year fished in San Francisco Bay and the connecting Delta; 15 percent of the total fishing days being spent in that area. Angling in the Bay, the Delta, and the ocean is estimated (7) to represent 45 percent, with 55 percent being in freshwater. The number of California anglers was estimated in 1965 as 1.17 million with an annual expenditure of more than \$107 million. A sizable, if unidentifiable, portion of this total is concerned with waters where quality of influent water is a factor, largely in the preservation of aquatic environments suitable for fish life.

Pleasure boating, water skiing, aesthetic enjoyment and other recreational activities involving large financial investment depend upon estuarine waters. In California alone there are estimated to be about 79,000 pleasure boats in operation (1962). However, the quality considerations of other estuarine resources are overriding and it seems unlikely that the public would tolerate a system of water quality management in which the needs of these activities would be the critical ones.

Unlike California, a significant portion of the commercial fishing of other seaboard states is done in estuarine waters. The oyster industry of the east, south, and pacific northwest depends upon maintenance of quality of such waters, as do other segments of the seafood industry. In British Columbia, 62 percent of the commercial catch

of salmon is made in estuarine waters. Its landed value was placed at \$50 million in 1963.

Industrial use of estuarine water is an important economic factor. Since this is mainly used for cooling purposes, temperature may become an environmental factor in sectors close to industrial return outfalls. Turning again to San Francisco Bay as an example, the 1962-63 average rate of industrial recirculation of water was 100 mgd (3). During that same year more than 81,000 acre-feet of Bay water was evaporated to produce industrial salts.

General Conclusion

Although the direct interchange of quality factors between the estuarine and freshwater sectors of the overall water resource is minimal, the resource values of estuarine waters impose limitations upon the quality of influent water. Therefore, any system of freshwater quality management must take into consideration the quality requirements of this link in the transport chain. Furthermore, population concentration around major U.S. estuaries, public awareness of unsatisfactory conditions so close to home, and the subtleties of aquatic environment relationships tend to increase the pressure for greater upstream quality control.

References

1. American Society of Civil Engineers. "Coliform Standards for Recreational Waters." Progress Report, Public Health Activities Committee, Sanitary Engineering Division. Journal of the Sanitary Engineering Division, SA4, p. 57, August 1963.
2. Butler, Philip A. "Reaction of Estuarine Mollusks to Some Environmental Factors." Biological Problems in Water Pollution. 3rd Seminar, August 13-17, 1962. U. S. Public Health Service, 1965.
3. California State Water Quality Control Board. Report on Collation, Evaluation, and Presentation of Scientific and Technical Data Relative to the Marine Disposal of Liquid Wastes. Sacramento, 1964.

4. Fischer, R. S., A. S. Corbet, and C. B. Williams. "The Relationship Between the Number of Species and the Number of Individuals in a Random Sample of an Animal Population." Journal of Animal Ecology, 12, 42, 1943.
5. McKee, J. E., and H. W. Wolf. Water Quality Criteria. 2nd ed. Report to California State Water Quality Control Board (SWQCB Publication 3A.) 1963.
6. Pearson, E. A. "Reduced Area" Investigation of San Francisco Bay. California State Water Pollution Control Board, Sacramento, July 31, 1958.
7. University of California. California and Use of the Ocean. Planning Study of Marine Resources prepared for California State Office of Planning. University of California, Institute of Marine Resources, IMR Ref. 65-21, October 1965.

XV

MARINE DISPOSAL OF WASTES

by R. E. Selleck

Introduction

Inevitably the ocean must be regarded as the ultimate sink into which all quality factors flow with water and in which they are left behind in the hydrological cycle. This does not mean, of course, that no concern need be held for the type of wastes the ocean may receive once they have survived the considerations of beneficial use, preservation of resources, and sentimentality which accompany quality management in the freshwater system. Beyond the limits of even the estuarine resources discussed in Chapter XIV lie resources of the ocean which grow in importance as human population of the land mass increases. Radioactivity and pesticides, for example, are among the quality factors which may be concentrated in marine life and spread rapidly over the world's oceans by marine organisms with results not yet fully evaluated by ecologists.

In general, however, it may be assumed that the upstream needs of mankind will engender these engineered systems which will effectively prevent water quality considerations of the ocean from becoming the controlling factor in freshwater quality management. Nevertheless, great population concentrations exist at the shoreline and the return flows from their domestic and industrial use of water must either be reclaimed or discharged into marine waters. In either case, most of the quality factors reach the ocean in either a raw or stabilized condition.

Life on the seacoast likewise generally involves shipping and other ocean transport activities. This historically has created cities where bays and estuaries provide harbor facilities. Consequently, the temptation, and often the necessity, exists for discharge of waste waters into the estuarine waters, or into the shallow ocean waters overlying

the continental shelf. If this is to be accomplished in a manner acceptable to human aesthetics, and without interference with his use of other shoreline resource values, it may be necessary to precondition waste waters for discharge by the engineered systems discussed in other chapters-- ponds, soil systems, conventional works, etc. In other cases direct discharge of raw waste waters may be feasible. But in any event an engineered system of discharge is required, the general principles of which are herein discussed.

Dilution, Dispersion, and Decay in Estuarine Waters

For simple geographical reasons the gravity sewerage system of a city developing around an estuary terminates at the shoreline in numerous separate outfalls. The simplest and initially least expensive expedient is to allow such multiple discharges to flow into the estuary and hope that the outgoing tide will transport them to the ocean. This is, of course, exactly what has been the engineering practice, only in many situations the tide was not notably cooperative. In essentially all instances the time arrived when pollution control was necessary, but by that time the community was often reluctant to assume the financial burden of intercepting these numerous outfalls and providing conventional waste treatment until legal action by regulatory agencies forced the issue. However, since the technology of waste water treatment does not achieve complete stabilization of organic matter the necessity continues for an understanding of the waste treatment potential of estuarine waters and for the explanation of such potential by engineered systems.

In Chapter XIV estuaries have been classified according to flow in tributaries (advection), i. e., positive, neutral, or inverse. They may also be classified according to their degree of stratification in a vertical plane.

1. Vertically well mixed
2. Partially mixed

3. Stratified

4. Intensely stratified (fjords)

The vertically well-mixed estuary is the type most studied and discussed in the literature, the reason being that this type of system can be described in mathematical terms. Nearly all estuaries are stratified to some degree. However, the intensity of water turbulence imparted by the tide is often sufficient to mix reasonably well a soluble constituent throughout the water column.

In the stratified estuary the net advective velocity of the fresh tributary water may be so great that the tidal forces are not sufficient to overcome vertical stratification. The less dense freshwater will then usually flow over the more dense ocean water, causing a difference in net velocities of the upper and lower layers, with the upper layer moving seaward and the lower layer moving landward.

The fjord is usually a relatively deep body of water having a sill at the ocean entrance or mouth. In such an estuary the stratification may be so intense that the dense lower layer may be entirely void of dissolved oxygen even when no waste water discharges are involved.

Some random examples of estuarine types are presented in Table 1-15.

From a consideration of Table 1-15 it is at once evident that diffusion of waste effluent throughout the mass of receiving water is a necessary objective of an engineered system intended to take advantage of any capacity of the estuary to handle such effluent. It is equally obvious that any continuous acceptance of effluent must also depend upon a positive seaward movement of the mixture during tidal cycles. For example, the southern sector of San Francisco Bay, although reasonably well mixed, has a residence period of some two weeks. Consequently, cities discharging to that end of the Bay are required to subject domestic and industrial return waters to a very high degree of treatment prior to discharge, whereas primary effluent and raw sludge are acceptable from communities located opposite the Golden Gate.

Table 1-15. Examples of Estuarine Types

Type	Example
Vertically well mixed	1. San Francisco Bay (most regions) (northern positive; southern inverse)
	2. Guanabara Bay, Brazil (generally neutral)
	3. Thames Estuary, England (positive)
Partially stratified	1. Straights of Juan de Fuca (positive)
	2. Straight of Georgia (positive)
Fjord	1. Saanich Inlet, Vancouver Island (inverse)
	2. Many British Columbia estuaries

The hydrographic observations necessary to classify an estuary are fairly straightforward and obvious. Less readily observed factors are involved in the equations of mixing and in the assumptions underlying engineering works to bring it about. Nevertheless, in evaluating the consequences of discharging any constituent into an estuary it is necessary to estimate its resultant concentration in the mixture.

Factors affecting constituent concentrations in a vertically well-mixed estuary include:

1. Net advection
2. Longitudinal eddy turbulence
3. Concentration and rate of discharge of constituent in outfall
4. Method of initial dispersion utilized
5. Rate of decay

6. Location of outfall
7. Other sources or sinks of constituent in estuary

A diffusion equation can be written to take into account the effects of eddy diffusion, advection and various types of sources or sinks. The one-dimensional, first order form is:

$$F_x = \underbrace{Qc}_{\text{Advection}} - \underbrace{AK \frac{dc}{dx}}_{\text{Diffusion}}$$

where F_x is the net mass flux of a constituent across a plane at x , Q the net advection, c the constituent concentration, A the cross-sectional area, and K the coefficient of longitudinal eddy diffusion (L^2/T).

By taking the partial of F with respect to x and considering the law of mass continuity, one can derive the second order equation

$$A \frac{\partial c}{\partial t} = - \underbrace{\frac{\partial (Qc)}{\partial x}}_{\text{Advection}} + \underbrace{\frac{\partial}{\partial x} (KA \partial c / \partial x)}_{\text{Diffusion}} - \underbrace{kAc}_{\text{(First Order Decay)}}$$

where the term kAc represents the decay or sink of the constituent (the letter "k" is the first order rate reaction constant). Most workers in this field have used the second order equation but in certain cases the first order equation is simpler to apply and visualize.

In most estuaries the coefficients Q and A are not constant with longitudinal distance. Unfortunately, the coefficient K is also not constant. It can vary at least as much as one order of magnitude in actual estuaries. Unless the coefficients Q , A , and K are relatively simple mathematical functions of the distance x , the diffusion equations cannot be integrated except by finite difference methods.

The coefficient A can be easily determined from hydrographic charts, and Q can often (but not always) be accurately estimated. At the present time nobody can predict accurately what the values should be for K . In general, K increases in magnitude as one progresses

from the landward end of an estuary to the ocean. (In the landward most portion of South San Francisco Bay this general rule does not hold true.) In actual estuaries the value of K may range from about 500 to 5000 feet²/sec, although it is still too early to make a definitive statement about the actual magnitudes of K .

The resolution of problems involving the diffusion of a waste effluent into a receiving water in such a manner as to limit the concentration of any particular constituent to that specified by some water quality criterion or objective is extremely complex. Usually rapid mixing is desired to prevent excessive local concentrations at the initial point or in the water mass during the transport and dispersion of the mixture into the ocean. To this end it is customary to assume, though hard to demonstrate, that waste water discharged from a line source is instantly mixed in the vertical plane of the line source.

In practice a line source is equivalent to a diffuser in which the waste water is released through several parts closely spaced along a submerged pipeline. The line source assumption is often used in the following cases:

1. Vertically well-mixed estuarine outfalls with or without diffuser if the waste discharge is relatively great in comparison to the boundaries of the estuary.
2. Marine (coastal) outfalls having a multipartite diffuser at the discharge end.
3. Stream outfalls under conditions similar to (1) above.

Although in a vertically well-mixed estuary the assumption of instantaneous mixing in a vertical plane may be relatively valid, the relationship between the concentration (c_o) of any constituent at that instant and its concentration (c_w) in the seaward moving water mass is extremely complicated.

Figure 1-15 represents the considerations from which equations for the c_w/c_o relationship can be developed. In it the element at o

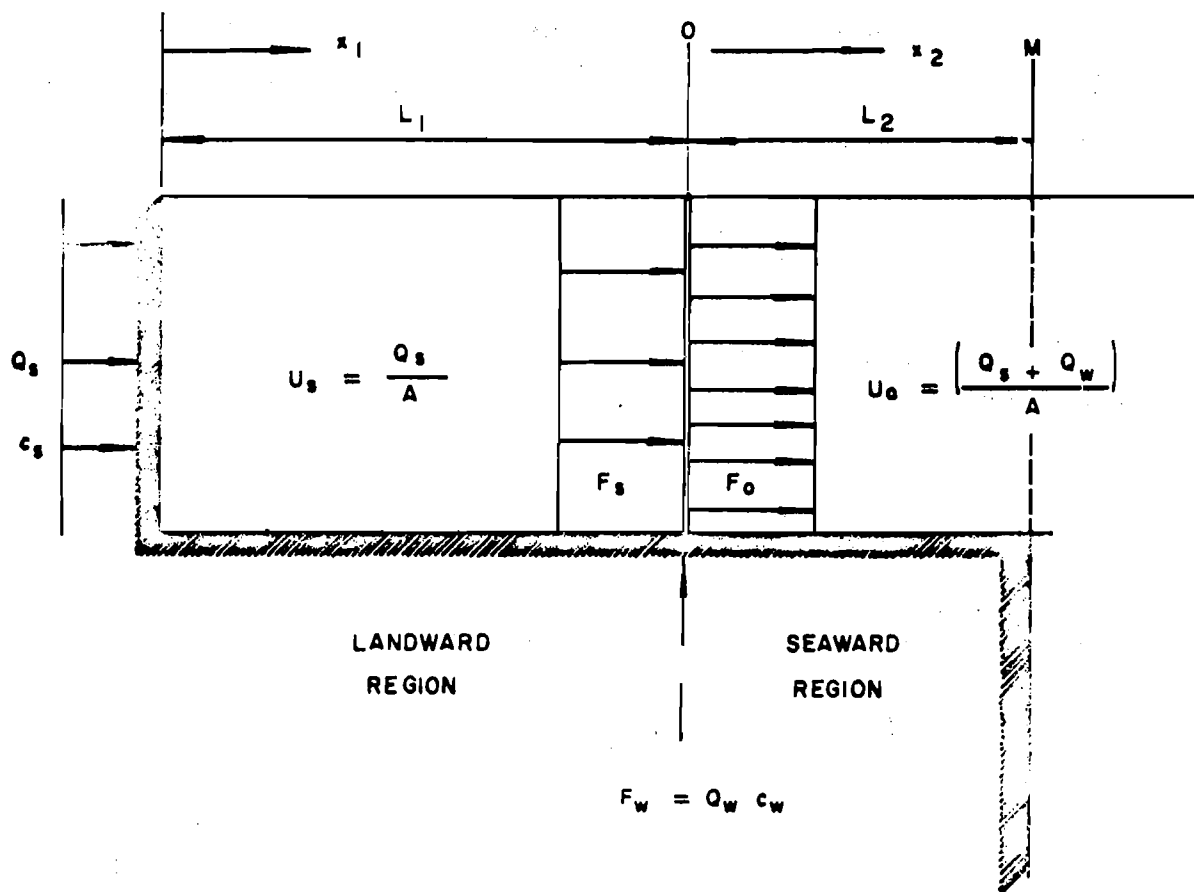


FIGURE 1-15. INITIAL DILUTION OF A LINE SOURCE

represents a region of instantaneous mixing of the waste water being released from a line source normal to the axis of the estuary. The subscript, *s*, signifies the coefficient to the landward, and, *o*, to the seaward. Subscripts 1 and 2 refer to distance in the landward and seaward reaches, respectively, U_s and U_o are net velocities, and F_s , F_o , and F_w are mass flux values. The system is assumed to be in a "steady state" condition, i. e., the average constituent concentration, as taken over a complete tide cycle, does not change from one tidal cycle to the next. If this is the case, then the mass flux into the element equals the flux leaving the element, or

$$F_o = F_s + F_w$$

Since $F_w = Q_w c_w$ where Q_w and c_w are the flow and concentration of the constituent in the waste, then

$$c_w = \frac{1}{Q_w} [F_o - F_s] \dots \dots \dots (1)$$

Since, in general, $F = Q_c - AK \frac{dc}{dx}$, then

$$F_s = Q_s c_o - A_o K_o \left[\frac{dc}{dx_1} \right]_o$$

and

$$F_o = (Q_s + Q_w) c_o - A_o K_o \left[\frac{dc}{dx_2} \right]_o$$

since the value of *c* at *o* (c_o) must be the same for both F_s and F_o . Therefore, Equation (1) becomes

$$\frac{c_w}{c_o} = 1 - \frac{A_o K_o}{Q_w c_o} \left[\frac{dc}{dx_1} - \frac{dc}{dx_2} \right]_o \dots \dots \dots (2)$$

Equation (2) is perfectly valid for any steady-state line source problem, but to determine the two concentration gradients at 0

something must be known about the coefficients A, Q, k, and K, as well as the boundary conditions.

For purposes of illustration, it is assumed that A, Q_s, Q_w, K, and k are constant and independent of x₁ and x₂. The boundary conditions are assumed to be F = 0 at x₁ = 0, c = 0 to the left of x₁ = 0, and c = 0 at x₂ = L₂. Using these conditions it can be shown that

$$\left[\frac{dc}{dx_1} \right]_0 = \frac{2c_o k}{U_s} \left[\frac{1}{j_s \operatorname{ctnh} a_s j_s L_1 + 1} \right] + \frac{U_s c_o}{K} \quad (3)$$

where

$$\begin{aligned} k &= \text{first order rate of constituent decay} \\ a_s &= \frac{U_s}{2K} \\ j_s &= \left[1 + \frac{4kK}{U_s^2} \right]^{1/2} \\ U_s &= Q_s / A \end{aligned}$$

For the downstream reach, it can be shown that

$$\left[\frac{dc}{dx_2} \right]_c = - \frac{U_o c_o}{2K} \left[1 + j_o \operatorname{ctnh} a_o j_o L_2 \right] + \frac{U_o c_o}{K} \quad (4)$$

where j_o and a_o are equivalent to j_s and a_s, respectively, except that U_o is substituted for U_s.

$$\left(U_o = \frac{Q_s + Q_w}{A} \right)$$

Substituting Equations (3) and (4) into Equation (2) yields

$$\frac{c_w}{c_o} = \frac{(Q_s + Q_w)}{2Q_w} \left[1 + j_o \operatorname{ctnh} a_o j_o L_2 \right] + \frac{2kKA}{Q_w U_s} \left[\frac{1}{j_s \operatorname{ctnh} a_s j_s L_1 + 1} \right] \quad (5)$$

Equation (5) gives the ratio of c_w/c_o at 0 (the outfall) for the assumptions made in the derivations. It is of interest to investigate this equation in detail to ascertain the importance of the coefficients K and Q_s , as well as the location of the outfall.

Highly positive estuaries. In highly positive estuaries, with Q_s being comparatively large, the importance of K is diminished. In fact, K may play an insignificant role in determining the value of the ratio c_w/c_o if the following conditions are fulfilled:

$$(1) \frac{4kK}{U^2} \rightarrow 0 \quad (\text{landward and seaward})$$

$$(2) \frac{k AK}{Q_w U_s} \rightarrow 0$$

and

$$(3) \frac{U^2 L^2}{4K^2} - \frac{k L^2}{K} \geq 16 \quad (\text{landward and seaward})$$

(Note: $\text{ctnh } X \rightarrow 1$ when $X \geq 4$.)

Note that condition (1) has the following form:

$$U^2 = \frac{(Q_s)^2}{A} \gg 4kK$$

If k were 0 (a conservative or nondecaying substance) then (1) is immediately fulfilled. If $k = 0.2/\text{day}$ (the approximate rate of BOD decay), then

$$\frac{(Q_s)}{A} \gg 2\sqrt{kK} = 0.107 \text{ ft/sec}$$

if K is taken equal to $5,000 \text{ ft}^2/\text{sec}$.

Condition (2) is automatically fulfilled if $k = 0$. Otherwise,

$$\frac{Q_w Q_s}{A^2} \gg kK = 0.0116 \text{ ft}^2/\text{sec}^2$$

for the same values of k and K as used previously.

Condition (3) depends on the location of the outfall as well as the parameters K , k , and U . For example, if $k = 0$, then

$$\frac{Q_s}{A} \geq \frac{40,000}{L_1} \left(\frac{\text{ft}}{\text{sec}} \right)$$

with L_1 in feet. A similar condition has to be fulfilled on the downstream side as well.

Neutral estuaries. In a neutral estuary, $Q_s = 0$. In this special case Equation (5) reduces to approximately

$$\frac{c_w}{c_o} = 1/2 + \frac{A\sqrt{kK}}{Q_w} \left[\text{ctnh } kL_2 + \frac{1}{\text{ctnh } \sqrt{kL_1}} \right]$$

If $k = 0$, Equation (5) becomes

$$\frac{c_w}{c_o} = 1/2 \left[1 + \text{ctnh} \left(\frac{Q_w L_2^2}{2AK} \right) \right]$$

Nontidal streams. In streams the coefficient K is generally much less than in estuaries, because there is a lack of tidal action and because the boundaries are usually more confined. Also, A is generally much less so that $U = Q/A$ is much greater. Finally, L_1 and L_2 may be very large. In most cases the inequalities (1), (2), and (3) are fulfilled and the effect of K is insignificant. In this case Equation (5) reduces to

$$\frac{c_w}{c_o} = \frac{Q_s + Q_w}{Q_w} \dots \dots \dots (6)$$

which is simple dilution effected by the net advection.

Marine outfalls with diffusers. In marine outfalls L_1 and L_2 are nearly unlimited so that the inequality is immediately fulfilled. In this case Equation (5) becomes

$$\frac{c_w}{c_o} = \frac{(Q_s + Q_w)}{2 Q_w} \left[1 + j_o \right] + \frac{2kKA}{Q_w U_s} \left[\frac{1}{1 + j_s} \right] \quad \dots \dots \dots (7)$$

More often Equation (6) is used in actual practice.

If Equation (6) could be made to apply, the concentration ratio c_w/c_o would be computable by quantities which might be estimated from hydrographic data. A test of the validity of using this simple equation might result from an example such as the following:

Given:

Waste Discharge - Domestic

$$Q_w = 10 \text{ MGD} = 15.4 \text{ cfs}$$

$$k = 0.008/\text{sec} \text{ (for coliform organisms)}$$

River

$$Q_s = 2000 \text{ cfs}, A = 1000 \text{ ft}^2$$

$$K = 20 \text{ ft}^2/\text{sec}$$

$$L_1 \text{ and } L_2 \rightarrow \infty$$

Estuary

$$Q_s = 2000 \text{ cfs}, A = 10,000 \text{ ft}^2$$

$$K = 500 \text{ ft}^2/\text{sec}$$

$$L_1 = 1000 \text{ ft}, L_2 = 10,000 \text{ ft}$$

Marine Outfall with 1000 ft diffuser

$$\text{Current} = 0.5 \text{ knot} = 0.85 \text{ fps}$$

$$\text{Effective depth of mixing} = 30 \text{ ft}$$

$$K = 10 \text{ ft}^2/\text{sec}$$

$$L_1 \text{ and } L_2 \rightarrow \infty$$

Calculate

c_w/c_o in each case:

Answers

River

$$U_s = \frac{2000}{1000} = 2 \text{ fps}$$

$$U_o = \frac{2015}{1000} = 2.02 \text{ fps} \approx U_s$$

By Equation (5), $c_w/c_o = 141$

By Equation (6), $c_w/c_o = 131$

Estuary

$$U_s = \frac{2000}{10,000} \approx 0.20 \text{ fps} = U_o$$

By Equation (5), $c_w/c_o = 2,610$

By Equation (6), $c_w/c_o = 131$

Marine Outfall

$$U_s = \frac{Q_s}{A} = 0.85 \text{ fps}$$

$$A = 1000 \times 30 = 30,000 \text{ ft}^2$$

$$Q_s = 0.85 \times 30,000 = 25,500 \text{ cfs}$$

$$U_o = \frac{Q_s + Q_w}{A} = U_s$$

By Equation (5), $c_w/c_o = 1,986$

By Equation (6), $c_w/c_o = 1,660$

It may be seen from these examples that all the terms included in Equation (5), except the advective term, are not particularly important in rivers, or even marine outfalls. In estuaries, however, significant differences may arise between the two equations (e.g., 2610 vs 131). From an engineering viewpoint this means that when a

line source is applied even in a vertically well-mixed estuary the concentration of any constituent in the water mass resulting from a waste discharge cannot be computed without taking into account longitudinal eddy diffusion. Furthermore, the parameters by which it can be taken into account are presently all but mathematically overwhelming. Hence it must be concluded that much additional experimental work must be done before engineered systems of predictable performance can be designed on the basis of quality objectives set forth for any individual estuary.

Dilution in Marine Waters

Although the use of Equation (6) to predict the c_w/c_o ratio for marine outfalls, subject to various assumptions, seems feasible the diffusivity cannot be overlooked in the practical case where ocean outfall design must be governed by the concentration of quality factors acceptable at beach areas. Development of the principles of ocean outfall behavior begins with a consideration of the dilution effected when a waste water is released from a single part into an overlying sheet of water of unlimited extent and having no advective velocity. Practical applications of such a concept might be the release of waste water into a relatively quiescent lake of comparatively great horizon. The lake water may or may not be stratified. The concepts and equations developed are of great value in estimating the dilution effected within the immediate vicinity of a rising jet. They must, however, take into consideration more complex problems of diffusion when the advection of ocean water is taken into account.

Forces acting on a rising jet. Two forces act to effect hydraulic dilution in a rising jet: these are the initial momentum of the jet and the buoyancy of the jet fluid in the surrounding medium. Hydraulically speaking, the momentum effect should be some function of the Reynolds number and the buoyancy some function of the Froude number. In

practical problems, however, the Reynolds number is so large as to have no appreciable influence on the dilution effected. The same is not true of the Froude number "F", where

$$\underline{F} = \frac{V}{\sqrt{D \frac{(P_s - P_w)}{P_w}}};$$

P_s and P_w are the densities of the surrounding medium and jetted fluid, respectively; D the diameter of the nozzle; and V the velocity of the discharging jet. However, as $P_w + P_s$, $\underline{F} + \infty$, so that in the case of sewage being discharged into freshwater of about the same temperature, \underline{F} will be large.

The effect of the water surface on the jet. Frankel and Cumming (5) investigated carefully the effect of a horizontal water surface on rising water jets of moderate Froude numbers in nonstratified waters. These investigators concluded that there exists a surface transition zone in which the dilution factor remains unchanged. In this zone the turbulence may be intense but additional dilution is scant because of relatively slight constituent concentration gradients. The effect of this transition zone appears to extend rather deeply along the axis of the rising jet. Frankel and Cumming estimated that this zone extended to a depth equal to 25 percent of the value of H/D , where H is the total depth of water above the port and D the diameter of the port.

Vertical jet of pure momentum ($\underline{F} = \infty$) in nonstratified waters. Assuming that a similar surface effect would be observed with water jets having an infinite Froude number as well as finite \underline{F} numbers, and using the theoretical equations of pure momentum dilution described by Abraham (1), the dilution effected along the axis of a vertical jet may be approximated by the following equations:

$$S_j = 0.192 \frac{V}{D}$$

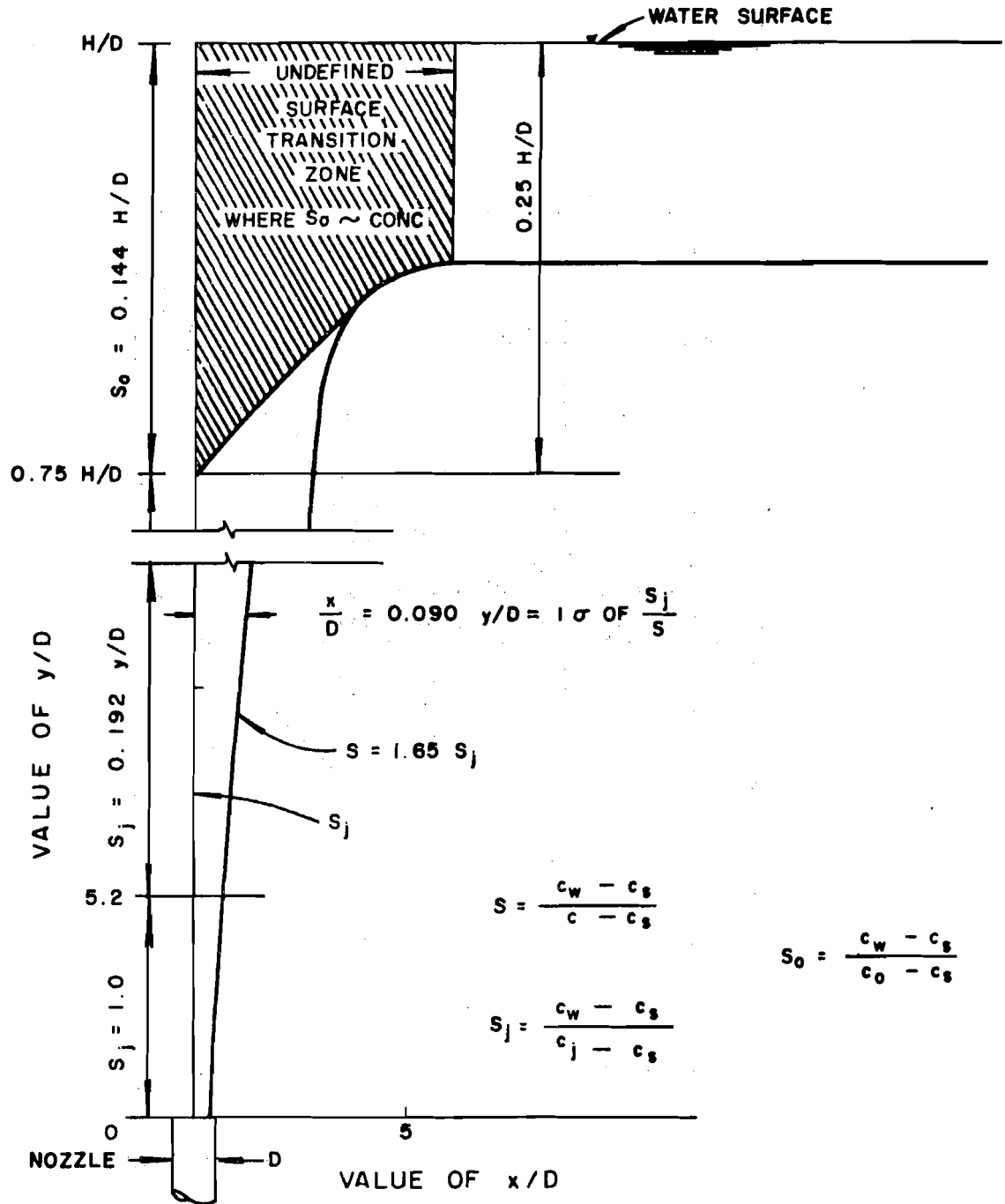


FIGURE 2-15. ANATOMY OF A VERTICAL JET WITH $F = \infty$

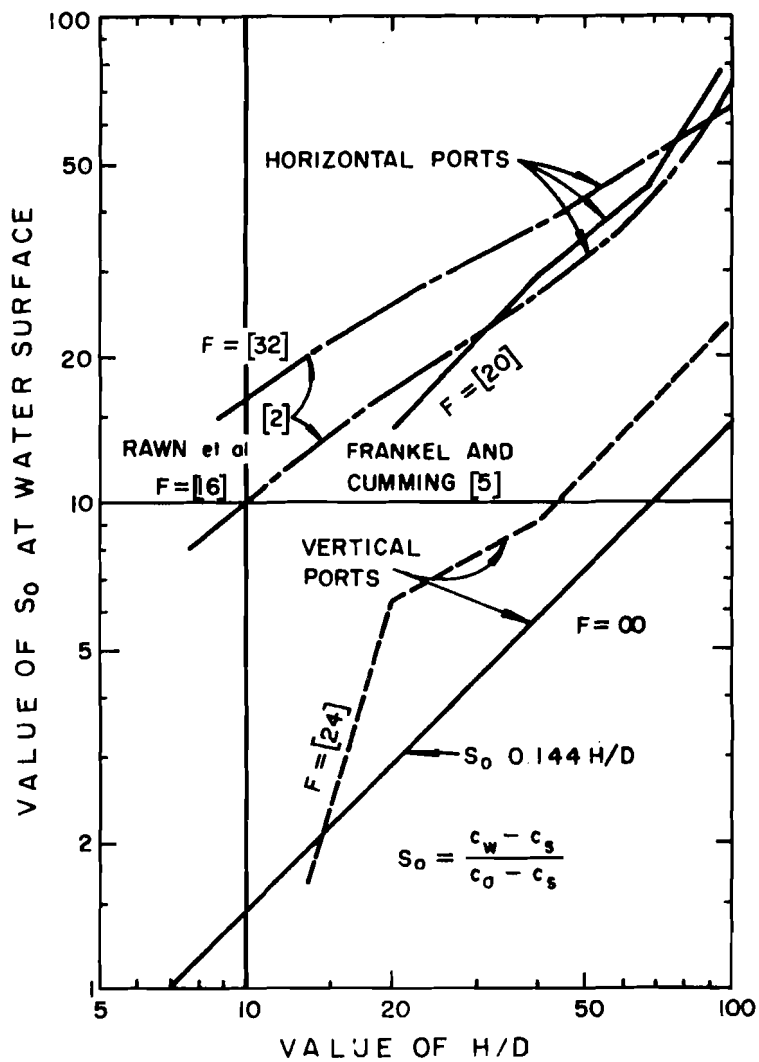


FIGURE 3-15. JET DILUTION AT HIGH FROUDE NUMBERS

The horizontal nozzles are much more effective in producing dilutions than vertical nozzles. Frankel and Cumming concluded that horizontal nozzles provide the best initial dilution, all other factors being held constant. The agreement between the horizontal jet observations of Frankel and Cumming (5) and those of Rawn and Palmer (9) is excellent considering the vast difference in the methods of conducting the two investigations. Both studies indicate that there is a comparatively small change in initial dilution effected for Froude numbers ranging from about 4 to 20 (data not presented in Figure 3-15). The observation with the greatest \underline{F} value (32) indicates an appreciable increase in dilution effected for the lower H/D ratios.

For vertical nozzles, Frankel and Cumming found that the value of S_0 increases with decreasing \underline{F} numbers, especially when $\underline{F} < 16$. However, S_0 appears to be decreasingly influenced by \underline{F} as \underline{F} increases (as predicted by theory) and appears to approach a lower limit as $\underline{F} \rightarrow \infty$.

Water stratification and depth of effective mixing. In the previous discussions of density of the waste effluent, P_w has been assumed to be always less than the density P_s of the surrounding water, or $P_w < P_s$. This gives a positive \underline{F} number.

In most actual cases of waste water being released into saline estuarine and marine waters, P_w is less than P_s . If P_s is approximately constant from the bottom to the water surface, then the waste water will rise to the surface and remain there (see Figure 2-15). The depth of the waste water field as it flows away from the source may be called the depth of effective mixing. In the case of nonstratified waters the depth of effective mixing will increase with distance from the source, reaching downwards until the bottom is attained. No doubt the time required to attain a uniform vertical distribution is dependent on the rate that the waste field is dispersed, both horizontally and vertically, and hence on the lateral and vertical coefficients of diffusion.

In stratified waters there will be a tendency for the waste field to be confined in one layer, since a density gradient acts as a physical barrier, limiting the exchange of waters from one layer to another. In this case the depth of effective mixing remains more or less constant.

In some cases the rising jet fluid will not penetrate a density gradient, but rather remains in the lower, more dense stratum. This situation is analogous to an inversion layer in the atmosphere in which waste gases are unable to penetrate the inversion layer and escape from a smog-bound basin.

In other cases, the residual momentum of the rising jet will be sufficient to penetrate the density structure but the dilution already effected has been so great that the waste plume will not maintain itself in the surface layer, but rather plunges back down into the lower layer. Hence, four cases can arise when a waste water is jetted into a receiving water:

1. The jet rises to the surface and then is gradually dispersed vertically from top to bottom in the receiving water (non-stratified case).
2. The jet rises to the surface and is confined in the layer situated above the density gradient.
3. The jet rises to the surface but plunges back downward into the layer lying beneath the density gradient.
4. The jet is always retained in the region beneath the density gradient.

The reason why a jet of waste water may be maintained in the lower layer is as follows: As the jet rises the waste water is diluted with the water of the denser bottom layer. If the dilution effected prior to reaching the gradient is sufficient, the water in the center of the rising jet will be actually more dense than the fluid of the upper layer. In this case the waste water will remain beneath the density gradient. A comprehensive discussion of this phenomenon is presented by Hart (6) (1961).

Unlike the problem of an inversion layer in atmospheric pollution, it is generally much more desirable to maintain the waste effluent beneath the density structure when considering problems of waste water disposal. In other words, the most critical case usually occurs when the rising jet penetrates the density structure and is confined in the uppermost stratum since this is the time when the waste constituents will be visually evident to the public. Hence, outfall designs are usually made for this case unless it is known that the density structure is of a permanent nature. However, if protection of bottom dwelling organisms becomes an objective of quality management, entirely different parameters must be used.

Status of engineered systems. From theoretical and experimental considerations the dilution of waste water by marine water in a rising jet may be estimated. Whether or not the mixed waters will reach the surface depends upon such factors as depth and the prevailing density-temperature structure. In a practical case the density depth characteristics of a particular site can be studied by such devices as the bathythermograph. However, if the site is subject to considerable upwelling of deep ocean waters, both temperature and salinity measurements are needed. From such information the likelihood that the waste-seawater mixture will reach the surface layer, where the most rapid transport occurs, is predictable. From other oceanographic data, nearshore circulation systems and the current structure at a given site can be evaluated in relation to the fate of the rising jet of mixed water and of any plume of the mixture as it flows from the jet.

On the basis of such factors as the foregoing, estimates have been made of water mass velocity, mixing depths, eddy diffusion, bacterial concentrations, and numerous marine outfalls based on these estimates have been designed and constructed. Among the largest ever undertaken is the 12-foot diameter submarine outfall of the City of Los Angeles, which terminates 5 miles offshore in 192 feet of water. Monitoring of

the area indicates that it is successful in keeping pollutants off the beaches and transporting the mixed waste and seawater away from the area beneath the surface.

For the most part, however, the linkage between theory and design remains tenuous in the extreme. Engineering judgment derived from theoretical analyses, oceanographic data, experience, and other factors cited in the literature (1, 2, 3, 4, 5, 6, 7, 8, 9) is the major factor in successful marine outfall design. A great deal more will have to be known before the engineer, given the quality requirements of the water mass for the protection of beaches, aquatic life, bottom organisms, etc., can design an outfall system of reasonably predictable performance.

References

1. Abraham, G. "Jet Diffusion in Liquid of Greater Density." Journal of the Hydraulics Division, ASCE, 86(HY6):1-15, June 1960.
2. Brooks, N. H. Report on Methods of Analysis of the Performance of Ocean Outfall Diffusers with Application to the Proposed Hyperion Outfall. Hyperion Engineers, Los Angeles, 1956.
3. Brooks, N. H. "Diffusion of Sewage Effluent in an Ocean Current." Proceedings, 1st International Conference on Waste Disposal in the Marine Environment, Berkeley, California, July 1959. Pergamon Press, 1960.
4. California State Water Quality Control Board. Collation, Evaluation, and Presentation of Scientific and Technical Data Relative to the Marine Disposal of Liquid Wastes. Sacramento, 1964.
5. Frankel, R. J., and J. D. Cumming. "Turbulent Mixing Phenomena of Ocean Outfalls." Journal of the Sanitary Engineering Division, ASCE, 91(SA2):33-59, April 1965.
6. Hart, W. E. "Jet Discharge into a Fluid with a Density Gradient." Journal of the Hydraulics Division, ASCE, 87(HY6):171-200, November 1961.

7. Pearson, E. A. An Investigation of the Efficiency of Submarine Outfall Disposal of Sewage and Sludge. California State Water Pollution Control Board Publication No. 14, 1955.
8. Rawn, A. M., F. R. Bowerman, and N. H. Brooks. "Diffusers for Disposal of Sewage in Sea Water." Journal of the Sanitary Engineering Division, ASCE, 86(SA2):65-105, March 1960.
9. Rawn, A. M., and H. K. Palmer. "Predetermining the Extent of a Sewage Field in Sea Water." American Society of Civil Engineers Transactions 94:1036-81, 1930.

XVI

QUALITY MANAGEMENT BY ENGINEERED PONDS

by W. J. Oswald

Introduction

The purposeful addition of organic wastes to surface ponds antedates history. During ancient times in the Orient and in Europe, and at present in many places throughout the world, ponds fertilized with organic wastes, as well as with inorganic fertilizer, have been constructed and operated to encourage algal growth and thereby greatly increase the areal yield of fish which feed directly or indirectly upon algae. (4) The purification of sewage in fish ponds has been a recognized art in Germany for nearly half a century. (15) In America, however, fish ponds have not been used intentionally for sewage treatment. In fact the first waste stabilization ponds in the United States evidently were built for the purpose of excluding waste waters from other sectors of the water resource in which they would be objectionable. Once built, however, the waste purification potential of ponds became increasingly evident to the observer. Following the description of ponds at Santa Rosa, California, in 1924 by Gillespie (6), a succession of papers described the behavior of several specific pond installations. More recently a growing body of technical and scientific literature (5) (11) have placed stabilization pond design on an increasingly rational basis.

It is now widely recognized that when properly designed and operated, stabilization ponds will develop a population of organisms which will degrade organic matter and subsequently convert the low energy products of degradation into high energy algal cells. If these cells are then harvested from the liquid, the final effluent is of a quality superior to that produced by conventional waste treatment processes. In terms of the aerobic cycle of growth and decay presented in Chapter III, it may be said that whereas the normal treatment system degrades

organic matter to stable fertilizer compounds which remain in the water without exerting an oxygen demand, the pond system goes further to pick up these fertilizers and incorporates them into living cells again. Thus if the cells are removed, the mineral content of the treated water is reduced and its ability to cause eutrophication of receiving waters greatly diminished. On the other hand, if algal cells are not harvested, the pond itself represents a highly eutrophied body of water but its effluent is as highly stabilized as is possible with any normal engineered system.

When the low cost of the stabilization pond is considered along with its ability to upgrade the quality of water, it is evident that such a system is a device for water quality management worthy of engineering attention, particularly where land areas and geographical relationships are favorable.

General Concept of Stabilization Ponds

The term "stabilization pond" is generally applied to artificially created bodies of water intended to retain waste flows containing degradable organic compounds until biological processes render them stable and hence either unobjectionable from an oxygen demand viewpoint for discharge into natural waters, or are removed by percolation and evaporation. The theoretical minimum time of such retention is that sufficient to permit biodegradation of organic matter and die-away of pathogenic bacteria and parasites. The theoretical maximum time, from a quality control viewpoint, is the maximum time plus that necessary to tie up the stable products of biodegradation in algal cells. In practice, however, the design detention period, or pond capacity, may be governed by requirements of controlled discharge imposed by quality management considerations of the receiving water.

Types of Stabilization Ponds

Stabilization ponds may be classified according to types of influent, outflow condition, methods of oxygenation, biological processes, etc.

Typical general classes are as follows:

1. Types of Influent

- (a) Raw sewage ponds, or lagoons: influent sewage directly from municipal sewer without treatment.
- (b) Screened sewage ponds: influent sewage screened or comminuted.
- (c) Primary sewage ponds, or oxidation ponds: influent sewage is effluent from primary sedimentation system.
- (d) Secondary sewage ponds: influent sewage is effluent from secondary sewage treatment system.

2. Outflow Conditions

- (a) Percolation beds: outflow by evaporation and percolation in soil exceeds influent rate.
- (b) Nonoverflow ponds: outflow by evaporation and percolation equals influent plus precipitation.
- (c) Intermittent ponds: no outflow during dry season but discharge effluent during wet periods.
- (d) Overflowing ponds: effluent discharged continuously.

3. Methods of Oxygenation

- (a) Mechanical aeration: water aerated essentially continuously by brushes, low-head propeller pumps, floating aerators, etc. (Principles of "total oxidation" activated sludge apply; sludge must be withdrawn.)
- (b) Photosynthetic oxygenation: during growth and photosynthesis, algae produce dissolved oxygen in amounts equal to or greater than the oxygen demand (BOD) of the applied waste.

4. Biological Processes

- (a) Aerobic ponds: loaded so that aerobic conditions prevail and biological processes mainly bio-oxidation and photosynthesis.

- (b) Anaerobic ponds: loaded to such extent that anaerobic conditions prevail through water mass. Biological processes primarily organic acid formation and methane fermentation.
- (c) Facultative ponds: divided by loading and thermal stratification into aerobic surface and anaerobic bottom strata.

From the foregoing summary, it is evident that any single pond may fall into several classifications. For example, a pond may be an aerobic primary or secondary pond, overflowing or intermittent, etc. On the other hand, it may not be a raw sewage nonoverflow pond.

Fundamental Principles of Stabilization Ponds

Although stabilization ponds are physically nothing more than simply constructed shallow (5-6 ft) earthwork basins, their effectiveness depends upon a complex interaction of physical, chemical, and biological processes. In natural ponds, however, these processes proceed without the watchful eye of highly competent chemists and microbiologists. Moreover, a minimum amount of engineering, construction, and mechanical equipment is required. These factors, together with the tendency for industrialized nations to utilize mechanized treatment processes, long diverted scientific attention away from the stabilization pond as a practical water quality control system. Engineering attention began largely in the context of providing a cheap substitute for sewage treatment for communities too poor to afford modern works, but as the merit of ponds became evident, attention was turned to the underlying principles and parameters of design.

One of the first fundamental principles underlying the most used types of stabilization ponds is that their action depends upon the simultaneous and continuous functioning of both the right-hand and left-hand sectors of the aerobic cycle of organic growth and decay (figure page 19). Here it is in contrast with the conventional system which carries out only the degradation process and leaves the growth potential

to be exerted in the receiving water as described in Chapter X. Figure 1-16 illustrates the synergistic activity of bacteria and algae in photosynthetic oxygenation. Here it is significant that although the system is internally self-sufficient the input is biodegradable dead organic wastes and the output is living organic matter at a higher energy level. Hence the potential oxygen demand (BOD) of the effluent may be greater than that of the influent, provided of course that the organic waste is sewage or other partially degraded organic matter. The living cells, however, are not quickly available for biodegradation because of their tenacity of life. Nevertheless, in terms of water quality, the stabilization pond effluent may substitute an aesthetic factor for the quality factors associated with biodegradation unless the algal cells are harvested.

To express these two factors in more precise terms it may be said that the waste matter entering the system has some definite BOD which when satisfied through biodegradation produces stable products having an Algal Growth Potential (AGP). AGP may be defined as the weight of algae which will grow at the expense of algae nutrients in a water when no factor other than nutrient is limiting to growth.

The relationship between BOD and AGP is illustrated in Figure 2-16. AGP, whether it be generated in a stabilization pond or in a conventional system must be considered a factor in water quality. The significant fact is that it may have to be controlled either by harvesting algae from the pond effluent or by nutrient removal from the conventional plant effluent, neither of which is economically acceptable at the present time. A further factor to be considered in relation to the water quality effects of stabilization ponds or conventional works is the possibility of growth stimulation by effluents from which nutrients have been removed. That is to say that effluents which in themselves do not contain nitrogen or phosphorus may contain other factors (trace elements, vitamins, etc.) capable of triggering eutrophication of receiving waters which contain nutrients but are limited by certain growth factors in

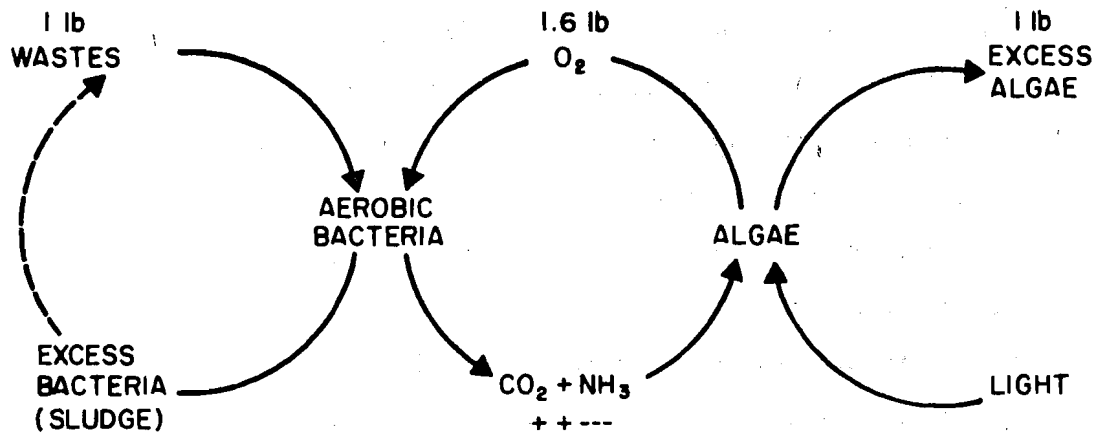


FIGURE 1-16. THE CYCLE OF PHOTOSYNTHETIC OXYGENATION

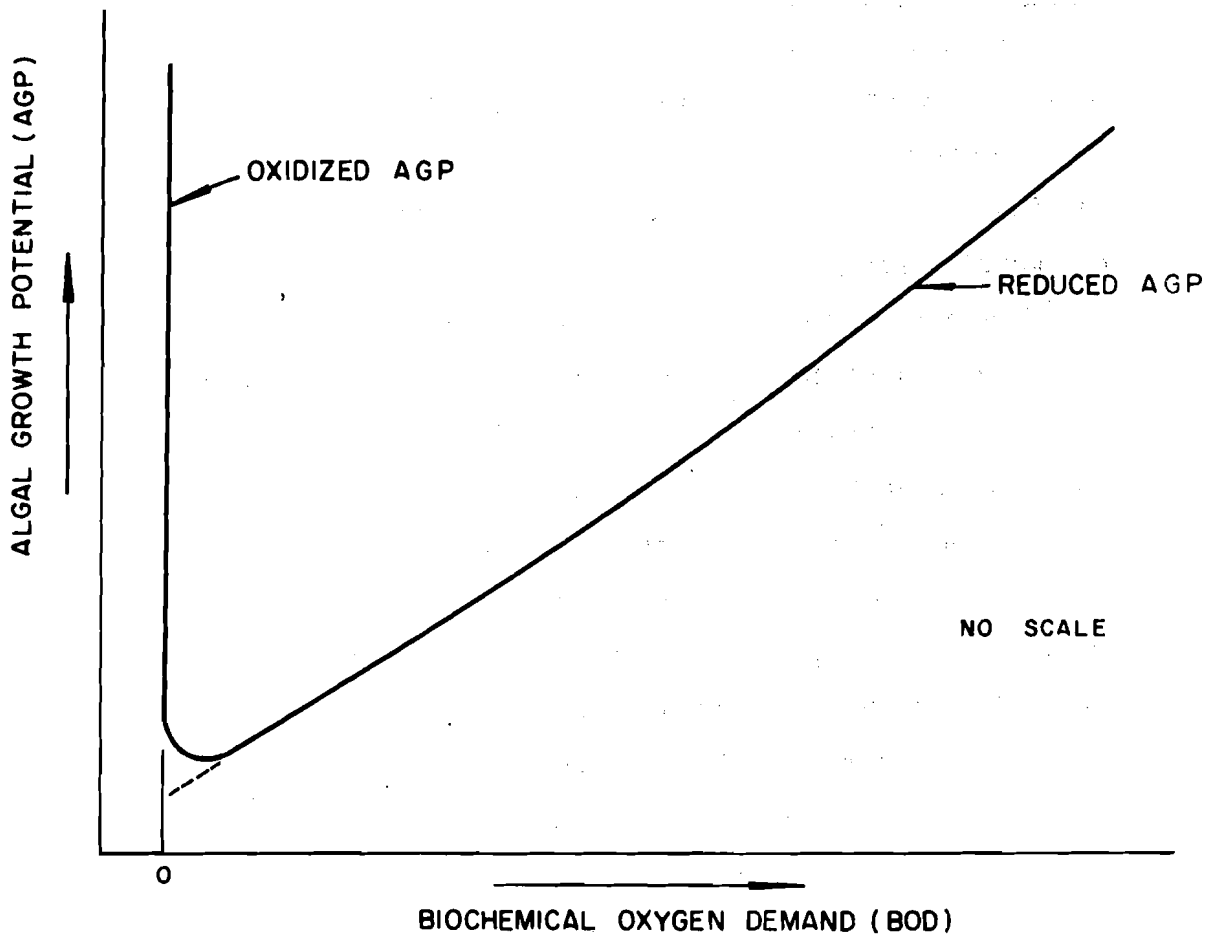


FIGURE 2-16. RELATIONSHIP BETWEEN AGP AND BOD

their ability to support life. Hence quality management may involve productivity tests not commonly utilized in the past.

The simultaneous processes of growth and decay in stabilization ponds are affected by numerous environmental factors. Insolation and radiation, temperature and thermal gradients, pond geometry, wind, gas exchange, and seeding are among the most important which have been evaluated experimentally (11). The biochemical activity involves typical carbon, nitrogen, sulfur, and phosphate transformations, as well as more subtle reactions, all of which vary with the type of pond. Principal reactions are summarized in Table 1-16 and their interactions shown schematically in Figure 3-16.

Engineering Design Considerations (12)(13)

A number of considerations enter into the design of a stabilization pond. In general they concern the physical integrity of the structure or the determination of pond size. For example, a nonoverflow pond must be of adequate size to dispose of the influent by a combination of evaporation and percolation at all seasons of the year. A mass diagram based on anticipated influent rates, seasonal rainfall, local evaporation rates throughout the year, and equilibrium percolation rates can be utilized in the normal engineering fashion to establish the surface area and embankment freeboard requirements. Most of these data can be readily estimated from normally available data. Percolation rates, on the other hand, are not so easily determined. The equilibrium rates for most soils may be quite small. In some small stabilization ponds in California percolation rates of 0.3 inch per day have been observed. Table 2-16 gives data for combined evaporation and percolation for some small ponds in central California.

Based upon currently available data, a conservative rule of thumb for estimating purposes in average soil in semiarid climates is 10,000 to 15,000 gallons per acre per day outflow via percolation and evaporation combined.

Table 2-16. Percolation Plus Evaporation Rates as a Function of Soil Types

Pond System Observed	Pond Size Acres	Pond Depth Inches	Soil Type	Approx. Terminal Rate*	
				Inches Day ⁻¹	Gallons Acre ⁻¹ Day ⁻¹
Woodland South	2	60	Heavy silty clay	0.40	11,000
Esparto, Jul., Aug.	2	72	Light silty clay	0.66 ¹	18,000
Esparto, Feb., Mar.	2	72	Light silty clay	0.25 ²	6,800
Woodland North	2	60	Alkaline silt	0.73	20,000
Woodland Pilot	1/4	60	Alkaline silt	0.75	20,200
Gonzales	3	72	Fine sand	1.3	35,000
Rio Lindo	1/2	72	Gravel with silt	1.5	41,000

* Includes evaporation which may average 0.1 inch per day, and equal 0.3 inch per day during summer. These rates apparently decrease in winter and increase slightly during summer f(viscosity) and (gasification).

¹ July, Aug. evaporation = 0.33 inches per day, therefore Perc. = 0.33 in/day.

² In California evaporation and precipitation are usually equal. In March therefore loss is primarily due to percolation alone.

Design parameters which must be established for stabilization ponds include detention period, hydraulic loading, organic loading, depth, recirculation, mixing, pond size and shape, and inlet and outlet system.

1. Detention Period

The detention period necessary to accomplish the function of a stabilization pond depends, of course, upon the type of pond and, hence, the nature of the reactions upon which it depends; the type of waste applied; and various environmental conditions. A summary of such characteristics and environmental factors for various types of ponds receiving domestic return flow is presented in Table 3-16.

In a pond of depth (d), length (l), and width (w), the detention period (D) is described by the simple equation:

$$D = \frac{\text{Volume (V)}}{\text{Influent rate (Q)}} = \frac{wld}{Q}$$

Selection of the appropriate detention period for various types of ponds is subject to the following considerations:

- (a) **Aerobic ponds:** Photosynthetic oxygen production is equated to the oxygen demand of the waste. A determinant time is required for accumulation by algae of sufficient sunlight energy to liberate the required oxygen, according to the following equation. (13)

$$\frac{d}{D} = \frac{0.66 FS}{L_a}$$

where F = oxygenation factor (Figure 4-16)

S = solar radiation (Table 4-16)

d, D, and L_a are as previously noted.

TABLE 3-16.

Summary of Characteristics and Environmental Requirements of
the Major Biological Reactions in Waste Disposal Ponds

Biological Reaction	Characteristics					Environmental Factors				
	Organisms	Usual Substrate	Major Products	Time Required (days)*	Odors Produced	Temp. °C Perm.** Opt.	Oxygen	pH	Light	Toxic Compounds
Aerobic Oxidation	Aerobic Bacteria	Carbohydrates, proteins	CO ₂ +NH ₃	5 - 10	None	$\frac{0-40}{15-30}$	Required	7.0- 9.0	Not required	Cr ⁺⁺⁺ , NH ₃ +
Photo-synthetic Oxygenation	Algae	CO ₂ , NH ₃	Oxygen, algae	10 - 20	None	$\frac{4-40}{15-25}$	Required Under Certain Conditions	6.5-10.5	Required	Ca ⁺⁺ , Cl ₂ , Cr ⁺⁺⁺
Acid Formation	Facultative Heterotrophs Bacteria	Carbohydrates, Proteins, Fats	Organic acids	10 - 20	H ₂ S Org. Acids	$\frac{0-50}{10-40}$	Required Under Certain Conditions	4.5- 8.5	Not required	Cr ⁺⁺⁺ Cl ₂
Methane Fermentation	Methane- Producers	Organic acids	CH ₄ , CO ₂ H ₂	40 - 50	H ₂ S	$\frac{6-50}{14-30}$	Must be excluded	6.8- 7.2	Not required	O ₂ , detergents

* Time required after first initiation of pond to develop a stable population.

** Permissible range
Optimum range

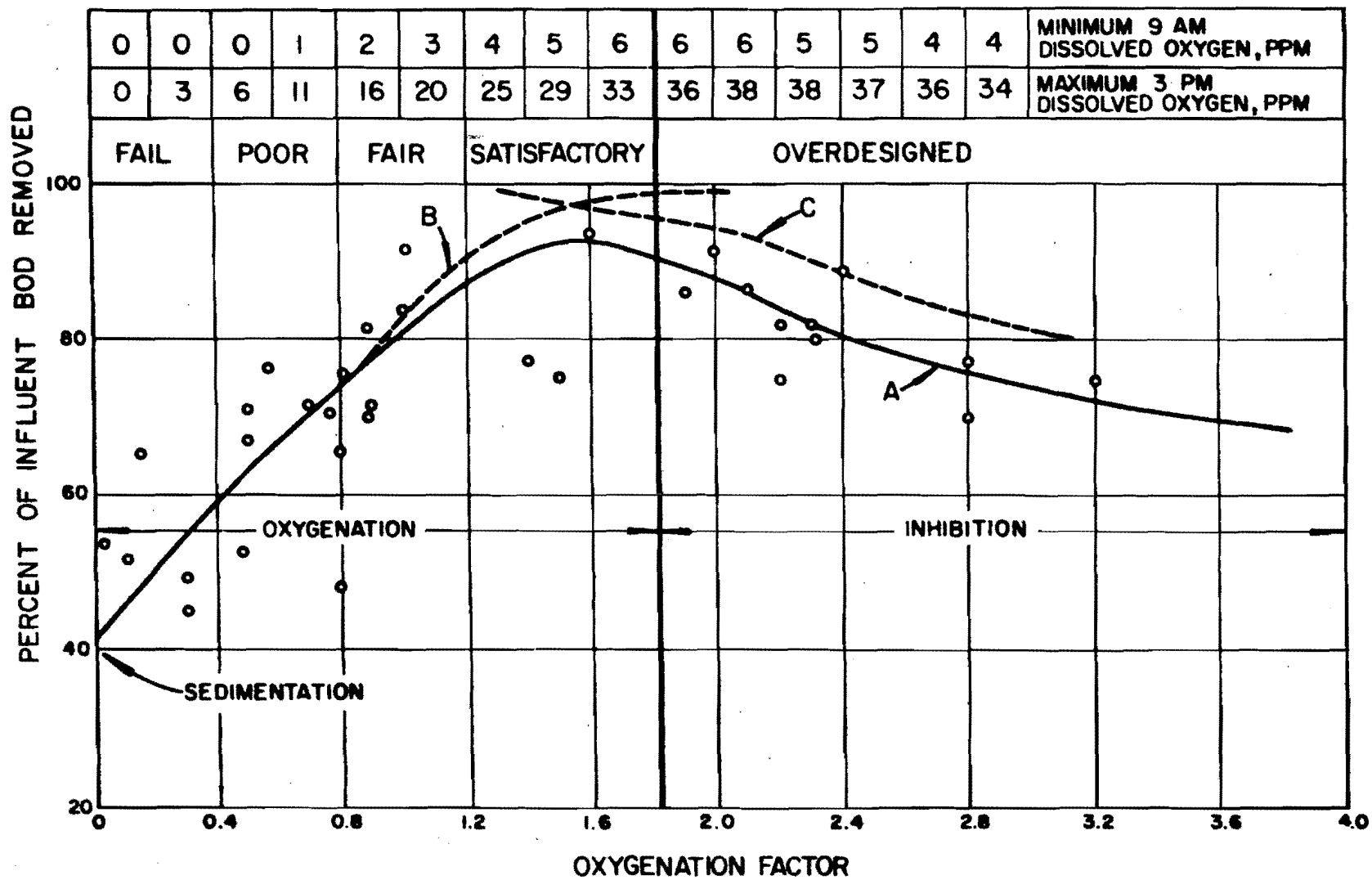


FIGURE 4-16. RELATIONSHIP BETWEEN OXYGENATION FACTOR AND BOD REMOVAL IN WASTE PONDS

TABLE 4-16.

Probable Values of Visible Solar Energy as a Function of Latitude and Month

Latitude	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 max	255 ^a	266	271	266	249	236	238	252	269	265	256	253
min	210	219	206	188	182	103	137	167	207	203	202	195
10 max	223	244	264	271	270	262	265	266	266	248	228	225
min	179	184	193	183	192	129	158	176	196	181	176	162
20 max	183	213	246	271	284	284	282	272	252	224	190	182
min	134	140	168	170	194	148	172	177	176	150	138	120
30 max	136	176	218	261	290	296	289	271	231	192	148	126
min	76	96	134	151	184	163	178	166	147	113	90	70
40 max	80	130	181	181	286	298	288	258	203	152	95	66
min	30	53	95	125	162	173	172	147	112	72	42	24
50 max	28	70	141	210	271	297	280	236	166	100	40	26
min	10	19	58	97	144	176	155	125	73	40	15	7
60 max	7	32	107	176	249	294	268	205	126	43	10	5
min	2	4	33	79	132	174	144	100	38	26	3	1

^a Values of S in cal per sq cm per day.

To determine average value of S: $S_{ave} = S_{min} + p (S_{max} - S_{min})$ in which p = total hr sunshine divided by total possible hr sunshine.

To determine yield of algal cell material, in lb of algal cell material per acre per day: $Y_c = 0.15 FS$.

To determine yield of oxygen, in lb of oxygen per acre per day: $O_2 = 0.25 FS$.

For best light utilization the required detention period rarely exceeds five days. In Table 4-16, values for visible solar energy are tabulated.

- (b) **Facultative ponds:** Detention period is selected to provide either suitable time for coliform die-away or sufficient time to permit combined evaporation and percolation to equal the influent volume, depending upon which of the two is required by pollution control considerations. It is rarely that the detention period is designed to be so short that suspended solids removal or even BOD removal is hampered by lack of time. However, even though detention periods may be as long as 120 days, effluent BOD rarely falls below 15 ppm.
- (c) **Anaerobic ponds:** Detention period selected to permit complete anaerobic breakdown without diminishing the organic load rate. To assure anaerobic conditions organic load should exceed 200 pounds per acre per day. Detention periods are best made long by providing as much depth as is feasible.

2. Hydraulic Loading

Hydraulic loading (U) is normally expressed in terms of inches per day, therefore it is equal to Q/A , or in terms of detention period:

$$U = \frac{d}{D}$$

Typical values for various types of ponds are:

- (a) **Aerobic ponds:** Hydraulic load usually limited to 2 to 10 inches per day.
- (b) **Facultative ponds:** Hydraulic load usually limited by overflow requirements. Overflow may be equated to evaporation

and percolation for nonoverflowing systems. Maximum recommended hydraulic load is about 1.5 inches per day for domestic waste.

- (c) Anaerobic ponds: Hydraulic load should be selected to give 40 or more days of detention period to permit complete digestion.

3. Organic Loading

Organic loading (L_o) is expressed in pounds of BOD per unit area of pond surface per day (pounds/acre/day). It is proportional to the hydraulic load and the organic concentration (L_a) or ultimate BOD. Therefore

$$L_o = 0.226 \frac{d}{D} L_a$$

in which the constant 0.226 is the conversion factor from mg/l BOD to pounds/acre/day.

Typical organic loadings for various pond types are:

- (a) Aerobic ponds: Maximum organic load about 200 pounds of ultimate BOD per acre per day, but load is dependent upon available sunlight energy. (12) A first approximation is

$$L_o = S$$

in which L_o is the ultimate BOD to be satisfied in pounds per acre per day, and S is the quantity of sunlight energy in cal per cm^2 per day. (See Table 4-16.)

- (b) Facultative ponds: Maximum load is based upon mass diagram for gas evolution, since evolution of methane is major method of carbon escape. Mass diagram of gas evolved from pond in Woodland, Northern California,

indicated an average rate of organic loading 50 lbs of ultimate BOD per acre per day. If 50 lbs of BOD per acre per day is exceeded continuously, it is believed that the effects of eutrophication will become evident within three to five years.

- (c) Anaerobic ponds: Permissible loading is a function of rates of methane evolution and organic overflow. Maximum BOD removal in anaerobic ponds is about 70 percent. Therefore anaerobic ponds must discharge to secondary ponds.

4. Depth

Considerations in the selection of pond depth and the normal values used are:

- (a) Aerobic ponds: Algae concentration is inverse function of depth; light conversion efficiency increases with depth. Yield of algae or oxygen is product of efficiency and concentration. Maximum yield and concentration occurs with pond depth held at 6 to 12 inch depths. However, if oxygen production is the sole objective, depths of 36-48 inches are desirable.
- (b) Facultative ponds: Selected depth should be such that the summer thermocline occurs several feet above the pond bottom, so as to provide a sufficiently deep stratum in which sludge accumulation and digestion can take place below the thermocline. This criterion is usually best met by maintaining depths of 60 to 72 inches. Ponds as deep as 96 inches are now observed to operate satisfactorily. A cone shaped central well surrounding a central inlet forms an excellent digester. Cone depths of 3 or 4 feet are used.
- (c) Anaerobic ponds: Depth selected to provide minimum surface area to volume ratio for heat retention and to provide

detention period for alkaline digestion. Criteria usually best met by maintaining depths of 96 to 168 inches.

5. Recirculation

Recirculation of the contents of stabilization ponds is necessary in some cases, and not in others.

- (a) Aerobic ponds: In high rate ponds recirculation is essential because it provides influent oxygenation and seeding. A recirculation rate of at least $2Q$ is desirable.
- (b) Facultative ponds: Recirculation is only justified if edge or corner inlet is used; if ponds are long and narrow; or, if loading in primary ponds of a series exceeds the maximum at which aerobic surface conditions can be maintained. In each case recirculation should be applied with incoming sewage and the anticipated temperature of recirculant should be considered in calculations so as to avoid cooling the influent sewage to temperatures below that needed for digestion.
- (c) Anaerobic ponds: Recirculation of actively digesting sludge from the anaerobic zone into incoming waste is feasible providing there is no entrainment of oxygen into the digesting bottom layer. Submerged application is recommended for the prevention of the escape of odors.

6. Mixing

- (a) Aerobic ponds:
 - (1) Mixing is essential for the commingling of the settleable bacterial sludge and the algae which remain in the supernatant. Mixing may be accomplished by flow-through, using air lift pumps, propeller pumps, brush aerators, or various other methods. Around the end baffles with propeller pumps believed to be most economical.

- (2) Mixing systems should create a velocity of at least 1/2 foot per second throughout the matrix of the culture. City of Concord mixing system uses velocity of 1/2 foot per second. University pilot high rate pond uses 1 foot per second.
- (3) Mixing best applied.
 - (a) At night during the period when dissolved oxygen is at a level below saturation (usually between midnight and 5 a. m.).
 - (b) When the pH of the culture exceeds 9.5, so that CO₂ may be replenished in the supernatant.
- (b) Facultative ponds:
 - (1) Mixing is not required for facultative ponds to which the BOD loading is 30-60 pounds per acre per day.
 - (2) In aerated facultative ponds mixing should be applied only to the aerobic zone, and then mainly at night.
- (c) The effect of mixing on anaerobic ponds has not been studied, but it is obvious that aeration with oxygen must be avoided since oxygen is toxic to the methane bacteria. Some mixing is naturally provided by rising gas bubbles when vigorous fermentation is in progress. Vigorous gasification prevents formation of thermocline.

7. Pond Size and Shape

- (a) Aerobic ponds (photosynthetic oxygenation): Maximum size of individual ponds should be about 10 acres. (Size is governed by depth, heat loss during mixing, and channel width.) An extensive mixing facility is required for channels which are in excess of 50 feet wide. Power for mixing is about 3 KWH per acre per day. A length to width ratio of 4:1 is optimum for overall pond. Channel lengths of 10,000 feet not uncommon.

(b) Facultative ponds:

- (1) Overflowing ponds: No size limitation other than cut and fill balance in earthwork consideration. However small ponds give superior performance. Small size is ideal since lateral percolation is maximized and problems of wind mixing and erosion minimized.
- (2) Nonoverflowing ponds: Percolation of liquid into levees may dispose of significant quantities of effluent into the ground. Individual ponds as small as 1/4 acre are feasible. Two acre square ponds arranged in tetrads is an excellent configuration. In square ponds, corner radii should not be less than 40 feet.

(c) Anaerobic ponds:

- (1) Overflowing ponds: One half to two acre sizes. Length to width ratio of 2:1 to 4:1 will provide inlet and outlet separation.
- (2) Nonoverflowing ponds: Size should be selected to minimize surface area to volume ratio, thereby conserving heat. May be square-shaped with rounded corners.

8. Inlet and Outlet Arrangements

- (a) Aerobic ponds: Arrange to avoid short-circuiting during periods when mixing is not in progress. Inlet is usually on discharge side of mixing system, outlet on intake side of mixing system. Check valves on pump outlets, avoid backflow. Outlet arranged to decant overflow.
- (b) Facultative ponds:
 - (1) Inlets. Central inlets superior to all others. Sludge deposition will then be entirely submerged and sludge will be protected from aeration. Inlet pipe should be turned up and extended about 18 inches to

avoid possibility of clogging. See Figure 5A-16.

(2) Transfer structures. Simple pipes through the levee are satisfactory providing erosion control at the discharge is used. A superior transfer structure uses the decanting and submerged discharge principle. A typical system is shown in Figure 5A-16.

(3) Outlet should be decanted from surface outlets, should be located downward so that outlet skims pond. Final pond in series may have submerged discharge to avoid putting scum in receiving body. See Figure 5B-16.

(c) Anaerobic ponds: Same as facultative ponds except that inlet pipe should extend upward about 5 feet to avoid clogging. (See Figure 5C-16.)

9. System Arrangements

The arrangements of ponds into systems of various types is diagrammed in Figure 6-16 in which flow patterns are shown for single ponds and for groups of two, three, and four ponds. Parallel ponds give maximum load distribution, whereas series ponds have the advantage of producing superior effluents (9).

10. Miscellaneous Design Considerations

(a) Pond Linings

(1) Aerobic ponds: Rapidly mixed photosynthetic oxygenation ponds should be lined if most effective oxygenation is to be attained. Lining is not essential if the velocity is low although mixing may cause undue turbidity, resulting in increased light adsorption and severe light limitations for the algae. Linings may be of asphalt, gunnite, or plastic. Galvanized sheet iron forms a suitable lining for small ponds, since carbon dioxide removal by algae causes the pond

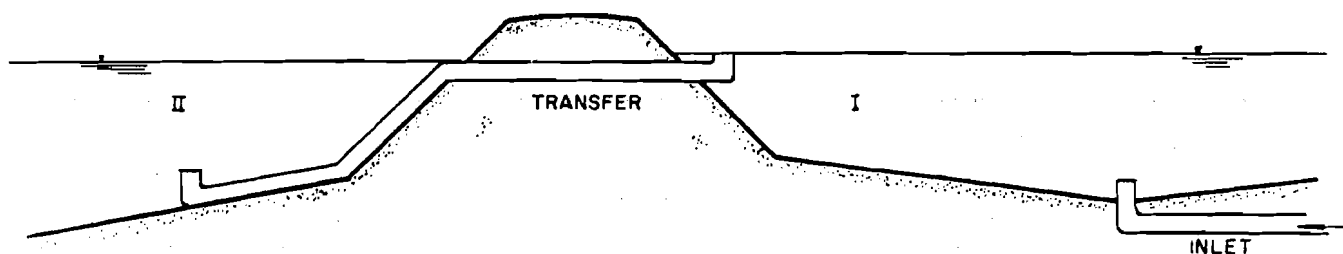


FIGURE 5A-16. SUPERIOR INLET AND TRANSFER STRUCTURE DESIGN

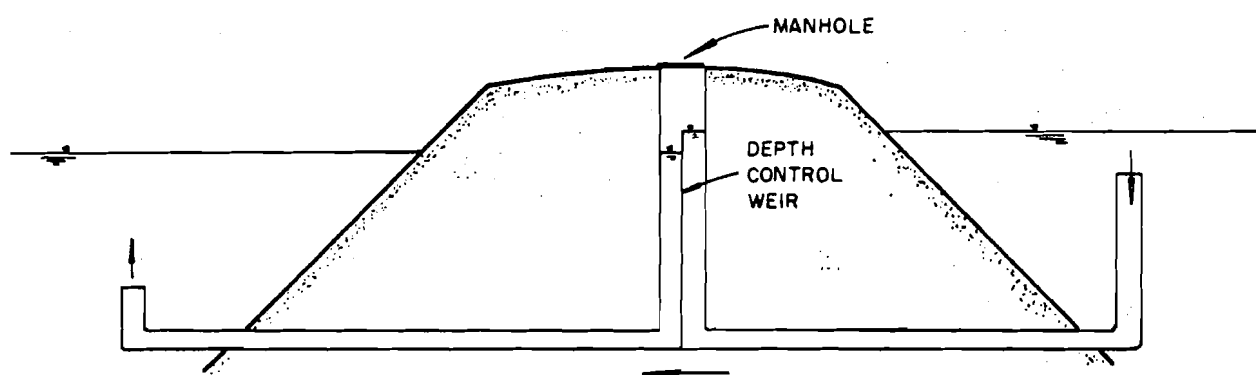


FIGURE 5B-16. SUBMERGED EFFLUENT STRUCTURE

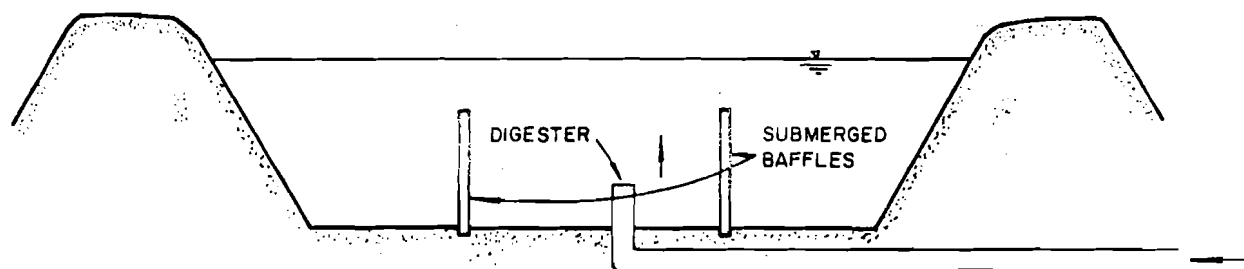


FIGURE 5C-16. TYPICAL USE OF SUBMERGED BAFFLES TO PROVIDE DIGESTER

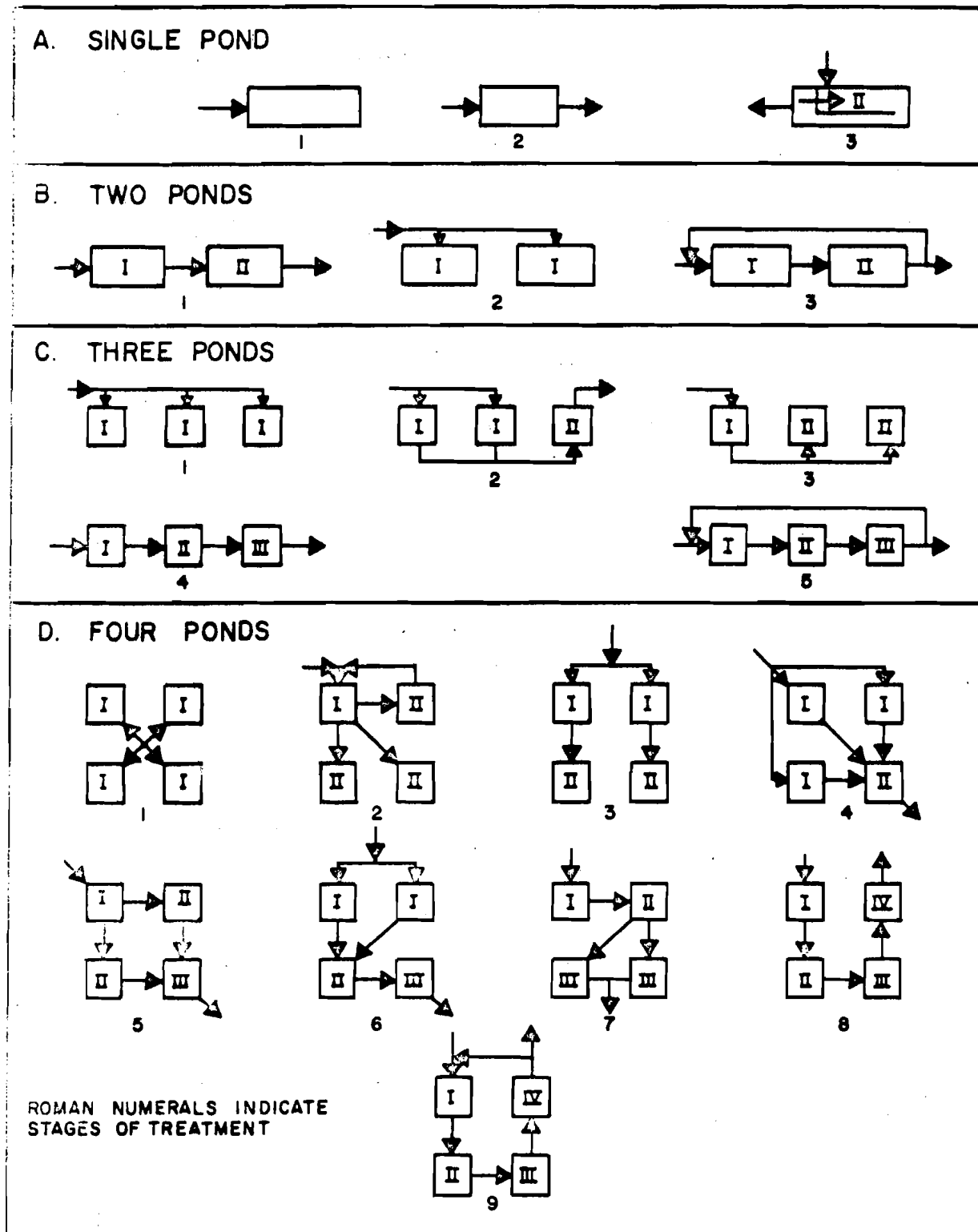


FIGURE 6-16. FLOW PATTERNS FOR WASTE STABILIZATION SYSTEMS

water to have a positive Langelier Index with deposition of insoluble substances on the metallic surfaces (7). Deep aerobic ponds need not be lined if scouring velocity is not exceeded, that is, if velocity is below 1/2 foot per second.

- (2) Facultative and anaerobic ponds: Linings not required for the fostering of any fundamental reactions. Linings may be applied to prevent excessive rates of percolation or bank erosion. Cost of linings is high because of the large pond areas involved. Liners may be of plastic, clay, or compacted earth.

(b) Levee Slopes

- (1) Aerobic ponds: Levees need not be high, and since they should be lined, may be constructed with slopes sufficiently flat to permit operation of paving machines. Recommended minimum slopes: 4:1.
- (2) Facultative ponds: Recommended interior levee slopes: 4:1 to 6:1. Exterior slopes: 3:1. Waterline may be paved to prevent beaching. Rip rap should not be used as a substitute for shallow slopes.

(c) Levees

- (1) Width: Since levees will provide percolation in proportion to their size, design size should be generous. Recommended minimum top width, 14 feet. Levee crown should be rounded to prevent impoundment of rainwater.
- (2) Redwood or precast concrete baffles may replace inner levees in high rate ponds or in overflowing ponds when water surface area must be kept at a maximum and land is at a premium. Submerged baffles may be used to create an anaerobic zone.

- (d) Freeboard: Minimum recommended freeboard, 2.0 feet. Maximum freeboard governed by anticipated wave size (usually 1/2 the depth).
- (e) Appurtenances
- (1) Meters: Provision should be made for inlet and outlet metering in every ponding system.
 - (2) Distribution systems: Usually are open boxes containing valves to control flow through pipes leading to the various ponds. Rotary distributors give superior performance but are costly.
 - (3) Facultative and anaerobic ponds: Single or multiple submerged vertical inlet pipes should be used. Vertical inlet height should be about 18 inches above pond bottom. Primary pond inlet should be at center of pond.
 - (4) Individual pond inlets: Aerobic ponds: No special inlet requirements except to avoid short-circuiting of influent sewage directly to effluent overflow.
 - (5) Drains: Each pond should be provided with a drain sump, with drainage pipes leading to the influent well. Ponds may thus be emptied into one another when one is to be removed from operation. Thus the key phrase "keep ponds full or empty" can be accomplished. Portable pumps and portable irrigation piping may be provided in lieu of permanent drains.
 - (6) Skimmers: Each pond should be provided with a surface skimming device located within a few feet of the levee-waterline intersection at the downwind edge of the pond. Skimmers should be adjustable and operable manually. Skimmers should drain to the influent or recirculation sump.

- (7) Outlet and interpond transfer systems: May be combined with pond drains or designed to operate as simple culverts through levees. In freezing climates submerged transfer or overflow lines should be connected through a manhole containing a depth control weir.

11. Management of Ponds

In a preceding section attention was called to the fact that the ability of a natural pond to function without scientific personnel led to an ignoring of the pond as a treatment device. This does not mean that the engineered pond functions without attention and maintenance. Such an assumption leads essentially all ponds to degrade to the status of an anaerobic pond with attendant objectionable aesthetic conditions. Such neglect has repeatedly occurred and has done much to obscure the merits of the engineered pond in some quarters.

The functioning of an aerated pond, an aerobic pond, or a facultative pond depends upon management techniques which maintain optimum conditions for the processes which the pond is intended to exploit. Proper operation and maintenance, therefore, are just as essential to the stabilization pond as to other engineered systems for quality management.

Performance of Stabilization Ponds

The effects of stabilization ponds on the quality of domestic return flows has been the subject of many experiments. BOD reductions which may be expected from various types of ponds are as follows:

1. Aerated ponds: Up to 95 percent, conversion to CO_2 and humus.
2. Aerobic ponds: Up to 95 percent, conversion to algae and humus.
3. Facultative ponds: 90 to 95 percent, conversion to methane and humus.

4. Anaerobic ponds: Up to 70 percent, conversion to methane and humus.

Conversion of BOD to algal cell material in aerobic ponds produces about one ton of algae per million gallons of domestic sewage ponded. The short detention period involved results in but small reduction of the coliform count. Facultative ponds, however, are more effective in reducing bacteria. A single pond at Santee, California, has been observed to remove 50 percent of influent coliforms. A series of facultative ponds providing an overall detention period of 60 days produce water of a quality suitable for golf course irrigation and landscaping. Coliform bacteria counts in the third of a series of ponds receiving domestic sewage are generally less than 10 per 100 ml. Fish, frogs, and invertebrate life likewise attest to good quality of water in tertiary ponds.

Observations (3) of pesticides in aerobic ponds show that many such are adsorbed on algal surfaces. In preliminary experiments with algal harvesting, 80 percent of pesticides were removed. Degradation of detergents in stabilization pond studies (8) are summarized in Table 5-16.

Table 5-16. Removal of Detergents in Stabilization Ponds

Type of Pond	Percent Removal and Degradation					
	ABS		LAS		Alcohol Sulfate	
	Removed	Degraded	Removed	Degraded	Removed	Degraded
Aerobic	15	2.9	56.2	35.3	95.3	94.2
Facultative	30	15.9	93.1	80.5	98.7	94.0
Anaerobic	Not observed. Other available systems ineffective.					

Status of Stabilization Ponds

Stabilization ponds are now employed to treat municipal return flows, and to retain or treat many types of industrial waste waters

throughout the United States and most civilized countries of the world. For example, in 1957 there were some 681 municipal ponds in the United States (1). By 1960 the estimated number was above 1,000 (16). Although data for the entire U.S.A. were not compiled in 1963 there were more than 800 municipal and industrial ponds in California alone, with new ones reported every few weeks. At Melbourne, Australia (14) ponds covering more than 500 acres are a major factor in treating the waste water from domestic use. Numerous ponds are in use in India, and the Middle East. In Israel more than 75 stabilization ponds were in operation in 1965 (10) and plans are well advanced (2) to utilize ponds in the treatment and reclamation of water from the city of Tel Aviv and the entire Dan Region in the amount of some 90 million cubic meters per day.

The range of applicability of stabilization ponds has not been fully explored. Domestic sewage, food processing wastes, animal manures, oil, and certain mineral wastes are among the water carried wastes which have been treated successfully. However, the feasibility of utilizing ponds for the biodegradation of solid organic wastes in a pond seems worthy of exploration. In such ponds there would be no overflow and the organic matter would be reclaimed by conversion to algal cells which could be harvested for animal feed supplements. In any event, for maximum quality objectives of the system as a water treatment device, provision should be made for removal of algal cells, although such removal is not implicit in the concept of the stabilization pond and has not yet been established on an economic basis.

Nevertheless, the design of stabilization ponds is rapidly being placed on a rational basis, and their usefulness as engineered systems for water quality management is certain to grow in importance as the objectives of such control become increasingly restrictive.

References

1. American Society of Civil Engineers. Manual of Engineering Practice No. 36, p. 185. 1959.
2. Amraury, A., B. Caspi, and A. Melamed. Dan Region Sewage Reclamation Project, General Project Outline. TAHAL, Water Planning for Israel, Ltd., P.N. 241, September 1962.
3. Crosby, Edwin. Department of Toxicology, University of California, Davis. Private Communication, 1964.
4. Edminston, F. E. Fish Ponds for the Farm. Chas. Scribner's Sons, 1947.
5. Fitzgerald, G. P., and G. A. Rohlich. Sewage and Industrial Wastes 30:1213, 1958.
6. Gillespie, C. G. Sewage Works Journal 16:740, 1944.
7. Golueke, C. G., W. J. Oswald, R. C. Cooper, J. H. Meyers, H. K. Gee. "Nutritional and Disease Transmitting Potential of Sewage Grown Algae." Second Progress Report (WP 00026), Sanitary Engineering Research Laboratory, University of California, Berkeley, 1964.
8. Klein, S. A. "Fate of Detergents in Septic Tank and Oxidation Pond Systems." Presented before the Water Pollution Control Federation, Fresno, California, April 1964. Journal of the Water Pollution Control Federation (publication pending).
9. Marais, G.V.R., and V. A. Shaw. "A Rational Theory for the Design of Sewage Stabilization Ponds in Central and South Africa." The Civil Engineer in South Africa, 3:11, 1-23, 1961.
10. Meron, A., M. Rebhun, and B. Sless. "Quality Changes as a Function of Detention Time in Wastewater Stabilization Ponds." Journal of the Water Pollution Control Federation, 37:12, December 1965.
11. Oswald, W. J. "Fundamental Factors in Stabilization Pond Design." Advances in Waste Treatment. Pergamon Press, 1963.
12. Oswald, W. J. "Light Conversion Efficiency of Algae Grown in Sewage." Transactions, American Society of Civil Engineers 128(III):47-83, 1963.

13. Oswald, W. J. "Advances in Stabilization Pond Design." Proceedings of the 3rd Annual Sanitary Engineering Conference, Vanderbilt University, Nashville, Tennessee, 1964.
14. Parker, C. D. "Microbiological Aspects of Lagoon Treatment." Journal of the Water Pollution Control Federation, 34(2):149-161, February 1962.
15. Schillinger, Von A. Von Wasser, II, 200, 1928. Merkel Von Dr. Ibid 214.
16. U. S. Public Health Service. Proceedings, Kansas City Conference on Waste Ponds, Kansas City, 1961.

XVII
QUALITY CHANGES
BY CONVENTIONAL ENGINEERED SYSTEMS*

Introduction

For the purpose of this discussion of water quality management a distinction is made between natural and artificial environments in which changes of quality may be brought about. Ponds, lakes, flowing streams, estuarine and marine waters, and the soil mantle of the earth are considered as natural environments, albeit subject to exploitation and optimizing by engineering works. In contrast, artificial environments are considered to be those maintained by suitable operational and scientific techniques within structures designed and constructed by man. A conventional engineered system is then one in which a series of units each designed to exploit some particular process or phenomenon, are put together in an optimum manner to accomplish a desired change in water quality. Specifically, the engineered works designed for filtration, sedimentation, aeration, softening or deionizing, and sterilizing water; or for fermenting, oxidizing, precipitating, or otherwise altering or removing any of its acquired constituents, are herein treated as conventional systems.

The processes involved in conventional systems are those which occur in nature under appropriate environmental conditions. The objective of the conventional system, however, is to provide structures in which water may be isolated from the water resource while these processes of quality change are accomplished under conditions that bring them about most rapidly and effectively. In achieving this

* A summary of the lectures presented by Mr. Donald Anderson, whose discussions of the subject drew heavily on standard textbook material.

objective new and complicating factors may be introduced. For example, the flowing stream receiving a burden of organic wastes degrades and recovers in quality in a sequence of environments. Ideally, if the streamflow and temperature relationships remained constant, the waste products of one group of organisms would be flushed away by flowing water to become the food supply of the next group downstream. Obviously such an ideal situation does not occur for many reasons ranging from flow variation to the fact that organisms themselves may be at the mercy of the current. Nevertheless, however dangerously a species may be forced to live, nature establishes an equilibrium in which a succession of organisms predominate. In contrast with this system the conventional system of sewage treatment must seek to carry out all of these processes within limited space. In the anaerobic digester, for example, the succession of organisms involved in biodegradation must all function simultaneously within a single tank. This environment is folded on environment and the welfare of each group of organisms depends upon the ability of the next to keep its waste products reduced to tolerable levels. Thus there is never a time in the life of an anaerobic digester when any of its several populations may falter either in numbers or efficiency if catastrophe is not to result. For the engineer this generates the familiar difficulties of digester operation, and a constant threat of imbalances man is as yet little prepared to correct.

In a similar fashion the aerobic cycle of degradation in an activated sludge tank depends upon the harmonious functioning of a mass culture of organisms. Here the watchful eye of experienced chemists and biologists is required to accomplish the results readily achieved by unattended nature, albeit at the expense of the quality needs of other users of the water resource.

The nature of conventional systems is well known to engineers and is described in many textbooks and published articles. Consequently it is not presented here in the same detail as are soil, pond, and

estuarine systems. Instead the processes exploited by conventional systems are summarized and evaluated in respect to their ability to change the quality of water at the present level of technology and economic acceptability. In this manner any gaps between the public objectives of water quality management and man's ability to attain such objectives can be identified and evaluated.

Summary of Conventional Processes

Many of the processes utilized in conventional systems of water quality control are applicable both to preparing water for some specific beneficial use or range of uses, and to upgrading the quality of return flows to levels required by resource quality objectives. Others are predominately used in one or the other of these two situations. In general, at the present time, those processes designed to stabilize degradable organic matter are applied primarily to return waters, whereas demineralization, when it is used at all, most commonly precedes beneficial use.

In the outline which follows, the normal applications of each type of process are indicated. While the table by no means covers all that has been feared concerning the conditions under which each process is optimized, it does indicate how extensively the knowledge of process performance is related to treatment systems as a whole rather than to the individual processes which make up a system.

From the standpoint of water quality management a consideration of conventional engineered systems underscores the fact that such systems are heavily oriented to the objectives of control of oxygen demand and of coliform organisms in receiving waters. These have been problems of first order magnitude in the past and will continue to be so in the future. Nevertheless, in looking back over the history of water quality control by engineered systems one cannot but be impressed at the little change in process that has occurred within the past 40 years.

Summary of Conventional Processes and Systems

Gravity Separation				
Type or Process	Common Applications	Approximate Limit of Quality Input	Principal Change in Quality Factors (Approximate)	Reference
	Reduction in suspended solids in raw water to be pumped.	No theoretical limit; 3000-5000 mg/l typical maximum in floodwaters.	Removes larger and heavier suspended solids.	
Plain Sedimentation	Primary sewage treatment	Unspecified	1. 50% reduction in suspended solids. 2. 35-40% reduction in BOD. 3. 50% reduction in turbidity.	
	Secondary sewage treatment	Unspecified	Unreported	
	Concentrated return activated sludge (secondary treatment)	Unspecified	Thickens sludge to 20-25% original volume.	
	Concentrating or reducing suspended solids in industrial wastes, organic and inorganic.	Unspecified	Highly dependent upon nature of waste treated.	
Plain Sedimentation plus Skimming	Grit removal - raw sewage	Unspecified	Removal of heavy suspended solids not transported at velocity of 1 ft/sec.	
	Primary sewage treatment	Unspecified	1. 25-40% reduction in BOD. 2. 40-70% reduction in suspended solids. 3. 25-75% reduction in bacteria 4. 2% reduction in detergents	[1]
Trickling Filter plus Plain Sedimentation	Various industrial wastes	Unspecified	Dependent upon nature of waste.	
	Secondary sewage treatment	0.25-3.0 # BOD/cu yd/cfilter	1. 80-95% reduction in BOD. 2. 70-92% reduction in suspended solids. 3. 90-95% reduction in bacteria. 4. 50-75% reduction in ABS. 5. 80-90% reduction in LAS.	[1] [1]
Activated Sludge plus Plain Sedimentation	Organic Industrial Wastes (e.g., milk process.)	Dependent upon waste treatment.	Dependent upon nature of waste.	
	Secondary sewage treatment	Unspecified	1. 80-95% reduction in BOD. 2. 80-95% reduction in suspended solids. 3. 75-90% reduction in bacteria. 4. 50% reduction in ABS. 5. 90-95% reduction in LAS.	[1] [1]
Sedimentation after Mechanical Flocculation	Raw sewage (experimentally)	Unspecified	64% reduction in turbidity. 40% reduction in suspended solids. 60% reduction in BOD.	
	Industrial wastes	Unspecified	Variable, depending upon nature of wastes treated.	
Sedimentation after Chemical Coagulation	1. Municipal and industrial water supply 2. Water softening	Unspecified	Seldom evaluated separate from filtration.	
	Raw sewage (not common)	Unspecified	1. 50-95% reduction in BOD. 2. 70-90% reduction in suspended solids. 3. 40-80% reduction in bacteria.	
	Industrial wastes	Dependent upon waste	Variable, dependent upon nature of waste.	
Chemical Coagulation plus Sedimentation	Municipal water supply	Unspecified	1. Coalesce and precipitate dispersed clay colloids. 2. Reduce turbidity. 3. Reduce color.	
	Phosphate removal from waste waters	Unspecified	Reduce soluble phosphates to trace amounts.	
	Lime-soda softening of water supplies	Applicable to waters containing Ca and Mg sulfates and bicarbonates. Iron and Mn in natural waters. (e.g., maximum from 10 mg/l; minimum, 5 mg/l.)	1. Hardness reduced to approximately 75 mg/l; by excess lime to 50-55 mg/l; by hot process to < 10 mg/l as CaCO ₃ . 2. Fe reduced to 0.1 mg/l (+). 3. Removes CO ₂ - requiring restabilization. 4. 80-100% reduction in bacto by excess lime.	[2]
Filtration [2], [3], [4]				
Slow Sand (Gravity)	1. Tertiary treatment of sewage effluent. 2. Water reclamation systems.	Relatively low turbidity.	1. 90-95% reduction in BOD. 2. 85-95% reduction in suspended solids. 3. 95-98% reduction in bacteria. 4. 90-95% reduction in surfactants.	
	Municipal water supply	Turbidity 40 mg/l.	1. 90% reduction in bacteria. 2. 95-100% reduction in turbidity. 3. 30% reduction in color 4. Odors and tastes removed. 5. 60% reduction in iron.	
Rapid Sand (Gravity)	Industrial wastes	Unspecified	Varies with nature of waste.	
	Municipal and industrial water supply (little used without coagulation)	Low turbidity, e.g., 20 mg/l, maximum < 115 cm MPN (100/100 ml)	1. 95% reduction in bacteria. 2. 95% reduction in turbidity.	

Summary of Conventional Processes and Systems (continued)

Filtration (2), (3), (4) (continued)				
Type or Process	Common Application	Approximate Limit of Quality Input	Principal Change in Quality Factors (Approximate)	Reference
Rapid Sand plus Chemical Coagulation (Gravity)	Municipal and industrial water supply	No limit specified for maximum turbidity. Maximum coliform MPN 5000-20000/100 ml.	1. 90-99% reduction in bacteria. 2. 100% (-) reduction in turbidity. 3. Color reduction to less than 5 mg/l. 4. Alk. increased 7.7 mg/l/gr. alum. 5. CO ₂ increased 6.6 mg/l/gr. alum. 6. Slight reduction in iron. 7. Odor and taste partially removed.	
Rapid Sand plus Chemical Coagulation, Chlorination, and Activated Carbon	Municipal and industrial water supply	No limit specified for maximum turbidity. Maximum coliform MPN 5000-20000/100 ml.	1. Approximately 100% reduction in bacto. 2. 100% reduction in turbidity. 3. Color reduced to near zero. 4. Iron and Mn reduced. 5. Taste and odor removed.	
Rapid Sand (pressure) (precoat with Chemical floc)	1. Small municipal supply 2. Swimming pools 3. Industrial supply and process 4. Emergency and military use	1. Generally unspecified 2. Low turbidity desirable	Similar to rapid sand filter but more variable in performance.	
Diatomaceous Earth (pressure and vacuum)	1. Small municipal supplies 2. Institutional water supply 3. Swimming pools 4. Industrial supply and process 5. Emergency and military use	None specified, but operation depends upon nature of water.	1. Capable of good clarification of water. Efficiency, however, not well documented. 2. 40-90% reduction in suspended solids. 3. 50% reduction in color.	
Contact Filters	Manganese removal Iron removal	None specified	1. Reduce to PHS Standards. 2. 88% reduction in iron	[5]
Bag Filters	Swimming pools	Unspecified	Strains out hair and coarser suspended solids. Reduces bacto to level controllable by chlorination practice.	
Microstraining	1. Primary clarification of water prior to filtration 2. Clarification of sewage effluents 3. Treatment of industrial wastes	1. Size of particles to be removed greater than screen size. 2. Material suitable for microstraining	1. 87-96% reduction in microscopic organisms.	[7]
			2. 60-90% reduction in microscopic particulates.	[8]
			3. 50-60% reduction in suspended solids trickling filter effluent 4. 30-40% reduction in turbidity.	[9] [7]
Fine Screening	Raw Sewage	None specified	1. 5-10% reduction in BOD. 2. 2-20% reduction in suspended solids. 3. 10-20% reduction in bacteria.	
	Industrial wastes (e.g., cannery, pulp mill, etc.)	None specified	Varies with nature of waste.	
Carbon Filters	Special municipal and industrial water applications	Very low turbidity, other not specified	1. Adsorbs exotic organic chemicals, including surfactants. 2. Removes tastes and odors. 3. Adsorbs miscellaneous gases.	
Aeration				
Diffusion	1. Municipal and industrial water supply 2. Industrial waste treatment	Unspecified	1. Release gases producing taste and odor. 2. Reduce CO ₂ in groundwaters to normal surface water levels. 3. Partial removal of H ₂ S 4. Partial removal of gases of decomposition. 5. Oxidation and removal of soluble iron in groundwaters. 50-75% reduction observed.	[5]
Pressure	Treatment of sewage and industrial wastes	Limits variable or unspecified.	1. Grit precipitated. 2. Grease concentrated at surface. 3. Separates various solids by flotation. 4. Maintains aerobic conditions in biological systems, e.g., activated sludge, aerated ponds. 5. Reduces ABS or LAS to 1-2 mg/l. 6. Reduces septicity of sewage.	
Oxidation Ponds (See Chapter 17)	Treatment of domestic sewage and organic industrial wastes	No toxic substances (See Chapter 17)	1. 75-96% reduction in BOD. 2. 90-99% reduction in suspended solids. 3. 98-99.9% reduction in bacteria. 4. 55-93% reduction in LAS.	
Demineralization				
Ion Exchange (Natural or Synthetic Zeolite)	Softening of groundwater supplies for municipal or industrial use.	1. Hardness (Ca and Mg sulfates and bicarbonates) in natural waters > 850-1000 mg/l CaCO ₃ 2. Iron < 1.5-2 mg/l. 3. Low in silica. 4. CO ₂ < 15 mg/l.	Increases sodium content by exchange with removed Ca and Mg.	[2]

Summary of Conventional Processes and Systems (continued)

Demineralization (continued)				
Type or Process	Common Applications	Approximate Limit of Quality Input	Principal Change in Quality Factors (Approximate)	Reference
Ion Exchange (Greensand or Styrene Base Gels)	Iron or Mn removal from groundwater	Iron less than approximately 2.0 mg/l.	1. 90-100% removal of iron. 2. Mn partially removed.	[5]
Ion Exchange (Organic Cation Exchangers)	Special water conditioning for industry and commerce	Unspecified	Removes all cations (Na, K, Mg, Fe, Cu, Mn).	
Ion Exchange (Anion Exchangers)	Special water conditioning for industry and commerce	Unspecified	Removes SO ₄ , Cl, NO ₃ , etc.	
Ion Exchange (Fluoride Exchangers)	Defluoridation of public water supply	More than 1.5 mg/l F in water supply.	1. Approximately 100% removal possible. 2. Normally reduce to < 1.5 mg/l.	
Electrochemical Desalting	1. Reclaiming water from saline sources, public and industrial supplies 2. Demineralizing municipal waste effluents	Applicable to highly saline or brackish waters.	Removes anions and cations.	[10]
Reverse Osmosis	Reclamation of water from brackish natural or waste waters. (Experimental.)	Brackish waters, upper limit not specified.	Reduces ions depending upon concentration difference across membrane. 97-98% reduction in TDS, ABS, and COD.	[10]
Distillation	1. Reclamation of water from saline sources. 2. Specialty industrial and commercial supplies	No limit.	Produces distilled water (may be contaminated with NH ₃ , volatile organics, etc.).	
Freezing	1. Reclamation of water from saline sources. 2. Specialty industrial and commercial supplies.	No limit.	(Experimental)	
Chlorination				
Liquid Cl ₂ and Cl ₂ Compounds	1. Public water supply. 2. Industrial water supply.	Turbidity low for waters to be sterilized by Cl ₂ .	1. Reduces bacto load on filters. 2. Oxidizes organic matter. 3. Reduces odor. 4. Assists in color removal. 5. 100% (-) reduction in bacteria. 6. Controls plankton growth in reservoirs. 7. Reduces Mn concentration at break-point	
	Municipal and industrial waste water treatment and management.	Unspecified	1. Assists in grease removal. 2. Controls filter fly nuisance. 3. Cleans air stones in aeration systems. 4. Removes H ₂ S. 5. Removes NH ₃ . 6. Controls slime formation in sewers and cooling towers. 7. Assists in control of digester foaming. 8. Disinfects effluent; 98-99% reduction in bacteria.	
Digestion				
	1. Stabilization of sewage solids. 2. Stabilization of organic industrial wastes.	1. pH above 6.8. 2. Acids limited. 3. No toxic substances in significant amounts. 4. Minimum of grit.	Reduces organic sludges to human and relatively stable chemical compounds.	

This period has seen the rise of industry as a major producer of wastes, as well as the growth of population which has overwhelmed the resource concepts suited to a pioneer society. In the waste water treatment field this period has likewise witnessed a thoroughgoing exploration of the limits of conventional approaches. Coagulation with lime or alum, and application to a trickling filter has characterized the response to each new waste problem, be it one of toxic metals or synthetic organic compounds. Thus it has been well established that new approaches to water quality management must be forthcoming, either at the production or at the treatment end of the scale if exotic organics, mineralized waters, growth factors in effluents, and similar substances are to be dealt with as effectively as are the biodegradable fractions of organic residues. While effective use of the capacity of soil and pond systems is a necessary adjunct, it will not be enough to offset the trend of public policy toward limited acceptance of man-generated quality factors in the water resource. This means that the engineered system of a "conventional" type must grow in importance. It must also grow in sophistication.

Obviously, an engineered system must be designed to exploit some known phenomenon. The future need, however, is for reduction in the mineral content of return flows, and in some cases, of the available water resource itself. Interestingly, and fortunately, the processes of demineralization listed in the table are those which have been least exploited, and are currently under greatest experimental study. It seems safe to predict at this time that the technology of conventional engineered systems will in the future expand in this direction under a revised concept of economic feasibility.

References

1. American Water Works Association. Water Quality and Treatment. A Manual. American Water Works Association, New York, 1950.
2. Carter, Rolf C., et al. Behavior and Evaluation of Microstraining for the Lytle Creek Supply. Paper presented before the California Section, American Water Works Association, Sacramento, California, October 27, 1961.
3. Clark, John W., and Warren Viessman, Jr. Water Supply and Pollution Control. International Textbook Company, 1965.
4. Cowser, K. E. "Iran Removal Practices with Illinois Ground Waters." Water and Sewage Works 98:12, 1951.
5. Fair, Gordon M., and John C. Geyer. Elements of Water Supply and Waste Water Disposal. John Wiley and Sons, Inc., New York, 1957.
6. Keefer, C. E. "Operating a Sewage Microstrainer." Water and Sewage Works, 101(7):356-358, 1954.
7. Klein, S. A., and P. H. McGauhey. "Degradation of Biologically Soft Detergents of Wastewater Treatment Processes." Journal of the Water Pollution Control Federation 37(6):857-66, June 1965.
8. Turre, G. J. "60-mgd Microstraining Plant Meets Denver's Growing Needs." Water Works Engineering, December 1961, pp. 1054-1056.
9. U. S. Public Health Service. Summary Report, Advanced Waste Treatment Research, January 1962-June 1964. AWTR-14. April 1965.

ERRATA

Chapter XIV

Page 169, line 5 from bottom. Change irrigation to obliteration.

Chapter XV

Page 184, line 16. Change parts to ports.

Page 184, line 10 from bottom. Change multipartite to multiport.

Page 192, line 7 under "Dilution in Marine Waters." Change part to port.

Page 193, equation. Change D_g to Dg .

Chapter XVI

Page 203, line 5 from bottom. Change maximum to minimum.

Chapter XVII

Page 234, line 12 from bottom. Change feared to learned.

Page 235, table.

Column 1. Remove line immediately above "Plain Sedimentation."

Column 4, line 6. Change turbidits to turbidity.

Column 3, line 13 from bottom. Change mg to Mg.

Column 3, line 11 from bottom. Change Mm to Mn.

Column 3, line 2 from bottom. Change maximun to maximum.