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DETECTION AND MEASUREMENT OF STREAM POLLUTION

By M. M. ELLIS

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DETECTION AND MEASUREMENT OF STREAM POLLUTION [1]

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INTRODUCTION

The menace of pollution to our inland streams and rivers is too well known to require definition. In fact, unsightly and noisome conditions due to pollution are encountered so often that they have come to be accepted by many as the usual order of things. It is true, however, that many cases of pollution could be remedied and the streams so affected restored to an acceptable state for recreation, fishing, and

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[1] Bulletin No. 22. Approved for publication, Sept. 1, 1936. The present study is presented as the first of three dealing with pollution hazards to fresh-water fishes. The second will discuss trade wastes and chemical effluents, and the third, the cumulative effects of dilute pollutants.

general use with reasonable expense, if all parties concerned would cooperate. To obtain this cooperation, it is necessary to understand the situation and to judge it fairly. Much confusion and misunderstanding has arisen in attempts to define the extent of pollution and to place the responsibility for damage to fisheries, because of the lack of available information on the conditions to be defined.

In the present paper findings from the widely scattered scientific literature supplemented by the experimental and field work of various agencies have been brought together covering (1) the conditions which should be maintained if good fish faunae are to thrive, and (2) the specific effects of various types and components of effluents which now pollute our streams.

It is hoped that the use of this information will make possible the definition of undesirable conditions with fairness both to the industrialist, who must use water and streams, and to the citizen, who is entitled to enjoy these same streams.

With the limits of both the required stream conditions and of the pollutant lethalities better understood, corrective measures can be recommended intelligently, for remedial action can only be instituted when the cause and the severity of the pollution are known. The United States Bureau of Fisheries is engaged at present in such investigations based on findings presented here.

STREAM POLLUTANTS AND AQUATIC ENVIRONMENT

PHYSICAL AND CHEMICAL CHARACTERISTICS OF WATERS SUITABLE FOR FRESH-WATER STREAM FISHES

The various effluents, municipal, industrial, and otherwise which comprise collectively stream pollutants may be detrimental to fishes and other aquatic life either indirectly through quantitative alterations in those substances which give fresh waters their inherent characteristics, as dissolved oxygen, carbonates, and hydrogen ions, or directly because of specific physiological and toxic effects on the aquatic organisms themselves. Many effluents are of complex composition, however, and are harmful to aquatic life through both changes in the aquatic environment and through definite toxic actions. Therefore, in determining the effects of stream pollutants on aquatic biota and particularly on fishes, it has been necessary to study both the modifications in the environment and the specific physiological actions attributable to the different pollutants.

The many substances which are carried in solution and suspension by a stream, collectively determine whether the waters of that stream in themselves present conditions favorable or unfavorable for fishes and other aquatic organisms; and any individual fish in the stream is affected not only directly by these substances, but indirectly through their action on other forms of aquatic life which comprise in a very restricted environment the food, the enemies, and the competitors of the particular individual. The definition of the amounts of these substances which should be present in water in order to maintain a suitable environment for fishes, or which may be tolerated by fishes under favorable conditions, is therefore much more involved than the designation of standards for water for human consumption, which concern but a single, air-breathing, non-aquatic animal, man.

Water standards for fishes and other aquatic organisms, moreover, are not identical with those standards which will define water as potable for human beings or satisfactory for industrial use. Water may be serviceable for many industries and yet not support fish life, or fishes may thrive in water which would be unsafe for human consumption due to the presence of particular bacteria as typhoid, or certain compounds harmful to man, as the western alkalis.

The definition of waters as suitable for aquatic life is complicated still further by the fact that various species of fishes and other aquatic animals and even individuals of different ages of the same species have different degrees of tolerance to deviations from the ideal environment, and to the cumulative effects of many stream pollutants. Consequently, the presence or even the survival for a time of fishes in waters suspected of pollution does not in itself constitute evidence that these waters are either satisfactory or safe for fishes.

In spite of the various confusing factors which have been set forth in the preceding paragraphs, it is essential in order to determine the extent and degree of pollution in any given stream to define as far as possible the limits of variation in the several components of those aquatic complexes which desirable fishes will tolerate and in which they will still thrive. Neither minimal lethal nor arbitrary standards will suffice. The limiting values for the various substances in stream waters, with references to the effects on aquatic life, as presented here have been obtained through the correlation of data of four sorts: (*a*) The amounts of these substances found in natural waters where fishes were successfully maintaining themselves, (*b*) studies of streams which as far as could be determined were unpolluted and which, therefore, presented natural conditions, (*c*) the physiological responses of fishes and other aquatic animals to variations in the concentrations of these substances, and (*d*) the survival of aquatic forms when exposed to these substances over long periods under controlled conditions. These data have been drawn from the existing literature, and from field and laboratory studies by the staff of the Columbia (Mo.) field unit of the United States Bureau of Fisheries during the past 5 years (Ellis, 1935a).

In the present consideration of water standards for fish and other aquatic animals the dissolved and suspended substances have been divided into two groups, namely, those constituting the complex favorable to fishes in natural unpolluted waters, i. e., those substances to which the fresh-water fishes are physiologically adapted; and, those substances which are added from time to time to natural waters by man and his agencies, and to which the individual fish must adapt itself. There is, of course, some overlapping between the two groups since certain forms of pollution merely alter the amounts of specific substances normally found in streams, as in the case of the acid wastes from wire-nail mills, which effluents raise the acid ions, the iron and the sulphates, all of which occur in small quantities in most streams, to levels toxic or detrimental for aquatic forms, with, of course, disastrous results.

Throughout the application of these data and standards it must be borne in mind that individual fishes and various species of fish have different degrees of resistance and tolerance. Consequently, some fishes may be found in waters where less favorable conditions than those here designated obtain, since both the minimal and maximal limits immediately compatible with life have been avoided, for these limits cannot be regarded as desirable or physiologically reasonable in determining a suitable environment for fishes any more than for man. An effort has been made, therefore, to present usable and reasonable standards of water suitability favorable to fish life; that is, standards defining waters in which a mixed fauna of fresh-water fishes of the common warm water types including desirable centrarchids, cyprinids, catostomids, and silurids, as well as such tolerant forms as carp and gar, will thrive. Various lethal limits are also set forth.

It must also be pointed out that these standards of suitability must be maintained throughout the periods of low water, maximal temperature, and maximal liability to pollution, since a deviation in the amount of any of several substances, as dissolved oxygen, acids, or salts, to the critical level for only a few hours may so change conditions in a considerable portion of an otherwise favorable stream, that months or years may be required to reestablish the former fish fauna and normal balance of aquatic species.

In a large series of field studies it has been shown that the natural, inherent water conditions of most streams can be ascertained satisfactorily for pollution studies as regards fisheries problems by determining repeatedly at different times of the night and day and at various seasons of the year the (1) dissolved oxygen, (2) pH, (3) ionizable salts, (4) carbon dioxide, fixed and free, (5) total ammonia, and (6) suspensoids, since the determinations of these factors not only give specific data concerning particular conditions, but also concerning several complexes which vary in even unpolluted streams and which are definitely affected by many forms of pollution.

From determinations made at many stations where good mixed fish faunae were present, it was found that the values from the above determinations in favorable waters, i. e., waters supporting good mixed fish faunae, fell within rather definite limits, and that deviations from these limits in our inland streams were almost always indicative of conditions unfavorable to aquatic life. However, these values alone, which cover only the more basic, inherent conditions which must be maintained in any stream if it is to support a good fish fauna and on which conditions of specific pollution are superimposed, will not suffice for the complete definition of water as favorable for aquatic life, since the absence of specifically toxic substances must also be demonstrated before the water can be finally approved as unpolluted.

GENERAL FIELD METHODS

Throughout these studies, both for the determination of water suitability standards and of pollution conditions, certain routine procedures were followed, in addition to the special investigations which the conditions in the particular locality required, in order that certain data from all localities could be compared fairly and without the skewing which results from haphazard sampling.

The stations at which samples were taken in each locality were selected as representative of the various complexes of conditions presented. Whenever possible, samples were taken at intervals throughout the night and day and at different times during the season. Many of the stations included in this report have been visited repeatedly during the past 5 years.

Although in this paper the detailed data concerning the findings on plankton, bottom organisms, fresh-water mussels, and fish population are not presented, since various general statements concerning findings on these animals have been included

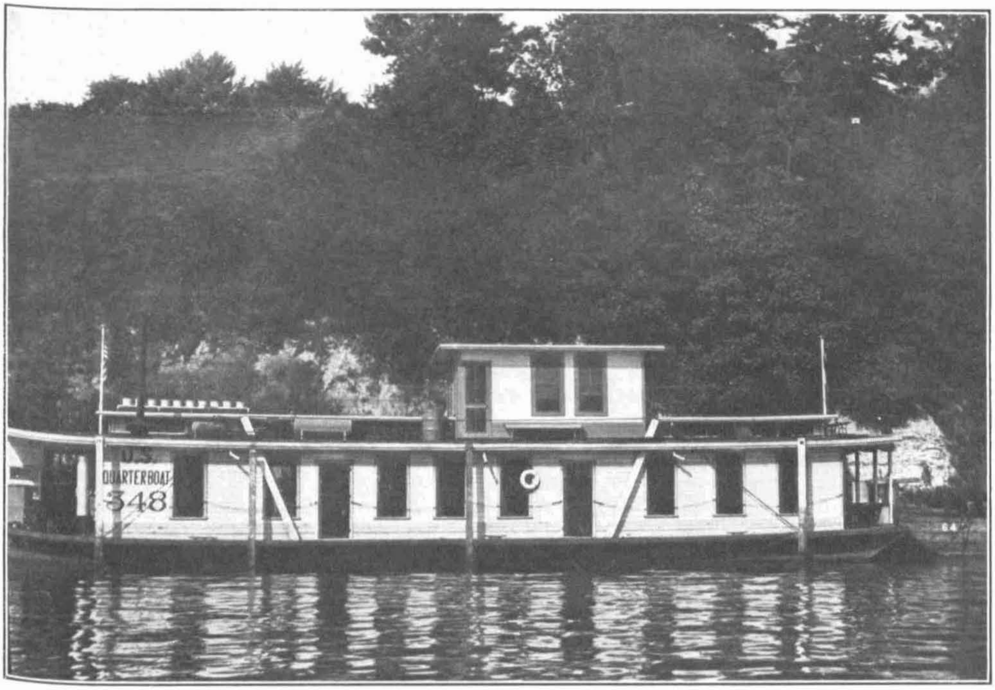

FIGURE 1.—U. S. Quarterboat *348*, the floating laboratory of the United States Bureau of Fisheries.

FIGURE 2.—U. S. Fisheries cruiser *56*, equipped with sounding and sampling booms and field-laboratory apparatus. Two such cruisers were used on the larger rivers and streams.

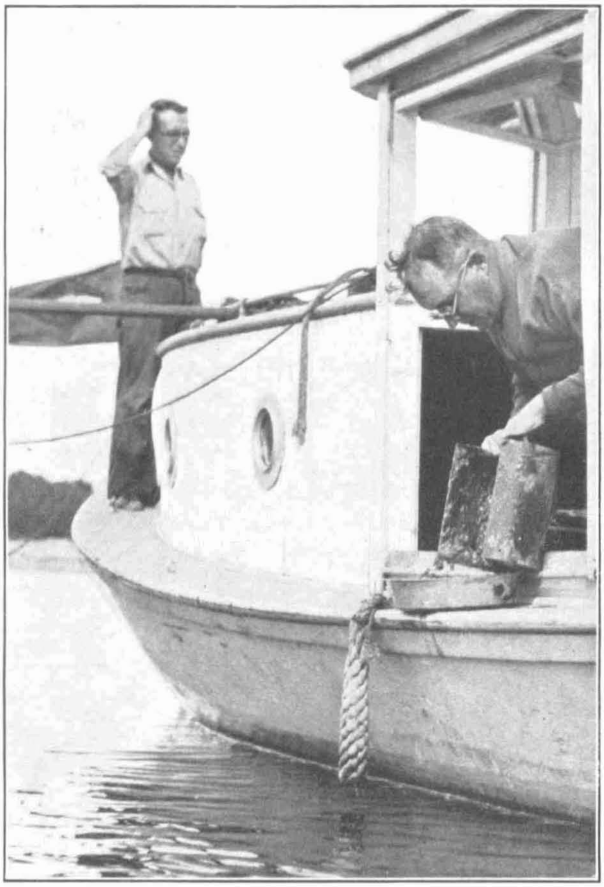

FIGURE 3.—Collecting bottom samples from cruiser with Peterson dredge.

FIGURE 4.—Mussel dredge in operation from catamaran. This dredge was used in the study of bottom conditions where rocks and other obstructions made use of Peterson dredge impossible.

and since the studies of these forms constitute part of the routine background for the interpretation of the pollution hazards, the field methods employed in connection with the entire pollution study operations have been given.

WATER SAMPLES

At each station water samples were collected by means of a brass sampler of the general type described by Kemmerer, Bovard, and Boorman (1923) and transferred at once without aeration to 300-cubic-centimeter glass-stoppered, self-sealing magnesium-citrate bottles. The first or top water samples were taken at a depth of from 1 to 2 feet, the actual surface water (the first few inches below the surface) being avoided in the general sampling because the dissolved gases in the water in immediate contact with the air do not present a true picture of the dissolved gases in the main mass of the water in the stream (this fact is discussed more fully under dissolved oxygen). Whenever the depth was greater than 3 feet a second set of water samples, bottom samples, were taken about 3 inches above the floor of the stream. Intermediate samples were collected between the top and bottom at levels from 5 to 10 feet apart wherever the depth of the water justified such sampling.

MUD SAMPLES

Bottom mud samples were obtained with a Peterson dredge properly weighted to bring up about one-half cubic foot of bottom from an area approximately 1 foot square. These mud samples were divided into aliquot parts, some of which were dried (see fig. 3) or fixed with various reagents for chemical determinations, and others were sieved through a series of Monell screens for qualitative and quantitative studies of the bottom fauna.

PLANKTON

Plankton counts were made from the catch obtained by pumping slowly 1 cubic meter of the water under consideration through a standard silk bolting cloth plankton net, supported in the water and provided with a glass trap bottle of 250-cubic-centimeters capacity in which the organisms accumulated uninjured. On some of the river lakes, as Lake Pepin and Lake Keokuk, a trawl supported by a boom and operated over the side of a cruiser was used both for plankton and the larger surface animals.

For purposes of quick field diagnosis of water conditions only net plankton were used, although in the detailed studies of plankton both nano- and macroplankton were determined.

FRESH-WATER MUSSELS

At the stations where fresh-water mussels were to be taken a heavy mussel dredge (see fig. 4) operated from a catamaran was used. This dredge, which was found to be very effective to a depth of 8 or 9 inches in the mud of the river floor, brought up approximately 1½ cubic feet of river bottom with the contained organisms. Quantitative as well as qualitative studies were possible, therefore, from these dredgings.

Fish

The fish fauna was studied from collections made with various types of nets and seines. Several hauls were made in each of the various portions of the habitat under consideration and usually the entire catch preserved. If the entire catch were too large, representative collections from it were made and the total bulk of the catch noted.

EQUIPMENT

In the field studies reported in this discussion several types of equipment have been used. In the major stream surveys U. S. Quarterboat *348* (see fig. 1), which is fully equipped with chemical and hydrobiological laboratories, together with living quarters for 12 people, was used as the base from which the operations were conducted. Attached to the quarterboat for these investigations were two 35-foot cruisers (U. S. Fisheries *53* and U. S. Fisheries *56*, see fig. 2) which were specially equipped with dredging, sounding, and sampling apparatus, together with portable chemical units for such determinations and preparations as required immediate attention in the field. On certain streams where it was not feasible to move the quarterboat and cruisers, support and cooperation in equipment was given by various Government, State, and private agencies, including the loan of vessels and the use of equipment at hand.

For certain stream studies automobile trucks carrying compact biochemical, biophysical, and hydrobiological apparatus were also used extensively. These mobile units were found to be very effective, as long distances could be covered quickly and the equipment taken to the specific site of the pollution problem to be investigated. (See fig. 5.)

The detailed experiments, most of the bioassay work, and various analyses and tests which could not be made in the field were conducted at the United States Bureau of Fisheries laboratories at the University of Missouri. Here, through the excellent cooperation afforded by the University of Missouri, the Bureau has a research laboratory suite of eight rooms specially equipped for biochemical, physiological, and biological work, in which various pieces of apparatus devised particularly for these pollution studies are in operation.

DISSOLVED OXYGEN

The modifications of the Winkler method for oxygen determinations as described by Kemmerer, Bovard, and Boorman (1923) and as given by American Public Health Association (1933) were followed in both the field and laboratory analyses for dissolved oxygen. The data are reported in parts per million (p. p. m.) unless otherwise specified.

In figures 6, 7, 8, and 9 are presented the results of 5,809 determinations of dissolved oxygen made at 982 stations on fresh-water streams and rivers of the United States during the months of June to September, inclusive, 1930–35. Natural lakes and ponds are excluded, the data covering only conditions in stream and river waters during the warm season. This season was chosen since the oxygen carrying power of water decreases and the metabolic demands of aquatic animals for oxygen increase as the temperature of water rises.

FIGURE 5.—One of the field-laboratory trucks, showing stream-side operations. These trucks were equipped with apparatus and chemicals, sampling and collecting outfits, dredges, and seines. Each truck unit was able, therefore, to make detailed investigations at any stream site which could be reached by car.

From these 5,809 cases, all determinations made at stations where good, mixed, fish faunae were found at the time of sampling, were selected for a composite regardless of the actual amount of dissolved oxygen present. For purposes of this comparison good, mixed, fish faunae were defined as faunae including representatives of the fine fish group (trout, or bass, sunfish, perch, and other spiny-rayed fishes), of the rough fish group (suckers, buffalo, and catfish), and of the minnow series, in good condition at the time the samples were taken. Naturally, the exact species composition of these good, mixed faunae varied to some extent with the river system.

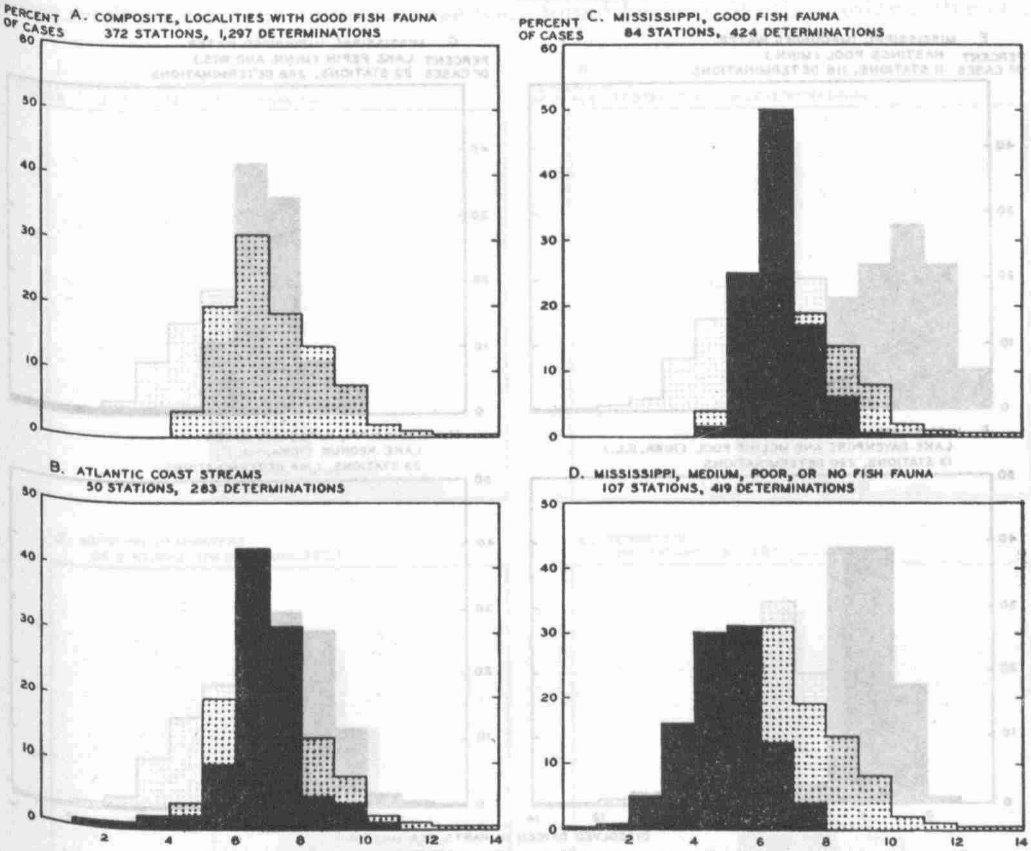

FIGURE 6.—The stippled graph is a composite of dissolved oxygen values for all stations at which good mixed fish faunae were found, each river system being given equal weight to avoid skewing due to differences in actual numbers of cases. Each solid black graph presents all oxygen data for a single river unit regardless of presence or absence of fish at sampling stations. Direct evaluation of each river unit can be made in terms of the preferences of good fish faunae from the stippled graph on which the black graph is superimposed.

This composite selected as explained, includes 1,297 determinations of dissolved oxygen from 372 stations. Figure 6*A* gives the distribution of the dissolved oxygen values for this composite. To avoid skewing due to uneven number of cases from the different localities the various river systems were given equal weights in determining the percentages.

From figure 6*A* it may be seen that during the warm season the waters at 96 percent of the good fish faunae stations carried 5 p. p. m. or more dissolved oxygen, and that in all of the 5,809 cases good, mixed fish faunae were not found in waters carrying less than 4 p. p. m. dissolved oxygen. These data collected from localities where the fish had had opportunity to choose for themselves point very strongly to 5 p. p. m. as the lower limit of dissolved oxygen, if the complex is to maintain a desirable fish faunae under natural river conditions.

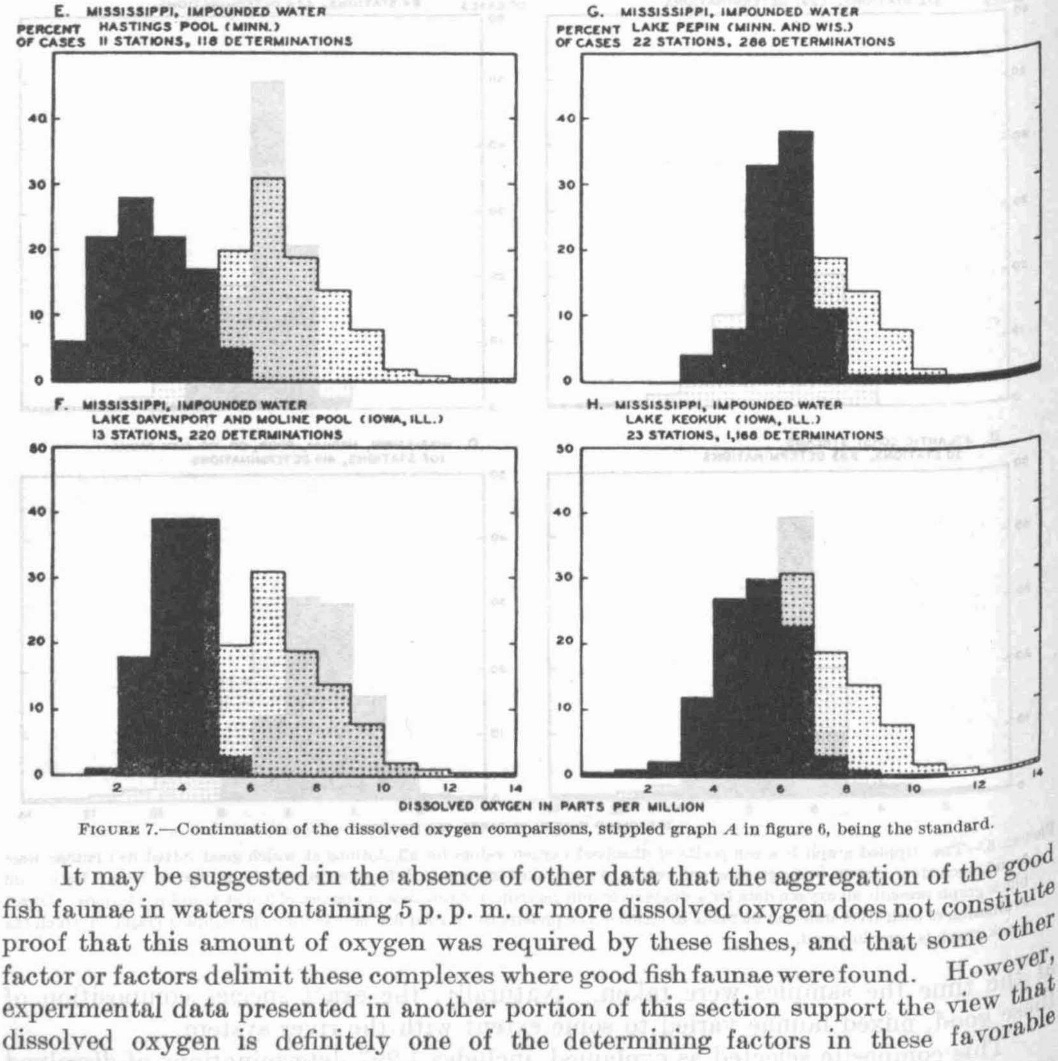

FIGURE 7.—Continuation of the dissolved oxygen comparisons, stippled graph *A* in figure 6, being the standard.

It may be suggested in the absence of other data that the aggregation of the good fish faunae in waters containing 5 p. p. m. or more dissolved oxygen does not constitute proof that this amount of oxygen was required by these fishes, and that some other factor or factors delimit these complexes where good fish faunae were found. However, experimental data presented in another portion of this section support the view that dissolved oxygen is definitely one of the determining factors in these favorable complexes.

A comparison of graphs *C* and *D* in figure 6, with the composite *A*, however, brings out the fallacy, for river waters at least, of the suggestion which has been made at times that the determination of dissolved oxygen or dissolved oxygen in terms of oxygen demand is sufficient alone to define water as suitable or unsuitable for fish life. Graph 6*C* gives the distribution of the dissolved oxygen value for all stations in the Mississippi River where good fish faunae were found and graph 6*D* for all stations in the Mississippi River where medium, poor, or no fish faunae were found regardless of type of pollution. In this comparison the water at over 98 percent of the stations where good fish faunae were found carried 5 p. p. m. or more dissolved oxygen, and the water at 52 percent at stations where medium, poor, or no fish faunae were found carries less than 5 p. p. m. dissolved oxygen, but the water at 48 percent of the stations where medium, poor, or no fish faunae were found because of other unfavorable conditions, carried 5 p. p. m. or more dissolved oxygen due to current action and other factors in spite of the polluting materials.

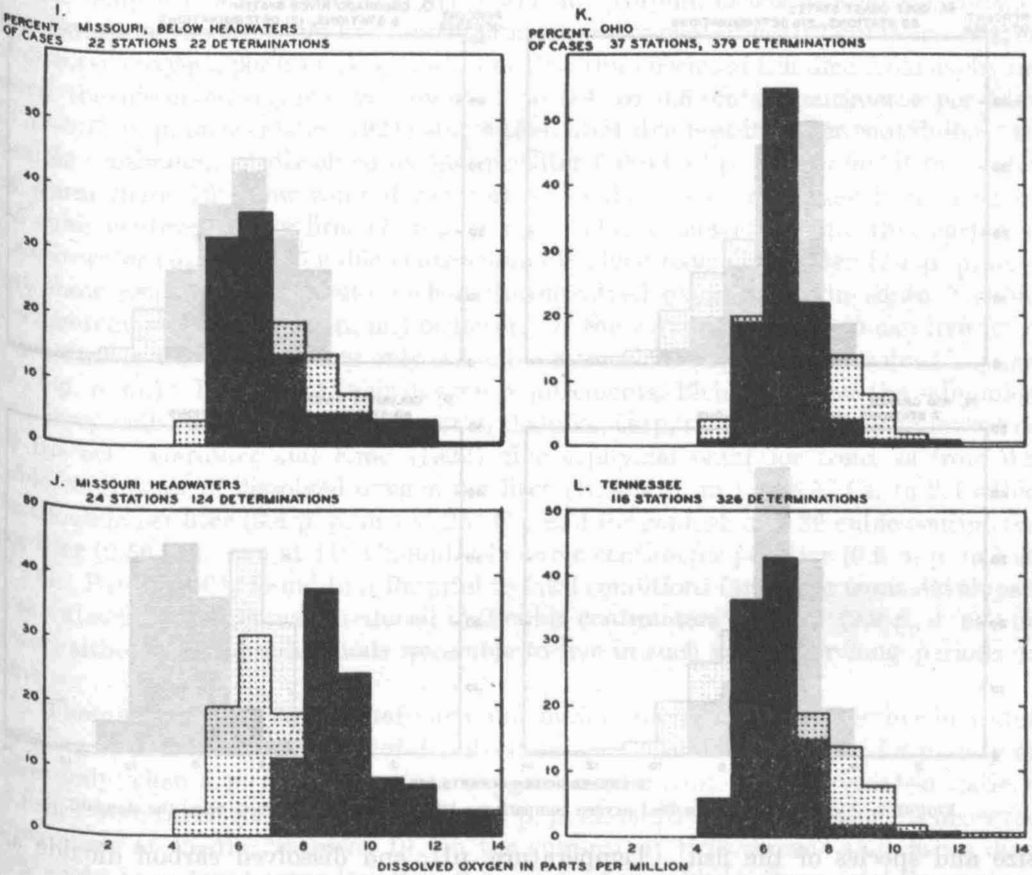

FIGURE 8.—Continuation of dissolved oxygen comparisons, stippled graph *A* in figure 6, being the standard.

Three other observations may be made from these studies of warm-season dissolved-oxygen values in the various streams and river lakes. Low dissolved oxygen was found more frequently in the impounded waters of streams, particularly if the impounded waters were subject to organic pollution, than in the more rapidly flowing portions of these same streams (see graph 7*E* of Hastings Pool, a notoriously polluted portion of the Mississippi River, and graphs 7*F* and 7*H*); headwater streams, especially those in mountainous regions usually have high dissolved oxygen, and the range of dissolved oxygen to be expected in flowing streams both polluted and unpolluted is in general from 0 to 14 p. p. m.

For the final evaluation of the various findings presented from the field studies on dissolved oxygen, experimental data covering the oxygen requirements of fresh-water fishes must also be considered, as both the amount of oxygen consumed by the fish and the minimal amount of dissolved oxygen which will barely support life vary with the combinations of environmental factors operating at the time, and with the size and species of the fish. Temperature, pH, and dissolved carbon dioxide are particularly important in this connection.

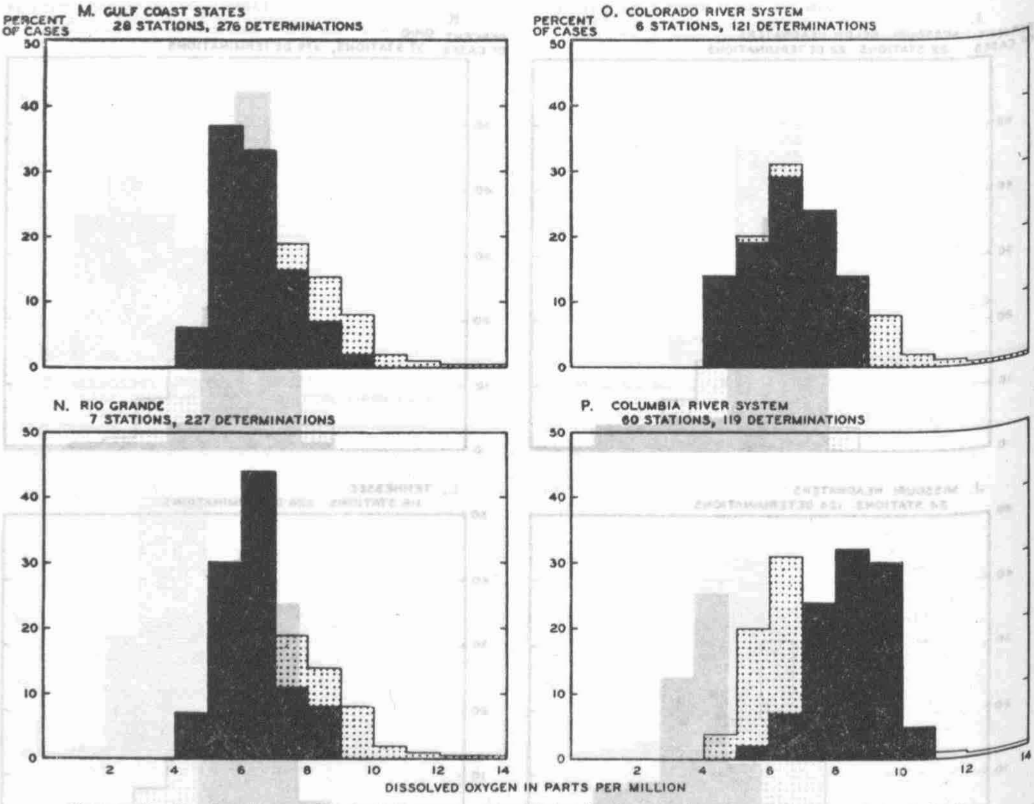

FIGURE 9.—Continuation of dissolved oxygen comparisons, stippled graph *A* figure 6, being the standard.

Many observers have pointed out that the metabolism of, and consequently the oxygen consumed by, fishes and other aquatic animals follows in general the van't Hoff law with reference to temperature so that the actual amount of oxygen removed from the water by the individual fish will vary with the temperature regardless of the amount of oxygen present until a near-lethal point is reached (Keyes, 1930). Ruttner (1926) states that the oxygen consumption of many aquatic animals is almost doubled with each rise of 10° C., within physiological limits, and Powers (1922 and 1932) has pointed out correlations between the utilization of oxygen by fishes at low oxygen tensions and the pH and carbonate systems.

The variation in the amount of oxygen consumed by fresh-water fishes of different species is apparent from the work of Gardiner, King, and Powers (1922) who give the oxygen consumption of the brown trout as from 90 to 200 cubic centimeters per kilo of body weight per hour at temperatures between 4° and 20° C.; of the goldfish as 16 to 90 cubic centimeters; and of the eel 9 to 60 cubic centimeters.

The lower limit for dissolved oxygen—that is, the point at which the dissolved oxygen—is so reduced as to present a lethal condition for fishes is equally difficult to define. Kupzis (1901) reports that in general the cyprinid, *Leuciscus erythrophthalmus* (the European roach), could live for sometime in water containing 0.7 cubic centimeter of dissolved oxygen per liter (1 p. p. m.) but that this species of fish died from asphyxia when the dissolved oxygen was reduced to 0.4 to 0.5 cubic centimeter per liter (0.57–0.71 p. p. m.). Plehn (1924) states that trout live best in water containing 7 to 8 cubic centimeters of dissolved oxygen per liter (10–11.43 p. p. m.), but if the water be warm these fish show some discomfort when the dissolved oxygen is reduced to 5.5 cubic centimeters per liter (7.86 p. p. m.). This author also states that carp live well in water containing 5 cubic centimeters dissolved oxygen per liter (7.1 p. p. m.), but show respiratory difficulties when the dissolved oxygen is reduced to 3 cubic centimeters per liter (4.3 p. p. m.) or lower. If the water be cold, carp can live for a short time in water containing only 0.5 cubic centimeter per liter of dissolved oxygen (0.71 p. p. m.). In order of their oxygen requirements, Plehn lists first the salmonids and coregonids, then the barbe, the rutte, the pike, carp, tench, goldfish, and lowest of all the eel. Gardiner and King (1922) give asphyxial point for trout as from 0.8 cubic centimeter of dissolved oxygen per liter (1.14 p. p. m.) at 6.5° C., to 2.4 cubic centimeters per liter (3.4 p. p. m.) at 25° C.; and for goldfish as 0.39 cubic centimeter per liter (0.56 p. p. m.) at 11° C., and 0.42 cubic centimeter per liter (0.6 p. p. m.) at 27° C. Paton (1904) found that harmful to fatal conditions for young trout developed if the dissolved oxygen were reduced to 2 cubic centimeters per liter (2.9 p. p. m.) or lower, although some individuals were able to live in such waters for long periods of time.

Thompson (1925) states that carp and buffalo have been found living in water carrying as little as 2.2 p. p. m. of dissolved oxygen. As a rule, he found a variety of fishes only when 4 p. p. m., dissolved oxygen were present, and the greatest variety of fishes were taken from waters carrying 9 p. p. m. of dissolved oxygen. His observations made at Peoria Narrows, Ill., in the summer of 1923 showed that fishes died over night in waters having less than 2 p. p. m. of dissolved oxygen. Of the various species of Illinois fish discussed by Thompson the dogfish, *Amia calva*, seemed to be the most sensitive to low oxygen tensions and the carp, the most resistant.

From the various observations cited above, which may be taken as representative of the voluminous literature on the oxygen requirements of fishes, it may be seen that the upper limit of dissolved oxygen at which asphyxia may be expected in fresh-water fishes if there be no unusual complicating factors, is in general about 3 p. p. m. at 25° C. In evaluating the dissolved oxygen level as a lethal hazard to fish life, this upper asphyxial limit must be considered rather than the lower minimal limit of dissolved oxygen which can be tolerated by some fish for varying periods, particularly under the conditions of rapid or abrupt oxygen reduction presented in so many of the experimental studies, since the actual hazard to fish life begins at the oxygen level where death may be expected even if some more hardy individuals survive temporarily or for some time at lower oxygen levels.

It is well established for many animals and man, however, that the asphyxial oxygen level, the oxygen level which will support life if profound compensations be made, and the oxygen level at which respiratory, cardio-vascular, and other systemic compensations begin are three quite different values. The latter—that is, the oxygen level at which respiratory and circulatory compensations are initiated—marks the lower limit as regards oxygen percentage of the favorable respiratory environment, although this oxygen level is much higher than the lethal oxygen level for these same species. It has been shown (Ellis, 1919) that although man lives in air normally containing 21-percent oxygen, and the collapse point for most human beings is reached when the oxygen in the air breathed is reduced to approximately 6 percent, that human respiratory compensation to reduced oxygen begins at about 18 percent oxygen. Applying this same principle to fishes in the present studies it has been found that individual goldfish, perch, catfish, and other species of fresh-water fishes in good condition and from favorable environments if placed in water of constant flow, favorable composition, and temperature (20° to 25° C.) may show respiratory compensations in rate and volume or both when the dissolved oxygen in this water is reduced only a little below 5 p. p. m. As there are various factors influencing the exact point at which this respiratory compensation begins, the details will be presented elsewhere; but the important finding in connection with the present discussion is that even under conditions as favorable as may be met with in fresh-water streams, respiratory compensations by fishes to oxygen reduction may begin when the dissolved oxygen level is still almost 5 p. p. m. From these studies the case of a perch which made respiratory compensation to reduced oxygen largely by rate is presented (fig. 10) as typical.

This finding that respiratory compensations by fresh-water fishes to oxygen reduction may begin when the dissolved oxygen of water is lowered only to approximately 5 p. p. m. is in accord with the statement of Plehn (1924) that carp show respiratory difficulties when the dissolved oxygen is reduced to 4.3 p. p. m. and gives physiological background for the differences in fish faunae between waters carrying 4 p. p. m. or less dissolved oxygen and those carrying 5 p. p. m. or more dissolved oxygen, as reported in our field studies.

Considering the data from all sources and particularly from the field and laboratory studies presented here 5 p. p. m. of dissolved oxygen seems the lowest value which may reasonably be expected to maintain in good condition varied fish faunae of warm-water fishes in our inland streams, if the water temperature be 20° C. or above. This statement does not mean that 5 p. p. m. dissolved oxygen is the lethal point for fresh-water fishes but designates 5 p. p. m. as approximately the lower limit of favorable conditions. The fact that fish on occasion can tolerate for a period of hours or even days water carrying less than 5 p. p. m. dissolved oxygen does not justify the acceptance of such conditions as defining any stream as suitable for fishes, in view of the data presented on the natural preference by fresh-water fishes for waters containing 5 p. p. m. or more of dissolved oxygen, and the experimental evidence from various sources that vital compensations may be called for in waters carrying less than 5 p. p. m. dissolved oxygen at temperatures of 20° C. or above.

Besides it is recognized in the various fields of animal husbandry, including aquiculture and pisciculture, that if any variety of animal is to be successful and thrive merely sublethal conditions are not adequate.

The application of this observation concerning sublethal conditions is particularly important in pollution investigations, for a reduction of dissolved oxygen increases the lethality of many stream pollutants, especially those injurious to the gills (v. i.). For example, it was found that certain concentrations of various metallic salts and acid wastes were consistently more injurious to fish when the dissolved oxygen contained in the water thus polluted was comparatively low, but still sublethal, than when the dissolved oxygen was high. This difference in lethality correlated with dissolved oxygen obtained in spite of the fact that these specific pollutants neither reacted with nor were removed by dissolved oxygen regardless of the amount of oxygen present.

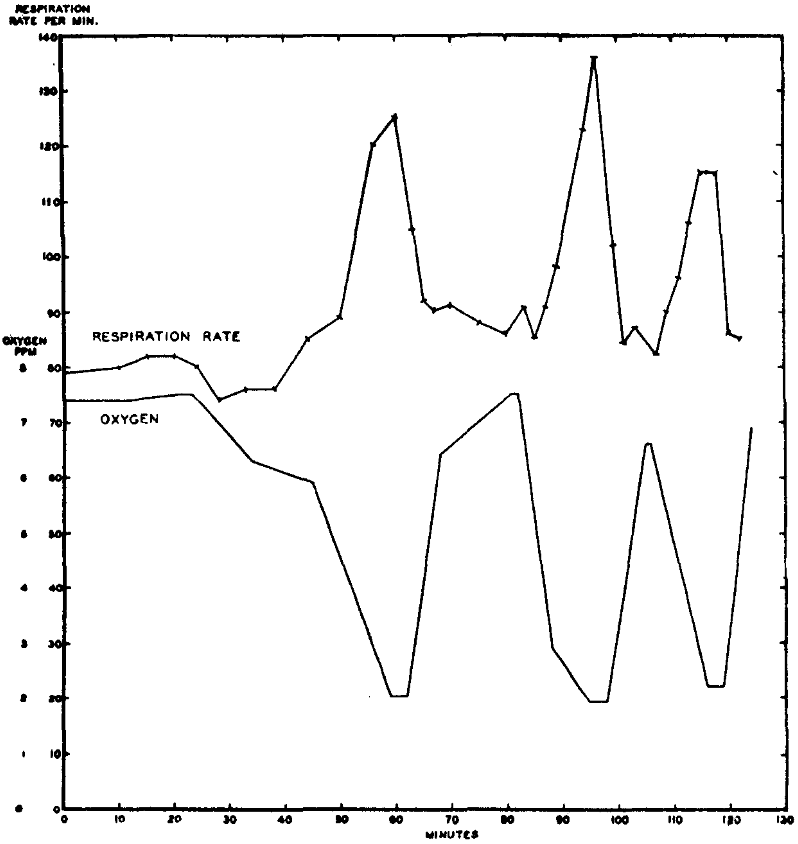

FIGURE 10.—Changes in the respiration rate of a 4½-inch yellow perch, *Perca flavescens*, correlated with changes in the dissolved oxygen content of the surrounding water, temperature 18 degrees centigrade.

The dissolved oxygen content of unpolluted streams normally varies with at least four major sets of factors, namely, (*a*) physical conditions such as stream flow, stream fall, and temperature, which influence the saturation of water with oxygen from the air; (*b*) oxygen produced by aquatic plants; (*c*) oxygen removed by aquatic organisms both plant and animal; and (*d*) the oxygen demand of the organic detritus in the stream. Effluents polluting streams alter this dissolved oxygen balance chiefly through increasing the oxygen demand. Pollutants may create oxygen demand in any of three ways or combinations of these; that is, by the addition of quantities of organic matter of a putrescible sort, among which may be mentioned domestic sewage, packing-plant wastes, beet-sugar waste, and hide vat liquor from tanneries; through the action of various reducing chemicals as certain sulphite wastes from paper mills, sulphide and iron wastes from mines, and certain spent dyes from leather works; and by killing large masses of aquatic vegetation which subsequently decompose. Many effluents which create oxygen demand are also harmful to aquatic organisms because of specific toxic effects.

The determination of the biochemical oxygen demand of various effluents affecting the dissolved oxygen balance in the stream does not necessarily, therefore, give a true evaluation of the pollution hazards produced by these effluents; for various species of warm-water fishes will live in water having high oxygen demand, due to domestic sewage or industrial wastes rich in organic material but without specific toxic substances, if the dissolved oxygen level be maintained above 5 p. p. m. and the aeration be sufficient to blow off the excess of other gases as carbon dioxide, methane, and sulphur derivatives. The biochemical oxygen demands of such effluents as have high oxygen demands must be taken into account, however, if these wastes are poured into streams, in order to compute the dilution required to prevent this oxygen demand from lowering the dissolved oxygen in the stream to an unfavorable level.

Two examples of the effect of dissolved oxygen on the lethality of effluents free from specific toxic substances but presenting large pollution hazards because of high oxygen demands will suffice. The tan vat liquor from a tannery on the upper Mississippi River in spite of the high oxygen demand of this waste was not only tolerated readily when properly aerated and unmixed with the toxic chemical effluents from the plant by various warm water fishes but materially increased the production of plankton when added to the river water. Findings from the sewage treatment system of the city of Munich, Germany, also demonstrate that high biochemical oxygen demand in itself need not be a pollution hazard to fresh-water fishes. In this system, water from the River Isar is mixed with prepared sewage and impounded for the commercial raising of rainbow trout and carp. This procedure was very successful over a period of years in the production of commercial quantities of both trout and carp. The following statement from a recent English review of the work of this plan (Engineering, 1935) may be quoted in this connection:

> The proportion of fresh water to sewage should be at least 5:1, and the proportion of oxygen not less than 5 cubic centimeters per litre (7.1 p. p. m.). If these conditions are maintained, the micro-organisms will flourish, absorbing and destroying all impurities and providing the food for the completion of the process. In such circumstances the fish will suffer no ill effects, although, as is well known, trout are most susceptible to any impurity.

The oxygen balance of streams may also be affected by oils which exclude oxygen from the surface of the stream and prevent proper reaeration of the water. Oil is rarely poured into streams in such quantities as to present this difficulty, however. Again sewage and industrial sludges are often particularly harmful in reducing the dissolved oxygen through their biochemical oxygen demands during the winter season when ice covers the stream surface and interferes with the reoxygenation of the water.

HYDROGEN-ION (pH) LIMITS

Hydrogen-ion concentration measurements in the laboratory and aboard Quarterboat *348* were made electrometrically with calomel and quinhydrone electrodes (Leeds, Northrup Co., Philadelphia, type 7701–A1). In the field the Youden apparatus (W. M. Welch Co., Chicago, type 5270) bridging the quinhydrone electrode against standardized phthalate solution was used because of greater portability. When field conditions were such that neither of these two pieces of apparatus were available, the determinations of hydrogen-ion concentrations were made colorimetrically by the method of Gillespie (1920). Sterile tubes, solutions, and stoppers were used in preparing the tube series for the Gillespie sets, which were calibrated against the calomel electrode and kept in a dark box except when measurements were being made. Although fractional values were recorded (i. e., hundredths), in presenting the data the value is given to the nearest tenth pH.

The hydrogen-ion concentration of the inland streams of the United States, southern Canada, and northern Mexico, excepting badly polluted portions of these waters, as seen in a review of some 10,000 readings made during the past 5 years, lies in general between values of pH 6.7 and pH 8.6, with the extreme range (in our data) of pH 6.3 and pH 9.0 in streams for which no specific pollution factor affecting the hydrogen-ion concentration was readily observable. Swamp waters, bog streams, and particularly swamp lakes not infrequently show an acidity between pH 4.5 and pH 6.0, yet at the same time may support mixed fish faunae. In some small western streams and pools containing fishes examined by the writer in North Dakota, Montana, and New Mexico an alkalinity of pH 9.5 was occasionally found in alkali districts or near mineral springs. In such waters small poeciliids and cyprinids were uniformily the dominant fishes.

In figures 11, 12, 13, and 14, 7,228 pH readings from inland stream waters representing 1,125 localities are presented. These data were collected during the warm season, June to September, 1930–35, and are comparable with the dissolved oxygen data in the preceding section. The composite, figure 11*A*, was constructed from 2,280 readings representing 409 localities where good fish faunae, as previously defined, were found. This composite covers a range between pH 6.3 and pH 9.0, with 97 percent of the cases between pH 6.7 and pH 8.6. Superimposing the graph of the composite on the graphs presenting the data from the various river systems, however, shows that, except in cases of extreme pollution, the pH values as such of stream waters, both polluted and unpolluted, do not differ materially from those of the composite.

The data from the various river systems (other than the composite) are presented without regard to pollution, except that no pH readings of water in the immediate vicinity of flumes and conduits from which effluents were escaping have been included. The extreme pH range of the flowing waters of inland streams of the United States, both polluted and unpolluted, as found in these field studies was pH 3.9 to pH 9.5, although various effluents poured into these same waters were found to range from pH 1.0 to pH 11.0 at the point of entrance into the stream. These observations show that dilution and the buffer action of various substances

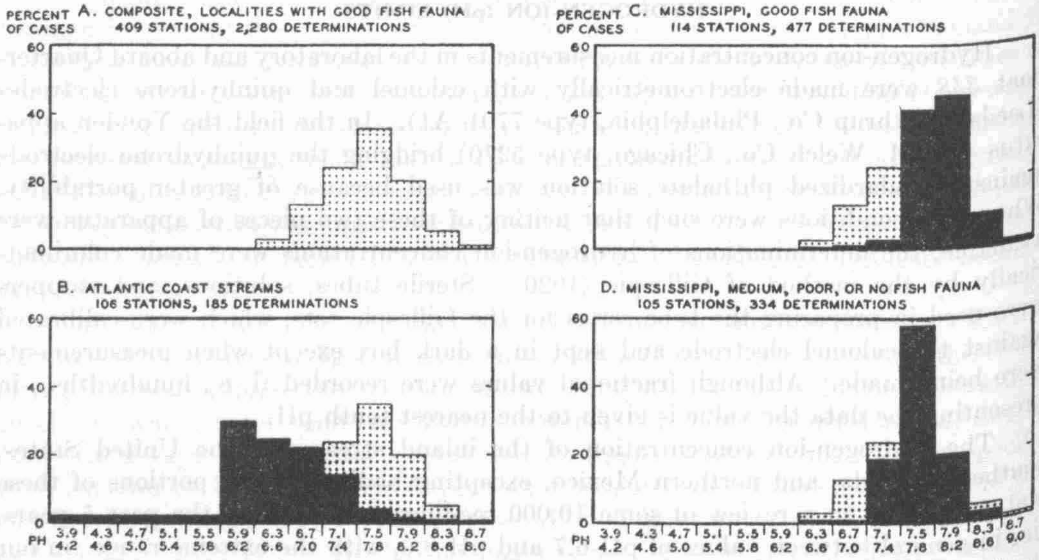

FIGURE 11.—Comparisons of pH values of various river units. Composite and black graphs as explained under figure 6.

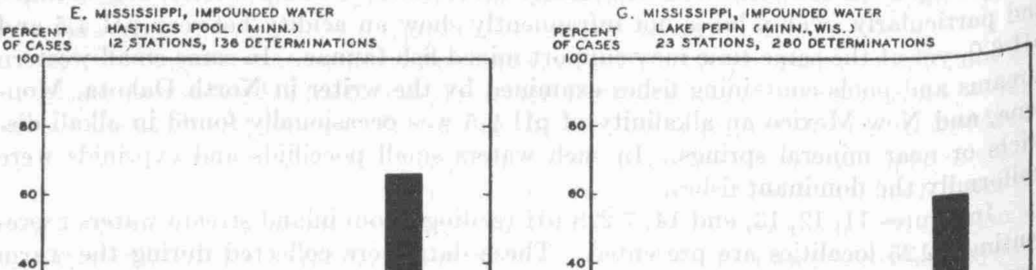

FIGURE 12.—Continuation of comparisons of pH values for various river units, stippled graph *A* figure 11, being the standard

in the river waters do change the pH values of the extremely acid and extremely alkaline wastes rather rapidly to the range of the composite pH 6.3 to pH 9.0.

Reviewing all of the field pH data it may be observed within the general range of unpolluted water, pH 6.7 to pH 8.6, that mountain streams, particularly headwater streams, are in general more acid than plains or lowland streams. The Columbia River data (fig. 14*P*) bring out this comparison in the bimodal distribution of the pH values, since portions of the Snake River flowing through plains and desert regions and the mountainous headwaters of both the Snake and Columbia Rivers are included in this graph. This same distribution of pH values is also apparent in the graphs presenting the findings in the two parts of the Missouri River system (figs. 13*I* and 13*J*). The explanation of these distributions of pH values is clear when the carbonates and conductivities of these waters are also considered (v. i.), as the headwater streams contain much less dissolved solid matter than the plains, lowland, and desert streams. The effects of acid pollution are evident in the Ohio River (fig. 13*K*), and of general pollution and some bog waters in the Atlantic coast streams (fig. 11*B*).

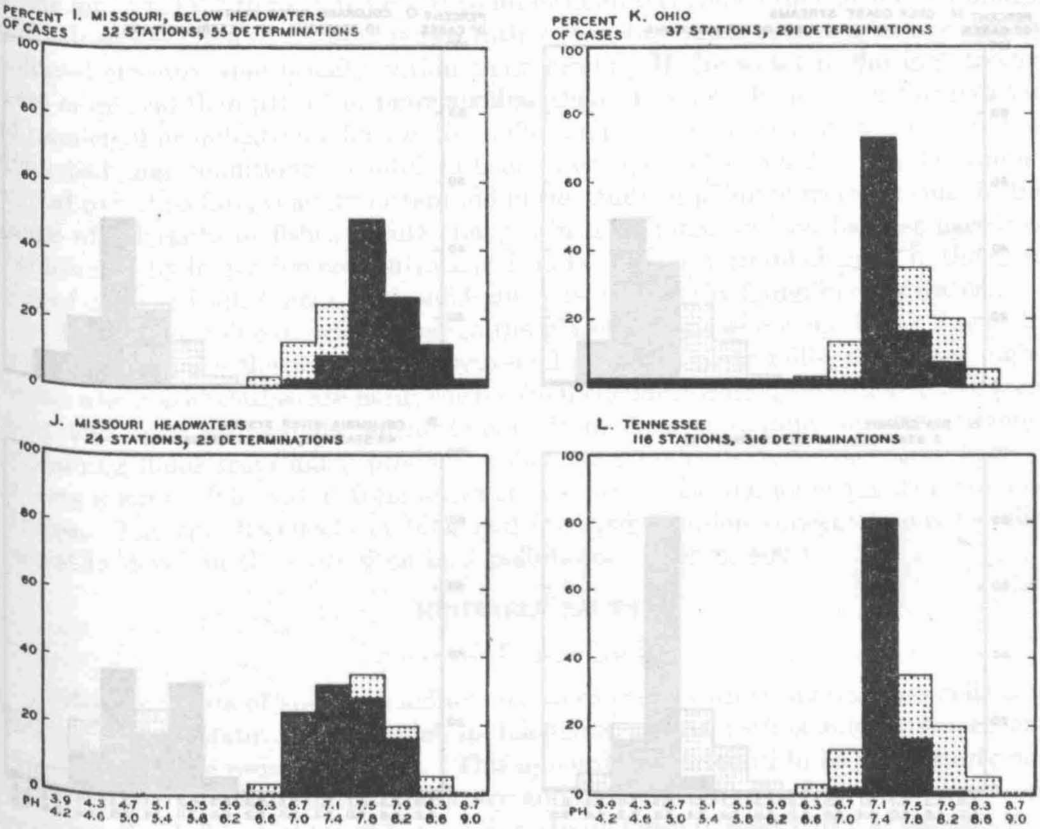

FIGURE 13.—Continuation of comparisons of pH values, stippled graph *A* figure 11, being the standard.

The field observations presented here agree in general with the statement made by Shelford (1929) that the hydrogen-ion concentration from pH 6.5 to pH 8.5 may be expected in most uncontaminated fresh-water streams and lakes; and with the observations of Powers (1921 and 1929); and of Juday, Fred, and Wilson (1924).

Experimental tests have demonstrated that many species of fresh-water fishes have a great tolerance for variations in hydrogen-ion concentrations over a wide range. Creaser (1930) showed brook trout to have a voluntary toleration of hydrogen-ion concentrations from pH 4.6 to pH 9.5. Brown and Jewell (1926) found catfish and perch living in apparently good condition in a bog lake, the water of which ranged from pH 4.4 to pH 6.4; and also in a glacial lake nearby, the water of which varied from pH 8.2 to pH 8.7. These workers demonstrated that the fishes from the two lakes survived transfer from either lake to the other. Wiebe (1931a) reports goldfish survive rapid changes from pH 7.2 to pH 9.6; largemouth black bass, from pH 6.1 to pH 9.5; smallmouth black bass, from pH 6.6 to pH 9.3; and sunfish from pH 7.2 to pH 9.6. Powers (1930) in reviewing the problem summarizes the existing data by saying that aquatic organisms are able to withstand a wide range in pH. The writer has confirmed this statement with gammarids, daphnia, unionids, and planaria, as well as for goldfish, perch, and catfish, in connection with pollution tests.

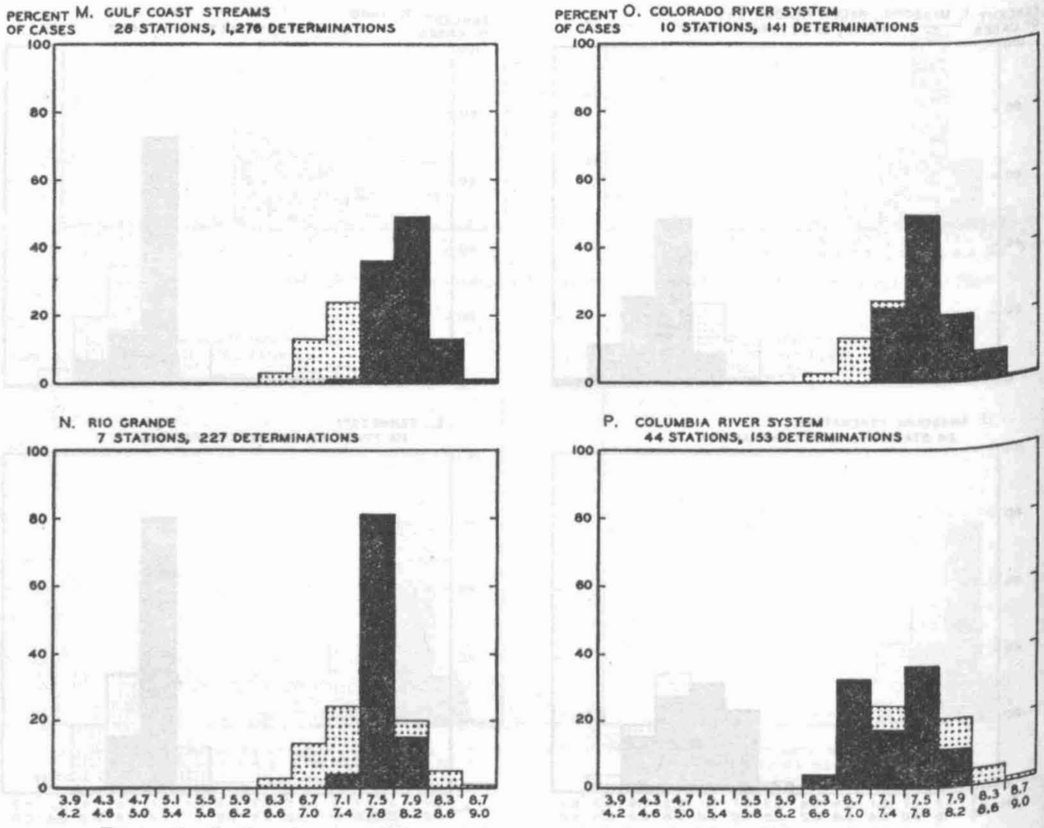

FIGURE 14.—Continuation of comparisons of pH values, stippled graph *A* figure 11, being the standard.

It might seem, therefore, from both the field data and laboratory findings that the pH values of stream water would be of little consequence in pollution studies and in determining standards of water suitability. However, the pH of natural water is determined by substances in solution—particularly carbonates, carbon dioxide, various salts, and a few organic substances—which collectively constitute a poor to fair buffer system; so that water more acid than pH 6.7 or more alkaline than pH 8.6 is not found generally in our inland streams, unless there be some unusual factor in the complex. Pond water, bog water, and lake water vary over a wider range, but the combination of stream flow, aeration and buffer substances holds the hydrogen-ion concentration of the larger rivers, the smaller streams, and even many brooks within the limits described. In pollution studies, therefore, it has been found advisable to view with suspicion any stream water having an hydrogen-ion concentration outside of the limits pH 6.7 to pH 8.6, until it could be definitely shown that such extra limital pH values were due to natural causes rather than to human agencies, as even badly polluted streams were usually within these limits. If the water of flowing streams were more acid than pH 6.7 or more alkaline than pH 8.6 as the result of the addition of municipal or industrial effluents the buffer and carbonate systems were usually so disturbed that conditions harmful to fishes were generally found. The determination of pH, therefore, is an important aid in the study of polluted water in spite of the range of tolerance of fishes to pH changes in unpolluted waters, because excessive variation in hydrogen-ion concentrations is indicative of harmful changes in the complex of dissolved substances, both solids and gases, normally found in river water.

Among the effluents which change the pH of stream water and break down the buffer systems are the wastes from wire-nail mills, tin-plate mills, and other metal works where acid washes are used; wastes from chemical works, particularly dye mordant and soda compounds; spent liquors from chrome tanning processes; whey-containing fluids from dairy products concerns; laundry waters; and some battery factory wastes. The waters from unsealed coal mines also add large quantities of acid wastes. The specific effects of high and low hydrogen-ion concentrations are discussed in detail in the section on acid pollutants. (See p. 409.)

IONIZABLE SALTS

Specific Conductance

Measurements of specific conductance were made with standard glass cells containing coated platinum electrodes in telephone circuit with a microhummer and standard variable resistance units. This apparatus was found to be very sturdy and was regularly used both in the laboratory and in the field. For convenience in presentation, the data are expressed as specific conductance in mho$\times 10^{-6}$ at 25° C.

Unpolluted natural waters contain in solution small quantities of carbonates, chlorides, phosphates, and sulphates, usually some nitrates and nitrites if organic matter be present, and traces of many other salts which vary with the region through which the stream flows. The metallic ions represented are largely calcium, magnesium, sodium, potassium, iron, and manganese, with traces of various other elements. Owing to the fact that carbon dioxide is supplied to stream water from so many sources, carbonates are the dominant salts; but because of the low solubility of most carbonates and also of most phosphates, the mineral content of river water never rises very high unless some particular substance is added to the water which will raise the solubility of these compounds or transform them into other more soluble compounds. All of the substances in solution in river water collectively exert osmotic pressure on the aquatic organisms living in the water, and many of these compounds are physiologically active, so that fresh-water fishes and other animals living in these streams have become adapted to the physical and physiological actions of this salt complex.

Small variations in several of these salts may cause small variations in the species composition, particularly the invertebrates, of the faunae at any given station. Most aquatic species, however, will tolerate changes of considerable magnitude in the relative amounts of these salts normally present in flowing waters, if the very small total amount which is usually present be not exceeded. For example, the fixed carbonates in the upper Tennessee River were found to vary from 0.4 to 30 cubic centimeters per liter (computed as CO_2 by volume) without affecting the general composition of the aquatic fauna, and from 0.3 to 55.5 cubic centimeters in Spider Creek, a tributary to the Wabash River.

The specific quantities of most of the substances comprising this salt complex are not so important as the total quantity of soluble matter involved (see section on osmotic pressure), since even the small quantities of these compounds present in ordinary soil run-off are in excess of the physiological needs of most fresh-water organisms. As in general these substances are ionizable, measurements of the specific conductance of a large number of polluted and unpolluted waters were made. The summarized data are presented in figure 15.

These determinations of specific conductance of inland fresh waters show that, excepting the streams in the plains and desert regions, the specific conductance of those portions of inland streams and rivers which were supporting good, mixed fish faunae in general lay between 150 and 500 mho $\times 10^{-6}$ at 25° C.

This uniformity of water composition in flowing streams holds even in the very deep holes of rivers. Two cases—Pan Eddy, in the Tennessee River, and the deep hole off Grand Tower, Ill., in the Mississippi River—are presented as typical in table 1.

Only in the very deep portions of river lakes, such as Lake Wilson in the Tennessee and Elephant Butte Reservoir in the Rio Grande, is there any marked stratification of the waters. In the deeper portions of some of these impounded waters (see table 4) definite thermal stratification, with the attendant changes in turbidity, dissolved oxygen, pH, and other physiochemical features of the water, develop in midsummer at levels variously determined by the general climatological features of the region and the level and amount of draw-off as made for the needs of industry and navigation. In such river lakes a warm, more turbid stream—the hyperlimnorrheum—flows over a colder, clearer lake—the hypolimnion—with a rather well-delimited thermocline lying between these. This condition of stratification obtains, however, only during a portion of the warm season. Specific data for one station on Lake Wilson (see table 4) show such stratification of the waters when it was at its height. During the colder portions of the year there is a rather complete mixing of the waters at all depths, even in Lake Wilson. Details of these hydrobiological data of various river lakes are presented elsewhere.

The specific conductance of mountain stream waters was generally in the lower part of this range, unless excess carbon dioxide were present. However, in the streams of the western plains and desert areas, particularly those carrying the more alkaline waters, as the Snake (Columbia River system), the Rio Grande (below headwaters), the Colorado and Gila Rivers, and the upper Missouri and Yellowstone below the mountains, a specific conductance of 2,000 mho was not unusual, the general range of specific conductance of these streams being between 200 and 2,000 mho, with extreme readings of almost 5,000 mho × 10^{-6} at 25° C. However, good mixed fish faunae of such species as normally inhabit these western streams were usually not found in waters with specific conductance greater than 2,000 mho × 10^{-6} at 25° C. These high conductivity values for certain western waters were clearly due to the natural high solids content of these waters which drain areas rich in the various soluble alkalis.

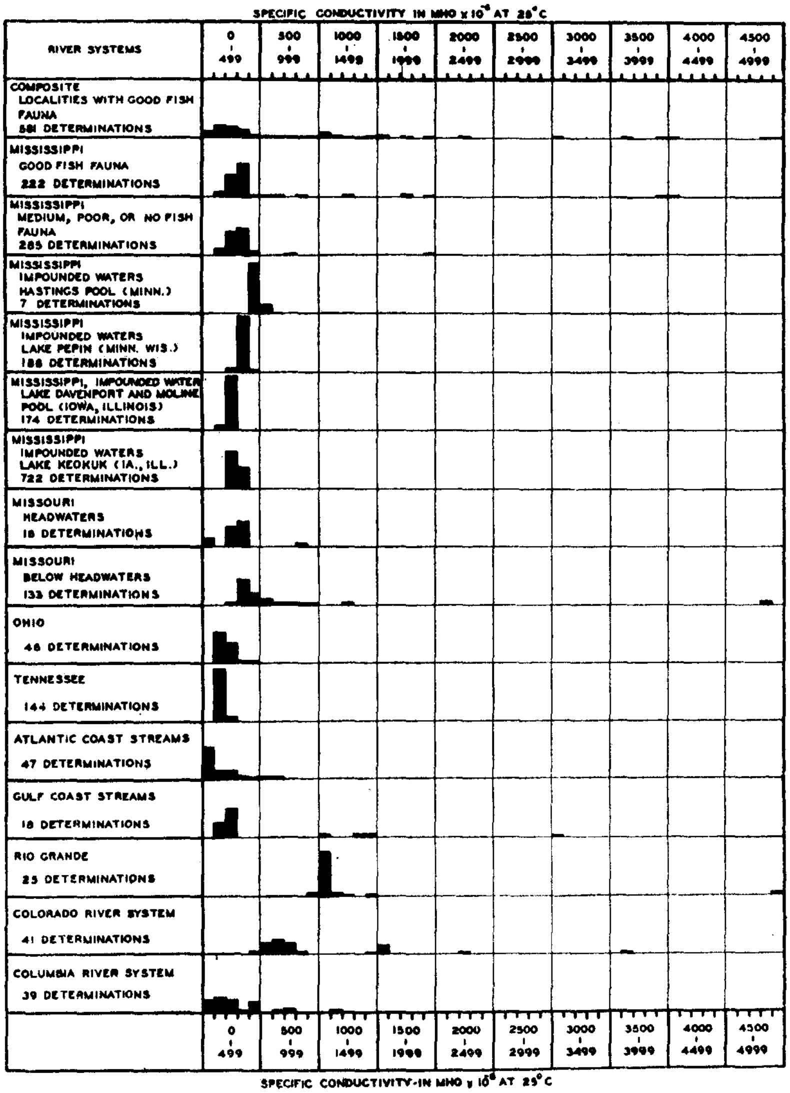

FIGURE 15.—A comparison of the specific conductivity values of the waters of various river units.

From the field studies on specific conductance it was found advisable in pollution studies to look for specific pollutant action if the conductivity of the water exceeded 1,000 mho in all types of streams except those draining the more alkaline regions, or 2,000 mho in the case of the western streams discussed above, for the specific conductance is very readily raised by acid and salt pollutions of several sorts.

Specific conductance, therefore, offers a ready method for detection of salt and acid pollution, as produced by water from oil wells, by wastes from industries using salts or strong acids, and by soluble salts of heavy metals. This method was used very satisfactorily by the writer in determining the extent of downstream pollution from lead and zinc mines in the Coeur d'Alene district in Idaho (Ellis, 1932), and in following pollution by acid mine waters from coal mines in Tennessee and West Virginia.

CARBON DIOXIDE

Determinations of free, half-bound and fixed carbon dioxide were made by the methods of Seyler as described by Kemmerer, Bovard, and Boorman (1923) and American Public Health Association (1933). The data are expressed as cubic centimeters of carbon dioxide per liter.

FIXED CARBON DIOXIDE (CHIEFLY CALCIUM AND MAGNESIUM CARBONATES)

In figures 16 and 17 the data from 6,770 determinations of fixed carbon dioxide in flowing streams of the United States and southern Canada collected during the warm season, June to September, inclusive, 1930–35, are presented. The extreme range of fixed carbonates varied from almost 0 to 70 cubic centimeters per liter, with 40 cubic centimeters per liter as the usual upper limit. A composite of determinations from waters where good fish faunae were thriving (fig. 16*A*) covered the entire range from 0 to 70 cubic centimeters per liter. In this composite 96 percent of the 2,190 analyses showed the stream water to carry less than 50 cubic centimeters per liter of fixed carbon dioxide and 53 percent lay between 10 and 30 cubic centimeters per liter. Comparing these findings with the classification of lake water given by Birge and Juday (1911), it may be seen that most of the flowing waters fell in the second class, designated as medium waters; and that the large percent of the river and stream waters could be classified as either soft or medium. Hard waters were distinctly in the minority.

Reviewing this composite in connection with the findings on fixed carbonates in the waters of the various river systems, it is evident that between 10 and 40 cubic centimeters of fixed carbon dioxide may be expected in most of the fresh-water streams of the United States. Fixed carbon dioxide in itself, however, does not seem to be a determining factor in classifying flowing waters as suitable or unsuitable for fresh-water fishes. Various limnologists have pointed out the importance of fixed carbonates in maintaining food supply, and, therefore, fish faunae of various lakes (Welch, 1935), but from the data on rivers and streams presented here it must be concluded that either carbonates are not limiting factors or that they are always present in sufficient quantities to meet the needs of the stream biota. An exception to this last statement, however, must be taken at least in the case of fresh-water mussels, as carbonates do constitute a very vital limiting factor for these animals.

In general, it was found that the fixed carbonates vary with the character of the country drained, mountain streams in regions where igneous rocks dominate being very low in fixed carbonates and streams traversing limestone country or alkaline soil being relatively high. However, it must be added that excepting the headwater streams in mountainous regions the fixed carbonate load of flowing stream water was rarely less than 5 cubic centimeters per liter.

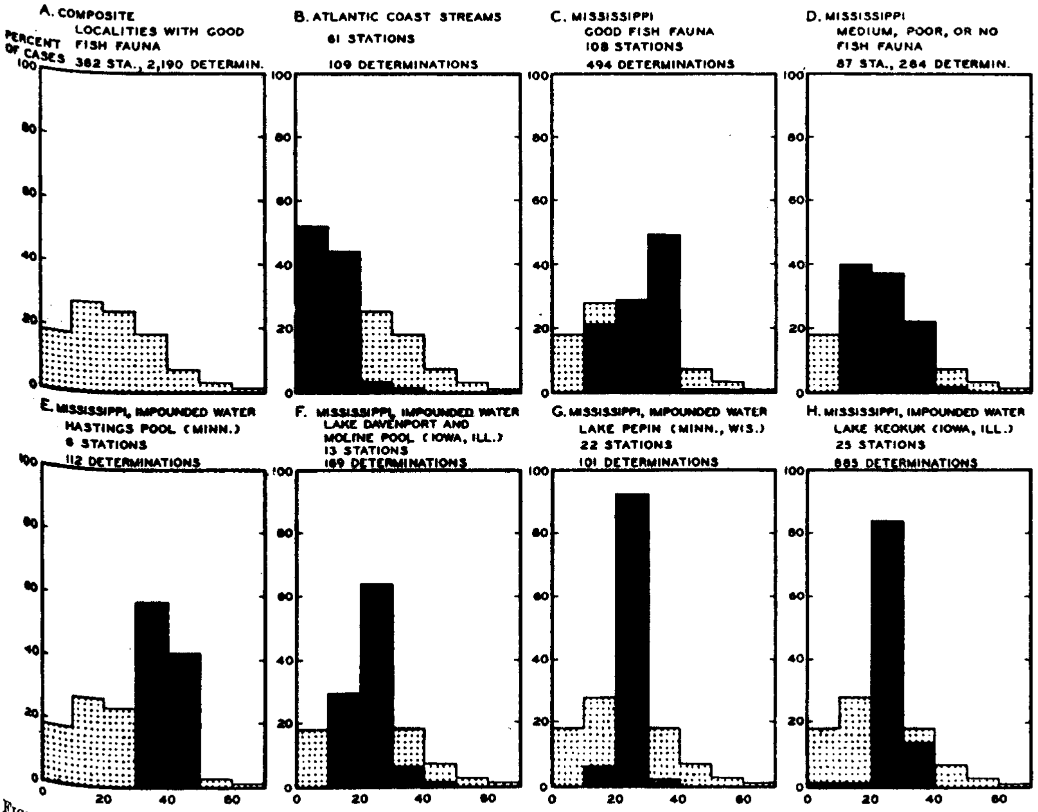

FIGURE 16.—Fixed carbon dioxide values (as cubic centimeters of carbon dioxide per liter, bottom line) for the waters of various river units. Stippled and black graphs composed as explained under figure 6.

In pollution studies, although fixed carbonates may not be important in defining particular water as suitable or unsuitable for good fish faunae, the fixed carbon dioxide is of large importance in evaluating the extent of certain types of pollution and in determining the amount of dilution required to render certain effluents relatively harmless to aquatic life. The fixed carbon dioxide of the stream water is the major buffer against which both acid and alkali pollutants act, and the fixed carbonate must be taken into consideration, therefore, when the maximal nontoxic dilution of any effluent is to be determined. This problem is discussed more fully under acid wastes, but it may be pointed out here that the toxicity to fishes and other aquatic life of many of the common acids is much greater in distilled water or water carrying very little fixed carbon dioxide than in water carrying 20 to 60 cubic centimeters per liter of fixed carbon dioxide. The reason is obvious because of the buffer and neutralizing actions of these fixed carbonates on free acids. Again, the fixed carbon dioxide is of considerable importance in detoxifying various effluents, particularly those carrying salts of heavy metals, by precipitating various compounds, since many carbonates are relatively insoluble and, therefore, are removed at least temporarily from the waters during precipitation. This is discussed more fully in the section on metallic poisons.

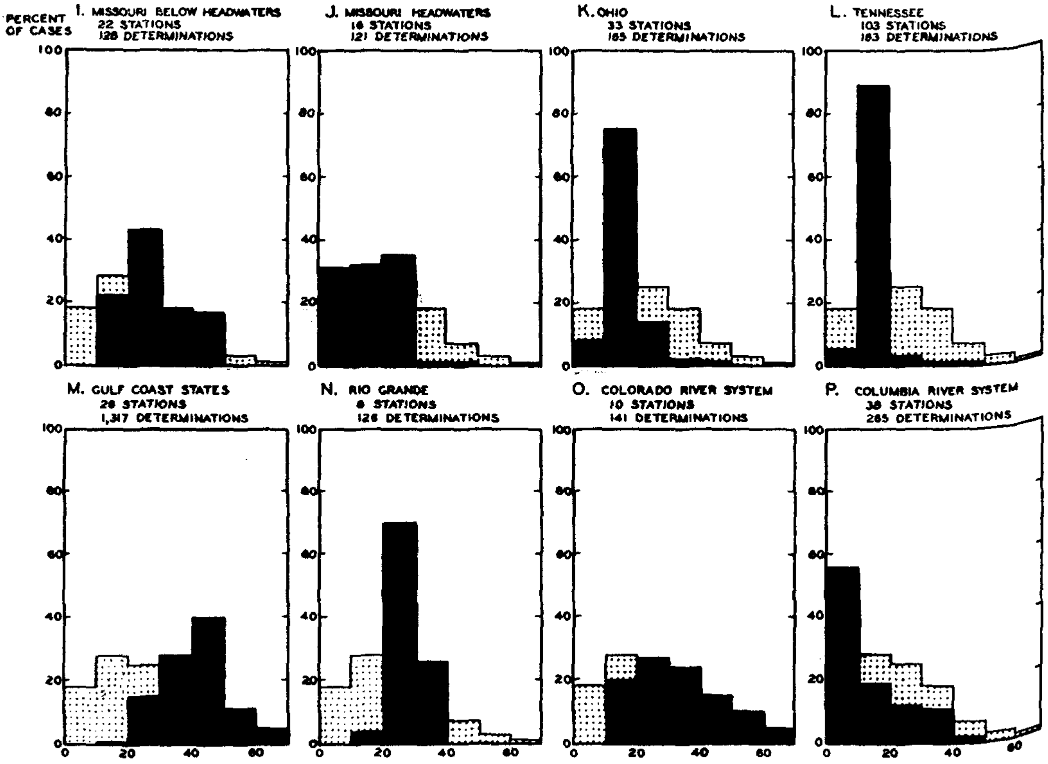

FIGURE 17.—Continuation of comparisons of fixed carbon dioxide values, stippled graph *A* figure 16 being the standard.

FREE CARBON DIOXIDE

Figures 18 and 19 present the data from 3,351 determinations of free carbon dioxide in various streams of United States. From these figures, and particularly from the graph of the composite, it may be seen that river and stream waters, where good fish faunae were found, carried consistantly less than 5 cubic centimeters of free carbon dioxide per liter, 90 percent of the waters where good fish faunae were taken carrying less than 2 cubic centimeters of free carbon dioxide per liter. It must be pointed out in this connection that conditions in moving streams are quite different as regards free carbon dioxide from those obtaining in lakes and ponds. Due to the constant turnover of river and stream waters because of current action, there is a very uniform mixing of water from surface to bottom (see data from Grand Tower on the Mississippi and Pan Eddy in the Tennessee (table 1)), so that the free carbon dioxide, as well as the other dissolved gases, is quite uniformly distributed throughout the stream. Again, the movement of the current facilitates the constant reaeration of stream waters with a tendency for these waters to lose carbon dioxide to the air as soon as the carbon-dioxide tension in the water exceeds that of the surrounding air, which is usually quite low (2 to 4 parts per 10,000). Both of these conditions, together with the usual presence of calcium and magnesium salts in stream waters, tend to keep these flowing streams more alkaline than pond, lake, and bog waters, so that in many river waters the alkalinity is raised to a point where there is little or no uncombined carbon dioxide.

TABLE 1.—*Characteristics of water at different depths in deep holes of flowing rivers, showing general uniformity of composition at any given station due to mixing action of current*

I. UPPER TENNESSEE RIVER, AT PAN EDDY, 18 MILES BELOW CHATTANOOGA, TENN., AUG. 21, 1931, AIR TEMPERATURE, 23° C.

Depth in feet	Water temperature, degrees centigrade	pH	Specific conductivity in mho × 10^{-6} at 25° C.	Fixed carbon dioxide, cubic centimeters per liter	Dissolved oxygen parts per million	Light penetration, millionth intensity depth in millimeters
S [1]	28.0	7.3	169	15.4	5.6	544
10	28.0	7.2	169	15.4	5.5	561
20	27.9	7.3	169	14.9	5.7	561
30	27.9	7.3	169	14.9	5.9	561
40	27.8	7.3	169	14.9	6.0	561
50	27.8	7.3	169	14.9	5.7	561
60	27.8	7.3	169	14.9	5.2	561
70	27.8	7.4	169	15.2	5.5	552
80	27.8	7.4	160	15.2	5.7	552
90	27.8	7.4	169	15.2	5.5	544
100	27.6	7.4	169	15.4	5.6	536
110	27.7	7.3	168	14.9	5.7	528
120	27.8	7.3	168	14.9	6.1	521
130	27.8	7.3	167	15.1	5.9	513

II. MISSISSIPPI RIVER, OFF TOWER ROCK, NEAR GRAND TOWER, ILL., SEPT. 8, 1931, AIR TEMPERATURE 30.5° C.

Depth in feet	Water temperature, degrees centigrade	pH	Specific conductivity in mho × 10^{-6} at 25° C.	Fixed carbon dioxide, cubic centimeters per liter	Dissolved oxygen parts per million	Light penetration, millionth intensity depth in millimeters
S [1]	26.2	7.5	340	26.4	5.3	129
10	26.0	7.5	341	26.6	5.1	125
20	25.8	7.6	339	26.8	5.3	125
30	26.0	7.5	337	26.4	5.3	122
40	26.0	7.5	338	26.4	5.3	129
50	26.0	7.5	340	26.4	5.3	120
60	26.0	7.5	331	26.6	5.3	122
70	26.2	7.4	338	26.7	5.3	122
80	26.0	7.4	342	26.7	5.3	125
90	26.0	7.4	339	26.8	5.4	122
100	26.0	7.4	338	26.8	5.4	119
110	26.0	7.4	341	26.8	5.3	124

[1] Surface, i. e., top 12 inches of water.

The specific toxicity of carbon dioxide for aquatic organisms is well known and is discussed under acid wastes. From all of the field data and in view of the experimental findings presented, the determination of free carbon dioxide was found to be a valuable aid in pollution studies, and river and stream waters carrying more than 3 cubic centimeters of free carbon dioxide per liter were checked carefully for some source of organic pollution. Values in excess of 3 cubic centimeters per liter usually were indicative of such pollution in our flowing inland streams. The relatively high free carbon dioxide as compared with the composite found in Hastings Pool in the upper Mississippi River and in the polluted portions of the Atlantic coast streams and other systems are evident from the graphs presented in figs. 18*E* and 18*B*.

IRON

Iron determinations were made by the method of American Public Health Association (1933), using permanent standards of cobalt and platinum salts.

A limited number of total iron determinations were made in typical localities for correlation with studies of water from abandoned coal mines. Eighty-three determinations of total iron in waters of Mississippi, Missouri, Ohio, Tennessee, Atlantic coast, and Gulf coast systems gave the following grouping:

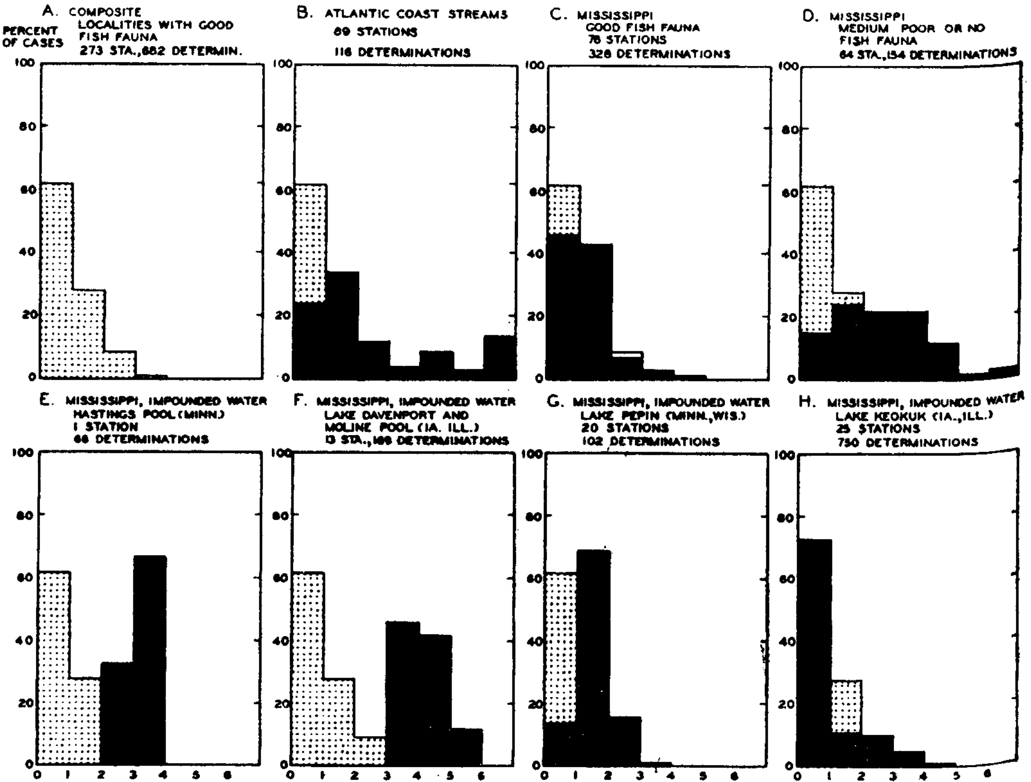

FIGURE 18.—Free carbon dioxide values (as cubic centimeters of carbon dioxide per liter, bottom line) for the waters of various river units. Stippled and black graphs composed as explained under figure 6.

At stations where good fish faunae were found (75 cases) the free iron ranged from a trace to 30 p. p. m., with 69 of these 75 cases below 10 p. p. m. In streams polluted with either mine waters or chemical effluents carrying iron compounds the total iron ran much higher, the maximum found in this series being 202 p. p. m. in waters of a stream of high acidity (pH 4.4) flowing from a coal mine in operation near Turley, Tenn. Iron in quantities above 100 p. p. m. was associated with acidity above average and when such conditions were found chemical or mine pollutions were suspected.

In the experimental tests (see section on heavy metals) it was found that 100 p. p. m. of total iron were not immediately harmful to either fish or daphnia; and that such quantities, unless a constant flow were maintained, were usually diminished during the first few days of experimental tests as a result of precipitation so that the free iron in the water did not exceed 20 p. p. m. Iron as it occurs in most natural flowing waters, therefore, is not a major limiting factor in the distribution of fishes in fresh-water streams. Besides in fresh-water streams and rivers the constant reaeration of water readily offsets any important oxygen loss through iron compounds, as has been reported from bog lakes and certain deep lakes where large quantities of iron were found.

In pollution studies of the inland fresh-water streams, therefore, the determination of total iron is helpful in locating the source of acid in highly acid waters, as a combination of high iron and high acidity suggest the source of acidity as pyrite or coal beds if no specific chemical effluent is responsible for these conditions.

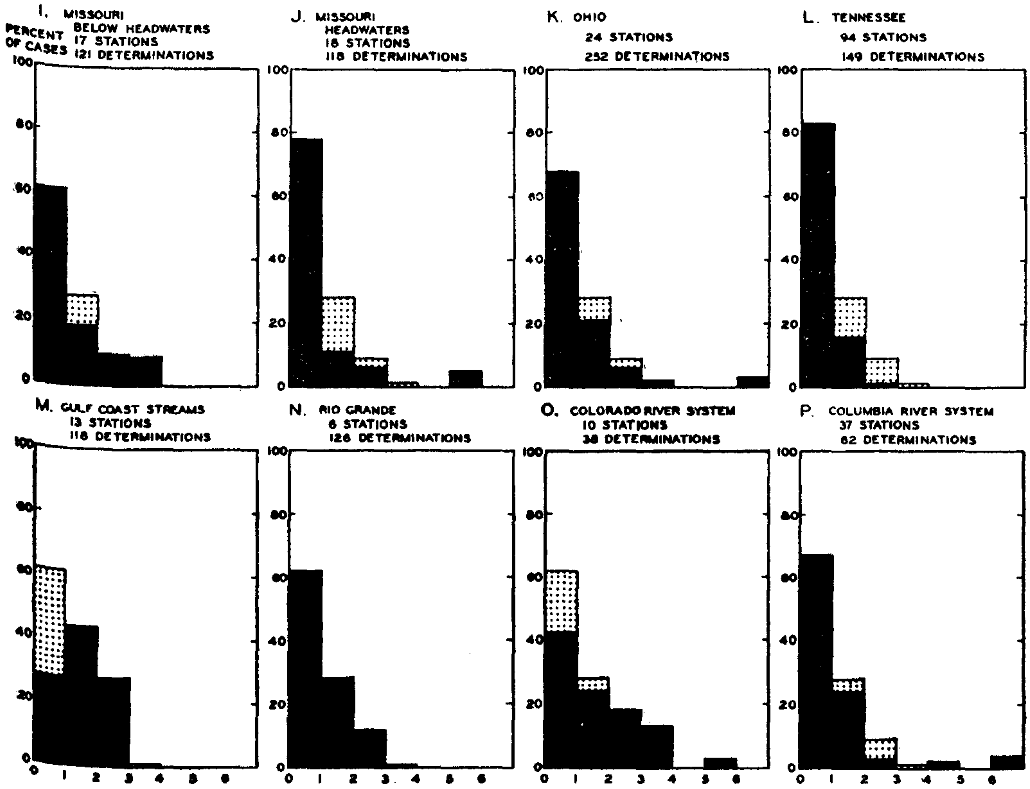

FIGURE 19.—Continuation of comparisons of free carbon dioxide values, stippled graph *A* figure 18, being the standard.

AMMONIA

Total ammonia determinations were made by the Nessler method as described by American Public Health Association (1933).

Decomposing organic matter, if nitrogenous, will liberate into stream water, ammonium compounds representing a considerable portion of the total nitrogen. As ammonium compounds present at once both a hazard due to the high toxicity of ammonium carbonate for most aquatic animals, and an important source of nitrogen for the lower plants in the aquatic food chain, ammonia determinations give a significant index of the balance between stream purification through the consumption and elimination of ammonium compounds formed during the disintegration of organic detritus, and the amount of such organic wastes received by the stream. In natural unpolluted waters organic detritus consists primarily of the remains of the organisms, both plant and animal, dying in the stream and adjacent waters, together with such organic matter as may be brought into the stream by surface run-off water. In unpolluted water, therefore, the amount of ammonia and ammonium compounds (chiefly ammonium carbonate) is usually very small.

The West Riding Rivers Board (1930) found the ammonia content of the River Wharfe, an unpolluted stream, to vary between 0.0 and 0.17 p. p. m.; Butcher, Pentelow, and Woodley (1927) state the ammonia content of the river Itchen, normally to be less than 0.1 p. p. m. with a maximum of 0.25 p. p. m.; Pearsall (1930) found the waters of various English lakes to carry less than 0.01 p. p. m.; Domogalla, Juday, and Peterson (1925) report the ammonia in Lake Mendota to vary between 0.0073 and 0.76 p. p. m.; and unpolluted portions of Wisconsin River above Rhinelander, Wis. (Wisconsin State Board of Health, 1927) averaged 0.096 p. p. m. ammonia. In field studies by the Columbia, Mo., unit similar ammonia values, all below 0.9 p. p. m., were obtained from analyses of unpolluted flowing stream waters.

Polluted streams, even if carrying only a very small load of organic wastes, present quite a different picture and, as Winslow and Phelps (1906) have pointed out, from one-third to one-half of the total nitrogen of sewage will be in the form of free ammonia, largely as ammonium carbonate; and sewage will carry from 15 to 35 p. p. m. or more of total nitrogen. Wiebe (1931b) reported a maximum of 0.224 p. p. m. ammonia in the Mississippi River at Fairport, Iowa. Ellis (1935b) found from 0.36 to 1.16 p. p. m. ammonia in the Mississippi River at Davenport, Iowa, during low waters in the month of July (1934) in portions of the river that were not badly polluted and which were at the time supporting bass, catfish, and other warm-water fishes; and from 0.24 to 3.80 p. p. m. of ammonia in the badly polluted waters of the Mississippi River during September 1935 between St. Louis, Mo., and Cairo, Ill. In the highly polluted Blackstone River, the Massachusetts State Board of Health (1913) reported 11.7 p. p. m. of ammonia. Similarly the writer has found 5.68 p. p. m. of ammonia in the Cache la Poudre River in Colorado at a point where there was heavy pollution with beet sugar factory wastes.

In table 2 a group of ammonia data typical of the field findings by the Columbia, Mo., unit are presented. These data include no determinations from the immediate vicinity of sewers or other outlets pouring organic wastes into the streams, and no determinations from restricted local portions of streams in which unusual organic pollution was found. These data show the general range of dissolved ammonia which may be expected in our flowing streams during the warm season, and under the usual conditions of municipal and industrial pollutions.

The composite series includes the ammonia values from all these stations collectively at which good fish faunae as previously defined were taken, and the Mississippi and coastal series include all stations in these systems regardless of fish faunae.

TABLE 2.—*Dissolved ammonia in various stream waters during the warm season, June to October, inclusive, 1934*

[For convenience of comparison, data are expressed as percents of total number of determinations for each stream unit]

River system	Number of stations	Number of determinations	Dissolved ammonia in parts per million						
			0.0–0.9	1.0 1.9	2.0–2.9	3.0–3.9	4.0–4.9	5.0–5.9	Greater than 6.0
Composite [1]	72	178	21	58	21	(2)	....	....	....
Entire Mississippi system	182	478	24	49	22	3	2	(2)	(2)
Coastal streams	58	91	7	55	33	1	1	1	....

[1] Derived from ammonia determinations at 72 stations throughout the entire Mississippi system and in coastal streams, at each of which stations good mixed fish faunae and associated organisms were thriving.

[2] Less than 0.5 percent.

It may be seen that excepting the restricted local areas where heavy pollution was found (data not presented in this table) the dissolved ammonia in flowing streams in general lies below 3 p. p. m. This is due to a variety of physical and chemical factors, chief among which is the constant turn-over of the moving stream waters. The good fish faunae showed a preference to waters containing less than 2 p. p. m. dissolved ammonia, as 79 percent of the cases of this group were found in water containing less than 1.9 p. p. m. dissolved ammonia. The remaining 21 percent were apparently thriving in waters containing between 2 and 3 p. p. m. dissolved ammonia, with one case (the maximal indicated by footnote 2 in the 3–3.9 column) in waters carrying 3.5 p. p. m. dissolved ammonia. This maximal dissolved ammonia value among the stations where good fish faunae were taken was found at Reeds Landing, Minn., where the Mississippi River was flowing rapidly over a sandy bottom at a point just below extensive beds of aquatic vegetation in the foot of Lake Pepin. It must be noted that without exception those waters carrying 2 to 3 p. p. m. ammonia and at the same time supporting the good fish fauna were high in dissolved oxygen; that is, 5.5 to 7 p. p. m., were of low turbidity, and were flowing over good bottoms. Toleration of dissolved ammonia above 2 p. p. m. under field conditions was always associated with otherwise good to exceptionally favorable conditions.

The toxic effects of ammonia compounds have been the subject of many investigations; and aquatic animals have been shown to be particularly sensitive to ammonium carbonate, the form in which ammonia is most frequently found in inland waters, (Shelford, 1917; Belding, 1928; Steinmann, 1928; and McCay and Vars, 1931). Thirty p. p. m. of ammonia will kill some tench, trout, and salmon rather rapidly (Weigelt, 1885), and 55 to 77 p. p. m. will kill shiners and carp in a few minutes to a few hours (Clark and Adams, 1913). A review of the literature on ammonia, however, shows that some observers obtained toxic effects with much smaller quantities.

Ellis and Chipman (1936) have repeated many of the earlier tests and extended the observations to daphnia and gammarids, as well as fish, finding that pH is a large factor in regulating the toxicity of ammonium compounds for aquatic animals, ammonium salts becoming more toxic in more alkaline media. This fact explains the relatively high toxicity of ammonium carbonate to aquatic organisms as compared with other ammonium salts. From these data (presented in section on ammonia pollutants) curves were drawn showing that the toxicity of ammonium compounds increases 200 percent or more between pH 7.4 and pH 8.0. The lower limit of toxicity (death in 10 days or less, depending upon conditions of experiments) was found to be near 2.5 p. p. m. of ammonia. Some acclimatization to ammonia is possible, and it is well known that individuals of various species of fish may be found in water containing 3 to 10 p. p. m. of ammonia. However, the existing literature and the data from our experiments indicate that under average stream conditions with pH value 7.4 and pH 8.5, 2.5 p. p. m. of ammonia will be harmful to many individuals at least of the common aquatic species.

Therefore, in view of the small amount of ammonia found in unpolluted natural flowing waters, 1.5 p. p. m. dissolved ammonia was considered the maximal amount of dissolved ammonia not suggestive of specific organic pollution. In flowing streams 2 to 3 p. p. m. were almost always associated with definite organic pollution and values above 3 p. p. m. in our field studies were always traceable to sewage or factory effluents.

SUSPENSOIDS

The amounts of finely divided suspensoids in various waters and light penetration into these waters were determined by a photoelectric apparatus described by Ellis (1934).

The suspensoids—that is, particulate matter in suspension in inland fresh waters—consists normally of erosion silt, organic detritus (as discussed under ammonia), bacteria, and plankton. Each component of this mixture, with the exception of plankton, may be greatly augmented by man's agencies, as quantities of powdered rock, cellulose pulp, sawdust, semisolid sewage, and other debris are added to natural waters.

Parts of some streams, as the Yellowstone and Missouri—draining areas in which natural erosion has been proceeding rapidly—have been muddy with their loads of erosion silt since before the earliest records by man and have as a result limited fish faunae. In a large proportion of the inland streams, however, erosion silt, organic detritus, and bacteria were formerly in balance over a considerable portion of the year and conditions favorable to aquatic life maintained, although now and then floods and other unusual conditions killed many aquatic animals in these streams by inundations of silt. With the advent of civilized man and unrestricted deforestation, agriculture, and other uses of the earth's surface, the erosion problem has become gigantic, and the effects of the loads of erosion silt carried by these once relatively clear streams overwhelming on aquatic life in many places.

Erosion silt and other suspensoids (disregarding any specific toxic action of suspensoid wastes) affect fisheries directly by covering the bottom of the stream with a blanket of material which kills out the bottom fauna, greatly reduces the available food, and covers nests and spawning grounds; and also by the mechanical and abrasive action of the silt itself which may clog and otherwise injure the gills and respiratory structures of various aquatic forms, including many fishes and mollusks (Ellis, 1936a). The mechanical action of silt and other suspensoids may not be severe or even harmful to the gills and other structures of the free-swimming fish which move about above the bottom and are not mired down by the settling deposits of the suspensoids, if the amounts of the suspensoids in the water are not too great and if the action of the suspensoids is uncomplicated by other pollutants. Normal fish and many other swimming animals secrete continuously quantities of mucus which wash away suspensoid particles as they lodge on the gills and other exposed parts. Consequently, healthy and uninjured fishes can move through very muddy water or water carrying considerable quantities of pulps (Cole, 1935b), sawdust, and other suspensoids and receive little or no mechanical injury to the gills. However, as has been pointed out by Marsson (1911), small amounts of various acids, chemical wastes, and other substances which in themselves either injure the gills or alter the flow of mucus may greatly augment the mechanical action of the suspensoids, with serious results to the fish, so that through the combined action of these chemical agents and the suspensoids the abrasive action on the gills may be increased or the gills matted with deposits which under more favorable conditions would have been washed away by the mucus.

Indirectly, but none the less effectively, erosion silt affects fisheries by screening out the light, by "laking down" organic wastes, and thus increasing the oxygen demand at the bottom of the stream, and by retaining many forms of industrial effluents as oils, chemical wastes, and pulps in beds on the floor of the stream, with disastrous results to the bottom fauna.

Summarized data on turbidity of and light penetration into various stream waters are presented in table 3.

TABLE 3.—*Turbidity of stream waters as measured by light penetration (millionth intensity depth in meters) in various river systems during June to September, inclusive, 1932–35*

[For convenience of comparison, data are expressed as percents of the total number of determinations for each stream unit]

River system	Number of stations	Number of determinations	Light penetration expressed as millionth intensity depth in meters					
			Clear	Cloudy	Turbid	Very turbid	Muddy	Very muddy
			5.00–∞	4.90–1.00	0.99–0.50	0.49–0.30	0.29–0.15	0.14–0
Composite, streams supporting good mixed fish fauna [1]	202	514	35	24	17	9	9	6
Mississippi, flowing streams, good fish fauna	52	237	4	11	8	16	25	36
Mississippi, flowing streams, medium, poor, or no fish fauna	79	260	1	18	11	14	38	18
Mississippi, impounded water, Hastings Pool (Minn.)	1	17	--------	100	--------	--------	--------	--------
Mississippi, impounded water, Lake Pepin (Minn.-Wis.)	12	73	11	88	--------	1	--------	--------
Mississippi, impounded water, Lake Davenport and Moline Pool (Iowa-Ill.)	13	175	--------	51	19	19	4	7
Mississippi, impounded water, Lake Keokuk (Iowa-Ill.)	16	571	--------	19	28	20	16	17
Missouri, headwaters, clear streams (Mont.-Wyo.)	5	15	--------	20	60	20	--------	--------
Missouri, below headwaters (Mont., Wyo., Colo., Nebr., Kans., Mo.)	19	23	44	31	4	--------	4	17
Ohio (Pa., W. Va., Ohio, Ky., Ind., Ill.)	41	82	12	5	15	7	48	13
Tennessee, flowing streams (Ky., Tenn., Miss., Ala.)	93	158	11	8	32	32	17	--------
Atlantic-coast streams (Maine to S. C., inclusive)	11	16	36	37	18	--------	--------	9
Gulf-coast streams (Fla. to Tex.)	11	111	--------	18	46	18	--------	18
Rio Grande, flowing streams (Tex., N. Mex., Ariz.)	6	25	88	--------	4	--------	--------	8
Colorado, flowing streams (Ariz.–Nev.)	7	36	67	22	8	3	--------	--------
Columbia, flowing streams (Idaho, Mont., Wash., British Columbia)	17	31	49	39	3	3	3	3

Grand totals: Stations, 585; light-penetration determinations, 2,344

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[1] Derived from light-penetration determinations made at 202 stations in the Mississippi, Missouri, Tennessee, Atlantic coast' Gulf coast, Rio Grande, Colorado, and Columbia systems, at each of which stations good mixed flish faunae and associated organisms were thriving. Each of these 8 stream units are given equal value in the expression of the composite.

From the fieldwork on unpolluted streams in areas where surface erosion was not materially influenced by man and where water conditions were otherwise favorable, it has been shown by Ellis (1936a) that the millionth intensity depth (i. e., the level at which the light entering the surface of the stream would be reduced to one-millionth of its surface intensity) for clear unpolluted streams carrying little or no erosion material is 50 meters or more, and that in streams carrying a heavy load of erosion silt, like the Missouri River, the millionth intensity level may be reduced to less than 100 millimeters. Until erosion is brought under control little can be done in demanding a minimum amount of silt and consequently no standard has been suggested here, but data from over 6,000 determinations on inland streams show that the silt load of these streams should be reduced so that the millionth intensity level would not be less than 5 meters, if conditions even approximating those of times past when erosion was held in check by forest and grasslands are to be restored, in the average inland stream of the United States. The detrimental nature of erosion silt as regards fisheries is discussed more fully by Ellis (1936a).

However, particulate matter introduced by man into streams can be regulated, and the detrimental action of various types of suspensoid pollutants is discussed under that heading.

DEPTHS

As various depths of water are selected by different species of aquatic animals, and even by different ages of the same species in many cases, there is naturally no single optimum depth of stream water for all types of aquatic life. Depth studies of streams and flowing waters, however, bring out differences between waters of natural lakes and those of flowing streams and river lakes.

Current action in flowing streams mixes the water so thoroughly and continuously that in general the composition of the aquatic environment as presented by the water itself varies but little from a few inches below the surface to a few inches above the bottom of the stream. The temperature of the water, its turbidity, dissolved solids content, pH, and even dissolved gases content are much the same throughout the bulk of the stream at any given station, if there be definite current action. Sloughs and other rather isolated lateral areas, particularly those containing large masses of aquatic vegetation, are of course excepted, but even in such cut-off portions of streams the actual differences in water characteristics as compared with the main stream mass are often small.

Of significance in pollution studies, these depth data show that pollutants may be expected to mix rather rapidly and completely with the waters in streams and even river lakes unless these river lakes be more than 50 feet deep, and even in those river lakes unless the seasonal conditions are such as to promote the stratification just described in the deeper portions of such lakes; and that the products of bottom pollution will also be distributed throughout the waters of the stream below such pollution.

TABLE 4.—*Characteristics of water at different depths in river lakes produced by impounding flowing rivers*

Depth in feet	Water temperature, degrees centigrade	pH	Specific conductivity in mho x 10⁶ at 25° C.	Fixed carbon dioxide, cubic centimeters per liter	Dissolved oxygen parts per million	Light penetration, millionth intensity depth in millimeters
I. LAKE WILSON[1]						
S[3]	30.2	7.4	177	13.4	7.5	2,053
10	30.2	7.6	178	12.9	7.3	2,053
20	29.5	7.4	181	13.2	6.1	1,297
30	29.0	7.5	178	12.9	5.8	1,075
40	28.6	7.5	175	12.9	5.7	1,075
50	28.2	7.5	173	12.9	5.1	972
60	27.8	7.3	161	12.9	3.6	1,075
70	22.9	7.2	167	15.4	.2	9,036
80	21.9	7.2	158	15.0	.2	9,036
90	21.5	7.1	159	15.0	.2	6,910
100	20.9	7.2	159	15.4	.1	6,262
110	20.8	7.2	162	15.9	.2	5,335
II. ELEPHANT BUTTE RESERVOIR[2]						
S[3]	33.0	8.1	1.009	29.5	7.1	6,823
3	33.0	8.1	1,062	28.7	7.2	6,823
6	23.8	8.1	1,024	28.7	5.9	14,344
10	23.0	8.1	1,017	28.1	5.5	13,414
20	22.8	7.6	1,022	28.4	6.1	28,874
30	21.5	7.6	1,081	29.3	5.9	30,254
40	19.8	7.6	1,107	29.1	6.2	63,987
50	19.6	7.6	1,068	29.2	6.5	63,987
60	18.8	7.6	1,070	29.0	6.6	63,987
70	18.0	7.6	996	29.6	6.8	61,237
80	17.8	7.6	1,067	29.8	5.1	61,237
90	17.6	7.6	1,045	30.2	5.1	63,987
100	17.1	7.6	1,059	30.7	5.3	63,987
110	16.9	7.6	1,052	30.4	5.1	61,237
125	16.9	7.5	1,123	30.7	4.7	63,987
III. LAKE KEOKUK[4]						
S[3]	27.8	7.5	285	27.8	6.7	1,170
10	27.5	7.5	287	28.0	6.6	1,170
20	27.0	7.5	285	28.3	5.8	1,103
33	27.0	7.5	290	28.3	5.4	1,065

[1] Tennessee River near Florence, Ala., station 385, July 30, 1931, air temperature 31.3° C. A deep river lake showing midsummer stratification.

[2] Rio Grande River, near Hot Springs, N. Mex., station 829, June 15, 1935, air temperature 33.0° C. A deep lake showing partial stratification at time of these observations.

[3] Surface, i. e., top 12 inches of water.

[4] Mississippi River near Keokuk, Iowa, station 80, Sept. 22, 1932, air temperature 30.3° C. A medium to shallow river lake showing little or no stratification.

TEMPERATURE

As the temperature of the water has bearing on several factors associated with the general problems of pollution, such as dissolved oxygen carrying power of the water, the rate of bacterial decomposition of organic pollutants, and the metabolic demands of the aquatic organisms themselves, the temperature range of flowing streams and river lakes during the warm season is presented in table 5. These data include no headwaters in mountainous regions, and give, therefore, the water temperature range to be expected in the average inland stream of the United States during the summer months, which season as has been pointed out under the discussion of dissolved oxygen presents certain specific pollution hazards.

TABLE 5.—*Water temperatures of inland streams, exclusive of headwaters in mountainous regions, during warm season, June to September, inclusive, 1930–35*

River system	Number of stations	Number of cases	Percent of cases						Minimum degrees, Centigrade	Maximum degrees, Centigrade
			14.0°–17.9° C.	18.0°–21.9° C.	22.0°–25.9° C.	26.0°–29.9° C.	30.0°–33.9° C.	Above 34° C.		
Composite [1]	726	4, 545	13	16	35	31	5	([2])	15. 0	36. 6
Entire Mississippi system	447	2, 887	12	12	46	27	3	([2])	15. 0	35. 2
Coastal streams into Gulf of Mexico [3]	39	1, 367	7	14	32	36	9	2	16. 8	36. 6

[1] Includes flowing streams at stations at which fish were found in Mississippi, Missouri, Tennessee, Ohio, coastal streams flowing into Atlantic Ocean and Gulf of Mexico, Rio Grande, Colorado, and Columbia system.

[2] Less than 1 percent.

[3] Exclusive of Mississippi system.

Considering the composite in table 5, it may be seen that in spite of the high air temperatures which prevail in many parts of the United States during the summer months, often for periods of days, stream temperatures above 34° C. are not common, and that 95 percent of the 4,545 cases listed in table 5 lie below 30° C. On the other hand, 66 percent of these 4,545 cases lie between 22° and 30° C. For comparison with the composite in this table, data from the entire Mississippi system and from the coastal streams of the Gulf States, Texas to Florida, inclusive, are also presented. In the Mississippi system 73 percent of the cases fell between 22° and 30° C., and 68 percent of the cases in the Gulf States have the same range.

In evaluating biochemical oxygen demand, dissolved oxygen content, and specific toxicity values for pollution studies therefor, a water temperature range during the warm season from 15° to 36° C. may be expected in the average inland stream of the United States, with the probability of 66 percent or more that these water temperatures will lie between 22° and 30° C. During the other portions of the year—that is, outside of the warm season—the water temperatures of these streams in localities north of the freezing line will fall, with 0° C. as the limit. Our field data also show that south of the usual freezing line—that is, in streams of southern Texas, Alabama, and Florida—temperatures as low as 10° C. are not unusual during the midwinter season.

The true headwater streams, particularly those in mountainous regions, present a different temperature range even during the summer months. The maximal temperatures for various streams which could be definitely classified as mountainous headwaters, as found in our field studies, were rarely above 10° to 15° C., with the average values lying around 10° C. or even lower.

BOTTOM CONDITIONS AS AFFECTED BY STREAM POLLUTION

In most stream-pollution studies, conditions at the bottom must be considered, since the bottom of the stream contributes a considerable part of the food of stream fishes through the organisms of the bottom fauna which are either eaten directly by fishes or which are included in the food chains of various species of fishes. Besides, portions of the bottom usually in the shallower parts of the stream provide nesting sites for certain species. However, as the stream bed may change from rock and coarse gravel to fine clay in the course of a few hundred yards, and as there is a wide variation in habitat preference of the many desirable organisms which inhabit stream bottoms, it is very difficult to define all of the conditions at the bottom of a stream which may or may not be suitable for bottom inhabitants and therefore affect the fish fauna; for over this already complicated association of rock, soil, debris, and living organisms pollution may spread a blanket of silt, sludges, pulps, and poisonous fluids.

Studies of the bottom faunae of polluted streams, particularly those carrying quantities of organic pollution, have shown that many of the bottom species of unpolluted streams are very sensitive to pollution conditions, so that as pollution progresses the normal bottom fauna changes giving way to certain more tolerant species of tubificid worms, chironomid midges, sphaeriid mollusks, and leeches. Consequently, various investigators (Marsson, 1911; Suter and Moore, 1922; Turner, 1927; Richardson, 1928; Wiebe, 1928), in connection with other data have correlated the presence of certain bottom forms with different degrees of stream pollution, and a few such species of bottom organisms have come to be used to some extent as indices of pollution. Richardson (1928) however, in discussing 49 bottom species definitely associated with pollutional or subpollutional conditions in the Illinois River points out the difficulties attending the use as indices of pollution, of even such species as the tubificid worm, *Tubifex tubifex*, and the midge, *Chironomus plumosus*, which are commonly regarded as characteristic of pollutional conditions bordering on septic. The problem of index species is greatly complicated by the fact that the number of individuals of any particular index species may vary from zero over a wide range in adjacent parts of any polluted stream as the result of conditions other than those produced by pollution.

In the present studies, bottom samples were taken throughout the field work as a part of the regular routine. Reviewing the results of the examinations of many hundreds of bottom samples, there is no doubt that bottom samples are a necessary part of any pollution study, and that the findings concerning the bottom organisms are very valuable when considered with the chemical and physical data. However, the writer agrees with the statement of Richardson (1928, p. 410), in connection with his Illinois River studies, that index species are of service in pollution studies only when used with the greatest caution, and when checking with other indicators.

With due regard to the limitation just discussed, three organisms—namely, the water mold, *Sphaerotilus natans*, the rattail maggot, *Eristalis* sp., and the sludge fly, *Psychoda* sp.—were often found helpful in delimiting the septic zone near the source of extensive organic pollution; and the tubificid worms, *Tubifex* sp. and *Limnodrilus* sp., and the larvae of the red midge, *Chironomus* sp. (particularly *Chironomus plumosus*), if their presence or absence were supported by the chemical and physical analyses and by the data concerning the biological complex as determined from repeated samplings, were frequently used in defining the extent of bad to moderate organic pollution. In the lesser degrees of organic pollution and in most cases of chemical pollution index species as such were of little value.

On the other hand, the abundance of the various species comprising the bottom fauna and particularly the species composition of the bottom fauna at various stations in the polluted area were usually of large value, regardless of the sort of pollution, when correlated with the physical and chemical data. Gross pollution of several kinds was quickly detected from bottom samples both by the physical and chemical conditions of the mud itself and by the paucity or absence of bottom fauna, often represented only by dead shells and other remains. Dredgings readily demonstrated such gross pollution by silt, sewage, pulps, tars and heavy oils, mine tailings, rock powders from quarry operations, and such organic wastes as starch effluents, sizings from cloth mills, and distillery slops.

Downstream from a region of gross pollution the biological analyses of the bottom faunae were often particularly significant when compared with the bottom faunae in similar situations in comparable unpolluted waters (if possible of the same stream) in showing the selective effects of some pollutants, and the downstream extent of pollution.

Many chemical wastes have high specific gravity and consequently tend to follow the stream bottom for some distance before complete mixing is accomplished by stream current action. Often downstream dredgings showed complete absence of bottom life of any type for some distance below the outlets of flumes carrying such chemical wastes, and the limits of the zones in which the bottom faunae had been killed out yielded valuable information concerning the points at which the effluent had been diluted to a nontoxic level.

ACTION OF POLLUTANTS ON FISHES

Regardless of the effects on the environment, many pollutants affect fishes directly by some specific action on the living organism itself. These pollutants can be grouped, therefore, according to the locus of injury and method of action of the various active substances which the effluents contain (Ellis, 1936b).

INJURIES TO GILLS AND EXTERNAL STRUCTURES

The higher concentrations of almost all effluents and all lethal concentrations of some types of pollutants kill by their actions on the gills of the fish before little, if any, of the material causing the death of the fish passes beyond the gills. Such substances kill, therefore, by a combination of chemical and physical injuries rather than by true toxic action. The salts of several heavy metals, some acids, and some special chemicals as trinitrophenol combine readily with the mucus secreted by the fish's skin, mouth, and gills, forming insoluble compounds.

If the dilution of the pollutant of this type be great enough, or if the supply of the pollutant be limited so that it acts on the fish only a short time, the secretion of additional mucus may wash away the precipitated compound as fast as it is formed, or may carry away the larger masses of the precipitate before serious damage to the fish results. If, however, the concentration and exposure time are large enough (very small quantities of several heavy metal salts suffice, v. i.), the precipitated insoluble compound covers the body, the lining of the mouth, and the gills. (See fig. 21.) Disastrous results follow the covering of the gills with these precipitates, and death supervenes very rapidly from the respiratory failure. In our experiments with salts of heavy metals and various other compounds producing death by precipitation of insoluble matter on the gills, the precipitate was found to cause death as the result of a combination of three conditions which individually or collectively disturbed the proper functioning of the respiratory and circulatory mechanisms.

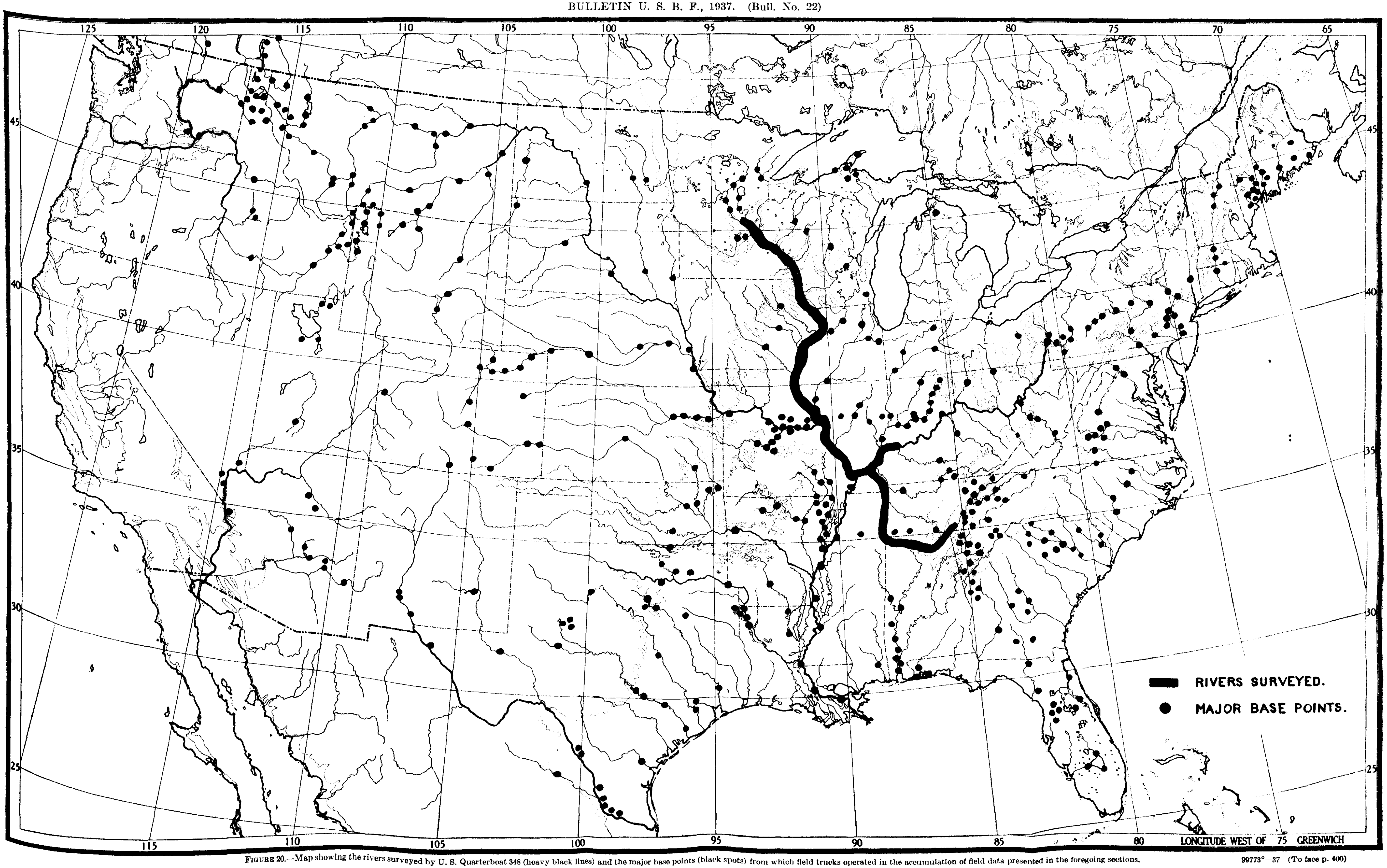

FIGURE 20.—Map showing the rivers surveyed by U. S. Quarterboat 348 (heavy black lines) and the major base points (black spots) from which field trucks operated in the accumulation of field data presented in the foregoing sections.

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In the weaker concentrations of such effluents and harmful substances, the precipitate coated the gill filaments and filled the filament interspaces so that the water pumped through the mouth and onto the gills for the aeration of the blood could not reach the cells of the gill filaments. Consequently, the aeration of the blood with its accompanying gas exchanges was prevented, and sooner or later death followed from a combination of anoxemia and carbon-dioxide retention.

If still larger masses of flocculent precipitate were formed, as was the case when the stronger effluents were tested, the interlamellar spaces were clogged and movement of gill filaments became impossible. This condition affected the circulation of the blood in the gills, in that stasis of the blood in the gill capillaries usually follows cessation of movement of gill filaments in a short time. Kolff (1908) in her studies of fish hearts found that the pulsation of the heart is only one of the forces necessary to drive the blood through the gill capillaries, and that the movements of the gills are important in maintaining the gill capillary circulation.

If the scales be removed from the midventral portion of the precardial region of a pithed goldfish and a tiny steel needle (the minuten nadeln on which entomologists mount very small insects) be forced through the body wall and into the pericardial cavity, when proper adjustment is made, this needle, if examined under a binocular microscope, can be seen to swing with each heart beat. Using this procedure the rate of the uninjured and unexposed heart in situ can be recorded for hours. Such fish, when the gills were perfused via the mouth with water containing salts of heavy metals or other substances producing these heavy mucoid precipitates, continued their normal respiratory movements and heart action until the precipitate clogged the gills and mechanically prevented the movement of the gill filaments. At that time an abrupt change in the activities of the heart was usually noted, the heart action dropping to about one-half its former rate. Heart block also often developed at this time. When these changes in heart rate and heart action were noted, the gill capillaries were always found to be gorged with blood on the efferent or cardiac side and showed practically complete to complete stasis of the blood in the capillaries. This same condition of blood stasis in the gill capillaries was noted in other fish in which anoxemia was produced by exposure to water containing little or no dissolved oxygen shortly after cessation of respiratory movements, so that the importance of the respiratory movements for the maintenance of capillary circulation in the gills was well established. After its rate had dropped to approximately one-half normal, the heart continued to beat for hours (in some cases for over 24 hours), although the circulation through the gills was completely blocked. In fishes which had ceased to make movements of any sort, either respiratory or general, after prolonged exposure to water low in dissolved oxygen, the hearts were found to be beating even when these fishes were opened under oil to exclude even momentary aeration of the pericardial fluid.

The various substances producing these heavy precipitates, as well as many other pollutants (acetic acid, volatile extracts of crude oil, and others) which did not form precipitates with mucous secretions on the gills, also produce death by asphyxia through direct damage to the gill filament cells, which in turn cause stasis of the blood in the gill capillaries. Death from anoxemia and circulatory failure in the gills, therefore, was regularly found in fishes dying either in waters containing low oxygen or in the stronger hypertonic solutions of various salts and other chemicals, regardless of the formation of any sort of mucoid precipitate.

In connection with gill damage, it must be pointed out that the weaker concentrations of various pollutants which do not damage the gills rapidly enough to cause speedy respiratory and circulatory failures must also be considered as pollution hazards if these solutions be even slowly toxic to the cells of the gill, for Smith (1929) has demonstrated that the gills of fresh-water fishes (carp and goldfish) are important excretory structures, removing from 6 to 10 times as much nitrogenous wastes as the kidneys. Keys and Willmer (1932) have found special cells associated with chloride secretion in the gills of various fishes, including fresh-water species. Damage to the gills from pollutant substances in the water can result, therefore, in the impairment of other functions, particularly those of salt balance and excretion in addition to respiration and circulation as already described, without actual toxic action on the internal vital organs of the fish.

POLLUTANTS ENTERING THE BODY OF THE FISH AND EXERTING TRUE TOXIC ACTION

The gills, the lining of the mouth, and the skin are the main portals of entry through which toxic substances can be absorbed into the body of the fish. However, Bond (1933) concludes that the bony fishes and many fresh-water invertebrates have little or no permeability to a variety of substances. The writer has been able to confirm this relative nonpermeability of the external structures of various fresh-water fishes, particularly the gills, for a number of substances. The active agents in various stream pollutants, therefore, may be still further subdivided into those which can enter the body of the fish through external structures as various volatile compounds from crude oil, dilute chlorine, ether, chloroform, methyl mercaptan, and formaldehyde, and those which do not enter or at least enter very slowly through the external structures as certain arsenic compounds.

The main internal channel for the absorption of injurious and toxic substances is the gastrointestinal tract. The writer, using colloidal dye methods, has found that many fresh-water fishes refuse to swallow water containing various types of effluents for sometime after being placed in such water, for as has been pointed out by Smith (1930) most of the water required for the formation of urine in the fresh-water fish is probably taken in through the lining of the mouth. However, after varying intervals, usually 48 hours or more, fresh-water fish swallow some of the surrounding water even if not fed, suggesting that the water needs of the body are not entirely supplied through absorption by the external surface or the lining of the mouth. The swallowing of polluted water allows any of the injurious or toxic substances which this water may contain direct access to the mucosa of the gastrointestinal tract. Harmful substances may, therefore, either damage the lining of the intestinal tract or may be absorbed from the gastrointestinal tract, and in this way gain access to the internal vital organs. Consequently, another group of pollutants can be designated as those acting on the fish after ingestion into the gastrointestinal tract. It is through this portal that many cumulative poisons enter the body of the fish during long-time exposures to concentrations of pollutants which may at the time seem harmless.

Arsenic may be cited as an example of a substance which can be accumulated by the fish via the gastrointestinal tract after long exposure to low concentrations.

To summarize, on the basis of locus of injury to the fish, stream pollutants may be classified as—

(1) Those substances injurious to the gills and other external structures of the fish without any marked absorption beyond the gills. Death of the fish exposed to these pollutants results from anoxemia, through respiratory and circulatory failure, and through interference with the excretory functions of the gills.

(2) Those substances killing the fish by specific toxic action after absorption through the gills, the lining of the mouth, and other external structures.

(3) Those substances killing the fish by specific toxic action after absorption from the gastrointestinal tract, which region they have reached in water swallowed by the fish.

LETHALITY OF SPECIFIC SUBSTANCES OCCURRING IN STREAM POLLUTANTS

GENERAL CONSIDERATIONS

In this section, data from the literature and from experimental assays made during the present studies are presented covering the lethality of various substances which are the active harmful agents in different types of stream pollutants. These biochemical and biophysical findings in general may be applied to pollution conditions ranging from acute to mild; although in the evaluation of all individual cases of pollution, caution must be exercised, as biological data of any sort are rarely suitable for rigid application. One particular component of a given waste may constitute the major pollution hazard of that waste; in fact, the dangerous qualities of many wastes center largely around one substance in each effluent rather than the effluent mixture as a whole. In such cases, lethality tables are particularly helpful, but the synergistic and antagonistic actions of other substances in the stream water as well as in the waste itself must be borne in mind always. For example, the lethality of copper sulphate for fishes under certain conditions is decreased by the presence of calcium chloride and increased by sulphuric acid, and both of these compounds occur free or combined in certain industrial wastes. Again the toxic actions of small amounts of chlorine and of ammonia on aquatic life singly are different from the actions of the same quantities of these substances when both are present, since together they may form either ammonium chloride or chloramine, depending upon conditions; and the toxicity of the resultant mixture may vary accordingly.

From the data presented in the following tables, however, the harmless, injurious, and lethal ranges of various substances may be computed readily with reasonable accuracy for particular pollution cases if due regard be given to the chemical and physical conditions of the water of the stream involved. Tests should be made, of course, to detect the presence of unusual and unexpected substances in the local complex which might alter the action of the pollutant.

In addition to the appraisal of the pollutant on the basis of the lethal action of its major component or components, when the pollution is acute, mild, or intermittent, under which headings a large percent of the pollution cases may be classified, the possibility of cumulative effects must be considered when determining remedial measures or dilutions. Cumulative effects from very low concentrations of some substances which seem harmless to fish life over a period of 10 to 14 days present difficult problems. Some of these are discussed in subsequent portions of this section.

TEST ANIMALS

In the course of the work on the lethality of stream pollutants 30 species of fresh-water animals (see table 6), including 17 species of fish, 6 species of crustaceans, and 7 species of fresh-water mussels, have been used in one connection or another as test animals.

TABLE 6.—*Species of test animals*

Species	Common name	Species	Common name
FISH		AMPHIPODS	
1. *Perca flavescens*	Yellow perch.	18. *Gammarus fasciatus*	Gammarid.
2. *Micropterus salmoides*	Largemouth black bass.	19. *Eucrangonyx gracilis*	Do.
3. *Lepomis incisor*	Blue gill.		
4. *Lepomis humilis*	Orange-spotted sunfish.	ENTOMOSTRACANS	
5. *Ameiurus nebulosus*	Common bullhead.	20. *Daphnia magna*	Daphnia.
6. *Ictalurus punctatus*	Channel cat.	21. *Bosmina sp*	Cladoceran.
7. *Agosia nubila*	Long-nosed dace.	22. *Cypris sp*	Ostracod.
8. *Leuciscus balteatus*	Dace minnow.	23. *Cyclops* sp	Copepod.
9. *Notemigonus chrysoleucas*	Golden shiner.		
10. *Notropis delicious*	Straw-colored minnow.	FRESH-WATER MUSSELS	
11. *Hybognathus nuchalis*	Silvery minnow.	24. *Tritogonia verrucosa*	Buckhorn.
12. *Pimephales promelas*	Fathead minnow.	25. *Megalonaias gigantae*	Washboard.
13. *Cyprinus carpio*	German carp.	26. *Quadrula trapezoides*	Small washboard.
14. *Carassius auratus*	Common goldfish.	27. *Fusconaia undata*	Pigtoe.
15. *Salmo irideus*	Rainbow trout.	28. *Actinonaias carinata*	River mucket.
16. *Salmo clarkii*	Cut-throat trout.	29. *Lampsilis anodontoides*	Yellow sand-shell
17. *Lepisosteus platostomus*	Short-nosed gar.	30. *Lampsilis siliquoidea*	Fat mucket.

From these studies and from the voluminous literature of bioassay methods and physiological and pharmacological experiments in which these and many other forms of aquatic life have been used as bioreagents, two animals—the common goldfish, *Carassius auratus*, and the entomostracan, *Daphnia magna*—were selected for the standard tests. This procedure, i. e., the use of standard test animals, is recognized in other fields of biological investigation in which the frog, the rat, and the guinea pig have established positions as assay animals, and makes possible direct comparisons of data on the actions of a variety of substances over a wide range of conditions. No single test animal combines all of the desirable qualities and in making a choice both availability and physiological suitability for the problem in hand must be considered. As the variety of aquatic animals which may be affected by stream pollution is large, a lethality range for each pollutant and effluent must be established, as the specific sensitivities of various aquatic species are not the same, although they may live in the same aquatic complex. However, if the pollutant destroys any one of the major species in the complex, the entire fauna in that part of the stream may suffer as a result. The selection of goldfish and daphnia gave a combination by which the maximal and minimal limits of toxicity of any given pollutant for different stream complexes could be ascertained rapidly and with reasonable accuracy.

GOLDFISH

Goldfish of any size up to 6 inches are easily obtainable in quantity from commercial goldfish farms, are relatively inexpensive, and stand shipment well. The practical considerations, although important in the selection of a test animal, are of course secondary to the physiological characteristics of the goldfish which make it particularly suitable for the bioassays of stream pollutants. The goldfish is tolerant of confinement and can be kept in laboratory containers and aquaria for months, making both short-time and long-time tests, uncomplicated by excitement and the attendant endocrine disturbances, possible under controlled conditions. The amount of oxygen consumed by the goldfish is not large per unit of weight, and this fish does not succumb to low oxygen as quickly as many other fresh-water fishes. In fact, the uninjured goldfish if permitted can obtain sufficient oxygen to maintain itself for some time in water very low in or even devoid of dissolved oxygen merely by skimming and breaking the surface film of the water. Because of these facts, the toxic action of many substances which would be volatilized or oxidized by the constant aeration of water required to maintain various other species of fish can be ascertained, using goldfish as reagents; and the specific parts played by the oxygen demand, the external action, and the internal effects of the pollutant on the fish determined separately. On the other hand, if the combination of anoxemia and toxic action of the pollutant are desired, goldfish can be placed in closed containers, or merely prevented from reaching the surface layer of the water by submerged strips of glass which do not interfere with either the movement of the water or with its surface reaeration.

By comparative tests the relative resistance of the goldfish to poisons, injury, and anoxemia was found to be equal to or greater than that of bass, perch, or catfish, and definitely greater than the resistance of trout or most fresh-water minnows. The minimal lethal concentration of any effluent or pollutant for goldfish established, therefore, approximately the maximal concentration of that pollutant which ought not to be exceeded if any fresh-water fish were to survive in waters polluted with such effluent.

An added advantage in the use of the goldfish as a test animal is the already large literature on this fish in both physiological and pharmacological fields, in which the usefulness of this animal as a bioassay reagent is well established (Munch, 1931; Powers, 1917).

The stock goldfish used for these tests were obtained in lots as needed from a commercial goldfish farm, and were held in flowing water in large hatchery tanks at a temperature ranging from 17° to 21° C. All goldfish were of the standard carp-form variety, i. e., the various ornamental varieties were excluded. The fish were fed regularly every third day a ration of prepared shrimp meal, and *Myriophyllum* growing in the tank was available at all times. For routine tests 3-inch goldfish (60 to 90 millimeters in length), weighing between 3 and 5 grams, were selected as standard. Larger sizes were used for special tests as required.

DAPHNIA MAGNA

The second test animal, *Daphnia magna*, which is found in the quiet backwaters of various river systems (Surber, 1936), and which is raised extensively as food for young fish, was chosen because of its high sensitivity to most stream pollutants. Comparative tests showed this animal to be more sensitive even than trout, so that the minimal lethal concentration for daphnia of a given pollutant gave approximately the maximal dilution from which damaging effects on fresh-water fishes and many other fresh-water animals could be expected (exclusive of certain cumulative effects). Consequently, between the minimal lethal concentration for daphnia on the one hand and the minimal lethal concentration for goldfish on the other, the gamut of lethal concentrations of any pollutant or effluent under conditions comparable to those of particular pollution cases could be defined rather definitely.

Daphnia proved to be an excellent test animal with which to obtain a quick orientation concerning the relative toxicity of effluents of unknown lethality, since this animal is quite free from the protective mucous secretion which safeguards fish for a time against many pollutants.

Daphnia were also valuable in studying the cumulative effects of some pollutants, as under favorable controlled conditions a new parthenogenetic generation could be expected every 5 to 8 days.

Like that of the goldfish, the scientific literature on daphnia is extensive, and the general physiology and reactions of this animal are well known. The use of daphnia as a bioreagent is also well established (Munch, 1931; Adams, 1927; Billiard, 1925).

The daphnia used in these tests were raised from original stock secured in Texas, pedigreed strains being established and lines of parthenogenetic clones secured for the assay work. The daphnia colony is maintained in a series of large glass jars, each containing four liters of water; and the animals fed bacterial nutrient material prepared from cottonseed meal as described by Chipman (1934).

All assay tests were made in a constant temperature cabinet (see fig. 22) at 25° C. One hundred fifty daphnia of the same age (usually 4 days old) from the same strain were placed in each jar containing 3 liters of the solution to be tested, i. e., in a known dilution of the pollutant, using water from the same source as that in which the daphnia were living as the diluent. No abrupt changes in temperature were permitted, and the solution was well aerated before the daphnia were placed in it. Every 48 or 72 hours, depending upon the type of test, the animals in each jar were concentrated in a pyrex glass trap devised for this work, counted, and returned to the same or fresh solution as desired. When young appeared they were removed and carried in separate jars containing the same concentration of the pollutant as that of the original jar. In this way the mortality of each succeeding generation as well as the rate of reproduction could be followed.

WATER TYPES

When determining the specific lethality of any given pollutant for a particular case, water from the stream into which the effluent was being poured, taken just upstream from the point at which the pollutant entered the stream and filtered through bolting cloth to remove large masses of suspensoids and the macroplankton was used as the diluent water. In this way the pollutant was mixed with the same water as

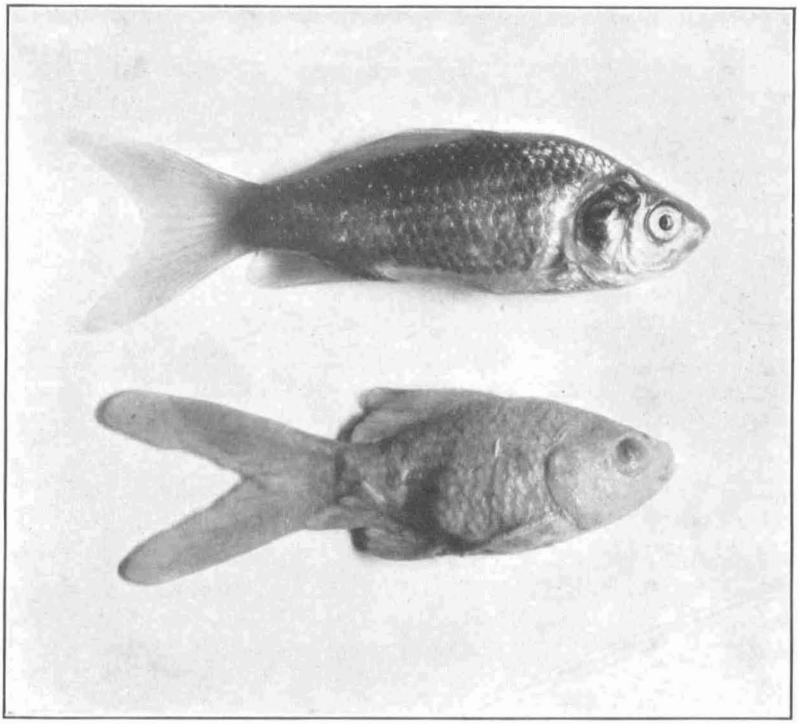

FIGURE 21.—Top, normal goldfish; bottom, goldfish killed in copper sulphate. Note thick deposit of opaque copper-mucoid precipitate covering body, fins, and eyes. This type of precipitate is produced by many wastes containing compounds of heavy metals.

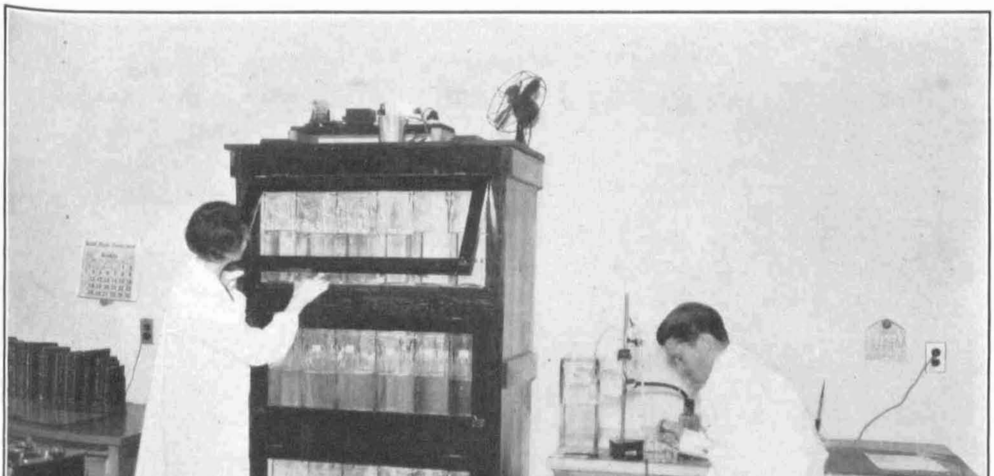

FIGURE 22.—Constant-temperature apparatus in which *Daphnia magna* were used as test reagents for toxicity of various stream pollutants. Assistant at the right is operating a concentrator preparatory to counting *Daphnia*.

in the actual case of pollution under consideration and the same chemical interreactions were possible. When it was not feasible to use stream water at the site of the pollution, unpolluted water from a comparable stream was diluted or fortified until the salt content, the conductivity, the carbonates, and the pH were essentially the same as those of the stream water in question. This was made possible by the field and laboratory analyses of the waters of the stream. This method of compounding a synthetic stream water, although laborious at times, gave very satisfactory comparative results. Control tests were also made in each investigation using glass-distilled water as the diluent for certain critical concentrations.

In making the assays of pollutants, regardless of the diluent water, no material was removed after making the dilution; i. e., even if precipitates or colloidal suspensions were formed on the addition of the pollutant to the diluent water, the fishes or daphnia were exposed to the action of the entire mixture. Many substances which are precipitated in stream and river water are nevertheless slightly soluble in water, particularly if small quantities of carbon dioxide and other compounds be present, so that portions of the precipitate might continue to redissolve for hours or days, and insoluble substances even though precipitated to the bottom of the stream constitute supplies of various ions which may be drawn into the water as others are removed. Again, some of these precipitated materials are dissolved or chemically changed by the action of various substances in or on the body of the fish or daphnia, or by the excretory products of these animals, so that particles of precipitated material lodging temporarily on the gills might be dissolved by the carbon dioxide there, or other particles swallowed by the fish might be acted upon by the digestive fluids of the animal. In view of these complicating factors, the tests made in stream waters are much more valuable in obtaining the actual hazards to aquatic life than those made in distilled water.

In the basic data tests (see tables 7, 8, 9, 10, 11, 12, and 13) four types of water were used as diluents, namely, glass-distilled water for the chemical controls in which the specific and uncomplicated action of the substance was studied, and soft, medium, and hard water (following the classification of Birge and Juday, 1911), i. e., with fixed carbonates less than 5 cubic centimeters per liter, 5 to 22 cubic centimeters per liter and over 22 cubic centimeters per liter, respectively, for the general lethality tests. Ranges of lethality were obtained in this way which are applicable within the limitations previously discussed to most stream waters of the United States, since the hardness of these natural stream waters is dependent almost entirely on the calcium and magnesium carbonates which exists in different degrees ot concentrations in the interior waters.

The soft and hard natural waters were obtained at Columbia, Mo.; the hard water representing a typical limestone drainage, and the soft water a typical clay drainage. The medium water was obtained from the upper Mississippi River. In the tables the pH and specific conductance are given both for the original water and for the mixture as modified by the pollutant, so that the fluctuations in the diluent water itself and in the mixture as the result of the action of the pollutant on the salt and buffer balances may be followed in each case.

SPECIFIC LETHALITY TABLES

OSMOTIC PRESSURE AND SODIUM CHLORIDE

Many effluents carry soluble substances exerting considerable osmotic pressure, and because of that property are capable when sufficiently concentrated of withdrawing water from the gills of fishes and from other delicate external organs of various aquatic organisms, with the attendant damage to the living cells. High concentrations of many sorts of pollutants present this danger quite independently of any toxic, chemical, or corrosive action they may have on aquatic life. The toxic and chemical actions of various salts in stream pollutants may be in part offset by the presence of other substances; but the osmotic action of all of the components of the mixture may be lethal regardless of their mutual antagonisms or specific toxicities, consequently the osmotic pressures of concentrated effluents must be regarded as potential hazards until these substances are sufficiently diluted to be within the limits of osmotic pressure tolerated by fresh-water fishes.

Garrey (1916) finds, using the straw-colored minnow, *Notropis blennius*, as a reagent, that fresh-water fishes tolerate an osmotic pressure of the external medium equal to that of their own blood if the various salts and substances in the water are balanced against each other so as to exclude the specific toxic effects. As the blood of fresh-water fishes contains approximately 0.7-percent sodium chloride, together with small quantities of calcium and potassium salts, the limit of osmotic pressure tolerated in the external medium by fresh-water fishes is therefore near 6 atmospheres, or the approximate equivalent of 7,000 p. p. m. of sodium chloride (common salt) in the surrounding water.

In table 7 data are presented showing the effect of common salt in medium water (Mississippi River water) on test goldfish. This water, of course, contained small quantities of calcium and magnesium salts, which served to some extent to offset the specific toxic action which sodium chloride has in distilled water. (See sodium chloride, p. 429.) These river-water tests confirm the work of Garrey (1916), as sodium chloride killed quickly in concentrations greater than 10,000 p. p. m., and was not lethal in concentrations of 5,000 p. p. m. or less. The survivals in a concentration of 10,000 p. p. m. sodium chloride in river water ranged from 4 to 7 days, and the predicted maximal nonlethal concentration of sodium chloride on the basis of osmotic pressure alone in terms of the osmotic pressure of fish blood would be approximately 7,000 p. p. m.

TABLE 7.—*Survival of goldfish in solutions of sodium chloride; diluent, filtered Mississippi River water* [1]

Concentration ration by weight	Parts per million	pH		Specific conductivity mho×10^{-6} at 25° C.		Survival time [2]
		Water	Solution	Water	Solution	
1:20	50,000	7.8	7.7	236	62,669	30 to 40 minutes.
1:50	20,000	7.8	7.7	235	31,336	1 to 2 hours.
1:67	14,925	7.8	7.7	235	25,254	10 to 12 hours.
1:80	12,500	7.8	7.7	235	25,200	24 to 36 hours.
1:100	10,000	7.8	7.7	235	18,772	4 to 10 days.
1:200	5,000	7.8	7.7	235	4,156	∞
1:1,000	1,000	7.8	7.7	235	2,328	∞
1:10,000	100	7.8	7.7	235	455	∞
1:100,000	10	7.8	7.7	235	245	∞

[1] Condition of experiments as described in table 8.

[2] Minimal and maximal survival times as found in these experiments. Infinity sign indicates survival greater than 25 days without any apparent injury to fish.

In practical pollution work, therefore, any effluent as long as its osmotic pressure is greater than 6 atmospheres may be expected to be lethal to fresh-water fishes regardless of any specific toxic properties. Below this osmotic pressure the toxic, chemical, and corrosive characteristics of wastes will be the major determining factors in its lethality. Brine wastes, however, often present pollution hazards largely because of their osmotic pressures.

ACIDS

High acidity is a characteristic of a large number of wastes, so that the action of uncombined acid is one of the major problems of stream pollution. In determining the lethality of acid wastes, both the actual acidity—that is, the pH or hydrogen-ion concentration of the polluted water carrying acid effluent—and the specific acid involved must be considered, as acid wastes do not kill merely because of a particular degree of acidity.

In table 8 a summary of an extensive series of experiments on the lethality of 11 acids found in stream pollutants is presented. It is obvious, first of all, from this table that it is futile to attempt to designate a given p. p. m. value as marking the lethal point for any particular acid as the buffer substances and dissolved salts of the water into which acid waste is poured will determine the amount of free acid or hydrogen-ions available. The actual conditions, therefore, presented to aquatic life following the addition of a given number of p. p. m. of a particular acid to soft water will be quite different from those presented by the same amount of that acid when added to hard water, with of course all sorts of intermediate possibilities between these two extremes. For example, 134 p. p. m. of sulphuric acid killed goldfish in from 6 to 90 hours when added to soft water, but were not lethal when added to hard water.

TABLE 8.—*Survivals of 700 goldfish in various concentrations of 11 acids found in industrial wastes* [1]

Substances	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity mho×10^{-6} at 25° C.		Survival time [2]	Constituent of—
				Water	Solution	Water	Solution		
Acetic acid	1:70	14,286	Hard	8.0	3.0	641	936	26 to 33 minutes	Beet-sugar wastes.
Do	1:201	4,975	do	8.0	3.5	641	749	30 to 36 minutes	
Do	1:631	1,585	do	8.0	4.0	641	673	50 to 60 minutes	
Do	1:1,000	1,000	do	7.8	4.5	645	693	50 minutes to 1 hour 30 minutes.	
Do	1:1,005	995	do	8.0	4.5	641	652	2 hours to 5 hours 50 minutes.	
Do	1:1,077	929	do	7.9	4.6	641	662	1 to 6 hours	
Do	1:2,365	423	do	8.0	5.0	641	676	4 hours 45 minutes to 20 hours.	
Do	1:2,871	348	do	8.0	5.5	641	675	20 hours to ∞	
Do	[3] 1:10,000	100	do	7.8	6.8	645	675	48 hours to ∞	
Do	[3] 1:100,000	10	do	7.8	7.3	645	688	∞	
Do	[3] 1:1,000,000	1	do	7.8	7.6	645	680	∞	
Benzoic acid	1:1,000	1,000	do	7.8	4.8	666	593	29 to 50 minutes	Coal-tar wastes.
Do	1:5,000	200	do	7.8	5.9	666	598	7 hours 16 minutes to ∞	
Chromic acid	1:1,000	1,000	Very soft	6.2	1.4	<50	3,680	15 to 23 minutes	Tannery wastes.
Do	1:1,250	800	Hard	7.8	5.4	647	844	3 hours 21 minutes	
Do	1:2,500	400	do	7.8	5.9	647	724	15 hours 18 minutes to 28 hours 24 minutes.	
Do	1:5,000	200	do	7.8	6.4	647	716	60 hours 24 minutes to 84 hours.	
Do	1:10,000	100	do	7.8	7.3	647	689	∞	
Do	1:10,000	100	Very soft	6.2	4.0	<50	469	30 to 35 minutes	
Citric acid	1:400	2,500	Hard	8.0	3.0	641	841	55 to 86 minutes	Citrus-fruit products wastes.
Do	1:698	1,433	do	8.0	3.5	641	654	3 hours to 3 hours 30 minutes.	
Do	1:1,119	894	do	8.0	4.0	641	542	4 to 28 hours	
Do	1:1,600	625	do	8.0	4.5	641	494	∞	

TABLE 8.—*Survivals of 700 goldfish in various concentrations of 11 acids found in industrial wastes* [1]—Continued

Substances	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity mho×10⁻⁶ at 25° C.		Survival time [2]	Constituent of—
				Water	Solution	Water	Solution		
Hydrochloric acid	[3] 1:1,000	1,000	do	7.8	1.8	680	3,481	10 to 15 minutes	Chemical wastes.
Do	1:5,100	196	do	8.0	3.0	641	1,221	1 hour 15 minutes to 1 hour 30 minutes.	
Do	1:5,614	178	do	8.0	3.5	641	930	1 hour 23 minutes to 2 hours 15 minutes.	
Do	1:6,011	166	do	8.0	4.0	641	912	4 hours 28 minutes to 6 hours 32 minutes.	
Do	1:6,299	159	do	8.0	4.5	641	853	∞	
Do	[3] 1:10,000	100	do	7.8	6.9	645	654	∞	
Do	[3] 1:100,000	10	do	7.8	7.5	645	650	∞	
Do	[3] 1:1,000,000	1	do	7.8	7.7	645	648	∞	
Lactic acid	1:326	3,068	do	8.0	3.0	641	1,100	40 to 50 minutes	Dairy industries wastes.
Do	1:706	1,416	do	8.0	3.5	641	765	1 hour 12 minutes to 1 hour 45 minutes.	
Do	1:1,530	654	do	8.0	4.0	641	600	6 to 43 hours	
Do	1:2,324	430	do	8.0	4.6	641	566	∞	
Nitric acid	1:1,333	750	do	7.8	3.4	666	1,625	30 to 50 minutes	Chemical wastes.
Do	1:5,000	200	do	7.8	4.9	666	818	∞	
Do	1:10,000	100	do	7.9	7.9	652	698	∞	
Oxalic acid	1:1,000	1,000	do	7.8	2.6	666	2,620	25 to 30 minutes	Dye, tanning and bleaching wastes.
Do	1:5,000	200	do	7.9	5.3	652	405	∞	
Do	1:10,000	100	do	7.9	6.8	652	524	∞	
Do	1:17,000	59	Very soft	6.2	4.5	<50	146	∞	
Do	1:40,000	25	do	6.2	5.8	<50	119	∞	
Do	1:100,000	10	Hard	7.9	7.6	652	662	∞	
Sulphuric acid	[3] 1:1,000	1,000	do	7.8	2.2	645	1,381	30 to 45 minutes	Coal- and iron-mine waters.
Do	1:5,922	169	do	7.8	3.0	640	1,203	50 minutes to 1 hour 10 minutes.	
Do	1:7,000	143	Soft	6.4	3.5	583	790	2 hours 30 minutes to 5 hours 17 minutes.	
Do	1:7,000	143	Hard	7.8	3.5	640	1,170	2 hours to 2 hours 20 minutes.	
Do	1:7,250	138	Soft	6.4	3.9	583	753	5 to 6 hours	
Do	1:7,250	138	Hard	7.8	4.0	640	868	4 hours to ∞	
Do	1:7,450	134	Soft	6.4	4.3	583	675	6 hours 12 minutes to 96 hours.	
Do	1:7,450	134	Hard	7.8	4.5	640	756	∞	
Do	[3] 1:7,500	133	do	7.8	5.0	645	673	∞	
Do	[3] 1:10,000	100	do	7.8	6.8	645	698	∞	
Do	1:17,000	59	Very soft	6.2	3.2	<50	450	1 hour to 1 hour 15 minutes.	
Do	1:60,000	17	do	6.2	4.5	<50	93	∞	
Do	[3] 1:100,000	10	Hard	7.8	7.5	645	692	∞	
Do	1:120,000	8	Very soft	6.2	5.6	<50	85	∞	
Do	[3] 1:1,000,000	1	Hard	7.8	7.5	645	695	∞	
Tannic acid	1:1,000	1,000	do	7.8	6.4	666	631	2 hours 38 minutes to 3 hours 48 minutes.	Tannery wastes.
Do	1:5,000	200	do	7.9	7.3	652	652	7 hours 26 minutes to 9 hours 26 minutes.	
Do	1:10,000	100	do	7.9	7.6	652	652	9 hours 40 minutes to 20 hours 20 minutes.	
Do	1:100,000	10	do	7.9	7.8	652	652	∞	
Tartaric acid	1:1,000	1,000	Very soft	6.2	3.2	<50	900	20 to 25 minutes	Winery wastes.
Do	1:1,000	1,000	Hard	7.8	3.9	655	727	3 hours to 3 hours 20 minutes.	
Do	1:5,000	200	do	7.8	4.6	655	700	∞	
Do	1:10,000	100	Very soft	6.2	3.6	<50	205	3 hours to 3 hours 33 minutes.	
Do	1:100,000	10	do	6.2	4.9	<50	<50	∞	

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[1] Standard goldfish weight 3 to 5 grams used. Each fish in individual glass container carrying 3 liters of solution. Dissolved oxygen 6 to 7 p. p. m.; temperature maintained between 18° to 23° C. Diluent waters discussed on page —.

[2] Minimal and maximal survival times as found in these experiments. Infinity sign indicates survival greater than 4 days without any apparent injury to the fish.

[3] Initial volume of 3 liters per fish replaced by constant flow apparatus at rate of 1 liter per hour.

Considering the actual acidity of the resultant mixture of acids and a given hard water, the most acid mixtures in which goldfish survive 4 days or more were pH 4.0, sulphuric acid; pH 4.5, hydrochloric and citric acids; pH 4.6, lactic acid; pH 4.9, nitric and tartaric acids; pH 5.5, acetic acid; pH 5.8, oxalic acid; pH 5.9, benzoic acid; pH 7.3, chromic acid; and pH 7.8, tannic acid. To this comparison, it must be added, as previously pointed out in the section on pH of natural water, that Brown and Jewell (1926) found fish living in a bog lake where the acidity of the water was pH 4.5 due to the action of carbon dioxide and organic acids leached from the surrounding bog vegetation. It is evident from all of the data in table 8 that no matter what the diluent water be, as far as hydrogen-ion concentration alone is concerned, the acidity near the magnitude of pH 4.0, regardless of the acid or acid-salt combinations producing this acidity, will be lethal for fresh-water fishes if that concentration of acidity be maintained. All acid concentrations more acid than pH 4.0 were lethal. In concentrations less acid than pH 4.0 the penetrative properties and the lethality of the kation of the acid must also be considered, for it may be seen that at any given pH the relative lethality varies with the particular acid involved.

On the basis of p. p. m. of acid present, disregarding the pH factor, the acids may be arranged in order of lethality as follows: Tannic acid, 10 p. p. m.; chromic acid, 100 p. p. m.; sulphuric acid, 130 p. p. m.; hydrochloric, 159 p. p. m.; benzoic, nitric, oxalic, and tartaric, each 200 p. p. m.; acetic acid, 348 p. p. m.; lactic, 430 p. p. m.; and citric, 625 p. p. m., in the particular hard water tested. The exact p. p. m. values are not so significant, for they will vary to some extent with the hardness of the diluent water; but the group shows the general order of magnitude of the relative lethality for these common pollutant acids.

Fishes are killed by acid wastes first through the precipitation and coagulation of the mucus on the gills and by the coagulation of the gill membranes themselves. If this coagulation of gills and gill secretions does not take place, the death of the fish is attributable to the lethal action of the kation of the acid. Combinations of these two actions are not uncommon, i. e., both precipitation and specific toxic action may contribute to the death of the fish. The precipitation of the mucus and of the proteins within the gill membrane cells themselves progresses rapidly when the relative acidity of the mixture is more acid than pH 4.5 because of the acidity itself, but this precipitation may be enhanced by the action of the kation of the acid. Tannic, chromic, and nitric acids all have marked affinity for living protoplasm, forming insoluble compounds with certain protein constituents of living tissue very promptly; in fact, all three of these acids are used as histological fixing agents to kill protoplasm. In the previous comparison on the basis of pH value, the minimal lethal concentration of these acids shows that tannic, chromic, and nitric killed goldfish in solutions less acid than the lethal solutions of sulphuric, hydrochloric, citric, and lactic acids. Acetic acid has high penetrative properties and causes a swelling of tissues which is very destructive to the living cells, so that although this acid does not coagulate the gill membrane and gill mucus like hydrochloric acid, it does disrupt the cells of gill membrane with disastrous results. Consequently, it is not surprising to find that acetic acid kills goldfish at pH of 5.5.

Reviewing all of the data on acid wastes, it seems that the truly acid effects must be limited largely to those acids which kill at a hydrogen-ion concentration more acid than pH 5.0; while in the cases of those acids killing at hydrogen-ion concentration less acid than pH 5.0, lethality factors other than hydrogen-ion concentration play the major part. Of course, as the hydrogen-ion concentration of the surrounding medium in which the fishes and other aquatic animals are living becomes more acid than pH 7.2 to 7.4 (the normal values for most living cells), detrimental effects which may act synergistically with the specific toxic actions of the substances producing such deviations in pH must be expected.

In this connection, it must be pointed out that although the lethality limits of acid wastes as given here are applicable to immediate or intermittent pollution the cumulative effects must also be considered. When goldfish were kept in water at pH 4.5 produced by addition of small quantity of sulphuric acid, this amount of sulphuric acid, although tolerated for a few days without apparent injury to the fish, seemed definitely detrimental to goldfish in exposures longer than 2 weeks, even though some fishes can tolerate pH 4.5 in the natural habitat when this degree of acidity is produced by carbon dioxide and acids from decaying vegetation in bog and swamp lakes. It may be necessary, therefore, to add sulphuric and other acids to the lists of those producing specific toxic effects when long-time experiments in progress are completed.

Table 9 presents data concerning the effects of acids on daphnia comparable to those given in table 8 for fishes. In the cases of daphnia which do not produce volumes of protective mucus to remove or in part buffer down the acid in the effluents to which they may be exposed, the maximal acidity of the solutions in which there was any survival by daphnia was around pH 5.4. It is significant in this connection to recall that the isoelectric point at which many proteins found in living tissue are precipitated is pH 5.5. The daphnia tests, therefore, suggest strongly that were fishes unprotected by mucus the lethal hydrogen-ion concentration for acids in general would be near pH 5.5, and explain the detrimental effects of acid wastes to the stream faunae in general even though the particular concentration may be survived by some fishes. In waters less acid than pH 5.5 the same relative lethalities of the various acids were found for daphnia as for fishes.

TABLE 9.—*Survivals of 4,500 Daphnia magna in various concentrations of 5 acids found in industrial wastes* [1]

Substance	Concentration ratio by weight	Parts per million	pH		Specific conductivity $mho \times 10^{-6}$ at 25° C.		Survival time	Final percent mortality
			Water	Solution	Water	Solution		
Acetic acid	1:1, 333	750	7. 4	4. 0	470	516	5 hours	100
Do	1:2, 000	500	7. 4	4. 6	470	491	do	100
Do	1:5, 333	188	7. 4	5. 0	470	461	do	100
Do	1:8, 000	125	7. 4	5. 4	470	460	24 to 72 hours	75
Citric acid	1:2, 666	375	7. 6	4. 0	425	532	1 to 2 hours	100
Do	1:4, 210	248	7. 6	4. 6	425	491	2 to 17 hours	100
Do	1:5, 405	185	7. 6	5. 0	425	490	10 to 17 hours	100
Do	1:8, 340	120	7. 6	5. 5	425	466	24 to 72 hours	40
Do	1:12, 500	80	7. 6	5. 9	425	440	∞	0
Hydrochloric acid	1:14, 545	69	7. 4	4. 0	452	660	1 to 4 hours	100
Do	1:15, 384	65	7. 4	4. 5	452	650	do	100
Do	1:16, 667	60	7. 4	5. 0	452	614	4 to 17 hours	100
Do	1:17, 777	56	7. 4	5. 4	452	595	17 to 72 hours	80
Lactic acid	1:3, 470	288	7. 6	4. 0	442	493	3 hours	100
Do	1:4, 280	234	7. 6	4. 5	442	463	do	100
Do	1:5, 230	191	7. 6	5. 0	442	443	6 to 48 hours	100
Do	1:5, 880	170	7. 6	5. 5	442	441	26 to 72 hours	66
Sulphuric acid	1:20, 000	50	7. 3	3. 5	324	610	1 to 3 hours	100
Do	1:26, 667	38	7. 3	4. 0	324	484	24 hours	100
Do	1:33, 333	30	7. 3	4. 5	324	389	do	100
Do	1:34, 479	29	7. 3	5. 0	324	381	24 to 72 hours	100
Do	1:50, 000	20	7. 6	6. 5	375	387	168 hours	0
Do	1:100, 000	10	7. 6	7. 3	375	375	do	0
Do	1:1, 000, 000	1	7. 6	7. 6	375	375	do	0
Do	1:10, 000, 000	0. 1	7. 6	7. 6	375	375	do	0

[1] Standard daphnia, 5 days old, from parthenogenic clones were used. For each dilution 150 animals were carried in glass jars containing 4 liters of the solution, and these jars held at 25° C. in constant temperature chamber. The diluent was soft water (see p. 406) from the same source as that in which the stock colonies of daphnia were living. A control of 150 animals in 4 liters of this water without test substance was maintained for each series.

COMPOUNDS OF VARIOUS METALS

Compounds of many metals are rapidly lethal, because these compounds coagulate and precipitate the mucus secreted by the gills of fishes (Carpenter, 1930) and many of the proteins in the living cells. This action has been explained in the discussion of the effects of pollutants on fishes (p. 400). In addition, some metallic salts, such as ferric chloride, if present in sufficient quantities may increase the acidity of the water to a level dangerous for aquatic life and combine this hazard with that of the metallic coagulant.

Since the carbonates and phosphates of many metals are relatively insoluble in water, the hardness of waters receiving effluents containing compounds of the heavier metals is an important factor in determining the immediate lethality of such effluents to fishes, as a considerable portion of these metals may be precipitated from the effluent by the salts in the water. This factor has led to much confusion concerning the absolute limits of lethality of metallic compounds for fishes, since various observers have used different kinds of test water, ranging from distilled to very hard. Unless the hardness of the water in question and particularly the amounts of carbon dioxide, both fixed and free, be known the limits of lethality of any particular metallic compound in any given water are difficult to estimate even though there may be ample data on the specific toxicity of that compound. Besides, the factors of synergy and antagonism between the metallic compound itself and other compounds in the water or effluent which do not precipitate this metallic compound must be considered. Examples of this action are presented in table 10 for copper sulphate.

TABLE 10.—*Influence of other salts in solution upon the toxicity of copper sulphate to gold fish* [1]

Series	Copper sulphate concentration		Sodium nitrate concentration		Calcium chloride concentration		pH		Specific conductivity mho × 10^{-6} at 25° C.		Average survival time
	Ratio by weight	Parts per million	Ratio by weight	Parts per million	Ratio by weight	Parts per million	Water	Solution	Water	Solution	
A	1:100,000	10					7.1	4.0	<50	112	2 hours 30 minutes.
B	1:100,000	10	1:2,000	500			7.1	5.7	<50	806	3 hours.
C	1:100,000	10	1:1,000	1,000			7.1	5.7	<50	1,478	3 hours 45 minutes.
D	1:100,000	10	1:500	2,000			7.1	5.8	<50	2,749	6 hours 10 minutes.
E	1:100,000	10	1:333	3,000			7.1	5.8	<50	4,020	6 hours 15 minutes.
F	1:100,000	10	1:250	4,000			7.1	6.0	<50	5,413	6 hours 30 minutes.
G	1:100,000	10	1:200	5,000			7.1	6.0	<50	6,668	6 hours 40 minutes.
H	1:100,000	10	1:167	6,000			7.1	6.4	<50	7,734	5 hours.
J	1:100,000	10	1:143	7,000			7.1	6.2	<50	9,013	5 hours 30 minutes.
K	1:100,000	10	1:125	8,000			7.1	6.3	<50	10,113	4 hours.
L	1:100,000	10	1:2,000	500	1:20,000	50	7.1	6.3	<50	1,513	5 hours 15 minutes.
M	1:100,000	10	1:1,000	1,000	1:20,000	50	7.1	6.3	<50	1,541	5 hours 30 minutes.
N	1:100,000	10	1:500	2,000	1:20,000	50	7.1	6.4	<50	2,825	6 hours 30 minutes.
O	1:100,000	10	1:333	3,000	1:20,000	50	7.1	6.5	<50	3,984	9 hours 30 minutes.
P	1:100,000	10	1:250	4,000	1:20,000	50	7.1	6.4	<50	5,350	12 hours 30 minutes.
Q	1:100,000	10	1:200	5,000	1:20,000	50	7.1	6.4	<50	6,573	12 hours 45 minutes.
R	1:100,000	10	1:167	6,000	1:20,000	50	7.1	6.5	<50	7,866	8 hours.
S	1:100,000	10	1:143	7,000	1:20,000	50	7.1	6.5	<50	8,763	7 hours.
T	1:100,000	10	1:125	8,000	1:20,000	50	7.1	6.5	<50	10,338	Do.
U			1:333	3,000			7.1	7.3	<50	4,221	(2).
V			1:250	4,000			7.1	6.7	<50	5,350	80 hours.
W			1:200	5,000			7.1	6.8	<50	6,620	37 hours.
X			1:167	6,000			7.1	6.9	<50	7,798	6 hours 30 minutes.

[1] Glass distilled water was used in these tests. Other conditions as described in table 8.

[2] Survival greater than 4 days, fish apparently unaffected.

It may be noted in this table that the addition of progressively larger quantities of sodium nitrate to the copper sulphate solution increased the survival time of fishes from 2 hours 30 minutes to 6 hours 40 minutes, up to a concentration of 1:200 for sodium nitrate. Beyond that concentration the osmotic action of the sodium nitrate became unfavorable (see osmotic pressure, p. 408) and the survival time decreased with a further increase of sodium nitrate, i. e., sodium nitrate, which does not precipitate copper, both increased and decreased the survival time of fishes exposed to the lethal action of same amounts of copper sulphate according to the concentration of sodium nitrate present. The second half of this table shows the marked increase in survival time from 2 hours and 30 minutes in the copper sulphate alone to 12 hours 45 minutes in the same strength of copper sulphate solution to which both sodium nitrate and calcium chloride were added. The amount of calcium chloride used was very small, namely, 50 p. p. m., and in this concentration no precipitate formed, yet this quantity of calcium chloride greatly enhanced the protective action of the sodium nitrate against the lethal action of copper sulphate.

These discussions of the precipitation of metallic compounds out of effluents and of the synergistic and antagonistic actions of compounds which do not precipitate the particular metal in question show, both specifically in the case of effluents carrying compounds of metals and in general in the case of all stream pollutants carrying chemical wastes, that field examinations of local conditions, analyses both of the effluents and the water receiving these effluents, and bioassays of the mixtures of the two must be made before the lethal limits of such wastes can be determined. In table 11 summarized data from a large series of tests covering the lethality limits of certain compounds of eight metals found in commercial effluents are presented. From these data the expected lethal ranges and the relative lethality of these eight compounds in various types of water, together with the changes in salt balance and relative acidity produced by these compounds, may be estimated if uncomplicated by substances other than those normally found in stream water, or by excessive amounts of those substances.

TABLE 11.—*Survivals of 850 goldfish in various concentrations of salts of 8 metals found in industrial wastes* [1]

Substance	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity mho×10⁻⁶ at 25° C.		Survival time [2]	Constituent of—
				Water	Solution	Water	Solution		
Aluminum potassium sulphate.	[3] 1:1,000	1,000	Hard	7.8	5.5	678	1,247	1 to 10 hours	Tannery wastes.
Do	[3] 1:10,000	100	do	7.8	6.8	678	736	12 hours to ∞	
Do	[3] 1:100,000	10	do	7.8	7.6	678	584	∞	
Do	1:1,000,000	1	do	7.8	7.7	678	677	∞	
Cobaltous chloride	1:1,000	1,000	Very soft	6.2	6.6	<50	1,906	28 to 29 hours	Electroplating wastes.
Do	1:1,000	1,000	Hard	7.8	7.2	647	2,265	30 to 31 hours	
Do	1:10,000	100	Very soft	6.2	6.5	<50	308	168 hours to ∞	
Cupric sulphate	[3] 1:1,000	1,000	Glass distilled	7.0	5.6	<50	1,123	1 to 2 hours	Copper and brass industries wastes.
Do	[3] 1:1,000	1,000	Hard	7.8	6.8	690	1,348	1 hour to 2 hours 20 minutes.	
Do	[3] 1:10,000	100	do	7.8	7.0	671	637	3 hours to 11 hours	
Do	1:10,000	100	do	7.9	7.0	635	637	3 to 41 hours	
Do	[3] 1:100,000	10	do	7.9	7.6	635	671	11 to 72 hours	
Do	1:100,000	10	do	7.9	7.7	635	700	48 hours to ∞	
Do	[3] 1:1,000,000	1	do	7.9	7.5	635	640	72 hours to ∞	

TABLE 11.—*Survivals of 850 goldfish in various concentrations of salts of 8 metals found in industrial wastes* [1]—Continued

Substance	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity $\text{mho} \times 10^{-6}$ at 25° C.		Survival time [2]	Constituent of—
				Water	Solution	Water	Solution		
Ferrous sulphate	[3] 1:1,000	1,000	do	7.7	6.4	594	1,307	2 to 10 hours	Wire and tin-plate mills wastes.
Do	[3] 1:10,000	100	do	7.7	6.7	594	649	∞	
Do	[3] 1:100,000	10	do	7.7	7.4	594	598	∞	
Do	[3] 1:1,000,000	1	do	7.7	7.6	594	600	∞	
Ferric chloride	1:1,000	1,000	Very soft	6.2	2.4	<50	2,156	1 hour to 1 hour 10 minutes.	
Do	1:10,000	100	do	6.2	3.4	<50	334	1 hour to 1 hour 20 minutes.	
Do	1:10,000	100	Hard	7.8	5.5	647	700	∞	
Do	1:100,000	10	Very soft	6.2	5.0	<50	<50	∞	
Lead nitrate	[3] 1:1,000	1,000	Hard	7.8	6.4	678	2,500	2 to 3 hours	Mining and smelting wastes.
Do	[3] 1:10,000	100	do	7.8	6.8	678	775	80 hours to ∞	
Do	[3] 1:100,000	10	do	7.8	7.4	678	678	∞	
Do	[3] 1:1,000,000	1	do	7.8	7.5	678	673	∞	
Nickelous chloride	1:1,000	1,000	Very soft	6.3	6.3	<50	1,876	6 hours to 18 hours 30 minutes.	Electroplating wastes.
Do	1:1,000	1,000	Hard	7.8	7.4	647	2,218	12 to 18 hours	
Do	1:10,000	100	Very soft	6.3	6.3	<50	253	19 hours 25 minutes to 50 hours 25 minutes.	
Do	1:100,000	10	do	6.5	6.5	<50	95	200 to 210 hours	
Stannous chloride	1:1,000	1,000	Very soft	6.4	3.5	<50	2,380	1 hour to 1 hour 30 minutes.	Brass industries wastes.
Do	1:1,000	1,000	Hard	7.8	3.8	647	1,609	4 to 5 hours	
Zinc sulphate	[3] 1:1,000	1,000	do	7.8	7.2	678	1,538	1 to 4 hours	Mining and smelting wastes.
Do	[3] 1:10,000	100	do	7.8	7.6	678	780	∞	
Do	[3] 1:100,000	10	do	7.8	7.6	678	678	∞	
Do	[3] 1:1,000,000	1	do	7.8	7.6	678	678	∞	

[1] Experimental conditions as in table 8.

[2] Minimal and maximal survival times as found in these experiments. Infinity sign indicates survival greater than 4 days without any apparent injury to the fish.

[3] Initial volume of 3 liters per fish replaced by constant flow apparatus at rate of 1 liter per hour.

Another hazard from wastes containing compounds of various metals is the cumulative effect. Even though precipitated out, compounds carrying these metals, as long as they remain in the stream, on the bank, or on the floor of the stream, are subject to re-solution if conditions in the waters change (in many cases only slightly), and to ingestion by fish and other aquatic animals during feeding.

The case of lead salts will suffice for example. Carpenter in a series of papers (1924, 1925, 1926, 1927, and 1930) has shown that the lethal action of lead compounds on fishes in cases where the more soluble lead salts are present is due to the precipitation of mucus and proteins in and on the gills by the lead ion, and that the absorption and, therefore, the internal poisoning of fishes by lead compounds under these conditions is negligible during moderately short exposures. This conclusion has been confirmed by Behrens (1925) using a very delicate test (the radio-activity of an isotope of lead) which demonstrated the distribution of lead throughout the body of the fish.

However, the writer in long-time experiments in which goldfish were kept in glass containers, the bottoms of which were covered with finely powdered lead ore (lead sulphide, which is very insoluble in water), found cumulative effects which resulted in the death of fish after 61 days of such exposure, although there were no casualties in the controls carried under identical conditions except for the presence of lead ore. Although these experiments which are being followed further do not in themselves prove that the cumulative action was that of lead alone or of lead in conjunction with some other substance (i. e., traces of other substances in the ore may have been responsible for these cumulative effects), these experiments do show that precipitated and insoluble substances on the bottom of the stream can be a definite pollution hazard over a long period of time due to cumulative action. Again, the writer has found that insoluble zinc ore (zinc sulphide) carried by a stream and deposited on flats adjacent to the main stream bed during high water when exposed to the actions of sunlight, air, and moisture produced quantities of zinc sulphate, a freely soluble and definitely toxic compound which was leached back through into the stream subsequently by rains and high waters (Ellis, 1932).

The synergistic physiological action of many compounds is well known, and the work of Macht and Leach (1930) on goldfish and other types of animals may be cited in this connection, as these writers found that two or more octylic alcohols were synergistic in their action on the respiratory and neuromuscular mechanisms of animals.

MISCELLANEOUS COMPOUNDS

In tables 12 and 13 the relative toxicities of 13 other substances found in industrial wastes or otherwise constituting stream pollution hazards are presented. The changes in hydrogen-ion concentration and salt balance are shown, as in the tables giving the data on acids and metallic compounds. It may be seen, however, that the substances listed in tables 12 and 13 do not kill because of changes either in pH or salt balance, i. e., in these two tables are included representatives of those substances which, if detrimental, are so because of specific toxic action after entering the body of the fish. Phenol produces paralysis of the neuromuscular mechanisms and hemolyzes the blood; potassium xanthate in high dilution acts after several days on the gastrointestinal tract; amyl alcohol quickly induces a semiparalyzed condition with marked incoordination, yet the fish may live for days in this state before dying; and sodium selenite causes a slow decline in the general activities of the fish.

TABLE 12.—*Survival of goldfish in solutions of sulphur and selenium compounds*[1]

Substance	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity mho$\times 10^{-6}$ at 25° C.		Survival time[2]	Constituent of—
				Water	Solution	Water	Solution		
Ammonium sulphide	[3] 1:1,000	1,000	Hard	7.7	7.9	681	938	15 minutes to 1 hour 30 minutes.	Sewage and organic wastes.
Do	[3] 1:10,000	100	do	7.7	7.8	681	735	72 hours to ∞	
Do	[3] 1:100,000	10	do	7.7	7.7	681	681	∞	
Do	[3] 1:1,000,000	1	do	7.7	7.7	681	681	∞	
Hydrogen sulphide	[3] 1:1,000	1,000	do	7.8	6.5	670	734	45 minutes to 1 hour	Do.
Do	[3] 1:10,000	100	do	7.8	7.3	670	676	3 to 4 hours	
Do	[3] 1:100,000	10	do	7.8	7.6	670	661	96 hours to ∞	
Do	[3] 1:1,000,000	1	do	7.8	7.7	670	670	∞	
Sodium sulphite	[3] 1:1,000	1,000	do	7.8	7.6	676	2,017	3 to 72 hours	Paper-pulp-mill wastes.
Do	[3] 1:10,000	100	do	7.8	7.6	676	864	96 hours to ∞	
Do	[3] 1:100,000	10	do	7.8	7.6	676	678	∞	
Do	[3] 1:1,000,000	1	do	7.8	7.8	676	677	∞	
Sodium selenite	1:1,000	1,000	Very soft	6.4	7.5	<50	753	1 hour to 1 hour 30 minutes.	Certain soils.
Do	1:1,000	1,000	Hard	7.8	7.4	647	1,141	1 hour to 2 hours 10 minutes.	
Do	1:10,000	100	Very soft	6.4	7.5	<50	107	20 hours 56 minutes to ∞.	
Do	1:10,000	100	Hard	7.8	7.7	647	723	8 hours to 19 hours 30 minutes.	
Do	1:100,000	10	Very soft	6.4	7.3	<50	<50	98 to 144 hours	

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[1] Conditions of experiments described in table 8.

[2] Minimal and maximal survival times as found in these experiments. Infinity sign indicates survival greater than 4 days without any apparent injury to the fish.

[3] Constant flow as described in table 8.

The specifically toxic substances which do enter the body of the fish can be grouped therefore according to their specific pathological and pharmacological effects much as in the case of man; and these poisons which do enter the body of the fish constitute important pollution hazards in high dilution, since the high dilutions may be tolerated by the fish for a short time without apparent harmful results. Consequently, the compounds in this miscellaneous group must be considered individually in evaluating pollution hazards.

TABLE 13.—*Survivals of goldfish in solutions of various chemicals found in industrial wastes* [1]

Substance	Concentration ratio by weight	Parts per million	Diluent water	pH		Specific conductivity mho×10⁻⁶ at 25° C.		Survival time [2]	Constituent of
				Water	Solution	Water	Solution		
Ammonium carbonate	[3] 1:1,000	1,000	Hard	7.7	8.1	718	2,644	1 to 2 hours	Organic wastes, gashouse wastes.
Do.	[3] 1:10,000	100	do	7.7	7.8	718	956	4 to 10 hours	
Do.	[3] 1:100,000	10	do	7.7	7.7	718	727	∞	
Do.	[3] 1:1,000,000	1	do	7.7	7.7	718	718	∞	
Amyl alcohol (iso)	1:1,000	1,000	do	7.8	7.8	647	666	17 to 71 hours	Distillery wastes.
Do.	1:10,000	100	do	7.8	7.8	647	647	82 hours-∞	
Do.	1:100,000	10	do	7.8	7.8	647	647	94 hours-∞	
Do.	1:1,000,000	1	do	7.8	7.8	647	647	161 hours-∞	
Bromine	1:1,000	1,000	do	8.0	6.7	646	673	20 to 40 minutes	Chemical industries wastes.
Do.	1:2,500	400	do	8.0	7.4	646	659	30 minutes to 1 hour 10 minutes.	
Do.	1:10,000	100	do	8.0	7.6	646	649	1 hour to 3 hours 25 minutes.	
Do.	1:50,000	20	do	8.0	8.0	646	646	15 to 96 hours	
Do.	1:100,000	10	do	8.0	8.0	646	646	∞	
Chlorine	1:10,000	100	do	7.9	7.4	653	640	54 minutes to 1 hour 30 minutes.	Do.
Do.	1:100,000	10	do	7.9	7.9	653	653	5 hours 15 minutes to 48 hours.	
Do.	1:500,000	2	do	7.9	7.9	653	653	17 to 48 hours	
Do.	1:1,000,000	1	do	7.9	7.9	653	653	96 hours to ∞	
Cresylic acid	1:1,000	1,000	do	7.8	7.8	639	654	14 to 30 minutes	Livestock disinfectants and flotation wastes.
Do.	1:10,000	100	do	7.8	7.8	639	641	5 to 31 hours	
Do.	1:100,000	10	do	7.8	7.8	639	640	46 to 96 hours	
Do.	1:1,000,000	1	do	7.8	7.8	645	645	93 to 120 hours	
Do.	1:10,000,000	0.1	do	7.8	7.8	645	645	120 hours to ∞	
Phenol	[3] 1:1,000	1,000	do	7.8	7.6	690	587	15 to 30 minutes	Livestock disinfectants and gashouse wastes.
Do.	[3] 1:10,000	100	do	7.8	7.6	690	593	60 to 72 hours	
Do.	[3] 1:100,000	10	do	7.8	7.8	690	690	72 hours to ∞	
Do.	[3] 1:1,000,000	1	do	7.8	7.8	690	690	∞	
Potassium xanthate	[3] 1:3,125	320	do	8.1	8.8	669	900	5 to 24 hours	Mine flotation wastes.
Do.	[3] 1:6,250	160	do	8.1	8.6	669	776	12 to 24 hours	
Do.	[3] 1:12,500	80	do	8.1	8.4	669	731	12 to 36 hours	
Do.	[3] 1:100,000	10	do	8.1	8.1	669	669	48 to 96 hours	
Do.	[3] 1:10,000,000	0.1	do	8.1	8.1	669	669	4 to 5 days	
Sodium chlorate	1:1,000	1,000	do	8.0	7.7	645	753	∞	
Sodium fluoride	1:1,000	1,000	Very soft	6.4	6.4	<50	2,162	12 to 29 hours	Distillery wastes and certain soils.
Do.	1:1,000	1,000	Hard	7.8	7.0	647	2,346	60 to 102 hours	
Do.	1:10,000	100	do	7.8	7.3	647	943	∞	

[1] Condition of experiment described in table 8.

[2] Minimal and maximal survival times as found in these experiments. Infinity sign indicates survival greater than 4 days without apparent injury to the fish.

[3] Constant flow as described in table 8.

LETHAL LIMITS OF 114 SUBSTANCES WHICH MAY BE FOUND IN STREAM POLLUTANTS

In this section summaries of the lethal limits of individual substances, together with bibliographic references and statements concerning the test animals used and conditions of the experiments, are presented. These data have been massed from the literature and from the writer's own experiments (M. M. E.). In these summaries no attempt has been made to include all existing references, but instead sufficient data to give a definite idea of the relative lethality of the substance in question under conditions which may be encountered in the streams of the United States. Only fresh-water fishes and fresh-water organisms have been considered. It is hoped that these summaries will prove helpful in evaluating specific pollution conditions when used in conjunction with the data presented in preceding sections. However, as has been pointed out repeatedly in this paper, arbitrary application of lethality data to specific pollution problems is absolutely impossible owing to the many limiting factors, various of which have been discussed in previous sections.

Any student of the toxicity of the components of industrial and municipal effluents to fishes and other aquatic life will find the pioneer work of Penny and Adams (1863) and of Weigelt, Saare, and Schwab (1885) starting points for the investigations of the commoner substances. However, much progress has been made in the study of the factors limiting the action of many pollutants, since these experiments and the lethality values given by these earlier observers have been quoted too often without regard to more recent findings.

Important advances have been made in the measurement of stream-pollution hazards of particular effluents through the isolation from these effluents of various compounds of highly toxic nature, which compounds were formerly overlooked or disregarded because the actual amounts of these substances present in the effluent were quite small. These highly toxic compounds, some of which are volatile or may otherwise disappear from the effluent after a time, have been responsible for the wide discrepancies in lethality of the waste as a whole as reported by different observers working on the same type of effluent.

In the present list of substances which may be participants in stream-pollution problems, several compounds have been included which are little known except to the professional chemist, although the harmful properties of these substances have been demonstrated in connection with certain industrial effluents. The list of these less familiar compounds will undoubtedly grow, both as investigations of particular effluents are completed and as chemical engineering produces new commercial processes. The long series of dyes, many of which are highly toxic to aquatic life, used in industries and arts have not been included in this list of possible stream pollutants because the dye wastes are largely mordant, bleach and processing liquors containing only traces of the dyestuffs themselves which industry has found too costly to waste. The conservation of these expensive dye compounds by the manufacturing concerns has been very apparent to the writer in several recent investigations of plants dyeing fabric, paper, and leather.

Acetic acid, $CH_3{\cdot}COOH$. Vinegar acid

Beet-sugar pulp waste; some winery wastes; soured fruit wastes; and vinegar works. Penny and Adams (1863), 114 p. p. m. killed minnows in 20 hours, but 286 p. p. m. not fatal to goldfish; M. M. E., 100 p. p. m. in hard water killed some goldfish, *Carassius auratus*, and 125 p. p. m. killed cladocerans, *Daphnia magna*, in 24–72 hours.

Acetone, $(CH_3)_2CO$

Gas and coal-tar wastes; paint and chemical industries. Shelford (1917), 14,250–15,050 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*.

Acridine, $C_6H_4(N.CH)C_6H_4$

Gas tar oils; dye industries; water sterilization. Adams (1927), 5 p. p. m. in Nile River water killed cladocerans, *Daphnia sp.*, and copepods, *Cyclops sp.*

Alcohols

See amyl alcohol, butyl alcohol, ethyl alcohol, methyl alcohol, and octyl alcohol.

Aluminium ammonium sulphate, $Al(NH_4)(SO_4)_2$· Ammonium alum

Dye works and cloth printing industries. Weigelt, Saare, and Schwab (1885), 523 p. p. m. in tap water caused large trout to float on side after 10 hours' exposure.

Aluminium potassium sulphate, $AlK(SO_4)_2$· Alum or potassium alum

Dye works; tanneries; leather works. Penny and Adams (1863), 250 p. p. m. killed goldfish and minnows; Weigelt, Saare, and Schwab (1885), 544 p. p. m. in tap water killed California salmon in 6 hours, and medium trout in 15 hours; M. M. E., 1,000 p. p. m. in hard water killed goldfish, *Carassius auratus* in 1–10 hours, 100 p. p. m. killed goldfish in 12–96 hours, although some survived this strength over 100 hours.

Alums

See aluminium ammonium sulphate, aluminium potassium sulphate, and ferric potassium sulphate.

Ammonia

See ammonium hydroxide.

Ammonium carbonate, $(NH_4)_2CO_3$

Gas wastes; wool-washings; tannery effluents. Clark and Adams (1913), 155–197 p. p. m. fatal to shiners and carp in a few minutes to a few hours; Shelford (1917), 600–800 p. p. m. killed orange-spotted sunfish, *Lepomis humilis* in 1 hour; M. M. E., 100 p. p. m. in hard water killed goldfish in 4–10 hours, 48 p. p. m. in 6 days, 10 p. p. m. tolerated for more than 100 hours without apparent effect.

Ammonium chloride, NH_4Cl. Sal ammoniac

Gas wastes; various chemical wastes. Clark and Adams (1913), 180 p. p. m. in tap water, no effect on shiners or carp; Wells (1915b), 535 p. p. m. in tap water killed bluegills, *Lepomis pallidus* in 4 hours 45 minutes, and same amount in distilled water killed bluegills in 18 days; Shelford (1917), 700–800 p. p. m. killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; Powers (1917), 1,712 p. p. m. in distilled water killed goldfish, *Carassius auratus*, in 6–18 hours; M. M. E. 268 p. p. m. in hard water, killed goldfish in 6 days; 535 p. p. m. killed cladocerans, *Daphnia magna*, in 6 hours.

Ammonium ferrocyanide $(NH_4)_4Fe(CN)_6$

Gas wastes. Shelford (1917), 150–200 p. p. m. killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Ammonium hydroxide, NH_4OH

Wool washings; chemical wastes; gas wastes. Since ammonia gas NH_3 unites readily on mixing with water forming the hydroxide, these two compounds are considered together here. Clark and Adams (1913), 9.4 p. p. m. (ammonium hydroxide) did not kill shiners, carp, and large suckers but 13 p. p. m. killed all these fishes, 20 p. p. m. being fatal in 15 minutes; Belding (1928), 6.25 p. p. m. killed brook trout in 24 hours; Weigelt, Saare, and Schwab (1885), 250 p. p. m. (ammonia) killed trout in 2 hours; Shelford (1917), 7–8 p. p. m. (ammonia) in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; M. M. E., 2–2.5 p. p. m. (ammonia) in hard water fatal to goldfish, *Carassius auratus*, and yellow-perch, *Perca flavescens*, in 24 hours to 4 days.

Ammonium nitrate, NH_4NO_3

Chemical industries; manufacture of explosives; in fertilizers. Wells (1915b), 800 p. p. m. in tap water killed bluegills, *Lepomis pallidus,* in 3.9 hours; in distilled water lethal to bluegills in 16 days; Powers (1917), 4,545 p. p. m. in distilled water killed goldfish, *Carassius auratus,* in 90 hours.

Ammonium sulphate, $(NH_4)_2SO_4$

Chemical wastes; gas wastes; fertilizers. Wells (1915b), 66 p. p. m. in tap water killed bluegills, *Lepomis pallidus,* in 3 hours, 30 minutes, in distilled water lethal to bluegills in 17 days; Shelford (1917), 420–500 p. p. m. in tap water killed *Lepomis humilis,* in 1 hour; M. M. E., 264 p. p. m. in hard water killed goldfish, *Carassius auratus,* in 6 days or less.

Ammonium sulphide, $(NH_4)_2S_x$

Chemical wastes; in wastes from some beet-sugar processes; in some gas wastes. M. M. E., 100 p. p. m. in hard water killed goldfish, *Carassius auratus,* in 72 hours, 10 p. p. m. in hard water, goldfish survived more than 100 hours of exposure.

Ammonium thiocyanate, NH_4CNS. Rhodanammonium

Gas wastes; chemical industries. Shelford (1917), 280–300 p. p. m. in tap water killed orange-spotted sunfish in 1 hour; Demyanenko (1931), 200 p. p. m. lethal for fish.

Amyl alcohol (iso), $C_5H_{11}OH$

Chemical wastes; in some distillery wastes. M. M. E., 100 p. p. m. in hard water killed goldfish, *Carassius auratus,* in 82 hours, 1 p. p. m. killed goldfish in 161 hours.

Aniline, $C_6H_5NH_2$

Dye wastes; chemical industries; gas wastes. Shelford (1917), 1,020–1,122 p. p. m. killed orange-spotted sunfish, *Lepomis humilis,* in 1 hour; Demyanenko (1931), 250 p. p. m. lethal for fishes.

Arsenic trioxide, white arsenic

See sodium arsenate.

Barium chloride, $BaCl_2$

Some chemical wastes; some alkaline pools. Powers (1917), 5,000 p. p. m. in distilled water killed goldfish, *Carassius auratus,* in 12–17 hours.

Benzoic acid, $C_6H_5 \cdot COOH$

Gas wastes. Shelford (1917), 550–570 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis,* in 1 hour; M. M. E., 200 p. p. m. in hard water killed goldfish in 7–96 hours.

Blue Vitriol

See cupric sulphate.

Bromine, Br_2

Chemical industries; bromine plant wastes. Penny and Adams (1863), 29 p. p. m. killed minnows and goldfish; M. M. E., 20 p. p. m. in hard water killed goldfish in 15–96 hours, 10 p. p. m. in soft water lethal for cladocerans, *Daphnia magna.*

Butyl alcohol (iso), C_4H_9OH

Paint and varnish solvents; some chemical industries. Powers (1917), 250 p. p. m. in distilled water killed goldfish, *Carassius auratus,* in 7–20 hours.

Cadmium chloride, $CdCl_2$

Pigment works; calico printing; chemical wastes. Powers (1917), 0.0165 p. p. m. in distilled water killed goldfish in 8 hours 40 minutes to 18 hours.

Cadmium sulphate, $CdSO_4$

Same sources as cadmium chloride. Carpenter (1927), 1,042 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in 3 hours.

Calcium chloride, $CaCl_2$

Wastes from bromine and salt works; in waters from oil wells; antidust road surfacing. Wells (1915b) 555 p. p. m. in tap water caused pathological degeneration of tail fin of rock-bass, *Ambloplites rupestris*, in an exposure of 1 week; Garrey (1916), 2,775 p. p. m. in distilled water killed straw-colored minnows, *Notropis blennius*, in 2–4 days, but this species did not succumb to 277 p. p. m. in distilled water in 5–7 weeks; Powers (1917), 7,752 p. p. m. in distilled water killed goldfish, *Carassius auratus*, in 22–27 hours; Wiebe, Burr, and Faubion (1934), 5,000 p. p. m. killed golden shiners, *Notemigonus crysoleucas*, in 143 hours.

Calcium hydroxide, $Ca(OH)_2$. Lime

Tannery-wastes; leather works. Weigelt, Saare, and Schwab (1885), 700 p. p. m. in tap water killed trout in 26 minutes; Marsh (1907), 18 p. p. m. (as calcium oxide) fatal to trout fry.

Calcium nitrate, $Ca(NO_3)_2$

Some chemical wastes. Powers (1917), 6,061 p. p. m. in distilled water killed goldfish, in 43–48 hours.

Calcium oxide, CaO. Unslaked lime

Forms calcium hydroxide, q. v., immediately on addition to water.

Carbon bisulphide, CS_2

Gas wastes; as a solvent in various chemical industries. Weigelt, Saare and Schwab (1885), a 7 minute exposure to 5,000 p. p. m. killed trout 2 days later; Shelford (1917), 100–127 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Carbon dioxide, CO_2

From sewage and any decomposing organic wastes (see section on carbon dioxide in natural waters). Wells (1918), 113,925–151,900 p. p. m. in tap water killed fresh-water fishes.

Carbon monoxide, CO

Motorboat exhausts; in water returned to streams from cooling systems of engines using fuel oil if mixed with exhaust gases. Wells (1918), 1,160 p. p. m. in tap water killed straw-colored minnow, *Notropis blennius*, in 1 hour; the blunt-nosed minnow, *Pimephales notatus*, in 1 hour 55 minutes; the orange-spotted sunfish, *Lepomis humilis*, in 5 hours 40 minutes; the green sunfish, *Lepomis cyanellus*, in 6 hours; 11,314 p. p. m. under same conditions killed the black bullhead, *Ameiurus melas*, in 9 hours 55 minutes.

Chloramine, NH_2Cl

Water purification systems either as chloramine or formed from small quantities of ammonia and chlorine in the water. Coventry, Shelford, and Miller (1935), 0.3–0.4 p. p. m. in tap water killed trout fry at once, and 0.06 p. p. m., trout fry in 48 hours; 0.4 p. p. m. killed sunfish and bullheads; 0.76 p. p. m., hardy minnows; and 1.2 p. p. m., large carp and bullheads.

Chloramine-T, $CH_3 \cdot C_6H_4SO_2NNaCl$

Water purification systems. Adams (1927), 5 p. p. m. in Nile River water killed cladocerans, *Daphnia sp.*, and copepods, *Cyclops sp.*

Chlorine, Cl_2

Water purification systems; various chemical wastes. Adams (1927), 2 p. p. m. in Nile River water killed cladocerans, *Daphnia sp.*, and copepods, *Cyclops sp.*; Davis (1934), 1 p. p. m. killed coarse fish; M. M. E., 1 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 96 hours; and 0.5 p. p. m. in soft water killed cladocerans, *Daphnia magna*, in 72 hours or more.

Chloride of lime, or bleaching powder

This substance is of uncertain composition as usually found. Its lethal properties as regards aquatic life are largely dependent upon the amount of chlorine which is liberated when the bleaching powder is added to the water. The potential amount of chlorine available in the sample under question must be known before its toxicity can be estimated. Much confusion exists in the previous reports because of that fact and consequently no limits are given here.

Chromic acid, H_2CrO_4

Chrome tannery wastes. M. M. E., 100 p. p. m. in hard water did not kill goldfish, *Carassius auratus*, in 100 hours' exposure; the same amount in very soft water killed goldfish in 30–35 minutes.

Citric acid, $(COOH)CH_2C(OH)(COOH)CH_2COOH$

Wastes from industries using citrus fruits. M. M. E., 894 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 4–28 hours; 625 p. p. m. in hard water was not lethal to goldfish in 100 hours exposure; 120 p. p. m. in soft water killed cladocerans, *Daphnia magna*, in 24–72 hours.

Cobaltous chloride, $CoCl_2$

Pigment works; chemical industries. M. M. E., 1,000 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 30–32 hours; 10 p. p. m. in soft water fatal to some goldfish in 168 hours; others survived exposure to this amount for longer periods.

Copper, Cu_2

See various cupric compounds. As Moore and Kellerman (1905) have pointed out and as is discussed here under the action of heavy metals, the amount of copper required to produce lethal results varies greatly with the water, and particularly the carbonates. These writers state that "in water containing carbonates, if the amount of dissolved CO_2 is very low the basic carbonate of copper formed may be considered insoluble; if, however, the water should contain a fair amount of CO_2 it would bring the copper carbonate at least partially into solution." Copper compounds are used as algicides and occur in many industrial wastes.

Cresol, general formula $C_6H_4(OH)(CH_3)$

A mixture of the various isomeric compounds of this group. The mixture and the individual compounds occur in gas wastes in varying proportions and the mixture is used in various sheep dips and other preparations for the disinfecting of livestock. Both gas wastes and dipping vats have on occasion been the sources of stream pollution by this substance. This mixture and two of the component isomers are discussed below.

Cresol

Adams (1927), 10 p. p. m. in Nile River water killed cladocerans, *Daphnia sp.*, and copepods, *Cyclops sp.;* Demyanenko (1931), 17–20 p. p. m. lethal for fishes.

Orthocresol

Shelford (1917), 55–65 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; M. M. E., 10–20 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 3–5 days.

Paracresol

Shelford (1917), 80–90 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; Southgate, Pentelow, and Bassindale (1933), 6.2 p. p. m. in tap water caused trout, *Salmo irideus*, to float helpless on their backs in 1 hour 40 minutes, if the water carried *circa* 10 p. p. m. of dissolved oxygen and in 13 minutes if the water carried only 3 p. p. m. dissolved oxygen.

Cresylic acid, a mixture of isomeric cresols and xylenols

Mine floatation wastes; sheep and cattle dips. M. M. E., 0.1 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 5 days and 1 p. p. m. in 6–48 hours; 0.1 p. p. m. in soft water killed cladocerans *Daphnia magna*, in 72 hours.

Cupric chloride, $CuCl_2$

Powers (1917), 0.0188 p. p. m. in distilled water killed goldfish in 3 hours 30 minutes to 7 hours; Carpenter (1927), 672 p. p. m. in distilled water killed the minnow, *Leuciscus phoxinus*, in 82 minutes.

Cupric nitrate, $Cu(NO_3)_2$

Dilling and Healey (1926), 0.0188 p. p. m. in tap water killed many tadpoles and interfered with the development of those which survived.

Cupric sulphate, $CuSO_4$. Blue vitriol

Because of the wide use of this compound in both industry and in aquatic investigations, and because of the variation in limits of lethality copper sulphate as given by many writers, owing to differences in water, in carbonate content, and in associated substances, a larger number of references have been included for copper sulphate than for most compounds in this list. Penny and Adams (1863), 10 p. p. m. fatal to goldfish and minnows, but 5 p. p. m. under the conditions of their tests were not lethal to these fishes; Moore and Kellerman (1905), 0.143 p. p. m. in hatchery water (Cold Spring Harbor, N. Y.), maximum strength tolerated by brook trout, and 0.33 p. p. m. maximum for carp and suckers, 0.4 p. p. m. for catfish, 0.5 p. p. m. for goldfish, 1.33 p. p. m. for sunfish, 2 p. p. m. for black bass; Carpenter (1927), 399 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in 62 minutes; Catt (1934), 0.5 p. p. m. in lake water not lethal to white perch and yellow perch in 15 hours, but 1 p. p. m. in lake water killed white and yellow perch in 1 to 10 hours; M. M. E., 2 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 24–96 hours; catfish, *Ameiurus nebulosus*, in 96–200 hours; 1 p. p. m., some goldfish in 72 hours; 1.25 p. p. m., the amphipods, *Gammarus fasciatus* and *Eucrangonyx gracilis*, in 17–20 hours; 10 p. p. m., the isopod, *Mancasellus macrourus*, in 16–48 hours; 1 p. p. m. in distilled water killed cladocerans, *Daphnia magna*, in 15 minutes to 2 hours, and 0.25 p. p. m. in distilled water in 30 minutes to 3 hours.

Ethyl alcohol, C_2H_5OH

Fermented organic wastes, particularly fruit pulps, brewery and distillery wastes. Weigelt, Saare, and Schwab (1885), a 2-hour exposure to 10,000 p. p. m. in tap water survived by tench, *Tinca vulgaris*, without injury; Powers (1917), 250 p. p. m. in distilled water killed goldfish in 6–11 hours.

Ethyl amine, $C_2H_5NH_2$

Gas wastes. Shelford (1917). 400–800 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Ferric chloride, $FeCl_3$

Dye industries; some ore milling operations; various chemical wastes. Powers (1917), 9 p. p. m. in distilled water killed goldfish in 20 hours; Carpenter (1927), 270 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in 90 minutes; M. M. E., 100 p. p. m. in very soft water killed goldfish, *Carassius auratus*, in 1 hour to 1 hour 30 minutes, but same quantity of ferric chloride in hard water was not detrimental to goldfish in a 96-hour exposure.

Ferric potassium sulphate, $FeK(SO_4)_2$. Ferric alum

Dye mordant; calico printing. Weigelt, Saare, and Schwab (1885), 1 minute exposure to 10,000 p. p. m. not fatal to tench.

Ferric sulphate, $Fe_2(SO_4)_3$

Chemical industries; as a coagulant for sewage precipitation. Clark and Adams (1913), 0.716 p. p. m. in distilled water killed shiners, carp, and suckers in 12–24 hours.

Ferrous sulphate, $FeSO_4$. Green vitriol or copperas

Waters from mines containing pyrites; in pickle liquor from industrial plants cleaning iron plate or wire. Weigelt, Saare, and Schwab (1885), 2,721 p. p. m. in tap water killed trout and California salmon in 31–66 minutes; Clark and Adams (1913), 2.9 p. p. m. in distilled water killed shiners, carp, and suckers in 4–24 hours; Carpenter (1927), 315 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in about 3 hours; M. M. E., 1,000 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 2–10 hours, 100 p. p. m. in hard water apparently not harmful to goldfish in a 96-hour exposure.

Gallic acid, $C_6H_2(COOH)(OH)_3$

Dye wastes; tannery wastes; some chemical wastes. Penny and Adams (1863), 143 p. p. m. killed goldfish and minnows.

Glycerol, $(CH_2OH)_2CHOH$. Glycerine

Soap factories. Weigelt, Saare, and Schwab (1885), tench survived 16-hour exposure at 8° C. to 100,000 p. p. m. in tap water without apparent effect.

Hydrochloric acid, HCl. Muriatic acid

In effluents from many chemical processes. Weigelt, Saare, and Schwab (1885), 1,000 p. p. m. in tap water caused trout to overturn helpless in 2–5 minutes; Wells (1915a), 3.6 p. p. m. in distilled water killed green sunfish, *Lepomis cyanellus*, in 48 hours. Standing Committee on Rivers Pollution (1924), 200 p. p. m. in distilled water produced general collapse in perch and roach; M. M. E., 166 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 4–7 hours; 157 p. p. m. in hard water apparently did not injure goldfish in over 100 hours' exposure; 56 p. p. m. in soft water killed cladocerans, *Daphnia magna*, in 17–72 hours.

Hydrogen sulphide, H_2S

Produced by decomposition of many types of organic effluents, both municipal and industrial, and occurs in many trade wastes, chemical wastes, and gas wastes. This gas which readily dissolves in water is not only harmful in itself but in its decomposition may produce colloidal sulphur, which is also a pollution hazard. Weigelt, Saare, and Schwab (1885), a 3-hour exposure to 100 p. p. m. in tap water was fatal to tench, *Tinca vulgaris*, 8 days later, and 10 p. p. m. in tap water caused trout to float on back in 15 minutes; Shelford (1917), 4.9–5.3 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; Belding (1929), 0.086 p. p. m. lethal for brook trout, *Salvelinus fontinalis*, 3.8 p. p. m. for the sucker, *Catostomus commersonii*, 4.3 p. p. m. for aquarium goldfish, *Carassius auratus*, and 6.3 p. p. m. for carp, *Cyprinus carpio;* M. M. E., 10 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 96 hours or less, 5 p. p. m. killed some goldfish in 200 hours, and 1 p. p. m. in soft water killed cladocerans, *Daphnia magna*, in 72 hours or less.

Iodine, I_2

Rarely found free in stream water. Penny and Adams (1863), 28.5 p. p. m. killed minnows and goldfish.

Iron, Fe_2

See various ferric and ferrous compounds.

Lactic acid, $CH_3CH(OH)COOH$

A component of various dairy industries wastes. M. M. E., 654 p. p. m., in hard water killed goldfish, *Carassius auratus*, in 6–43 hours, but 430 p. p. m. in hard water apparently was not harmful to goldfish in exposures of over 100 hours; 170 p. p. m. in soft water killed cladocerans, *Dapghnia magna*, in 26–72 hours.

Lead, Pb_2

Compounds of this metal are found in many industrial wastes and in effluents from various mining and ore milling operations. These compounds are highly toxic as has been discussed under action of heavy metals on fishes and other aquatic organisms. Two general statements concerning the lethality of lead may be given here. Other references follow under the several salts of lead. Carpenter (1927) believes that as little as 0.33 p. p. m. of lead may be lethal to fresh-water fishes, and Dilling, Healey, and Smith (1926) found that 4 p. p. m. of colloidal lead retarded the growth of young plaice.

Lead acetate, $Pb(C_2H_3O_2)_2$. Sugar of lead

Rushton (1922), 10 p. p. m. in stream water killed yearling trout; Carpenter (1925), 5 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in 4–16 hours, and 10 p. p. m. in distilled water, if renewed every other day, killed goldfish in 12 days.

Lead nitrate, $Pb(NO_3)_2$

Rushton (1922), 10 p. p. m. in stream water killed trout in 2 hours 15 minutes; Carpenter (1925), 250 p. p. m. in distilled water killed goldfish in 4–5 days and minnows, *Leucisus phoxinus*, in 2–3 hours; Dilling and Healey (1926), 1.6 p. p. m. retards growth of tadpoles and 3.3 p. p. m. lethal for tadpoles in tap water; Carpenter (1930), 165 p. p. m. in distilled water, if given sufficient exposure will kill steel-colored minnow, *Notropis whipplii;* common shiner, *Notropis cornutus;* blunt-nosed minnow, *Hyborhynchus notatus;* silver-mouthed minnow, *Ericymba buccata;* sucker-mouthed minnow, *Phenacobius mirabilis;* creek chub, *Semotilus atromaculatus;* stoneroller, *Campostoma anomalum;* common sucker, *Catostomus commersonii;* chub sucker, *Eriomyzon sucetta;* Johnny darter, *Boleosoma nigrum;* fan-tailed darter, *Etheostoma flabellare;* log perch, *Percina caprodes;* and bluegill, *Lepomis pallidus;* M. M. E., 100 p. p. m. in hard water fatal to goldfish, *Carassius auratus*, in 80 hours; 10 p. p. m. in hard water, without apparent injury to goldfish, in 96 hours' exposure.

Lead sulphate, $PbSO_4$

Carpenter (1925), 25 p. p. m. in distilled water killed goldfish, *Carassius auratus*, in 4 days, and minnows, *Leuciscus phoxinus*, in 2–3 hours.

Lithium chloride, LiCl

Found in some mineral springs. Powers (1917), 3,750 p. p. m. in distilled water killed goldfish in 22–27 hours.

Magnesium chloride, $MgCl_2$

A component of various waste waters from oil wells, and some industrial wastes. Garrey (1916), 476 p. p. m. in distilled water killed straw-colored minnow, *Notropis blennius*, in 4–6 days; Powers (1917), 6,757 p. p. m. in distilled water killed goldfish in from 78 hours to 21 days; Wiebe, Burr, and Faubion (1934), 5,000 p. p. m. in distilled water killed golden shiner, *Notemigonus crysoleucas*, in 96 hours.

Magnesium nitrate, $Mg(NO_3)_2$

Powers (1917), 12,500 p. p. m. killed goldfish in 14–16 hours.

Mercuric chloride, $HgCl_2$. Corrosive sublimate

Weigelt, Saare, and Schwab (1885), 500 p. p. m. in tap water killed large trout in 54 minutes; Carpenter (1927), 13.6 p. p. m. in distilled water killed minnow, *Leuciscus phoxinus*, in 42 minutes.

Methyl alcohol, CH_3OH

A solvent in many industrial operations. Weigelt, Saare, and Schwab (1885), a 2-hour exposure to 10,000 p. p. m. in tap water was tolerated by trout without apparent injury; Powers (1917), 250 p. p. m. in distilled water killed goldfish in 11–15 hours.

Methyl mercaptan, CH_3SH

A highly toxic constituent of sulphite paper pulp waste. Cole (1935a), 1 p. p. m. in lake water killed white bass, *Roccus chrysops*, in 1 hour, 45 minutes, or less; yellow perch (*Perca flavescens*), largemouth black bass (*Micropterus salmoides*), smallmouth black bass (*Micropterus dolomieu*), and bluegill (*Lepomis pallidus*), in 6–8 hours; and rock bass (*Ambloplites rupestris*), in 11 hours.

Muriatic acid

See hydrochloric acid.

Naphthenic acids and naphthene derivatives

These compounds are listed among the solutes which may occur in refinery wastes (American Petroleum Institute, 1935), and Kupzis (1902) believes the naphthenic compounds to be among the most toxic substances to fish, passing from crude oil into water. Kupzis (l. c.), using fractions containing the naphthenic acids extracted from various crude oils, gives the following lethality findings for this naphthenic acid fraction (which of course must not be considered as representing a single pure compound in this case). In tap water (hard) 3 p. p. m. killed percoid fishes, *Acerina cernua*, in 6–12 hours; 5 p. p. m. killed pickerel, *Esox lucius*, 36–48 hours; the minnow, *Abramis brama*, 72 hours; the red-eyed minnow, *Scardinius erythrophthalmus*, 26 hours; and the perch, *Perca fluviatilis*, in 16–23 hours; 20 p. p. m. killed carp, *Cyprinus carpio*, in 26–36 hours, and goldfish, *Carassius auratus*, in 8–16 hours. Several other European species tested are not listed here.

Naphthalene, $C_{10}H_8$

Aniline and coal-tar industries. Demyanenko (1931), 10 p. p. m. lethal to fish.

Nickelous chloride, $NiCl_2$

Electroplating wastes; various industrial wastes. Thomas (1924), 8.1 p. p. m. in tap water killed the top-minnow, *Fundulus heteroclitus*, in a few hours. This species, which can also live in salt water, tolerated 259.2 p. p. m. when in salt water without apparent injury during a 2-week exposure. M. M. E., 100 p. p. m. in very soft water killed goldfish, *Carassius auratus*, in 19–50 hours, and 10 p. p. m. in very soft water killed in 200–210 hours.

Nitric acid, HNO_3

Occurs in many wastes from chemical industries. It is easily broken into water and oxides of nitrogen. Weigelt, Saare, and Schwab (1885), trout after 34 minutes in 1,000 p. p. m. in tap water were helpless; Carpenter (1927), sufficient quantities to bring the water to pH 4.4 killed the minnow, *Leuciscus phoxinus*, in 7 hours, while quantity sufficient to bring the water to pH 5.2 was without apparent effect on this species of fish; M. M. E., 750 p. p. m. in hard water (see section on acids) killed goldfish, *Carassius auratus*, in 30 minutes to 1 hour, and 200 p. p. m. in hard water were without apparent effect on goldfish in exposures of over 100 hours.

Octyl alcohols, general formula $C_8H_{17}OH$

Macht and Leach (1930), 66.7 p. p. m. of primary octynol produce respiratory and neuromuscular paralysis in goldfish, *Carassius auratus*, in 15 minutes. The specific toxicity for fish of the individual octyl alcohols varied in the series of 23 which these observers studied, secondary octylic heptanol being among the least toxic, 200 p. p. m. producing paralysis in goldfish in 4 hours.

Oxalic acid, $H_2C_2O_4$

Bleaching, dying, and various chemical industries. M. M. E., 1,000 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 25–30 minutes; 200 p. p. m. in hard water produced no apparent injury during exposures of 100 hours. This acid is readily precipitated out of waters by calcium salts.

Oxygen, O_2, and **Ozone,** O_3

Although the usual problem in stream pollution is to secure enough oxygen, some of the proposed treatments for organic wastes involve high oxygenation or ozonation. It seems worth while therefore to list here some tests on the effects of high oxygen and nascent oxygen. Wiebe (1933) found changes from 5.7 p. p. m. to 40.3 p. p. m. dissolved oxygen were tolerated by largemouth black bass, *Micropterus salmoides*, smallmouth black bass, *Micropterus dolomieu*, white crappie, *Pomoxis sparoides*, bluegill, *Lepomis incisor*, orange-spotted sunfish, *Lepomis humilis*, golden shiner, *Notemigonus crysoleucas*, and goldfish, *Carassius auratus*, for at least 24 hours. Hubbs (1930) states that minnows may be killed by 0.033 p. p. m. of nascent oxygen in the water and that fishes are irritated by ozone in quantities less than 0.01 p. p. m.

Para-dichlorobenzene, $C_6H_4Cl_2$

Demyanenko (1931), 50 p. p. m. lethal to fishes.

Phenol, C_6H_5OH. Carbolic acid

An important constituent of gas wastes, many chemical effluents and even some sewage products. Phenol may also come into streams from sheep dips and other establishments where livestock are disinfected. Shelford (1917), 70–75 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; Powers (1917), 51 p. p. m. in distilled water killed goldfish in 1 hour 30 minutes to 2 hours 20 minutes; Demyanenko (1931), 16.6–20 p. p. m. lethal to fishes, some can live in 15 p. p. m., but their flesh acquires phenolic smell; Alexander, Southgate, and Bassindale (1935), 0.4–0.6 p. p. m. caused trout to overturn in 8 hours 20 minutes; Adams (1927), 10 p. p. m. in Nile River water killed cladocerans, *Daphina sp.*, and copepods, *Cyclops sp.*; M. M. E., 10 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 72 hours or less, 1 p. p. m. apparently not injurious to goldfish in exposures of 100 hours; 8 p. p. m. in soft water killed cladocerans, *Daphnia magna.*

Potassium bicarbonate, $KHCO_3$

Penny and Adams (1863), 2,000 p. p. m. killed minnows and goldfish.

Potassium chloride, KCl

Garrey (1916), 373 p. p. m. in distilled water killed straw-colored minnows, *Notropis blennius*, in 12–29 hours; Powers (1917), 74.6 p. p. m. in distilled water lethal for goldfish in 4 hours 40 minutes to 15 hours.

Potassium cyanide, KCN

Ore milling operations; chemical works; electroplating; and in effluents from coke ovens. (See Tupholme, 1933.) Powers (1917), 0.78 p. p. m. in distilled water killed goldfish in 43–118 hours; Calatroni (1928), 15 p. p. m. in tap water immobilized tadpoles with fatal results; McArthur and Baillie (1929), 65 p. p. m. killed cladocerans, *Daphnia magna;* Southgate, Pentelow, and Bassindale (1933), 0.27 p. p. m. KCN (equal to 0.11 p. p. m. CN) at temperature of 7°–9° C. caused trout to float helpless on back in about 2 hours if the dissolved oxygen in the water were *circa* 11 p. p. m., but in 10 minutes if the water carried only 3 p. p. m. dissolved oxygen; Alexander, Southgate, and Bassindale (1935) find 0.5 p. p. m. KCN (0.2 p. p. m. CN) will cause trout to overturn and become helpless in 15 minutes; M. M. E., 1 p. p. m. in river water caused glochidia of fresh-water mussels to close, rendering them incapable of attachment on fishes, and 0.1 –0.3 p. p. m., in hard water killed goldfish in 3–4 days.

Potassium dichromate, $K_2Cr_2O_7$

Ore floatation processes; chemical industries. M. M. E., 100 p. p. m. in hard water apparently not harmful to goldfish in exposures of 108 hours, 500 p. p. m. lethal to goldfish in 3 days.

Potassium ferricyanide, $K_3Fe(CN)_6$. Red prussiate of potash

Penny and Adams (1863), 2,000 p. p. m. not lethal to minnows and goldfish.

Potassium ferrocyanide, $K_4Fe(CN)_6$. Yellow prussiate of potash

Penny and Adams (1863), 2,000 p. p. m. not lethal to minnows and goldfish; Weigelt, Saare, and Schwab (1885), trout survived 1 hour exposure to 8,723 p. p. m. in tap water without symptoms.

Potassium hydroxide, KOH. Caustic potash

Soap works; from some types of ashes. Wells (1915), 56 p. p. m. in distilled water killed bluegills, *Lepomis pallidus*, in 4 hours 25 minutes, 28 p. p. m. apparently not harmful to bluegills in 10-day exposures.

Potassium nitrate, KNO_3. Saltpeter

Wells (1915b), 1,203 p. p. m. in tap water killed bluegills, *Lepomis pallidus*, in 15 days.

Potassium permanganate, $KMnO_4$

This powerful oxidizing agent is frequently used to disinfect hatchery tanks and can be applied with caution to fish themselves. Adams (1927), 5 p. p. m. in Nile River water killed cladocerans, *Daphnia sp.*, and copepods, *Cyclops sp.;* M. M. E., 10 p. p. m. in hard water killed goldfish, *Carassius auratus*, in 12–18 hours.

Potassium sulphate, K_2SO_4

Wells (1915b), 869 p. p. m. in tap water killed bluegills, *Lepomis pallidus*, in 4 days.

Potassium xanthate or potassium ethyldithiocarbonate $C_2H_5{\cdot}O{\cdot}CS{\cdot}SK$

Used in ore floatation processes and on occasion to free soil from insect pests, and it is highly toxic to fishes. M. M. E., 10 p. p. m. in hard water killed goldfish in 48–96 hours, 0.1 p. p. m. in 4–5 days.

Pyrethrum

The volatile oil in this plant product is quite toxic to fishes. Bandt (1933) 5–10 p. p. m. toxic for carp.

Pyridine, C_5H_5N

In gas wastes, also in waters draining recently burned-over areas where combustion near ground has been incomplete. Shelford (1917), 1,477–1,576 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour; Powers (1917), 1,869 p. p. m. in distilled water killed goldfish in 10–30 hours; Demyanenko (1931) states 1,000 p. p. m. to have a feeble effect on fishes.

Quinoline, $C_6H_4N:CHCH:CH$

Gas wastes. Shelford (1917), 52–56 p. p. m. and 65 p. p. m. isoquinoline in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Saponin, a glucoside

Found in various plants. Ebeling (1928) points out that wastes from potato starch factories carry sufficient saponin to be dangerous to fishes, and that consequently these wastes should be highly diluted. M. M. E., 10 p. p. m. of saponin in hard water produced marked distress in goldfish in 5 hours, 100 p. p. m. rapidly fatal, killing goldfish in 7–24 hours.

Sodium arsenite, commercial preparation usually a mixture of several sodium and arsenic compounds

Some dye and tanning processes; removal of aquatic vegetation. Since arsenic trioxide is usually dissolved in sodium hydroxide, and since each lot of commercial sodium arsenite must be assayed for its arsenic content, arsenic, arsenic trioxide, and sodium arsenite are considered under this single heading. Wiebe (1930), 7 p. p. m. of As_2O_3 in Mississippi River water was not detrimental to largemouth black bass, *Micropterus salmoides*, smallmouth black bass, *Micropterus dolomieu*, white crappie, *Pomoxis sparoides*, bluegill, *Lepomis pallidus*, golden shiner, *Notemigonus crysoleucas*, bullhead, *Amieurus nebulosus*, and goldfish, *Carassius auratus*, in 148-hour exposures as shown by 3 months subsequent observation. Surber and Meehan (1931), 2 p. p. m. As_2O_3 in Mississippi River water survived by the important fish food organisms, but 2.5–4 p. p. m. killed chironomid larvae, mayfly nymphs, the fresh-water shrimp, *Hyalella*, and odonata nymphs; the isopod *Asellus* sp., survived 10–21 p. p. m.; M. M. E., 1.3 p. p. m. As_2O_3 in distilled water killed *Daphna magna*, 8 p. p. m. hard water had no appreciable effect on the fresh-water mussel, *Amblema peruviana*, but 16 p. p. m. in hard water was fatal to *Amblema peruviana* in 3–16 days.

Sodium carbonate, Na_2CO_3

Found in many chemical effluents. Clark and Adams (1913), 250–300 p. p. m. killed shiners, carp, and large suckers in tap water in a few hours; Wells (1915b), 530 p. p. m. in tap water killed bluegills, *Lepomis pallidus*, in 3 days.

Sodium chlorate, $NaClO_3$

In some effluents from chlorine and bromine works. Not markedly toxic. M. M. E., 1,000 p. p. m. in hard water produced no apparent injuries in goldfish during exposures of 5 days duration.

Sodium chloride, NaCl. Common salt

Brine works; waste waters from oil wells; effluents from some dairy industries. Garrey (1916), 2,500 p. p. m. in distilled water killed straw-colored minnow, *Notropis blennius*, in 9–24 days (solution, $\Delta = 0.105$); Powers (1917), 11,765 p. p. m. in distilled water killed goldfish in 17 hours; Wiebe, Burr, and Faubion (1934), 5,000 p. p. m. in distilled water killed golden shiners, *Notemigonus crysoleucas*, in 148 hours and largemouth black bass in 200–250 hours; M. M. E., 1 p. p. m. distilled water killed cladoceran, *Daphnia magna*, in 3 hours, 5,000 p. p. m. in Mississippi River water apparently not harmful to goldfish in 25-day exposure, but 10,000 p. p. m. in Mississippi River water killed goldfish in 4–10 days.

Sodium fluoride, NaF

In certain brewery and distillery wastes; also found in some soils. M. M. E., 1,000 p. p. m. in hard water killed goldfish in 60–102 hours.

Sodium hydroxide, NaOH. Caustic soda

Soap factories; wood ashes. Clark and Adams (1913), 96 p. p. m. in tap water killed shiners, carp, and suckers in 2–10 minutes; Standing Committee on River Pollution (1924), 50 p. p. m. in distilled water was not fatal to perch and roach in a 2-hour exposure.

Sodium nitrate, $NaNO_3$. Chili saltpeter

Fertilizers. Powers (1917), 1,282 p. p. m. in distilled water killed goldfish in 14 hours; M. M. E., 4,000 p. p. m. in hard water killed goldfish in 80 hours but 3,000 p. p. m. apparently did not injure goldfish in 100-hour exposures.

Sodium selenite, Na_2SeO_3

Component of certain soils; pottery works. M. M. E., 100 p. p. m. in hard water killed goldfish in 8–20 hours, 10 p. p. m. in hard water killed in 98–144 hours.

Sodium sulphate, Na_2SO_4. Glaubers salt

Harukawa (1922), 500 p. p. m. in tap water not injurious to goldfish in 24 hours.

Sodium sulphide Na_2S

In some beet-sugar factory effluents and in some paper-pulp wastes. Weigelt, Saare, and Schwab (1885), a 1-hour exposure to 1,150 p. p. m. in tap water kill tench, *Tinca vulgaris*, 6 days later.

Sodium sulphite, Na_2SO_3

Component of various paper pulp wastes and some beet sugar factory wastes. M. M. E., 100 p. p. m. in hard water killed goldfish in 96 hours.

Stannous chloride, $SnCl_2$

M. M. E., 1,000 p. p. m. in hard water killed goldfish in 4–5 hours.

Strontium chloride, $SrCl_2$

Powers (1917), 15,384 p. p. m. in distilled water killed goldfish in 17–31 hours.

Strontium nitrate, $Sr(NO_3)_2$

Powers (1917), 9,615 p. p. m. in distilled water killed goldfish in 32–146 hours.

Sugar, cane, $C_{12}H_{22}O_{11}$. Sucrose

Garrey (1916), 34–218 p. p. m. in distilled water ($\Delta = 0.198$) killed straw-colored minnow, *Notropis blennius*, in 24–48 hours.

Sulphur, colloidal, S_2

Lime-sulphur mixtures and dips; following decomposition of hydrogen sulphide in water. Harukawa (1922), 1,600 p. p. m. in tap water fatal to goldfish in 3 hours 30 minutes to 5 hours 15 minutes, and 2,100 p. p. m. in 48–71 minutes.

Sulphur dioxide, SO_2

Bleaching works; various chemical industries. Weigelt, Sarre, and Schwab (1885), 10 p. p. m. in tap water caused trout to float helpless in 10 minutes; Shelford (1917), 16–19 p. p.m. in tapwater killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Sulphuric acid, H_2SO_4. Oil of vitriol

Pickle liquor from sheet metal and wire factories; waters from coal and iron mines; various chemical wastes. Wells (1915), 7.36 p. p. m., in distilled water killed bluegills, *Lepomis pallidus*, in 60 hours, but 3.68 p. p. m. apparently harmless over period of 1 month. M. M. E., 59 p. p. m. in very soft water killed goldfish, *Carassius auratus*, in 1 hour to 1 hour 15 minutes, 138 p. p. m. in hard water in 4 hours, 100 p. p. m. in hard water apparently not injurious to goldfish in 100-hour exposures; 29 p. p. m. in soft water killed cladocerans, *Daphnia magna*, in 24–72 hours.

Tannic acid, $C_{14}H_{10}O_9$

Tannery wastes; leachings from some barks and sawmill wastes. M. M. E., 100 p. p. m. in hard water killed goldfish in 9–20 hours, but 10 p. p. m. apparently not injurious in 100-hour exposures.

Tartaric acid, $COOH(CHOH)_2COOH$

Dye wastes; mordant liquors; leather works; various chemical effluents; some winery wastes. M. M. E., 1,000 p. p. m. in hard water killed goldfish in 3–4 hours, 200 p. p. m. in hard water not injurious apparently in exposures of 100 hours, 100 p. p. m. in very soft water killed goldfish in 3 hours to 3 hours 30 minutes.

Thiophene, C_4H_4S

Gas wastes. Shelford (1917), 27 p. p. m. in tap water killed orange-spotted sunfish, *Lepomis humilis*, in 1 hour.

Tin, Sn_2

See stannous chloride.

Trade wastes

At end of this section.

Zinc nitrate, $Zn(NO_3)_2$

Dilling and Healey (1926) found that tadpoles survived 3-month exposure to 1.89 p. p. m. but failed to develop limb buds, that 5.7 p. p. m. killed most tadpoles and that 94.7 p. p. m. killed tadpoles quickly.

Zinc sulphate, $ZnSO_4$. White vitriol

Wastes from electrolytic refineries of zinc; incrustations developing from exposed zinc sulphide ores; mine tailings; several chemical effluents. Carpenter (1927), 404 p. p. m. in distilled water killed minnows, *Leuciscus phoxinus*, in 3 hours 20 minutes; M. M. E., 1,000 p. p. m. in hard water killed goldfish in 1–4 hours, 100 p. p. m. fatal to many goldfish in 5 days.

Trade wastes

Lethal limits which will be inclusive cannot be defined for sewage and trade wastes because sewage and even such specific effluents as Steffens house waste (from certain types of beet-sugar refineries) are not constant either in composition or concentration. The effects of colloidal sulphur or ferric chloride on fishes and other aquatic animals can be determined under a variety of conditions which can be duplicated, or the toxicity of any particular sample of Steffens waste, or pickle liquor from tin-plate mills, or deazoting fluid from dye works can also be ascertained with accuracy, but to attempt to define the minimal lethal concentration or the maximal dilution for all pickle liquors from samples obtained at any plant or series of plants is both unsound scientifically and unfair to the industry. Already much confusion, often to the detriment of fisheries interests, has resulted from the misuse in this connection of various statements in the literature concerning the tolerance of fishes for a given number of p. p. m. of a particular waste, when these observations were intended to apply to a specific case.

In practical tests the writer has found that wastes taken directly from their sources in the plant, i. e., not from sewers or flumes, differ widely in toxicity to aquatic life, at different plants using the same general process. Several factors contributed to these differences. For example, the process of tanning hides with chromium compounds is basically the same in all establishments using this process, but as is well known the plant chemists in the interests of economy and efficiency frequently make minor or at times even drastic changes in the process, with, of course, resultant changes in the effluents. Variations in raw material, emergencies in plant operation, and many other conditions also call for changes in procedure which result in changes in effluent composition and concentration. There is, therefore, no standard hide vat liquor waste or pickle liquor or winery effluent, even when taken at the source, which may be used with either fairness or accuracy in the estimation of the probable hazards of another plant engaged in the same work.

Besides, as the waste moves away from its source through conduits and flumes, these differences become greater owing to the addition of cooling water, wash waters, and other effluents from different parts of the plant; so that the final mixture as poured into the stream varies not only in concentration, but also in composition as the result of the sequence in which the different effluents were mixed.

However, from the studies of various wastes before mixing, the general changes which these effluents will produce in the stream complex and the types of their actions on aquatic life can be ascertained with considerable accuracy. In table 14 the usual effects of 29 common industrial wastes and of municipal sewage on the aquatic environment and the critical features of these actions as shown by a large series of field studies have been pointed out.

TABLE 14.—*Usual fisheries hazards of 30 common types of municipal and industrial effluents* [1]

Types of wastes	Changes in water affecting fishes						Bottom pollution blanket	Specific toxic action on fishes
	Decrease in dissolved oxygen	Hydrogen-ion concentration		Increase in specific conductance	Increase in turbidity	Increase in ammonia		
		Increase in acidity	Increase in alkalinity					
MINERAL WASTES, LITTLE BACTERIAL ACTION								
1. Erosion silt	None	None	None	None	Critical	None	Critical	None.
2. Limestone sawmills	do	do	Possible	Moderate	do	do	do	Do.
3. Asbestos works	do	do	do	do	do	do	do	Possible.
4. Mine flotation	Possible	Possible	do	do	do	do	do	Possible to critical.
5. Coal- and iron-mine drains	do	Critical	None	do	None	do	Possible	Possible.
6. Crude oil	do	None	do	None	do	do	Possible to critical	Possible to critical.
7. Salt water from oil wells	None	do	Possible	Critical	do	do	None	Do.
ORGANIC, BACTERIAL ACTION								
8. Municipal sewage	Critical	Possible	do	Possible	Possible	Critical	Possible to critical	Do.
9. Dairy industries	do	Critical	None	Moderate	Moderate	Moderate	do	Possible.
10. Packing plants	do	Moderate	do	do	do	Critical	Critical	Do.
11. Canning factories	do	Critical	Possible	do	do	do	Possible to critical	Do.
12. Breweries and distilleries	do	None to moderate.	None to moderate	do	Possible	Possible	do	Do.
13. Beet sugar, pulp wastes	do	Critical	None	do	do	do	do	Possible to critcial.
14. Paper pulp	Possible to critical.	Possible	Possible	Possible	do	do	Critical	Possible.
15. Sawdust	do	do	do	do	do	do	do	Do.
CHEMICAL PROCESSES								
16. Coal-gas wastes	Possible	do	do	Moderate	None	Critical	do	Critical.
17. Spent lubricants	do	do	None	Possible	do	None	do	Possible to critical.
18. Metal refineries	None	do	Possible	do	Possible	Possible	Possible to critical	Critical.
19. Laundries and wool washings	Moderate	None	Moderate to critical	Moderate	Moderate	Moderate to critical.	Possible	Possible.
20. Steffens house waste	do	do	Critical	Critical	do	None	do	Critical.
21. Sulphite pulp	Moderate to critical.	Possible	Moderate to critical	Moderate	do	Possible	Possible to critical	Do.
22. Strawboard waste	do	None	Critical	do	do	do	do	Do.
23. Chemical works (a)	None	do	do	do	Possible	do	None	Do.
24. Chemical works (b)	Possible	Critical	None	do	None	None	do	Do.
25. Tanneries	Moderate	Possible to critical.	Possible to critical	do	Possible	Possible to critical.	Critical	Do.
26. Dye works	Possible	None to moderate.	None to moderate	do	None	None	Possible	Do.
27. Bittern liquors	None	Critical	None	Critical	do	do	None	Possible to critical.
28. Tin-plate and wire mills	None to possible.	do	do	Moderate	None to possible.	do	Possible to critical	Do.
29. Starch factories	Possible to critical.	do	do	do	Possible	Possible	do	Do.
30. Cloth sizing	do	Possible to critical.	do	Possible	Moderate	do	do	Possible.

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[1] In this table increases in both acidity and alkalinity are noted in some cases, due to the facts that two or more kinds of effluents are mixed, with one predominating at times and to changes which take place in the stream after the effluent is added.

From this table the general effects of a given effluent or comparable waste on the aquatic complex can be predicted. By field tests at the site of pollution covering the critical factors as indicated for the particular effluent (dissolved oxygen, pH, conductivity, carbonates, and other determinations for the polluted stream as the case may be), the degree of pollution can be estimated when these field data are compared with the standards given in the section on stream pollutants and aquatic environment. When specific toxic action is indicated (last section, table 14) the limits for the expected detrimental substances can be found in the section on lethal limits.

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