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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

FISH AND WILDLIFE SERVICE
Albert M. Day, Director

Special Scientific Report No. 2

WATER PURITY STANDARDS FOR FRESH-WATER FISHES

by

M. M. Ellis

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Explanatory Note

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INTRODUCTION

The various 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 fish and other aquatic organisms, and if 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 determination of the quantities 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, nonaquatic animal, man.

Water standards for fishes and other aquatic organisms 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 fish may thrive in water which would be unsafe for human consumption due to the presence of particular bacteria such as typhoid, or certain compounds harmful to man, as the western "alkalis". The statement which is so often quoted, that the water leaving a particular manufacturing establishment or flowing in a given stream, is "good enough to drink", and therefore by inference is favorable for fish life, is without a scientific basis, and must be refuted.

The definition of waters as suitable or unsuitable 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 constitute evidence that these waters are either satisfactory or safe for fishes.

The problem is so complex that no one index can be used for the measurement of stream pollution. Various proposals have been made that a given dissolved oxygen level, a particular ratio between dissolved oxygen and the biochemical oxygen demand, or a certain survival time for minnows in the suspected water, be taken as satisfactory criteria, particularly for legal purposes, of water purity for fish and aquatic organisms. Such standards alone become purely arbitrary and have little real value since no single standard gives a measure of the deleterious effects of all stream pollutions. The use, therefore, of a single standard has been very justly criticized by most writers on stream pollution.

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, (a) 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 (b) 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 content of acid ions, iron and sulphates, all of which occur in small quantities in most streams, to levels toxic for aquatic forms, with disastrous results.

The limiting values for the various substances in stream waters, with reference to the effects on aquatic life, as presented here have been obtained through the correlation of data of three sorts, (a) the quantities of these substances found in natural waters where fish were successfully maintaining themselves, (b) the physiological responses of fishes and other aquatic animals to variations in the concentrations of these substances, and (c) 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 (Missouri) Field Unit of the U. S. Bureau of Fisheries during the past 4 years.

In 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 so that some fishes may live under less favorable conditions than those here designated since both the minimum and maximum limits immediately compatible with life have been avoided, for those limits cannot be regarded as desirable or physiologically reasonable in determining a suitable environment for fish any more than for man. An effort has been made to present usable standards of water purity 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 such as carp and gar, will thrive.

It must also be pointed out that these standards of purity must be maintained throughout the periods of low water, maximum temperature and maximum liability to pollution, since a deviation in the amount of any of several substances, 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 re-establish the former fish fauna and normal balance of aquatic species. Finally it must be remembered that even though the water conditions be favorable to fish life the productiveness of any stream will also depend upon the stream configuration, rate of flow, character of bottom, lateral areas, and various other factors.

General Water Conditions Limiting Aquatic Life in Inland Streams.

A large series of field studies has shown that the natural water conditions favorable or unfavorable to fish and other aquatic life can be ascertained 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) total ammonia, and the (5) suspensoids, since these determinations not only yield specific data concerning particular conditions, but also concerning various complexes which vary in even unpolluted streams and which are also specifically affected by many forms of pollution.

From determinations made at many stations where good mixed fish faunas were present it was found that the values from the above determinations for favorable waters were within rather definite limits, and that deviations from these limits in our inland streams were almost always indicative of conditions unfavorable to aquatic life. These values alone, however, will not suffice for the complete definition of water favorable for aquatic life. The standards of purity from these determinations cover the more basic conditions which must be maintained in any stream and on which conditions of specific pollution are superimposed.

(1) Dissolved oxygen: From over 5,000 determinations of dissolved oxygen in waters from various streams of the Mississippi, Missouri, Tennessee, and Ohio River Systems and other streams flowing into the Gulf of Mexico, made at all hours of the night and day by this field unit, it was found that the mid-summer dissolved oxygen values during periods when streams were low and water temperatures high, were consistently above 5 p.p.m. (parts per million) in the cleaner portions of the large rivers at stations where both game fish and rough fish were taken, and above 5 p.p.m. in the relatively unpolluted tributaries. Many of these oxygen determinations were above 7 p.p.m. At the same time few if any fish (for the most part only carp and gar) were found where the dissolved oxygen was below 4 p.p.m. A dissolved oxygen level of 5 p.p.m. or above was clearly indicated from the field studies as necessary to support a mixed fauna of warm-water fishes and the other aquatic animals upon which fish depend, during the season when the oxygen carrying power of the water was low and when, because of the metabolic activity of the fishes due to the high water temperatures (20° to 30° Centigrade), the oxygen consumption of the individual fish was high. Many observers have pointed out that the metabolism and consequently the oxygen consumed by fish 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); brown trout

requiring from 90 - 200 c.c. of oxygen per kilo of body weight per hour, at temperatures between 4° and 20° C.; goldfish from 16 to 9 c.c.; and eels from 9 to 60 c.c., (Gardiner, King, and Powers, 1922). As a very definite breaking point between a good fish fauna and few or no fish was found in the field studies between 5 p.p.m. and 4 p.p.m. of dissolved oxygen during the summer months, these values were compared with the lethal dissolved oxygen level for various fresh-water fishes. Kupzis (1901) reported that the cyprinid Leuciscus erythrophthalmus, (the European roach), can live for some time in water containing 1 p.p.m. of dissolved oxygen but that fish of this species died from asphyxia when the oxygen was reduced to 0.6 or 0.7 p.p.m. Plehn (1924) stated that trout live best in water containing 10 to 11.4 p.p.m. of dissolved oxygen, and if the water be warm these fish will show some discomfort when the oxygen is reduced to 7 p.p.m. This author also stated that carp live well in water containing 7 p.p.m. of dissolved oxygen, but show respiratory difficulties when the dissolved oxygen is reduced to 4.3 p.p.m. or lower, although if the water be cold carp can live for a short time in water containing only 0.7 p.p.m. dissolved oxygen. In order of their oxygen requirements Plehn (l.c.) listed first the salmonoids and coregonids, followed by the pike, carp, tench, goldfish, with the eel the lowest of all. Gardiner and King (1922) gave the asphyxial point for trout as from 1.1 p.p.m. dissolved oxygen at 6.5°C. to 3.4 p.p.m. at 25°C., and for goldfish as 0.56 p.p.m. at 11°C., and 0.60 p.p.m. at 27°C. Thompson (1925) stated that carp and buffalo have been found living in water carrying as low as 2.2 p.p.m. of 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 when the water containing 9 p.p.m. or more of dissolved oxygen. His observations made at Peoria Narrows in summer of 1923 showed that fishes died over night in water having less than 2 p.p.m. of dissolved oxygen. 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 and cardiovascular compensations begin are quite different, and that the latter, that is, the oxygen level at which respiratory and circulatory compensations are initiated marks the lower limit of the favorable respiratory environment, although this oxygen level is much higher than the lethal oxygen level for the same species. It has been shown (Ellis, 1919) that although man lives in an atmosphere containing 21 percent oxygen and that the collapse point for most human beings is near 6 percent oxygen, that respiratory compensation begins at about 18 percent oxygen. Applying this same principle to fishes the writer has found that goldfish, perch, catfish and other species of fresh-water fishes when maintained in water of constant flow, composition and temperature (20 to 25°C.) show respiratory compensations (in both rate and volume) when the dissolved oxygen is reduced to slightly below 5 p.p.m. This 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 fauna between waters carrying 4 p.p.m. dissolved oxygen and those carrying 5 p.p.m. or better, as reported from our field studies.

In view of the data from all sources, and particularly from the field and laboratory studies presented here, 5 p.p.m. dissolved oxygen seems the lowest value which may reasonably be expected to maintain a varied fish fauna of warm-water fishes in our inland streams if the water temperature be 20°C. or above. Cold-water fishes require even a higher dissolved oxygen level as will be shown in discussion of the oxygen requirements of trout to be published elsewhere.

The dissolved-oxygen content of an unpolluted stream 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 the 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 of the stream. Effluents polluting streams alter this balance chiefly through increasing the oxygen demand. Pollutants creating oxygen demand are of two types, those which add quantities of organic matter of a putresible nature, among which may be mentioned domestic sewage, packing plant wastes, beet sugar wastes, and hide vat liquor from tanners; and those which add various reducing chemicals such as the sulphite wastes from paper mills, wastes from mines, carrying sulphides of heavy metals and certain spent dyes from leather works. Many of these effluents are also harmful in addition to their oxygen demands because of specific toxic effects. The determination of the biochemical oxygen demand of such substances therefore does not give a true evaluation of the pollution hazards. Many species of warm-water fishes, however, will live in water having a high oxygen demand due to domestic sewage or industrial wastes rich in organic material but without specifically toxic substances, if the oxygen level be maintained above 5 p.p.m. and the aeration be sufficient to blow off the excess of other gases like carbon dioxide, methane, and sulphur derivatives. In fact, the tan vat liquor from a tannery on the upper Mississippi River, in spite of a high oxygen demand was not only tolerated readily, when properly aerated and unmixed with the chemical wastes from the factory, by various warm-water fishes but materially increased the production of plankton when added to river water. The biochemical oxygen demands of such effluents must be taken into account, however, if these substances be poured into streams, in order to compute the dilution required to prevent this oxygen demand from lowering the dissolved oxygen below 5 p.p.m. at any time.

The oxygen balance of the stream also may 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, however, as to present this difficulty. 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.

(2) pH Limits: The pH (hydrogen-ion concentration) of inland streams, excepting badly polluted portions, as seen in a review of nearly 10,000 readings made during the past four years, lies in general between the values of pH 7.4 and pH 8.5 with the extreme range (in our data) of pH 6.6 and pH 9.0 in streams for which no specific factor causing the deviation of hydrogen-ion concentration was readily observable. Swamp waters, bog streams, and particularly swamp lakes, frequently show an acidity from pH 6.0 to pH 4.0, yet at the same time support a good, mixed, fish fauna. 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, although in such waters small poeciliids and cyprinids were the dominant fishes. These field observations agree, in general, with the statement made by Shelford (1929) that the range of hydrogen-ion concentration from pH 8.5 to pH 6.5 may be expected in most uncontaminated fresh-water streams and lakes; and with the observations of Powers (1921 and 1929); and Juday, Fred and Wilson (1924).

Experimental tests have demonstrated that many species of fresh-water fish have a great tolerance for variations in hydrogen-ion concentration over a wide range. Creaser (1930) showed brook trout to have a voluntary toleration to concentrations from pH 4.6 to pH 9.6. Brown and Jewell (1926) found catfish and perch living in apparently good condition in a bog lake at pH 4.4 to pH 6.4 and in a glacial lake nearby at 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 (1931b) reported that goldfish survived 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 summarized the existing data by saying that aquatic organisms are able to withstand a wide range in pH. The writer has confirmed this statement with *Gammarus*, *Daphnia*, unionids and *Planaria* in connection with pollution tests, as well as with goldfish, perch, and catfish. It might seem, therefore, that the pH value of stream water would be of little consequence in pollution studies and in determining standards of purity for water. However, the pH of natural water is determined by substances in solution, particularly carbonates and carbon dioxide, and various salts and other materials which constitute a fair buffer system, so that water more acid than pH 7.0 or more alkaline than pH 8.5 rarely is found in our inland streams, unless there be some unusual factor in the complex. Pond waters, bog waters, and lake waters 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 a hydrogen-ion concentration outside of the limits pH 7.0 and pH 8.5 until it could be definitely shown that the deviation was due to natural causes rather than pollution through human agencies. Even rather badly polluted streams were usually within those limits and when sufficient material had been added to the waters to produce a hydrogen-ion concentration more acid than pH 7.0 or more alkaline than pH 8.5, the buffer salts and carbonate systems were definitely disturbed and conditions harmful to fishes usually were found. The determination of pH therefore is an important aid in the study of polluted waters in spite of the range of tolerance of fishes to pH changes in unpolluted waters, because excessive variation in the hydrogen-ion concentration is indicative of harmful changes in the complex of dissolved substances normally found in river waters.

Among the effluents which change the pH of stream waters and break down the buffer systems are the wastes from wire-nail mills, tin plate mills, and other sheet-metal works where acid washes are used; wastes from chemical works, particularly those manufacturing dye mordants; wastes from chrome tanning processes; from daily products concerns; and from battery factories. The effluent from unsealed coal mines is also a large source of acid pollution.

(3) Ionizable salts: 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 fauna at any given station but most aquatic species will tolerate changes of considerable magnitude in the relative amounts of these salts present, if the very small maximum which is normally present be not exceeded. For example, the fixed carbonates in the upper Tennessee River were found to vary from 0.4 c.c. to 30 c.c. per liter (computed as CO_2 by volume) without affecting the general composition of the aquatic fauna, and from 0.3 c.c. to 55.5 c.c. in Spider Creek, a tributary of the Wabash

River. As the specific quantities of most of the substances comprising this salt complex are not so important as the total quantity of soluble matter present, and as most of these substances are ionizable, measurements of the specific conductance of a large number of polluted and unpolluted waters were made. These determinations show that the specific conductance of these portions of inland streams and rivers which were supporting a good mixed fish fauna in general lay between 150 and 500 mho x 10^{-6} at 25°C. when carbon dioxide supplied the dominant acid. If chlorides or sulphates rose, either from introduction of salt waters or mineral acids and the specific conductance exceeded 1,000 mho x 10^{-6} at 25°C. conditions detrimental to fish, plankton, mollusca, and many insect larvae were generally found. Specific conductance therefore offers a ready method for detection of salt and acid pollutions, as produced by water from oil wells, by wastes from industries using salts or strong acids, and by heavy metal pollutants. This method was used very satisfactorily in determining the extent of down stream pollution from lead and zinc mines in the Coeur d'Alene district in Idaho (Ellis, 1940a). In some western streams and irrigation reservoirs alkaline water (Rio Grand River, near Ft. Hancock, Texas, water pH 7.8, conductance 4,917 mho x 10^{-6}) was found with a conductance above 1,000 mho x 10^{-6} but such waters were supporting a very limited fish fauna, primarily of poeciliids and small cyprinids (discussed more fully in another publication).

(4) Ammonia: 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 available 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 the 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 organisms, both plant and animal, dying in the stream and adjacent waters and such organic matter as may be brought into the stream by surface run-off water. In general in unpolluted waters the amount of ammonia and ammonium compounds (chiefly ammonium carbonate) is very small, averaging less than 0.1 p.p.m. The West Riding Rivers Board (1930) found the ammonia content of the River Wharfe, an unpolluted stream, to vary from 0.0 to 0.17 p.p.m.; Butcher, Pentelow and Woodley (1927) stated 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. O. Domogalla, Juday and Peterson (1925) reported the ammonia in Lake Mendota to vary between 0.0073 and 0.76 p.p.m. and unpolluted portions of the Wisconsin River above Rhinelander (Wisconsin State Board of Health, 1927) averaged 0.096 p.p.m. ammonia. In field studies by the Columbia unit similar

ammonia values from analysis of unpolluted waters were obtained, all below 0.9 p.p.m. Polluted streams present quite a different picture, for 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 total nitrogen. Wiebe (1931a) reported a maximum of 0.224 p.p.m. ammonia in the Mississippi River at Fairport, Iowa. Ellis (1940b) found from 0.36 to 1.16 p.p.m. ammonia in the Mississippi River at Davenport, Iowa, during low water in the month of July 1934, in portions of the river that were not badly polluted and which were supporting bass, catfish and other warm-water fishes; and between St. Louis and Cairo, Illinois, in badly polluted water of the Mississippi River from 0.24 to 3.80 p.p.m. of ammonia, during September 1935. In the highly polluted Blackstone River the Massachusetts Public Health Department (1913) reported 11.7 p.p.m. of ammonia.

The toxic effects of ammonium 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 found most frequently in inland waters, (Shelford, 1917; Belding, 1928; Steinmann, 1928; and McCay and Vars, 1931). Thirty parts per million 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 of ammonia, however, shows that some observers obtained toxic effects with much smaller quantities. Ellis and Chipman (1935) have repeated many of the earlier tests and extended the observations to <u>Daphnia</u> and <u>Gammarus</u> as well as fish, finding that pH is a large factor in regulating the toxicity of ammonia compounds for aquatic animals, the ammonium salts becoming more toxic in more alkaline media, which explains the relatively high toxicity to aquatic organisms of ammonium carbonate as compared with other ammonium compounds. From experiments involving over 11,000 cladocerans, 2,500 gammarids and 300 goldfish, curves were drawn showing that the toxicity of ammonium compounds increases 200 percent or more between pH 7.4 and pH 8.0. Perch were found more sensitive to ammonia than goldfish. The lower limit of toxicity (death in 10 days or less depending upon conditions of experiment) was found to be near 2.5 p.p.m. of ammonia. Some acclimatization was 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 a pH value between pH 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 waters 1.5 p.p.m. of ammonia seems the maximum value allowable in standards for favorable water conditions.

(5) <u>Suspensoids</u>: The suspensoids, i.e., particulate matter in suspension in inland fresh waters consists normally of erosion silt, organic detritus (as discussed under ammonia), and bacteria. Each component of this mixture may be greatly augmented by man's agencies and quantities of powdered rock, cellulose pulps, sawdust, semi-solid sewage, and other debris added.

In the average unpolluted stream the first three factors formerly were in balance over a considerable portion of the year and conditions favorable to aquatic life maintained, although now and then the floods and other unusual conditions killed off many aquatic animals 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 inland streams overwhelming on aquatic life in many places. The addition of erosion silt and other suspensoids (disregarding any specific toxic action which some suspensoid wastes have) affect fisheries directly by covering the bottom with a blanket of material which kills out the bottom fauna and therefore greatly reduces the available food, also by the mechanical effects in clogging gills and respiratory tubes of aquatic forms, and by abrasive injuries to the gills of many fishes and molluscs. Indirectly, but nonetheless effectively, erosion silt affects fisheries by screening out the light, by "laking down" organic waste 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.

From the field work on unpolluted streams in areas where surface erosion was not influenced by man and where water conditions were otherwise favorable it has been shown by Ellis (1935b) 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, in 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 mm. Until erosion is brought under control little can be done in demanding a minimum amount of silt and consequently no standard has been urged here, but data from over 5,000 determinations on inland streams show that the silt load of these streams ought to 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 forests and grasslands are to be restored. The detrimental nature of erosion silt as regards fisheries is discussed more fully by Ellis (1936).

However, particulate matter of a hardness greater than one (mineralogical standards), i.e., wastes other than sewage and organic matter introduced by man into streams, can be regulated. Particulate matter of a hardness greater than one if held in suspension by current action or otherwise will injure the gills and other delicate exposed structures of fishes, molluscs and insects if the particles be large enough. A large series of experiments at the Columbia laboratories have demonstrated that rock powders, blast-furnace slags, cinder particles, and even coal washings will cut and injure both fish gills and the mantle and gills of unionid molluscs if the particles be larger than those which will pass through a 1,000-mesh (to the inch) screen. In the actual tests the larger the particles and the greater their hardness and angularity the greater the possibility of injury to gill structures. These abrasive injuries not only cut the gills but provide entrance for disease organisms. Even erosion silt which will pass through a 1,000-mesh screen produces copious flows of mucous from bivalve molluscs and increases the secretion of slime by fish gills if the quantity in suspension be great enough. Besides, particles larger than those which will pass through a 1,000-mesh screen will soon settle out in the quieter portions of streams and blanket the stream floor with a layer of rock waste which will smother out the bottom fauna, just as erosion silt is doing in so many of our inland streams. Mines, stamp mills, asbestos factories, limestone sawmills, and blast furnaces are among the chief sources of this form of pollution.

From the standpoint of aquatic life therefore all particulate matter introduced by man of a hardness of one or greater should be so finely pulverized that it would pass through a 1,000-mesh screen, and should be so diluted that the resultant turbidity would not reduce the millionth intensity level to less than 5 meters. The quantity should be controlled so that the stream could carry the powder away without blanketing the bottom to the depth of more than one quarter of an inch.

Particulate matter of a hardness less than one presents slightly different problems. Semi-solid sewage, organic wastes from packing plants and canneries, the various pulp wastes from beet sugar mills and paper mills, and sawdust and wood refuse from the lumber mills are included here. Sewage, organic wastes and cannery wastes if diluted enough to meet the oxygen pH and ammonia standards as given, will rather rapidly disappear from the stream and may contribute nitrates, nitrites, and phosphates of value in the maintenance of the aquatic food chains. However, ample solution must be provided for before these wastes can be regarded as assets rather than liabilities.

Cellulose pulps of all sorts and sawdust should be excluded completely from streams. The decomposition of cellulose is slow under stream conditions and with this decomposition goes an oxygen demand and certain bacterial complications. The absolute exclusion of these pulps, disregarding their oxygen demands and toxic possibilities, is justified by the fact that these cellulose wastes line the stream margins and cover the stream floor for miles below the source of pollution, harboring bacteria, becoming entangled with the gills of small fishes and other aquatic animals, and smothering out various bottom forms valuable for fish food. If other wastes are also introduced the mats of pulp collect these wastes and maintain even greater pollution hazards.

Stream Pollutants and Aquatic Life

If the general conditions requisite for aquatic life are to be maintained in the inland streams, from the standpoint of fisheries no substance which will produce a deviation from the ideal aquatic environment unfavorable to fish and those other aquatic organisms which interdependently constitute the particular unit in which man is interested should be admitted to a stream, i.e., a pollution disturbance is significant as soon as conditions become unfavorable and long before they become lethal. Natural erosion, mineral springs, and geysers, for example, have caused some stream pollution, but most of the stream pollutants are traceable to man or man's agencies.

Collectively stream pollutants regardless of the source can be grouped into three classes, namely, (a) those pollutants which disturb the balance of general conditions required to maintain aquatic life, (b) those which have specific toxic action on fish and other aquatic forms, and (c) those which combine both hazards.

The first group has been discussed in connection with the general conditions limiting aquatic life, and includes various effluents both municipal and industrial which reduce the dissolved oxygen, alter the pH, or otherwise modify the general stream conditions.

The second and third groups may be considered together because of the common hazard of toxicity to living things. In these groups are the various metallic poisons, dyes, organic, and sulphur derivatives, noxious gases as chlorine, and compounds like cyanids which enter the streams as by-products or wastes from numerous types of industrial activities.

Experiments at the Columbia laboratories of the U. S. Bureau of Fisheries have demonstrated that even the lethal limits of many of these specifically toxic substances are very difficult to define owing to the fact that slight changes in pH, relative salinity, dissolved oxygen and buffer salts will materially alter the toxicity of many compounds. Copper sulphate, for example, was found to be toxic to most fish and aquatic animals in water from one stream in a dilution of 1:4,000,000 although in the water from another stream a dilution of 1:1,000,000 was readily tolerated by the same species due to differences in the other dissolved salts carried by the two streams. It is very unwise, therefore, to attempt to set standards for these toxic pollutants without giving the details of the conditions to be met, and these conditions can only be presented in extensive accounts of the actions of the specific substances.

However, two statements can be made here covering these toxic pollutants, namely all cumulative wastes, that is those not readily oxidizable or removable by the stream as gas factory wastes, should be entirely excluded. This is particularly true of wastes carrying metallic ions, including copper, arsenic, lead, zinc, and even iron, since these metals are often temporarily removed from stream waters by precipitation, only to be redissolved in quantity at some other time. Deposits of wastes carrying heavy metals constitute, therefore, potentially acute pollution hazards at all times, especially since many metallic salts are active protoplasmic poisons. Second, no substance should be admitted to a stream until it has been shown that the material in question will be not only nontoxic under the conditions and in the dilutions as operative in the stream to receive this effluent, but that the substance will not produce unfavorable cumulative effects.

The successful survival of fishes, as of any other organisms, calls for conditions which are favorable, not merely sublethal.

SUMMARY

(1) Extensive field and laboratory studies of the fresh-water streams of the United States show that general water conditions favorable to, not merely sublethal for, mixed faunae of game and food fishes of the "warm-water" types and supporting organisms, present a complex defined by:

(a) Dissolved oxygen not less than 5 p.p.m.

(b) pH range between 7.0 and 8.5.

(c) Ionizable salts as indicated by a conductivity between 150 and 500 mho x 10^{-6} at 25° Centigrade and in general not exceeding 1,000 mho x 10^{-6} at 25° Centigrade.

(d) Ammonia not exceeding 1.5 p.p.m.

(e) Suspensoids of a hardness of 1 or greater, so finely divided that they will pass through a 1,000-mesh (to the inch) screen; and so diluted that the resultant turbidity would not reduce the millionth intensity depth for light penetration to less than 5 meters.

(2) Experimental data are submitted supporting these field and laboratory findings.

(3) If such favorable conditions for fishes are to be maintained and fishes and other aquatic organisms are to be protected against the toxic actions of many stream pollutants, all pollutants not readily oxidizable or removable by the stream should be excluded, including particularly all cellulose pulps, wastes carrying heavy metallic ions and gas factory effluents. Other types of wastes should be diluted to concentrations nontoxic to the aquatic life of the particular stream. No substance should be added to stream waters which would cause a deviation in general conditions beyond the limits outlined above.

Literature Cited

Belding, D. L.
1928. Toxicity experiments with fish in reference to trade waste pollution. Transactions of the American Fisheries Society, Vol. 57, 1927 (1928), pp. 100-114. Washington.

Brown, H. W. and Jewell, M. E.
1926. Further studies on the fishes of an acid lake. Transactions of the American Microscopical Society. Vol. XLV, pp. 20-34. Menasha, Wisconsin.

Butcher, R. W., Pentelow, F. T. K. and Woodley, J. W. A.
1927. The diurnal variation of the gaseous constituents of river waters. Parts I and II. Biochemical Journal. Vol. XXI, pp. 945-957 and 1423-1435. Cambridge, England.

Clark, H. W. and G. O. Adams.
1913. Studies of fish life and water pollution. Forty-Fourth Annual Report of the State Board of Health of Massachusetts, 1912 (1913), Public Document No. 34, pp. 336-345. Boston.

Creaser, C. W.
1930. Relative importance of hydrogen-ion concentration, temperature, dissolved oxygen, and carbon dioxide tension, on habitat selection by brook trout. Ecology, Vol. II, pp. 246-262. Lancaster, Pa.

Domogalla, B. P., Chancey Juday, and Peterson, W. H.
1925. Forms of nitrogen found in certain lake waters. Journal of Biological Chemistry, Vol. 63, No. 2, pp. 269-285. Baltimore.

Ellis, M. M.
1919. Respiratory volumes of men during short exposures to constant low oxygen tensions attained by rebreathing. American Journal of Physiology, Vol. L, No. 3, pp. 267-279. Baltimore.

1936. Erosion silt as a factor in fresh-water environment. Ecology, Vol. 17, pp. 29-42. Lancaster, Pa.

1940a. Pollution of the Coeur d'Alene River and adjacent waters by mine wastes. U. S. Bureau of Fisheries, Special Scientific Report No. 1 (mimeographed).

1940b. A study of the Mississippi River from Chain of Rocks, St. Louis, Mo., to Cairo, Ill., with special reference to the proposed introduction of ground garbage into the river by the City of St. Louis. U. S. Bureau of Fisheries, Special Scientific Report No. 8 (mimeographed).

Ellis, M. M. and Chipman, W. A.
1935. Studies of the toxicity of ammonium compounds for aquatic animals. In MS.

Gardiner, J. A., King, George, and Powers, E. B.
1922. The respiratory exchange in fresh-water fish. Part III. Goldfish. Biochemical Journal, Vol. XVL, pp. 523-529. Cambridge, England.

Gardiner, J. A. and King, George.
1922. The respiratory exchange in fresh-water fish. Part IV. Further comparison of goldfish and trout. Biochemical Journal, Vol. XVI, pp. 729-736. Cambridge, England.

Juday, Chancey, Fred, E. B. and Wilson, F. C.
1924. The hydrogen-ion concentration of certain Wisconsin lakes waters. Transactions of the American Microscopical Society, Vol. XLIII, pp. 177-190. Menasha, Wisconsin.

Keyes, A. B.
1930. Influence of varying oxygen tension upon the rate of oxygen consumption of fishes. Bulletin of Scripps Institute of Oceanography, Technical Series, Vol. 2, No. 7, pp. 307-317. La Jolla, California.

1901. Ueber den niedrigsten fur das Leben der Fische notivenigen Sauerstoffgehalt des Wasser und uber die fur dieselben giftstigen Mengen in Wasser geloster Kohlensaure. Zeitschrift fur Untersuchen der Nahrungs-und Genussmettel, sowie der Gebrauchs-gegonstande, Bd. 4, s. 631-638. Berlin.

Massachusetts State Board of Health.
1913. Forty-Fourth Annual Report of the State Board of Health of Massachusetts, 1912 (1913). Public Document No. 34. Massachusetts State Board of Health, Vol. VI, pp. 1-779. Boston.

McCay, C. M. and Vars, H. M.
1931. Studies upon fish blood and its relation to water pollution. In Biological Survey of the St. Lawrence Watershed; Supplement to Twentieth Annual Report of the New York Conservation Department, pp. 230-233. Albany.

Pearsall, W. H.
1930. Phytoplankton in the English Lakes, I. The proportion in the waters of some dissolved substances of biological importance. Journal of Ecology, Vol. 18, pp. 306-320. London.

Plehn
~~Ehn~~, M.
1924. Praktikum der Fischkrankheiten. In Handbuch der Binnenfischerei Mitteleuropas, Bd. I, s. 301-470. Stuttgart.

Powers, E. B.
1921. Experiments and observations on the behavior of marine fishes toward the hydrogen-ion concentration of the sea water, in relation to their migratory movements and habitat. Publications, Puget Sound Biological Station, Vol. 3, 1921-1925 (1925), pp. 1-22. Seattle.

1929. Fresh-water studies: The relative temperature, oxygen content, alkali reserve, the apparent carbon dioxide tension and the pH of the waters of certain mountain streams at different altitudes in Smoky Mountain National Park. Ecology, Vol. 10, pp. 97-111. Lancaster, Pa.

1930. The relation between pH and aquatic animals. American Naturalist Vol. LXIV, pp. 342-366. Boston.

Shelford, V. E.
1917. An experimental study of the effects of gas waste upon fishes, with especial reference to stream pollution. Bulletin of Illinois State Laboratory of Natural History, Vol. XI, Art. VI, pp. 381-412. Urbana.

1929. Laboratory and Field Ecology. 608 pp. Williams and Wilkins Company, Baltimore.

Steinmann, Paul.
1928. Toxikologie der Fishche. Handbuch der Binnenfischerei Mitteleuropas, Bd. 6, s. 289-342. Stuttgart.

Thompson, D. H.
1925. Some observations on the oxygen requirements of fishes in the Illinois River. Bulletin of the Natural History Survey, Vol. XV, Art, VII, pp. 423-437. Urbana.

Weigelt, C.
1885. Die Schadigung von Fischerei und Fischzucht durch Industrie und Haus Abwasser. Archiv fur Hygiene, Bd. 3, s. 39-117. Munchen und Berlin.

West Riding River Board, Laboratory Staff of.
1930. Biological Survey of the River Wharfe. I. Dissolved substances of biological interest in the waters. Journal of Ecology, Vol. 18, pp. 274-285. London.

Wiebe, A. H.
1931a. Dissolved phosphorus and inorganic nitrogen in the water of the Mississippi River. Science, Vol. 73, No. 1902, p. 652, Lancaster, Pa.

1931b. Notes on the exposure of several species of pond fishes to sudden changes in pH. Transactions of the American Microscopical Society, Vol. L, No. 4, pp. 380-393. Menasha, Wis.

Winslow, C. E. A. and Phelps, E. B.
1906. Investigations on the purification of Boston Sewage. United States Geological Survey, Water Supply and Irrigation Papers, No. 185, 163 pp. Washington.

Wisconsin State Board of Health.
1927. Stream Pollution in Wisconsin, Special Report, a joint report of the Conservation Commission and the State Board of Health of Wisconsin, concerning activities in the control of stream pollution, from July 1, 1925, to December 31, 1926, 328 pp. January 1927. Madison.

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