NOTES ON THE DISSOLVED CONTENT OF WATER IN ITS EFFECT UPON FISHES.

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NATURAL IMPURITIES IN WATER.

Since fishes are confined to water as their natural habitat, and since water strictly pure scarcely exists naturally upon the earth, they live habitually in water containing a certain amount of foreign substance in solution—in other words, in impure water. There is also nearly always some foreign matter held mechanically. Since these so-called impurities may vary greatly in kind and degree, the study of the reactions which take place between fishes and impure waters of various nature can not fail to be of both theoretical interest and practical importance.

It is profitable to inquire first whether these impurities are merely incidental to the life of the fish as they are to the water, or are essential and necessary. That air dissolved in the water is necessary to support fishes is a matter of common knowledge and observation, for they die quickly if the water is not aerated. It may likewise readily be shown by experiment that water containing dissolved air alone is not sufficient even though plenty of food is supplied. For this purpose, 5 liters of water were distilled through glass apparatus. Contrary to what seems the general impression, distilled water has considerable air dissolved, even immediately after the distillation. A portion of this water from the receiving flask was tested for oxygen during the distillation and contained, at 15° C., 5.48 c. c. of oxygen per liter. Twelve quinnat salmon fry in the sac stage were placed in the 5 liters of water in a glass jar, with a current of air in small bubbles constantly passing to the bottom of the jar and bubbling up through the water. A control was set in exactly the same way, save that Potomac tap water was used instead of distilled water. Three and one-half hours after the beginning of the experiment, the water in each jar being at 14° C., oxygen was determined. The Potomac sample held 7.25 c. c. per liter, the distilled sample 7.09 c. c., each therefore almost air-saturated with oxygen. In the distilled water, after 24 hours, 2 fry were dead, after 27 hours 3 fry, after 37½ hours all were dead. All the fry in the control remained alive. During the experiment the aeration of the control was never greater than that of the distilled sample, and was usually less.

Rain water was tried in substantially the same way and with mummi-chogs, sunfish, perch, and trout, with the same result. The mummichogs were the most resistant, living 41 hours.

One is led to conclude from this that foreign matter other than dissolved air is a necessary accompaniment of water that supports fish life, and that water can be too pure for fishes. The law is probably of wide application, for low forms of life are known to die readily in distilled water. It is natural to infer also that death is brought about in these cases by some osmotic reactions through the gills, which bring the blood, known to contain various salts essential to the life of the fish, into intimate relation with the water. It is an assumption open to several objections to explain the death as due to the dissolving out of salts or other substances from the blood. Certain obscure poisonous products are believed to be generated in the distillation of water and, conceivably even in rain water, these may have a toxic action on fish. If so, their toxicity is neutralized by contact with many simple substances. It is known that some toxic principles in ordinary water are thus neutralized, as will appear later.

For practical fish-cultural purposes it may be assumed that a certain minimum of dissolved solids is necessary to water before it is suitable for fishes, and no doubt there is also a maximum which should not be exceeded, though a wide adaptability must exist, as some fishes can frequent both fresh and salt water. Where either of these limits lies can not be at present stated. Of course natural waters which contain fishes furnish the safe conditions both as to quantity and quality of these necessary impurities, which are common substances—carbonates, sulphates, chlorids, in combination with calcium, magnesium, sodium, and other common metals. Potomac water had in October, 1905, 240 parts per million; the spring water at the White Sulphur Springs (W. Va.) hatchery had in February, 1906, 484 parts. Neither of these amounts is objectionable so far as known. Many waters have a total solid content below 50 parts per million, and fishes inhabit waters containing no more than 20. It is perhaps true that water with much less solid matter than this would support fishes. It would be interesting to find if possible some natural water fatal to fishes solely on account of its high purity.

It seems that these considerations about the quantity of dissolved solids may become of some practical importance when fish are transferred from one water to another, as from one high in total solids to one low in total solids. Possibly one water may differ so greatly from another in this respect alone that a gradual transfer by slowly mixing the two waters is advisable, in order that the fish may adjust itself from the one to the other. Trout, for instance, do not always thrive after transfer, even when both waters seem admirably adapted to the trout already in them.

POISONOUS SUBSTANCES.

The substances the variations of which have been referred to are substances not harmful in themselves; that is, the action is not a poisonous one. Substances not commonly held in natural waters are usually unfavorable in their action upon fishes, and in some cases there is a poisonous action tremendously greater than with the same substance in higher animals. For instance, copper sulphate is not extremely poisonous to mammals, but 1 part to 6½ millions of water has been observed to kill domesticated brook trout within 24 hours. The fatal amount varies greatly even with the same species in different waters. At the state hatchery at Bayfield, Wis., brook trout were not killed until the concentration reached 1 to 400,000. Some waters precipitate the copper faster than others, but there was probably also a greater resistance to copper sulphate among the trout themselves. General statements of fatal concentrations of such salts must apply only to the water in which the experiments were made and to the fish adapted to that water.

Silver nitrate is even more highly toxic than the salts of copper. In experiments with Chinook salmon fingerlings three months old, one part of silver nitrate to 20 million parts of water was fatal in a few hours and 1 to 22½ million was fatal within 48 hours. With 1 to 25 million the solution is so dilute that about half the number of fish used were killed during 48 hours, the rest surviving; 1 to 30 million and weaker solutions had no recognizable effect.

Many of the metals are poisonous to fishes by lying in the same water with the fishes. Copper is the most active of the common metals in this respect. Twenty square inches in about 6 quarts of Potomac water killed 8 of 10 salmon fry within 24 hours. Ten square inches in the same amount of Potomac water killed 4 of 6 free swimming salmon fry within 2 days and 18 hours and all of them within 3 days and 2 hours. The temperature was never higher than 68° F., and the controls were good.

Zinc, lead, and aluminum are toxic in the order named. Even tin seems to have a very slight poisonous action. In vessels of any of these metals harm to fishes is nearly always prevented by even a slight flow of water. It is when the water is not changed that the injurious action is seen. Iron seems to have no effect. Galvanized iron and lead, and asphaltum and enamel paints all have more or less toxic action, but containers made of or painted with these substances become less harmful with use. Usually considerable time is required before the toxic substance becomes in sufficiently concentrated solution in standing water to have an effect, and this is the reason such containers are often used successfully for transporting fishes. They have, however, been repeatedly identified with certainty as the cause of loss of fish.

Various industrial wastes are of course injurious in sufficient concentrations, but the actual effect of some of these has been exaggerated, perhaps partly because they are sometimes highly colored and of unsavory appearance. Paper-pulp mills which use the sulphite process spend a dark-brown liquor of strongly acid reaction which contains, besides the chemicals used for extraction, the extractive matters themselves, organic compounds of comparatively complex nature. These latter are themselves often toxic to fishes, as well as the extracting agent, and the effluent containing both is presumably always quickly destructive to fish life in its undiluted condition. When discharged into streams it quickly undergoes great dilution, and it becomes of interest to know at what point it is rendered harmless. A sample from Covington, W. Va., at a dilution of 1 to 200 did not injure salmon fry during 2 days. It is evident that tremendous amounts would be required to raise the water of a stream of any size to a fatal concentration. It has been suggested that when wastes containing sulphites kill fishes the loss of dissolved oxygen due to the reducing power of the sulphite contributes to the result by tending to asphyxiation. A sample experimented with by the writer had little or no reducing action on the dissolved oxygen in the water, and it is likely that it kills by its direct action alone.

Other industrial pollutions, such as the wastes of paper-pulp mills using the soda process, tannery wastes, and dye wastes from knitting mills, will kill fishes, but the most toxic of them are made harmless to such fishes as black bass and yellow perch by the addition of a few hundred parts of water, usually 200 parts. Wastes from the manufacture of illuminating gas, however, require some hundreds of thousands parts of water to dilute them to harmlessness. The water soluble substances in bark and in the wood of some trees are capable of killing fishes, but while such products are undesirable in streams the amounts of bark and wood necessary to affect fish in flowing streams are so large that it is not likely that they do much direct damage to fishes by the substances which dissolve from them.

Tobacco ashes have been said to kill trout fry in transportation cans. After trials with salmon fry no effect whatever could be detected unless the fry were in the sac stage and lying on the bottom with the free ash, when they would suffocate from clogging of the gills. If the ash was wrapped in a cloth or if the fry were free swimming there was no effect. It is possible that the ash from other samples of tobacco would give a different result.

Fishes are very susceptible to acid water and succumb to the mineral acids in very weak solutions which scarcely taste sour. Hydrochloric acid kills mummichogs and sunfish when enough has been added to destroy the alkalinity and make about 8 parts of acid per million. Some 40 hours were required for the sunfish. The mummichog or bull minnow is more susceptible than the sunfish.

About 12 parts of sulphuric acid per million kill the same species within 24 hours. According to the degree of alkalinity of the water considerable acid may be added before the water becomes acid in reaction.

This matter of changing the reaction of water is important in connection with some industrial pollutions. An interesting case occurred during the spring of 1905 in the Potomac above Cumberland, Md. A large number of fishes, largely minnows, were found dead and dying along the shore, and still greater numbers were sick and weak and could be picked up in the hand. Twenty-nine miles above Cumberland a paper mill sewers into the river a highly alkaline waste, several tons of lime sludge passing in daily. Shortly below this point Georges Creek enters, carrying an acid waste from the coal-mine regions. It contains free sulphuric acid and salts of acid reaction. The creek water is distinctly sour to the taste and is said to contain no life of any sort. When the two wastes mix at and below the mouth of Georges Creek they neutralize each other, and besides improving the river from a sanitary standpoint permit the fishes of the river to thrive. They must be usually fairly well balanced, since fishes have usually been in some abundance. In October, 1900, on the occasion of a sudden occurrence of dead fishes in the river a sample of water was reported to contain free sulphuric acid, to which the loss of fishes was attributed. On the more recent occasion referred to the water, which was only examined as the fishes were recovering, was not acid, but the alkalinity was reduced, was very low and was rising, and therefore the probability is that the river had just been acid and was recovering its normal alkalinity. It could hardly be expected that the two extensive pollutions mentioned would be invariable in amount, and it can hardly be doubted that the acid occasionally predominates and kills fishes. The acid pollution is by far the more important in its effect upon fishes.

The courts have on occasion held that in the case of coal-mine wastes damages can not be collected nor the mine owners enjoined, since the pollution is a natural one and occurs to some extent independently of mining operations. In the instance cited it would seem that each pollution is the salvation of the river from the other; that the net result is a beneficial one, and that it would be unwise to meddle with either unless it were possible completely to remove both.

Some natural waters have been observed to acquire a selective toxicity by remaining in tin cans for some time. They become, for instance, fatal to rainbow but not to brook trout. During the spring of 1907 some results in this respect of much interest were obtained from the city water of Norfolk, Va. Samples transported in new tinned fish cans were uniformly fatal to fry of the rainbow trout, but had little effect on brook-trout fry. Samples transported in tinned fish cans which had been in use a long time and become rusty on the inside gave contradictory results but were often likewise toxic, though less

markedly so, while samples carried in glass containers had no toxic quality. No toxicity was imparted to Potomac water by repeated and long-continued trials in such cans. The toxic element in the water was not identified, but it is of interest to find that it was destroyed or neutralized by some very simple means. Boiling made the water harmless, and heating to 75° C. greatly reduced the poisonous effect. It was also corrected in large part, sometimes almost completely, by the addition of a portion of either sea water, common salt, calcium sulphate, sodium carbonate, residue from the evaporation of Potomac water, or ordinary earth.

Water brought in fish cans from Newport News, Va., had a similar selective toxicity and was corrected by most of the agents mentioned above and also by the presence of fish in the water, especially by the dead bodies. Thus a sample of this water by standing with the bodies of the fry it had killed became less able to kill other fry of the same species. Shaking and soaking with bone black diminished the toxicity somewhat. These experiments suggest that for aquarium exhibits on close circulation or for the temporary holding of fish in standing water, water which it is dangerous or impossible to use may be made fit for fishes by dissolving in it some of the cheap and easily procurable substances mentioned. .

ABNORMAL GAS CONTENT.

DISSOLVED AIR CONTENT OF WATER FROM A DRIVEN WELL.

This well was driven in May, 1906, and is 83 feet 10 inches deep. It passes for most of the distance through clays, which include two strata of water-bearing gravel and sand between the 34 and 52 foot levels, and finally takes water from fine sand and coarse sand and gravel beyond a depth of 80 feet. A 6-inch casing reaches the whole depth of the well and contains a 4-inch pipe through which the water is pumped. The casing is perforated for several feet near the 50-foot level, so that the water-bearing gravel at this level contributes to the supply of water.

The water level in the well stands about 21 feet below the surface of the ground. The electric pump installed was able to lower the level to about 28 feet, where it remained constant. The pump as ordinarily run delivered 24 gallons per minute, but could be made to deliver 32 gallons per minute. The temperature of the water was about 15° C. (60° F.).

It was intended that the water be used in the trout aquariums during the summer in order to avoid the expense of refrigerating Potomac water. On April 11, 1907, the water was turned into an aquarium containing trout. They soon showed marked distress and the water was then shut off. The next day the pump was started again and by delivering part of the flow into a glass jar

it was seen that a continuous stream of minute bubbles of gas was always contained in the water issuing from the well. On dippering the water in the jar a marked white cloudiness caused by very minute bubbles appeared after a fraction of a minute. This cloudiness disappeared after a few minutes and the water became quite clear. On dippering again the same occurrence took place, and this could be repeated several times before the water ceased to cloud upon dippering.

Trout placed in a jar of the water just as it was delivered from the pump were immediately in great distress and within one minute turned over apparently suffocated. If then immediately removed to Potomac water, they revived. Trout placed in the well water after dippering it considerably lived a few hours, but then died. From the behavior of trout in the water and the release of gas from it, it was inferred that the water had a considerable excess of nitrogen or carbon dioxide, or both, and at the same time a very marked deficiency of oxygen. A determination of the oxygen alone showed only 0.2 c. c. per liter of water, while the water was probably capable of taking up from the atmosphere at least 30 times this amount of oxygen. The lack of oxygen accounted for the immediate suffocation of trout.

By various experiments in exposing the water to the atmosphere, such as allowing a slender jet of it, issuing with considerable force from a glass tube drawn out to a small orifice, to impinge upon the center of the bottom of a tall glass cylinder or battery jar laid horizontally, it was found that brook trout would live in the water thus very thoroughly exposed to air. The introduction of air into the water by means of the usual linden wood liberators accomplished the same end provided there was no renewal or flow of water. It was necessary in the case of a large aquarium full of water to let the air current flow for some time before introducing fish in order to give the water a chance to take up enough oxygen to keep the fish from immediate suffocation while the oxygen content was further increasing.

The method mentioned above of breaking up in part into spray a jet of water, even when three air liberators were delivering finely divided air into the aquarium which received the water, did not succeed in air saturating the water with oxygen. That is, it did not fill the water with as much dissolved oxygen as it was capable of absorbing from the air. It raised the oxygen content, however, from 0.2 c. c. to 4.6 c. c. per liter. By cutting off the flow of water and allowing the liberators to run air into the tank full of standing water for some 40 hours in the presence of two yearling brook trout the water then held 6 c. c. of oxygen per liter at 11.5° C.

The water was thought of such interest on account of its peculiar air content and other features that a determination of the nitrogen dissolved was

desirable. Accordingly a number of samples were boiled and the constituents of the gas obtained in this way determined quantitatively by absorption. The following table gives the results for the water just as it is delivered from the well and before it has undergone any appreciable exposure to the air:

TABLE I.—CARBON DIOXIDE, NITROGEN, AND OXYGEN IN CUBIC CENTIMETERS PER LITER OF THE UNTREATED WATER FROM THE ELECTRIC PUMP.

[In all tables the gases are reduced to 0° C. and 760 mm. (of mercury) pressure, and corrected for tension of aqueous vapor. These are the standard conditions for stating gas measurements.]

No.	Date.	Tempera-ture of water.	CO_2.	N.	O.
		°C.			
1	April 28, 1907	15.5	52.8	55.2	0.71
2	1 hour later	15.5	39.8	24.5	0.28
3	April 29, 1907, 11 a. m	15.5	49.0	24.5	0.45
4	April 29, 1907, 3 p. m	15.5	35.4	21.4	0.20
5	April 30, 1907, 10 a. m	15.5	37.5	19.1	0.0
6	April 30, 1907, 3 p. m	15.75	39.7	21.7	0.06

The carbon dioxide obtained by boiling water shows the amount dissolved in the water as gas and part of that dissolved as bicarbonate salts, since the latter decompose on boiling, liberating carbon dioxide as gas. This is not a satisfactory method of determining carbon dioxide in water, and the figures are included here only because it is necessary to obtain them in order to determine the oxygen and nitrogen. They are not of especial significance. Probably, however, a large part of this carbon dioxide is dissolved as the gas.

The first determination is much higher in each gas than any of the others. There is no satisfactory explanation for this. No. 5 and no. 6 were made after the pump had been working continuously for 24 and 29 hours, respectively, and are to be compared with no. 3 and no. 4, which were made at the beginning of this continuous run. It appears from this that the water does not improve particularly with continued pumping.

Water at 15.5° C. can take up from the atmosphere about 13.7 c. c. of nitrogen and therefore this well water has an excess of about 5 to 10 c. c. of nitrogen, or the normal and proper content has been increased 39 to 79 per cent. This is the largest nitrogen superaeration that has been determined in Fisheries station water, although at Woods Hole an excess of 5 or 6 c. c. in the sea water was experimentally induced. It is known that such an excess is fatal within a day or two at most, to many fishes, and that an excess of 2 or 3 c. c. is sufficient to make considerable trouble. In this well water, however, the effect of the excess of nitrogen upon fishes can not be observed since the deficiency of oxygen

is so great that the fishes are immediately suffocated before the nitrogen has time to cause any symptoms. When the oxygen is increased by aeration, the nitrogen, of course, is at the same time decreased.

The oxygen, as shown by boiling determinations, agrees approximately with that shown by titration, in no case rises to 1 c. c. per liter, and varies from less than 0.1 c. c. to 0.45 c. c. (excluding first sample). This deficiency is probably practically as bad, as far as fishes are concerned, as if the water were absolutely lacking in dissolved oxygen.

COMPARISON OF MEANS OF CORRECTION.

Having thus a water in which the coexisting deficiency of oxygen and the excess of nitrogen were each more extreme in degree than in any case yet met with, it was thought desirable to experiment in correcting it by exposing it to the atmosphere, and to compare methods or devices for accomplishing a thorough exposure. The question of what was the best general method was submitted to Mr. H. von Bayer, the architect and engineer of the Bureau, who recommended flow along sanded and pebbled troughs on a gentle incline as theoretically best adapted to expose and correct small or moderate volumes of water. Wooden troughs were accordingly made under his direction and when finished were substantially as follows: Total trough length 44 feet, 6 to 8 inches wide. The water flowed 22 feet through two joined troughs with a fall of 2 inches, then fell 10 inches to the second set of two troughs and returned through 22 feet, with a fall of 2 inches, and was delivered into an aquarium. The troughs were painted with asphalt and sanded on the moist asphalt. When dry, pebbles of various sizes were strewn along the bed of the troughs, thus imitating natural flow in pebbly brooks.

The troughs were suspended one set above the other near the ceiling in the aquarium grotto and the water delivered into the head of the upper from a rubber tube. Two trials were made in the sanded troughs, but without pebbles, with a flow of 2 liters per minute. The following table shows the correcting effect of such troughs.

TABLE II.—WATER FROM ELECTRIC PUMP BEFORE AND AFTER PASSING THROUGH SANDED TROUGHS WITHOUT PEBBLES.

Date.	Sample.	Water temperature.		CO_2.	N.	O.
		Entering troughs.	Leaving troughs.			
		°C.	°C.			
May 3	Well water, untreated	15.5		38.1	21.0	0.1
May 4, 12.30 p. m.	Well water, at exit of troughs	15.5	17.5	19.2	14.9	4.5
May 4, 2 p. m.	do	15.5	17.5	13.9	14.1	4.4

Since the determination of May 3 on untreated water agrees approximately with the figures obtained several days earlier, it may be assumed that the water does not vary beyond the limits shown in table I. This variation, however, is considerable and as two samples could not be determined at the same time, it is not known exactly what the condition of any treated water sample was at the time it entered the troughs. It is known approximately, however, and it is apparent that the 2-liter flow water is considerably but not completely corrected for nitrogen and that much oxygen has been added but not enough to air-saturate with oxygen. At this point the pump ceased to deliver water on account of clogging with sand. No more determinations were made until May 14. In the meantime a small hydraulic pump was connected with the well and succeeded in pumping some 4 gallons per minute. This pump, however, changed the aeration of the water considerably.

The electric pump had its pumping cylinder entirely immersed and some 30 feet below the surface of water, so that all pipes were filled with water under pressure instead of suction. There was therefore no opportunity for atmospheric air to enter the pipes. The hydraulic pump on the other hand was located on the surface of the ground and had a suction pipe some 22 feet long. Though no leak was discovered, the pump delivered gas in large bubbles, much more in quantity than ever came from the electric pump. This gas, or air, must have entered the suction area at some point and though insufficient to stop the pump, modified the air content in an interesting way, as shown by comparing the "untreated" samples in table III with table I. Oxygen has been increased, while the nitrogen has not been materially changed or has even been reduced somewhat. The explanation is found in the atmospheric air which gains access to the hydraulic pump. The water having scarcely any oxygen loses little or none in the suction pipe, but takes up considerable in the pressure pipes between the pump and the point of delivery, on account of air taken in at the suction and propelled in company with the water past the pump, where it is then under pressure. The water having an excess of nitrogen must lose considerable in the suction pipe on account of the reduction of pressure. This nitrogen which comes out of solution remains within the pipe as free bubbles and together with the atmospheric air sucked in, passes on with the water past the pump when the pressure then causes nitrogen to be forced back into solution in the water. The resultant of these two opposite processes is evidently a slight diminution in the nitrogen content. This is reasonable, since the suction below the pump is greater than the pressure above it.

It is thus seen that although a leaky suction pipe in pumping systems usually injures the water from a fish-cultural point of view, in this case it improved it somewhat, by adding oxygen and subtracting nitrogen. It did so because of the great length of suction pipe, the small head pumped against, and

the extreme faults of the water in the well with respect to both oxygen and nitrogen.

In addition to the troughs, tin pans with perforated bottoms were used to correct the water. Usually the water was passed through a series of 6, arranged one above the other, with a fall of 4 inches from one bottom to the next. The pans were rectangular, about 31 by 19.6 by 5 centimeters, and contained 345 circular holes 1 millimeter in diameter, regularly placed, punched from the inside with a steel punch. In table III the results with these pans may be compared with those from the troughs, on 2, 4, and 6 liter flow. The "untreated" samples were taken directly from the delivery pipe before appreciable contact with air. In comparing the results, or when considering in any case the amount of air or any gas dissolved in water, the temperature of the water must always be borne in mind, the colder water holding or being capable of holding more gas dissolved than warmer water.

TABLE III.—WELL WATER FROM HYDRAULIC PUMP, UNTREATED, AFTER PASSING THROUGH SANDED AND PEBBLED TROUGHS, AND AFTER PASSING THROUGH SIX PERFORATED PANS.

Sample.	Date.	Flow per minute.	Temperature of water.		CO_2.	N.	O.
			Entering troughs.	Leaving troughs.			
		Liters.	°C.	°C.			
Untreated	May 14, 3 p. m	6	17.5		44.0	16.9	4.6
Do	May 14, 4 p. m	6	17.0		46.4	16.8	3.7
Do	May 15, 9.30 a. m	6	16.5		45.7	21.0	2.6
Through troughs	do	2	16.75	18.75	8.5	13.2	5.6
Do	May 15, 5 p. m	4	16.0	18.0	12.5	13.7	5.2
Do	May 16	6	15.5	15.0	15.2	15.1	5.1
Through 6 pans	May 15, 3 p. m	2	16.5	17.5	7.9	13.3	5.8
Do	May 16, 4 p. m	4	16.25	17.25	11.4	14.0	5.3
Do	May 16, 12 noon	6	15.5	15.5	13.9	14.8	5.4
Untreated	May 16, 9 a. m		15.5		45.6	23.0	1.1
Do	May 16, 1.30 p. m		15.5		45.8	22.5	1.2

Several facts of interest appear from the trials of the pans and troughs. In the first place, neither succeeds in completely correcting the water with respect to either gas. After passing either system the water could, by further exposure, take up a little more oxygen and release more nitrogen. With the 2-liter flow, however, the correction is very nearly complete for oxygen, but it must be remembered that the hydraulic pump had already added some oxygen. The correction is less complete by both troughs and pans as the flow grows

larger. As between the two systems, the troughs and perforated pans, the difference is insignificant on the smallest flow (2 liters) and is in favor of the pans. As the flow increases in volume, the advantage of the pans becomes somewhat more appreciable, but even with the 6-liter flow the troughs are a practicable method of correcting water. Unfortunately, larger flows than this were not tested with the troughs. The following two determinations were made on a flow of 12.5 liters per minute, delivered May 3 by the electric pump and passed through pans each perforated by 345 holes of irregular size, but all of them considerably larger than 1 millimeter. The condition of the water before treating is shown by the "untreated" sample, and is substantially in agreement with that shown by table I.

Sample.	Hour.	Temperature of water.	CO_2.	N.	O.
		°C.			
Untreated _	2 p. m	15. 5	38. 1	21. 0	0. 13
Through 5 pans _	11 a. m.	15. 5	27. 2	17. 4	4. 0
Through 6 pans _	1 p. m.	15. 5	16. 8	15. 9	4. 8

The water after passing 6 pans still has about 2 c. c. too much nitrogen and about 1 c. c. too little oxygen per liter. The correction is less complete than in any other case, on account of the larger flow and the larger holes in the pans.

From tables II and III it is seen that the pebbles contained in the troughs add considerably to the efficiency.

The practical application of these experiments may be found in their showing that aeration and deaeration sometimes require an extremely thorough or intimate exposure of water to the atmosphere to restore the dissolved air content to the normal. The water must be spread into very thin sheets, as in troughs, or if subdivided into streams, as by perforated pans, must be reunited and subdivided repeatedly. By increasing the lengths of trough or the number of pans, the correction can finally be made complete. Troughs have practically the efficiency of pans under the conditions of trials described herein. The objection to them lies in their warming of the water if the air temperature is high, their expense and cumbersomeness. One great advantage they possess is that they require little vertical space, and therefore they could be used where the fall from tap to trough is too short to permit the insertion of a sufficient number of pans, provided there is sufficient room laterally.

When pans are used, the diameter of the holes must be controlled largely by the volume of water, the amount of fall available, and especially by the sediment the water carries. The smaller the holes the better, as far as

exposure to air is concerned, but they readily clog with suspended matter. Moreover, they do not allow the delivery of so much water as larger holes, unless the pressure is increased by deepening the pan, but this takes up vertical space. Larger holes to avoid clogging may be compensated by more pans. The size and depth of pans, number and size of holes, will be a resultant of the various factors mentioned, and may be determined by the judgment of the fish culturist for each particular case, or by trial and experiment.

Since the water from the well under consideration has a temperature of 15.5° C. or 60° F., when it arises, it can not undergo warming and remain fit for trout. Could it be passed through an efficient aerating apparatus of pans, trout could probably be maintained in it even during the heated season, since the passage through pans is rapid enough to warm the water but little. Any form of aeration, however, will seriously interfere with the clearness of this water, since it contains about four parts of iron per million dissolved as some one of the salts of iron. On exposure to air most of this iron is precipitated, and causes a marked turbidity. On standing, the particles of iron oxide settle and the water becomes clear; but for constant-flow aquariums it would require filtering before use. This would warm the water, and its use therefore would involve more trouble and expense than that which the well water was intended to obviate.

Thus this well water is of peculiar interest in having two faults, the correction of which induces a third almost as serious for exhibition aquarium purposes. The excess of nitrogen or the deficiency of oxygen are either of them singly sufficient to kill all the fishes placed in the water. Both are remedied simultaneously by one process, thorough exposure of the water to air; but this process creates, by oxidation and precipitation of dissolved iron, a turbidity which ruins the water for the purposes of aquarium exhibit.

DETERMINATION OF SUITABILITY OF WATER FOR FISH CULTURE.

Entirely aside from any question of parasitism, and speaking only of dissolved substances, it must be admitted that there is at present no sure method of determining by chemical tests the suitability of water for fish culture. Much of course may be assumed in favor of unpolluted natural streams, as trout streams for trout culture. With spring water nothing may be assumed. Something may be learned from a chemical examination, but it must be adapted to the purposes of fish culture. Ordinarily, if a sample is submitted to a chemist he will make what is called a sanitary analysis, which determines whether water is fit for drinking and domestic uses—is healthful for human consumption. For fish culture this is almost useless. Water with a good sanitary showing may kill fishes in a short time, and on the other hand, in rivers fishes are not

necessarily harmed by water which any chemist would pronounce unfit from a sanitary standpoint.

There must be established what may be called a fish-cultural analysis, and the information this will give should cover, among other things, the reaction and degree of alkalinity or acidity, hardness, total solids, sulphates, nitrates and chlorides, the carbonic acid, the dissolved oxygen, nitrogen, and carbon dioxide; and an ordinary mineral analysis with special tests for any unusual metals which there is any reason to suspect. The determinations of the atmospheric gases named should be made on the perfectly fresh sample. The dissolved air is the most important, and the nitrogen as important as or more so than the oxygen. Temperature, turbidity, color, etc., are physical characters which the chemist will note. Having obtained these results, not all of them can yet be accurately interpreted. For the atmospheric gases one can form immediately a fairly definite opinion, but as for total solids and the minerals present, we know but little of the limits of safety. Therefore it is that the final test is experience itself. A long experience with fish culture and aquarium experiments in water whose contents are accurately known will ultimately lead to the establishment of definite standards which will be useful to fish culture, just as the long-continued chemical examination of service waters in the light of the results of their usage has led to standards confessedly not well defined, but which are nevertheless useful in selecting sanitary waters.