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A chemical study of the waters of the Middle Rio Grande Conservancy District as related to fish culture.

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The University of New Mexico Bulletin

A CHEMICAL STUDY OF THE WATERS OF THE MIDDLE RIO GRANDE CONSERVANCY DISTRICT

as related to

FISH CULTURE

By JOHN D. CLARK *and* HILLARD L. SMITH

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FOREWORD

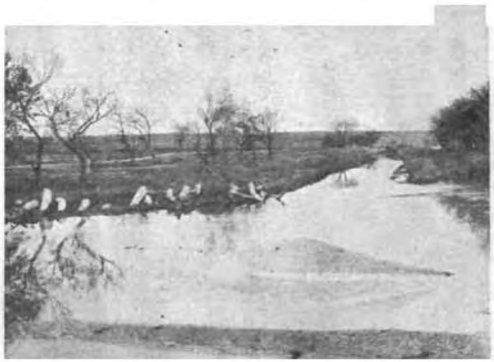
The research described by Dr. Clark and Mr. Smith in this bulletin is of value from a number of angles. In the first place, it illustrates the immensely practical results to fish culture of accurately determined physical and chemical data. The requirements of fish must be met if fish culture is to be successful and the conditions for fish life must be determined *in advance* of plantings if wasteful experiments with costly young fish are to be avoided.

This research is also of particular interest in demonstrating the proper relation between a state university and an executive branch of the state government (in this case, the State Fish and Game Commission). It should be a function of research at such universities to solve the scientific problems of fish and game culture and management in order that the Commission may have the *facts* upon which to base their plans for the maintenance and improvement of fishing and hunting for the sportsman.

The study of the Conservancy District, described by the authors of this Bulletin, presents the facts in terms which an intelligent layman can understand and furnishes definite recommendations for future stocking and improvement of conditions for fish life in order that the angler, who supports the Fish and Game Commission, may secure the benefit.

A. S. HAZZARD,
Associate Aquatic Biologist,
U. S. Bureau of Fisheries.

July 10, 1935.



(Upper) Station III just below Old Town on Albuquerque Riverside Drain.

(Lower) Station IV. The Corrales Lateral Drain empties into the Rio Grande at this point.

(Upper) Station I on the Albuquerque Riverside Drain.

(Lower) Station II on the Albuquerque Riverside Drain.

A CHEMICAL STUDY OF THE WATERS OF THE MIDDLE RIO GRANDE CONSERVANCY DISTRICT AS RELATED TO FISH CULTURE

INTRODUCTION

This bulletin has been prepared primarily for the person who is interested in fish culture. It is assumed that the reader is none too familiar with the science involved, so an attempt has been made to use language meaningful to the average person. A full and detailed report covering this subject, and one in which technical terms have not been avoided, is to be found in a thesis on file in the library of the University of New Mexico, which thesis bears the title of this bulletin. It was prepared by the junior author, under direction and guidance of the senior author.

In the Middle Rio Grande Valley of the State of New Mexico a Conservancy District was established a few years ago. Lands needed improvement for agricultural use. Outstanding among the engineering works of the district are large drainage canals.[1]

Soon after the canals were constructed, fish of various species were placed in their waters. These fish seemed to thrive in some locations while from others they disappeared. No study of the waters had been made before the original planting of fish and because of the apparently different conditions existing in the drains, sportsmen became interested in the subject of fish culture, and were soon able to interest the Biology Department of the University of New Mexico in making a biological study of these waters.[2]

The State Fish and Game Commission had, in recent years, solved some of the hatchery problems, with the assistance of chemists from the University of New Mexico, and

1. Clark and Mauger, "The Chemical Characteristics of the Waters of the Middle Rio Grande Conservancy District," Bulletin 217, University of New Mexico, August, 1932.

2. Shettles, Landrum B. Some Biological Aspects of Fish Culture in the Middle Rio Grande Conservancy Drains. Thesis, University of New Mexico Library.

when it appeared that no information concerning the waters of the drainage ditches (also spoken of as canals) would be complete unless a chemical study of the waters, over a period of time and under the various naturally occurring climatic conditions, was made, the Commission appropriated funds to meet the expense of this study, and to the Commission the authors express their appreciation.

In order that fish may live and propagate in any stream or lake a number of conditions must be met. The water must have the requisite physical properties, such as proper temperature and clarity, must meet known chemical standards, such as proper percentage of dissolved oxygen, and degree of acidity or alkalinity. To these all-important factors may also be added a knowledge of free carbon dioxide content of the water, and its contents of carbonates and bicarbonates. If the physical and chemical properties and components of a water are favorable for aquatic life, then there follows the biological work which is concerned with fish food, parasites, predators, etc.

The drains which were selected as typical of the Conservancy are: the Albuquerque Riverside Drain, the Corrales Lateral Drain, and the Atrisco Riverside Drain. Six stations were established: three on the Albuquerque Riverside Drain, one on the Corrales Lateral Drain, and two on the Atrisco Riverside Drain. The sections investigated extend a distance of twenty-two miles, from the Albuquerque Riverside Drain bridge near the town of Alameda to the Isleta Indian Pueblo Grant.

A review of available literature on the above physical and chemical factors was made in an effort to determine the ideal condition for each of these factors as set up by other investigators and to compare them with the conditions found in the drains studied. From these comparisons an effort has been made to determine the suitability of these drains to fish culture.

The Need for Fish Culture in the Conservancy Canals

The Middle Rio Grande Valley is more thickly populated than most districts in New Mexico because here the wide flat valley has an adequate supply of water for irrigation. As a result of this, agriculture has been established and industries and mercantile centers have been built.

Sportsmen living in this valley must motor long distances to reach places for angling. Trips to Elephant Butte, the Pecos River, the upper Rio Grande, the Jemez streams, and others, require considerable time, and often are made only over a week-end. In order to have angling nearer home, the sportsman is very much interested in fish culture in the many miles of canals which are near at hand.

If these canals, practically at the back door of the sportsman, were found suitable for propagation of trout and bass, then there would be over two hundred miles of fishing stream in this valley from Bernalillo to Belen. This would afford angling for those persons who cannot make the longer fishing trips, as well as permit more fishing in a season.

The need for fish culture in these canals is fully realized if one will only visit them on a warm, spring Sunday. Perhaps an angler has previously caught a good trout or bass; he is back for more sport. He in turn tells his friends and they will be seen fishing the next week-end.

In New Mexico, even along the side of the most distant streams, beaten paths show that anglers are increasingly abundant, yet fishermen have gone to these distant places to secure more privacy and better fishing. As a result of this demand for fishing, artificial lakes have been built and in the future more will be constructed. Better stocking policies must be adopted, and streams improved by artificial dams and deflectors. Better still, the protection of the stream bottom from excessive use by live stock, either by fencing of these areas, or by other means, will effectively restore the natural environment for trout, now so often lacking. These conservancy drains, if suitable for fish propagation, can take a considerable load from the fishing streams and lakes of the state. This would be especially true in a dry year, like that of 1934, when some streams and lakes dried up, and other lakes were drained for irrigation. The anglers now must seek other locations for fishing until these streams and lakes are again productive. At present all anglers in the state are looking forward to the time when the new big El Vado Dam reservoir, now just filled with water, and stocked with half a million trout, will produce the "big ones."

A Review of the Literature on Chemical Aspects of Fish Culture

Oxygen

As is well known, fish absorb oxygen through their gills, and unless there is a proper amount of oxygen in any water, it will not sustain fish life. It is conceivable that a given piece of water may have a shortage of oxygen only during one day a year. On that day fish perish. Even though conditions are completely satisfactory during the other 364 days, that piece of water is not adapted for fish culture.

The amount of oxygen dissolved by a unit volume of water is dependent upon the partial pressure of the oxygen in the air. When the atmospheric pressure is decreased (by altitude or otherwise), the partial pressure of oxygen is correspondingly decreased and the amount of oxygen which a unit volume of water will absorb is decreased in the same proportion.

The solubility of oxygen in distilled water has been determined at a pressure of 760 mm. (29.9 inches of mercury) by Fox[1] and tabulated by Birge and Juday.[2] Birge and Juday state that the amount of oxygen one liter (approximately a quart) of water will absorb from the atmosphere is decreased approximately one per cent for each 270 feet of altitude.

The influence of diminished oxygen content of water on fish has been investigated by Duncan and Happe-Segler,[3] Winterstein[4] and various European workers. Some of the

1. Fox, Chas. J. On the coefficients of absorption of the atmospheric gases in distilled water and sea water. Washington, Government printing office, 1924, p. 70. (U. S. Bureau of Fisheries. Bulletin, v. 39.)

2. Birge, Edward A. and Juday, Chauncy. The inland lakes of Wisconsin; the dissolved gases of the water and their biological significance. Madison, Geological and natural history survey, 1911. 259 p. (Wisconsin geological and natural history survey. Bulletin No. 22, Scientific series No. 7.)

3. Duncan, F. C., and Happe-Seglar. Beitrage zur kenntniss der Respitation der Fishche. (Ecology, v. 10, p. 77, January, 1929.)

4. Winterstein, H. Beitrage zur Keuntniss der Fischatmung, arch fur die Jesanunte Physiologie des Menschen und Thiere. (Pfluger's archiv. v. 125, no. 73-98, 1908; Ecology, v. 10, p. 97, January-October, 1929.)

best work, especially in relation to trout, seems to be that of Gardner[5] and his associates. They performed very careful experiments with brown trout, taking especial care to avoid complication from carbon dioxide.

The oxygen content of water, below which trout are asphyxiated, is from 1.3 to 1.6 parts per million. Trout remaining some time at the lower concentration of oxygen are fairly certain to die, even though later removed to water of larger oxygen content, though trout remaining in water of about 1.6 p.p.m. in oxygen (which is too low to sustain life for long) will recover when placed in better water. The amount of oxygen which is just too low to sustain life varies with the temperature of the water. At from 34.5 to 50.0 F. asphyxiation takes place with 1.13 to 1.16 p. p. m., at 62.6° with 1.96, at 64.4°F with 2.13, at 75.2°F with 2.81, and at 77°F with 3.4. These investigators report that the oxygen consumed by trout from fully saturated water doubles for a rise to 18°F.

Gardner and Leetham compiled the following table:[6]

ASPHYXIAL POINTS FOR BROWN TROUT

Temperature Degrees Fahr.	Oxygen in parts per million below which brown trout die
43.5-50	1.13-1.16
62.6	1.96
64.4	2.13
75.2	2.81
77.0	3.4

It is well known that trout can tolerate fairly high temperatures for some days if the waters are shaded.

That water in a forested area can be two to three degrees higher than in an open country, and still be suitable for trout, has commonly been stated in New Mexico in these terms: *"Sunshine and suckers; shadows and trout."* One

5. Gardner, J. A., and others. The respiratory changes in fresh-water fish. Part 3: Gold fish. (Ecology, v. 10, p. 77, January, 1929.)

6. Gardner, J. A., and Leetham, Constance. The respiratory exchange in fresh-water fish. (Ecology, v. 10, p. 91, January, 1929.)

SOLUBILITY OF OXYGEN IN FRESH WATER AT VARIOUS TEMPERATURES WHEN EXPOSED TO AN ATMOSPHERE CONTAINING 20.9 PER CENT OF OXYGEN[1]

(Calculated by G. C. Whipple and M. C. Whipple from measurements of C. J. J. Fox.)

Temperature		Dissolved oxygen in parts per million		Difference in dissolved oxygen in parts per million per 100 parts per million chloride
Centigrade	Fahrenheit	760 mm Pressure	635 mm[2] Pressure	
0	32.0	14.62	12.22	0.0165
1	33.8	14.23	11.89	.0160
2	35.6	13.84	11.56	.0154
3	37.4	13.48	11.26	.0149
4	39.2	13.13	10.97	.0144
5	41.0	12.80	10.70	.0140
6	42.8	12.48	10.43	.0135
7	44.6	12.17	10.17	.0130
8	46.4	11.87	9.92	.0125
9	48.2	11.59	9.68	.0121
10	50.0	11.33	9.47	.0118
11	51.8	11.08	9.26	.0114
12	53.6	10.83	9.05	.0110
13	55.4	10.60	8.86	.0107
14	57.2	10.37	8.66	.0104
15	59.0	10.15	8.48	.0100
16	60.8	9.95	8.31	.0098
17	62.6	9.74	8.14	.0095
18	64.4	9.54	7.97	.0092
19	66.2	9.35	7.81	.0089
20	68.0	9.17	7.66	.0088
21	69.8	8.99	7.51	.0086
22	71.6	8.83	7.38	.0084
23	73.4	8.68	7.25	.0083
24	75.2	8.53	7.13	.0083
25	77.0	8.38	7.01	.0082
26	78.8	8.22	6.87	.0080
27	80.6	8.07	6.74	.0079
28	82.4	7.92	6.62	.0078
29	84.2	7.77	6.49	.0076
30	86.0	7.63	6.38	.0075

1. Taken from Standard Methods of Water Analysis. Sixth edition, p. 62.

2. The average pressure at Albuquerque, New Mexico, is 635 mm. (U. S. Weather Bureau.)

wonders how many more miles of fishing streams might be restored if proper bank cover were allowed to come back.

The best work done so far seems to be that of Gutsell.[7] Investigations of certain aspects of water chemistry in relation to trout were undertaken in the Aquicultural Laboratory of Cornell University, and, to a limited extent, on a few trout streams in the Ithaca, New York, region. Three species of trout were used: brook trout, *Salvelinus fontinalis;* rainbow trout, *Salmo shasta;* and a third species which was supposed to be *Salmo levenensis* or Loch Leven trout, but which, because of some doubt on that point, due to the close relationship between *S. levenensis* and *S. fario* or brown trout, is referred to as brown trout.

Oxygen contents of 3 p. p. m. or less, at a temperature of 67°F., caused labored breathing or distress to trout introduced from well-oxygenated water. With 2.5 p. p. m., a large proportion of the rainbow trout and brown trout present were asphyxiated. At 68°F or less, brook trout in good condition were able to survive a content of 2.3-2.5 p. p. m. oxygen even when accustomed to 6 or 7 p. p. m. When transferred from water of this latter oxygen content, trout were asphyxiated in water containing 1.3 p. p. m. oxygen or less.

Trout gradually accustomed to low oxygen survived for a few days a content of approximately 1.6 p. p. m. at a temperature of 66.2°-68°F but perished in water containing 1.17 parts. Certain brook trout even survived for a day or so in water containing but 1.2 p. p. m. of oxygen at a temperature of 60°F. Trout in an asphyxial condition recovered in water containing as little as 2.67 p.p.m. oxygen at 66.6°F and 28 p.p.m. of carbon dioxide.

In the spring of 1925, Gutsell noted that when trout were introduced into water low in oxygen (2.5 p. p. m., 50°-51.8°F), the brook trout would breathe hard and show other symptoms of distress, but that a large percentage of the rainbow or brown trout would be asphyxiated. On

7. Gutsell, James S. Influence of certain water conditions, especially dissolved gases, on trout. (Ecology, v. 10, p. 77-97, January-October, 1929.)

August 10, 1926, three brook trout and four brown trout were introduced into water containing 0.94 p. p. m. oxygen, 39 p. p. m. carbon dioxide, and at 66.4°F. One brook trout was asphyxiated in seven minutes and the others in twelve minutes. All of the brown trout were asphyxiated in one and one-half minutes. This is worthy of consideration in view of the decided preference shown by brook trout for our purest streams, and the broader tolerance exhibited by brown and rainbow trout.

Shaperclaus [8] concludes that the values for the ratios of carbon dioxide and oxygen can be secured under varying climatic conditions. The exchange of gases of the water is the resultant of the activities of the self-nourishing organism, (plants) which employ sunlight to convert carbon dioxide into organic compounds, setting free the oxygen, and the non-self-nourishing organisms (animals) which reverse this process.

The oxygen stratification of dissolved oxygen in lakes results from the combined effect of the contour of the bottom and the work of the wind in the horizontal plane.[9] The oxygen consumption of dead, decomposing plankton organisms which sink to the bottom may be an important factor in bringing about the stratification of the dissolved oxygen.

The peculiar character of winter stratification of dissolved oxygen in lakes is due to the decomposition of organic substances in the bottom deposits.[10] Partially decomposed organic matter sinking to the bottom uses up oxygen rapidly, from the water nearby, when decomposition goes on to completion. Some of these rapidly decomposed substances diffused upward from the bottom and affect the oxygen content of the water some distance above.[11] The oxy-

8. Shaperclaus, W. New conceptions of gaseous equilibrium of natural waters and their significance for fishes. (Biological abstracts, v. 1, p. 226, April, 1927.)

9. Alsterberg, Gustaf. Oxygen stratification of lakes. (Biological abstracts, v. 4, article 6960, March, 1930.)

10. Rossalimo, L. L. Oxygen stratification in lakes. (Biological abstracts, v. 4, article 20949, July, 1930.)

11. Most careful study of oxygen stratification during the late fall and early winter is necessary on many New Mexico lakes. These studies will have to be made if fish culture in these waters is to be successful.

gen stratification is convex, due to the difference in the character of the bottom material in the shallow and deep water.

It is well known that rooted plants, in water, will remove the dissolved oxygen rapidly under certain conditions or not at all, under other conditions.[12] Among the environmental characters are the temperature of water and the insulation of the shoot.

The cut ends of leafy branches of a few species of shrubs and trees were kept in distilled water for various lengths of time and the oxygen content of the water was determined at the beginning and at the end of the experimental periods. It was found in every instance, that the oxygen content of the water was decreased. A similar result was obtained with cut flowers.

It is concluded from the experiments that the temperatures of the water had little influence on oxygen content as far as oxygen removal by plant roots is concerned. It is possible that the rate of removal of oxygen is related to the intensity of the light to which the shoot is exposed. In four experiments, for example, with leafy branches of the mulberry, the rate of removal was greater in darkness than in light.

Carbon Dioxide

It seems that more work has been done on the oxygen requirements of trout over a wide range in temperature than has been done concerning the toxic effect of carbon dioxide upon fish. Carbon dioxide has been associated with the studies of the biology of fishes for twenty or twenty-five years. The effect of carbon dioxide would be expected to be poisonous since it is an animal waste product.

Weigelt[13] reported two experiments with carbon dioxide and trout: (1) one trout immediately showed violent

12. Cannon, W. A., and Purer, Edith A. The removal of oxygen from water by cut branches. (Science, v. 81, p. 100, January 25, 1935.)

13. Weigelt, C. Die schadigung von Fisherei und Fischzucht durch Industrie und Hansabwasser. (Ecology, v. 10, p. 97, January-October, 1929.)

symptoms of distress when placed in water at 46.4°F containing 100 p. p. m. carbon dioxide; was on its side for the second time in eight minutes, and at the end of two minutes more was removed to running water in which it recovered; (2) a large trout immediately showed signs of distress when it was placed in water at 48.2°F containing 75 p. p. m. carbon dioxide. In 1903, Weigelt reported an experiment in which a large trout was definitely quiet on its side after one and one-half minutes in water at 50°F containing 1,000 p. p. m. carbon dioxide (recovered in running water).

Winterstein [14] found the suffocating point for perch to be about 140-150 p. p. m. free carbon dioxide, and for goldfish to be about 550 p. p. m. carbon monoxide.

Reuss,[15] in his work with rainbow trout in water well supplied with oxygen and at a temperature of about 50°F, found that respiration became seemingly painful when the water had about 30 p. p. m. of carbon dioxide, and that, with 50, 63, and 83 p. p. m., erratic movements were induced, and with 88 and 107 p. p. m. the trout turned on their backs.

Shelford and Allee [16] state that fishes give definite negative reactions to small increases in carbon dioxide and consequently that, except for strongly alkaline waters, carbon dioxide content is probably the single index as to suitability for fish. In 1913, they found that carbon dioxide "in concentrations probably used to produce reversals of reaction in some of the invertebrates, is poisonous to fishes, producing death very quickly." An *Ameiurus* (genus of catfish family, which includes smaller brown catfish, horned pout, or bullhead) was "narcotized" in water containing about 320 p. p. m. carbon dioxide and 1.43 p. p. m. oxygen.

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14. Winterstein, H. Beitrage zur Keuntniss der Fischatmung. arch fur die Jesanunte Physiologie des Menschen und Thiere. (Pfluger's archiv., v. 125, no. 73-98, 1908; Ecology, v. 10, p. 97, January-October, 1929.)

15. Reuss, H. Die Wirking der Kohlensaure auf die Atmung der neideren Wirbeltiere, insbesondere der Fische. (Zeit fur biol. v. 53, p. 555-587, 1910; Ecology, v. 10, p. 77-97, January-October, 1929.)

16. Shelford, V. E. and Allee, W. C. The reaction of fishes to gradients of dissolved atmospheric gases. (Ecology, v. 10, p. 80, January, 1929.)

Wells[17] attributed the toxic effect of carbon dioxide to acidity and stated that a low oxygen and high carbon dioxide combination was more fatal to fish than a low oxygen and low carbon dioxide content. He indicated that a certain degree of acidity is essential to normal fish life.

Krogh and Leitch,[18] in their work on blood of marine fishes and of trout, found that fish have an oxygen-carrying capacity nearly as great as that of mammals, but that this oxygen-carrying capacity is very much reduced by the presence of a small amount of carbon dioxide.

Jacobs[19] found that a saturated solution of carbon dioxide was by far more toxic to tadpoles than solutions of hydrochloric acid, acetic acid, and other acids of the same strength, (accurately, same pH) and concluded that this may be due to superior penetration. He also found[20] that free carbon dioxide even in a basic solution produced intercellular acidity, and[21] that the viscosity of living protoplasm is affected by exposure to carbon dioxide.

Gutsell[22] concluded that water deficient in oxygen was more quickly fatal with 39 p. p. m. carbon dioxide than with 24 p. p. m., a content which seems not to have been markedly harmful. One rainbow trout was normal and healthy after remaining in water containing 28 p. p. m. carbon dioxide for several days. Of two brook trout and two rainbow trout, three survived for days in water containing 32 or 33 p. p. m. In one instance a brook trout was alive after two hours in water containing about 37 p. p. m. carbon dioxide with oxygen varying from 2.25 to 1.77 p. p. m. Gutsell concluded

17. Wells, M. M. The resistance of fishes to different concentrations and combinations of oxygen and carbon dioxide. (Ecology, v. 10, p. 81, January, 1929.)

18. Krogh, A., and Leitch, I. The respiratory function of the blood in fishes. (Ecology, v. 19, p. 79, January, 1929.)

19. Jacobs, M. H. To what extent are the physiological effects of carbon dioxide due to hydrogen ions? (Ecology, v. 10, p. 79. January, 1929.)

20. Jacobs, M. H. The production of intracellular acidity by neutral and alkaline solutions containing carbon dioxide. (Ecology, v. 10, p. 79, January, 1929.)

21. Jacobs, M. H. The effects of carbon dioxide on the consistency of protoplasm. (Ecology, v. 10, p. 79. January, 1929.)

22. Gutsell, James S. Influence of certain water conditions, especially dissolved gases, on trout. (Ecology, v. 10, p. 77-97, January-October, 1929.)

from his work that carbon dioxide to the extent of about 40 p. p. m. or 20 cubic centimeters per liter is not markedly harmful to tront.

Temperature

Embody [23] states that the role of water temperature as a limiting factor in the successful stocking of fish has long been recognized. It is a well known fact that the temperature tolerance of different species of fishes varies greatly. The tolerance which the various fresh water species (trout, etc.), will undergo is of much more interest than the tolerance of the warm water fishes. These warm water fishes will tolerate a wide range of temperature in natural waters, although warm waters are more favorable for them than cold. The trout seem to have a relatively limited temperature range. Any policy of fish culture is greatly concerned with the upper limits of temperature which occur in any body of water occupied by trout. These upper limits are all important. Yet water can be too cold, and when any water is too cold for optimum growth of trout, the fish culturist is also concerned.

The following tables were compiled by Dr. G. C. Embody:[24]

RELATION OF AIR AND WATER TEMPERATURES IN TROUT STREAMS LOCATED IN OPEN COUNTRY UP TO 1,000 FEET ELEVATION

At air temp. deg. Fahr.	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0
Brook trout water should not exceed deg. Fahr.	65.0	66.5	68.0	70.0	71.5	73.0	74.0	75.0
Brown and rainbow trout water should not exceed deg. Fahr.	69.0	70.5	72.0	73.5	75.0	76.5	78.0	79.0

23. Embody, G. C. Report upon a study of the fish-producing waters of Tompkins county. Albany, New York, J. B. Lyon Co., 1933. (State of New York conservation department. Biological survey. Bulletin no. 7.)

24. Embody, G. C. Biological survey of the Oswego river system. Albany, New York, J. B. Lyon Co., 1933, p. 31. (State of New York conservation department. Biological survey. Bulletin no. 7.)

RELATION OF AIR AND WATER TEMPERATURES IN TROUT STREAMS LOCATED IN FORESTED COUNTRY ABOUT 1,000 FEET ELEVATION

At air temp. deg. Fahr.	80	82	84	86	88	90
Brook trout water should not exceed deg. Fahr.	71	72	73	74	75	76

The different species of trout have a variation in the temperature requirements. These variations have been determined by Dr. G. C. Embody,[25] of the Aquicultural Laboratory of Cornell University, for the brook, brown, and rainbow trout. In favorable conditions for brook trout, the water temperature should not go above 68°F; for tolerant conditions the temperature may range upward to 75°F, but not higher. The rainbow and brown trout are somewhat more tolerant than the brook trout. Both of these fish can tolerate temperatures up to 80°F.[26] The above results have been recently checked by Hubbs,[27] Greely, and Tarzwell, on trout streams in Michigan. They further suggested that natural waters varying between 60° and 70°F are more suitable to the growth of brook trout than those which remain at lower temperatures. Brown trout show a more rapid growth and attain larger size in the large streams which range between 70° and 80°F. Rainbows will tolerate as high temperatures as browns and will also thrive in cold water suitable for brook trout.

Creaser[28] concluded that the maximum temperature for natural self-sustaining brook trout water is 66°F. This is the toleration limit for waters of ordinary aeration and is the deciding factor in determination of habitat of brook trout. Streams with water approaching the maximum tem-

25. Embody, G. C. An outline of a stream study and the development of a stocking policy. Albany, New York, J. B. Lyon Co., 1933. p. 29. (State of New York conservation department. Biological survey. Bulletin no. 7.)

26. And somewhat higher, for several days, if the waters are fairly well shaded.

27. Hubbs, C. L., and others. Methods for the improvement of Michigan trout streams. Ann Arbor, University of Michigan, 1932. p. 14. (Institute for fisheries research. Bulletin no. 1.)

28. Creaser, C. W. Relative importance of hydrogen-ion concentration, temperature, dissolved oxygen and carbon dioxide tension, on habitat selection by brook trout. (Ecology, v. 11, p. 246-262, April, 1930.)

perature tolerated by trout are more favorable for rapid growth of the fish than those of very cold water; therefore, it seems that the best trout streams are in a delicate balance. The effect of temperature is not an indirect result of the influence on dissolved oxygen content, since in natural streams the variation in dissolved oxygen content was not closely related with the temperature but seemed to be most influenced by the abundance of oxygen-consuming materials, such as decaying organic matter.

While it is true that as temperatures rise the amount of oxygen needed to sustain trout increases, more rise in temperature alone (and we know that the solubility of oxygen in water decreases as the water temperatures rise) is not as responsible for greatly diminished oxygen content of water, as is the effect of this increase in temperature in causing rapid oxidation of oxygen consuming material in the water.

McCay [29] and associates, after some feeding experiments with brook trout under conditions of decreasing water temperature, indicate that spawning is a function of size as well as of age. These workers conclude that temperature shows no influence upon the growth rate when a condition of optimum nutrition is maintained. The decline of the growth rate during the spawning period is correlated with the attainment of sexual maturity. If growth rate bears a relation to temperature, it must be an indirect one. The results suggest a method for the control of the spawning season by the simultaneous manipulation of food and water temperature.

29. McCay, C. M., and others. Influence of water temperature upon growth and reproduction of brook trout. (Ecology, v. 11, p. 30-34, January, 1931.)

Hydrogen Ion Concentration (pH) [30]

According to Saunders [31] the hydrogen ion concentration of natural waters depends on: (1) the concentration of dissolved carbonates and bicarbonates; (2) the concentration of carbon dioxide; (3) the concentration of the natural salts; and (4) the temperature.

Jewell [32] found fish and other animals apparently thriving in a stream containing mineral acids. Jewell and Brown [33] found fish inhabiting a very acid lake (pH 4.4), the acidity of which they decided was not due to carbon dioxide, but probably acids from sphagnum (bog or peat mosses). Brown and Jewell [34] found that fish transferred directly from decidedly basic lake water to the lake containing acid water suffered no ill effects. In a gradient tank supplied at one end with water from the acid lake and at the other from the basic lake, fish from the acid lake chose the acid end, those from the basic lake, the basic end, and those from water intermediate in pH the middle of the gradient. Some brook trout showed preference for the neutral zone.

Shelford [35] reports that the ill effects of low oxygen is increased by high pH and insisted that this is principally due to the free hydrogen ions.

30. The hydrogen ion concentration, often referred to as pH, is an indication of alkalinity or acidity of the water. If H ions and OH ions are present in the water in equivalent amounts, the water is said to be neutral or has a pH 7. When H ions are more abundant than OH ions, the values in the pH scale are lèss thn 7.0. An excess of OH ions present gives a greater pH than 7.0. Everyone is familiar with the Fahrenheit thermometer. On this scale, 32° represents the freezing point of water. For the sake of illustration, we shall assume that values above and below 32° represent degrees of heat and coldness respectively. Thus, any values higher than 32°, such as 34 deg., 36 deg., 40 deg., etc. denotes an increase in heat, the degree of heat increasing as the numbers increase. On the other hand, any values below 32 deg., such as 30 deg., 28 deg., 20 deg., etc. denotes an increase in coldness, the degree of coldness increasing as the numbers decrease.

In an exactly similar manner, the degree of acidity or alkalinity of a solution is expressed by the Hydrogen-Ion scale. Instead of being called degrees, as in the case of the thermometer, the units on this scale are called pH values. It is apparent that it is not necessary for a person to know the derivation of the term "degree Fahrenheit" in order to determine the temperature of the solution. It is equally true that the worker need not know the meaning of the term "pH" in order to use this method for measuring acidity and alkalinity. On the Hydrogen-Ion scale, a value of pH 7.0 represents neutrality. This means that if the material being tested has a pH of 7.0, it is neither acid nor alkaline.

Hall [36] found that young whitefish died more rapidly in water low in oxygen but with carbon dioxide added to acidity, than in basic water low in oxygen, and that fish which would choose the acid end of a tank in which a pH gradient of from 6.4 to 9.0 was maintained would choose the basic end in a gradient of 8.0 to 9.0.

Creaser and Brown [37] found trout abundant and completing their entire life-history in basic waters, and concluded that the hydrogen ion concentration has little to do with the toleration of brook trout for a given habitat, but that temperature is the deciding factor. Creaser [38] states that the range of pH for brook trout extends from 4.1 to 9.5, a range greater than the maximum and minimum values found in natural waters.

Gutsell [39] found that slightly acid water of a hatchery spring was satisfactory for trout until oxygen became de-

36. Hall, Ada R. Effects of oxygen and carbon dioxide on the development of whitefish. (Ecology, v. 6, p. 104-116, April, 1925.)

37. Creaser, C. W., and Brown, H. W. The hydrogen-ion concentration of brook trout waters of northern lower Michigan. (Ecology, v. 8, p. 98-105, January, 1927.)

38. Creaser, C. W. Relative importance of hydrogen-ion concentration, temperature, dissolved oxygen and carbon dioxide tension, on habitat selection by brook trout. (Ecology, v. 11, p. 246-262, April, 1930.)

39. Gutsell, James S. Influence of certain water conditions, especially dissolved gases on trout. (Ecology, v. 10, p. 77-97, January-October, 1929.)

Following the illustration of the thermometer given above, any values higher than pH 7.0, such as 7.2, 7.4, 8.0, 9.0, 10.0, etc., denote alkalinity, the degree of alkalinity increasing as the numbers increase. Analogously, any values lower than pH 7.0, such as 6.8, 6.6, 6.0, 4.0, 2.0, etc., denote acidity, the degree of acidity increasing as the numbers decrease. This will be clear from the following tabulation of pH values:

Acid	*Neutral*	*Alkaline*
etc.6.0, 6.2, 6.4, 6.6, 6.8	7.0	7.2, 7.4, 7.6, 7.8, 8.0, etc

31. Saunders, J. T. The hydrogen-ion concentration of natural waters. I. The relation of pH to the pressure of carbon dioxide. (British journal of experimental biology, v. 4 (1), p. 46-72, 1926; Biological abstracts, v. 2, no. 9-11, article 15800, September, 1928.)

32. Jewell, Minna E. The fauna of an acid stream. (Ecology, v. 3, p. 22-28, January, 1922.)

33. Jewell, Minna E., and Brown, H. The fishes of an acid lake. (American microscopic society. Transactions. Indianapolis, 1924. v. 42, p. 77-84.)

34. Brown, H. W., and Jewell, Minna E. Further studies on the fishes of an acid lake. (American microscopic society. Transactions. Indianapolis, 1926. v. 45, p. 20-34.)

35. Shelford, V. E. The determination of hydrogen-ion concentration in connection with fresh-water biological studies. Urbana, Illinois, natural history survey, 1923. p. 379-395. (Illinois natural history survey. Bulletin, v. 14.)

pleted. Because of these findings he concludes that trout are hardy to a considerable variation in pH.

Schaperclaus [40] concluded that the buffer action of carbonates, chiefly calcium carbonate present in most German waters, is a carbon dioxide regulator. Depletion of carbon dioxide by plants is compensated by liberation of carbon dioxide from calcium bicarbonate (sufficient in waters of New Mexico) in waters that have a high titratable alkalinity, but in soft waters this causes an enormous increase in pH and may be a factor in air bladder disease in trout. Increase of carbon dioxide does no harm unless aided by strong acids or their highly ionized salts of weak bases. Fishes are euryionic, i. e., capable of living in a wide range of pH. The lower limit is sharply defined at the lethal point for fresh water fishes (pH 4.8). The upper limit is indefinite, probably well above pH 8. Evidence is given that there is a tendency to move toward the optimal pH (7-8).

Chemical Factors with Relation to Fish Food

In order to support animals and plants continuously, water must contain certain minerals and gases in solutions.[41] Salts (carbonates, sulfates and chlorides) of magnesium, calcium, potassium, and sodium, and salts of iron and silicon are practically always in solution in water and their presence in definite proportions has been shown to be essential to the life of organisms.

Free oxygen is considered necessary to most organisms except anaerobic bacteria. Juday has shown that a large list of common protozoa, worms, insects, etc., can live for a long time without free oxygen. These organisms occur in organic muds of the bottoms of lakes and ponds. They evidently obtain oxygen from some chemical compounds.

Powers [42] concludes that aquatic organisms are able to

40. Schaperclaus, W. The acidity of fresh water and its relation to fish. (Biological abstracts, v. 4, no. 3, article 6926, March, 1930).

41. Ward, H. B., and Whipple, G. C. Fresh-water biology. p. 25-60.

42. Powers, E. B. The relation between pH and aquatic animals. (Biological abstracts, v. 5, article 19411, August, 1931.)

withstand wide ranges in pH. They are affected in their physiological processes and behavior by changes in carbon dioxide and oxygen content; of the two, the carbon dioxide is the more effective. Their internal environment is regulated to harmonize with the external environment, the rate and the range of which are characteristic of the species and are no doubt factors in determining their distribution and migratory movements.

Lowndes[43] states that a gradual change in pH has no direct or toxic influence on copepods, though there may be an optimum value of hydrogen-ion concentration preferred by each species.

Titcomb[44] found that *Grammarus limnaeus* (fresh-water shrimp) thrives only in water having a total hardness of at least 200 p. p. m. as determined by the soap method, while *G. fasciatus* is found in waters of hardness from 16 to 22 p. p. m. *G. limnaeus* introduced into soft waters disappears quite rapidly.

Nitrates are necessary for the growth of aquatic plants and insufficient quantities are secured from mineral soil.[45] Nitrogen can be fixed only by nitrogen fixing bacteria (anaerobes and aerobes). These bacteria occur on plants and animals in the mud at the bottom of bodies of water. Plants and animals provide carbon compounds for the bacteria and bacteria provide nitrates or nitrites. The quantity of life in water is believed to be in proportion to the available nitrogen compounds. Dissolved oxygen is necessary for some of the nitrogen fixing processes. Oxygen is necessary for the production of carbon dioxide, which is in turn essential for starch building of chlorophyl-containing plants and animals. These green organisms form the chief food basis of all other organisms.

43. Lowndes, A. G. Fresh-water copepods and pH concentration. (Biological abstracts, v. 3, article 474, January-March, 1929.)

44. Titcomb, John W. The fresh-water shrimp for replenishing food in trout streams. Hartford, Connecticut, American fisheries society, 1927. p. 15-161. (American fisheries society, Transactions, v. 27.)

45. Ward, H. B., and Whipple, G. C. Fresh-water biology. p. 25-60.

Comments on Biological and Other Physical Factors

In streams, the strength of the current is a function of volume of water and slope of stream bed.[46] The amount of sediment carried and the size of the sediment particles is determined by the strength of the current and by the character of the materials eroded. The bottom of a swift stream eroding sandy soil is very unstable and the fauna very scarce. Such streams are essentially aquatic deserts (Drainage ditches when first completed) and only a few burrowers are able to live in them. Sand bottomed streams with sluggish current have a luxuriant fauna of burrowers and flora of rooted vegetation. Rock and stony streams have rich faunas of clinging and hiding animals. Many aquatic animals use the bottom materials in the construction of their cases, nests, etc. Thus the caddis worms build cases of sand grains weighted at the sides by small pebbles, also from wood.

The amount and kind of rooted vegetation are very important to animals. The vegetation of young streams consists largely of holdfast algae similar to those among the rocky shores of a lake. Those are of importance to animals. Sluggish streams have rooted aquatic vegetation. This vegetation is used as breeding places.

Numbers of animals select the same environment because of physiological similarity. All the animals occupying a relatively uniform habitat constitute an animal community. Animals living beneath stones show a preference for weak light; those living on stones, medium light; those among stones, strong light. The pool community shows striking difference from the rapids community. Each animal prefers certain food. Any marked change of conditions will disturb the balance in an animal community.

The causes of fluctuations of numbers of organisms are numerous. Cold winters often destroy aquatic vertebrates.

46. Ward, H. B., and Whipple, G. C. Fresh-water biology. p. 25-60.

Heavy rainfall dilutes the plankton, and in streams, carries it away.[47] Too little sunshine causes a poor production of the chlorophyll-bearing organisms which are the food of others. Open winters favor denitrification and may be unfavorable to certain lower invertebrates. Various aquatic organisms must possess natural immunity for the various decomposition products of fresh water.

The different food needs of a fish species at different stages dictate that there must be a proper supply of the right type of food at the right time for the carrying of young[48] or adult fish, for production depends upon the completion of an entire life cycle, not upon the superabundance of a food organism suitable for adults and scarcity of organisms suitable for young. In many waters, the key to the explanation of the decline of game fishes, as well as the possible path toward restoration of game fish, centers about the food problem. As often has been the case, partial depletion of the trout supply has led someone to try bass, perch, or other species which have usually proven a poor exchange. The trout waters which now remain unspoiled are worth every effort that can be given toward keeping them unspoiled. When the environment is ruined, protection and propagation are powerless to bring back the trout.

47. A serious condition in many New Mexico streams. Overgrazing leaves watersheds very poor in water-retaining vegetation. Some of the bare mountain slopes on the Pecos, which were denuded by goats, are pitiful to look at.

48. It is surprising how the fishing improves in any water having large submerged rush piles placed around near its shores. The brush, in decaying, furnishes plant food, small insects gather to eat the plants, small fish to eat the insects and to gain cover. Large fish thus have an increased food supply.

Results of This Study

Station One is located on the Albuquerque Riverside Drain about one hundred yards east of the Rio Grande bridge at Alameda. Two and one-tenth miles down the Albuquerque Riverside Drain is located Station Number Two. The third station on this drain is located west of Old Albuquerque, six miles down stream from Station Two and eight and one-tenth miles below Station Number One. Water samples were taken from this drain from March 3, 1934, to February 24, 1935.

The Corrales Lateral Drain empties into the Rio Grande at the bridge at Alameda on the west side. About four hundred yards above the mouth of this drain is located Station Number Four. Water samples were taken from this station from April 7, 1934, to February 24, 1935.

Six miles south of Albuquerque and east of the old tobacco farm on the Atrisco Riverside Drain is located Station Five. Station Six is eight miles south of Station Five on the Atrisco Riverside Drain near Isleta. These stations were established May 5, 1934, and samples were taken until February 24, 1935.

Water samples were taken at seven-day intervals with few exceptions. However, in December, January, and February samples were taken only once a month.

The temperature of the water at Station One ranged from 42.8°F. on March 3, 1934, to 82.4°F. on August 3, 1934. Dissolved oxygen was 5.10 parts per million May 19, 1934 (59.9°F., after rain), and 11.56 p. p. m. August 18, 1934. On May 19, 1934, the water was 60.71 per cent saturated with oxygen and on August 3, 1934, it was 173.11 per cent saturated.[49] Free carbon dioxide was not found present (one exception—March 10, 1934—0.10 p. p. m.) until September 30, 1934. The highest amount obtained was February 24, 1935, which was 3.50 p. p. m. The phenolphthalein alkalin-

49. Oxygen liberating plants abundant, and cause supersaturation.

ity showed a variation from 2.10 p. p. m. on May 12, 1934, to 16.90 p. p. m. on June 23, 1934. Methyl orange alkalinity showed 114.7 p. p. m. on August 11, 1934, and 171.5 p. p. m. on July 27, 1934. The pH range was from 8.13 to 8.60.

There is very little difference in the range of temperature at Station Two and One. The p. p. m. of dissolved oxygen varies from 4.44 on July 12, 1934, to 14.36 August 11, 1934. The saturation of the water with oxygen shows 57.29 per cent July 12, 1934, and 211.61 per cent August 3, 1934. Very little free carbon dioxide was found until September 30, 1935. The free carbon dioxide ranged from 1.00 p. p. m. to 3.00 p. p. m. The phenolphthalein alkalinity varied from 2.10 p. p. m. to 18.80 p. p. m. and the methyl orange alkalinity showed a variation from 115.9 p. p. m. to 179.0 p. p. m. The pH range was the same as that for Station One.

For Station Three, the temperature, free carbon dioxide, phenolphthalein, and methyl orange alkalinity, and pH ranges are practically the same. The parts per million of dissolved oxygen shows a variation of 5.92 on May 19, 1934, to 9.20 on January 12, 1935. Saturation of water with oxygen is less than in Stations One and Two. It ranges from 70.57 per cent March 3, 1934, to 119.13 August 18, 1934.

At Station Four the temperature ranged from 44.6°F. February 24, 1935, to 95°F. August 11, 1934. The free carbon dioxide, phenolphthalein, and methyl orange alkalinity and pH ranges at this station are about the same for Stations One, Two, and Three. Parts per million of dissolved oxygen varies from 5.70 on August 18, 1934, to 9.12 on April 7, 1934, and the percentage saturation ranges from 72.93 October 7, 1934, to 108.83 May 5, 1934.

Temperatures at Station Five ranged from 48.2°F. on February 24, 1935, to 84.2°F. on July 21, 1934. Free carbon dioxide appeared only in four water samples taken, and then only in small amounts (0.0–1.50 p. p. m.), The range of phenolphthalein alkalinity is from 0.60 p. p. m. on December 2, 1934, to 14.10 p. p. m. July 5, 1934, and the methyl orange range is from 123.5 p. p. m. August 25, 1934, to 221.8 p. p. m. July 28, 1934. Dissolved oxygen varies from 3.58 p. p. m. on July 28, 1934, to 11.40 p. p. m. on October 7, 1934, and with a saturation of 47.67 to 175.38 per cent on the respective days. The pH ranges from 8.2 to 8.60.

Station Six temperatures ranged from 44.6°F. February 24, 1935, to 83°F. August 3, 1934. Free carbon dioxide appeared in September and was still present February 24, 1935. The range was from 0.50 p. p. m. February 24, 1935, to 5.80 p. p. m. October 19, 1934. The pH and alkalinity range was about the same as for Station Five. The range of dissolved oxygen was rather wide—4.00 p. p. m. October 19, 1934, and 15.82 p. p. m. July 21, 1934, with a saturation of 51.22 to 238.25 per cent on the same dates.

STATION NO. 1

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free CO_2 Parts Per Million	Alkalinity Parts per Million Calcium Carbonate		Dissolved Oxygen		pH	Remarks
		Air	Water		Phenol-phthalein	Methyl Orange	Parts per Million	Per Cent Saturation		
3/ 3/34	9:30	46.4	42.8		2.80	149.8	7.20	69.03		Clear
3/10/34	5:00	63.5	51.8	0.1		146.4	7.80	84.23		Clear
3/17/34	4:00	55.4	51		4.10	150.4	8.30	87.64		Windy—Unsettled
3/23/34	4:00	44.6	48.2		5.90	175.9	8.30	85.74	8.23	Unsettled—Snowing
3/31/34	4:00	72.5	50		4.00	165.4	8.28	87.48	8.13	Windy—Sandstorm
4/ 7/34	4:00	68	54.5		5.50	154.7	8.20	91.52	8.13	Clear
4/15/34	10:00	70.7	51.8		4.00	155.8	7.40	79.91	8.23	Windy—Cloudy
4/18/34	4:30	64.4	57.2				7.32	84.43		
4/21/34	4:30	71.6	56.3		2.00	148.2	6.56	74.89	8.13	Partly Cloudy—Windy
4/28/34	3:30	73.4	60.8		5.00	147.5	7.62	92.81	8.23	Partly Cloudy
5/ 5/34	4:00	87.8	60.8		3.00	147.7	7.42	90.38	8.03	Clear
5/12/34	5:00	86	59		2.10	147	6.20	73.11	8.23	Clear
5/19/34	6:15	75.2	59.9		8.70	154.6	5.10	60.71	8.33	Windy—Rain
6/ 2/34	3:15	83.3	66.2		8.30	158.2	7.18	91.23	8.20	Windy
6/10/34	2:15	91.4	71.6		13.20	161.3	7.38	100.00	8.30	Clear
6/14/34	3:15	93.2	71.6		12.80	164.6	8.36	113.28	8.30	Clear
6/23/34	2:00	82.4	74.3		16.90	165.8	9.26	128.79	8.60	Cloudy—Hot
6/31/34	4:15	86	74.3		8.00	148.2	8.40	116.83	8.40	Cloudy
7/ 5/34	2:15	95	78.8		10.50	156.1	10.06	146.43	8.40	Clear
7/12/34	9:00	87	67.1		6.60	164.2	8.46	109.30	8.30	Cloudy—Windy
7/21/34	10:30	82.4	72.5		10.20	162.2	11.06	149.36	8.50	Cloudy—Windy
7/27/34	10:15	86	67.1		9.10	171.5	10.72	139.00	8.40	Clear—After Rain
8/ 3/34	4:30	93.2	82.4		11.50	138.1	11.46	173.11	8.50	Recent Heavy Rains
8/11/34	3:30	86	80.6		10.20	114.7	10.26	152.22	8.40	Cloudy—Windy
8/18/34	11:15	87.8	74.3		7.40	126.7	11.56	160.78	8.40	Clear
8/25/34	7:45	77	73.4		6.30	138.8	8.68	119.72	8.40	Cloudy
8/28/34	2:15	67.1	65.3		6.70	146.2	8.06	102.50	8.40	Continuous Rain—2 days
9/ 5/34	8:30	73.4	62.6		5.40	144.9	7.48	91.89	8.30	Clear
9/30/34	10:00	68.9	60	2.00		156.0	7.30	86.90	8.40	Clear
10/7/34	9:30	66.2	59	1.50		154.0	6.20	73.11	8.40	Clear
10/19/34	10:00	62.6	62.6	3.00		153.0	6.30	77.40	8.40	Cloudy—Rain
10/27/34	10:00	59	58.1	1.40		155.0	6.80	77.62	8.40	Clear
11/18/34	9:45	59	57.2	1.20		153.0	6.40	73.82	8.40	Clear
11/25/34	10:45	48.2	55.4	2.70		167.0	7.20	82.26	8.40	Clear
1/12/35	11:00	42.8	48.2	1.00		166.0	8.60	88.84	8.60	Clear
2/24/35	10:00	41	44.6	3.50		170.0	7.42	72.96	8.60	Clear

STATION NO II

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free CO_2 Parts Per Million	Alkalinity Parts per Million Calcium Carbonate		Dissolved Oxygen		pH	Remarks
		Air	Water		Phenol-phthalein	Methyl Orange	Parts per Million	Per Cent Saturation		
3/ 3/34	10:00	46.4	42.8		3.00	154.0	6.70	64.24		Clear
3/10/34	5:30	62	51.8		2.90	156.9	7.28	78.62		Clear
3/17/34	4:30	53	51		8.00	154.1	9.20	97.87		Windy—Unsettled
3/23/34	4:30	43.8	47		8.40	154.9	8.90	90.65	8.13	Unsettled—Snowing
3/31/34	4:30	69.8	50		5.00	164.1	8.70	91.87	8.13	Windy—Sandstorm
4/ 7/34	4:30	68	57.2		6.10	156.5	8.52	98.27	8.28	Clear
4/15/34	11:00	71.6	53.6		5.00	151.6	8.50	93.92	8.13	Cloudy—Windy
4/18/34	5:00	63.5	56.3				7.64	87.21		
4/21/34	3:30	74.3	59.9		3.20	151.0	7.90	94.05	8.23	Partly Cloudy—Windy
4/28/34	3:00	78.8	60.8		6.00	151.0	8.38	100.84	8.23	Partly Cloudy
5/ 5/34	4:45	84.2	62.6		5.00	145.7	7.76	94.86	8.18	Clear
5/12/34	5:15	84.2	59.2		2.10	150.2	6.80	80.76	8.33	Clear
5/19/34	6:40	75.2	60.8		14.00	159.0	5.80	69.79	8.33	Windy—Rain
6/ 2/34	3:30	82.5	66.2		7.00	152.9	8.36	107.04	8.20	Windy
6/10/34	2:45	92	72		14.40	156.4	8.30	112.92	8.30	Clear
6/14/34	3:00	90	75.2		18.70	160.7	10.32	144.74	8.20	Clear
6/23/34	2:30	84	72		15.30	157.6	11.22	152.65	8.50	Cloudy—Hot
6/30/34	5:00	86	72		10.20	151.5	11.78	160.27	8.50	Cloudy
7/ 5/34	3:00	96	77		11.50	146.9	10.98	156.86	8.60	Clear
7/12/34	9:30	87.8	67	0.2		169.1	4.44	47.29	8.20	Cloudy—Windy
7/21/34	10:45	81	69.8		3.20	164.9	7.28	96.94	8.2	Cloudy—Windy
7/27/34	9:30	82	65		2.10	175.2	5.74	72.47	8.2	Clear—After Rain
8/ 3/34	5:00	92	81		18.80	137.1	14.22	211.61	8.5	Recent Heavy Rains
8/11/34	3:45	86	79		11.2	118.8	14.36	209.63	8.4	Cloudy—Windy
8/18/34	11:30	88	72	0.50		143.1	7.94	108.03	8.3	Clear
8/25/34	7:00	74	75		10.2	115.9	12.48	178.99	8.6	Cloudy
8/28/34	3:00	68	64		3.8	145.8	7.42	92.63	8.4	Continuous Rain—2 Days
9/ 5/34	9:00	73	63		6.9	133.3	7.62	93.96	8.4	Clear
9/30/34	10:30	68.9	60.8	1.80		156.0	7.20	86.64	8.4	Clear
10/ 7/34	10:00	69.8	59.9	3.00		153.0	5.80	69.05	8.4	Clear
10/10/34	10:30	62.6	62.6	2.55		151.8	5.80	65.11	8.2	Cloudy—Rain
10/27/34	10:25	59	58.1	2.30		151.0	6.40	73.06	8.4	Clear
11/18/34	10:15	62.6	50.1	1.70		154.0	6.76	77.17	8.4	Clear
11/25/34	11:00	50	55.4	2.30		165.0	7.14	80.59	8.4	Clear
12/ 2/34	10:30	37.4	53.6	2.20		179.0	7.20	79.56	8.4	Clear
1/12/35	11:30	46.4	48.2	1.00		173.0	8.60	88.84	8.6	Clear
2/24/35	10:20	42.8	44.6	2.50		170.0	7.04	69.22	8.6	Clear

STATION NO. III

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free Co_2 Parts Per Million	Phenol-phthalein	Methyl Orange	Dissolved Oxygen		pH	Remarks
		Air	Water		Alkalinity Parts per Million Calcium Carbonate		Parts per Million	Per Cent Saturation		
3/ 3/34	10:30	47	44		3.00	149.2	7.24	70.57		Clear
3/10/34	6:00	60	51		1.00	159.2	6.94	73.83		Clear
3/17/34	5:00	51	50	0.10		148.0	7.30	77.66		Windy—Unsettled
3/23/34	5:00	42.8	46.4		6.30	158.3	7.42	74.80	7.93	Unsettled—Snowing
3/31/34	5:00	66	49		2.90	150.3	8.00	83.51	7.93	Windy—Sandstorm
4/ 7/34	5:00	68	57.2		4.00	148.0	7.70	88.81	8.03	Clear
4/15/34	11:30	71.6	53.6		5.00	151.3	7.80	86.19	8.13	Windy—Cloudy
4/18/34	5:30	63.5	56.3				7.10	81.05		
4/21/34	4:00	77.9	59.9		2.00	143.1	7.38	87.86	8.03	Partly Cloudy—Windy
4/28/34	2:30	75.2	62.6		2.00	143.7	7.70	94.13	8.23	Partly Cloudy
5/ 5/34	6:30	84.2	62.6		3.50	144.2	6.84	83.62	8.03	Clear
5/ 6/34	3:00	89.6	66.2		7.00	145.0	7.20	92.31	8.03	Clear
5/12/34	5:45	84:2	59.9	1.10		142.4	6.58	78.33	8.23	Clear
5/19/34	6:00	75.2	61.7		6.10	154.6	5.92	71.93	8.33	Windy—Rain
6/ 2/34	4:30	82	68		3.60	154.8	6.70	87.47	7.90	Windy
6/10/34	3:30	91	72		12.40	160.4	6.74	91.70	8.20	Clear
6/14/34	4:00	90	75.2		9.00	153.4	6.72	94.25	8.30	Clear
6/23/34	8:00	84	77.9		8.10	159.7	6.78	97.69	8.60	Cloudy—Hot
7/ 1/34	4:00	85.1	76		4.50	161.0	6.34	89.55	8.40	Cloudy
7/ 5/34	3:30	96	82		8.40	163.2	6.80	101.04	8.20	Clear
7/11/34	7:30	90	77		6.70	162.0	6.26	89.43	8.40	Cloudy—Windy
7/21/34	11:15	81	75		8.00	176.9	7.86	110.08	8.4	Cloudy—Windy
7/27/34	11:30	86	75.2		8.50	157.1	7.00	98.18	8.3	Clear After Rain
8/ 3/34	5:30	90	81		7.70	155.0	6.34	94.34	8.3	Recent Heavy Rains
8/11/34	4:20	90	85		8.00	143.2	6.90	107.14	8.4	Windy—Cloudy
8/18/34	12:10	92	82		6.90	141.6	8.22	119.13	8.4	Clear
8/25/34	6:00	75	79		5.80	136.0	6.84	99.85	8.4	Cloudy
8/28/34	4:00	68	65		3.10	142.7	8.24	104.04	8.3	Continuous Rain —2 Days
9/ 5/34	9:45	78	63		4.50	166.8	6.48	79.90	8.4	Clear
9/30/34	11:00	71.6	62.6	1.50		157.5	7.00	86.00	8.4	Clear
10/ 7/34	10:30	73.4	62.6	2.00		156.5	6.90	84.77	8.4	Clear
10/19/34	11:00	66.2	62.6		1.00	157.0	7.04	86.49	8.4	Cloudy—Rain
10/27/34	10:45	60.8	59	1.70		149.0	7.40	87.26	8.4	Clear
11/18/34	10:45	62.6	57.2	1.60		153.5	7.08	81.66	8.4	Clear
11/25/34	11:30	54.5	55.4	1.60		170.0	7.80	88.04	8.4	Clear
12/ 2/34	11:00	37.4	51.8	2.00		174.0	8.20	88.55	8.4	Clear
1/12/35	12:00	48.2	50	0.50		164	9.20	97.15	8.6	Clear
2/24/35	11:30	42.8	44.6	3.00		167.0	8.16	80.24	8.6	Clear

STATION NO. IV

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free CO_2 Parts Per Million	Alkalinity Parts per Million Calcium Carbonate		Dissolved Oxygen		pH	Remarks
		Air	Water		Phenol-phthalein	Methyl Orange	Parts per Million	Per Cent Saturation		
4/ 7/34	4:30	68	59.9		8.80	157.7	9.12	108.57	8.23	Clear
4/15/34	10:00	71.6	55.4		5.00	143.0	7.64	86.23	8.03	Windy—Cloudy
4/18/34	4:30	64.4	59.9				7.40	88.34		
4/21/34	4:30	71.6	59.9		2.50	134.0	7.80	92.86	8.03	Partly Cloudy—Windy
4/28/34	4:00	75.2	66.2		5.10	135.5	8.38	107.30	8.23	Partly Cloudy
5/ 5/34	4:00	87.8	68.9		5.20	139.0	8.28	108.83	8.13	Clear
5/12/34	4:45	86	64.4		5.30	140.3	7.42	93.10	8.13	Clear
5/19/34	6:30	75.2	64.4		12.30	145.4	7.40	92.85	8.23	Windy—Rain
6/ 2/34	3:00	82	70.7		7.40	142.7	7.06	93.02	8.20	Windy
6/10/34	2:00	90	77		12.30	159.4	7.48	106.85	8.20	Clear
6/14/34	2:30	94	77		13.20	170.6	7.52	107.43	8.40	Clear
6/23/34	1:45	85	82		10.50	168.7	7.10	105.50	8.40	Cloudy—Hot
6/30/34	4:00	86	82		7.90	162.8	6.84	101.63	8.40	Cloudy
7/ 5/34	2:00	95	91		14.70	176.3	6.68		8.40	Clear
7/12/34	8:00	86	72		8.90	202.4	6.90	93.88	8.30	Cloudy—Windy
7/21/34	10:15	85	81		5.30	169.6	6.54	97.32	8.40	Cloudy
7/27/34	10:00	84.2	75.2		5.20	148.6	7.14	100.14	8.20	Clear After Rain
8/ 3/34	4:00	93	90		6.60	141.9	7.26		8.20	Recent Heavy Rains
8/11/34	3:00	87	95		11.80	148.3	6.94		8.50	Windy—Cloudy
8/18/34	11:00	90	82	1.80		151.9	5.70	84.69	8.30	Clear
8/25/34	7:30	77	77		7.00	127.7	6.64	94.86	8.40	Cloudy
8/28/34	2:00	65	65		4.90	114.1	7.78	98.23	8.3	Continuous Rain—2-day
9/ 5/34	8:15	72	63		4.70	142.8	7.04	86.81	8.3	Clear
9/30/34	9:30	69	57.2	2.80		156.0	7.60	87.66	8.4	Clear
10/ 7/34	9:00	73.4	56.3	3.00		152.0	6.60	72.93	8.4	Clear
10/19/34	9:30	62.6	62.6		2.00	150.0	7.20	88.45	8.4	Cloudy—Rain
10/27/34	9:45	59	54.5	3.50		151.0	7.20	80.36	8.4	Clear
11/18/34	9:30	59	51.8	2.60		151.0	7.60	82.07	8.4	Clear
11/25/34	10:30	48.2	50.9	1.40		174.0	7.60	81.11	8.4	Clear
12/ 2/34	10:00	35.6	46.4	1.70	1	174.0	7.56	76.21	8.4	Clear
1/12/35	11:15	42.8	48.2	1.70		178.0	9.00	92.98	8.6	Clear
2/24/35	10:00	41	44.6	2.50		166.0	8.20	80.63	8.6	Clear

STATION NO. V

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free CO_2 Parts Per Million	Alkalinity Parts per Million Calcium Carbonate		Dissolved Oxygen		pH	Remarks
		Air	Water		Phenol-phthalein	Methyl Orange	Parts per Million	Per Cent Saturation		
5/ 6/34	4:00	87.8	68		12.90	165.8	7.80	101.83	8.23	Clear
5/12/34	4:00	89.6	65.3		1.50	162.6	7.40	93.79	8.33	Clear
5/19/34	5:30	78.8	64.4		5.70	180.4	6.78	85.07	8.43	Windy—Rain
6/ 2/34	5:30	80	60.8		4.40	189.9	7.48	90.01	8.30	Windy
6/ 9/34	7:00	78	69.8		8.70	182.8	5.08	67.64	8.20	Clear
6/14/34	5:30	91	78		12.50	182.8	7.34	105.76	8.30	Clear
6/23/34	4:30	86	73		7.40	188.6	7.34	100.83	8.50	Cloudy—Hot
7/ 1/34	5:00	86	77		9.10	182.9	6.36	90.86	8.50	Cloudy
7/ 5/34	5:00	95	80		14.10	193.2	8.52	125.66	8.60	Clear
7/11/34	4:15	81	73	0.30		192.1	4.96	88.13	8.20	Cloudy—Windy
7/21/34	4:45	86	84.2		7.00	172.6	7.84	120.80	8.40	Cloudy—Windy
7/28/34	9:00	75.2	69.8	1.50		221.8	3.58	47.67	8.20	Continuous Rain—2-day
8/ 3/34	7:00	83	75.2		2.10	179.1	4.36	68.16	8.20	Recent Heavy Rains
8/11/34	3:45	90	82		6.50	175.5	7.24	107.58	8.30	Windy—Cloudy
8/18/34	2:00	97	90		8.10	158.8	9.42		8.20	Clear
8/25/34	5:30	82	80		7.50	123.5	8.38	125.26	8.40	Cloudy
8/28/34	4:45	69.8	65		8.90	154.2	8.34	111.62	8.50	Continuous Rain—2-day
9/ 5/34	11:30	84	69.8		12.10	152.9	9.76	129.96	8.60	Clear
9/30/34	12:00	78.8	62.2		4.50	155.5	10.60	130.22	8.40	Clear
10/ 7/34	11:00	73.4	62.6		6.50	154.0	11.40	175.38	8.60	Clear
10/19/34	12:00	75.2	66.2		6.40	156.0	10.00	128.04	8.60	Cloudy—Rain
10/27/34	11:30	68	60.8	0.60		156.0	10.00	120.34	8.60	Clear
11/18/34	11:15	68	59.9		2.00	156.3	8.60	102.38	8.60	Clear
11/25/34	2:30	54.5	59		1.50	179.5	9.12	107.55	8.60	Clear
12/ 2/34	11:30	37.4	51.8		0.60	179.6	7.94	85.75	8.60	Clear
1/12/35	2:30	44.6	51.8		3.00	184.0	9.60	103.67	8.60	Clear
2/24/35	11:10	44.6	48.2	1.00		181.0	8.20	84.71	8.60	Clear

STATION NO VI

Date	Time Sample Taken	Temperature Degrees Fahrenheit		Free CO_2 Parts Per Million	Alkalinity Parts per Million Calcium Carbonate		Dissolved Oxygen		pH	Remarks
		Air	Water		Phenol-phthalein	Methyl Orange	Parts per Million	Per Cent Saturation		
5/ 6/34	4:30	89.6	69.8		22.90	176.9	11.98		8.33	Clear
5/12/34	3:30	89.6	68.9		6.80	182.1	13.14	173.03	8.43	Clear
5/19/34	5:00	77	62.6		14.90	195.5	13.50	165.85	8.53	Windy—Rain
6/ 2/34	5:15	80	62		3.00	205.3	8.56	104.39	8.30	Windy
6/ 9/34	7:30	77	69.8		6.20	200.7	8.22	109.45	8.20	Clear
6/14/34	5:00	93	76		16.50	196.9	13.00	184.13	8.20	Clear
6/23/34	4:00	86	72		11.20	195.6	12.36	168.16	8.50	Cloudy—Hot
7/ 1/34	4:30	86	77		7.60	187.6	13.68	195.43	8.50	Cloudy
7/ 5/34	4:30	96	78		10.20	192.0	13.68	197.12	8.30	Clear
7/11/34	8:30	87.8	77		3.70	185.6	8.22	117.48	8.30	Cloudy—Windy
7/21/34	4:00	86	82		14.30	173.8	15.82	238.25	8.60	Cloudy—Windy
7/28/34	9:30	75.2	78		2.10	188.2	8.02	115.56	8.20	Clear After Rain
8/ 3/34	6:30	84	83		9.00	180.4	12.16	193.46	8.30	Windy—Cloudy
8/11/34	4:30	88	82		10.30	159.2	13.02	193.46	8.30	Windy—Cloudy
8/18/34	1:30	92	82		1.80	163.3	7.20	106.98	8.20	Clear
8/25/34	5:00	86	75		11.30	152.7	8.96	125.49	8.40	Cloudy
8/28/34	6:00	69.8	68		6.80	169.3	10.40	135.77	8.50	Continuous Rain—2-day
9/ 5/34	10:45	83	63	0.60		182.6	6.28	77.44	8.30	Clear
9/30/34	11:30	80.6	57.2	4.50		179.0	5.96	68.74	8.20	Clear
10/ 7/34	11:30	73.4	57.2	5.00		178.0	6.60	76.12	8.40	Clear
10/10/34	11:30	71.6	66.2	5.80		191.0	4.00	51.22	8.20	Cloudy—Rain
10/27/34	12:00	64.4	53.6	5.00		176.0	8.40	92.82	8.40	Clear
11/18/34	11:15	68	59.9		2.00	156.3	8.60	102.38	8.60	Clear
11/25/34	3:00	54.5	55.4	4.00		198.0	5.12	57.79	8.60	Clear
12/ 2/34	12:00	41	46.4	3.00		204.0	6.00	60.48	8.40	Clear
1/12/35	3:00	44.6	46.4	5.50		207.3	5.60	56.45	8.60	Clear
2/24/35	11:30	44.6	44.6	0.50		201.0	10.64	104.62	8.60	Clear

Summary

In unshaded water no trout can long tolerate a water temperature of more than 80°F. However, where shade is plentiful, this temperature can be exceeded by 3° or 4°F. for some period of time. For short periods of time the waters of the project do exceed 80°F. At places there is some shade. It is also a fact that trout have grown to large size in the ditches. This research indicates that if compatible with the use of the canals for drainage, every encouragement should be given to the growth of shade trees and rushes along the sides of the ditches. Dr. A. S. Hazzard,[50] of the U. S. Bureau of Fisheries advises the placing of many anchored, floating rafts in the canals.

No trout can live in water containing less than 1.16 p. p. m. dissolved oxygen. The higher the temperature of the water the more oxygen is needed, as for example, at 77°F. the trout needs 3.4 p. p. m. The lowest oxygen content found at any time during this study was 3.58 p. p. m. at 70°F. A heavy rain had swept debris into the ditch and the oxygen content dropped from 7.84 p. p. m. to 3.58 p. p. m., but promptly rose again when the debris moved on. This research indicates that there is always plenty of dissolved oxygen in the ditches, but that the quantity of oxygen falls too near the danger point, with ingress of debris from heavy showers, and that prevention of the entrance of debris is most desirable.

Regardless of temperature, trout seem to show no distress from dissolved carbon dioxide if the quantity does not exceed 40 p. p. m. The largest concentration found in the ditches was 5.8 p. p. m. and occurred when, in the fall, dead aquatic vegetation was decomposing. This decomposition, in autumn, of plants which had been alive in summer, might be of some consequence in a shallow pond or lake, but in the

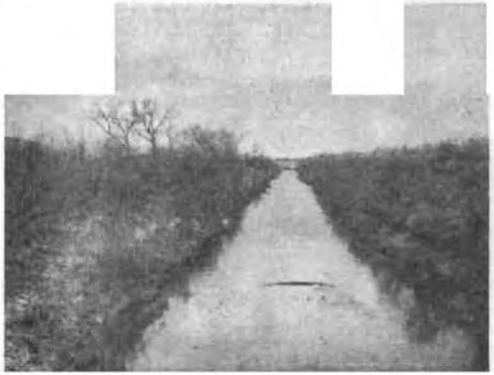
50. Private communication.

moving water of the canals, appears to be of little significance.

All fish seem to tolerate a wide range of pH (acidity and alkalinity). No waters of the ditches were acid, but rather all on the side of mildest alkalinity, the highest pH being 8.6.

A final conclusion: Any fish other than trout can live in the ditches as they are. Temperature is the controlling factor for trout. With plenty of shade, trout can probably thrive in the ditches, for even during the super-hot summer of 1934, excessive water temperature existed for only the briefest periods.

"Sunshine and suckers. Shadows and trout."



(Upper) A new canal showing aerations.

(Lower) The Atrisco Riverside Drain at Station V.

(Upper) New canal. Note the absence of bank cover.

(Lower) Just below Station II. This drain is six years old.