Original: Fish Division
Educ.-Game
Inst. for Fish. Res.
C. T. Yoder
R. S. Marks
H. L. Peterson
K. M. Mackenthun, Wisc. State Board of Health
E. E. Schultz

INSTITUTE FOR FISHERIES RESEARCH
DIVISION OF FISHERIES
MICHIGAN DEPARTMENT OF CONSERVATION
COOPERATING WITH THE
UNIVERSITY OF MICHIGAN

GERALD R. COOPER PH.D.
DIRECTOR

ADDRESS
UNIVERSITY MUSEUMS ANNEX
ANN ARBOR, MICHIGAN

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EFFECTS OF BRINE POLLUTION ON AQUATIC ORGANISMS IN THREE MICHIGAN STREAMS[1]

By Edward E. Schultz[2]

Expansion of chemical industries using brine from wells has increased the possibility of brine pollution in Michigan waters. For the present study, three streams were selected to determine the effects of brine pollution on aquatic life. Fish, bottom-dwelling organisms, and water samples were collected during the summer of 1956. One of these streams was studied again in 1957.

The Shiawassee River, Saginaw County, was selected for investigation, because construction of a brine processing plant in the vicinity of Chesaning had been proposed. The plant would have released excess brine into the Shiawassee River. Water at the two study stations established on this stream contained an insignificant quantity of chloride.

The Big Salt River, Midland County, was studied because its water has been contaminated with brine for a number of years. Other sources of pollution are negligible.

Mansfield Creek, Arenac County, was studied at two locations in 1956 and 1957. Fish collections were made at a third station in 1957. This creek was chosen for study because it has carried a high concentration of brine in past

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[2] Research assistants in the field were Donald J. Goyette, Eugene B. Welch, Thomas L. Wenke, and Asa T. Wright. The author was the field party leader.

years and still is appreciably contaminated. In 1941, Locke (1951) found the concentration of brine so high that no fish were living in the east branch or main stream. The principal source of brine, a flowing well (Washburn and Greenbank, 1942), was capped in 1944, but pollution continues from surrounding oil wells. One objective of this study was to determine the extent of recovery of aquatic life subsequent to the capping of the main well.

Results from brine pollution studies in other states (Clemens and Jones, 1955; Clemens and Finnell, 1957; Wiebe, Burr and Faubion, 1934) cannot be directly applied to Michigan streams. The species of fish which they observed are not found in Michigan, and the proportions of the various negative and positive ions in the brines studied were different from those of Michigan brines. Some reports are based on short-term laboratory experiments (Hubbs and Washburn, 1943) or have considered the action of a single salt (Anderson, 1950).

Methods

The methods of study at each station on the three streams were kept as nearly alike as possible. Collections of fish were made by three men using a 230-volt, 10.9-ampere, direct-current electric shocker. One man pulled the shocker boat that carried the gasoline-driven generator and a tub of water for the captured fish. The other two men shocked fish with the positive electrodes and picked them up with scap nets. When shocking was completed, the large fish were measured, scale-sampled, and released. Smaller fish were preserved in ten percent formaldehyde for identification in the laboratory.

A number of measurements and observations, such as length of stream shocked, time spent shocking, air and water temperatures and stream-bottom soil type, were made and recorded at each station. Three water samples were taken at each station. Two of the samples were sent to the Division of

Laboratories, Michigan Department of Health, for chemical analyses. The third sample was used for a conductivity measurement.

In 1956, four bottom samples were collected with a Surber square-foot bottom sampler on gravel areas at each station. The bottom samples were placed in trays and the field party sorted the animals from the debris by hand-picking. The animals from each sample were placed in a bottle of ten percent formaldehyde and identified at a later time. Notes were made of animals and plants that were observed in or adjacent to the streams.

In 1957, collecting was repeated at the sampling stations on Mansfield Creek; the number of bottom samples at each station was increased to eight and the area of each sample was reduced to one-half square foot. The entire sample was preserved in ten percent formaldehyde. Later the organisms were separated from the debris by the sugar-flotation method (Anderson, 1958).

Chemical characteristics

Chemical analyses of the water samples from the three streams showed different concentrations of brine (Table 1). Concentration as parts per million (ppm) of chloride is used as an index of brine concentration in this report. Several other chemicals were present that may affect the toxicity of the brine. Clemens and Jones (1955) and other investigators have shown that the toxic effects of salts on some fish and invertebrates vary with different combinations of salts. Also, chloride salts containing the alkaline earth metals (calcium and magnesium) are more toxic than combinations of the alkali metals (sodium and potassium). Analyses showed that sodium, potassium, and chlorine are the most abundant elements in the brine of these streams (Table 1).

The Shiawassee River had the lowest chloride content. The upstream station (SH-1), located at Parshallburg in Saginaw County, contained 26 ppm of

Table 1.--Locations of sampling stations and physical and chemical features at each station in three Michigan streams, 1956-1957

Item	Stream, and station								
	Shiawassee River		Big Salt River		Mansfield Creek				
	SH-1	SH-2	SA-1	SA-2	MA-2	MA-4	MA-1	MA-3	MA-5
Location									
County	Saginaw	Saginaw	Midland	Midland	Arenac	Arenac	Arenac	Arenac	Arenac
Town, North	9	9	15	15	20	20	20	20	20
Range	3 E.	3 E.	1 W.	1 W.	4 E.	4 E.	4 E.	4 E.	4 E.
Section	29	4	7	7	6	6	4	4	4
Date	9-12-56	9-12-56	9-7-56	9-10-56	9-6-56	8-1-57	9-6-56	7-31-57	8-1-57
Average width, ft.	120	135	35	60	11	10	7	6	3
Average depth, in.	10	12	8	6	4	3	4	3	2
Velocity	Moderate	Slow	Moderate	Slow	Moderate	Moderate	Moderate	Moderate	Moderate
Water color	Colorless	Colorless	Colorless	Colorless	Brown	Light brown	Brown	Brown	Light brown
Turbidity	Turbid	Turbid	Slightly turbid	Slightly turbid	Slightly turbid	Slightly turbid	Clear	Clear	Clear
Vegetation	Common	Common	Common	Sparse	Sparse	Sparse	Common	Common	None
Bottom soils									
Clay, %	0	0	30	0	12	5	30	5	0
Silt, "	15	25	15	40	10	15	17	15	60
Sand, "	55	65	35	55	25	55	50	60	40
Gravel,"	15	10	20	3	50	15	3	10	0
Rubble,"	15	0	0	2	3	10	0	10	0
Water analysis[1]									
Cl, ppm	26	32	220	234	1,000	480	1,450	1,710	740
Ca, "	76	76	108	116	148	104	184	225	113
SO_4, "	50	43	185	195	19	15	12	16	15
HCO_3,"	284	278	190	203	190	206	156	180	134
Mg, "	45	45	66	58	62	27	83	49	23
Na+K,"	10	9	106	124	490	230	710	840	370
Total hardness, ppm	300	300	430	430	520	370	660	760	375
Conductivity[2]	518	565	1,162	1,202	3,242	1,660	4,130	4,700	2,242
Water temp., °F.	63	69	63	60	64	66	62	71	67
Length shocked, feet	1,000	550	750	650	650	410	600	320	210
Time shocked, minutes	41	27	26	24	29	23	18	22	9

[1] Chemical analyses of water samples were made by the Division of Laboratories, Michigan Department of Health.

[2] Given in reciprocal megohms (μ mhos) at 18° C.

chloride. At station SH-2, six miles downstream from SH-1, or one mile below Chesaning, the chloride concentration was 32 ppm. This slight increase is probably accounted for by raw sewage from the town of Chesaning and the wastes from a large meat-packing plant which enter the river between the above stations.

The Big Salt River in Midland County contains brine, but a negligible quantity of other pollutants. The two sampling stations were similar chemically. At SA-1, the upstream station at North Bradley, the chloride concentration was 220 ppm; about one mile downstream, at station SA-2, located at the U. S. 10 highway bridge, it was 234 ppm.

The stations on Mansfield Creek, Arenac County, were quite different from each other in their chemical and biological characteristics. Chloride content was lowest at the downstream station (MA-2 in 1956 and MA-4 in 1957) because the brine was diluted by the inflow of unpolluted water from the North Branch of Mansfield Creek. In 1956 the chloride content was 1,000 ppm, but it was only 480 ppm in 1957.

The second station on Mansfield Creek (MA-1 in 1956 and MA-3 in 1957) was about two miles upstream from station MA-2. It was just below the major source of brine pollution. The brine concentrations have fluctuated considerably at this location during the past 17 years. During 1940 and 1941, when brine flowed intermittently into the stream from a nearby well, Locke (1951) found that the chloride varied from 673 ppm to 30,700 ppm. On June 20, 1956 the concentration was 1,850 ppm, but 2,600 ppm was encountered on July 26. At the time the biological samples were taken (September 6, 1956) the chloride concentration had fallen to 1,450 ppm. At the time the second series of collections were made (July 31, 1957), the concentration was 1,710 ppm.

The third station on Mansfield Creek investigated in 1957 was above the major source of brine pollution. This station (MA-5), more than one mile upstream from MA-1 and MA-3, showed a chloride content of 740 ppm. Only a

fish collection was taken at this point. Since no gravel was present, bottom samples could not be collected from a bottom type similar to that found at other stations.

Biological characteristics

Domestic sewage and slaughter-house wastes flow into the Shiawassee River, but the Big Salt River and Mansfield Creek are relatively free of pollutants other than brine. These organic pollutants undoubtedly affect the aquatic life in the Shiawassee River and make direct comparison with the other two streams difficult. The average width and depth of the three streams are quite different (Table 1). The Shiawassee River is over 100 feet wide, while the Big Salt River varies from 35 to 60 feet wide. Mansfield Creek averages 11 feet at the widest station but only 3 feet at station MA-5. The size of a stream has some influence upon the character of the fish fauna.

Fish collections in 1956 from the two stations in the Shiawassee River contained 394 fish of 26 different species. Rock bass were the most abundant fish at station SH-1, but downstream at SH-2 the more abundant species were the common shiner and carp. Many more carp were in the river than is indicated in Table 2; their large size and wariness made capture difficult. Compared to the Big Salt River, the Shiawassee River had only a moderate-sized population of fish.

The two collections from the Big Salt River contained 701 fish of 25 species. Rock bass were the most abundant fish, but seven other species of game fish were collected (Table 2). The size range of the game fish (Table 3) indicated that young fish could tolerate the level of brine pollution present at this point. Hubbs and Washburn (1943) showed that small and young trout tolerated less brine than large, old trout. They also found that brook trout fingerlings were able to tolerate about twice the concentration of brine that

Table 2.--Numbers and species of fish collected by direct-current shocker at the sampling stations in three Michigan streams, 1956-1957

Species[1]	Stream, station, year of collection, and number of minutes of electrofishing								
	Shiawassee River		Big Salt River		Mansfield Creek				
	SH-1	SH-2	SA-1	SA-2	MA-2	MA-4	MA-1	MA-3	MA-5
	1956	1956	1956	1956	1956	1957	1956	1957	1957
	41	27	26	24	29	23	18	22	9
Game fish									
Brook trout	...	...	...	...	...	1	...	...	...
Northern pike	1	...	...	...	...	...	...	...	...
Yellow perch	...	...	...	2	...	...	...	...	...
Smallmouth bass	4	1	12	12	...	...	...	...	...
Largemouth bass	...	1	2	2	...	...	...	...	...
Pumpkinseed	...	1	...	7	...	...	...	...	...
Longear sunfish	1	7	...	1	...	...	...	...	...
Bluegill	1	17	2	6	1	...	...	...	...
Green sunfish	2	1	...	...	...	...	...	...	...
Rock bass	139	20	93	103	...	...	...	...	...
Black crappie	...	10	...	7	...	...	...	...	...
Coarse fish									
White sucker	5	...	6	4	11	1	6	...	...
Hog sucker	4	1	27	4	17	1	...	...	...
Golden redhorse	...	...	...	2	...	...	...	...	...
Silver redhorse	...	...	...	1	...	...	...	...	...
Greater redhorse	...	2	...	...	...	...	...	...	...
Yellow bullhead	10	4	...	...	...	...	...	...	...
Stonecat	5	...	11	4	...	...	...	...	...
Obnoxious fish									
Carp	...	7	...	4	...	...	...	...	...
Sea lamprey	...	...	...	...	...	1	...	...	...
Forage fish									
Creek chub	...	...	3	...	107	61	97	81	19
Pearl dace	...	...	...	...	5	1	36	137	26
Hornyhead chub	25	23	44	6	...	...	...	...	...
River chub	3	...	...	...	...	...	...	...	...
Blacknose dace	...	...	...	...	136	7	43	130	3
Longnose dace	...	...	...	...	6	3	...	1	...
Finescale dace	...	...	...	...	2	1	...	6	6
N. redbelly dace	...	...	...	...	...	6	...	57	68
Common shiner	4	64	54	22	31	1	...	...	...
N. mimic shiner	2	...	49	2	...	...	...	...	...
Rosyface shiner	...	2	...	...	...	...	...	...	...
Spotfin shiner	...	3	...	...	...	...	...	...	...
Brassy minnow	...	...	...	...	20	15	...	44	9
Bluntnose minnow	...	...	44	11	12	...	...	...	...
Fathead minnow	...	...	...	...	...	...	...	...	27
Central stoneroller	...	1	29	...	24	...	1	1	...
Mudminnow	...	...	...	...	...	...	...	7	55
Blackside darter	7	10	6	10	7	1	...	...	...
N. logperch	2	...	3	4	...	...	...	...	...
Johnny darter	...	1	18	13	10	21	...	...	...
Rainbow darter	3	...	64	4	30	...	...	...	...
Brook stickleback	...	...	...	...	...	1	...	17	299
Amer. brook lamprey	...	...	...	...	2	4	...	...	...
N. brook lamprey	...	...	...	3	...	...	...	...	...
Total number of fish	218	176	467	234	421	126	183	481	512
Number of species	17	19	17	23	16	16	5	10	9

[1] See Bailey (1956) for scientific names of fishes.

Table 3.--Size range in inches of the non-forage fish collected at sampling stations in three Michigan streams, 1956-1957

Species	Stream, and station								
	Shiawassee River		Big Salt River		Mansfield Creek				
	SH-1	SH-2	SA-1	SA-2	MA-2	MA-4[1]	MA-1	MA-3[1]	MA-5[1]
Game fish									
Brook trout	...	...	...	...	...	10.2	...	...	...
Northern pike	8.9	...	...	...	...	...	...	...	...
Smallmouth bass	5.5 - 6.3	2.6	2.6 - 8.9	2.5 - 11.3	...	...	...	...	...
Largemouth bass	...	10.4	2.3 - 2.8	2.6 - 3.0	...	...	...	...	...
Pumpkinseed	...	3.7	...	3.1 - 4.8	...	...	...	...	...
Longear sunfish	3.2	2.2 - 3.2	...	3.2	...	...	...	...	...
Bluegill	5.1	3.9 - 5.3	3.6 - 4.6	3.7 - 4.8	2.5	...	...	...	...
Rock bass	1.2 - 7.6	2.5 - 6.5	1.1 - 7.4	1.4 - 6.9	...	...	...	...	...
Black crappie	...	3.4 - 4.7	...	4.6 - 8.5	...	...	...	...	...
Yellow perch	...	...	...	4.1 - 4.5	...	...	...	...	...
Coarse fish									
White sucker	6.6 - 8.0	...	2.9 - 11.5	6.6 - 8.9	3.8 - 6.4	5.4	1.6 - 2.4	...	...
Hog sucker	6.4 - 11.0	3.6	2.5 - 11.1	5.3 - 10.9	1.7 - 6.5	6.3	...	...	...
Golden redhorse	...	...	...	8.1 - 8.5	...	...	...	...	...
Silver redhorse	...	...	...	7.7	...	...	...	...	...
Greater redhorse	...	13.4 - 18.0	...	...	...	...	...	...	...
Yellow bullhead	6.5 - 9.8	6.5 - 9.8	...	...	...	...	...	...	...
Stonecat	4.6 - 6.2	...	1.9 - 7.6	6.3 - 7.4	...	...	...	...	...
Obnoxious fish									
Carp	...	5.7 - 25.0	...	17.0 - 25.0	...	...	...	...	...

[1]Collections made in 1957; all other collections made in 1956.

killed brook trout eggs. Similar differences in salt tolerance were found between fingerlings and sac fry of brown trout. Such sensitivity to brine by eggs and fry would tend to prevent successful reproduction, and thereby eliminate the young fish.

The 220 to 234 ppm of chloride found in the Big Salt River apparently had little or no effect upon the composition of the fish population and seemed to have little, if any, influence upon the rate of growth of the fish. Rock bass from the Big Salt and Shiawassee rivers were growing at rates approximately equal to the state-wide average rates for this species in Michigan lakes (Table 4).

A bluegill taken at station MA-2 in 1956, and a brook trout taken here in 1957 were the only game fish captured in Mansfield Creek. One sea lamprey larva and 18 other species of coarse and forage fish were collected at this station (Table 2). The species composition was similar for the two years, but the total number of fish captured decreased from 421 in 1956, to 126 in 1957. The chloride concentration had dropped from 1,000 ppm in 1956 to 480 ppm in 1957. Although the cause for the decrease in numbers of fish collected is not known, the following factors probably were influential. Six minutes more time was spent shocking and 240 more feet of stream were covered in 1956 than in 1957. This additional length included the headwaters of an active beaver pond that the beavers had abandoned by 1957. Collecting was done a month earlier in 1957, and the water level of the stream was lower than in 1956. Also, the lower electrical conductivity of the water in 1957 may have decreased collecting efficiency.

Station MA-1 and MA-3, two miles upstream from MA-2 and MA-4, had a chloride content of 1,450 ppm in 1956, and 1,710 ppm in 1957. A 600-foot section of stream upstream from Greenwood Road was shocked in 1956 (MA-1) and a 320-foot section (MA-3) was shocked in 1957. Five species of fish were captured at this station in 1956, and ten in 1957.

Table 4.--Average length in inches for each age group of rock bass collected in the Shiawassee and Big Salt rivers, 1956, compared to the state-wide averages for this species from lakes

(Number of fish in parentheses)

Location and collection number	Age group					
	0	I	II	III	IV	V
Shiawassee -1	1.2 (1)	3.0 (105)	4.3 (20)	6.1 (8)	6.8 (4)	7.6 (1)
Shiawassee -2	...	2.9 (10)	4.5 (6)	5.5 (2)	6.1 (2)	...
Big Salt -1	1.5 (28)	2.8 (32)	4.5 (9)	5.3 (11)	6.5 (6)	6.6 (7)
Big Salt -2	1.6 (11)	2.7 (41)	4.2 (26)	5.3 (23)	6.1 (2)	...
State average	1.5	3.2	4.3	5.2	6.2	7.3

In 1957, fish were collected at station MA-5, one mile upstream from MA-1 and MA-3. A total of 512 fish of nine different species were collected from water containing 740 ppm of chloride. The greatest difference from the downstream collections was the capture of 299 brook sticklebacks (58 percent of the collection) from 210 feet of stream in nine minutes of shocking (Table 2).

The numbers and kinds of animals in the bottom samples give an indication of the extent of pollution. At the two stations in the Shiawassee River (eight one-square-foot bottom samples), 191 mayfly nymphs were collected. Such a large number of individuals of a form intolerant of pollution indicates that contamination was not serious. A detailed list of the numbers and kinds of aquatic organisms found in each sample in 1956 is given in Table 5.

Brine in the Big Salt River apparently does not affect aquatic life adversely. Several kinds each of mayfly, dragonfly, damselfly, and caddis fly larvae were present in fair abundance (Table 5).

The bottom fauna at station MA-2 (1956) in Mansfield Creek, where the chloride content was 1,000 ppm was distinctly different from the fauna found in the two other streams. No mayfly or damselfly nymphs and only two dragonfly nymphs were found in four bottom samples. These samples had the largest volume and number of animals collected at any station in 1956. The greater volume was due largely to 191 caddis fly larvae and 37 large larvae of Diptera. The eight one-half-square-foot samples collected here in 1957, designated as station MA-4, gave similar results except that the number of Diptera larvae was greater (Table 6). This increase was due almost entirely to minute Tendipedidae larvae and pupae. The sugar-flotation method used in 1957 for separating organisms from debris was apparently much more efficient than hand-picking done in 1956. The 1957 samples, collected 36 days earlier than the 1956 samples, contained many Tendipedidae pupae not found in 1956.

Table 5.--Numbers of invertebrates collected in one-square-foot bottom samples in three Michigan streams, 1956

Type of organism	Stream, station, and sample numbers: Shiawassee River, Station SH-1						Station SH-2					
	1	2	3	4	Total	Average	1	2	3	4	Total	Average
Turbellaria	...	...	...	...	...	...	...	...	...	...	...	...
Oligochaeta	...	...	...	...	...	...	...	2	...	3	5	1.3
Lumbricidae	...	...	...	...	...	...	...	...	...	...	...	...
Glossiphonia	...	...	...	...	...	...	...	...	...	1	1	0.3
Sphaerium	...	...	...	1	1	0.3	...	...	...	...	...	...
Physa	...	...	...	...	...	...	...	...	...	...	...	...
Ferrissia	...	...	...	1	1	0.3	...	...	...	...	...	...
Hyalella	...	...	1	...	1	0.3	...	...	...	...	...	...
Gammarus	...	...	...	...	...	...	...	...	...	...	...	...
Baetis	7	5	29	6	47	11.8	36	20	29	19	104	21.0
Baetisca	...	...	...	...	...	...	...	...	...	...	...	...
Caenis	...	1	...	...	1	0.3	...	...	...	...	...	...
Paraleptophlebia	...	...	...	...	...	...	...	...	...	...	...	...
Pseudocloeon	...	...	...	...	...	...	...	...	6	...	6	1.5
Tricorythodes	...	...	2	2	4	1.0	2	1	...	4	7	1.8
Ephemera	...	...	...	...	...	...	...	...	...	...	...	...
Potamanthus	1	...	...	...	1	0.3	...	2	...	3	5	1.3
Heptagenia	...	1	2	...	3	0.8	...	...	...	...	...	...
Stenonema	6	1	5	...	12	3.0	...	1	...	...	1	0.3
Gomphidae	...	...	1	...	1	0.3	...	...	...	...	...	...
Ophiogomphus	...	...	...	...	...	...	...	...	...	...	...	...
Progomphus	...	...	...	...	...	...	...	...	...	...	...	...
Boyeria	...	...	...	...	...	...	...	...	...	...	...	...
Cordulegaster	...	...	...	...	...	...	...	...	...	...	...	...
Agrion	...	...	...	...	...	...	...	...	...	...	...	...
Argia	...	...	...	...	...	...	...	...	...	...	...	...
Nehallenia	...	...	...	...	...	...	...	...	...	...	...	...
Sialis	...	...	...	...	...	...	...	...	...	...	...	...
Chauliodes	...	...	...	...	...	...	...	...	...	...	...	...
Helicopsyche	...	...	...	...	...	...	...	...	...	...	...	...
Hydropsyche and Cheumatopsyche	7	...	9	3	19	4.8	...	3	1	3	7	1.8
Oecetis	...	...	...	...	...	...	...	...	...	...	...	...
Psephenus	1	...	1	...	2	0.5	...	...	...	...	...	...
Elmidae	1	1	4	1	7	1.8	...	...	...	1	1	0.3
Antocha	...	...	...	...	...	...	...	...	...	...	...	...
Eriocera	...	...	...	...	...	...	3	...	...	...	3	0.8
Rhaphidolabis	...	...	...	...	...	...	...	...	...	...	...	...
Simulium	...	...	4	...	4	1.0	...	2	...	1	3	0.8
Tendipedidae	1	1	2	...	4	1.0	3	21	2	17	43	10.8
Tabanus	...	...	...	...	...	...	...	...	...	...	...	...
Atherix	...	...	...	...	...	...	...	...	...	...	...	...
Tetanoceridae	...	...	...	...	...	...	...	...	...	...	...	...
Hemerodromia	...	...	...	...	...	...	...	...	...	...	...	...
Total number	24	10	60	14	108	27.0	44	52	38	52	186	46.5
Total volume (milliliters)[1]	0.06	0.03	0.16	0.03	0.28	0.07	0.23	0.08	0.12	0.14	0.57	0.14
Number of different forms	7	6	11	6	15	7.5	4	8	4	9	12	6.3

[1] Molluscs not included in volume measurements.

(continued)

Table 5.--Numbers of invertebrates collected in one-square-foot bottom samples in three Michigan streams, 1956

Type of organism	Stream, station, and sample numbers: Big Salt River, Station SA-1						Station SA-2					
	1	2	3	4	Total	Average	1	2	3	4	Total	Average
Turbellaria	...	...	...	...	...	...	...	...	...	...	...	...
Oligochaeta	...	...	...	...	...	...	...	...	...	...	...	...
Lumbricidae	...	...	...	...	...	...	...	...	...	...	...	...
Glossiphonia	...	...	...	...	...	...	...	...	...	...	...	...
Sphaerium	...	6	2	1	9	2.3	1	...	...	...	1	0.3
Physa	...	3	...	6	9	2.3	...	1	...	...	1	0.3
Ferrissia	...	...	...	...	...	...	...	...	...	...	...	...
Hyalella	...	...	...	...	...	...	...	...	...	...	...	...
Gammarus	...	...	...	...	...	...	...	...	1	...	1	0.3
Baetis	4	3	3	5	15	3.8	1	1	2	1	5	1.3
Baetisca	...	...	...	...	...	...	1	...	...	1	2	0.5
Caenis	...	...	...	...	...	...	...	7	...	2	9	2.3
Paraleptophlebia	...	3	...	...	3	0.8	...	...	...	...	...	...
Pseudocloeon	...	...	...	...	...	...	...	...	...	...	...	...
Tricorythodes	...	...	1	...	1	0.3	...	3	...	8	11	2.8
Ephemera	...	2	1	...	3	0.8	...	...	1	1	2	0.5
Potamanthus	...	...	...	...	...	...	...	...	...	...	...	...
Heptagenia	1	...	...	1	2	0.5	...	...	...	2	2	0.5
Stenonema	...	9	2	2	13	3.3	...	7	5	16	28	7.0
Gomphidae	...	1	2	2	5	1.3	...	1	3	6	10	2.5
Ophiogomphus	...	...	...	...	...	...	...	1	1	7	9	2.3
Progomphus	...	...	...	...	...	...	...	1	...	1	2	0.5
Boyeria	...	...	1	...	1	0.3	...	...	...	...	...	...
Cordulegaster	...	...	...	...	...	...	...	...	...	...	...	...
Agrion	...	...	...	...	...	...	...	...	...	1	1	0.3
Argia	...	5	5	1	11	2.8	...	...	...	...	...	...
Nehallenia	...	1	...	...	1	0.3	...	...	...	...	...	...
Sialis	...	1	...	...	1	0.3	...	...	...	...	...	...
Chauliodes	...	...	...	...	...	...	...	...	...	...	...	...
Helicopsyche	...	5	...	4	9	2.3	1	...	1	...	2	0.5
Hydropsyche and Cheumatopsyche	24	5	5	38	72	18.0	...	1	10	22	33	8.3
Oecetis	...	...	...	3	3	0.8	...	2	...	1	3	0.8
Psephenus	...	1	...	...	1	0.3	...	...	...	...	...	...
Elmidae	...	4	4	1	9	2.3	...	...	...	4	4	1.0
Antocha	...	...	...	...	...	...	...	...	...	...	...	...
Eriocera	...	3	5	7	15	3.8	...	...	4	1	5	1.3
Rhaphidolabis	...	...	...	...	...	...	...	...	...	...	...	...
Simulium	...	...	...	...	...	...	...	...	1	...	1	0.3
Tendipedidae	4	2	1	5	12	3.0	...	...	...	5	5	1.3
Tabanus	...	...	...	...	...	...	...	...	...	...	...	...
Atherix	...	...	...	1	1	0.3	...	...	...	...	...	...
Tetanoceridae	...	...	...	1	1	0.3	...	...	...	...	...	...
Hemerodromia	...	...	...	...	...	...	...	...	...	...	...	...
Total number	33	54	32	78	197	49.3	4	25	29	79	137	34.3
Total volume (milliliters)[1]	0.50	0.38	0.37	0.48	1.73	0.43	0.01	0.52	0.52	0.86	1.91	0.48
Number of different forms	4	16	12	15	22	11.7	4	10	10	16	21	10.0

[1] Molluscs not included in volume measurements.

(continued)

Table 5.--Numbers of invertebrates collected in one-square-foot bottom samples in three Michigan streams, 1956

Type of organism	Stream, station, and sample numbers											
	Mansfield Creek											
	Station MA-1						Station MA-2					
	1	2	3	4	Total	Average	1	2	3	4	Total	Average
Turbellaria	...	...	...	...	...	...	...	...	...	1	1	0.3
Oligochaeta	...	...	...	...	...	...	...	3	3	38	44	11.0
Lumbricidae	...	1	...	...	1	0.3	1	...	...	...	1	0.3
Glossiphonia	...	...	...	...	...	...	...	...	...	...	...	...
Sphaerium	...	...	...	...	...	...	...	...	...	4	4	1.0
Physa	...	...	...	...	...	...	...	1	...	23	24	6.0
Ferrissia	...	...	...	...	...	...	...	...	...	...	...	...
Hyalella	...	...	...	...	...	...	...	...	...	...	...	...
Gammarus	...	...	...	...	...	...	...	...	2	7	9	2.3
Baetis	...	...	...	...	...	...	...	...	...	...	...	...
Baetisca	...	...	...	...	...	...	...	...	...	...	...	...
Caenis	...	...	...	...	...	...	...	...	...	...	...	...
Paraleptophlebia	...	...	...	...	...	...	...	...	...	...	...	...
Pseudocloeon	...	...	...	...	...	...	...	...	...	...	...	...
Tricorythodes	...	...	...	...	...	...	...	...	...	...	...	...
Ephemera	...	...	...	...	...	...	...	...	...	...	...	...
Potamanthus	...	...	...	...	...	...	...	...	...	...	...	...
Heptagenia	...	...	...	...	...	...	...	...	...	...	...	...
Stenonema	...	...	...	...	...	...	...	...	...	...	...	...
Gomphidae	...	...	...	...	...	...	...	...	...	...	...	...
Ophiogomphus	...	...	...	...	...	...	...	1	...	...	1	0.3
Progomphus	...	...	...	...	...	...	...	...	...	...	...	...
Boyeria	...	1	1	...	2	0.5	...	...	...	...	...	...
Cordulegaster	...	...	...	...	...	...	...	...	1	...	1	0.3
Agrion	...	...	...	...	...	...	...	...	...	...	...	...
Argia	...	...	...	...	...	...	...	...	...	...	...	...
Nehallenia	...	...	...	...	...	...	...	...	...	...	...	...
Sialis	...	...	...	...	...	...	...	...	...	...	...	...
Chauliodes	...	...	...	...	...	...	...	...	1	1	2	0.5
Helicopsyche	...	...	...	...	...	...	...	24	19	22	65	16.3
Hydropsyche and Cheumatopsyche	1	...	1	1	3	0.8	1	7	13	104	125	31.3
Oecetis	...	...	...	...	...	...	...	...	...	1	1	0.3
Psephenus	...	...	...	...	...	...	...	...	...	...	...	...
Elmidae	...	...	...	...	...	...	...	3	22	21	46	11.5
Antocha	...	...	...	...	...	...	...	1	...	6	7	1.8
Eriocera	...	...	...	...	...	...	...	...	1	...	1	0.3
Rhaphidolabis	...	...	...	...	...	...	...	...	...	4	4	1.0
Simulium	...	...	1	...	1	0.3	...	...	...	...	...	...
Tendipedidae	1	1	4	11	17	4.3	...	1	...	3	4	1.0
Tabanus	...	12	7	11	30	7.5	...	1	...	1	2	0.5
Atherix	...	...	...	...	...	...	...	...	8	11	19	4.8
Tetanoceridae	...	...	...	...	...	...	...	1	1	6	8	2.0
Hemerodromia	...	...	...	1	1	0.3	...	...	...	...	...	...
Total number	2	15	14	24	55	13.8	2	43	71	253	369	92.3
Total volume (milliliters)[1]	0.03	0.21	0.14	0.16	0.54	0.14	0.11	0.65	1.12	2.20	4.08	1.02
Number of different forms	2	4	5	4	7	3.8	2	10	10	16	20	9.5

[1] Molluscs not included in volume measurements.

Table 6.--Numbers of invertebrates collected in one-half square-foot bottom samples in Mansfield Creek, July 31 and August 1, 1957

Type of organism	Station and sample numbers MA-3									
	1	2	3	4	5	6	7	8	Total	Average
Nematoda	...	...	...	...	...	...	...	...	...	...
Oligochaeta	5	70	13	38	31	35	35	72	299	37.4
Placobdella	...	...	...	...	...	...	...	...	...	...
Gammarus	...	...	...	...	...	...	...	...	...	...
Cambarus	...	...	...	1	...	...	...	...	1	0.1
Plecoptera	...	...	...	...	...	...	...	...	...	...
Baetis	...	...	...	...	...	...	...	...	...	...
Tricorythodes	...	...	...	...	...	...	...	...	...	...
Gomphidae	...	1	...	...	...	...	...	...	1	0.1
Chauliodes	...	...	...	...	...	...	...	...	...	...
Glossosoma	...	...	...	...	...	...	...	...	...	...
Hydroptilidae	...	1	...	...	...	...	...	1	2	0.3
Hydropsyche and Cheumatopsyche	...	1	...	2	...	...	...	6	9	1.0
Psychomyiidae	...	...	...	...	...	...	...	...	...	...
Leptoceridae	...	...	...	...	...	...	...	...	...	...
Elmidae	...	...	...	...	...	...	...	...	...	...
Tipula	...	...	...	...	...	1	...	...	1	0.1
Antocha	...	...	...	...	...	...	...	...	...	...
Simulium	17	14	30	6	21	2	1	9	100	12.5
Tendipedidae	152	255	64	23	308	61	589	864	2,316	289.5
Tabanus	...	...	...	...	...	...	...	...	...	...
Chrysops	6	7	6	...	3	4	3	8	37	4.6
Atherix	...	....	1	1	1	...	1	1	5	0.6
Dicranota	...	...	...	...	...	...	...	...	...	...
Stratiomyiidae	...	1	...	...	...	...	...	...	1	0.1
Anthomyiidae	...	...	...	...	...	1	...	...	1	0.1
Hemerodromia	...	...	...	2	2	...	...	...	4	0.5
Total number	180	350	114	73	366	104	629	961	2,777	347.1
Total volume (milliliters)	0.05	0.12	0.04	0.02	0.12	0.03	0.06	0.13	0.57	0.07
Number of different forms	4	8	5	7	6	6	5	7	13	6.0

(continued)

Table 6.--Numbers of invertebrates collected in one-half square-foot bottom samples in Mansfield Creek, July 31 and August 1, 1957

Type of organism	Station and sample numbers MA-4									
	1	2	3	4	5	6	7	8	Total	Average
Nematoda	1	...	...	...	...	...	...	...	1	0.1
Oligochaeta	3	...	1	16	...	6	4	10	40	5.0
Placobdella	1	...	...	...	...	...	...	...	1	0.1
Gammarus	1	...	5	1	7	...	...	2	16	2.0
Cambarus	...	...	...	...	...	...	...	...	...	...
Plecoptera	...	...	...	...	...	...	...	1	1	0.1
Baetis	2	...	2	2	...	...	...	...	6	0.8
Tricorythodes	1	...	2	...	...	...	1	...	4	0.5
Gomphidae	...	...	...	...	...	...	...	...	...	...
Chauliodes	...	...	1	1	...	...	...	...	2	0.3
Glossosoma	1	...	1	1	...	...	...	...	3	0.4
Hydroptilidae	8	...	5	...	...	...	...	1	14	1.8
Hydropsyche and Cheumatopsyche	77	2	80	25	2	3	1	21	211	26.4
Psychomyiidae	1	...	...	...	...	...	...	...	1	0.1
Leptoceridae	...	...	1	...	...	...	...	...	1	0.1
Elmidae	22	4	37	4	8	...	1	2	78	9.8
Tipula	...	...	...	...	...	...	...	...	...	...
Antocha	11	3	21	1	...	...	...	1	37	4.6
Simulium	...	10	1	3	1	13	1	21	50	6.3
Tendipedidae	106	38	115	39	122	21	21	66	528	66.1
Tabanus	...	...	1	...	...	...	...	...	1	0.1
Chrysops	1	1	...	...	9	1	3	5	20	2.5
Atherix	1	...	...	...	...	...	...	...	1	0.1
Dicranota	1	...	...	...	...	...	...	...	1	0.1
Stratiomyiidae	...	...	...	...	1	...	...	...	1	0.1
Anthomyiidae	...	...	...	...	...	...	...	...	...	...
Hemerodromia	...	...	...	...	...	...	...	...	...	...
Total number	238	58	273	93	150	44	32	130	1,018	127.3
Total volume (milliliters)	0.20	0.08	0.37	0.08	0.15	0.04	0.04	0.06	1.02	0.13
Number of different forms	16	6	14	10	7	5	7	10	22	9.4

The four bottom samples at MA-1 (1956) in Mansfield Creek contained 55 animals of eight different kinds. Both the number of individuals and the number of kinds of animals was the smallest found at any of the sampling stations, and the chloride content of the water was the highest (1,450 ppm). The eight, one-half square-foot samples taken at this station in 1957 (designated as MA-3) yielded 2,777 animals. The increase in number over the 1956 collections was due to 2,316 Tendipedidae larvae and pupae, 299 Oligochaeta, and 100 Simulium larvae (Table 6). The use of the sugar-flotation method probably accounted for most of the higher count. Results for both 1956 and 1957 indicated that brine pollution was a factor which limited the kinds of invertebrate animals at this station.

Some observations and notes were made on other forms of life and on bank and stream features at the collecting stations. Mud-plantain and filamentous algae were the only plants in Mansfield Creek at station MA-1 (chloride value, 1,450 ppm); and few living trees were among the dead trunks on the banks. No unusual floral features were noted at the other six study sites.

Crayfish were seen or captured from water with chloride values of 220 to 1,450 ppm. Frogs were seen or captured from water having as high as 1,000 ppm of chloride; none were seen at station MA-1. There were fresh beaver cuttings and a beaver dam just below station MA-2 on Mansfield Creek.

Conclusions

The results of this study indicate that while moderate concentrations of the brines under consideration appear to have no adverse effects on fish and fish-food organisms in streams, unfavorable effects begin to appear when the concentration of chloride reaches about 1,000 ppm. Fish and invertebrate animals seem to be unaffected by the concentrations found in the Shiawassee and Big Salt rivers, where the range was 26 to 234 ppm. At one location on Mansfield Creek,

where the water had a chloride content of 1,000 ppm, the effect upon benthic animals and fish was not very pronounced. At another location on Mansfield Creek, where 1,450 ppm of chloride had been recorded, the more sensitive invertebrates were absent and the fish population was definitely limited.

Maximum concentrations of brine probably are much more important than average concentrations, in the restriction of aquatic organisms. It is quite likely that a high concentration of chloride for a relatively short period of time kills or drives out fish and other animals that at most other times could live in a moderately polluted stream. It is clear that Mansfield Creek has been subject to highly variable concentrations of brine. It is conceivable that concentrations at times in recent years have been much higher than the maximum value recorded for the stream during the course of this study.

Further work is needed to define more precisely the concentration at which aquatic life begins to suffer from brine pollution. In such a study, measurements of the concentration of the pollutant should be made on a year-around basis.

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Approved by G. P. Cooper

Typed by M. S. McClure