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Arden R. Gaufin
University of Utah

Clarence M. Tarzwell
University of Utah

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Environmental Changes in a Polluted Stream During Winter

Arden R. Gaufin¹ and Clarence M. Tarzwell

*Department of Health Education, and Welfare, U. S. Public Health Service
Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio*

Year round studies of environmental conditions in Lytle Creek, a stream polluted with organic wastes, were initiated late in 1949, by the Biology Section of the Public Health Service's Environmental Health Center.² Lytle Creek is a tributary of the Little Miami River which enters the Ohio River at Cincinnati. It is about 11 miles long, and has an average width and depth of 15 feet and 1 foot respectively, during normal summer flows. Widths range from 3 to 35 feet and depths from a few inches to a maximum of 6 feet. Surface runoff comprises the major portion of the natural stream flow. During the summer months the stream has only one functional tributary below the outfall from the primary sewage treatment plant of the city of Wilmington which contributes 80 to 90 percent of the total stream flow. This large amount of organic waste quickly blots out normal stream conditions in the summer and a definite septic zone is established below the sewage outfall. However, all well recognized pollutional zones are established and the stream returns to essentially clean water conditions before it joins Todds Fork of the Little Miami River.

The aims of the Lytle Creek Study were to relate environmental conditions in various portions of the stream to the qualitative and quantitative composition of the aquatic population found in these sections; to observe seasonal changes in the fauna and the environment; and to collect other related data essential for the correlation of past ecological conditions with the composition and abundance of the aquatic fauna. The Lytle Creek investigation is one phase of an overall study designed to develop a biological method which can be used throughout most of the year and in most streams for indicating the pollutional conditions due to organic wastes which have prevailed over a considerable period in the past. Such a method would be desirable in reconnaissance surveys for indicating the severity and extent of organic pollution and the degree of stream recovery.

Ecological conditions and the composition of the fauna of Lytle Creek during spring and summer have been described by Gaufin and Tarzwell (1952). Fall and winter conditions have also been studied during the past two years. These investigations have followed the movement of ecological or pollutional zones in the stream with the seasons and with changes in flow.

Under summer conditions the stream has only one functional tributary below the source of pollution. During the winter months, however, several tributaries support a varied and abundant fauna which is contributed to the main stream during flash floods.

¹ Present address: University of Utah.

² Now the Robert A. Taft Sanitary Engineering Center.

PROCEDURES

The studies which have been carried out in Lytle Creek during the past two years have been made under diverse seasonal and climatic conditions. During this period special attention has been given to ecological variations accompanying seasonal changes. Seven stations judged to be representative of the various zones or sections of zones, were selected for monthly sampling. These stations were designated by their distance in miles upstream from the

Fig. 1.—Range in dissolved oxygen, Lytle Creek

mouth as shown in fig. 1. Monthly water samples were taken at these stations for the determination of dissolved oxygen, pH, CO_2 , methyl orange, and phenolphthalein alkalinity, and temperature. Diurnal and seasonal variations in physical and chemical conditions were determined by taking hourly samples at each of the stations for a 24-hour period during each season. Continuous flow records were obtained by means of a sharp crested, rectangular contracted weir and continuous float level recorder placed in the stream about 3 miles above its mouth.

Quantitative bottom samples were taken at monthly intervals at each station in pools, runs, and riffles. A Surber square foot sampler was used for taking samples from riffle areas, while a Peterson or Ekman dredge was used in other areas. Marginal samples were also taken from all sections of the stream by means of a special surface sampler, and a Needham handscreen sampler was often used in qualitative reconnaissance studies.

Biological, physical, and chemical data collected during the first year of the study showed a striking difference between summer and winter in the ecological conditions and faunal associations in the various zones of the stream. In order to gain a better idea of these differences an intensive qualitative and quantitative survey of the bottom and surface fauna of the entire stream was made during the period of May 1951 through February 1952.

During periods of high and rapid flows which are characteristic of the winter months and during which there is an abundance of dissolved oxygen throughout the stream, special attention was devoted to determining whether

clean water organisms could survive after drifting into the stream section which had been septic in summer. The fate of pollutional forms which were carried downstream was also carefully noted. Effects of seasonal changes were correlated with the life histories and habits of the organisms concerned.

RESULTS

Physical and chemical conditions.—During the last two winter seasons minimal flows in Lytle Creek have been in excess of 6 cubic feet per second (cfs) with frequent floods of 40 cfs or more. During these periods of high water the time of flow from the sewage plant to the mouth of the stream was generally less than 36 hours. Scouring floods have been frequent during the winter season. By contrast, in late summer and fall, stream flows at the weir averaged 1 cfs and the time of flow from the sewage plant to the mouth of the stream was 7 to 8 days.

A comparison of the oxygen concentrations in the stream under summer and winter conditions is given in fig. 1. It will be noted that, during the late summer, septic conditions exist in the stream from the sewage outfall to a point two miles downstream. The two miles of stream just below this section represent a zone of recovery, and the remaining two miles to the mouth represent clean water conditions. Under winter conditions, oxygen concentrations have been well in excess of the minimal requirements of most if not all aquatic organisms. The lowest oxygen value recorded during the winter of 1951-52 was 7.8 ppm on February 25, 1952, at midnight at a point 0.7 miles below the sewage outfall. This represented 57% of saturation. Water temperatures range from 32° to 50°F during the three winter months.

Biological conditions.—Reconnaissance surveys conducted during October 1951, revealed ecologic conditions quite similar to those encountered during the late summer. Well defined zones of pollution still existed in the stream and the composition of the fauna present was not much different from that reported in the stream for August 1951 (Gaufin and Tarzwell 1952). By the middle of November, however, the biota indicated that the effects of pollution were moving downstream. By January the carpet of *Sphaerotilus*, bacteria, and protozoa characteristic of the summer septic zone extended three miles downstream to the formerly clean water zone. The lower two miles of the stream exhibited pollutional fauna intermixed with clean water forms.

Many of the clean water organisms found in the lower part of the stream during the summer disappeared during the winter. It is assumed that some of these as the Coleoptera and Odonata burrowed deeper into the stream bed or banks and were not taken by the sampling methods used. Other forms had emerged and were replaced by a winter fauna. Many were washed downstream or destroyed by the molar action of floods. The continued existence of those that remained was imperiled by a slimy growth of *Sphaerotilus* which blanketed the bottom. That this growth offered formidable competition to the aquatic insects was evidenced by the fact that nymphs of the mayfly, *Stenonema femoratum*, a clean water form, were found on several occasions so densely covered with *Sphaerotilus* that their continued existence seemed an impossibility (fig.2).

Many clean water forms were washed by floods from the upper section of the stream or from winter time tributaries into the unfavorable habitat

Fig. 2.—Mayfly, from zone of recovery covered with *Sphaerotilus*, showing effects of pollutional blanket on macro-invertebrates.

offered by the stream below the sewage plant. Some of these forms were even encountered in leaf drifts directly below the sewage outfall during such high flows. Their existence was short-lived, however, as no clean water forms could be found alive in the formerly septic zone after the flow had become more stabilized.

During January and February 1952, pollutional tolerant tubificid worms and *Chironomus decorus* larvae, the most abundant members of the summer septic and recovery zones, were found in large numbers in riffles extending even to the mouth of the stream. As many as 3,000 tubificids per square foot were collected in a formerly clean water area. At Station 2.8, a clean water station in summer, these forms had largely replaced the clean water fauna. In some instances, however, many of the worms showed incomplete adaptation to their new habitat, as indicated by their beaded condition.

A comparison of the number of species present and the species composition of the population in the stream under autumn and winter conditions offered further evidence of ecological change. During October 1951, 43 species of macro-invertebrates were taken from the clean water section above the sewage plant, 8 different forms from the septic zone, 9 from the recovery zone, and 70 from the lower clean water section. During January and February 1952, 52 species were collected from the first mentioned section, 18 from the summer season septic zone, 5 from the recovery zone, and only 25 from the lower section of the stream. Among the 18 species collected during the winter from the summer septic zone, 10 were drift forms directly traceable to nearby tributaries. The marked reduction in the number of species in

the lower section was largely due to the extension of a pollutional blanket over much of the stream bottom. The species composition of the populations found at the different stations in the stream during the autumn and winter surveys are given in table 1.

A comparison of the number of species present and the species composition of the fauna in the different pollutional zones of the stream during the autumn and winter not only offers evidence of seasonal ecological changes but also reveals the lasting effects of pollution. In the two mile section of stream below the sewage outfall only one-fifth as many species of macro-invertebrates occurred during both seasons as were found in the upper two miles of the stream. This was due not only to the eliminating effects of oxygen depletion during periods of high temperature and low flow but also to changes in the nature of the stream bottom, and to different faunal associations. Reference to table 1 and fig. 3 will reveal a striking reduction

Fig. 3.—Macro-invertebrate distribution, Lytle Creek, fall and winter conditions.

in the number of different species in the mile section above the sewage plant that cannot be attributed to the effects of the sewage effluent. This change in species number and composition of the population was brought about by the introduction into the stream during periods of heavy runoff of drainage from the streets of Wilmington, and raw sewage from a break in the sewage line siphon where it passes under Lytle Creek. Although these wastes were insufficient to produce severe and lasting periods of oxygen depletion such as occurred below the sewage plant, they were still present in sufficient quantity and often enough to stimulate the growth of *Sphaerotilus*, tubificids, and pollution tolerant forms that crowded out or destroyed a balanced clean water fauna. In the portion of this section immediately below the point of entry of the street drainage ditch, a mayfly, *Stenonema femoratum*, and numerous tubificid worms were found associated in riffles even during periods of low flow. As the breakdown of oil, street, and other wastes proceeded, changes in the stream bottom and oxygen content resulted in the elimination of mayflies from the fauna. In the lower half of this section no mayflies, stoneflies, or caddis flies were found during October and only drift forms were taken during the winter.

Analyses of the preferred habitats, habits, and life histories of some of

TABLE 1.—Distribution of Invertebrates in Lytle Creek
October and January-February 1951-52

Organisms	October 1951 Stations ¹							January-February 1952 Stations						
	8.7	7.6	6.5	5.2	4.2	2.8	1.0	8.7	7.6	6.5	5.2	4.2	2.8	1.0
DIPTERA														
<i>Polypedilum illinoense</i>						C	C	C	C	F				
<i>Microtendipes pedellus</i>								F						
<i>Chironomus decorus</i>	F ²			C	C	F	F	F		F	C	C	C	C
<i>Polypedilum</i> spp.				F		F		C						
<i>Anatopynia dyari</i>	F					F	F	F						
<i>A. fastuosa</i>	F													
<i>Cricotopus bicinctus</i>	F					F	F	F						
<i>Corynoneura scutellata</i>	F													
<i>C. sp.</i>	F													
<i>Stictochironomus varius</i>	C					F		C					F	F
<i>Hydrobaenus obumbratus</i>	F							C						
<i>H. sp.</i>								F						
<i>H. spp.</i>	C	F				C	F	C		F	F		F	F
<i>Pentaneura flavifrons</i> (?)	F	F						F						F
<i>P. melanops</i>	F	F								F				
<i>P. monilis</i> (?)	F						F	F						
<i>Tanyus stellatus</i>	F													
<i>Tanytarsus nigripilis</i>								F						
<i>T. similatus</i>								F						
<i>Anopheles punctipennis</i>	F			F			F							
<i>Culex pipiens</i>			F			F	F							
<i>Eristalis bastardi</i>			C			F				F				
<i>Tabanus atratus</i>	F						F			F				
<i>Tabanus</i> sp.						F	F							C
<i>Simulium vittatum</i>	C			F		C	C	F		F				
<i>Pilaria</i> sp.								F						
<i>Limnophila</i> sp.	F						C							F
<i>Tipula abdominalis</i>								F						
<i>T. sp.</i>	F	F					F							
<i>Hemerodromia</i> sp.							F							
<i>Dictya</i> sp.						F	F							
<i>Argyra</i> sp.											F			
COLEOPTERA														
<i>Peltodytes G. maculatus</i>							C							
<i>P. lengi</i>							C				F			
<i>P. duodeno-punctatus</i>							C							
<i>P. edentulus</i>	C						F			F				
<i>Gyrinus lugens</i>						C				F				
<i>Dineutes americanus</i>				F		C								
<i>Psephenus lecontei</i>							F							
<i>Stenelmis crenata</i>	C									C				
<i>S. sexlineata</i>	C									C				
<i>Helichus lithophilus</i>							C							F
<i>H. basalis</i>							F							
<i>Agabus stagninus</i>										F				
<i>Hydroporus pulcher</i>		F								F				
<i>H. wickhami</i>										F				
<i>H. mellitus</i>										F				
<i>Coptotomus i. interrogatus</i>					F									
<i>Laccophilus maculosus</i>		F					C	F		F				
<i>L. fasciatus</i>							F							
<i>Tropisternus lateralis nimbatu</i>							C	F						

TABLE 1.—(Continued).

Organisms	October 1951 Stations							January-February 1952 Stations						
	8.7	7.6	6.5	5.2	4.2	2.8	1.0	8.7	7.6	6.5	5.2	4.2	2.8	1.0
<i>T. mexicanus striolatus</i>							C							
<i>T. natator</i>	F	F		F			F	F		F				
<i>Laccobius agilis</i>	F						F							
<i>Helochares maculicollis</i>							F							
<i>Enochrus pygmaeus nebulosus</i>			F				C							
<i>Berosus peregrinus</i>							F							F
EPHEMEROPTERA														
<i>Ameletus</i> sp.							F							
<i>Blasturus collinus</i>									F					
<i>B.</i> sp.														
<i>Baetis parvus</i>	C					C	C							
<i>Callibaetis</i> sp.	F					F								
<i>Caenis</i> spp.	C						C		F					
<i>Isonychia albomanicata</i>							F							
<i>Stenonema femoratum</i>	C					C	C	C	F	F	F			F
<i>S. tripunctatum</i>						C	C	C	F					F
<i>S. interpunctatum</i> group							F	F						
TRICHOPTERA														
<i>Cheumatopsyche</i> sp.								C						
<i>Hydropsyche bifida</i>							F							
<i>H. betteni</i>	C					C	C	C						
<i>Helicopsyche borealis</i>							F							
<i>Hydroptila</i> sp.	F						F							
<i>Psychopsyche</i> sp.								F						
<i>Rhyacophila lobifera</i>								C	F				F	C
PLECOPTERA														
<i>Actoneuria evoluta</i>								F						
<i>Allocapnia viviparia</i>								N	F	F	F			F
<i>Isoperla confusa</i>								F						F
<i>I. decepta</i>								C	F					
<i>Neophasganophora capitata</i>							F							
NEUROPTERA														
<i>Corydalus cornutus</i>						F	C						F	F
<i>Sialis</i> sp.						F	C	F						
ODONATA														
<i>Boyeria vinosa</i>							F							
<i>Dromogomphus</i> sp.							F							
<i>Gomphus</i> sp.	F						F							
<i>Anax junius</i>							C							
<i>Libellula lydia</i>	F	C			F	C	C		F	F			F	F
<i>Libellula pulchella</i>							F							
<i>Agrion</i> spp.	F	C				C	C		F					
<i>Argia</i> spp.	F	C				C	C		F					F
<i>Enallagma</i> spp.		C			F	C	C		F		F		F	F
HEMIPTERA														
<i>Belostoma</i> sp.				F		C	F	F						
<i>Corixidae</i>	F					C	C				F			

TABLE 1.—(Continued).

Organisms	October 1951 Stations							January-February 1952 Stations						
	8.7	7.6	6.5	5.2	4.2	2.8	1.0	8.7	7.6	6.5	5.2	4.2	2.8	1.0
Gerris sp.	F					F	F							
Microvelia sp.						C	C							
Notonecta sp.						F								
Nepa sp.						F								
Ranatra sp.						F	F							
Trepobates sp.	F													
CRUSTACEA														
Asellus sp.			F			F								
Mancasellus sp.	F							C		F				F
Cambarus rusticus								C						
Gammarus sp.								C	F	F				
PLATYHELMINTHES														
Planaria sp.								C	C		C			
NEMATHELMINTHES														
Nematoda sp.							F							
Paragordius sp.											F			F
ANNELIDA														
Pristina sp.						C	C							
Stylaria sp.	F					F	F							
Dero spp.							F							
Limnodrilus sp.	F	N	N	N	N	F	F	F	C	C	N	C	C	C
Tubifex sp.		C	C	C	C				N	C	C	C	C	C
Helodrilus chloroticus								F	F	F	F	F		F
Eiseniella tetraedra								F	F	F	F	F		F
Lumbricus sp.			F					F		F	F			
Glossiphonia sp.						F	F	F						
MOLLUSCA														
Physa integra	F	C	F	C	C	C	F	F	F			F	F	F
Ferrissia rivularis							C							F
Musculium transversum							F							
Pisidium casertanum	F								F					
Sphaerium solidulum		C	F					C	C					
Lymnaea humilis modicella	F					F								
Total species per station	43	15	8	8	9	44	70	52	18	18	13	5	10	25

¹ The stations are classified into zones of pollution as follows: Clean water, 8.7, 2.8, and 1.0; Septic Zone, 6.5 and 5.2; Zone of moderate pollution or recovery, 7.6 and 4.2.

² F=Few, occasional specimen to 2 per square yard

C=Common, 3-50 per square yard

N=Numerous, 51 or over per square yard

3a, b, c. Includes 7, 10, and 3 drift forms respectively from clean water areas.

the organisms listed in table 1 yields rather interesting information as to their value as indicators of pollution in a stream. Diptera or fly larvae are adapted to live under a wide variety of environmental conditions but only 7 of 23 species collected during the winter period were able to survive the effects of the polluttional stream bottom blanket which moved downstream. The only

species which was widely distributed throughout the stream was *Chironomus decorus*. In October it was the most common invertebrate found in the riffles in the lower septic and the recovery zones but only an occasional specimen was found in clean water areas. During the winter as the pollutional blanket moved downstream *C. decorus*, upon being washed downward, congregated in large numbers in riffles in even the formerly clean water zone. One species of Diptera, *Culex pipiens*, which was found in large numbers in the septic zone during the summer, disappeared completely in the winter. Another, *Eristalis bastardi*, was represented by only a single specimen during the winter, that from the zone which had been septic under summer conditions.

Reference to the orders Ephemeroptera, Trichoptera, and Plecoptera reveals that all representatives of these orders were restricted to clean water areas during the October survey. Only one or two species from each group were taken during the winter from the formerly septic zones. Of these forms, *Stenonema femoratum*, a mayfly, was found to possess considerable tolerance to pollutional conditions if the dissolved oxygen supply was present in ample quantities. Nymphs of this species were found associated with *Chironomus decorus* and tubificid worms in riffles where other invertebrates had been eliminated by the pollutional blanket.

Larvae of the caddisfly, *Rhyacophila lobifera*, and nymphs of the stonefly, *Allocaonia viviparia*, were also collected from areas which showed definite signs of pollution, but only directly following heavy floods. Wherever they occurred they were present in very small numbers and were found clinging to masses of drifting leaves or debris. Neither species seemed to be able to adapt itself to the polluted conditions in the stream and disappeared when the flow became stabilized. The source of both species in all such instances was found to be the numerous intermittent tributaries which feed Lytle Creek during the winter time.

DISCUSSION

In order to utilize aquatic populations as an index in evaluating the degree, severity, and duration of pollution in a stream, it is essential to have a knowledge of the species composition and abundance of the various organisms in the population. Further, consideration must be given to the fact that pollution with organic waste is only one of several environmental factors determining the composition of aquatic populations. Other environmental factors such as the nature of the stream bed, variations in flow, severity of floods, water temperatures, location, type, and population of tributaries, and the character of the watershed are all important in determining the make-up of aquatic populations.

Under winter conditions oxygen depletion is not a limiting factor to the distribution of aquatic invertebrates in Lytle Creek. With a decrease in water temperatures and an increase in the volume and velocity of flow, the pollutional carpet of organic and mineral matter deposited in the septic and recovery zones during low flow extends further downstream encroaching on or eliminating the former recovery and clean water zones. Bottom organisms from the clean water, recovery, and septic zones congregate together in riffles during floods making a delineation of biological zones of pollution difficult if not impossible. Tributaries, during times of flood, contribute fauna not

normally found in the main stream, thus necessitating a consideration of the source and habits of the forms collected before an adequate interpretation of the data can be made. In winter as well as in summer the mode of occurrence of the organisms in the stream must be taken into account in determining the effects of pollution. A relatively large number of pollution-tolerant forms as tubificids associated with very few clean water forms may be indicative of past floods and an extension of pollutional conditions. Inability of the clean water forms to continue to survive attests to the critical conditions imposed by organic pollution even in the presence of an ample oxygen supply. This is demonstrated by the significant reduction in the number of species in the lower clean water section of Lytle Creek during the winter of 1951-52, and by the downstream extension of bottom conditions characteristic of the septic zone (fig 3).

A knowledge of the life histories of the various groups of aquatic insects often is essential in interpreting the meaning of their distribution. The presence of such forms as *Culex pipiens* and *Eristalis bastardi* in large numbers in the septic zone during summer and their absence during cold winters should be considered as a normal phase of their developmental pattern. The disappearance of certain beetles, dragonflies, and damselflies from a polluted stream during winter should not be necessarily interpreted as indicative of more unfavorable pollutional conditions but rather as a normal response of hibernating under winter conditions. Thus, one who is acquainted with the distribution, habits, and life histories of aquatic organisms can learn considerable about the pollutional conditions in a stream even when physical chemical indications of pollution are least evident.

SUMMARY

In the summer months during periods of high temperature and low flow, the septic and recovery zones are shortened, and most of the biochemical oxygen demand is satisfied in a relatively short section of the stream, about 70% in 2 miles in Lytle Creek. During the summer, diurnal variations in dissolved oxygen are at a maximum and severe oxygen depletion occurs; the effects of pollution are most evident and the life zones are more clear cut and readily observed. The fauna occurring in the septic and recovery zones are able to exist in the absence of free oxygen, have low oxygen requirements, or have special adaptations for obtaining oxygen. With an abundance of food and an absence of competition from other forms these organisms thrive and build large and distinctive populations.

In the winter months, stream flow in Lytle Creek is greater and more rapid, metabolic activity is at a lower level; life zones become longer or lose their identity, and diurnal variations in dissolved oxygen are at a minimum, the lowest concentrations never approaching those of summer. The increased rate of flow and shorter retention time in the stream coupled with a slower rate of bacterial action serves to carry higher concentrations of organic material into the lower sections of the stream. As a result of this greater organic content, the pollutional carpet of bacteria, protozoa, and entrapped organic materials which is characteristic of the septic zone in summer, extends further downstream. When severe floods do not occur for considerable periods the pollu-

tional carpet reaches the upper end of the clean water zone of summer.

This downstream extension of the polluttional carpet in the winter of 1951-52 brought about a significant reduction in the variety of macro-invertebrates in the lower clean water section of Lytle Creek. Even though dissolved oxygen is adequate this carpet and other factors constitute a definite barrier to the establishment of clean water insects. Such forms migrating or washed into the main stream from the upper clean water zone or from tributaries did not long survive in the former septic or recovery zone of summer. In these areas they are found only in leaf drift piles after floods. However, this introduction of clean water organisms from the tributaries to the main channel of a polluted stream during high winter flows constitutes a factor which should be considered in evaluating the reliability of macro-invertebrates as indicators of stream conditions. Also during the winter months bottom organisms characteristic of the septic and recovery zones during summer may be carried to points further downstream. Riffles in the clean water area may serve to collect organisms normally found in pools or along margins in other sections of the stream. It is apparent, therefore, that some knowledge of the habits, habitats, and life histories of many macro-invertebrates is essential for their effective use as biological indicators of pollution.

Because the composition and abundance of stream populations are determined by environmental conditions which have prevailed or by extremes which have occurred during their life cycle, organisms having an annual life cycle are especially valuable as biological indicators of past environmental conditions. The absence of long life history and clean water forms is much more significant than the presence of short life history and tolerant forms. A knowledge of the habits and environmental requirements of bottom organisms enables the aquatic biologist, by means of a brief qualitative quantitative survey to gain some knowledge of past conditions, the severity and extent of pollution, and the degree of recovery.

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